M. Management – Mission Schedule, Cost, and Programmatics

Executive Summary

We have shown in this study report that the New Worlds Observer has compelling science, technology that is implementable with modest development, and is ready for mission development in the near term. An outline of a preliminary project plan is included in this appendix keeping this near-term implementation in mind. A summary of the costing exercises is included. Our main costing efforts were concentrated on a facility-class baseline mission in the manner of HST and JWST.

The team that coalesced around the Astrophysics Strategic Mission Concept Study (ASMCS) includes approximately 43 people at eight institutions under the management of GSFC. It brought together a wide range of expertise in all the crucial areas to address this unique design and study problem.

Table M-1: The NWO Study Team Organizations Showing Responsibilities, Capabilities and Experience

Organization	NWO Responsibilities	Unique Capabilities	Relevant Experience
University of Colorado	▪ PI ▪ Science Operations ▪ Science Team ▪ Optical Design ▪ Systems Analysis ▪ EPO	▪ Space Science Mission Development	▪ PI for HST Cosmic Origins Spectrograph (COS) ▪ Optical Design for Far Ultraviolet Spectrographic Explorer (FUSE) ▪ Cassini, Gallileo ▪ MESSENGER
GSI	▪ Lead Scientist		
NASA Goddard Space Flight Center	▪ Science Team ▪ Project Management ▪ Mission Systems Engineer ▪ Safety & Mission Assurance ▪ Space & Ground Segment Manager ▪ Mission Operations Manager ▪ Flight Dynamics ▪ Instruments ▪ Telescope	▪ Space Science Program Management ▪ Space Flight Mission Operations ▪ Space Flight Project Management ▪ Instrument Dev. and Management	▪ HST ▪ GLAST ▪ JWST ▪ SWIFT ▪ WMAP ▪ SDO ▪ EOS ▪ GOES ▪ JDEM ▪ Many more
NASA Glenn Research Center	▪ Propulsion Systems	▪ Advanced Propulsion Technology Dev.	▪ NEXT Development Program
Northrop Grumman Aerospace Systems	▪ Deployable Occulter Mission Design ▪ Deputy PI ▪ Starshade Manager ▪ Launch System Manager ▪ Science Team	▪ Large Scale Deployable Space Structures	▪ Chandra ▪ TDRSS ▪ EOS Aura/Aqua ▪ Classified Programs
Ball Aerospace	▪ Spacecraft Bus Trajectory and Alignment Control ▪ Telescope Manager ▪ Payload Manager ▪ Instruments	▪ Spacecraft Buses for Deep Space Missions	▪ Deep Impact ▪ Kepler ▪ Chandra Aspect Camera
USNO	▪ Alignment Sensor	▪ Astrometry ▪ Instrumentation	▪ Joint Milliarcsecond Pathfinder Survey Mission
University College of London	▪ Science Team	▪ Exoplanet spectral modeling	▪ ESA ExoPlanet Roadmap Advisory Team ▪ Group coordinator for ExoPlanet atmospheres ▪ Co-I for ExoPlanet obs on VLT-Crires, IRTF, Spitzer, Hubble ▪ TPF-C, TPF-I/Darwin, SEE-Coast Concepts Working Groups; Co-I THESIS concept

The NWO organizations are shown in Table M-1. After delivery of the ASMCS in April, the team will continue to work on refining the concept, developing technology and verification and validation plans, and conducting research in our testbeds. Particular attention will be given to addressing the higher priority technology development and mission risk items identified with the goal of better understanding the technical issues, through both modeling and prototype hardware. These efforts will establish a more reliable assessment of risk than could be achieved during our concept study. The PI, lead scientist, and team continue to work on furthering collaborations, partnerships and increasing the science community support for NWO, both domestically and internationally. Discussions continue with ESA and JAXA in particular.

For development and implementation of the NWO facility-class mission we would expect the management structure to follow a NASA "top-down" approach where the mission goals are identified and delineated by the Science Mission Directorate Exoplanet Program Office based on community input from National Academies studies, such as this Decadal Survey, as well as other advisory groups. Some or all of the individual instruments on NWO would be competed. Industry partners would be competed for selection of other mission components, for example, the telescope, spacecraft, and starshade developments, with some mission elements developed in-house or managed by NASA Centers. The overall project management would be assigned to a

NASA Center. A project scientist would oversee the NWO science program with the science working group and science team. Figure M-1 shows the NWO organizational structure.

The schedule is presented in Figure M-2. If the mission were to start Phase A in March 2010, NWO could be ready for launch in June 2018. The bulk of the expenditures would come starting in FY2014 when (hopefully) JWST will be past the peak of its funding cycle.

In addition to the Executive Summary, this appendix includes sections M.1 Organization and Responsibilities, M.2 Decision Making, M.3 Study Team Capabilities and Experience, M.4 Mission Systems Engineering, M.5 Risk Management and NWO Top Risks, M.6 Management of Reserves and Margin, M.7 Management of Reserves and Margin, M.8 Project Schedule, M.9 Work Breakdown Structure, M.10 Project Reviews, M.11 Acquisition Strategy, M.12 Examples of NWO Team Member Facilities, M.13 Preliminary Project Plan Outline.

M.1 Organization and Responsibilities

Management Structure

For the proposed NWO facility-class mission implementation, we would expect the management structure to following a NASA "top-down" approach where the mission goals are identified and delineated by the Science Mission Directorate Exoplanet Program Office based on community input from National Academies studies, such as this Decadal Survey, as well as other advisory groups. A proposed organization is shown in Figure M-1. Some or all of the individual instruments on NWO would be competed. Industry partners would be competed for selection of other mission components, for example, the telescope, spacecraft, and starshade developments, with some mission elements developed in-house or managed by NASA Centers. The overall project management would be assigned to a NASA Center and would also coordinate international participation. A project scientist would oversee the NWO science program with the science working group and science team.

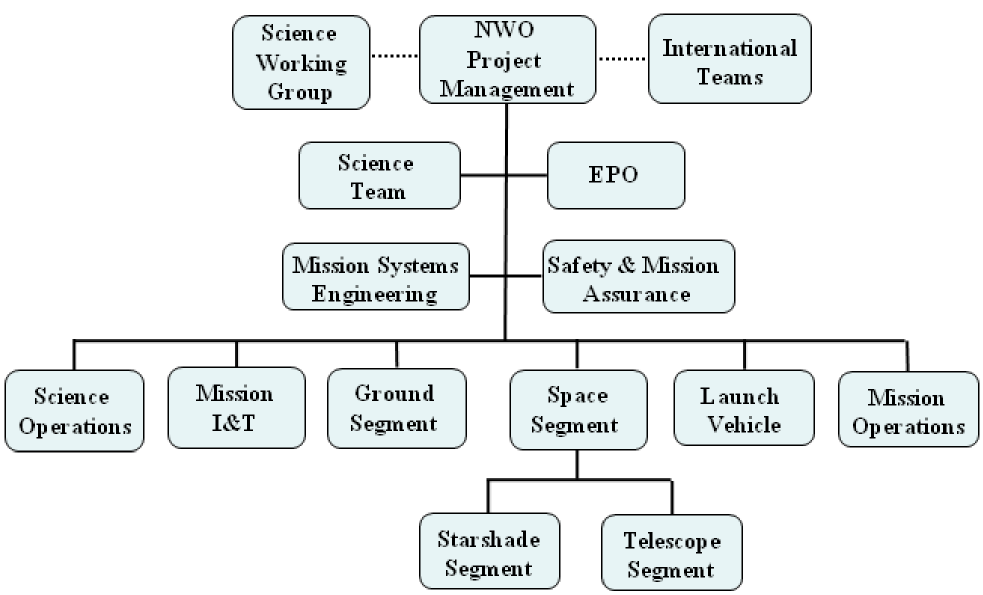


Figure M-1. New Worlds Observer Proposed Project Organization

M.2 Decision Making

Decision making on the New Worlds project will be characterized by a team-based environment within a formal framework of contractual relationships, controlled SOWs and interfaces, and clear lines of authority. The PM with concurrence from the project scientist (PS) will have final authority for decisions that affect mission goals, science requirements, EPO, and deviations from the baseline project budget and schedule. Within those boundaries, the PM will be responsible for day-to-day decisions affecting mission implementation. The PM, and all managers, will hold weekly management teleconferences, and the full New Worlds management team including the leads from all New Worlds partners will meet for a monthly status review. Technical decisions will be coordinated through the Systems Engineering Working Group (SEWG) chaired by the mission systems engineer (MSE). The SEWG will include the lead systems engineers (SEs) at each of the New Worlds partner organizations, a delegate from the science team. The SEWG will coordinate all trade studies, risk management, configuration management, interface management, and a "Top Ten" list of current technical issues. A configuration management office at the mission implementing NASA Center will control all New Worlds requirements and interface documents. Level I requirements (mission goals, launch date, etc.) will require approval at the NASA SMD level. Level II requirements (science requirements, top-level budget, and schedule) will be controlled at the Project level, and Level III requirements (derived engineering requirements, interface requirements, and subsystem allocations) will be controlled by the MSE. The project scientist and the science team will establish the priorities among the exoplanet and general astrophysics objectives and the operations team will use these priorities in scheduling the activities of the two spacecraft. The exoplanet observations get high priority, but the general astrophysics get the bulk of the observing time >70%. The large field of regard and the lack of constraints due to the L2 orbit mean that the general astrophysics objectives can be met even with the uncertainties in the duration of the exoplanet observations.

Communication and Control

The NWO one team philosophy integrates all organizations involved in the development and implementation of the NWO Mission. All managers from the PM down will encourage communications among all team participants to be as open as possible, without violating any contractual arrangements. The PM's bi-weekly staff meetings will ensure efficient communications of progress, decisions, issues, risks, and changes. Communications with the element developers will occur through regular reporting methods, ad hoc and planned communication paths such as those described above, and regular and frequent on-site visits, both by managers and engineers. On-line databases will be kept by the Project. This includes a risk list, a current list of open and retired risks, and an issues list, which lists all current open and retired issues which are being tracked. The risk list will be managed as described in the risk management section. The issue list will be managed through weekly Project staff meetings, and will be kept by the Configuration Control Manager.

M.3 Study Team Capabilities and Experience

Our NWO team has been addressing the performance, feasibility, readiness, and affordability of the external starshade concept. Our team, which has been developing this concept since 2004, comprises the creator of the breakthrough concept (CU), two fully functioning starshade laboratory testbeds (CU & NGST), the leaders in large precision deployable structures (NGAS), the leaders in space telescopes and instrumentation (NGAS & Ball), and NASA's lead Center for space telescopes (GSFC). These institutions have developed the New Worlds concept as a team since its inception and bring a depth of direct experience to this study that is simply unavailable outside the team. We have quantitatively assessed the mission and found it practical and affordable for launch in the next decade. We now propose to take this study to next level and make the full realities of the New Worlds concept available to the upcoming decadal review.

Table M-2 summarizes the responsibility, capabilities, and relevant experience of each study team member organization.

Table M-2 The NWO Study Team Organizations Showing Responsibilities, Capabilities and Experience

Organization	NWO Responsibilities	Unique Capabilities	Relevant Experience
University of Colorado	▪ PI ▪ Science Operations ▪ Science Team ▪ Optical Design ▪ Systems Analysis ▪ EPO	▪ Space Science Mission Development	▪ PI for HST Cosmic Origins Spectrograph (COS) ▪ Optical Design for Far Ultraviolet Spectrographic Explorer (FUSE) ▪ Cassini, Gallileo ▪ MESSENGER
GSI	▪ Lead Scientist		
NASA Goddard Space Flight Center	▪ Science Team ▪ Project Management ▪ Mission Systems Engineer ▪ Safety & Mission Assurance ▪ Space & Ground Segment Manager ▪ Mission Operations Manager ▪ Flight Dynamics ▪ Instruments ▪ Telescope	▪ Space Science Program Management ▪ Space Flight Mission Operations ▪ Space Flight Project Management ▪ Instrument Dev. and Management	▪ HST ▪ GLAST ▪ JWST ▪ SWIFT ▪ WMAP ▪ SDO ▪ EOS ▪ GOES ▪ JDEM ▪ Many more
NASA Glenn Research Center	▪ Propulsion Systems	▪ Advanced Propulsion Technology Dev.	▪ NEXT Development Program
Northrop Grumman Aerospace Systems	▪ Deployable Occulter Mission Design ▪ Deputy PI ▪ Starshade Manager ▪ Launch System Manager ▪ Science Team	▪ Large Scale Deployable Space Structures	▪ Chandra ▪ TDRSS ▪ EOS Aura/Aqua ▪ Classified Programs
Ball Aerospace	▪ Spacecraft Bus Trajectory and Alignment Control ▪ Telescope Manager ▪ Payload Manager ▪ Instruments	▪ Spacecraft Buses for Deep Space Missions	▪ Deep Impact ▪ Kepler ▪ Chandra Aspect Camera
USNO	▪ Alignment Sensor	▪ Astrometry ▪ Instrumentation	▪ Joint Milliarcsecond Pathfinder Survey Mission
University College of London	▪ Science Team	▪ Exoplanet spectral modeling	▪ ESA ExoPlanet Roadmap Advisory Team ▪ Group coordinator for ExoPlanet atmospheres ▪ Co-I for ExoPlanet obs on VLT-Crires, IRTF, Spitzer, Hubble ▪ TPF-C, TPF-I/Darwin, SEE-Coast Concepts Working Groups; Co-I THESIS concept

M.4 Mission Systems Engineering

Mission Systems Engineering (MSE) will be accomplished by an integrated team of SEs. Overall activity will be managed and coordinated by the implement ting NASA Center project lead MSE who will ensure that mission elements are defined for function, performance, and interface so they operate as a system to accomplish the mission. The project MSE will be the systems technical warrant holder for the project and will have access to the NASA Independent

Technical Authority through the NASA Center’s Office of Mission Success. The MSE will establish and maintain top-level mission functional architecture and physical architecture. These will contain the performance levels and responsible partners that constitute the implementation architecture.

The MSE controls the interfaces in these architectures. The MSE team will develop and maintain all mission system documentation. A detailed System Engineering Management Plan (SEMP) will be baselined during Phase A. An automated system for requirements management will be selected during Phase A. It will identify the specific test, analysis, inspection, or other appropriate verification and validation methods that ensure requirements are satisfied. This system will be used by the MSE and team throughout the mission life cycle.

The MSE team will perform integrated systems analyses and simulations that cross physical and institutional interfaces to perform system-level functions. The MSE will be responsible for a simulation of mission telemetry. This telemetry will be processed by a simulated ground system. The resultant data products will be delivered to the science team for evaluation in meeting mission objectives and requirements.

M.5 Safety and Mission Assurance

The Safety and Mission Assurance (SMA) function ensures that NWO will be built to NASA standards and tested to meet the mission requirements. The NWO assurance program approach will be designed where the NWO project takes advantage of existing team experts, processes and procedures to implement a comprehensive and cohesive NWO Safety and Mission Assurance (SMA) Program.

The integrated process, as being implemented, will be consistent with pertinent NASA standards and will be compliant to AS9100. A NWO Safety, Mission Assurance Plan will be developed during Phase B to document the processes.

Elements of the NWO SMA program are system safety, reliability, quality, problem/failure reporting, EEE parts selection, materials and processes, and software assurance.

The NWO Project will have ultimate responsibility for the entire SMA program. The Systems Assurance Manager (SAM) is a key member of the Project Manager's staff and will support NWO throughout all lifecycle phases including Phase A. The SAM will draw upon parts, reliability and materials experts to assist in problem resolution, participate in reviews or technical exchange meetings, and support inspections/audits.

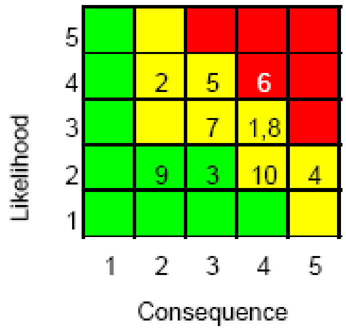
M.6 Risk Management and NWO Top Risks

The continuous risk management (CRM) process provides technical rigor and coordination to minimize risk across the mission. The NWO Project Office will implement a system of continuous risk management in accordance with NPG 8000.4 and Center guidelines. The PM owns the CRM plan and process. The Risk Management Board (RMB), chaired by the PM, manages the Risk Program ensuring that risks identified for each element are properly addressed and tracked, and that risk mitigation activities are scheduled and meet milestones. A central web-based risk management tool and database will track status of all program risks. The team has already used early risk identification and mitigation (i.e., tall poles document) to effectively influence mission and system designs with the goal of achieving a simple, straightforward mission concept with robust margins.

The technology development needs of a program can be quantified in terms of risk. By assessing the technical risk of starshades, and analyzing the most probable mode of failure, we can chart a program towards mitigating these risks. The top 10 technical risks for starshades as assessed for the NWO project are shown in Table M-3. The risk level is shown along with the definitions for the likelihood and consequence scale. Deployment is the starshade's high risk item. Our development roadmap will mitigate this risk and is described in detail in the technology section of the study report.

Table M-3: New Worlds Observer Top Risks

Category	#	Technical Risk	Likelihd.	Cons.	Risk Level
Starshade Optical Performance	1	If the starshade simulation is inaccurate due to optical complexity of the starshade, then on-orbit performance may be significantly worse than predicted	3	4	25
	2	If, due to higher fidelity analyses, the starshade requires more perimeter control than can be accommodated in the current design, then the starshade will have to be modified	4	2	20
	3	If light scatters off the starshade due to inadequate membrane & edge control, then it may overwhelm planet light	2	3	13
Starshade Deployment and Shape Maintenance	4	If the starshade does not deploy due to deployment design complexity, then the mission is invalidated because we cannot occult target stars	2	5	29
	5	If the starshade deployed shape does not meet requirements due to manufacturing errors, then its optical performance will degrade significantly	4	3	25
	6	If the starshade deployed shape does not meet requirements due to launch or L2 environmental impacts, then its optical performance will degrade significantly	4	4	32
	7	If the starshade membrane loses opacity due to environmental impacts of launch L2, then starlight may leak and overwhelm planet light	3	3	18
Trajectory and Alignment Control (TAC)	8	If the TAC does not have sufficient control authority due to complexities in the software algorithm, or operations, then mission science return may be reduced or delayed	3	4	25
	9	If, due to higher fidelity analyses, the TAC sensor requires better performance than the current capabilities, then the TAC sensors will have to be modified	2	2	8
	10	If the thruster firing overwhelms the starshade ACS due to starshade-spacecraft dynamic coupling, then the spacecraft may go out of control	2	4	20



Rating	Likelihood of Risk	Rating	Consequence
5	>50%	5	>50% Loss
4	30% - 50%	4	25%< Loss < 50%
3	10% - 30%	3	5%< Loss < 25%
2	1% -10%	2	0%< Loss < 5%
1	< 1 %	1	0% Loss

The risks in Table M-3 include perceived risks, where insufficient information regarding the system and state of the art capabilities leads to the perception of a technical challenge. Most of these can be assessed via low-cost laboratory tests. The Technology section of this study report outlines a series of laboratory tests that are immediately implementable and that can put to rest many of these perceived technical challenges and allow us to determine if any of these technologies needs further development. In addition, a starshade technology white paper[1] was submitted to the Astrophysics Decadal Committee.

M.7 Management of Reserves and Margin

Schedule, cost and technical reserves will be maintained at the PM's level. This process ensures that costs are controlled at the Project level. The implementing NASA Center would follow established policies for management of reserves and margins. If the implementing NASA Center were GSFC, then the Goddard Procedural Requirements (GPR) 7120.7 documents the schedule margins and budget reserves requirements for formulating a flight project at the Goddard Space Flight Center (GSFC) and describes how those margins and reserves are to be tracked during the Implementation Phase. In the planning stages of a flight project, the following schedule margins shall be used: from Confirmation to delivery to Observatory Integration and Test (I&T): 1 month per year; from start of I&T to shipment to launch site (or to planned storage): 2 months per year; from delivery to launch site to launch: 1 week per month. At the Center's Monthly Status Reviews, project managers shall present their schedule margin status relative to the margins specified above (or to the margins agreed to with Headquarters at the Confirmation Review). If the schedule margins fall below the agreed-to levels, the presentations shall include explanations as to the reasons for the shortfall as well as a description of any activities initiated to mitigate the trend. For budget reserves this GPR documents at the time of Initial Confirmation (Key Decision Point-B [KPD-B]), flight projects should have a budget reserves level of 30% or higher through Phase D. This is a goal, not a requirement. At the time of Confirmation (KDP-C), flight projects shall have a budget reserves level of 25% or higher through Phase D. Deviations from this level of budget reserves shall require concurrence of the Center Management Council at the Confirmation Readiness Review. At the time of delivery to

[1] "**Starshade Technology Development", Astro2010 Technology Development White Paper** Submitted to: *Electromagnetic Observations from Space* (EOS), Primary Author: Amy S. Lo, Northrop Grumman Corporation
Primary Co Authors: **Webster Cash**, University of Colorado, **Tupper Hyde**, Goddard Space Flight Center
Ronald Polidan: Northrop Grumman Corporation, **Tiffany Glassman**, Northrop Grumman Corporation
& the *New Worlds Observer Study Team*

the launch site, flight projects should have a budget reserves level of 10% or higher through Phase D. This is a goal, not a requirement. At the Center's Monthly Status Reviews, project managers shall present their budget reserves status relative to the levels specified above (or to the levels agreed to with Headquarters at the Confirmation Review). If the budget reserves fall below the agreed-to levels, the presentations shall include explanations as to the reasons for the shortfall as well as a description of any activities initiated to mitigate the trend. Technical reserves such as mass, power and volume are managed by the mission systems engineer (MSE). GSFC's recommendations for technical resource margins by mission phase are shown in Table M-5. Allocations are established, and are continually monitored by the Project. While the MSE is responsible, these resources are also monitored by the PM to determine if action is necessary to keep within the required limits. Typically after selection of the instruments, telescope and observatory contractors, a percentage of the project reserves-technical, cost, schedule-are allocated to the developers. The exact amount will be tailored according to the specific risks for each development during formulation (Phase A/B). These values are documented in interface documents with the Project. The NWO Project will follow these guidelines.

Table M-5. Technical Resource Margins

All values are assumed to be at the end of the phase

Resource	Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E
Mass	≥30%	≥25%	≥20%	≥15%	0	
Power (wrt EOL capacity)	≥30%	≥25%	≥15%	≥15%	≥10% *	
Propellant	3σ***				3σ	
Telemetry and Command hardware channels**	≥25%	≥20%	≥15%	≥10%	0	

Margin (in percent)= (Available Resource-Estimated Value of Resource)/Estimated Resource X 100

*At launch there shall be 10% predicted power margin for mission critical, cruise and safing operating modes as well as to accommodate in-flight operational uncertainties.

** Telemetry and command hardware channels read data from hardware such as thermistors, heaters, switches, motors, etc.

*** The 3 sigma variation is due to the following: 1. Worst-case spacecraft mass properties 2. 3-sigma low launch vehicle performance 3. 3-sigma low propulsion subsystem performance (thruster performance/alignment, propellant residuals) 4. 3-sigma flight dynamics errors and constraints 5. Thruster failure (applies only to single-fault-tolerant systems)

M.8 Project Schedule

The planned operational lifetime of the NWO mission is 5 years, project start in 2010, Phase A duration of 18 months, Phase B duration of 24 months, 60 month development period, two spacecraft vendors building separate spacecraft in parallel, specialized test facilities for the starshade development, separate launch vehicles for both spacecraft (telescope launch June 2018 and the starshade launch February 2019), 60 months of operations (i.e., Phase E primary mission), and 14.3 months of funded schedule reserve on the critical path.

Reviews will be conducted according to the NASA Procedural Requirements (NPR) document 7120.5D. Section M.10 describes Project reviews in more detail. Integrated Independent Reviews (IIRs) and Critical Milestone Reviews of the NWO project will be conducted. The IIRs are used to evaluate the status of a flight project at the mission system level and at the major system element level (i.e., spacecraft, instrument(s), and ground system).

IIRs are supported by project-conducted Engineering Peer Reviews (EPRs) which assess the status of subsystem or lower assembly levels. The results of the EPRs constitute a key input to the IIRs. Milestones and key decision points (KDPs) consistent with NPR 7120.5D will be implemented. The project-level reviews are shown on the mission schedule in Figure M-2 and include the mission definition review (MDR), system definition review (SDR), preliminary design review/confirmation review (PDR/CR), critical design review (CDR), system integration review (SIR), mission operations review (MOR), pre-environmental review (PER), flight operations review (FOR), pre-ship review (PSR), launch readiness review (LRR).

The critical path lies along the telescope/payloads/spacecraft part of the schedule. Payload development includes two instruments needed for exoplanet research, a high resolution camera and spectrometer, along with two instruments for trajectory alignment and control, the astrometric sensor assembly (on the starshade) and shadow sensor assembly (on the telescope). The general astrophysics instruments include a high-throughput far-UV spectrometer, an integral field spectrograph and a wide-field camera/guider. The telescope and instrument development and integration and test (I&T) are allocated 630 days. The telescope spacecraft development is 644 days. The telescope spacecraft integration and test is 263 days. The telescope spacecraft launch and early orbit checkout is 21 days, and cruise to the L2 orbit and checkout is 66 days. During this time general astrophysics observations can be conducted.

The starshade/payloads/spacecraft will be developed by a separate vendor from the telescope/payloads/spacecraft but will be developed in parallel. The starshade instrument development and I&T is 611 days. Starshade development and testing is 654 days. The starshade spacecraft development/testing is 644 days. Starshade spacecraft I&T is 407 days. Starshade spacecraft launch/early orbit checkout is 21 days and the cruise to L2 orbit and checkout is 67 days. The starshade launch is approximately 8 months after the telescope launch.

The NWO schedule includes a total of 14.3 months of schedule reserve along the critical path, and exceeds the GSFC recommendations (GPR 7120.7) by about 3 months. There is 6.2 months of reserve on the critical path for the telescope and instrument development and integration and test, spacecraft bus assembly and test, and telescope spacecraft integration and test, and preparation for launch. The starshade, payloads and spacecraft have 8.1 months of reserve. The NWO budget includes funding for this schedule reserve and is $150M.

The transition to normal operations is July 2019 with the mission operating five years.

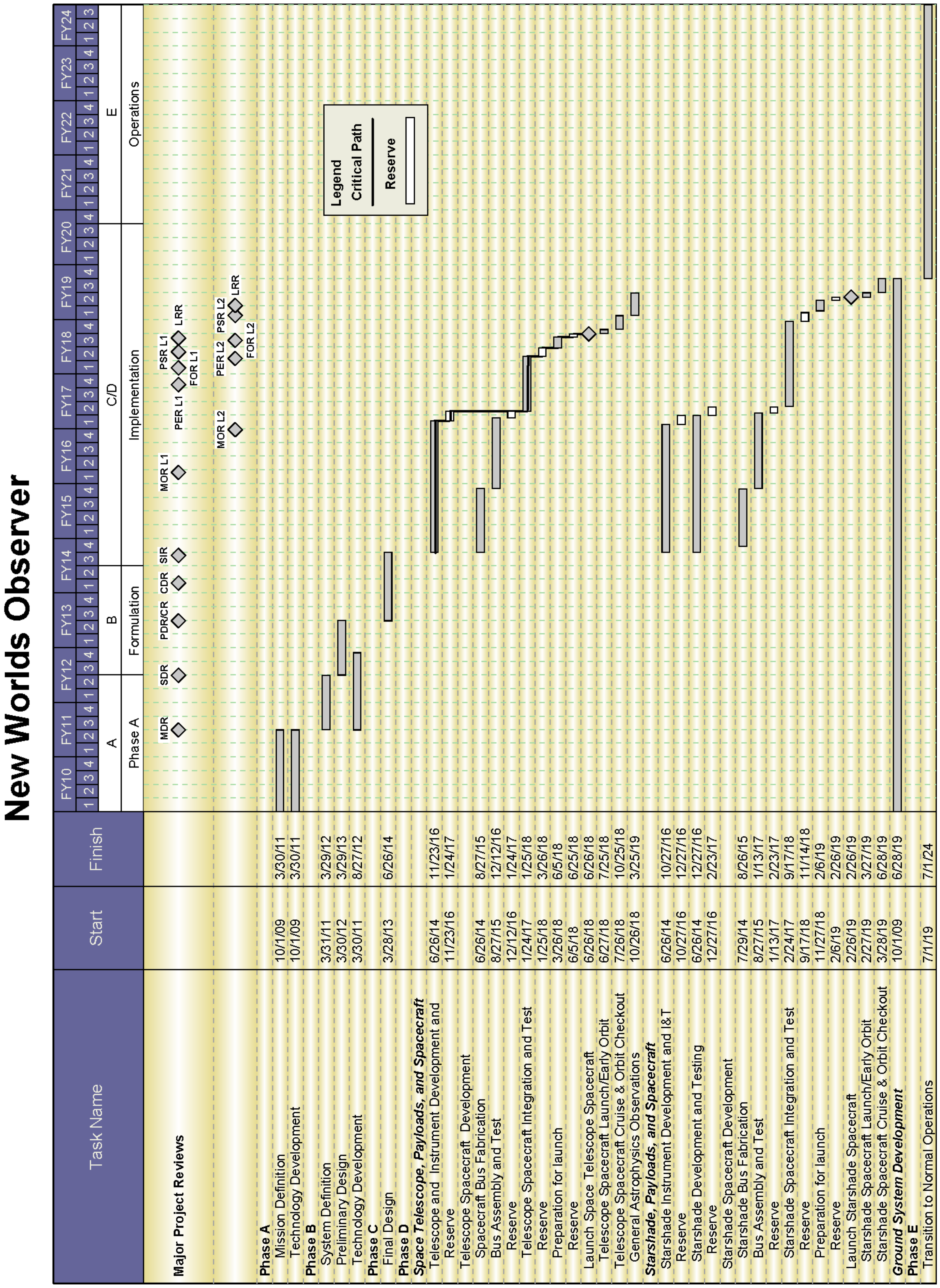


Figure M-2. New Worlds Observer Integrated Baseline Mission Schedule

M.9 Work Breakdown Structure

Figure M3 contains the WBS structure for the New Worlds Observer baseline mission. The NWO structure follows the NASA NPR 7120.5D, Appendix G for Space Flight Project Work Breakdown Structure.

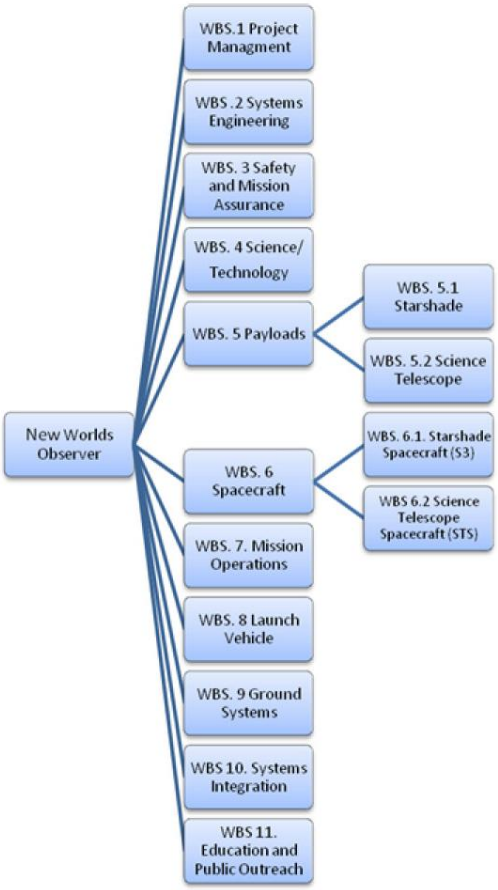


Figure M-3. NWO WBS Structure

The WBS dictionary that will be developed for the NWO Project will follow the guidelines in NPR 7120.5D. The standard space flight project WBS dictionary is as follows and was used as the basis for developing the NWO WBS:

Space Flight Project Standard WBS Dictionary

Element 1 - Project Management: The business and administrative planning, organizing, directing, coordinating, analyzing, controlling, and approval processes used to accomplish overall project objectives, which are not associated with specific hardware or software elements. This element includes project reviews and documentation, non-project owned facilities, and project reserves. It excludes costs associated with technical planning and management and costs associated with delivering specific engineering, hardware and software products.

Element 2 - Systems Engineering: The technical and management efforts of directing and controlling an integrated engineering effort for the project. This element includes the efforts to define the project space flight vehicle(s) and ground system, conducting trade studies, the integrated planning and control of the technical program efforts of design engineering, software engineering, specialty engineering, system architecture development and integrated test planning, system requirements writing, configuration control, technical oversight, control and monitoring of the technical program, and risk management activities. Documentation products include requirements documents, interface control documents (ICDs), Risk Management Plan, and master verification and validation (V&V) plan. Excludes any design engineering costs.

Element 3 - Safety and Mission Assurance: The technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This element includes design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground systems, mission operations, and payload(s) meet performance requirements and function for their intended lifetimes. This element excludes mission and product assurance efforts directed at partners and subcontractors other than a review/oversight function, and the direct costs of environmental testing.

Element 4 - Science / Technology: This element includes the managing, directing, and controlling of the science investigation aspects, as well as leading, managing, and performing the technology demonstration elements of the Project. The costs incurred to cover the Project Scientist, science team members, and equivalent personnel for technology demonstrations are included. Specific responsibilities include defining the science or demonstration requirements; ensuring the integration of these requirements with the payloads, spacecraft, ground systems, and mission operations; providing the algorithms for data processing and analyses; and performing data analysis and archiving. This element excludes hardware and software for onboard science investigative instruments/payloads.

Element 5 - Payload: This element includes the equipment provided for special purposes in addition to the normal equipment (i.e., GSE) integral to the spacecraft. This includes leading, managing, and implementing the hardware and software payloads that perform the scientific experimental and data gathering functions placed on board the spacecraft, as well as the technology demonstration for the mission.

Element 6 - Spacecraft(s): The spacecraft that serves as the platform for carrying payload(s), instrument(s), humans, and other mission-oriented equipment in space to the mission destination(s) to achieve the mission objectives. The spacecraft may be a single spacecraft or multiple spacecraft/modules (i.e., cruise stage, orbiter, lander, or rover modules). Each spacecraft/module of the system includes but is not limited to the following subsystems, as appropriate: Power, Command & Data Handling, Telecommunications, Mechanical, Thermal, Propulsion, Guidance Navigation and Control, Wiring Harness, and Flight Software. This element also includes all design, development, production, assembly, test efforts, and associated GSE to deliver the completed system for integration with the launch vehicle and payload. This element does not include integration and test with payloads and other project systems.

Element 7 - Mission Operations System: The management of the development and implementation of personnel, procedures, documentation, and training required to conduct mission operations. This element includes tracking, commanding, receiving/processing telemetry, analyses of system status, trajectory analysis, orbit determination, maneuver analysis, target body orbit/ephemeris updates, and disposal of remaining end-of-mission resources. This element does not include integration and test with the other project systems.

Element 8 - Launch Vehicle / Services: The management and implementation of activities required to place the spacecraft (s) directly into its operational environment, or on a trajectory towards its intended target. This element includes launch vehicle, launch vehicle integration, launch operations, any other associated launch services (frequently includes an upper-stage propulsion system), and associated ground support equipment. This element does not include the integration and test with the other project systems.

Element 9 - Ground System(s): The complex of equipment, hardware, software, networks, and mission-unique facilities required to conduct mission operations of the spacecraft systems and payloads. This complex includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the Mission Operations software. This element includes the design, development, implementation, integration, test, and the associated support equipment of the ground system, including the hardware and software needed for processing, archiving, and distributing telemetry and radiometric data and for commanding the spacecraft. Also includes the use and maintenance of the project testbeds and project-owned facilities. This element does not include integration and test with the other project systems and conducting mission operations.

Element 10 - Systems Integration and Testing: This element includes the hardware, software, procedures, and project-owned facilities required to perform the integration and testing of the project's systems, payloads, spacecraft, launch vehicle/services, and mission operations.

Element 11 - Education and Public Outreach: Provide for the education and public outreach (EPO) responsibilities of NASA's missions, projects, and programs in alignment with the Strategic Plan for Education. Includes management and coordinated activities, formal education, informal education, public outreach, media support, and website development.

M.10 Project Reviews

There are standard reviews for flight projects as outlined in the NASA NPR 7120.5D. The NWO Project will follow these guidelines and conduct the required reviews. The NWO schedule shows a few of the standard reviews required (see figure M-2). In addition the NWO Project will follow the NASA Center procedural requirements for integrated independent reviews. Figure M-4 shows reviews as conducted for a GSFC project lifecycle.

Milestones and key decision points (KDPs) consistent with NPR 7120.5D will be implemented as shown in figure M-5 as appropriate. A KDP is an event where the Decision Authority determines the readiness of a program/project to progress to the next phase of the life cycle. As such, KDPs serve as gates through which programs and projects must pass. KDPs associated with programs are enumerated with numerals, starting with zero; KDPs associated with projects are labeled with capital letters, the letter corresponding to the project phase that will be entered after successfully passing through the gate. Within each phase, the KDP is preceded by one or more reviews, including the governing program management council (PMC) review. These reviews enable a disciplined approach to assessing programs and projects.

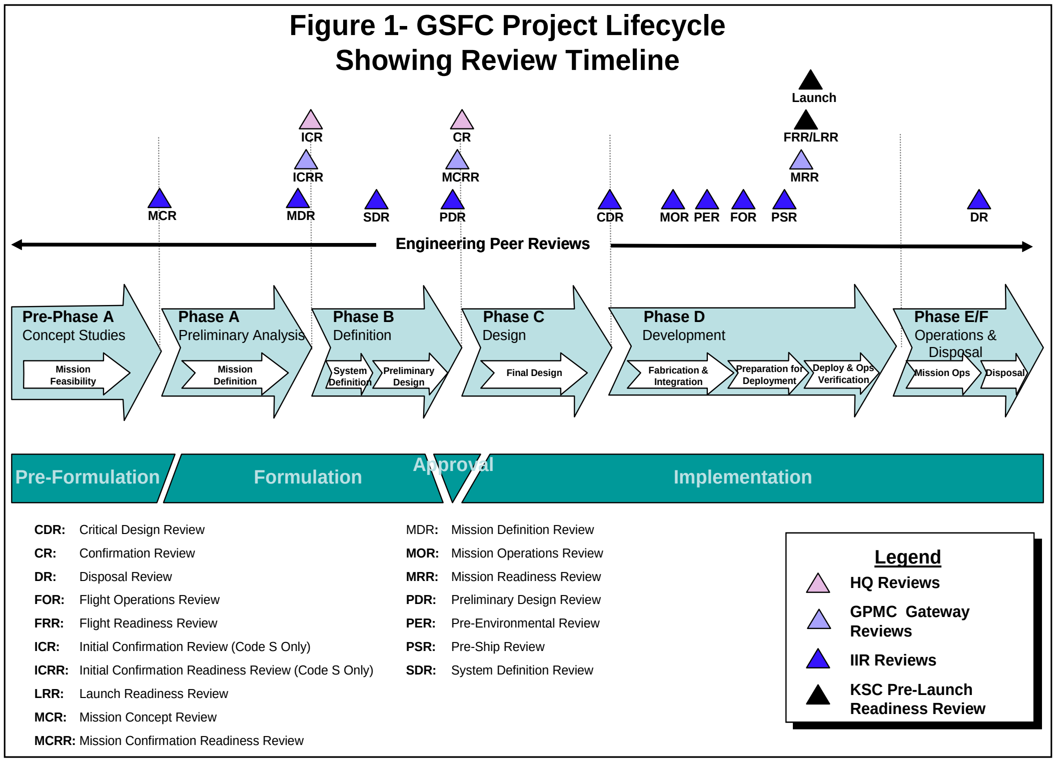


Figure M-4: Integrated Independent Review Schedule

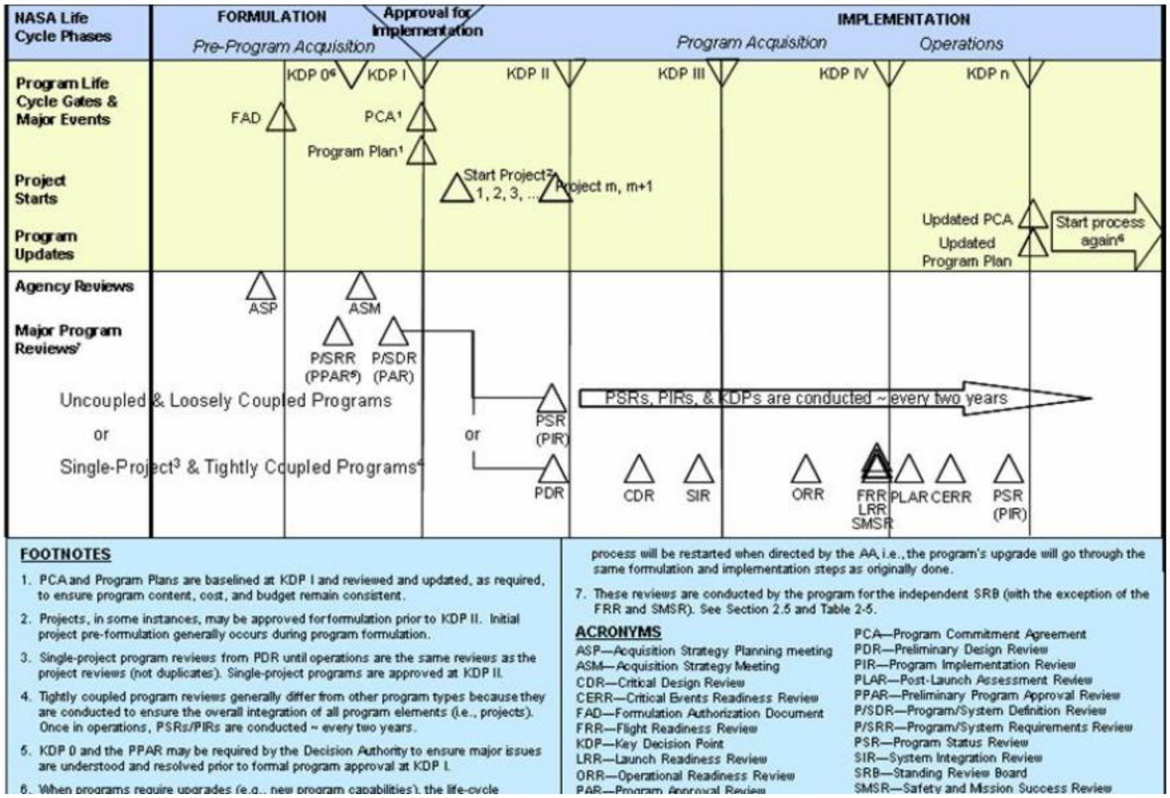


Figure M-5: NASA Project Lifecycle Reviews

M.11 Acquisition Strategy

As defined in NPR 7120.5D, project categorization defines NASA expectations of project managers by determining both the oversight council and the specific approval requirements. Projects are either Category 1, 2, or 3 and are assigned to a category based initially on (1) the project life-cycle cost (LCC) estimate, the use of nuclear power sources, and whether or not the system being developed is for human space flight; and (2) priority level, which is related to the importance of the activity to NASA, the extent of international participation (or joint effort with other government agencies), the degree of uncertainty surrounding the application of new or untested technologies, and spacecraft/ payload development risk classification (see NPR 8705.4, *Risk Classification for NASA Payloads)*. A flagship mission such as NWO would be considered a category 1 by NASA (see table M-9).

Primary activities during project formulation (Phase A/B) are to develop and define the project requirements and cost/schedule basis and to design a plan for implementation (including an acquisition strategy, contractor selection, and long-lead procurement). The acquisition strategy meeting (ASM) is held near the end of formulation but prior to approval to start implementation, and is convened as early as practicable and prior to partnership commitments. The purpose of an ASM is to obtain senior management approval of acquisition strategy (e.g., make-or-buy, Center assignments, and targeted partners. The ASM meeting also delineates if a Procurement Strategy Meeting (PSM) is required for each acquisition under consideration. The project ASM may be held in conjunction with the project systems requirements review (SRR), but must be held prior to KDP B. The supporting materials for the ASM include appropriate program/project documentation that covers budget, schedule, requirements, and risk.

For all flagship missions, NASA releases an Announcement of Opportunity (AO) for the instrument suite with a cost cap that typically includes all reserve, margin. We would expect this to be true for the New Worlds Observer mission. Industry partners would be competed for selection of other mission components, for example, the telescope, spacecraft, and starshade developments, with some mission elements developed in-house or managed by NASA Centers. The general astrophysics program on NWO will be managed from the science operations center. Calls for proposals will be issued and selected proposers will be awarded grant funding to perform their science investigations.

Table M-9. NASA Project Categorization

Priority Level	LCC < $250M	$250M ≤ LCC ≤ $1B	LCC > $1B, use of nuclear power source, or human space flight
High	Category 2	Category 2	Category 1
Medium	Category 3	Category 2	Category 1
Low	Category 3	Category 2	Category 1

Note: The threshold values in Table 2-1 are updated annually as part of the Agency's strategic planning guidance.

M.12 Examples of NWO Team Member Facilities

A brief description of selected NWO team member facilities is included below. Facilities described have application to the NWO mission. For example, either the organization has relevant experience in developing flight hardware, or similar instruments, detectors, and sub-systems that could fly on NWO were tested there.

Ball Aerospace has all the facilities needed to build and test the entire space telescope (OTA, bus, and instruments) with the following size-related exceptions:

- Vibration testing capability needs further study; we may need to contract with another aerospace company for some of this testing with the fully integrated STS, or to conduct those tests at GSFC.
- Subsystem thermal-vac tests can be performed at the level of the full bus, instrument module, and perhaps the OTA; but another chamber is needed for the integrated system. Several chambers in the US are capable of handling this size, but a significant constraint is the need for cleanliness adequate for UV optics. That might limit the choices to a small number of these existing chambers, such as the Lockheed Delta chamber. Ball has plans for a chamber this size, and has a building which was made to hold it; those plans are currently not moving forward.

Ball Aerospace

Ball has a test apparatus which can be used for 4m OTA performance verification in thermal-vacuum testing, assuming a sufficiently large vacuum chamber. Test GSE for the individual instruments will be designed and built from scratch to match the instruments.

Ball has the facilities for building the TAC sensors, and for full performance verification of the shadow sensor. Performance verification of the astrometric sensor currently is not to flight requirements. But this exception is close to being resolved. Ball's facility for testing high-precision star trackers is designed to test performance on boresight-related metrics, which are different from astrometry metrics needed by the astrometric sensor. Ball's facility has proven performance that is numerically close to the minimum requirement on the astrometric sensor, enabling the NWO starshade to begin shadowing the telescope. But the performance on astrometry-related metrics in this facility is still unknown. This will be overcome quickly with early technology development efforts.

Ball has the facilities to test the formation control algorithms, using simulated stimuli for the flight hardware, or for the flight algorithms running on EDU hardware. Final testing is needed for functional demonstration of the algorithms (sign check) on the integrated flight system.

Northrop Grumman Aerospace Systems

The satellite facilities located at Northrop Grumman at shown in table M-10.

Table M-10: NGAS Satellite Production Facilities as of 2000

Highbays	
R7A Highbay	7,000 SF Class 10,000 clean room, 30-ton crane with approximately 43 ft. hook height, personnel airlocks and gowning room, 1,500 SF Class 10,000 cleanroom and airlock/staging area
TF2 Technology Cleanroom	5,000 SF Class 100 cleanroom; 57 ft. hook height; 50 ft. vertical access; air showers and multiple airlocks into cleanroom
TF2 Staging Area	6,000 SF Class 100,000 cleanroom; 10-ton crane; protected entrance into Class 100 cleanroom
M1/M2 Highbays	Five Class 100,000 highbays over 40,000 SF
M2 Space Vehicle Production Facility	25,000 SF Class 10,000 cleanroom and staging area; 30 ton and 5 ton cranes, gowning area, airlocks, separate control room, and portable EMI/EMC enclosure.
Thermal Testing Areas	
M4 Environmental Test Facility	Large 22 x 46 ft. thermal vacuum test capability, clean cryogenic pumping train with 10^{-7} torr range, thermal cycle and thermal vacuum testing
M1 Environmental Test Facility	35-ft. diameter thermal vacuum chamber sphere; clean cryogenic pumping train with 10^{-7} torr range; thermal cycle and thermal vacuum capability
Dynamic Testing	
M1 Acoustic Test Facilities	Large Chamber 26 x 32 x 62 ft. test cell, develops 154 dB sound pressure level; Medium Chamber 21 x 25 x 30 ft test cell, develops 154 dB sound pressure level
M1, M4 and M5 Environmental Test Facilities	Full dynamic testing capability to 40,000 ft-lbs, 5 isolated hard floors, up to 16 x 38 x 4 ft or 20 x 24 x 6 ft, for modal testing.
EMC Testing	
EMC Facility	Four tri-cell chambers. Main semi anechoic cells range in size from 30 x 25 x 19 ft. down to 20 x 10 x 13 ft; 2 antechambers per main cell, ranging in size from 10 x 10 x 12 ft to 18 x 10 x 12 ft.

University of Colorado

The Astrophysical Research Laboratory (ARL) is located in the University of Colorado's Research Park on the East Campus, about a mile from the center of the main campus. It is a single storey building situated in the wetlands of Boulder Creek and has free and plentiful parking for its users. With a total of about 35,000 square feet it includes laboratories dedicated to space astronomy and offices for the scientists, engineers and students who work on the projects. The building was constructed in 1985, and renovated for astronomy in 1995 when CASA moved in. In August 2004, CASA completed a new office wing to ARL designed to support the additional needs for data analysis when the Cosmic Origins Spectrograph is installed on the Hubble Space Telescope. The building is wired for high speed communications and computing. CASA's staff provides support for computer needs in both the laboratories and the offices.

Features of ARL include:

1. Six private laboratories that can be isolated from traffic and darkened as needed by the experimenters.
2. An 8000 square foot high bay that allows for long baseline optical work and which houses some of the large common usage vacuum facilities.
3. A class 1000 Clean Room
4. A dedicated room for Bonded Storage
5. A dedicated room for Bonding and Cleaning
6. A Machine Shop
7. A large vacuum tank that opens into the clean room for calibration and testing of flight quality components and systems.
8. A facility for vacuum bakeout, cleanliness assessment and thermal cycling.
9. A 20 foot long 30" diameter vacuum facility with Newtonian telescope for calibration and testing of x-ray and ultraviolet experiments in less rigorous contamination environment.
10. A vacuum facility for calibration of optics and detectors. Fed by both x-ray and UV monochromators, the facility has a six axis goniometer, resident detectors and calibration transfer standards.

ARL, although less than ten years old, already has an extensive history in support of astronomical instrumentation. It has been used in support of:

1. The spectrograph for the Far Ultraviolet Spectroscopic Explorer (FUSE).
2. The optics for the Cosmic Origins Spectrograph (COS).
3. Numerous sounding rocket experiments in the ultraviolet, extreme ultraviolet and soft x-rays
4. SOFIA, NASA's infrared stratospheric facility
5. Bolocam, a deep infrared ground based project
6. X-ray Interferometry for MAXIM and the Black Hole Imager
7. NICFPS, a focal plane package for APO.

<u>Goddard Space Flight Center</u>

Specific GSFC facilities relevant to NWO include a scatterometer testbed (FAUST), a formation flying testbed (FFTB), the detector characterization laboratory (DCL), and the Advanced Interferometric Metrology (AIM) laboratory. The Fully Automated Ultraviolet Spectrographic Tester (FAUST) developed in the Diffraction Grating Evaluation Facility at NASA's GSFC is a robust, easy-to-use, automated scatterometer operating in the vacuum ultraviolet (VUV) through near infrared wavelength range (100 to 1100 nm), measuring bi-directional reflectance (BRDF) of optical surfaces over a wide range of scatter angles. Various types of light sources (spectrally narrow lasers and VUV lamps) and detectors are employed to cover the spectral range. The entire system, including data acquisition and analysis, is fully automated and controlled via a personal computer with a user-friendly program written in Labview. Scatter measurements are reduced to standard BRDF, accounting for a well-characterized instrument signature. The instrument has a dynamic range of over 11 decades (in units of inverse steradians), with a noise level limited by Rayleigh scattering in the air surrounding the sample and by electronic noise. It is capable of very low angle (few arcseconds) and very wide-angle (up to 120 degrees) scatter measurements under zero to 90 degrees angle of incidence variations using the same set-up. High dynamic range of the instrument allows measurements of the scattering properties of both very specular (mirror-like) and very rough surfaces with high accuracy. A 2 m long, rotating arm affords an angular resolution of 0.001 degree over a 120 degree range for reflectance measurements. The sample mount is capable of 3 arcseconds incident angle resolution and can hold samples up to 30 cm in diameter. The FAUST scatterometer's modular design allows fast and easy modification of the instrument's set-up. FAUST has been tailored to represent certain instrument configurations for the HST Cosmic Origins Spectrograph (COS) to successfully measure vacuum ultraviolet scatter for that instrument's flight gratings. The NWO team intends to use the FAUST facility to measure scatter off candidate starshade materials provided by NGAS.

Figure M-6: GSFC Detector Characterization Laboratory (DCL). Shown is the WFC3 test setup.

The FFTB provides a hardware-in-the-loop test environment for formation navigation and control. The FFTB is evolving as a modular, hybrid, dynamic simulation facility for end-to-end guidance, navigation, and control (GN&C) design and analysis of formation flying spacecraft. The Flight Executive (FE) processes GPS, Crosslink, or other sensor measurements for orbit determination, navigation, and control. As a core capability, the FFTB provides support for testing software algorithms with hardware in-the-loop. Testing software in the presence of essential hardware allows for risk reduction/mitigation and aids mission planning and design. The FFTB architecture is designed to reduce the software development burden associated with integrating components and features into the test-bed, leaving more time for testing and evaluation.

The GSFC Detector Characterization Laboratory (DCL; Figure M-6) is a purpose-built facility for the integration and test of flight detector systems, with emphasis on large-format arrays in the λ=180 nm to beyond 5 µm wavelength range. The DCL has two main facilities for testing large format detector arrays, each with its own cleanroom, control room, and non-cleanroom fabrication, integration, and test areas. In one, the visible CCDs and infrared HgCdTe arrays (1.7 µm λ_{co}) for the Wide Field Camera 3 (WFC3) instrument for the Hubble Space Telescope (HST) have been tested. The design and test of hardware for HST's Advanced Camera

Figure M-7: AIM Laboratory at GSFC

for Surveys (ACS) instrument repair mission was performed in this laboratory. GSFC's previous testing of photon-counting e2v L3 CMCCDs was also done in this laboratory. In addition to the usual CCD tests mentioned above, exoplanet science (and photon counting in general) requires careful control of spurious charge. Spurious charge can arise within the CMCCD itself, e.g. clock-induced charge (CIC) and/or dark current in the charge multiplier (CM), or from shortcomings in the test setup including light leaks. Our experience testing e2v's n-channel CMCCDs suggests that understanding spurious charge in the CM will be a major focus with the first-generation parts. For example, we have found that we can separate CIC from dark current in the CM by varying clock rates and dwell times per pixel. This distinction is important because design changes to address dark current in the CM are different from those to control CIC.

GSFC also has an Advanced Interferometric Metrology (AIM) Laboratory that is home to the Wide-field Imaging Interferometry Testbed (WIIT). WIIT is a laboratory demonstrator for observational and computational techniques for synthetic aperture imaging of wide fields of view at angular resolutions far higher than that possible by diffraction-limited imaging by its individual collecting apertures. This testbed's operation in the AIM lab is helping to validate observational techniques and data analysis tools for space interferometry and formation flying in space. The AIM lab's environmental stability and vibrationally-isolated optical setup space are essential to the continual collection of interferometric data products which are of the highest possible quality. There are two isolated rooms (11 m x 5 m), an external control room and conduit pathways for electrical, chilled water, etc. Other AIM laboratory characteristics include:

Thermal
- Plenum within a plenum to cancel out heat gain/loss from roof
- Separate AC control for each room with environmental control
- Temperature controlled to (±1° F, ±.5° C) and humidity (±5%,)
- Table tops are single sheet of Invar

Acoustic
- Walls are a sandwich of sand filled masonry block separated from an acoustically absorbent face panels
- Acoustically absorbing floors

Air Flow
- Cleanliness controlled to class 10,000
- Variable low velocity gravity airflow
- Air flows from ceiling plenum through perforated ceiling panels
- The air returns are perimeter floor mounted

Vibration

- Vibration isolation table uses 6-axis piezoelectric active control isolation system
- Isolation to 3 Hz
- Isolation system cancels vibration in real time by sensing floor vibration
- The rooms are decoupled from the existing building's structural frame, roof and external sheathing

NASA Glenn Research Center

The world-class Electric Propulsion Laboratory (EPL) facilities at NASA Glenn Research Center will be used to perform NEXT ion propulsion system verification testing. EPL features two very large space environment simulation chambers; intermediate and smaller environment simulation chambers suitable for testing small engines or components; bell jars used for component-level testing; and support areas including an electronics shop, machine shop, clean room, and office space. The space simulation chambers have been enhanced to support the unique requirements of electric propulsion testing. Vacuum Facility-5 (VF-5) cryopumps 3.5 million liters of air per second with its 33.5 sq meter of 12 K helium cryopanels. VF-6 has a large 25' diameter that allows testing of complex systems, cryopumps 900,000 liters of air per second, and includes a solar simulator and nitrogen cold wall to support a variety of test objectives. A NEXT System Testbed, established under the NEXT technology development project, is compatible with both VF-5 and VF-6 to provide system integration test capability. In addition, VF-16 was developed specifically to support NEXT thruster life testing. This facility will be available to support NWO-specific thruster wear tests. The staff of EPL have been supporting electric propulsion testing for over 40 years and have developed technology leading techniques with precision thrust balances, thruster erosion diagnostics, plume characterization, and EMI/EMC.

M.13 Preliminary Project Plan

The ASMCS guidance for including a project plan from NASA HQ is the following: "For mission concepts that could either launch or begin development (i.e.Phase C) within the next decade (medium class size missions) a notional or preliminary project plan including a description of the phased mission costs and cost estimation methodology and a description of the technical feasibility of the mission." The NWO team concentrated on developing a detailed mission concept that is feasible for the 4 meter telescope and 50 meter starshade architecture. Work was not performed on developing a notional project plan. However, many sections of the NWO ASMCS report are indeed parts of a project plan that would be developed during formulation. Many of the remaining sections can be easily developed upon further study.

As defined in NPR 7120.5D, the Project Plan is an agreement among the Project Manager, Program Manager, Center Director, and as required, the Mission Directorate Associate Administrator (MDAA). Other Center Directors providing a significant contribution to the project also concur with the Project Plan to document their commitment to provide required Center resources. It defines, at a high level, the scope of the project, the implementation approach, the environment within which the project operates, and the baseline commitments of the program and project. The Project Plan is consistent with the Program Plan. The Project Plan is updated and approved during the project life cycle in response to changes in program requirements on the project or the baseline commitments. In the Project Plan, all subordinate plans, collectively called Control Plans, are required. They are based on requirements in NASA Policy Directives (NPDs) and NASA Procedural Requirements (NPRs) that affect program/project planning. Certain Control Plans (the SMA Plan, Risk Management Plan, SEMP, and Software Management Plan) are required to be stand-alone plans with summaries and references provided in the Project Plan. The remaining Control Plans can either be part of the Project Plan or separate stand-alone documents referenced in the appropriate part of the Project Plan. In the case of the latter, the Project Plan contains a summary of and reference to the stand-alone document; the approval authority for the stand-alone Control Plan is the Project Manager. If a section of the Project Plan is not applicable to a particular project, this can be indicated by stating that in the appropriate section and providing a rationale. If a section is applicable but the project desires to omit the section or parts of a section, then a waiver must be obtained in accordance with the waiver process for NPR 7120.5D. This waiver approval is documented in Part 4.0, Waivers Log, of the Project Plan. The outline of the Project Plan per NPR 7120.5D is shown below.

1.0 Project overview
- 1.1 Introduction
- 1.2 Objectives
- 1.3 Mission description and technical approach
- 1.4 Project authority, governance structure, management structure and implementation approach
- 1.5 Stakeholder definition

2.0 Project Baseline
- 2.1 Requirements baseline
- 2.2 WBS baseline
- 2.3 Schedule baseline
- 2.4 Resource baseline

3.0 Project Control Plans
- 3.1 Technical, schedule and cost control plan
- 3.2 Safety and mission assurance plan
- 3.3 Risk management plan
- 3.4 Acquisition plan
- 3.5 Technology development plan
- 3.6 Systems engineering management plan
- 3.7 Software management plan
- 3.8 Review plan
- 3.9 Mission operations plan
- 3.10 Environmental management plan
- 3.11 Logistics plan
- 3.12 Science data management plan
- 3.13 Information and configuration management plan
- 3.14 Security plan
- 3.15 Export control plan