Technology for the next generation space telescope

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ABSTRACT

The Next Generation Space Telescope (NGST) is a major element of NASA's Origins Program. It is planned to be a deployable infrared telescope with an 8m diameter aperture and a sensitivity ≈1000 times greater than any currently existing infrared telescope. The scientific goals of NGST include imaging and spectroscopic characterization of the earliest galaxies and proto-galaxies, which formed following the "big bang". Several years ago, NASA embarked on an aggressive technology development effort covering a number of technical areas including optics, detectors, deployable structures, wavefront control, passive cooling, operations, etc. This paper presents an overview of the status of the program NASA is pursuing to provide the necessary technologies, which will enable an exciting, affordable NGST mission.

Keywords: NGST, telescope technology, large optics, cryogenic optics, IR astronomy

1. INTRODUCTION

The Next Generation Space Telescope (NGST) mission[1] is a key element in NASA's Astronomical Search for Origins strategic theme. The current NGST vision evolved from the report of the "HST and Beyond" blue ribbon committee entitled, "*Exploration and the Search for Origins: A Vision for Ultraviolet-Optical-Infrared Space Astronomy*,"[2] which recommended development of a general-purpose, near infrared observatory equipped with a primary mirror larger than 4 meters, cooled to ≤70K, optimized for 1-5 micron observations and placed far from the earth to achieve a sensitivity up to 1000 times greater than any existing or planned facility.

A series of detailed studies beginning in 1996 and continuing to the present has concluded that, with appropriate development of advanced enabling technologies, a large space based infrared telescope with an 8m diameter aperture, can provide supreme science return in a timely and cost effective manner. A well planned, adequately funded technology program was recommended, progressing from key laboratory innovations, to ground based demonstrations, to selected flight validations and space qualification. Such a program was initiated in late 1996 and continues to date. The planning process and details of the initial NGST Technology Plan were presented previously.[3] This paper presents an overview of the current status of technology development activities for NGST.

2. MISSION REQUIREMENTS

Top level requirements for NGST have continued to evolve as architecture and science studies have progressed.[4-6] Certain "Baseline" requirements have been adopted for study purposes. Specific NGST science requirements will continue to be reviewed and assessed by NASA and finalized prior to the end of the Formulation Phase of the Mission. In the interim, technologies are being developed and evaluated consistent with mission parameters which include an 8m aperture, an operational wavelength range of 0.6-≥10μm, diffraction limited performance at 2μm, zodiacal light limited sensitivity in a sun-earth L2 orbit and a ≥5 year duration. The anticipated instrument suite includes a vis/near-IR wide field camera and spectrometer and potentially a mid-IR camera and spectrometer. As technology products are developed and data is generated in validation testing, the information is being fed back to refine the integrated models[7] and generate more accurate performance predictions and requirements definition.

3. KEY NGST TECHNOLOGIES

Early NGST architecture studies conducted by joint NASA, industry, and academia teams, beginning in 1996 and continuing to the present have yielded a set of key technologies and prioritized recommendations for their development. The prioritization was based on perceived criticality to the mission and the existing state of maturity in the 1996 timeframe. These recommendations were largely the basis for formulating the NGST technology development plan and program. Ten key technology products have been identified for acquisition and/or development and delivery to the mission prior to the implementation phase. The desire is that these products will be developed, demonstrated and validated to a level of maturity consistent with the NASA Technology Readiness Level (TRL) 6 or greater prior to delivery to NGST. TRL 6 requires a successful system/subsystem model or prototype demonstration in a relevant environment (ground or space). These ten key technology products are shown in Table 1.

Table 1. NGST key technology products

• Lightweight Cryogenic Primary Mirror
• Cryogenic Actuators
• Cryogenic Deformable Mirror
• Wavefront Sensing & Control Methodology
• Large Format, Low Noise IR Detectors
• Precision Deployable Structures
• Vibration Control Methodology
• Low Vibration. Long Life Cryo-Coolers
• Lightweight Sunshade
• Advanced Operations Methodology

The technology development effort was broken down into five major Technology Development Elements, each with a cognizant lead center and a set of defined technology products for which that element is responsible. The primary elements of the plan, the cognizant organization, and areas of responsibility are described below.

3.1. Optics technology

The NASA Marshall Space Flight Center (MSFC) has led NGST optics technology development. MSFC is responsible for development and validation of technologies for the lightweight cryogenic primary mirror, various types of cryogenic actuators and the cryogenic deformable mirror that may be required by NGST. The NASA Langley Research Center (LaRC) and the Jet Propulsion Laboratory (JPL) have supported MSFC in development of the cryogenic deformable mirror and actuators.

3.2. Wavefront sensing and control technology

The GSFC and JPL with support from the MSFC, are co-leads for the development and validation of wavefront control technology for NGST including system level methodology, hardware and software for alignment, phasing and wavefront sensing & control of a segmented space telescope.

3.3. Detector technology

NGST detector technology development has been led by the NASA Ames Research Center (ARC). ARC is responsible for the development and validation of the large format, low noise vis/near IR and mid IR detectors for NGST including both the sensing arrays and the readout electronics.

3.4. Spacecraft technology

Development and validation of a number of spacecraft related technologies reside in this element including precision deployable structures, vibration control, low vibration cryo-coolers and a lightweight sunshade. The technology providers include several NASA centers and industry partners and consequently, the GSFC has responsibility for this area.

3.5. Operations technology

NGST operations technology development and validation responsibility has been assigned to the Space Telescope Science Institute with support from GSFC. Specific capabilities under development include an Autonomous Scheduler and a Scientist's Expert Assistant for aid in proposal writing and observation planning. Future efforts will develop and validate advanced and autonomous operations methodology for both the flight and ground portions of NGST operations.

4. TECHNOLOGY PRODUCT DEVELOPMENT STATUS

A brief description of the approach and current status for development and validation of each of the ten technology products listed in Table 1 follows. The products have been grouped according to the five NGST Technology Development Elements described in Section 3.

4.1. Optics technology

4.1.1. Lightweight cryogenic primary mirror

The NGST primary mirror is anticipated to be a segmented deployable optic with segment size being in the range of 1-3m depending on the details of the architecture. The secondary mirror will likely be a monolith similar in size to one of the primary mirror segments. Over the past 4 years the NGST program has initiated and implemented an aggressive lightweight cryogenic mirror technology program. The program was designed to challenge and excite the optical community in reaching a new standard in production of lightweight optics. The goal was to develop optics at ≤ 15 kg/m^2, operational at ≈ 40K and meeting the overall NGST observatory requirement for diffraction limited performance at 2µm. In order to meet the NGST needs, technology efforts were initiated to investigate and develop mirrors in a variety of materials, which held promise for the program. The basic technology approaches have initially targeted the production of large mirrors in the 1.2-2.0m diameter range (or side-to-side distance in the case of hexagonal optics). Although this size may not be the final size of an NGST primary mirror segment, it was felt that a 1.2-2.0m optic would be of sufficient size to understand the mirror material and fabrication processes which drive the cost and schedule of mirror production. The ultimate goals of the technology program are both to demonstrate mirrors meeting the NGST performance requirements, and to establish cost and schedule credibility for producing and implementing the mirrors for the NGST flight system. As discussed later in this section, establishing cost and schedule credibility is essential to NGST which is a cost capped mission, with past program experience demonstrating that the optics will be a large portion of the total cost of the program. The first two years of the program were dedicated to understanding the various applicable materials, funding those materials to various levels of maturity and implementing the first large mirror procurement, the NGST Mirror System Demonstrator (NMSD), in order to establish a benchmark for the state-of-the-art in lightweight optics and to establish credibility that the goals of NGST could be achieved. The past two years of the program has seen major steps in the development of several mirror materials, which not only might have NGST applicability but could also support other programs for other customers. Additionally, a second large mirror procurement, the Advanced Mirror System Demonstrator (AMSD), has been implemented providing a focal point to complete the mirror technology development and lead ultimately to the production of mirrors that will fly on NEXUS (the NGST flight experiment- discussed below) and NGST.

Areas of focus in the preceding years of NGST technology have supported the ongoing large mirror procurements with investigations of a number of smaller scale optics. The goal of investigating a variety of materials, developing the basic material capabilities and furthering that basic technology to the development of demonstration mirrors in the 0.25 meter to 0.5 meter size has provided a path for many of the materials to the larger 1.2 to 1.5 meter sized optics being procured by the NMSD and AMSD efforts. In the past three years, materials of interest have included CVD and reaction bonded silicon carbide (SiC), carbon infused silicon carbide (CSiC), replicated nickel (Ni), silicon (Si), beryllium (Be) and glass including ULE, fused silica, and zerodur. Several of the concepts investigated involve hybrid designs incorporating one of the above materials for the reflective surface with a lower precision composite support structure. Although many of these materials have been used for mirrors in the 25-100 kg/m^2 range, none of them have been taken to the 15 kg/m^2 required by the NGST technology program. The progression of the technology program in developing basic manufacturing processes leading to development of mirrors in the 0.25 to 0.5 meter class has provided substantial benefit to the advancement of the NGST mirror technology. For example, early in the technology program a material called CSiC, developed by IABG in Germany, was brought to the attention of the NGST program. Although at the time, the suppliers felt that the material was too heavy to meet the 15 kg/m^2 requirement of the program, the company was challenged to attempt to look at new and innovative means of reducing areal density. As a result of the small-scale technology efforts implemented by NASA with IABG, CSiC has not only been produced within the NGST guidelines for areal density, but also a 0.5m mirror has been produced, polished and tested. This is true for many of the materials NGST investigated early in the program including single crystal Si/poly-foam mirrors developed by W.J. Schaffer which showed good promise in 7.5cm samples during cryogenic tests. Replication techniques for Nickel and CVD SiC were investigated for their potential as an effective means of producing lightweight mirrors with a substantially reduced cost and production schedule. Although both Nickel and CVD SiC replication have not shown the maturity required for NGST flight mirrors, the technology program advanced this interesting technology which may some day be used as cost effective materials for ground or space based optics. For Be optics, funding was provided for basic material investigations including the development of bonding techniques to support joining experiments for Be pieces in order to avoid the costly expense of facilitation to produce larger Be blanks. Since the production of Be mirror blanks is currently limited to approximately 1.4m symmetrical segments, joining could allow larger segments without NASA investing in significant facility costs. Since glass mirrors have significant heritage, although not in the 15 kg/m^2 range, limited funds were invested early in basic glass mirror technology although glass was later addressed by the NMSD effort, the first major NGST mirror procurement.

In 1997, the NGST program challenged the optical community and attempted to gauge the likelihood of producing mirrors meeting the NGST requirements. The NMSD program was initiated in order to investigate the development of 1.5 to 2.0 meter mirrors again at 15 kg/m^2 areal density. It was apparent from the evaluation of the submitted proposals that, for a variety of reasons, the community felt that, at that time, only glass mirrors (or glass hybrids) could meet the NMSD requirements. Evaluation of this led to four basic conclusions: 1) The optical community was not fully ready to accept a challenge of producing mirrors at 15 kg/m^2; 2) Be was expensive and could not meet the 2 year schedule for production; 3) SiC was not mature enough to meet the technical or schedule requirements of NMSD; and 4) the NGST program had not advanced many of the materials mentioned in the preceding paragraph to the point to legitimately propose them for NMSD. The two mirrors selected for production were a glass meniscus mirror developed by the University of Arizona (UofA) and a glass hybrid mirror developed by Composite Optics, Inc. (COI) of San Diego, California in collaboration with REOSC outside of Paris, France. Both mirrors were to be produced in a two year time period with final cryogenic testing around April, 1999. The UofA mirror[8] represents a high authority approach where many actuators and load spreaders are use to provide figure adjustment on the mirror itself. The COI/REOSC mirror[9] is considered a semi-rigid mirror, which has limited figure adjustment with the primary capability being radius of curvature control. Although neither contractor was able to meet the proposed schedule for manufacturing and the mirrors are still in the process of development, many lessons have been learned from these initial attempts to produce lightweight optics at the 1.6(COI/REOSC) and 2.0(UofA) meter size. Not only has the experience been useful for the NMSD contractors, it has provided invaluable input for the implementation of the AMSD procurement. The COI/REOSC mirror, shown in Figure 1a, will go through the first round of cryogenic testing in March, 2000. Due to a material processing problem, resulting in a flawed blank and leading ultimately to a mishap with the first meniscus produced, the UofA is in the process of completing a second glass facesheet and should be ready for integration with its support structure and cryogenic testing later this summer.

Due to the fact that no Be mirror was selected for development as part of NMSD, and that it looked like a potentially promising material for the program, a procurement was initiated in late 1997 to investigate development of a subscale Be mirror. Since Be mirrors have a history of cost, schedule and performance issues it was felt that by producing a subscale Be mirror the NGST program might gain some advancements in understanding the performance, cost and production issues for beryllium while keeping the financial risk to the program low. The Subscale Beryllium Mirror Demonstrator (SBMD) was awarded in December, 1997 to Ball Aerospace teamed with Tinsley Optics for the production of a 0.5m semi-rigid Be mirror. This procurement was geared to the production of the facesheet only in order to focus on understanding the production issues for the Be material. The SBMD optic, shown on its test fixture in Figure1b, was delivered to NASA within specification and went through the first cycle of cryogenic testing in November, 1999 with very encouraging results, including low surface roughness and low hysteresis on thermal cycling. It is currently in a cryo-figuring cycle and appears likely to be a promising candidate for NGST optics as well other cryogenic applications.

Figure 1a. COI/REOSC 1.6m NMSD mirror

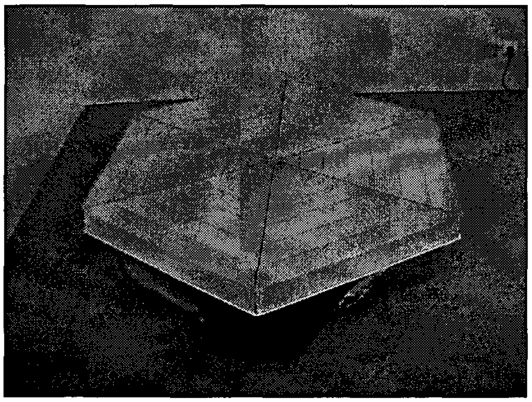
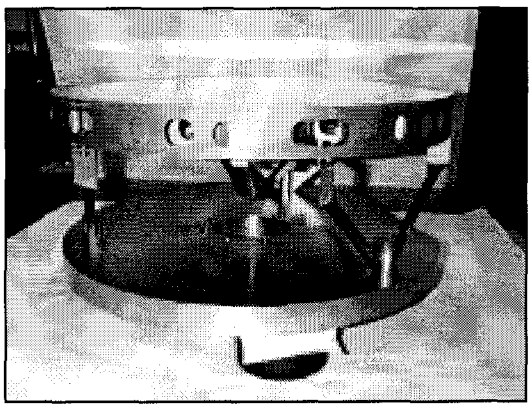


Figure 1b. Ball/Tinsley 0.5m SBMD mirror



In the summer of 1998 the NGST program initiated bold new discussions with several other partners regarding similar interests and needs for lightweight mirror technology. Out of these discussions was born the AMSD effort. The goals of the program are two fold: 1) develop mirrors which meet technical specifications and provide a path for reduction of cost and schedule in producing lightweight optics, and 2) develop mirror technology meeting the partner's various needs for both cryogenic and ambient applications. The procurement was setup as a phased down-select with Phase I, the design phase, being completed in September, 1999. The first goal in this procurement was met by exciting the optical community which took the challenge of producing lighter weight optics and directing attention to reducing schedule and production costs. The Phase I solicitation brought multiple offerers with 16 design proposals. The selection process resulted in funding of 8 designs among 5 vendors. The designs included a variety of materials such as Be, SiC, glass and glass hybrids and a range of approaches for producing the mirrors from meniscus or high authority to semi-rigid or rigid (low authority) mirrors. Phase II of this procurement is now in the final stages of selection for fabrication and testing of these new lightweight mirror technologies. This activity is expected to be completed by February, 2002.

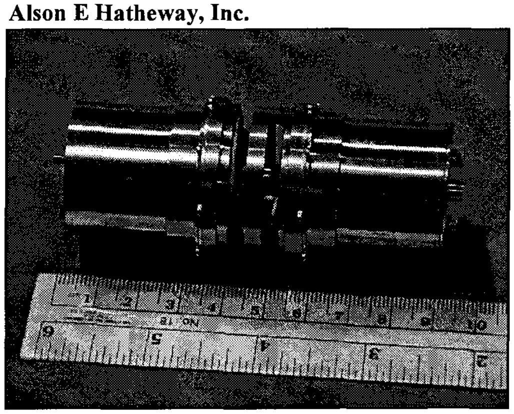
In order to provide a common test capability and facility for evaluation of the various developmental NGST mirrors, NASA has modified the X-Ray Calibration Facility located at the Marshall Space Flight Center.[10] This facility was previously utilized for testing of the Chandra X-Ray Telescope optics. A helium shroud, cooled with a closed cycle refrigerator and capable of accepting up to 2m optics for testing with the optical axis in the horizontal orientation, was added along with a vibration isolated interferometer. The initial use of this facility was to test the SBMD mirror. The future NMSD and AMSD mirrors will be tested in this facility. Potentially, this facility could be modified for cryogenic testing of the NGST flight optics.

The goal of the overall NGST lightweight cryogenic mirror technology program is to bring the technology to a readiness level by the Non-Advocate Review (NAR) which provides a clear path to the NGST flight mirrors. The technology and programs described above support this goal and have served NASA and industry well in developing a new outlook on the production of lightweight optics not only for missions like NGST but also for even lighter weight optics which will be needed to meet the future need of NASA and other applications.

4.1.2. Cryogenic actuators

Cryogenic actuators for rigid body motion and, potentially, deformation of the NGST mirror segments are key elements of the NGST system concept. Five technology development efforts were funded by NGST, under the direction of the LaRC, to develop position actuators and force actuators meeting the NGST requirements for stroke, resolution, power, mass, and cryogenic performance. The suite of devices studied included electro-mechanical devices, electroceramic devices and magnetostrictive devices. Several useful prototype actuators were built and tested at the cryogenic actuator test facility at JPL. The Alson E. Hatheway, Inc. electro-mechanical actuator shown in Figure 2, proved to be one of the most successful devices demonstrated as part of this effort and is currently under further development.

Figure 2. Precision cryogenic actuator from Alson E Hatheway, Inc.



4.1.3. Cryogenic deformable mirror

Achieving diffraction limited performance from the NGST optical system may require correction of the wavefront using a cryogenic deformable mirror at an image of the pupil. Deformable Mirrors (DMs) with up to 1000 actuators or more are common in adaptive optics systems for ground based telescopes. However, these devices are not currently suitable for NGST because they do not operate at cryogenic temperatures and they require massive, high power drive electronics. The NGST cryogenic actuator development effort described previously included two activities aimed at producing small (10 x 10) actuator arrays meeting the NGST cryogenic DM requirements for stroke, resolution, power, mass, and cryogenic performance. Two different schemes were investigated including one based on electroceramic actuators and another based on magnetostrictive actuators driven by superconducting electronics. While significant progress was demonstrated toward development of both devices, the electroceramic based system investigated by Xinetics, Inc. appeared to present the most promise. Currently, a significant development effort is in progress at Xinetics, under the auspices of the MSFC with support from JPL, to build a fully functional, flight qualified, prototype mirror including the necessary low mass, low power drive electronics and software.

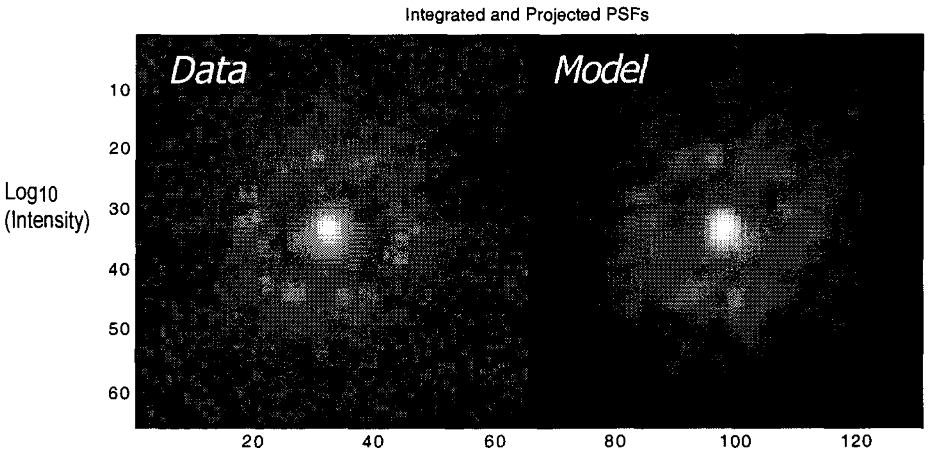
4.2. Wavefront sensing & control technology and methodology

Wavefront control (WFC) is at the core of the NGST system, from the rigid body positioning and control of the primary mirror segments and the secondary mirror to high bandwidth compensation for jitter associated with mechanical disturbances. A WFC architecture concept for NGST[11] was developed by JPL, GSFC and MSFC early in the NGST study phase and a plan was developed for investigation of it through a WFC testbed. The concept involves a layered control approach utilizing image based wavefront sensing with the science camera. Hardware and software technology for alignment, phasing and wavefront sensing and control of a large segmented telescope has been developed and integrated into an NGST WFC testbed at GSFC. The phase 1 testbed has been completed and extensive investigations of the basic WFC elements have been completed. The testbed currently includes a telescope simulator[12] consisting of a white light point source, along with a low resolution DM and phase plates to aberrate the wavefront, thus simulating the effects of an imperfect telescope. The critical WFC hardware includes an active optics (AO) bench with provision for all of the key elements of the baseline wavefront control architecture developed for NGST including relay optics, a second higher resolution DM, a fast steering mirror and a coarse and fine wavefront sensor. Testbed software includes all the algorithms to analyze the phase information and wavefront errors and calculate the required corrections, as well as the drivers for the various active elements. The testbed is being used to investigate and evaluate techniques for coarse and fine wavefront sensing, coarse alignment of primary mirror segments, phasing of the primary mirror segments, wavefront correction with a DM, and image stabilization with a fast steering mirror. Results are compared to predictions from the NGST integrated modeling activity.

The first stage of the NGST WFC scheme is the initial segment capture and phasing -- the initial telescope setup following deployment. A Dispersed Fringe Sensor[13] (DSF), similar to the devices used in large ground based interferometers to phase the siderostats, is used to precisely measure the magnitude and sign of segment to segment piston differences. The DSF provides information for correction of piston errors in the mm range, with accuracy to about 1um. For NGST, the DFS will be applied to each segment in turn for comparison to a central reference segment, and actuators will be utilized for rigid body position correction until the entire pupil is aligned and phased. Recent testbed experiments have confirmed the performance of the DFS system and predictions of our models. Blind testing of several different phase plates with calibrated steps simulating the effects of displaced, unphased segments has shown the high accuracy of the DFS technique. Model results indicate that the DFS will achieve excellent performance even in the presence of large aberrations, misalignments, or actuator errors.

Fine wavefront sensing and control is the second, clean-up stage of figure control for NGST, reducing the error from a few waves down to the level of diffraction limited performance. WFC testbed experiments have been performed beginning with the introduction of mid-to-low spatial frequency aberrations onto the source wavefront with the telescope simulator DM. This aberrated wavefront is injected into the AO bench optical train and passed through the all AO bench optics to the science camera. Wavefront sensing is achieved through a few cycles of (1) taking in-focus and out of focus images with the science camera; (2) processing the images using phase retrieval and phase unwrapping algorithms[14] to get a phase estimate; and then (3) computing and applying new settings to the higher resolution AO DM which attempts to correct the wavefront. At the end of this iterative process, the in-focus point spread function (PSF) has been dramatically improved. Figure 3 shows and example of deep PSF data recorded on the testbed following correction of the wavefront along with model predictions.

Figure 3. Experimental and predicted PSF data from the NGST WFC testbed



This PSF shows the expected features of a DM-corrected wavefront, characterized by (1) a tight core; (2) a "dark hole" with very little light surrounding the core; and (3) a halo of scattered light at the spatial frequency Nyquist limit of the DM. The data are well predicted by the model calculations at the 633nm wavelength. In this case, the final wavefront error was $\approx\lambda/20$ in the visible, which corresponds to $\approx\lambda/60$ in the near IR. Systematic experiments are underway to define dynamic range and ultimate performance of this WFC architecture. So far, wavefront sensing repeatability is better than $\lambda/100$ in the visible over a variety of conditions. Performance has been found to be robust with respect to jitter and other blurring effects due to laboratory disturbances. Test results to date indicate that the NGST baseline WFC system can provide a superb IR imaging system.

Several upgrades are planned for the NGST WFC testbed to more fully explore NGST WFC issues. First, the telescope simulator module will be replaced by a small three mirror segmented telescope with rigid segments. With the implementation of this element, the ability to autonomously align and phase segments based on the predictions from the DFS will be demonstrated. Secondly, the fast steering mirror will be added to the system to demonstrate jitter control. Finally, a telescope simulator with high authority segments may be added to investigate the trade space between wavefront correction at the primary mirror verses at a tertiary DM.

4.3. Detector technology- Large format, low noise IR detectors

Focal plane detector technology will play a central role in the overall system performance and scientific return of NGST. To allow detection of extremely faint sources over extended fields of view, advances are needed to assure that very large format, extremely sensitive, well-characterized detector arrays are available to the instrument teams.

NGST will require focal planes with sensitivity levels beyond the present state-of-the-art, and will require that these excellent detectors be assembled into very large formats (e.g., modules of about 16 Mpixels in the 0.6 to 5 μm range). Overall, the key challenges are achieving unprecedented levels of array sensitivity, and developing means to closely-pack "building block" arrays into very large arrays, without loss in pixel-level sensitivity.

A number of development projects are now underway to demonstrate candidate technologies in time for instrument selections.[15] For the 0.6 – 5 μm range, InSb and 5 μm-cutoff HgCdTe projects are funded. Both are pushing to reduce read noise and dark current, and are presently developing 1k x 1k (InSb) and 2k x 2k (HgCdTe) arrays for NGST. Both are also extending measurements into the visible, to support the concept of both science and pointing use of these arrays. In the mid-IR, two candidate projects are underway. Arsenic-doped silicon (Si:As) arrays with reduced dark current and large (412 x 512, and 1k x 1k) formats are being developed. Also, a backup project is nearly completed, which would produce Si:Ga devices, which would provide partial far-IR spectral coverage at somewhat higher detector operating temperatures. Figure 4 shows two examples of developmental NGST arrays.

In the very near future, NGST plans to initiate hardware contracts to address the problem of multi-chip module producibility, demonstrating concepts for electrical interconnects, and means to close-butt the arrays. Work to improve the manufacturing technology associated with these arrays is also planned.

For the flight arrays, the selected instrument teams will manage the final development stages. Tasks during this implementation phase will include ground-based laboratory and astronomical testing, and iterative improvement of sensitivity and module performance of these large arrays.

Figure 4a. 2k x 2k HgCdTe array

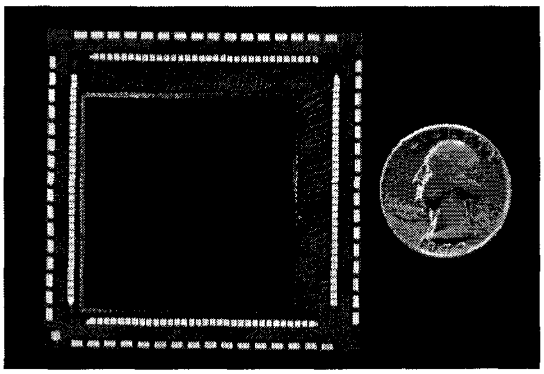
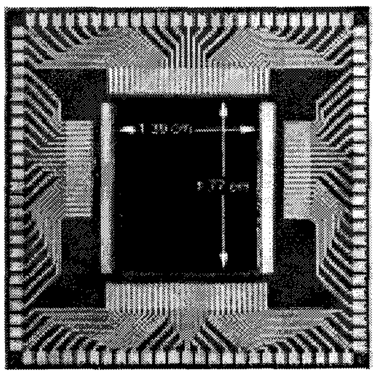


Figure 4b. 412 x 512 Si:Ar array



4.4. Spacecraft technology

4.4.1. Precision deployable structures

The technology for precision deployment is fairly mature in light of the requirements anticipated by NGST. Considerable expertise in this area resides in the US aerospace industry. Thus, the principal source for technology to deploy the primary mirror, the secondary mirror and possibly other large structural elements of NGST is the potential NGST system contractor teams led by Lockheed-Martin and TRW/Ball. Several testbeds have been or will be constructed to evaluate different schemes for precision deployment. Initial results have shown that the capability to deploy precision structures to meet NGST requirements is currently in hand. Stability, including microstability of large deployed structures will be evaluated in relevant environments. The results will be compared to the anticipated dynamic range of the NGST optical control system and will be used to upgrade and validate the integrated models.

4.4.2. Vibration control methodology

It is anticipated that the technology to stop vibrations arising from, for example, the spacecraft reaction wheels, from reaching the Optical Telescope Assembly (OTA), through a combination of passive and active isolation and control will be available on the time scale that NGST enters its implementation phase. Other NASA missions, including the Space Interferometry Mission and their contractors, including Lockheed-Martin and TRW are developing or have already demonstrated techniques in this area that will meet the NGST needs at frequencies >1Hz. Very low frequency vibrations that may be associated with the large sunshade will be eliminated with the fine guidance control system. All of these efforts will be monitored along with the progress in the development of quiet reaction wheels and the results will be integrated into the NGST vibration control methodology development strategy.

4.4.3. Low vibration, long life cryo-coolers

A substantial effort in the development of quiet coolers for astronomical applications is on-going under the NASA Cross Enterprise Technology Development Program. Two coolers are currently under development, which might meet the needs of NGST. The baseline NGST cooler is a miniature version of Turbo-Brayton Cooler that is being developed out of GSFC at Creare, Inc. A moderate size version of this cooler has been developed for the NICMOS instrument on the Hubble Space Telescope. The design and fabrication of a smaller version for NGST is in progress at Creare. As a backup, NGST has the sorption cooler technology currently being developed for the Far Infrared and Submillmeter Space Telescope (FIRST)/Planck mission at JPL. NGST plans substantial investments over the next several years potentially along with its sister Origins mission, the Terrestrial Planet Finder, to ensure availability of the necessary cooler technology.

4.4.4. Lightweight sunshade

A large, lightweight sunshade will be necessary to shield NGST from solar radiation and allow it to passively cool to its operational temperature. Several designs have emerged utilizing multiple membranes which operate like multi-layer insulation and which can be stowed efficiently for launch. A reliable deployment mechanism is required. Schemes much like those that enable large antennas such as TDRSS to be deployed are possible for the NGST sunshade, however, another possibility is an inflation deployed shade. The technology for the inflation deployment methodology and the inflatable structure, including rigidization techniques, has been developed by NGST at ILC Dover and L'Garde, Inc.[16] A laboratory demonstration of deployment of a 1/2 scale prototype NGST shade was recently accomplished at ILC Dover's facility in Dover, Delaware (see Figure 5).

Figure 5. 1/2 scale inflation deployed sunshade demo

The first NGST flight validation experiment, the Inflatable Sunshield In Space (ISIS) experiment is planned to carry a 1/2 scale inflation deployed sunshade and deploy it from the Space Shuttle. A further description of the status of ISIS is included below.

4.5. Operations technology- Advanced operations methodology

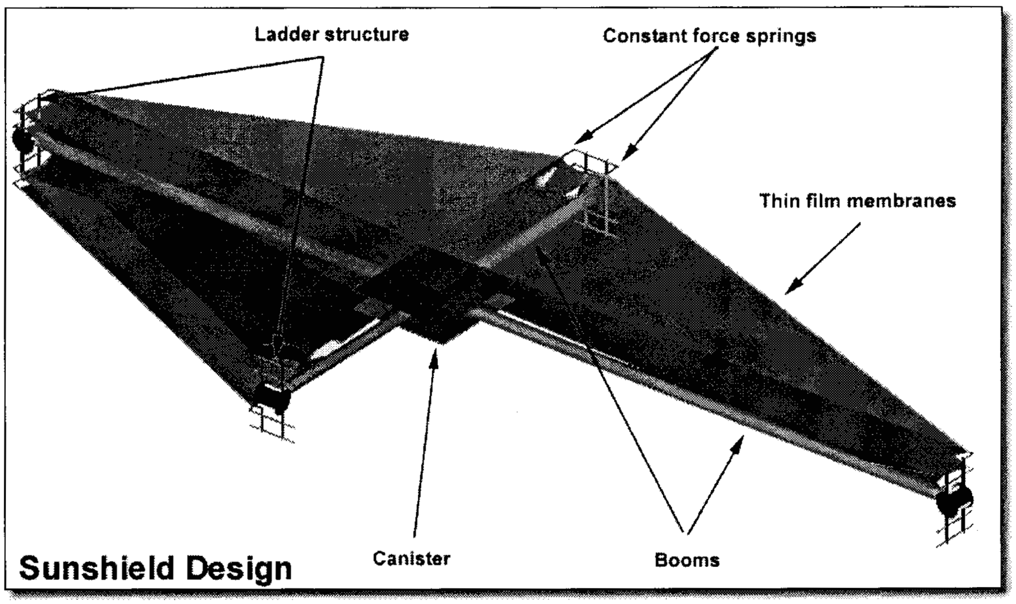
The NGST operations technology development is largely being performed under the guidance of the Space Telescope Science Institute (STScI), the designated NGST operations center. Among the principal products planned are an adaptive scheduler, and a planning tool called the scientist's expert assistant. The adaptive scheduler is currently under development. This is an object oriented code that will eliminate the need to time tag each event in a sequence and will enable autonomous execution of tasks by the spacecraft. The scientist's expert assistant has been developed as a tool that will reduce the need for potential PI's to access "contact scientists". It will facilitate proposal writing and observational sequence planning. This tool is planned to be beta-tested by STScI with the Hubble Advanced Camera. Future efforts include development of advanced flight software methodology.

5. ISIS FLIGHT EXPERIMENT

The Inflatable Sunshield in Space (ISIS) flight experiment[16] is scheduled to fly as a Hitchhiker payload aboard the Space Shuttle in October, 2001. The ISIS mission is designed to reduce risk for the NGST mission by advancing technology associated with design, fabrication, and assembly of large tensioned membranes. During the three day mission, ISIS will be the first space flight experiment to deploy an inflatable structure in a controlled and stable manner, rigidize an inflatable structure in space and obtain flight data to validate dynamic modeling and analysis capability of large tensioned thin-film membranes. The ISIS sunshield is a cuneiform shape, 11m x 5m with four 1 mil, Kapton membrane layers deployed by 13 cm. diameter inflatable booms. The inflatable tubes are a woven composite material impregnated with epoxy resin and will be heat cured after deployment. The Space Shuttle will be used to excite the dynamics of the sunshield and to obtain the on-orbit measurement data that will be used to produce a high-confidence flight-validated sunshield analytical model.

The design for all flight experiment hardware (shown in Figure 6) is complete, and ground testing of a full-scale engineering model will begin this summer with a full deployment in a large thermal vacuum chamber to evaluate system performance. ILC Dover is providing the inflatable tubes, controlled deployment system and flight membranes to the NASA flight experiment team.

Figure 6. Cut-away view of the ISIS sunshield design



6. NEXUS FLIGHT EXPERIMENT

The most significant and final NGST flight experiment, termed NEXUS[17], is planned to demonstrate deployable optics in the space environment. This is perhaps the most important technology demonstration to validate a deployable telescope as a practical approach to large space telescopes and reduce the risk for using large deployable optics for space telescopes. The NEXUS goal is to build, launch and operate a segmented, deployable 2.6m diameter aperture telescope, using flight versions of AMSD mirror segments and demonstrate diffraction limited imaging of a bright star or other celestial object. At least one of the segments will be deployed in space. The telescope itself will mimic the NGST architecture to the extent practical. NEXUS is currently in the design phase. The flight, planned for 2004, will be near the end of the formulation phase, approximately at the time of the Non-Advocate Review of NGST and along with the Flight System Testbed developed by the system contractor, and other accomplishments, will provide evidence that the NGST team is ready to proceed to the implementation phase.

7. SUMMARY

Early development of advanced technologies from ultra-lightweight mirrors to autonomous ground and flight operations will enable the Next Generation Space Telescope to provide astronomers with maximum science return in a timely and cost effective manner. A well planned, adequately funded technology program, with significant participation from multiple NASA centers and industry, is progressing to develop, demonstrate and validate the key technologies, as described in this paper, that will provide all the necessary elements for an exciting, affordable NGST mission.

8. ACKNOWLEDGMENTS

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