Collapsible Space Telescope (CST) for Nanosatellite Imaging and Observation

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ABSTRACT

Nanosatellites have gained broad use within the university and scientific communities for a variety of applications ranging from Space Weather, Space Biology and Astrobiology. There is great interest to develop high-quality nanosatellite imaging applications to support Earth Observations, Astrophysics and Heliophysics Missions. NASA Ames Research Center is developing a low cost, deployable telescope that, when coupled with the appropriate imager, will provide high-resolution imaging for Earth and Space Observations. The collapsible telescope design is a Strain Deployable Ritchey Chrétien Cassegrain telescope that can fit within the volume of 1U x 4U portion of a 6U nanosatellite platform.

Additional telescope optical prescriptions compatible with the same deployable architecture are being explored. For example, a faster Ritchey-Chretien Cassegrain shortens the deployable volume and allows better matching to a slit- or integral field unit spectrometer instrument where a modest-sized evenly illuminated field size is a driver. The revised packaging may enable room for field-flattener lenses for imaging applications. Our prototype instrument backend is a remote sensing compact spectropolarimeter with no moving parts, currently under development.

The ability to integrate a deployable Cassegrain telescope into a nanosatellite platform matches desires outlined within the TA08 Remote Sensing Instruments/Sensors Technical Area Roadmap and represents game changing technologies in small satellite subsystems to include the potential for swarm missions with distributed apertures.

INTRODUCTION

Increased launch opportunities for 1U – 3U nanosatellites continue to spur the development and utilization of these small satellite platforms. The desire to conduct ever more complex tasks in these platforms is pushing the nanosatellite structure to the next logical size, which is the 6U. The ability to integrate a 6-8" aperture telescope in a 6U nanosatellite spacecraft, demonstrates the applicability of nanosatellites for spaceborne visible imaging and observation systems including astronomy, earth and environmental observation, target surveillance identification and tracking, and other research and operational uses. Utilization of the 6U nanosatellite platform assures low-cost and frequent access to space for both technology demonstrations and operational utilization.

COLLAPSIBLE STRUCTURE DESIGN

In 2010, NASA Ames, in collaboration with the National Society for Black Engineers, conducted a design study to develop a prototype 15-20 cm diameter Collapsible Space Telescope (CST) in a 12 kg 6U nanosatellite [1]. The effort included the definition and specification of telescope and camera optics, physical structure and deployment mechanism, spacecraft interface and integration subsystem, and specification of the target spacecraft performance parameters. A critical design requirement for the Collapsible Space Telescope was that it be fully contained within a 20x20x10cm nanosatellite payload enclosure, and when deployed, extends fully open to 20x20x120cm with f8 target aperture. The study resulted in the demonstration of the collapsible telescope deployment mechanisms. Figure 1 shows renderings of the results of this study with the collapsible telescope integrated within the 6U spacecraft.

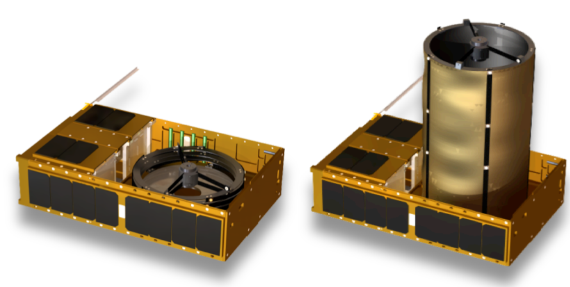

Figure 1. Deployable Telescope in 6U Nanosatellite.

OBSERVATION APPLICATION

Low cost ground imaging satellites are of great interest to the government, scientific and commercial communities. Current 3U based designs have aperture limitations. A 6U design greatly increases the aperture while still maintaining compatibility with existing Cubesat accommodation standards. NASA Ames examined a 6U imaging satellite concept to determine the quality of the image one might expect from a diffraction-limited telescope.
A measure of a telescope's power is its' aperture. For space applications, the user needs to know how clear of an image their telescope is capable of achieving. This clarity is usually referred to as the Ground Separation Distance (GSD), the ability to distinguish distance between two objects when observed from a distance. Table 1 shows the theoretical GSD at various apertures.

Table 1. GSD At Various Apertures and Altitudes

Aperture (mm)	102	127	152	178	240
Alt (km)	G(m)				
200	1.4	1.2	0.96	0.82	0.06
300	2.1	1.7	1.4	1.2	0.09
400	2.9	2.3	1.9	1.6	0.12
500	3.6	2.9	2.4	2.0	0.15
600	4.3	3.4	2.9	2.5	0.18
700	5.0	4.0	3.4	2.9	0.21
800	5.7	4.6	3.8	3.3	0.24

In considering the use of the telescope for Earth Observation, a conservative maximum aperture of 152.4 mm was selected to ensure that adequate space was available for clearance of telescope components, deployment mechanisms, and satellite structure. Also, an f-number of eight is chosen as a compromise between Field of view (FOV), surface resolution, viewable surface contrast and physical focal length requirements.

FOV and maximum resolution is a function of both the telescope configuration and the imaging sensor. The simulation configuration is shown below in Figure 2, and is used to simulate the FOV and resolution capabilities of a small space telescope. Using the specifications similar to a Canon EOS Mark II sensor (representing a high quality commercial imaging sensor), a plot is overlaid on an image obtained from Google Earth of Moffet Field CA showing horizontal FOV of 7.37 km (shown as black box) and a 400 m object (shown as a square box) as approximately the smallest object viewable without pixilation when zoomed to occupy 25.4 mm (1 inch) on monitor. As a note, for most viewers 300 pixels per inch is threshold for normal viewing without a distinguishable pixel structure. Images can be digitally enlarged beyond this point, however quality will be diminished by pixilation.

In addition to the simulation shown above, an amateur Orion 152.4 mm f/9 Ritchey Chrétien telescope is fitted with a Canon EOS Mark II digital camera with a WTF-E4 wireless transmitter to simulate the Ritchey Chrétien strain deployed configuration proposed for the CST. Images of the Moon are taken from Moffet Field CA. to obtain practical performance expectations for this configuration. The results of this field test show that an estimated moon surface resolution of 40 km and a wide field of view are obtainable, even when JPG compression is used and typical atmospheric turbulence is present. This lunar surface resolution of 40 km equates to an angular resolution of 0.099 µrad, or an estimated 25 m ground resolution at 250 km orbit looking down at the earth. It is important to note that this surface resolution is defined here as the smallest object that can be recognized in the image. When enlarged, this object will have pixilation, as seen in Figure 3, therefore this is smaller, estimated to be about 1/8 of the ground distance, than the non-pixilated resolution which is used to determined the size of red boxed area in Figure 2. The results of the moon photographs show that simulated calculations shown are a reasonable, if not conservative, approximation of the telescope performance for the configuration detailed in this report.

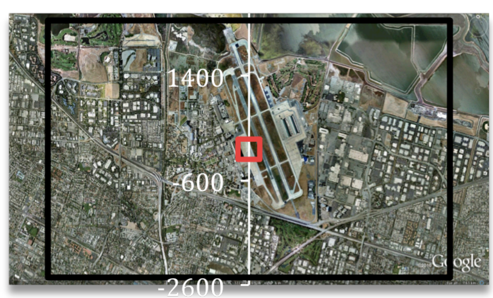

Figure 2: FOV simulation of a 152.4 mm f/8 telescope front end to a Canon EOS 5D Mark II sensor (Pixel size of 6.4 µm and a resolution of 5616 by 3744 pixels) in a 250 km orbit.

Though it did not conform to the present Cubesat standard, the PRISM satellite, launched in 2009, by the Intelligent Space Systems Laboratory (ISSL) of the University of Tokyo demonstrated a strain-deployed telescope in a 8.5 kg small satellite platform. They were able to acquire images of 30-meter ground resolution. Optical performance can be greatly improved in subsequent satellites with improved on orbit lens alignment, larger aperture, higher pixel count CCDs, and improved satellite stabilization.

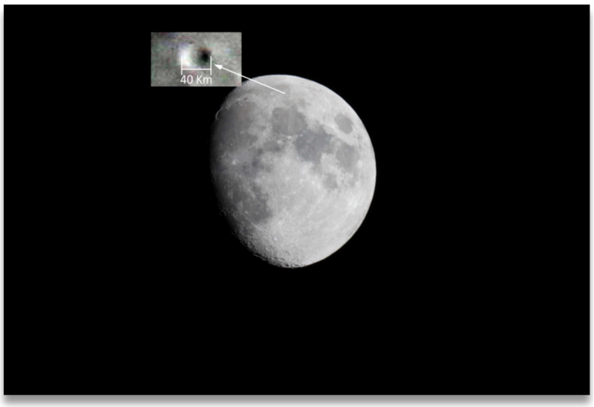

Figure 3. Field test image captured from Moffett Field with 40 km crater easily distinguished in the image.

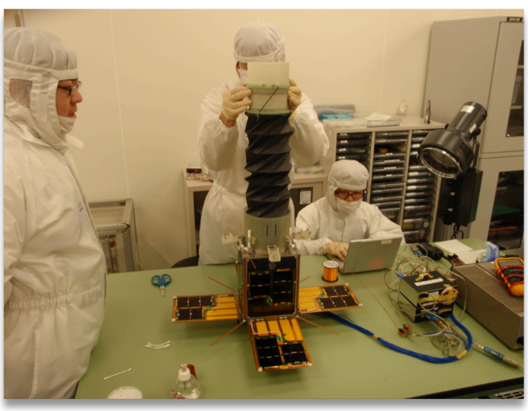

Figure 4. University of Tokyo PRISM team member assembling the PRISM space telescope [2].

SPECTRAPOLARIMETER APPLICATION

Deployable high-throughput telescopes enable scientific investigations on a small spacecraft platform that would otherwise have required larger packaging environments. Specifically, a collapsible telescope format packaged in the small-satellite architecture enables a larger diameter field of view. Funded by a Center Innovation Fund, we have adopted the baseline f/8 design and made optical-mechanical modifications to enable compatibility with a compact spectropolarimeter, under design at NASA's Ames Research Center.

Our spectropolarimeter requires a high-throughput entrance aperture fully-illuminating an entrance slit. The instrument's compact format (13.8 x 20.3 x 7 cm, 1.6 kg) makes it ideal for small-satellite and rover-based architectures. Prior to this effort, our instrument's baseline aperture diameter, compatible with a small-sat architecture, was 76.2 mm (3-inch). With a collapsible telescope doubling our diameter to 152.4 mm (6-inch), our collecting area increases by a factor of four, improving our estimated sensitivity performance. Obtaining a smallsat-compatible packaging for a telescope and spectropolarimeter provides a unique instrument for future astrobiology remote sensing applications of Earth, Mars, outer planet icy moons, and biosignature studies of exoplanets.

We have examined six different optical designs with an effective f/# of 3-6, to comply with our slit-based spectropolarimeter's optical prescription. The final design chosen met our other requirements of (1) 91.6 cm^2 unobscured collecting area, (2) distance between the back of primary mirror and system focus to be at least 6 cm, (3) a fully-illuminated the field over the 50 micron x 5 mm slit area, and (4) a bore-sight repeatability of at least 100 microradians.

Table 2. Top optical parameters for f/6 deployable telescope for 5mm (long) x 50um (wide) slit-spectropolarimeter

System f/#	5.93
Back focal length	355.3 mm
Primary focal length	486.55 mm
Primary Diameter	152.4 mm
Field Diameter	5 mm
Slit FOV	0.316° x 0.003°
Unvignetted FOV dia.	1.8°
Secondary diameter	63.5 mm
% Obstruction (Dprim/Dsec)	41.67%
Mirror separation	295.32 mm
Astigmatism	1.046e-4 mm
Curvature of focal plane	-2.792e3 mm

Top parameters of the final design are summarized in Table 2. We are re-using a 152.4 mm (6 inch) primary from Orion Telescopes in this activity. We have completed a Foucault test to measure its conic constant. A custom secondary mirror is being made by Optical Mechanics (Iowa, USA). The design is diffraction limited at 65 nm

For the mechanical design, we are using rapid-prototyping techniques to quickly refine the design and make it adaptable for future iterations (e.g., remote focus mechanisms, thermal assessment). Figure 5 is a compilation of an SolidWorks model (left) of the spider assembly for the secondary indicating the location of alignment mirror and adjustment screws and (right) a prototype version used for the initial design.

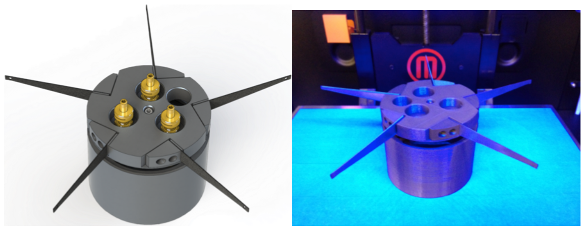

Figure 5. Spider assembly for f/6 system. (left) rendering of back end with 3 adjustment screws, and hole for alignment mirror. (right) Earlier prototype printed by a 3D printer to test out the alignment and locking screw configuration.

The mechanical assembly consists of five 0.81mm x 7.87mm graphite-composite rectangle rods (Coilable Longerons) that provide the stain energy required for the majority of deployment and are tied to 3 aluminum rings (Batten Rings) at pivot points along the longerons. Spectra fibers (Diagonal Stringers) are fed through each pivot point at each longeron-ring hinge interface and are tensioned at full deployment to mechanically constrain the truss-like structure to provide rigidity. Figure 6 shows the configuration of these primary structural components.

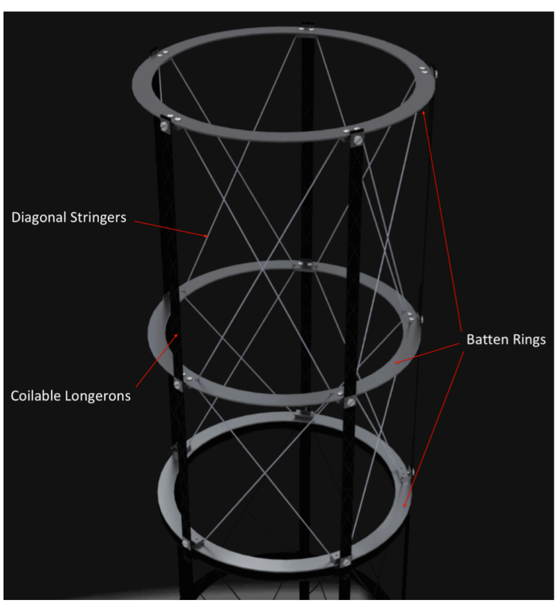

Figure 6. Deployable tube primary structure.

This structure is mounted to an interface plate where the primary mirror holder and a fiber spooling mechanism is attached to the opposite side. Rate of deployment is controlled through a motor driving the spool and final tension is applied to the Spectra fiber by applying a torque to the spool using a linear spring that is mechanically released at a detent in the spool mechanism once the majority of the stain energy of the longerons has been exhausted. To control stray light, the 3 Batten Rings are sized and positioned to serve as annular baffles with additional non-structural aluminum rings hinged at appropriate locations along the longerons. A spider assembly with an adjustment mechanism to position and hold the secondary mirror is mounted to the hinge points at the entrance ring of the telescope. Figure 7 shows a rendering of the mechanical structure in the deployed (top) and collapsed (bottom) configuration. Finally a collapsible shroud wraps this structure to block stray light.

The baseline deployable structure was modified for the specific optical prescription selected for the spectropolarimeter. This included resizing the length of the longerons and the location of the structural and non-structural baffle rings. A manually actuated secondary mirror spider assembly is designed with alignment mirrors to measure relative displacements, post deployment, and provide a simple means for measuring and correcting misalignments. The imaging sensor will be mounted 60mm aft of the primary on an separate adjustment platform to allow access for measurement equipment for lab testing, but a focusing assembly is designed to integrate onto the primary mirror support for mounting a SLR camera during field tests.

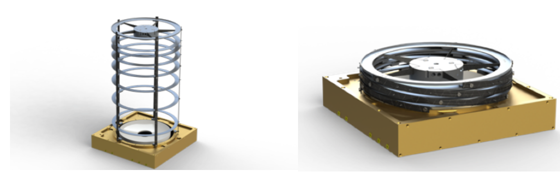

Figure 7: Rendering of mechanical structure (minus light shroud) shown deployed above and collapsed below.

We have identified our baseline optical test program that includes lab and field-testing first with a visible imager to address image quality, boresight alignment, and image performance repeatability. At the end of a 9-month activity, we aim to bring the optical-mechanical design from TRL 2 to 4, completing an end-to-end optical performance tests in a relevant configuration (i.e. attached to a camera and spectrometer).

CONCLUSION

The nanosatellite platform is proving to be a disruptive technology that is providing a means to demonstrate innovative low cost, rapidly deployed technologies for use in science and government applications. One of the areas of interest at ARC is to exploit the platform to conduct earth and space observation missions. In this quest we examined the feasibility and application of a Collapsible Space Telescope. There is growing interest by the commercial sector to provide imaging and observation services. This technology can be readily adapted for a number of observation missions requiring fore optics for sensors.

Acknowledgments

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References

1. Agasid, E., Rademacher, A., McCullar, M., Gilstrap, R. "Study to Determine the Feasibility of a Earth Observing Telescope Payload for a 6U Nanosatellite. Moffett Field, CA, October 2010.
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