Deployable spare telescopes for planetary and astronomic] missions

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Abstract

A telescope folded into minimum volume for launching can be a powerful technique for maximizing the aperture size that can be accommodated in a given launch vehicle shroud. As an example we show our concept for a 1 'olded Astronomic-al Space Telescope (FAST) where a 2.4-m 1 lubble Space Telescope (11 S'1') class of telescope can be packaged in a 1.5-m diameter cylinder. The enabling rationale, general configuration, and optical system technologies for such a telescope will be presen (d.

2. Introduction

1 arge expensive science spacecraft are not on the realizable horizon for the first decades of the 21 st Century. The guidelines today are *small, quick* and *affordable*. To *meet* these goals future large spare optical telescopes need to be significantly different from the classical and conservative form represented by the 11s'1'. The goal is to provide a 3- to S-meter class precision astronomical telescope that can be launched on a mdium-sized unmanned booster, such as Atlas or Delta.

Deployability is important for large optical systems that, when combined with a fast primary focal ratio, can reduce system mass to enable use of a smaller launch vehicle and thereby achieve a significant reduction in mission cost compared to that of the 11s'1'. Deployability is not important for small telescopes for planetary missions, which are often only a small part of the spacecraft, for example the small but versatile camera for the Pluto Mission. We will address the case where the telescope is the largest part of the spacecraft and show how significant gains in lowered mission cost can be accomplished through use of deployability.

3. Background

The proposed Large Deployable Reflector (LDR) was an ambitious attempt to provide astronomers with a 20-meter diameter telescope for infrared and sub-millim - observations. A total of 96 mirror segments were required. Studies addressed several modes for achieving such a large telescope using the dimensional and mass constraints of the Space Shuttle. In the! Course of these studies deployable and space-assembled options were addressed. However, it became apparent that the 1.1)1{ would require both multiple Shuttle missions and assembly at a Space Station. The concept of two- stage optics] was developed to ease the precision required in assembly of the primary mirror segments, the final phasing being done at a 1-meter diameter segmented mirror located at an exit pupil. The estimated costs for the several scenarios showed that such an extremely large telescope as the LDR was unaffordable.

4. Philosophy

The philosophical approach to a Folded Astronomical Space Telescope (FAST) is to reduce the cost to a point so that replacement rather than in-orbit refurbishment would be the most cost effective option. This would provide more missions, economics of a sustained production line, and modular construction. More important, each telescope would be optimized for a particular set of science objectives. The goal would be to provide the resolution and light grasp required for post-HST astronomy.

To meet the new guidelines of *small, quick* and *affordable* we thus propose the concept of a minimally deployable primary mirror that is folded for launch into a compact package. This could provide the means to reach the goal of an HST-class telescope at an acceptably low cost. Coupled with this configuration would be a very fast primary focal ratio such that the deployed telescope would still be very compact and have a minimum moment of inertia.

5. Cost leverage

In order to see how costs can be lowered to where telescopes larger the HST can be achieved within the constraints of fiscal reality we need to examine how the mission cost arises. There are five principal cost elements with fractions as follows:

Telescope	10%
Focal plane instrumentation	10%
Balance of spacecraft	20%
Booster (STS or major booster)	30%
Non-hardware program costs	30%

The fast focal ratio and folded launch configuration would have leverage on costs through a smaller telescope structure and mass. The added complexity of the deployable aspects of the mirror and light shield probably would raise costs and offset gains from the smaller size of the telescope structure. The smaller mass combined with smaller dimensions would mean a smaller moment of inertia, which would lead to a smaller power requirement for control of the spacecraft. Most important the compactness and small mass of the payload would lead to a smaller booster. This possibility is show in Fig. 1 where the size of a 3-meter deployable telescope is shown relative to the HST. Altogether these several factors would provide leverage on 60% of the total mission cost.

Selective, optimized science would have leverage on only 10% of the mission cost. A compact set of instruments is essential to keeping the total size of the spacecraft minimized.

Streamlined decision, contracting and review processes one could yield a shorter time to launch and leverage on 30% of the mission cost.

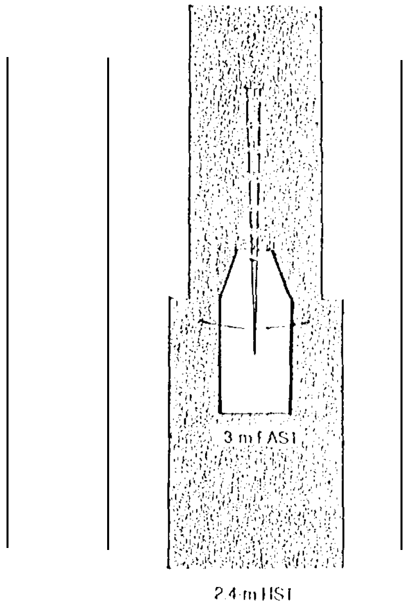

Fig. 1. Comparison of the folded size of a 3-m deployable telescope with the size of the 2.4-m Hubble Space Telescope, showing the relatively small size of the booster shroud required for the former.

6. Deployable optics

There are several ways in which deployability can achieve cost reductions:

1. Shortened overall length through use of fast focal ratios,

2. A segmented primary minor folded to minimize package diameter,

3. Lightest possible mass per square meter for the primary mirror segments, with wavefront upgrading within the ensuing optical train to correct mirror deficiencies.

Fast focal ratios, for example F/0.8 and even faster, are now possible at acceptable cost through the use of advanced optical polishing and testing techniques. These techniques include computer-controlled polishing laps (Roger Angel), stressed mirror polishing (Jerry Nelson), with final touch-up to required tolerances by ion polishing (Kodak), and ion-assisted polishing (Hughes Danbury). The compact length of a telescope using an F/1 mirror is shown in side view in Fig. 2.

A front view of FAST in Fig. 3 shows the telescope both as folded and as deployed. Our conceptual design folds eight equally-shaped mirror segments into two rings, four in each ring, as shown in Fig. 4. The deployed primary mirror has small gaps around the periphery to maximize both light-gathering power and the modulation transfer function.

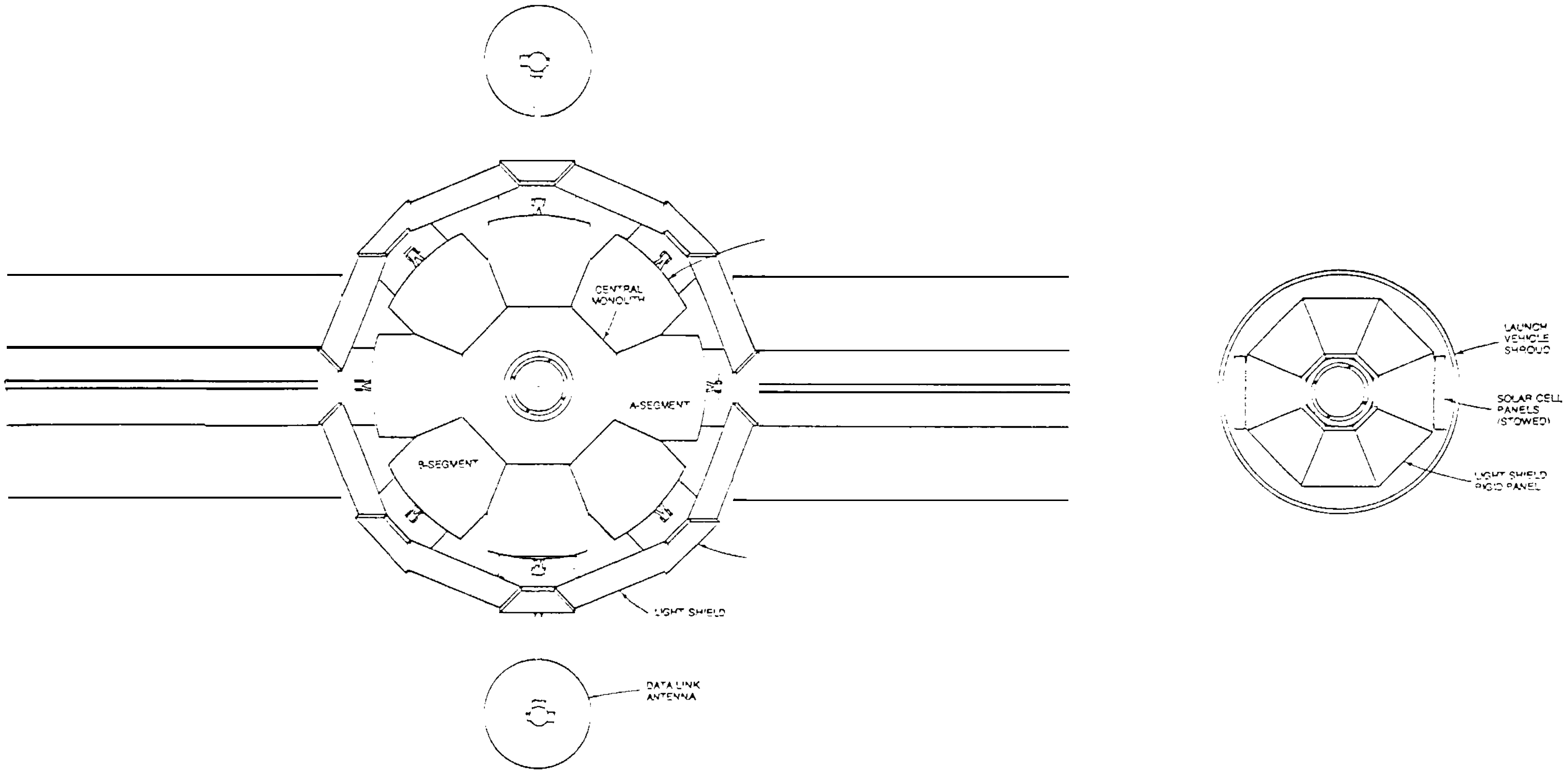

Fig. 3. Front view of a Folded Astronomical Space Telescope configuration having an eight-segment primary mirror.

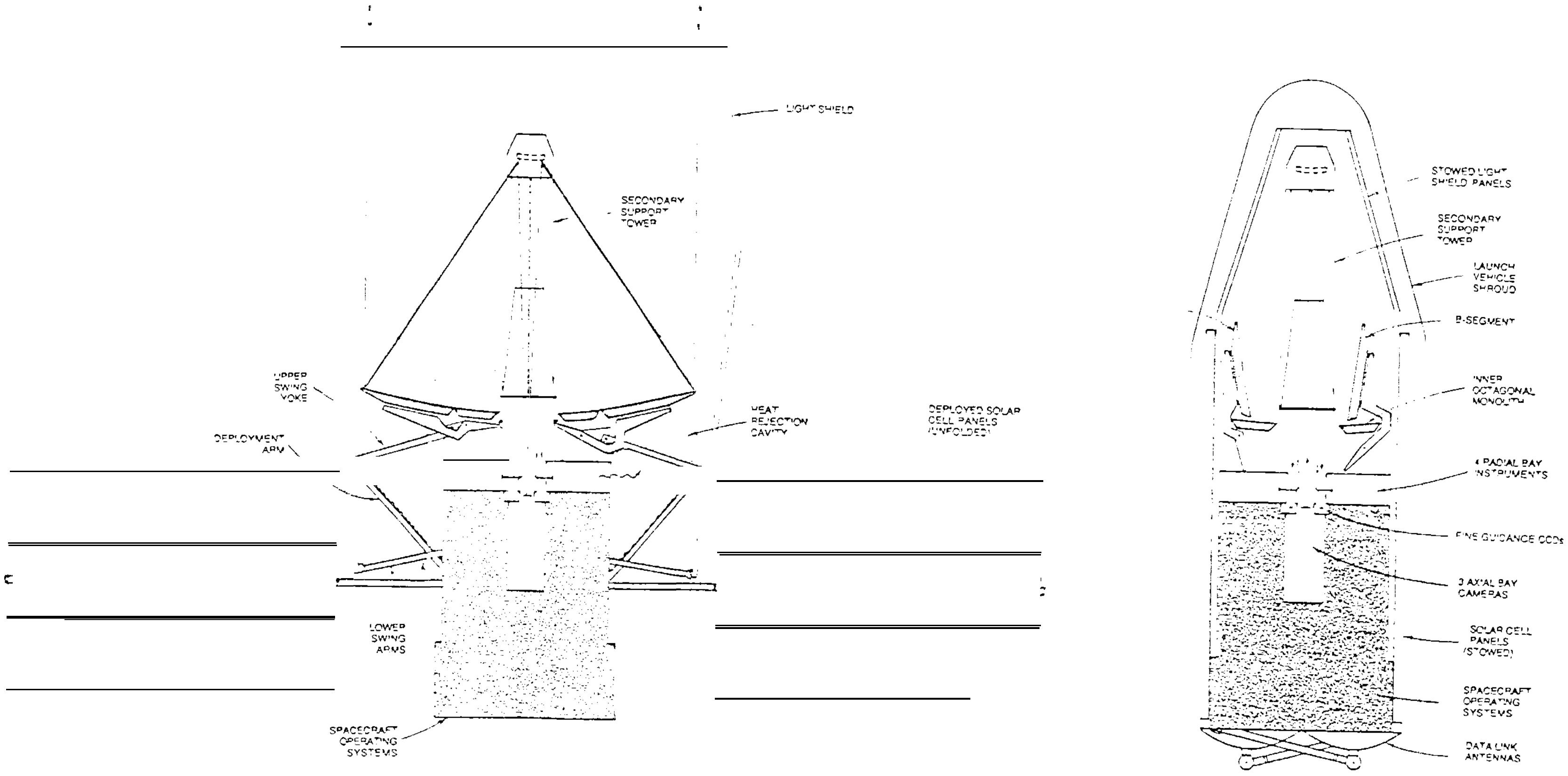

Fig. 2. Side view of a two-mirror Folded Astronomical Space Telescope configuration showing the means for deploying both the primary mirror and the light shield.

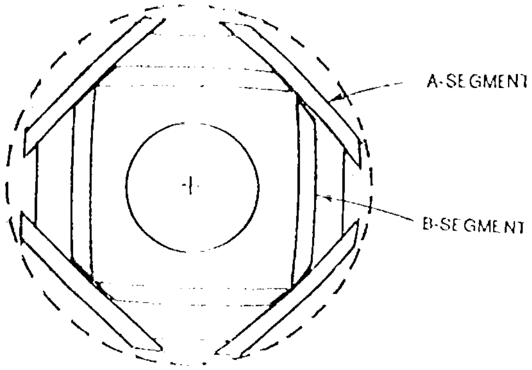

Fig. 4. Front view of the stowed configuration for eight mirror segments, arranged in two rings.

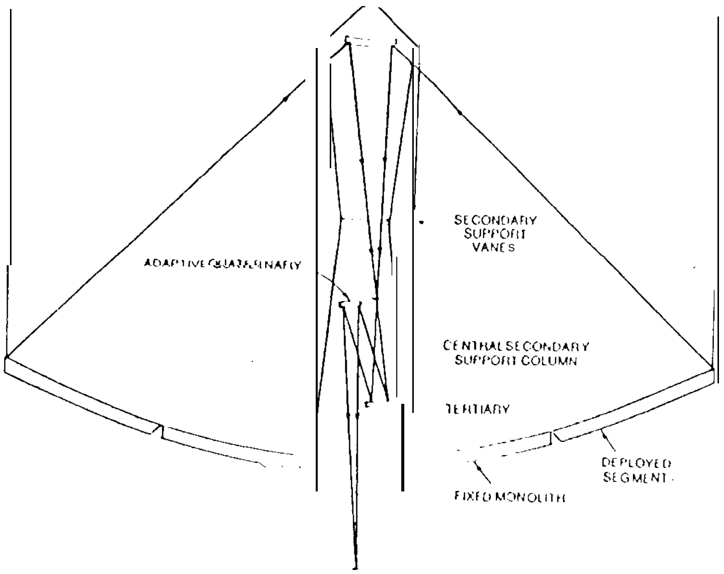

Fig. 5. A possible two-stage optical variant of a Folded Astronomical Space Telescope where wavefront upgrading is done at the small off-axis quaternary mirror.

The major challenge is how to deploy segmented, folded mirror segments to the required wavefront accuracy. High precision mechanical positioning mechanisms and sensing subsystems have been developed that could align segments to the required accuracy for infrared systems without need for wavefront sensing and fine adjustment complications. For visible and ultraviolet high resolution astronomy wave front upgrading after deployment is required. Many techniques for error sensing and actuators to correct this error, either on the primary mirror segments or exit pupil segments, were explored during the LDR program, but few were actually constructed or tested.

It seems to be both a feasible and an advisable next step toward low cost large optical telescopes to pick up the technology demonstration phase where it was left off after LDR.

We have done a preliminary engineering evaluation of how to deploy both the primary mirror as well as the telescope light shield and solar cell panels for FAST. The means for deploying the mirror segments are shown in the side view in Fig. 2. A single mechanism has also been explored that simultaneously deploys the solar cell panels and the light shield, not shown.

7. Wavefront upgrading

The wavefront can be upgraded either at the primary mirror or within the optical train. For far ultraviolet observations the minimum number of reflections is essential to maintain high throughput, so in this case upgrading should be done at the primary mirror. If two added reflections are acceptable then upgrading may be more convenient and less expensive if done at an image of the primary mirror[1] as shown in Fig. 5. One also can upgrade the wavefront within the instrument packages, as was done in correcting the HST for its huge spherical aberration error.

8. Technology challenges

Our examination of a preliminary mechanical design for FAST shows that the required technology is not outside that currently under exploration and development within the optics community. Much was pioneered on the LDR program. The NASA Optics initiative could address the options that we have identified in the FAST concept.

9. Acknowledgments

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10. References

1. A. B. Meinel and M. P. Meinel, "Two-stage optics: high acuity performance from low-acuity optical systems," *Opt. Eng.* 31, 2271-2281 (1992).