Development of an Alignment Monitoring System for High Energy Replicated Optics Scientific Balloon Payload

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Introduction

The High Energy Replicated Optics to Explore the Sun (HEROES) scientific balloon payload is a hard x-ray and solar imaging telescope that will be utilized for astrophysical and heliophysical research. HEROES focuses x-ray sources using a plane of nested arrays of paraboloid and hyperboloid mirrors over a six meter length optical bench to a plane of detectors. Fig. 1 illustrates that the shallow incident angles from the mirrors allow the x-rays to be reflected on the mirror surface rather than pass through the surface. It is critical that the the mirror and detector planes constantly remain aligned in order for x-ray data collection. Misalignment of these planes may occur from bending or twisting along the length of the optical bench due to thermal expansion or external forces on the payload as seen in Fig. 2. The telescope uses a co-aligned, optical charge-coupled device focused at infinity, known as the star camera, to reference star patterns to a database and determine pointing direction. Slight misalignments between the star camera and optical bench axes, shown in Fig. 3, can impair the payload's ability to collect x-ray data from a known source or cause the incorrect assignment of collected data to a referenced sky position. To account for the possible internal misalignments within the payload, a continuously examining alignment monitoring system was developed that independently monitored both the alignment of the mirror and detector planes as well as the alignment of the star camera and optical bench axes.

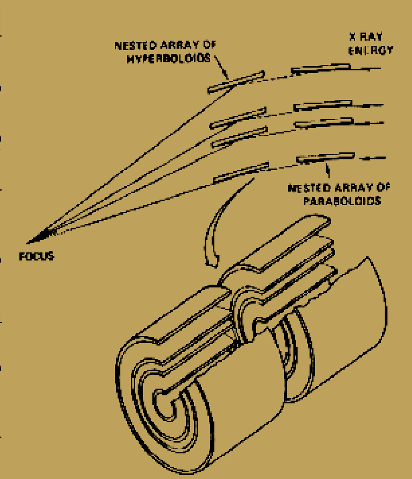

Fig. 1

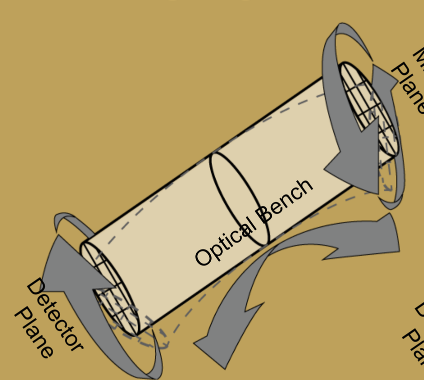

Fig. 2

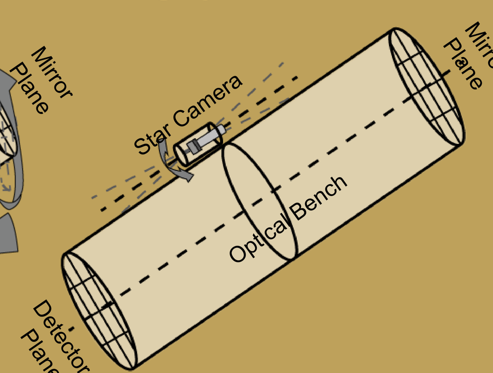

Fig. 3

Concept

To monitor the alignment of the mirror plane and the detector plane, a pair of opposing CCD cameras will continuously take footage of each plane as shown in Fig. 4. A known, non-symmetric pattern of infrared LEDs are placed across the mirror and detector plane flanges. During flight, an occasional snapshot from each of the CCDs will be transmitted from the payload. On the ground, a pattern detection computer algorithm will compare the snapshots from the CCDs to determine if any misalignment has occurred. To monitor the alignment of the optical bench to the star camera, a high energy green laser path is reflected onto an infrared filtered CCD, as shown in Fig. 5. The CCD camera will continuously take footage of the location of the reflected laser on the CCD pixel array. At specified intervals, snapshots from the CCD will be transmitted to the ground. Each image will be compared to the previous snapshot in a computer algorithm to determine the movement of the laser. Based on the distance of the laser movement, a misalignment angle of the star camera may be determined, and the pointing direction may be corrected.

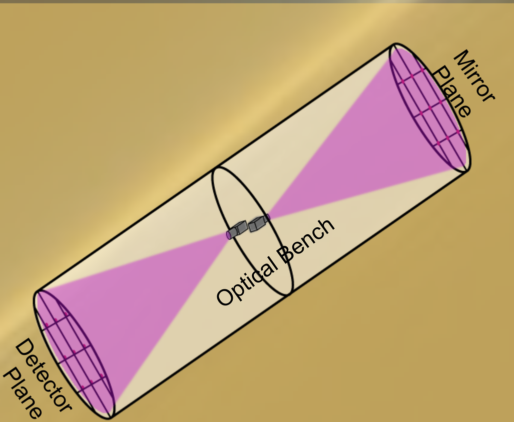

Fig. 4

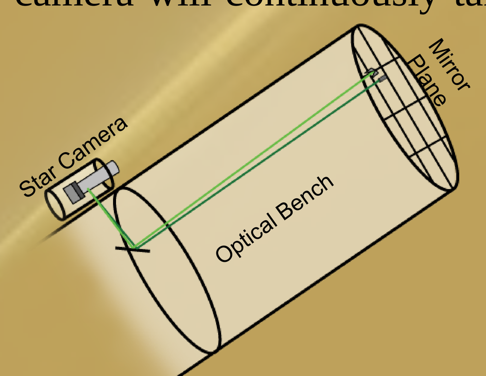

Fig. 5

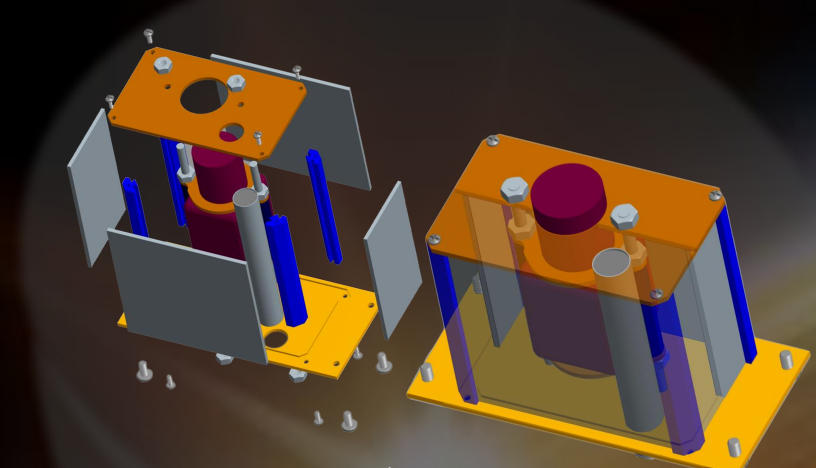

Fig. 6

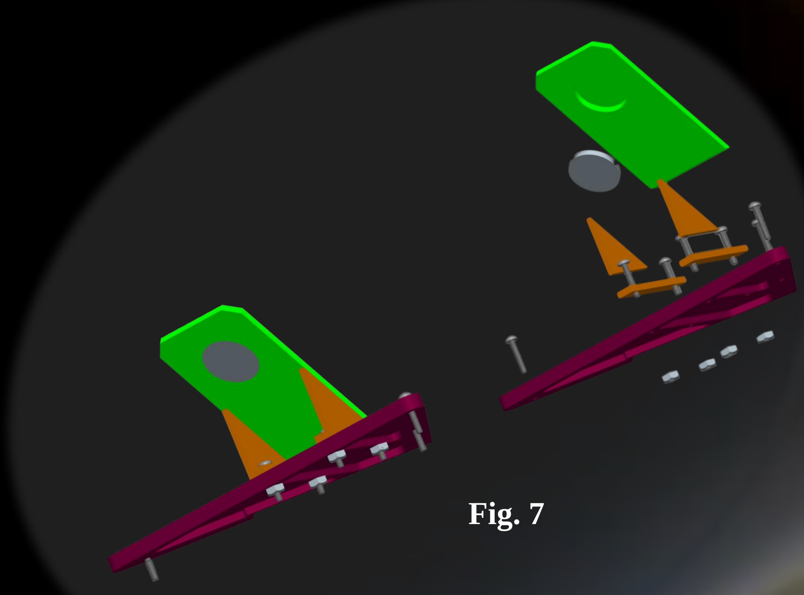

Fig. 7

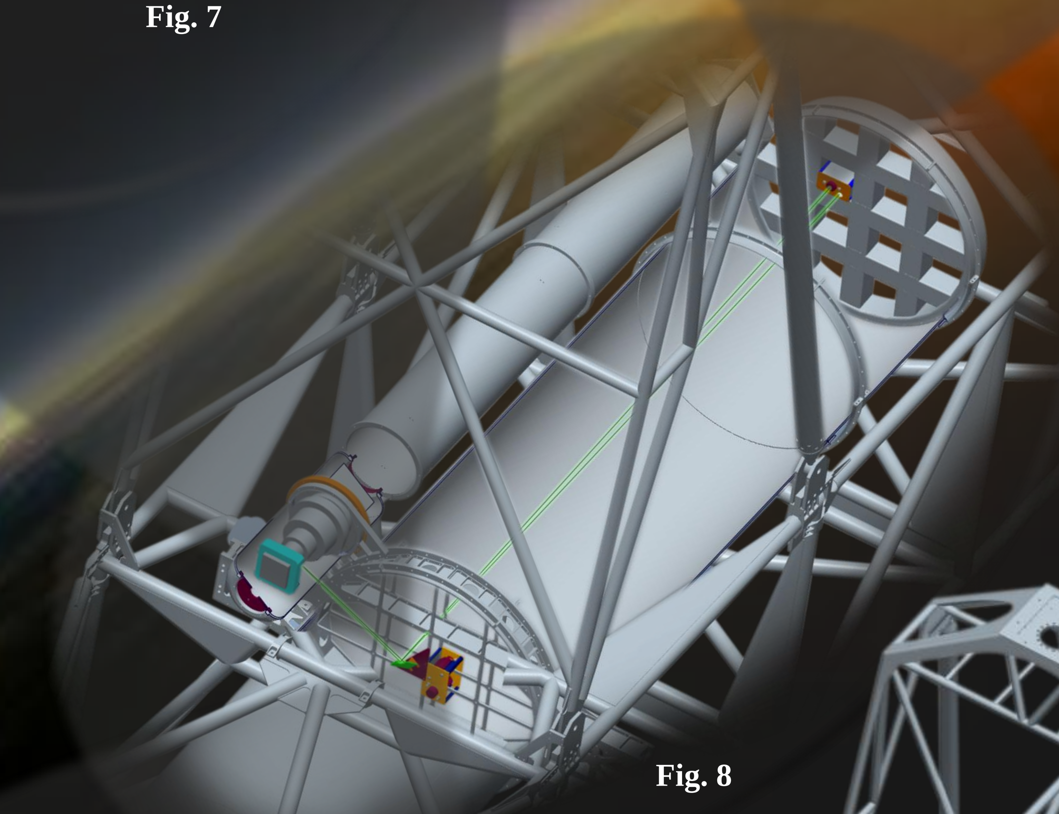

Fig. 8

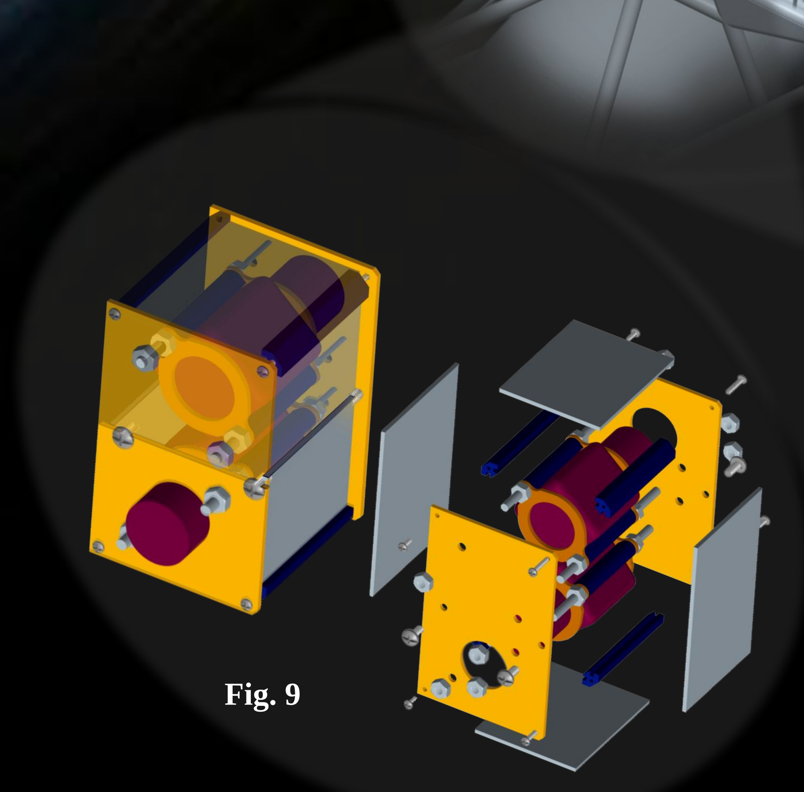

Fig. 9

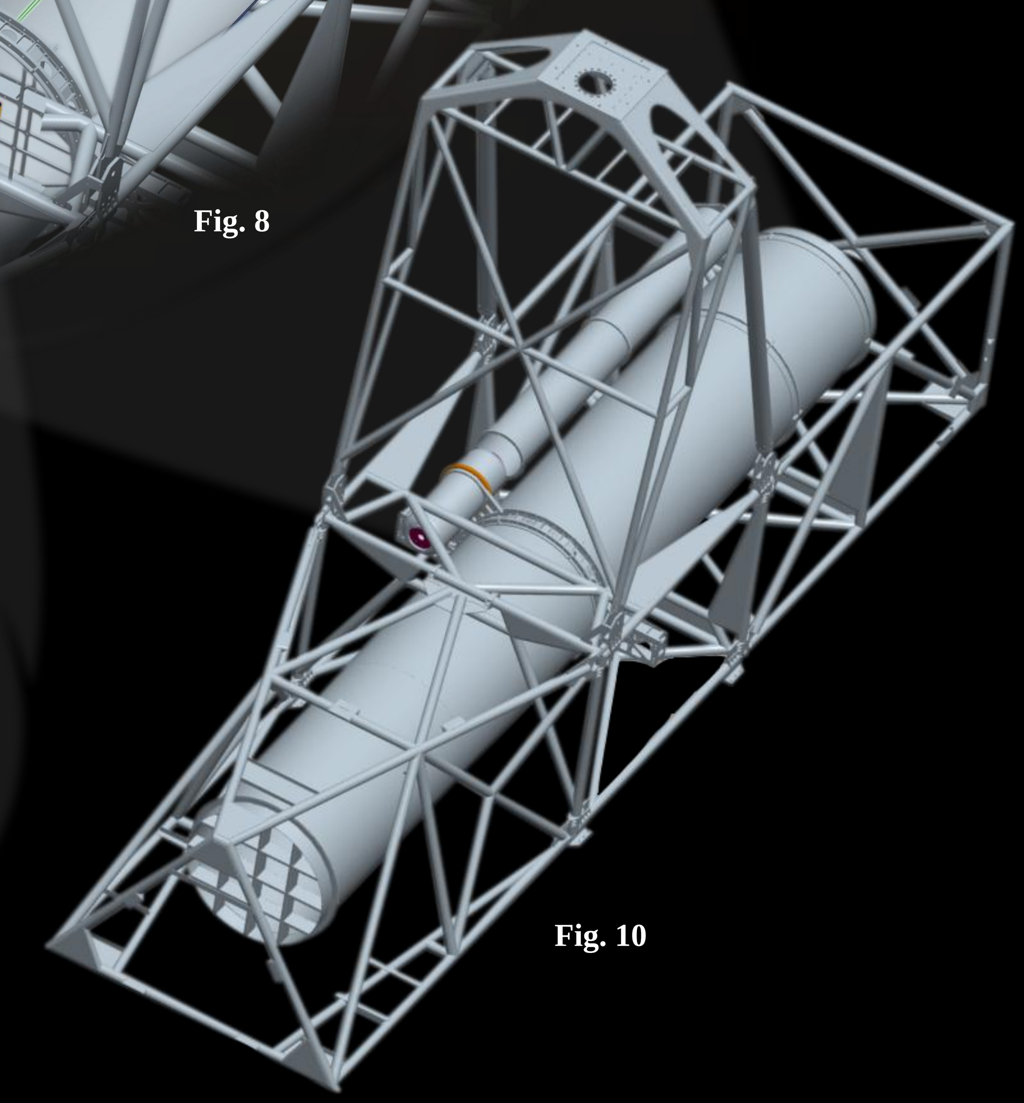

Fig. 10

Component Descriptions

Figure 6 – Star Camera Alignment Monitoring System Thermal Enclosure

A partial cut-away and exploded view of the star camera alignment monitoring system hardware thermal and structural enclosure. The laser detector CCD and laser source are restrained within an aluminum outer housing (yellow, blue, and orange) and silicone foam insulating walls with a reflective internal coating. The assembly is rigidly mounted to the mirror plane flange in the optical bench as shown in Fig. 8.

Figure 7 – Star Camera Alignment Monitoring System Optic Reflector

An isometric and exploded view of the star camera alignment monitoring system laser optic reflector that directs the source laser both into the star camera housing as well as back to the CCD detector. The system is rigidly mounted to the center flange in the optical bench shown in Fig. 8.

Figure 8 – Combined Alignment Monitoring System Representation

A partial cut-away of the HEROES assembly optical bench that illustrations the placement of the thermal enclosures, optic reflectors, and laser path utilized in the alignment monitoring systems.

Figure 9 – Optical Bench Alignment Monitoring System Thermal Enclosure

A partial cut-away and exploded view of the optical bench alignment monitoring system hardware thermal and structural enclosure. Two CCD subassemblies are restrained within an aluminum outer housing (yellow and blue) and silicone foam insulating walls with a reflective internal coating. The assembly is rigidly mounted to the center flange in the optical bench as shown in Fig. 8.

Figure 10 – HEROES Scientific Balloon Payload Representation

A representation of the full HEROES scientific balloon payload assembly. The assembly includes the optical bench support gondola, optical bench, and co-aligned star camera.

Conclusion

The set of alignment monitoring systems will allow for detection of misalignments to a precision of less than one arcminute. The ability to detect and correct for such small angles will allow for high confidence in acquired in-flight data. A highly accurate scientific balloon payload would have a profound impact on the collection of astrophysical and heliophysical data in that research missions may be conducted in frequent, low cost flights that travel far enough into the atmosphere to neglect the atmospheric absorption that hinders ground-based systems.

Future Work

- Develop additional fine adjustment assemblies within the star camera alignment monitoring system to account for optical bench post flight deformations.
- Build and test ground computer systems for analysis of captured alignment monitoring CCD images for analysis and correction.
- Perform in-flight systems testing and proof of concept.

References

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