Specific Investigations on Freeform optics for Space Applications

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by

B. Vishweshwar Rao

Department of Physics

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Thiruvanathapuram – 695547

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Abstract

The rapid advancement of space imaging systems demands the development of innovative optical solutions to achieve high-performance imaging in the visible to Infrared spectral regions. This research focuses on the design, manufacturing and evaluation of freeform optics for space imaging systems, with a specific emphasis on addressing the fabrication challenges associated with convex freeform secondary mirrors and developing robust test and evaluation methods. The main objectives of present research work are to investigate the optical designs of convex freeform surfaces and their performance optimization, the optical fabrication of one of the freeforms and its optical testing. At the end, the improved performance of a TMA optical telescope with the integration of the one of the realized freeform had also been successfully demonstrated.

The envisaged compact optical telescope, operating in the visible region of the spectrum (500-900nm) is meant for space application, with the intent of significantly improving the overall performance in the extended field of regard. The study began by exploring the fundamental principles and advantages of freeform surfaces, highlighting their ability to correct aberrations and enhance optical performance with reduced weight and volume in the given layout. The thesis explored four distinct two-mirror optical telescope configurations, each system leveraging freeform surfaces to achieve superior optical performance compared to its conventional counterpart. Techniques such as Zernike overlays and mirror surface tilts were strategically applied to enhance aberration correction and optimize the optical performance across the entire field of view. Advanced optical design software with efficient optimization algorithms simplified complex design iterations and simulations to effectively attain near-diffraction-limited image quality.The optical fabrication of the Zernike-overlaid convex freeform is carried out with CNC machining and the required surface accuracy specification of less than 15nm rms achieved using bonnet polishing and figuring techniques. The realized convex freeform secondary mirror is successfully tested in conjunction with the primary and tertiary conic mirrors as a TMA telescope system, meeting all the performance requirements satisfactorily.

Additionally, a design simulation exercise is carried out by employing freeform optics in the RC telescope to correct static aberrations in the lucky imaging regime, resulting in improved image quality and resolution. The analytical results presented in the research work will be quite useful for ground telescopes that operate in the lucky imaging mode.