System Design of the Miniaturized Distributed Occulter/Telescope (mDOT) Science Mission

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This paper presents the results of a system design for the miniaturized distributed occulter/telescope (mDOT) science mission conducted by Stanford University and NASA Ames research center under contract from the NASA Mission Directorate. mDOT consists of an occulter microsatellite (270 kg, 192 W End-of-Life) and a telescope CubeSat (6U, 12 kg, 40 W) launched together as a secondary payload into a sun-synchronous low earth orbit (98° inclination, LTAN of noon or midnight, 600km mean altitude). During nominal operations, the telescope images the vicinity of a target star with unprecedented sensitivity in the near-ultraviolet spectrum from within the deep shadow produced by the occulter.

The primary objective of mDOT is to measure the density of debris disks surrounding nearby sun-like stars. These measurements will enable validation of estimation techniques based on excess infrared flux measurements from ground campaigns and identification of systems in which dust may prevent detection of planets. These results can be used to improve the science plans and yield estimates for future flagship exoplanet imaging missions. A secondary objective for the mission is the demonstration of autonomous formation flying technologies for small satellites which are expected to enable entirely new classes of low-cost, high-impact distributed space telescopes.

This paper presents a rigorous point design for the mission which closes with healthy margins on all relevant technical and programmatic budgets, increasing the concept maturity level of mDOT. Specifically, science target selection, optical and orbit design, mission operations, and ground and space segments are addressed in details all the way to bus and payload subsystem sizing, selection, accommodation, and analysis. Special emphasis is given to the guidance, navigation, and control (GN&C) subsystem and to the unique autonomous aspects of mDOT.

The nominal science plan includes ten relevant target stars which are directly imaged five times each for a cumulative exposure time of fifteen minutes per target over a period of one year. The optical system consists of a 3 m diameter occulter at a distance of 500 km from a 10 cm aperture telescope. The occulter is designed to provide a contrast of $10^{-7}$ or better in the B-band (360-520 nm) within a shadow 30 cm in diameter and 10 km in length. The telescope uses a tip-tilt mirror to achieve 0.2 arcsecond image stabilization for diffraction-limited imagery. The formation is equipped with a precise relative navigation system that uses differential carrier-phase Global Navigation Satellite System (GNSS) measurements to achieve centimeter-level relative navigation in real-time. The occulter microsatellite is precisely and autonomously controlled to keep the telescope CubeSat within the deepest part of the shadow using a set of eleven 5N green-propellant thrusters with a total delta-v capacity of 700 m/s. The relative orbit is selected to minimize the delta-v cost of observations by ensuring that the formation is aligned in the cross-track direction. Besides the baseline design, this paper identifies key open trades and demonstrates how mDOT can enable valuable science at low cost while providing a compelling demonstration of the capabilities of small spacecraft.

1: Stanford University  
2: NASA Ames