National Aeronautics and Space Administration

FY24 Topic Areas Research and Technology Development (TRTD)

Micro-thruster Based ACS Architecture Enabling Spacecraft Ultra-fine Pointing Control

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Strategic Focus Area: GNC and Mission Design

Objectives:

Establish JPL capability in the design, modeling, and optimization of micro-thruster spacecraft precision pointing, an enabling technology that could support the demanding stability requirements of next generation telescopes such as Habitable Worlds Observatory (HWO)

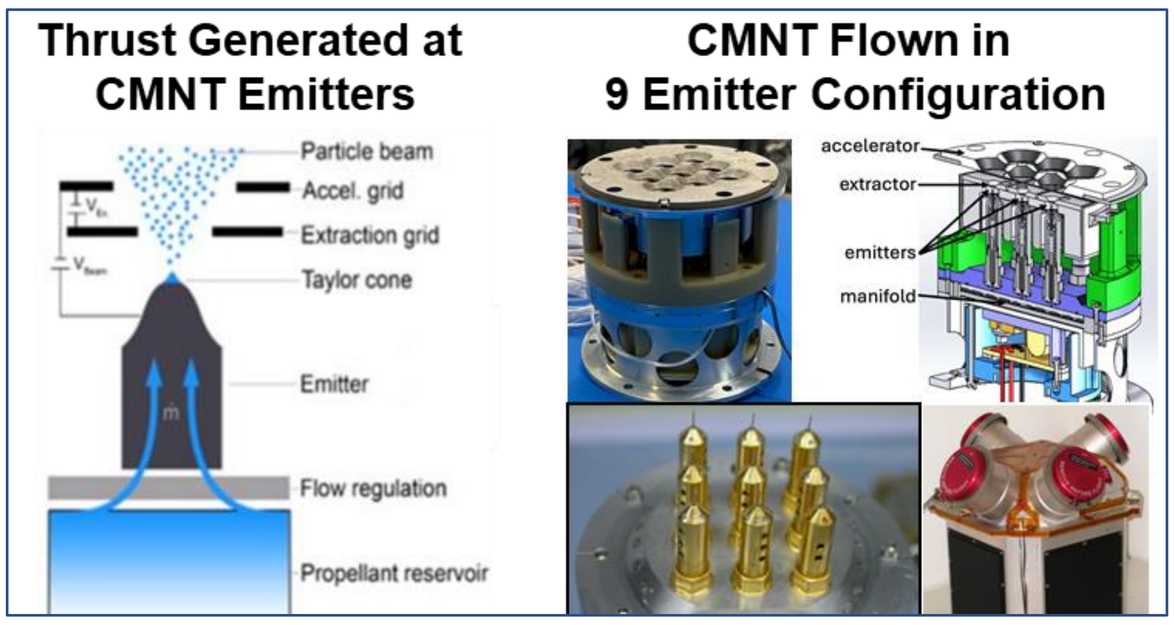
Examine “thrusters-only” ACS that eliminates reaction wheels (and their induced disturbances) in favor of RCS thrusters for maneuvering and micro-thrusters for pointing

Expand on Habitable Exoplanet Observatory (HabEx) micro-thruster research to analyze micro-thruster ACS on more recent JPL and NASA developed design concepts for HWO

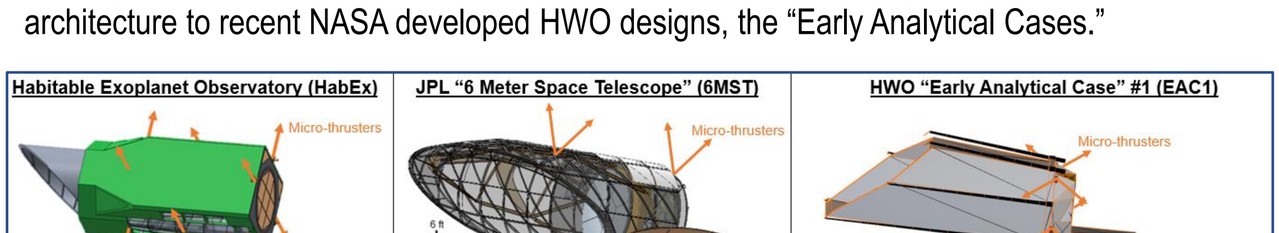
Background:

The Astro2020 goal to conduct imagery and spectroscopy of exo-Earths dictates stringent HWO pointing stability requirement. Starlight suppression with high-contrast coronagraphy drives HWO to order-of-magnitude stability improvement over state-of-the-art wheel-based ACS.

HabEx baselined the Busek Colloid Micro-Newton Thruster (CMNT), an electrospray micro-thruster flight-demonstrated on LISA Pathfinder (LPF) in 2016. Electrospray micro-thrusters apply high electric potential to conductive charged liquid at the end of a hollow needle emitter to accelerate charged droplets and generate extremely low-noise thrust (Ref. 1).



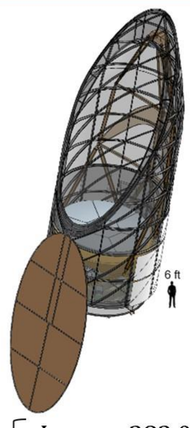
Following Astro2020 recommendations, JPL developed the “6 Meter Space Telescope” (6MST) reference design for HWO. This R&TD has primarily examined the CMNT paired with 6MST to develop a time and fuel-efficient ACS architecture. FY24 work has applied this same ACS architecture to recent NASA developed HWO designs, the “Early Analytical Cases.”



Approach and Results:

A high-fidelity ACS/Observatory simulation has been developed in MATLAB/Simulink to evaluate micro-thruster ACS architectures for HWO. The sim incorporates a flight-validated CMNT performance model from LISA Pathfinder. Work in FY23 and the first half FY24 has focused on providing an end-to-end demonstration of the “thrusters only” ACS architecture on 6MST, which included an examination of a single target repoint on conventional RCS followed by convergence to a desired science pointing stability on micro-thrusters. The key elements of the ACS architecture model on 6MST is summarized below (and fully described in Publication A).

“6 Meter Space Telescope” (6MST)

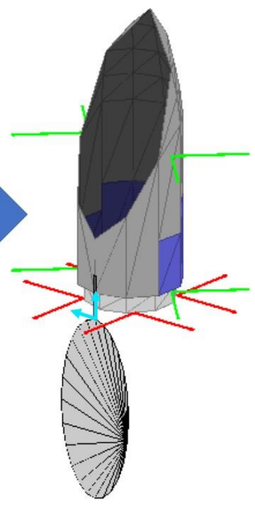


Estimated Mass Properties (BOM)

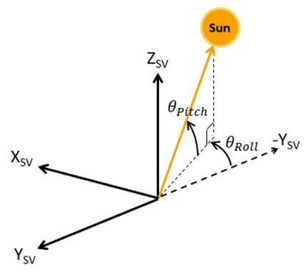
$I_{SV\_XX} = 383{,}000\ kg \cdot m^2$
$I_{SV\_YY} = 368{,}000\ kg \cdot m^2$
$I_{SV\_ZZ} = 189{,}000\ kg \cdot m^2$
$m_{SV\_Dry} = 25800\ kg$
$m_{Solar\_Sail} = 130\ kg$
$m_{Fuel\_RCS} = 2000\ kg$

Observatory Model and ACS Configuration

SV and ACS Actuator Geometry



SV Frame and Sun Orientation:

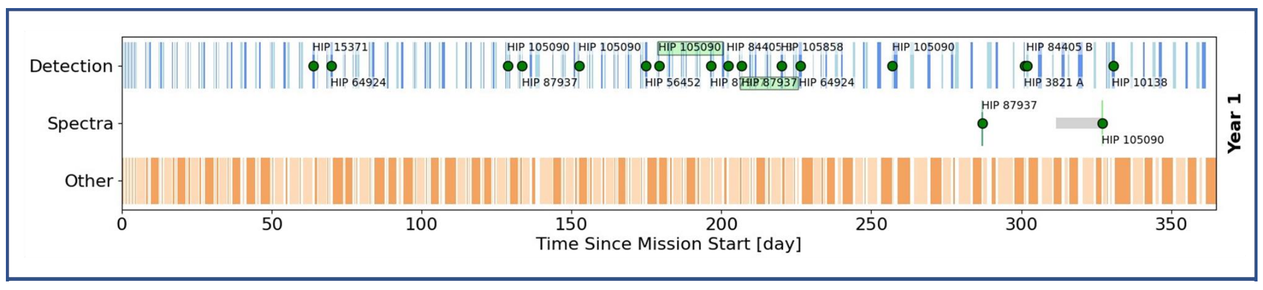


ACS Actuators:
8 Micro-thruster Clusters (Busek CMNT)
8 RCS Thrusters (MRE-1.0 4.4N Thrusters)
2 Solar Sail Gimbals (NGST Rotary Actuators)

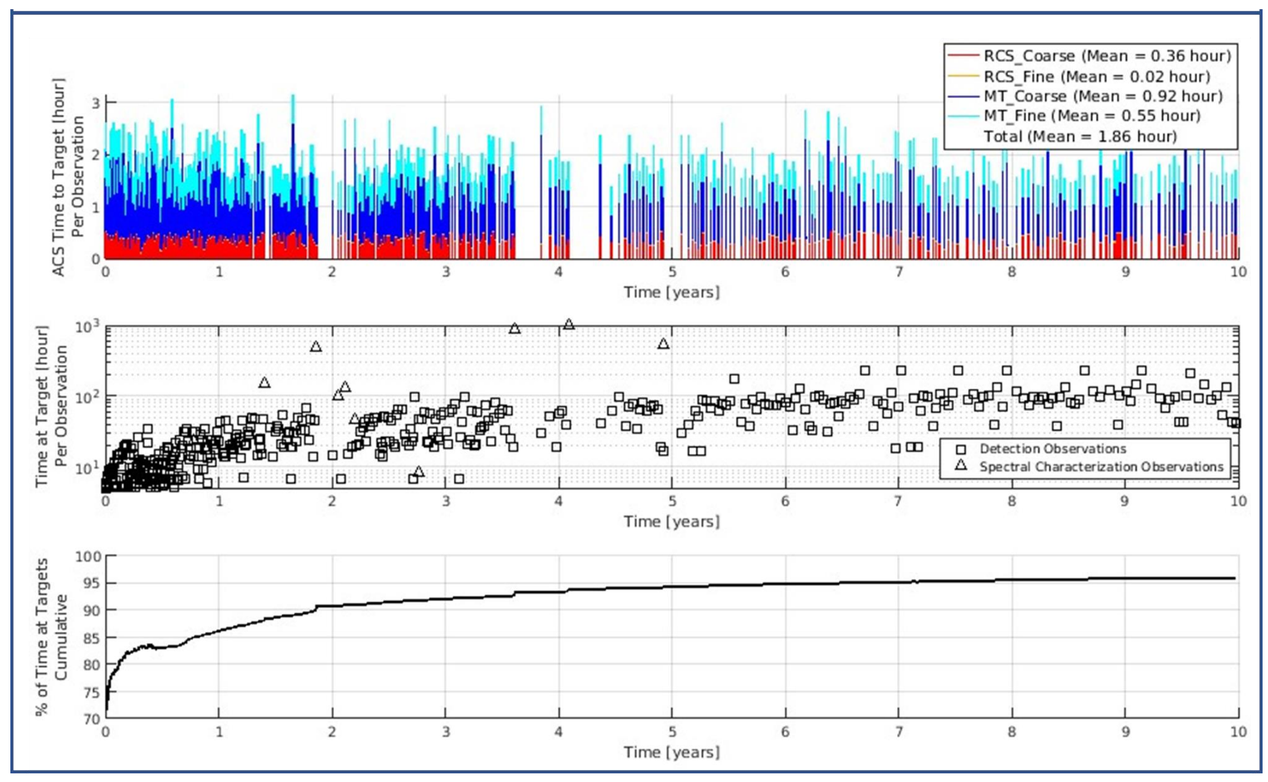
ACS Sensors:
Inertial Reference Unit (Astrix 200)
Star Tracker (Sodern Hydra, 3 Heads)
Fine Guidance Sensor (HabEx performance model)

Surface Properties:
Multi-layer insulation on all surfaces (90% reflective)

Micro-thruster ACS performance on 6MST was then evaluated using a JPL developed 10-year design reference mission (DRM) for HWO. The DRM is constructed using an observation timeline from EXOSIMS science yield modeling simulations for a 6-meter observatory (Ref. 2). Green circles mark successful exo-planet detections. Green boxes mark confirmed habitable zone exo-planets promoted for further spectral characterization. Target star names are indicated.

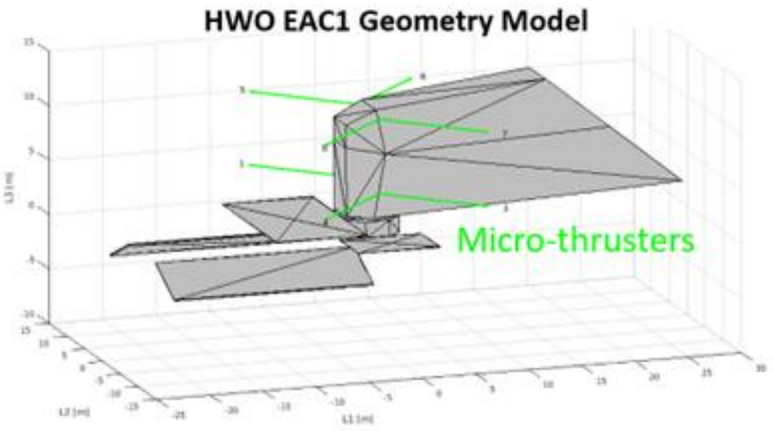


ACS evaluation metrics over the DRM include estimated fuel use and total observation time efficiency. These results are part of a detailed description of the “thrusters only” micro-thruster ACS on 6MST published at the 46th AAS GNC Conference in February 2024 (Publication A).

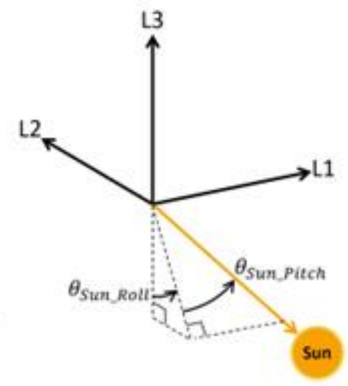


This R&TD has leveraged its simulation capability to assess micro-thruster ACS on NASA’s recent EAC1 design for HWO, focusing on key design challenges: 1) recommending optimal micro-thruster locations and orientations 2) estimating solar radiation pressure torque for all Sun directions 3) deriving micro-thruster sizing and fuel for a 10-year mission. This analysis has quantified the impact of geometric asymmetries that occur at large Sun roll angles, which increases the magnitude of SRP disturbance torques and resulting micro-thruster fuel use.

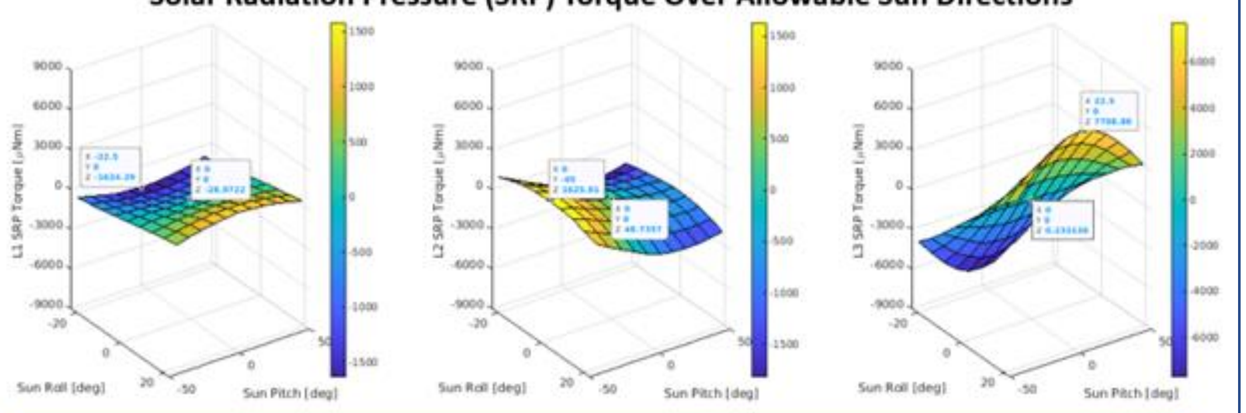
HWO EAC1 Geometry Model



Sun Angle Definitions



Solar Radiation Pressure (SRP) Torque Over Allowable Sun Directions



Microthruster Fuel Use Over 10 Years		
Sun Pointing Only ($\theta_{Sun\_Roll} = 0$, $\theta_{Sun\_Pitch} = 0$)	Observations Distributed Over Allowable Sun Pitch	Observations Distributed Over Allowable Sun Pitch and Sun Roll
17 kg	55 kg	325 kg

Significance/Benefits to JPL and NASA:

R&TD leverages JPL’s expertise in electrospray micro-thrusters to establish Lab as technical leader in micro-thruster precision pointing. NASA created the Science, Technology, Architecture Review Team (START) and Technical Assessment Group (TAG) on 9/6/2023 to guide technology maturation activities for HWO. This R&TD has allowed JPL to directly inform on-going ACS architectural trades for HWO as part of NASA’s “Great Observatory Maturation Program.”

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Publications:

[A] C. Haag et al., “Micro-thruster ACS Architecture for Precision Pointing of 6-meter Exo-Earth Imaging Space Telescope,” 46th AAS GNC Conference Proceedings, 24-073, Feb. 2024

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References:

[1] J. Ziemer et al., “In-Flight Verification and Validation of Colloid Microthruster Performance,” *2018 Joint Propulsion Conference*, 2018
[2] R. Morgan et al., “An exploration of expected number of exoplanets for a 6m class direct imaging observatory,” Proceedings from SPIE Astronomical Telescopes + Instrumentation, No. 10.1117/12.2630609, 2022.