

HALCYON

Integrated Non-Toxic Chemical Propulsion Systems FIRST FLIGHT HERITAGE - 2021

PRODUCT HIGHLIGHTS

The flight-proven Halcyon is our flagship product line developed for high-thrust cubesat through ESPA satellite operations. Our systems offer best-in-class specific impulse using High-Test Peroxide, improving safety, cost, and logistics of propellant acquisition and loading. Our turn-key systems remove common customer pain points with on-time delivery, simplified spacecraft integration, and operational reliability.

MISSION-OPTIMIZED TECHNOLOGY

Benchmark offers a robust collection of gualified 'Off-The-Shelf' components and subsystems for developing mission-optimized mobility packages. The Halcyon line features a range of monopropellant and bipropellant thrusters, propellant tank sizes, and system architectures, resulting in a comprehensive toolbox for right-sizing countless configurations for target total impulse, maneuver types, and a host of bus characteristics.

Our broad organic technology portfolio and partnership network seamlessly integrate under a common interface, creating a single-point mobility-partner with the most extensive mission capability coverage.

MISSION-CAPABILITY & HERITAGE

Halcyon is designed to support high-thrust and impulsive spacecraft operations including orbit insertion and transfers, dynamic space operations including rapid collision avoidance and pointing, controlled de-orbit and re-entry, as well as RPO and Docking. The Halcyon system has proven mission success on commercial and government missions from common circular orbits with a single thruster, to advanced service and logistics vehicles with four to sixteen-thruster configurations.

Shown below is a 4x 22 N Halcyon Avant system used to successfully complete a 700 km orbital raise in its debut mission aboard Spaceflight's LTC OTV.



APPLICATIONS























Servicing



Orbit Insertion

Collision Avoidance

Transfer

Station Keeping

Pointing

Extension

Momentum Management

HALCYON	HALCYON AVANT	
Monoprop	Biprop	
1-10 N	2-22 N	
150-155 s	285-300 s	
Configuration Specific		
Configuration Specific		
80 mN·s	80-600 mN·s	
-31C - 71C per SMC-S-016		
Bounding over NASA GEVS, F9 RPUG and similar		
-5° C to 25° C		
24-34 V		
15-20 mins for ideal performance		
June 2021	Sept 2022	
	Monoprop 1-10 N 150-155 s Configurat Configurat 80 mN·s -31C - 71C p Bounding over NASA GE -5° C t 24- 15-20 mins for id June 2021	

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Multiple Halcyon monopropellant systems launched on an undisclosed government mission and OrbitFab's Tenzing refueling demo mission.

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MORE MISSION. LESS COST.

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XANTUS

Metal Plasma Thruster Systems Designed for Small Satellites



MPT, an AASC Technology

PRODUCT HIGHLIGHTS

Xantus Metal Plasma Thruster (MPT) is the first electric propulsion offered by Benchmark, with a license obtained from Alameda Applied Sciences Corporation ("AASC", aasc.space). Each Xantus delivers up to 5 kN·s of impulse using quasineutral pulsed plasmas created from solid metal propellant.

Xantus Features:

- ✓ Produces highest total impulse in its size
- Constant efficiency across 1-100 W input power range
- ✓ 10 µN⋅s impulse bit precision
- ✓ 0 W standby power with instant cold start
- ✓ Broad propellant compatibility, including ISRUs
- ✓ 4-month product lead time

Xantus DOES NOT Require:

- × An ion neutralizer
- × Gas or liquid propellants
- × Heaters or DC high voltage electronics
- × Ground loading of propellant (ships fueled)

MISSION-OPTIMIZED TECHNOLOGY

Xantus metal plasma thrusters are designed to support most cubesat missions as well as microsat and ESPA class missions. Multiple Xantus can be integrated into a single spacecraft to optimize delta-V and control authority for high-endurance station keeping, ultra-precise pointing, rendezvous, and docking operations. This technology enables Benchmark to offer integrated chemical + electric hybrid systems for microsats and will serve a prominent role in In-Space Servicing, Assembly and Manufacturing (ISAM) operations.



Xantus fires all four engines in sequence during vacuum chamber tests.









Orbit

Transfer













Orbit Insertion

Collision Avoidance

Station Keeping Precision Pointing Mission Extension

Momentum Management

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RPO and Servicing

	MPT Benefits	
Solid Metal Propellant	Can be stored indefinitely and shipped with no fueling or ground operations required	
Simple Power and Control Unit	22 – 36 V across all power modes with operation down to 14 V input	
Pulsed Operation, Precise Impulse Bits	$10\ \mu N\cdot s$ Min. Imp. Bit and controllable firing sequence delivers precise linear and torque maneuvers in one device	
Modular Design	5 kN·s (max) per $^{1\!\!2}$ U package, can be combined with additional $^{1\!\!2}$ U packages or chemical thrusters	
Wide Operational Range	With 0 W stand-by and no warm-up time, activates instantaneously and operates with 1-100 W	
Parameter	Value	
Wet Mass	1.4 kg	
Dry Mass	0.85 kg	
Propellant	Solid Molybdenum*	
Volume	0.58 L (94mm x 94mm x 66mm)	
ISP	1764 s (varies by propellant)	
Minimum Impulse Bit	10 μN·s	
Thrust/Power Ratio	10 μN/W	
Total Impulse	5000 N·s	
PPU	Simple, 45 V Max DC	
SC Interface	RS-422	
Standby and Threshold Power	0 W	
Turn-on Delay	Instant Cold Start	
First Flights	January 2023 USSF EWS ROCCI Mission (Electro-Optical Weather System) March 2024 USSF EWS ROCCI-2 Mission (Electro-Optical Weather System)	

*Alternate metal propellants available

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HTP THRUSTERS

Monopropellant and Bipropellant Configurations

PRODUCT HIGHLIGHTS

Benchmark offers our full line of thrusters packaged with our valves (COTS and modified COTS) as subassemblies gualified for your mission profile. We work with our customers and partners to maximize the benefits of our technology and expertise, and ensure your mission achieves the performance, cost, and lead time benefits that our thrusters offer.

Our thruster offerings feature cold gas, resistojet, catalytic combustion, High-Test Peroxide (HTP) monopropellant, and catalytic combustion dual-mode HTP + fuel bipropellant thrusters ranging from 100 mN through 22 N.

MISSION-OPTIMIZED TECHNOLOGY

Benchmark's focus on delivering turn-key integrated propulsion systems and mobility packages has led to volume production of several thruster configurations. Designed with readily available, low-cost catalyst materials, our thrusters deliver rigorously tested, mission-proven performance at excellent cost and lead times.

shown: 2N Lynx Thruster



APPLICATIONS



Insertion



Collision Avoidance

















Transfer Keeping Pointing

Mission Extension

Management

RPO and Servicina Deorbit

CONFIGURATION EXAMPLES

Additional options available

Value	Felicette – 1N	Lynx – 2N	Ocelot – 22N
Thrust (Biprop)	-	2 N	22 N
Thrust (Monoprop)	1 N	1 N	11 N
Steady Isp	150-155 s	280-300 s	285-300 s
Propellant(s)	НТР	HTP+Octane (Other fuels available)	HTP+Octane (Other fuels available)
Total Pulses	10,000	10,000	10,000
Min. Impulse Bit	80 mN·s	80 mN·s	600 mN·s
Preheat (Optional)	4 Wh	3.75 Wh	16 Wh
Qualified Temp Range	-34 - 71 C		
Environments	Bounding over NASA GEVS, F9 RPUG and similar.		
Operating Range	Qualified in accordance with SMC-S-025		
Radiation	Rad. Tolerant; radiation-hardened (optional)		
Electrical Interface	Connectorized		
Voltage Input	24-34 V		

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Hotfire test of 22 N Ocelot thruster

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SmartAIM[™]

Advanced Onboard Propulsion Control Software



IMPROVED OPERATIONAL EFFICIENCY

SmartAIM™ is an onboard Guidance, Navigation and Control (GNC) software layer that can intelligently interpret or create maneuver commands to actively control propulsion and other mobility subsystems. The functionality expands small satellite capabilities, from improved collision avoidance to on-orbit servicing in congested earth orbit and cislunar domains, while enabling unprecedented maneuver efficiency and operational autonomy. SmartAIM™ reduces integration costs and time by accepting highlevel GNC commands rather than bespoke, discrete component inputs, extending operational capability as well as constellation scalability with intelligent onboard propulsion control for optimized and precise maneuvers.

MANUEVER OPTIMIZATION



SmartAIM[™] desktop tools offer digital twin and simulation models to plan or verify maneuvers in advance and can be paired with Benchmark's Hardware-in-Loop testing capability.

APPLICATIONS



Orbit Insertion



Collision Avoidance



Transfer

Station



Pointing

Mission

Extension









Momentum Management

Servicina





SOFTWARE SPECIFICATIONS

SmartAIM[™] Maneuver Control Software is Offered in Tiers for Your Mission Mobility Needs

SmartAlM™ Level		Command Packet	Command Frequency	As	
1	Command propulsion system thrust vector	Forces and torques	Fixed frequency (100 hz to 1 hz typical)	sisted	
2	Command a change in pointing or velocity	Delta-angle and/or delta-velocity	Once per maneuver	AL	
3	Command a maneuver	Attitude and completion criteria	Once per maneuver	Itono	
4	Command an orbit	Orbital elements and collision avoidance criteria	Once per mission phase	mous	

Included in all levels:

- Operators can manually command a maneuver or disable SmartAIM™.
- Operators can set abort criteria for each maneuver, to be monitored and utilized by SmartAIM[™].
- Onboard maneuver planning results can be evaluated by the operator prior to maneuver execution.
- Levels 2-4 allow scheduling maneuvers by time, attitude, and position as hardware capability allows.



SmartAIM[™] uses embedded sensors and an inner-control loop for thrusters and can incorporate additional effectors, sensors, and data input to eliminate positioning and propulsion command latency and generate more efficient and effective maneuvers than state-of-the-art operations.

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MAAVRIC Modular Propulsion Controller

Standard ~1U Footprint Minimum Package Size

PRODUCT HIGHLIGHTS

MAAVRIC is Benchmark's robust, modular propulsion controller system, architected to work with all sizes of propulsion systems with minimal NRE. The controller is plug-and-play to a satellite operator's GNC software, or Benchmark's SmartAIM[™] propulsion control layer.



Single Comms Interface

Commanded via standardized CSP over RS-422 or CAN



Modular

Scalable to any chemical, electric or hybrid propulsion system



Radiation Configurable

COTS, rad-tolerant, or rad-hardened to fit mission CONOPS and price-point



Connector Agnostic

Configurable for square connectors (standard) or circular connectors



Load Simulators Available

Simulate full prop system on the ground using our rack-mounted system

OPTIMIZED FOR PROPULSION

Independent Effector Control (valves / heaters)

- Tight timing on synchronizing valves and heaters (<1ms)
- Tight timing on command to actuation (<10ms in asynchronous mode, <1ms in synchronized timing mode)
- Spike & hold PWM on all effector channels
- Closed-loop heater control
- GSE bypass for direct control during fill ops

High Accuracy, High Precision Sensor Inputs

- <0.5% full scale error per channel
- Fully integrated analog front end, optimized for mV/V sensors, single ended or differential
- Integrated cold-junction compensation for thermocouples
- RTD support available upon request

Robust System by Design

- All active components rad-tolerant by design
- Other critical components available as radtolerant or COTS variants
- All components derated per EEE-INST-002
- Nominal 28V system (24-36V input)



PROPULSION-SPECIFIC AVIONICS

MAAVRIC is designed specifically to optimize propulsion performance and scale to meet your mission.

Propulsion Specific Functionality			
System Configurations	Up to 64x Effectors (valves/heaters) and 64x Sensors Inputs		
Physical Envelope (min system)	124mm x 117mm x 32mm		
Safety	Designed for Power Domain Isolation & 91-710 Range Operation		
Radiation Tolerance	Designed for 30krad / 40MeV·cm ² /mg		
Design Specs / Qualification	NASA GEVS GSFC-STD-7000A, EEE-INST-002		
Development Support	Development models and full system load-sims available		

PRODUCT, CONFIGURATION, AND PRICING INQUIRIES: Sales@Benchmark-Space.com MAAVRIC BLOCK DIAGRAM



DRIVING SPACE LOGISTICS

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COLA Kit

Rapid Maneuver Collision Avoidance Kit

Based on our Heritage Halcyon System

PRODUCT HIGHLIGHTS

Benchmark's Collision Avoidance Kit is a high-thrust, plug-and-play subsystem specifically designed to be easily integrated and operated in various spacecraft configurations and missions. Configured as a 1N blow-down system with intelligent control electronics, it is designed with reliability and affordability in mind.



COLA Kit - Selection Guide

*Based on a nominal 1 km raise/lower maneuver

APPLICATIONS























Orbit Insertion

Collision Avoidance

Orbit Transfer

Keeping

Precision Pointing

Mission Extension

Product lead time: Four months

Momentum Management **RPO** and Servicina



MISSION-OPTIMIZED TECHNOLOGY

Designed with Benchmark's flight-proven 1N thruster, the COLA Kit can deliver up to dozens of unplanned maneuvers. The Kit is right-sized for microsats and ESPA class spacecraft to provide rapid sidestep maneuvers to enable low thrust or non-propulsive spacecraft to quickly evade conjunction risks and orbital debris.

Parameter	ColA -1	ColA -2	CoLA -4	CoLA -6
Total Impulse	1000 N-s	2000 N-s	4000 N-s	6000 N-s
Thrust Level	1N	1N	1N	1N
Propellant Volume	0.5 L	1 L	2 L	3 L
Propellant Mass	0.7 kg	1.4 kg	2.8 kg	4.2 kg
System Wet Mass	2.5 kg	3.5 kg	5.7 kg	7.9 kg
Integrated System Envelope*	250x120x130 mm	330x120x130 mm	370x130x140 mm	395x150x160 mm
Tank Envelope	150x110x130 mm	230x110x120 mm	270x130x140 mm	295x150x160 mm

*not including thruster or adjustable mount



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STARLING

Cold Gas Propulsion Systems

PRODUCT HIGHLIGHTS

Benchmark's Starling line of gas propulsion systems is designed with unprecedented safety and configurability. With propellant options that include traditional pressurant gas or our patented On-Demand Pressurization System (ODPS[™]) gas generation technique, and a patent-pending resistojet thruster option, Starling is an ideal system when robust and reliable propulsive capability is essential to mission success. Starling can be configured with 1-4 thrusters, often used for momentum management and attitude control and can be scaled down for primary cubesat operations.

Benchmark's ODPS[™] utilizes a non-toxic powdered propellant that is inert and DOT-approved for shipping and can be pressurized on-orbit with as little as 15 W of power, improving safety and providing a path to ISS compatibility. For missions with 100 W of available power, a resistojet configuration can be used to double specific impulse over traditional cold gas systems.

The Starling Ardent system shown above features a 1 U resistojet configuration.

APPLICATIONS



Insertion

Collision

Avoidance



Transfer



Keeping



Mission









Precision Pointing

Extension

Momentum Management

RPO and Servicina

Parameter	Starling	Starling Ardent
Thrust	10 - 5000 mN	100 - 1000 mN
Specific Impulse	70 s	70 - 140 s
Max Throughput / Firing Time	No throughput limitations	
Preheat	N/A	<10 Minutes
System Dimensions	0.5 U +	1U+
Minimum Impulse Bit	As low as 5 mN⋅s	
Average Power Draw (Idle/Firing)	<4 W	10 - 100 W
Pressurization Time	10 - 15 minutes for ODPS™ (one time event) N/A if launching pre-pressurized	

Benchmark's 250 mN "Mia" resistojet thruster shown below is available in the Starling Ardent configuration.



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