



CYCLE AUTOMATED MASS FLOW (CAMFLOW) CONTROLLER FOR HALL AND ION THRUSTERS JULY 2024

CUA's Cycle Automated Mass Flow (CAMFlow) system is a highly reliable, fixed-frequency flow controller for electric propulsion systems. CAMFlow uses an innovative control scheme that enables stable operation, even for the low flow rates necessary for sub-kW Hall effect thrusters. This methodology reduces system complexity, places the onus of reliability on valve cycle life, and allows for a direct correlation between system life and valve cycle life.

The CAMFlow system consists of multiple modular sections: (1) the Pressure Management Assembly (PMA) accepts $\geq 3,500$ psia of input pressure; (2) the primary Xenon Flow Controller (XFC) controls the output flow rate to $< \pm 2\%$; and (3) a secondary, optional XFC provides an initial boost to the cathode flow leg and allows operation with heaterless cathodes. Through the use of less expensive space-rated components, CAMFlow provides a reliable low-cost flow controller that is well-suited for sub-kW Hall and ion thrusters. The system is single fault tolerance through entire system and dual fault tolerant for valves in series.

While CAMFlow units are presently focused on smaller Hall-effect or gridded-ion electric propulsion systems having a flow rate in the 0 – 15 mg/s range, the technology is scalable and can be adapted for a large range of flow rates.

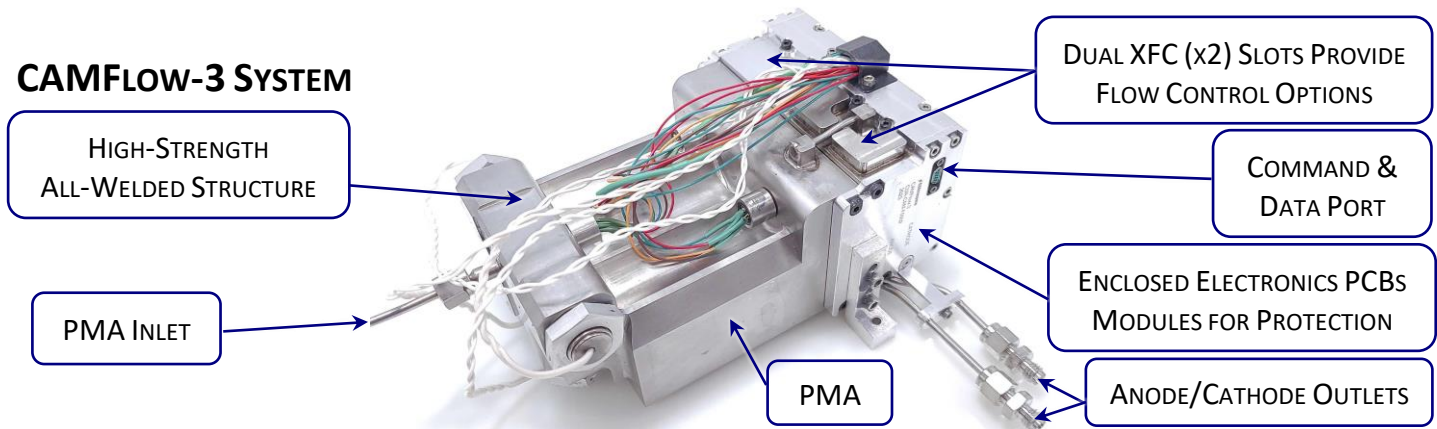
The CAMFlow control technology was successfully tested and validated on a 600-Watt Hall thruster. This included open loop, closed loop, and cold cathode "hard" start operations. The control valves were cycled > 120 million pulses (the equivalent of 300 kg Xe throughput at 3 mg/s) while maintaining very low leak rate. The system passed environmental qualification and is TRL 6.

CAMFlow-3 Performance	XFC	PMA
Anode Flow Rate [mg/s]*	0 – 15	0 – 15
Flow Split to Cathode*	0 – 15%	N/A
Heaterless Cathode Start Flow Rate [mg/s]†	0 – 15	0 – 15
Flow Pressure Variation at Outlet	$< 2\%$	100 +20/-80
On/Off Cycles	$> 1 \times 10^8$	$> 55,000$
Inlet Pressure [psia]	30 – 100	100 – 3500
Outlet Pressure [psia]	< 6	30 – 100
Total Throughput [kg]	≥ 300	≥ 300
Working Gases (others possible)	Xe, Kr, Ar	Xe, Kr, Ar
Gas Cleanliness – Inline Filter [μm]	10	10
Mass [kg]	0.7	2.1
Volume [liters]	0.4	1.1
Internal Leakage [scc/s of He]	$< 1 \times 10^{-4}$	$< 1 \times 10^{-4}$
External Leakage [scc/s of He]	$< 1 \times 10^{-6}$	$< 1 \times 10^{-6}$

*Fixed setpoint, customer selectable.

†Requires second XFC

CAMFLOW-3 SYSTEM



Two hardware configurations:

- Single XFC provides anode and cathode flow with fixed flow split
- Dual XFC provides additional cathode flow during startup (optional)

Analog Electronics Option

- Controlled externally by PPU and BUS
- Requires externally generated voltages
- Logic inputs for enabling system and redundant valves
- Analog voltage input for main throttle
 - PPU to close feedback loop with hall thruster current
 - Heaterless cathode throttle proportional to PMA pressure
- Analog outputs for temperature and all pressures
- Automatic PMA recovery from a stuck valve fault

Reliable Lee Co. valve technology:

- Valves tested to > 120 million cold gas firings
- System is two-failure-tolerant against leakage

Microcontroller Electronics Option

- Significantly more autonomous
- Requires communications inputs and single bus power input
- Can internally provide closed loop control
 - Still requires thruster current target and reading

Life span: 5+ years (based on propellant load)

System can be used with other common gaseous propellants

PMA/XFC bodies can be lightweighted by replacing stainless w/ titanium

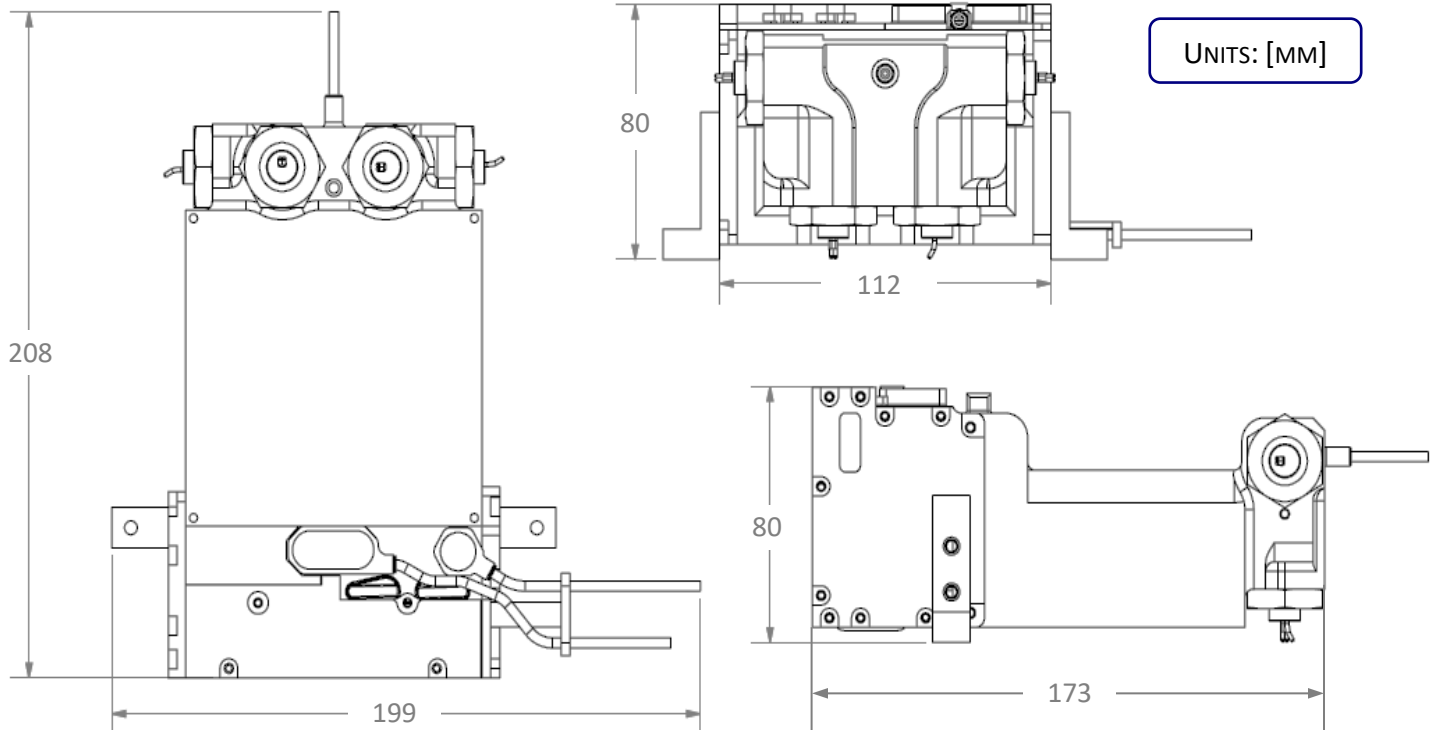
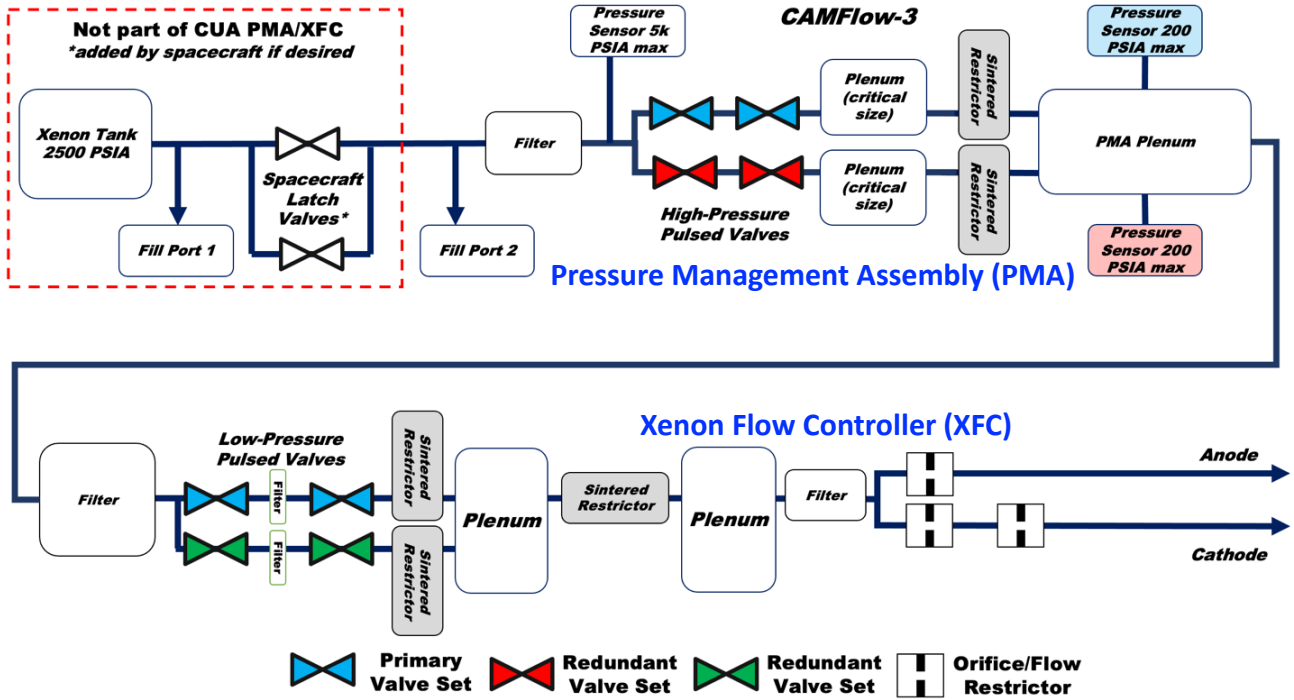
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BASELINE DESIGN FOR CAMFLOW-3 SYSTEM



Dimensions of the baseline CAMFlow-3 unit are for illustrative purposes only. The smaller ground test PMA pressure sensors can be substituted with larger space-rated higher cost sensors as desired. CAMFlow is highly adaptable to a wide range of customer-specific geometries. Inquire to see how CUA can adapt CAMFlow to meet your mission requirements.