



# CYCLE AUTOMATED MASS FLOW (CAMFlow) CONTROLLER FOR HALL AND ION THRUSTERS DECEMBER 2021

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 up to 2,500 psia of input pressure; (2) the primary Xenon Flow Controller (XFC) controls the output flow rate to  $\pm 3\%$ ; 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 CAMFlow control scheme 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 350 kg Xe throughput at 3 mg/s) while maintaining very low leak rate.

While CAMFlow units are presently focused on smaller Hall-effect or gridded-ion electric propulsion systems having a flow rate in the 0 – 8 mg/s range, the technology is scalable and can be adapted for a large range of flow rates.

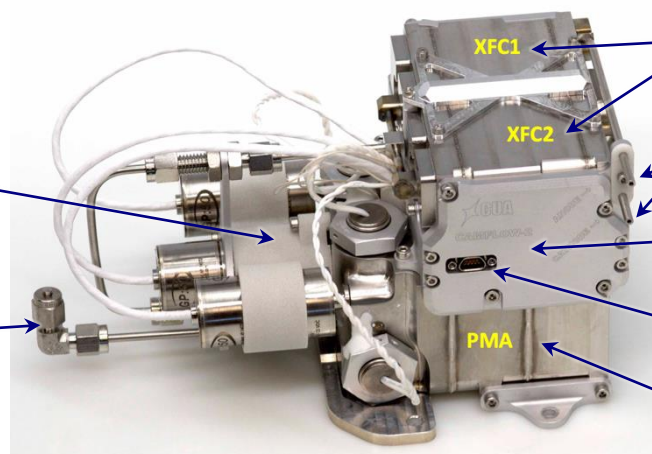
CAMFlow-2 Performance	XFC	PMA
Anode Flow Rate [mg/s]*	0 – 8	0 – 8
Flow Split to Cathode*	0 – 15%	N/A
Heaterless Cathode Start Flow Rate [mg/s]†	0 – 8	0 – 8
Flow Pressure Variation at Outlet	$< 3\%$	100 $\pm$ 20/–80
On/Off Cycles	$> 1 \times 10^6$	$> 20,000$
Inlet Pressure [psia]	40 – 100	40 – 3000
Outlet Pressure [psia]	$< 2$	40 – 100
Total Throughput [kg]	$> 100$	$> 100$
Working Gases (others possible)	Xe, Kr	Xe, Kr
Gas Cleanliness – Inline Filter [ $\mu\text{m}$ ]	10	10
Mass [kg]	0.7	1.5
Volume [liters]	0.4	0.7
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-2 SYSTEM

LOW-MASS AND HIGH-STRENGTH STRUCTURE

PMA INLET



DUAL XFCs (x2) PROVIDE FLOW CONTROL OPTIONS

ANODE/CATHODE OUTLETS

ELECTRONICS PCBs SANDWICHED BETWEEN MODULES FOR PROTECTION

COMMAND & DATA PORT

PMA

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

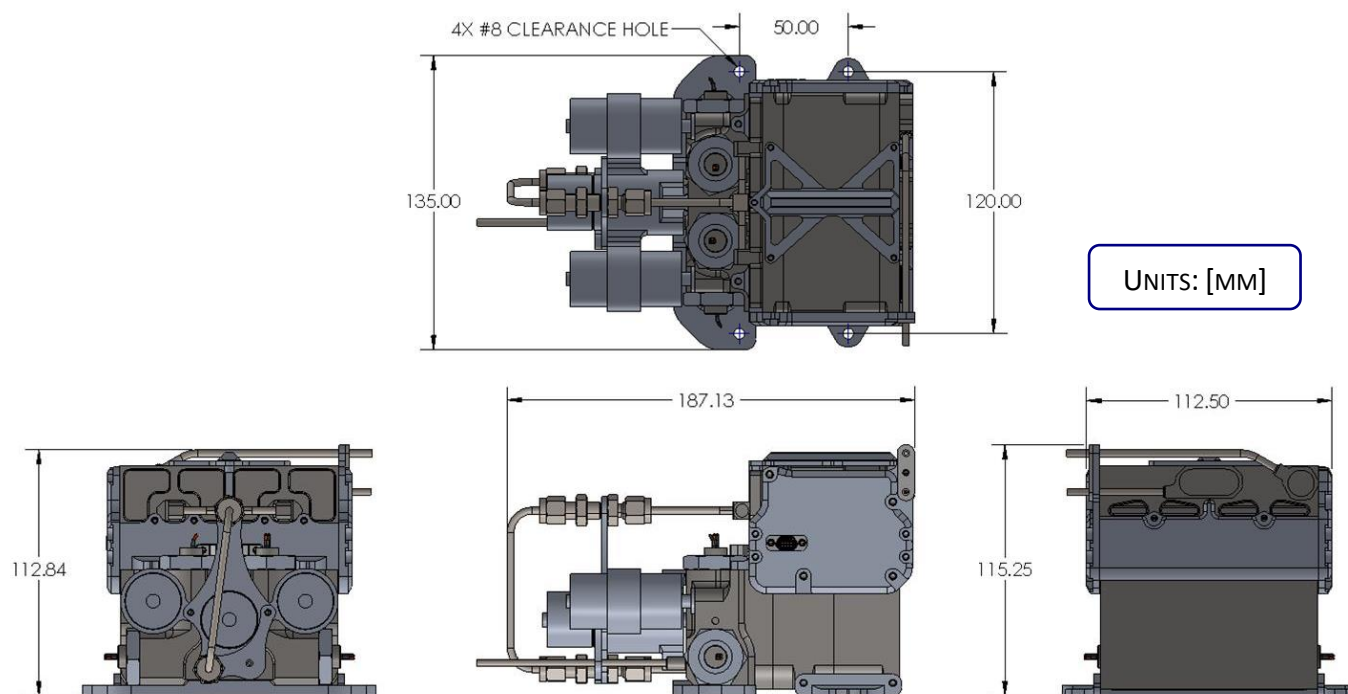
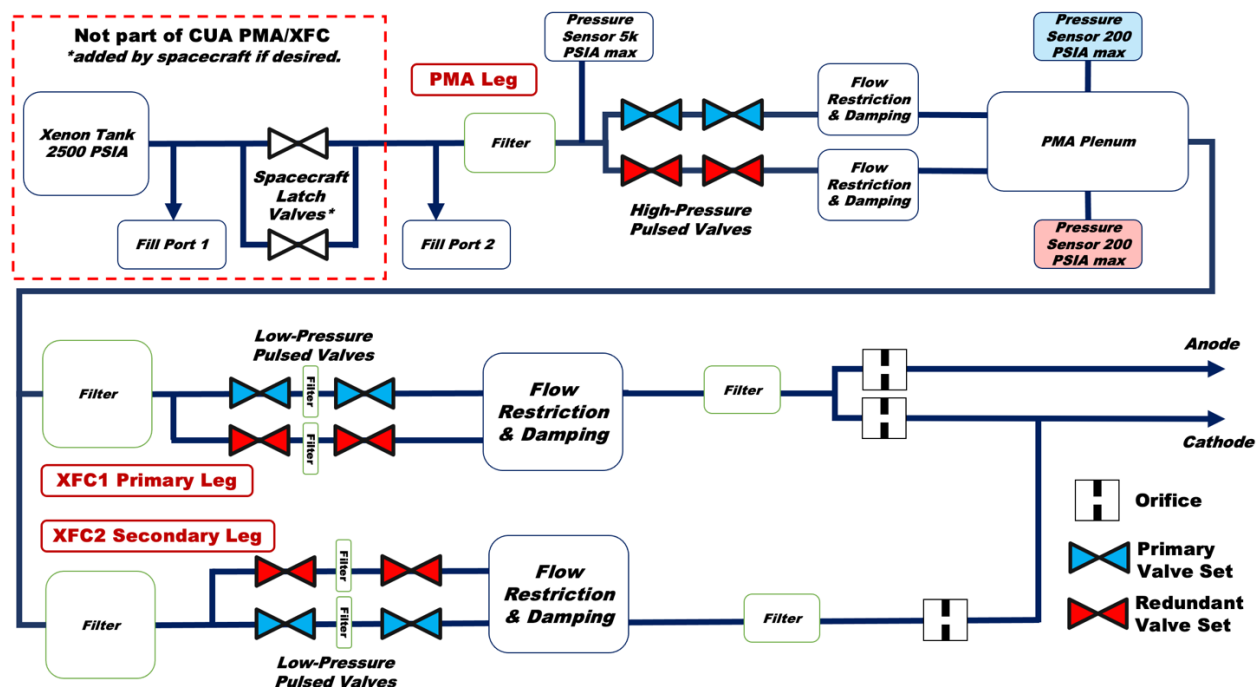
CUA | 3001 NEWMARK DRIVE | CHAMPAIGN, IL 61822

T: (217) 239-1701 | INFO@CUA.SPACE | WWW.CUA.SPACE

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## BASELINE DESIGN FOR CAMFLOW-2 SYSTEM



Dimensions of the baseline CAMFlow-2 unit are for illustrative purposes only. Larger PMA pressure sensors can be substituted with smaller 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.