FLIGHT WORKS, Inc.

Pumps for space propulsion, refueling, cooling and more…

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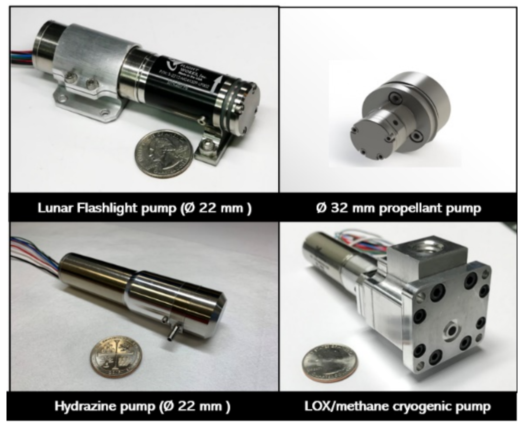
1. Overview


Lunar Flashlight pump (Ø 22 mm) | Ø 32 mm propellant pump | Hydrazine pump (Ø 22 mm) | LOX/methane cryogenic pump

In the late 2000's, Flight Works pioneered the idea of providing CubeSats and Nanosats with significant propulsion capability by using micropumps. Today, Flight Works provides game-changing micropump solutions for smallsat propulsion and more…
These pumps can be used in spacecraft propulsion, propellant management (such as refueling) and other in-space fluid management (such as cooling). The high power-density of Flight Works micropumps requires extremely precise parts, with tolerances typically measured in microns for the critical components. Materials vary depending on the applications but typically include Titanium and Hastelloy alloys, ceramics such as silicon carbide, and various high-performance plastics (e.g., PEEK). Depending on mission requirements, they are specially designed for the launch and space environments (vibration, vacuum, radiation). Examples of micro-pumps developed for space applications include:

- "Green" propulsion (100 mN to 100 N): ASCENT (AF-M315E) & HPGP (LMP-103S)
- Hydrazine and hypergols for on-orbit transfer and propulsion (100 mN to 1,000 N)
- Cryogenics: LOX, LN2, LCH4, Propylene
- Other: R134a, water, ethylene glycol, etc.

A wide range of applications is covered by the family of small 22 mm-diameter pumps as illustrated in Figure 1 (next page). For propulsion, typical requirements for a 5-7 lbf biprop thruster are shown in the figure for illustration. Larger pumps suitable for thrusters up to 200 lbf have been developed and demonstrated (see Sect. 2.3 below). Typically, the pumps are designed to provide up to 100-400 psid per stage for low viscosity fluids like hypergols. A pressure rise higher than 1,000 psid can be reached for fluids with higher viscosity like the HAN-based AFM315E. These pumps have typical power efficiencies between 30% and 60%, depending on fluids and operating conditions.


Astronaut handling experiment onboard the ISS (FW pump in system)

For example, for a 100 lbf MMH/NTO thruster, assuming a pressure rise of 300 psid from the tank to the inlet of the thruster, typical fuel and oxidizer pump power efficiencies of 50% and 40%, respectively, the total power required to drive both pumps would be around 500 W. This is approximately 250 W for each propellant, as shown in Figure 2 below for one of the hypergolic propellants. Fuel and oxidizer pumps can be made interchangeable, and their control during operations allow for optimum feed pressure to the thruster regardless of tank pressure variations due to temperature or increase in ullage volume.

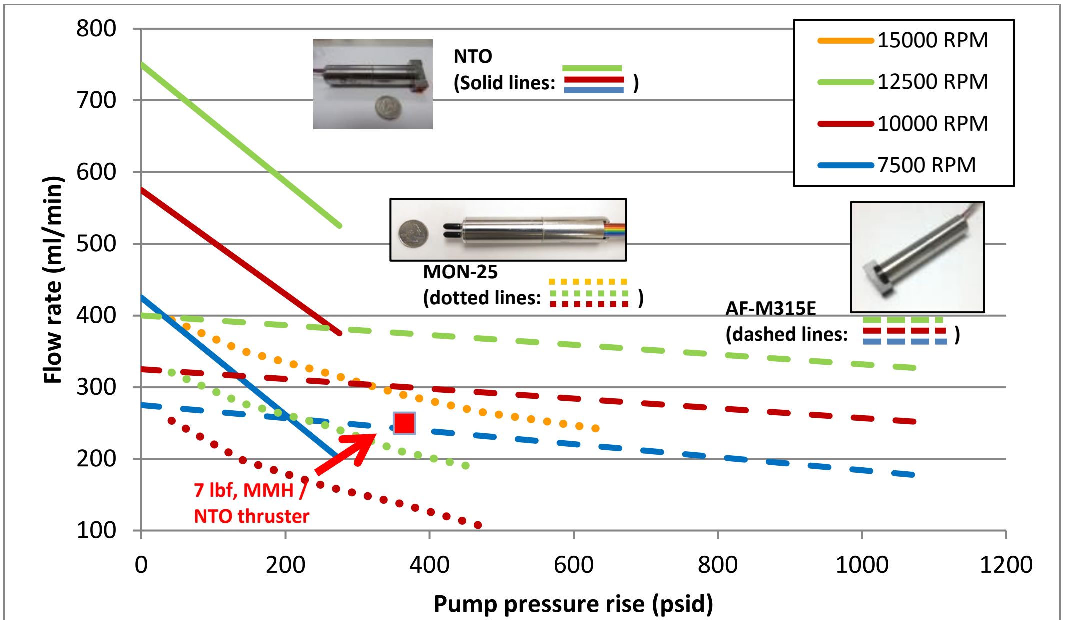


Figure 1. Flight Works 22-mm-diameter-class micropumps demonstrated performance with NTO (solid lines), MON-25 (dotted lines) and HAN-based propellant (dashed lines).

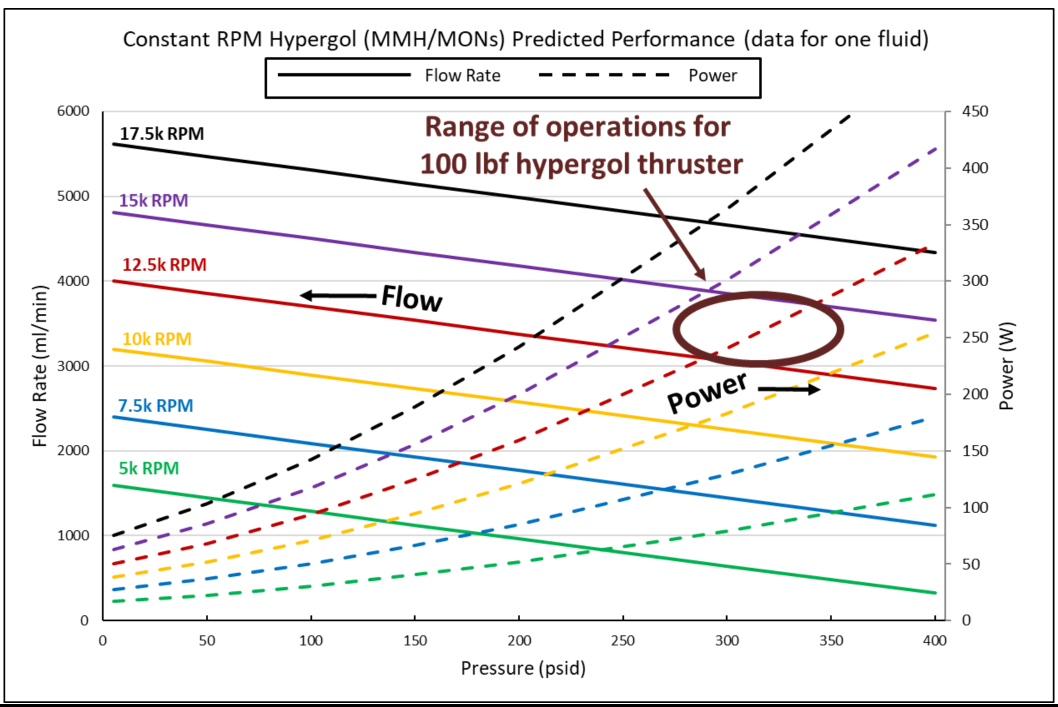


Figure 2. Typical performance map of a propulsion micropump suitable for 100 lbf thrust-class hypergol thruster (performance for one of the propellants; MMH/hydrazine, MON-3/MON-25)

2. Examples of pumps developed for propulsion and other space applications

2.1. Refrigerant, cryogenic fluid (LOX, methane…) and water pumps

The pump technology is based on miniature, high-precision gear pumps driven by electric motors. In most cases, a magnetic coupling is used to separate the pump section from the motor, thus removing any dynamic seal and allowing large temperature differences between the pump section and the electronics.

Some pumps include an integrated check valve, like the small 22 mm R134a refrigerant space pump shown in Figure 3a. Shown below it on the left -and at the same scale- is a cryogenic magnetically-driven micropump designed for liquid oxygen, liquid propylene, and liquid methane. The one on the right is a small 110 g pump used for water transfer.

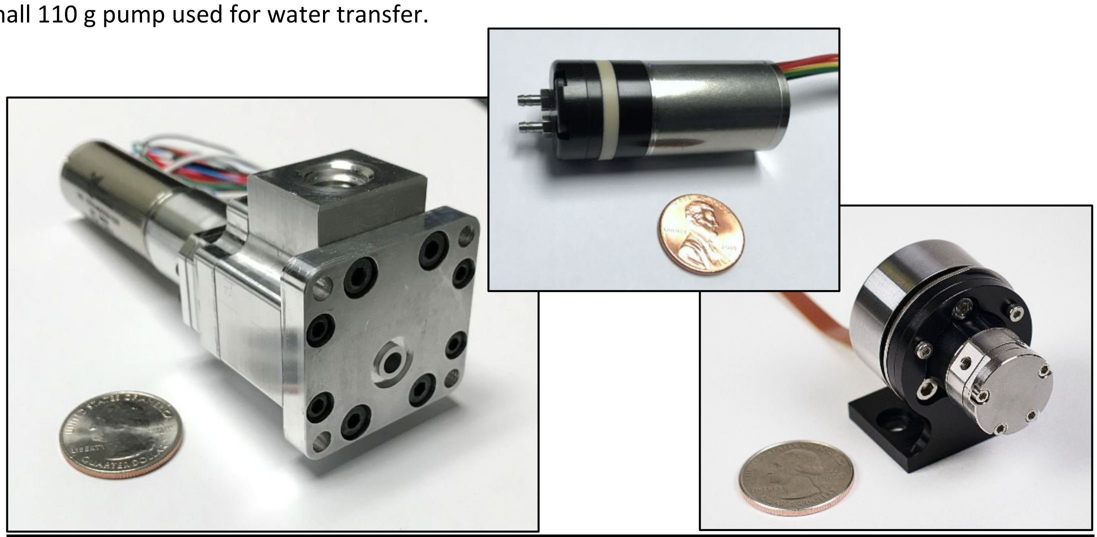
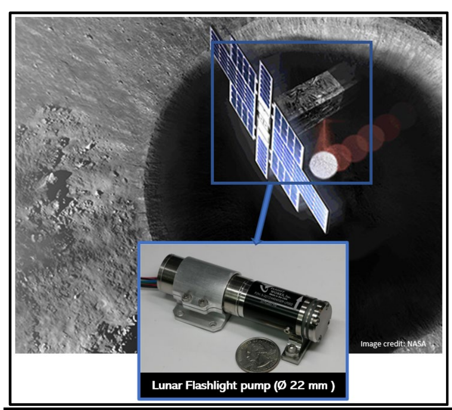


Figure 3. 22 mm R134a refrigerant space pump with integrated check-valve (top), cryogenic micropump (2 L/min and 22 mm motor) suitable for LOX and methane with a custom manifold (left), and small water pump (right)

2.2. Micropumps for CubeSat propulsion, including NASA's Lunar Flashlight System

Flight Works designed, built and spaceflight-qualified a small ASCENT (formerly known as AF-M315E) propellant pumps for the Lunar Flashlight Propulsion System. A conventional pressure-fed system could not meet all mission requirements; the introduction of the pump in the propulsion system enabled that mission.



Micropump for NASA's Lunar Flashlight Propulsion System

A hydrazine pump (shown on p. 1) is also used for the NASA's Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission. Advanced Space of Boulder, Colorado, is developing and will operate CAPSTONE. Tyvak Nano-Satellite Systems of Irvine, California, is building the CubeSat platform. Stellar Exploration, Inc. of San Luis Obispo, California, is providing the propulsion system the spacecraft will use during the transfer to the moon after separation, for station-keeping in the NRHO, and for end-of-life disposal.

2.3. Hydrazine and hypergol (MMH, NTO) pumps for on-orbit refueling

Flight Works developed a series of pumps for NTO, hydrazine and MMH which were used for testing a propellant transfer system engineering development unit, aimed at developing capabilities for on-orbit "refueling".

For illustration of the refueling application, Figure 4 shows a performance map for a 22-mm-diameter-class micropump with hydrazine or MMH. If the power available is limited to 50W, it depicts the operating conditions that can be achieved. The pump RPM can be modulated to obtain flow rates from around 10 ml/min to 460 ml/min at pressure rises of up to 400 psid. For example, at 15,000 RMP, the flow rate for a pressure rise of 400 psid is approximately 340 ml/min using around 48 W and, at 17,500 RPM, the flow rate for a pressure rise of 300 psid is approximately 460 ml/min using around 43 W. Similar performance can be achieved with oxidizers.

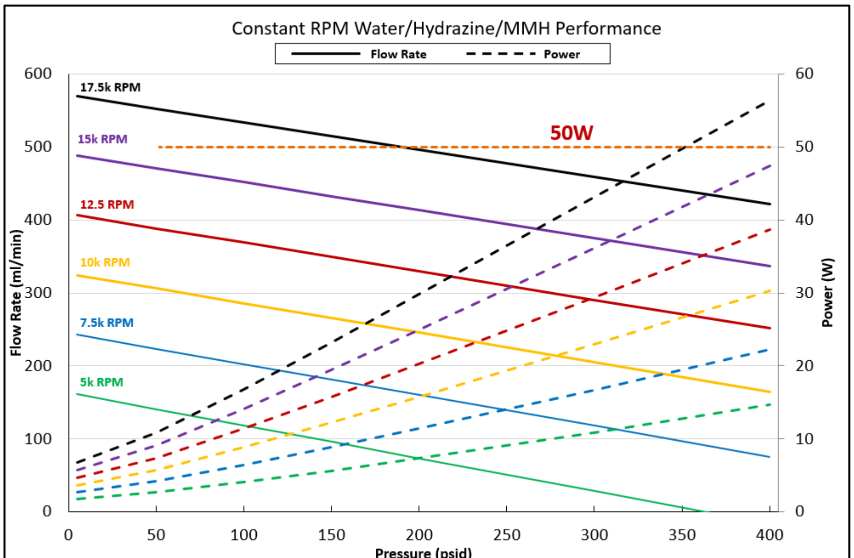


Figure 4. Flight Works 22-mm-diameter-class micropump detailed performance map with water/hydrazine/MMH.

2.4. Micropumps for MON-25/MMH Propulsion and Attitude Control

As part of Phase I and Phase II SBIRs, Flight Works developed "small" and "medium" pumps for 20-30 N (5-7 lbf) and 900 N (200 lbf) class hypergolic MON-3/MMH and MON-25/MMH bipropellant thrusters, respectively.[1] Total power efficiencies of 40% to 50% were demonstrated for oxidizer and fuel (approx. 45% to 55% pump head efficiencies combined with motor efficiencies around 90%). A hot fire test series with thermally conditioned MMH/MON-25 was completed with the larger pump. An example firing is shown Figure 5 at ignition, where ice that had condensed on the exterior of the propellant tank housing and can be seen falling toward the thruster.

[1] Andrea Besnard, Sudathsi Tennakoon, Jose Torres, and Eric Besnard, "Preliminary Results of a Micropump for MON-25/MMH Propulsion and Attitude Control," AIAA Paper 2019-4028, Aug. 2019

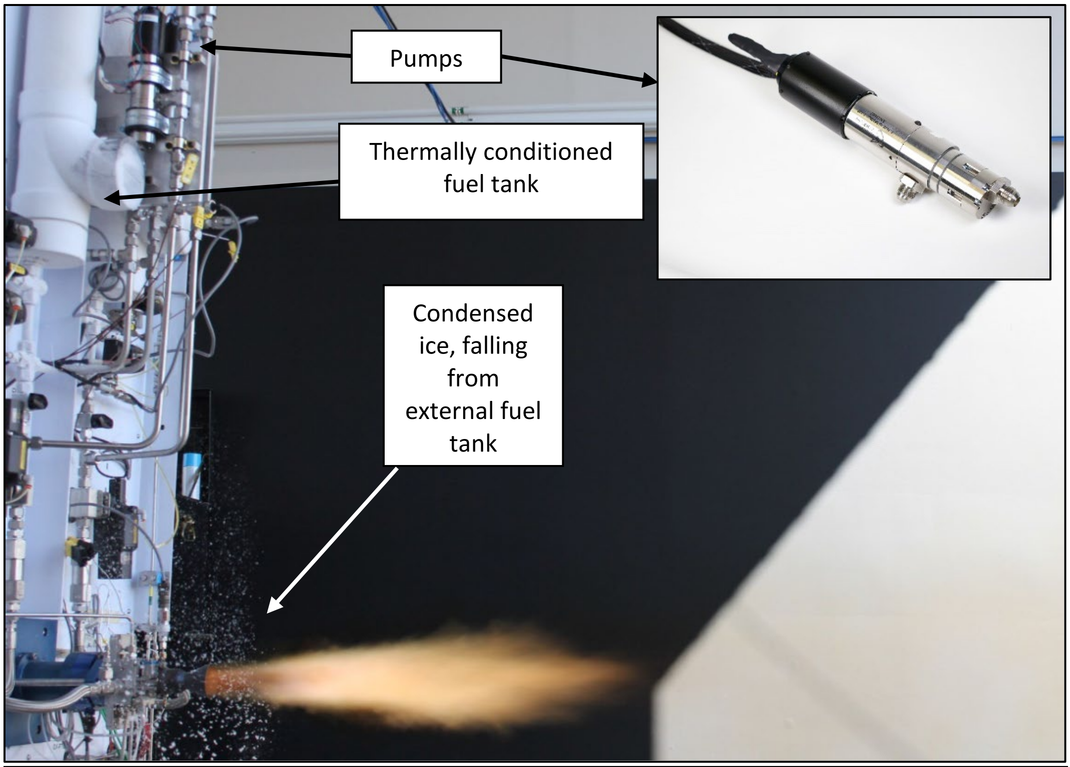


Figure 5. Ignition of pump fed MMH/MON-25 1000 ms hot fire test. Ice from thermally conditioned propellant tanks (-20 to -15 °C) can be seen falling off near the thruster.

3. About Flight Works

Flight Works, Inc. was formed in 2002 and is located in the heart of the aerospace industry in the USA, Southern California. It is a small high-tech firm with deep-rooted technical expertise servicing the aerospace community. Its personnel has a wide experience ranging from the development of precision components to that of entire systems, such as launch vehicles and spacecraft. Its commercial activities are focused on the OEM market for micropumps. In this market, it has expanded its reach and product line from the initial application to turbojets to include UAV engines, methanol fuel cells, space propulsion and other products pumping many fluids. Complementing this activity is extensive R&D in micropump-fed spacecraft chemical propulsion encompassing cryogenic fluids (e.g. LOX/methane), hypergolic propellants (hydrazine, MMH, NTO, MON-25) and green monopropellants (AF-M315E, LMP-103S). This activity has resulting in the production and delivery of mission-critical spaceflight hardware for several customers, including for commercial companies testing their systems on ISS and NASA lunar missions.

The company has in-house design, analysis, manufacturing, and testing capabilities. Its facility includes engineering offices, two enclosed assembly/testing rooms, and a machine shop area. Design and analysis tools include state-of-the-art computer Aided Design (CAD), and Finite Element Analysis (FEA) for thermal and structural analyses, including random vibration, and multi-domain physics-based simulation software for analyzing fluid/mechanical systems.

With its CNC (computer numerically controlled) and DRO-equipped lathe, milling machines and grinders, the company can develop rapid component prototypes made from various aluminum alloys, Nickel-alloys (such as Inconel and Hastelloy), stainless steels, titanium, and high-performance engineering plastics such as PEEK and PTFE. It has precision tooling and measurement devices such as a Mitutoyo toolmaker's microscope and a Keyence measurement system to inspect parts in the micron range as necessary for high performance and repeatability. Assembly, integration and test (AIT) capabilities include Class 100 cleanliness accomplished with laminar flow bench (Figure 6). It also has developed a series of test stands which have the capability for testing multiple pumps for tens of hours without interruption with various fluids including jet fuels, kerosene, water, ethylene glycol, acetone, and CFC 113 (Freon). Some of these test stands use modern data acquisition and control systems based on National Instrument hardware and LabVIEW software.

Figure 6. Thermal-vacuum chamber, laminar flow bench, precision measurement, vibration testing

Flight Works also has the in-house capability to perform random and sine vibration and thermal-vacuum environmental testing of small components like pumps, either for risk reduction, ATP or qualification.

Flight Works' quality management system has been certified to AS9100 and ISO 9001 since 2015. Every section of the QMS was audited for conformity, including items like risk management in the design process, comprehensive instrument calibration, and component traceability throughout the manufacturing and assembly process.