Pistonless Pump for Safe and Reliable Space Access

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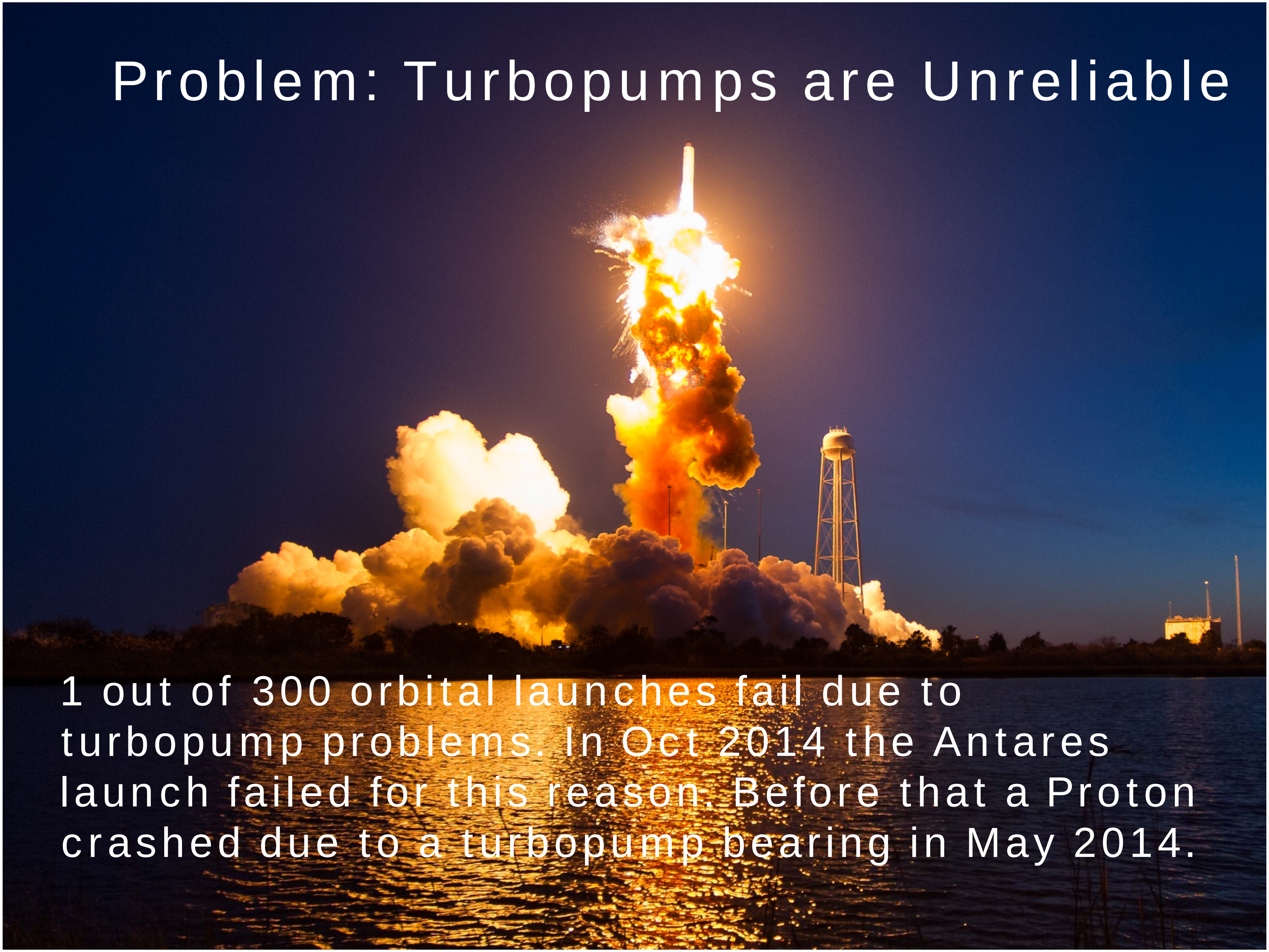
Photo: Atlas Vernier with Pistonless pump

FLOMETRICS


Problem: Turbopumps are Unreliable
1 out of 300 orbital launches fail due to turbopump problems. In Oct 2014 the Antares launch failed for this reason. Before that a Proton crashed due to a turbopump bearing in May 2014.

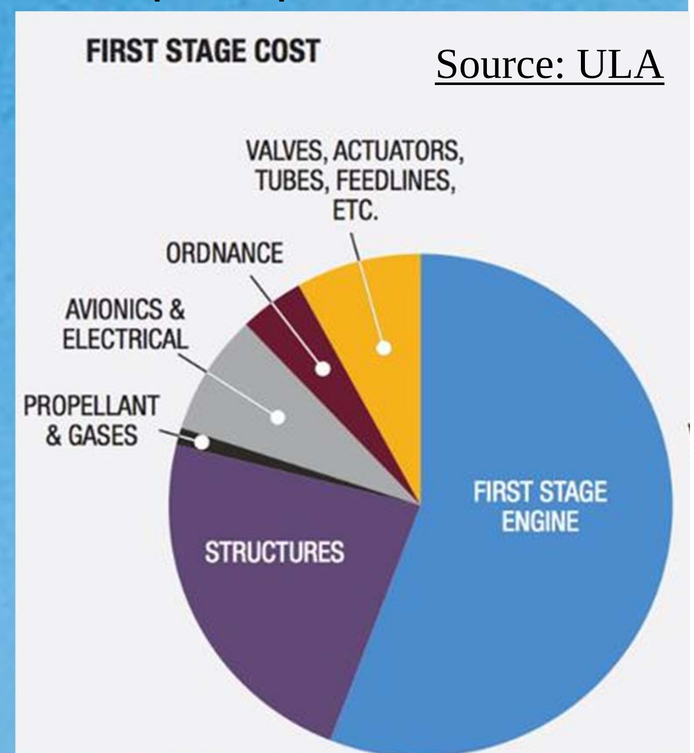
Solution: Pistonless Pump

- Performance equivalent to or better than gas generator turbopump systems
- Inexpensive materials and processes. Lowers vehicle cost.
- Safer: Failure modes are benign, main tank pressures are lower
- No precision parts. Inherent reliability.
- Robust system; can pass contaminants.
- One design will work with many propellants.
- 100% Throttleable
- Mass producible and scalable
- Transition from pressure fed static test to pump fed is simple and quick.

Market:

- The launch industry represents $5.9B* of the $203B in global revenue for 2014 of the satellite industry
- In 2015 there were 82 satellite launches, with average cost $72M. Most launchers use turbopumps which cost approximately $10M per vehicle, the rocket propellant pump market is $820M

•Half of the market are national security missions, not available.
•The Pistonless pump sells for 25% of the turbopump with good margins
•The total addressable market is $100M



Source: ULA

*Tauri Group 2015 State of the Satellite Industry Report

Go to Market Strategy

- Rocket Scientists are risk averse. Pistonless pump must be proven to be considered.
- First step is to integrate the Pistonless pump with engines of increasing thrust levels to prove scalability.
- Next step is integrate and test fly in a small to moderate size vehicle for a reference mission

•Sales opportunities happen when a new vehicle is on the drawing board, or when an existing vehicle explodes spectacularly due to turbopump problems.

Sea Launch 2007

Target Customers

- Best customer is not risk averse, has a tight development schedule, and is well funded.
- Potential applications include:
  - Scalable rocket powered vehicle for DARPA programs
  - Small thrusters for attitude control and backup propulsion for a vehicle with a turbopump main engine. (NASA)
  - Cyrogenic propellant transfer on orbit without adding heat (DARPA/NASA)
  - Cubesat Launch vehicles
  - Space Tourism Vehicles
  - Scalable Launch Vehicles

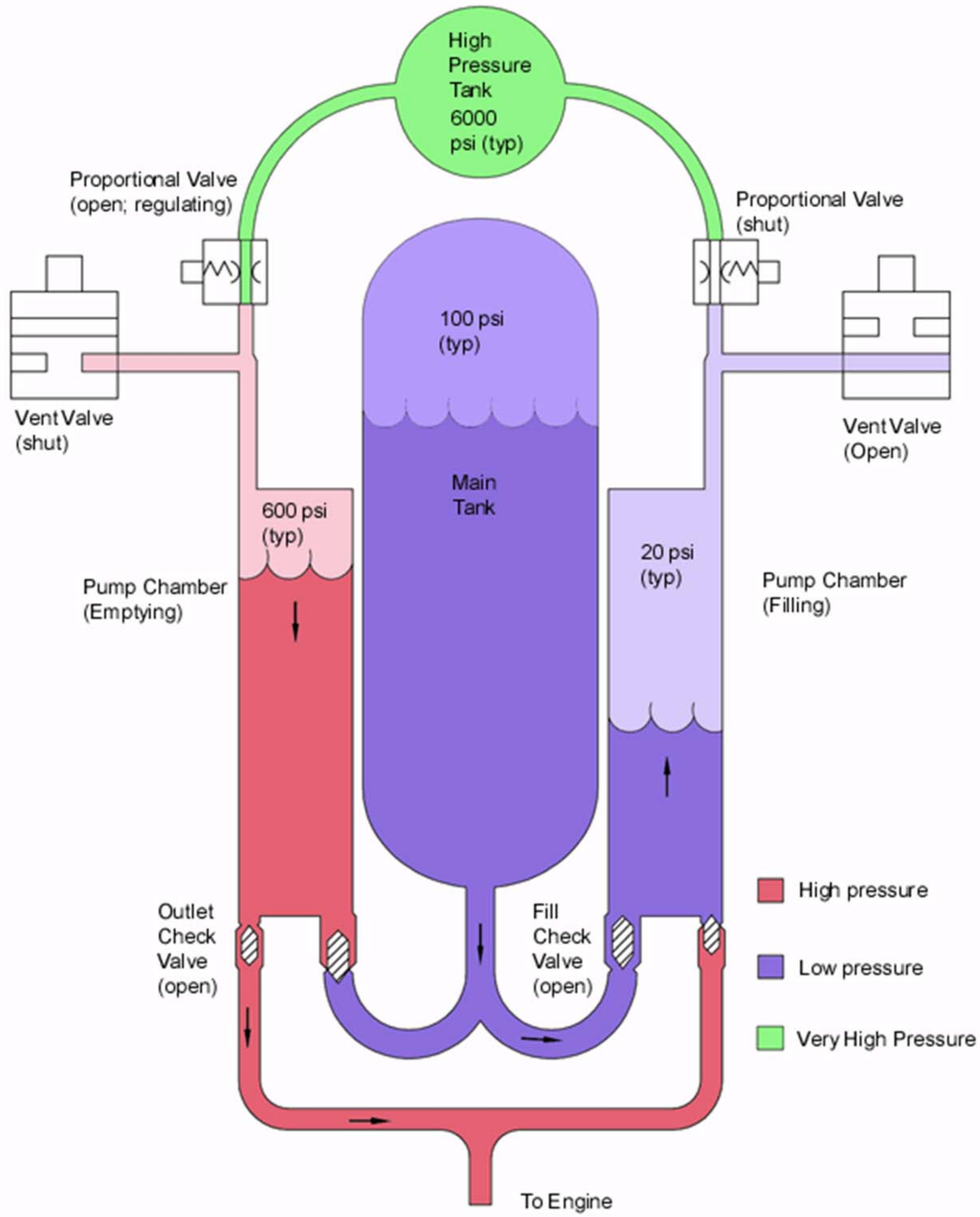
Competition

- Gas Generator Turbopump 1st stage has a 2.9% ΔV penalty, primarily for pump propellant
- Pistonless Pump 1st stage with heated liquid Helium pressurant has a 1.3% ΔV penalty, primarily for pump mass

Competitor	Product Description	Competitive Analysis
Barber-Nichols/AJR	Turbopumps	•Expensive •Long Time to Develop
Various	Standard Pressure Fed System	•Long History of Use •Tank Mass •Cold gas pressurant+tanks
LLNL	Piston Pumps	•Has been used for flight •Issues Sealing
Xcor	Piston Pumps	•Under Development

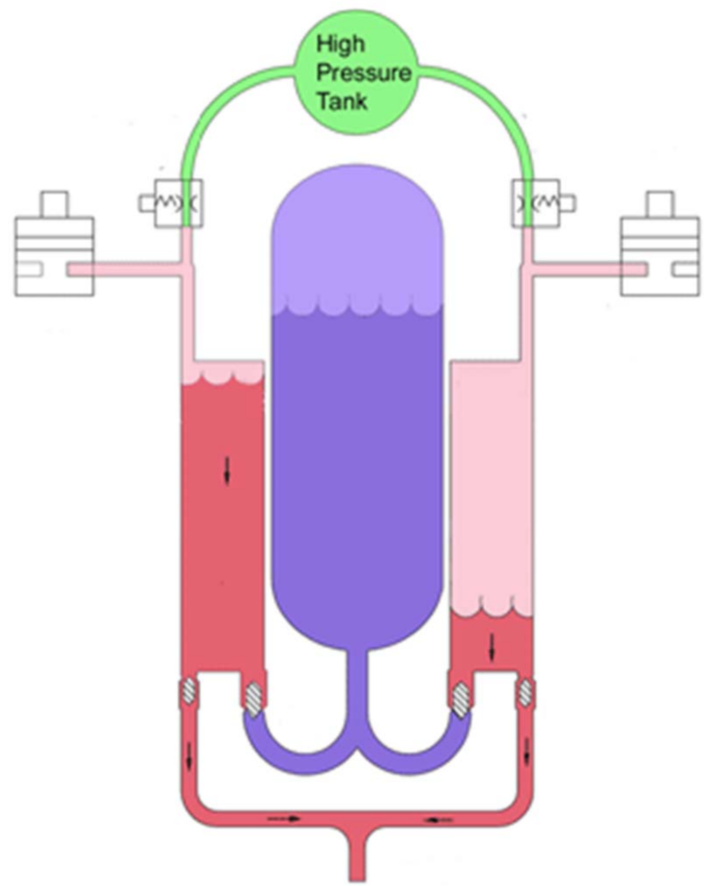
How it works:

1. Drain the main tank at low pressure into a pump chamber.
2. Pressurize the pump chamber and feed to the engine.
3. Run two in parallel, venting and filling one faster than the other is emptied.
4. Overlap allows for steady flow and pressure



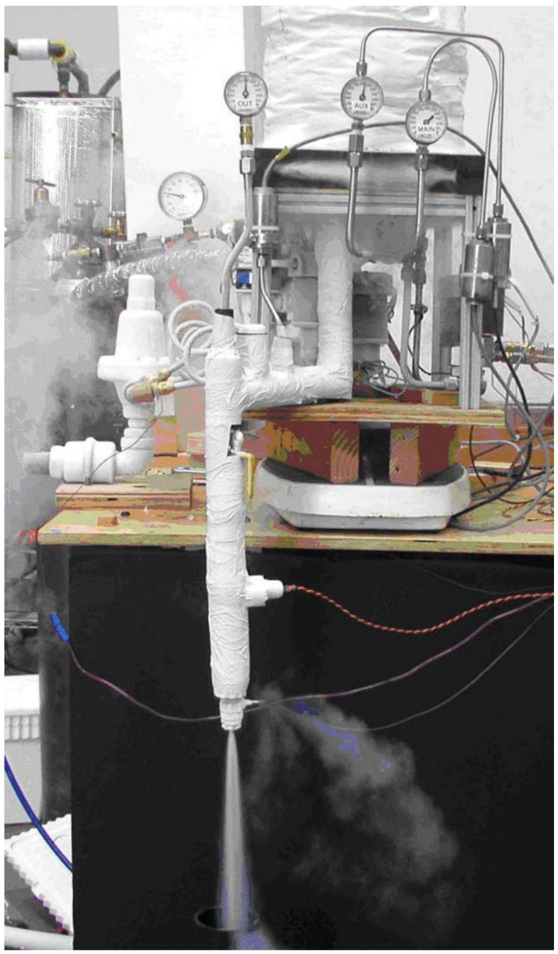
Pump Animation

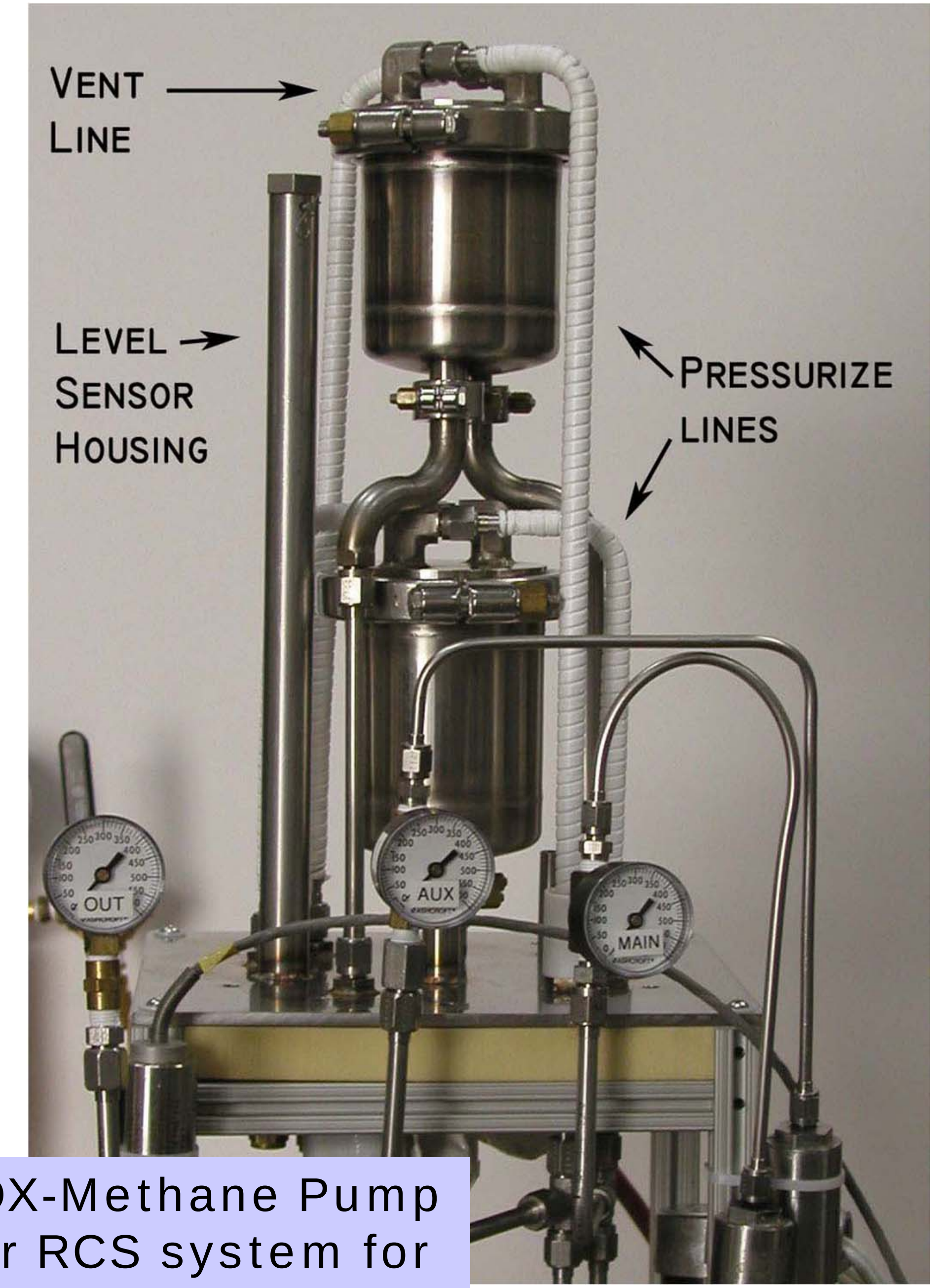
1. Pump starts with both chambers full, in thermal equilibrium.
2. One chamber is pressurized, and fuel is delivered until level gets low in that chamber.
3. The pressure is applied to both chambers, and fuel is delivered briefly from both chambers.
4. Then the nearly empty chamber is vented and refilled and the cycle repeats.



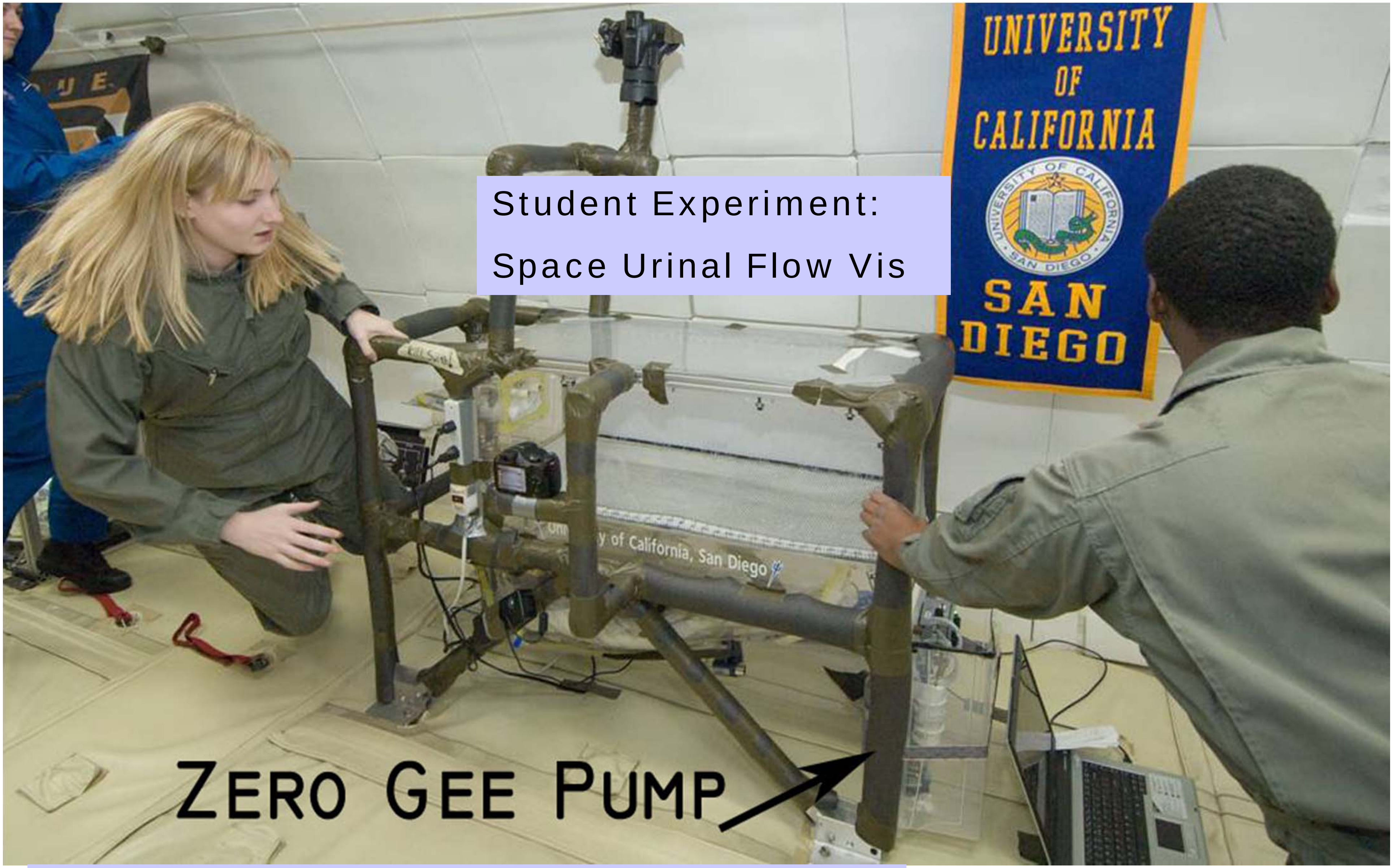
Rocket Pump Development SBIR

Built pump for NASA Glenn, met all technical milestones, plus demonstrated operation in Zero gee plane. Current DARPA SBIR for 100 & 1000 lbf



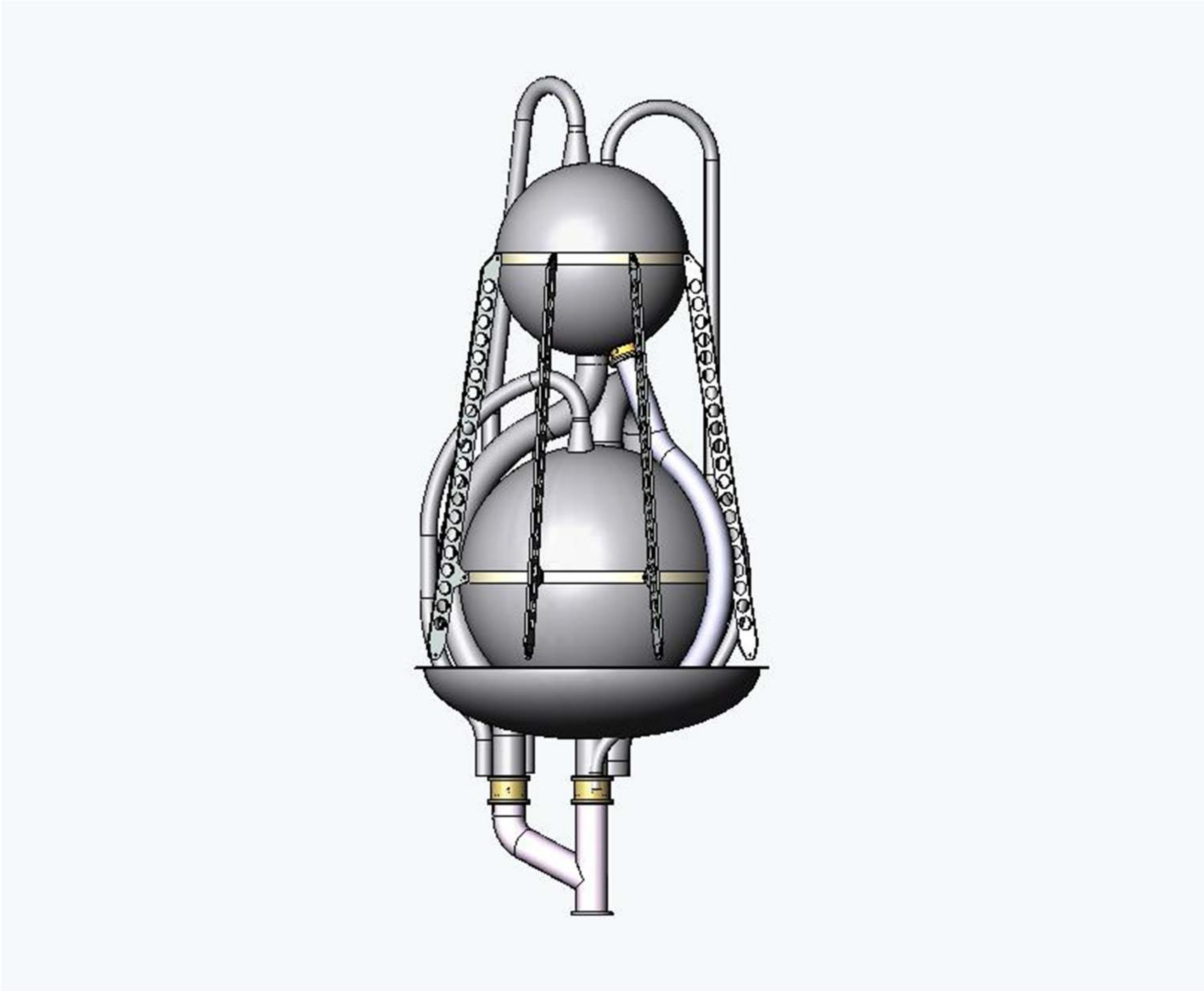


LOX-Methane Pump For RCS system for Lunar Lander



Pump test. Flown on zero gee plane as a secondary experiment run at the Microgravity University at JSC

In tank Design with Spherical Chambers for Launch Vehicle



Flometrics Experience

- $1M of Pistonless pump based supercomputer liquid cooling systems in production (Chilldyne)
- Flow loop for testing hydrazine flow meters
- UAV liquid cooling system for Northrop Grumman
- Analysis, testing and flying of liquid propellant (LOX/RP) rocket systems.
- Pumps, cooling systems, valves, heat exchangers, fluid sprayers and regulators
- Patented technology on the market:
  - Airlife constant positive airway pressure device.
  - Eclipse portable oxygen concentrator
  - Cymer NanoLith™ 7000 Lithography Light Source
  - Philips Espirit Medical Ventilator
  - Scrubbing Bubbles Automatic Toilet Cleaner

Conclusions/ Future Plans

- Pump based system weight and cost are low and it works as designed.
- Replace turbopumps for spacecraft and launch vehicles at reduced cost with increased safety and reliability.
- Next steps:
  - Team up with vehicle and engine builders to make launch vehicle and space propulsion systems more safe, reliable and affordable.