High Performance Pump-fed Steam Resistojets for CubeSats

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Key Cubesat Propulsion Issues

Benefits of propulsion to cubesats

1. A wider range of rides, if a cubesat can get to a better orbit itself.
2. Longer missions at lower altitude (less debris, better earth imaging).
3. Close-inspection missions, if you can safely rendezvous with something.
4. Greater relevance of cubesat projects to more ambitious spacecraft

The key challenge for all secondary payloads is ***"First do no harm!"***

1. You must show that your secondaries cannot harm the primary mission.
2. The more benign you are, the more options you have for convenient rides.
3. Propellants that are non-flammable, non-toxic, and unpressurized help.
4. Being provably non-propulsive until properly commanded may be hard.

Why Use Water in a Resistojet?

Benefits:

1. Not flammable, toxic, or high-pressure.
2. Isp scales roughly with Sqrt(SteamTemp)
3. Higher impulse/volume than ammonia.
   - *Important, since cubesats are usually volume limited.*

But there are some drawbacks:

4. Local ice formation can cause problems.
5. And the oxygen in hot steam can oxidize the heater & nozzle.
   - *If the oxide is flaky, it can plug the nozzle throat.*
   - *If the oxide is volatile, the throat will erode and expand over time.*

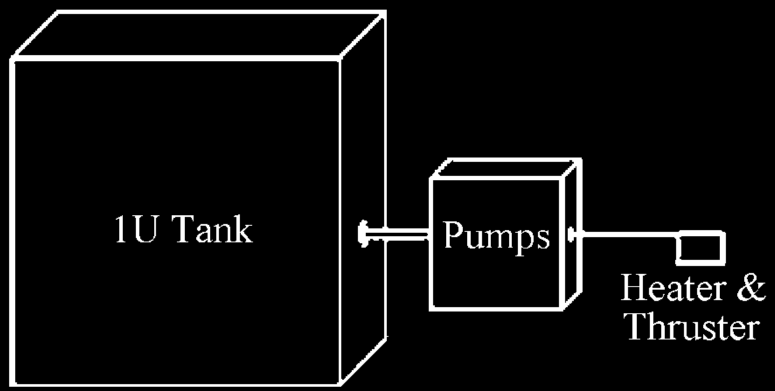
Why Use Pumps in a Resistojet?

What do small high-pressure thrusters allow?

1. Small heaters can afford high-temp metals like platinum, which raise Isp.
2. High pressure also raises Isp by cutting viscous losses (key at low power!).
3. Small thrusters can heat up & vary thrust quickly, allowing precise control.

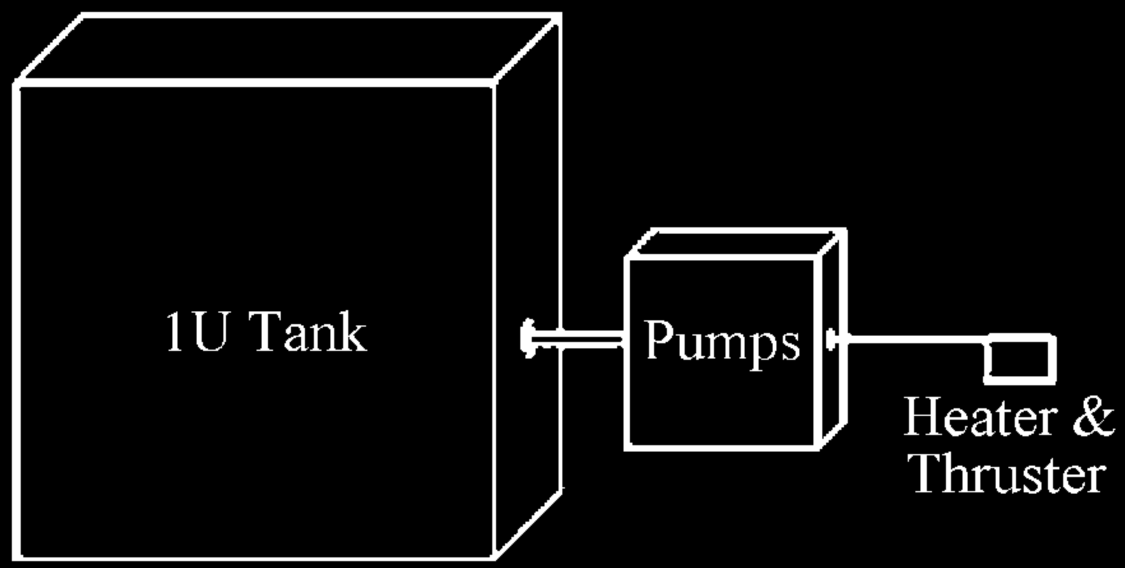
How do pumps benefit overall satellite design?

4. They allow throttling, to use available power (5-20W?) most efficiently.
5. Higher pressure shrinks hot-section size & cuts heat soakback into body.
6. Low-pressure storage lets light tanks fit & fill unusual storage envelopes.
   - ***Using available volume better may be the biggest payoff for most cubesats!***



Key Pieces of a Pump-fed Resistojet

1. Tank w/liquid feed features (adaptable in size & shape)
2. Pumps (both low & high pressure, each redundant)
3. Hot section (heater + nozzle)
4. Plumbing, actuators, and sensors
5. Dedicated microcontroller with power converter
6. Optional 2-axis gimbal (vs 3 separate thrusters)



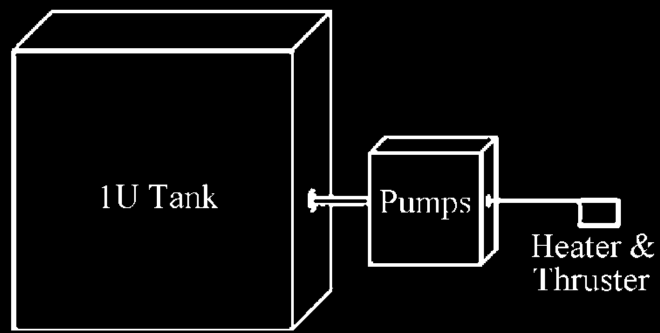
Low-pressure Storage Tank Design

Goal: hold maximum usable propellant in minimum total mass & volume.

1. Even a ¼-U water tank may be most of a propulsion system's mass & volume!
2. Minimize unusable propellant plus propellant acquisition mass & volume.
3. Ensure liquid feed even near empty, with adverse accel & temp gradients.
4. Allow use of flat walls if that eases overall volume-limited satellite design.

Strawman design: Unsealed box holds low-permeability film bladder.

1. Some packaging films have low enough permeability for multi-year missions
2. Use dual bladder (with eg. ethanol pressurant), and/or zero-NPSH pumps.
3. No negative-pressure loads before launch (air fills bladder/box gaps)
4. Pressure load on box in vacuum is limited to water or ethanol vapor pressure.
5. Box & bladder can be easily customized to fit any available storage envelope.



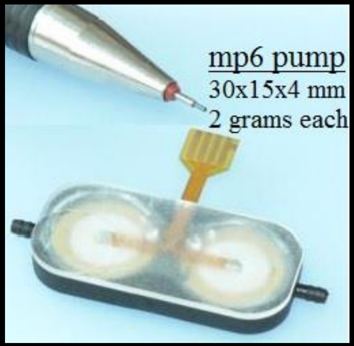
Redundant Low & High-pressure Pumps

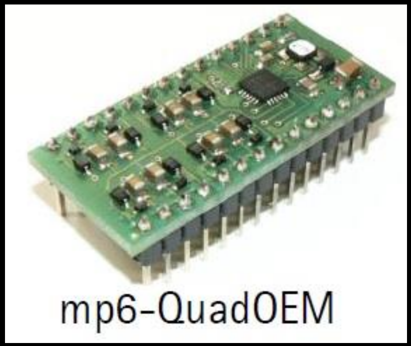
Key design drivers

1. High reliability at low mass and acceptable purchase + integration cost
2. Must acquire liquid even near-empty, with adverse temp gradients
3. Efficiency is not critical, since heating power >> pumping power
   - *But heat dissipation by pumps can vaporize water, complicating pumping*

Strawman design features:

1. Mount mp6 piezo pumps (2 grams, 30x15x4mm) near corners of bladder
2. Use temp sensors to select coldest corner of tank and pump from there.
3. Use other piezo-electric or other pump types for high-pressure pumping.



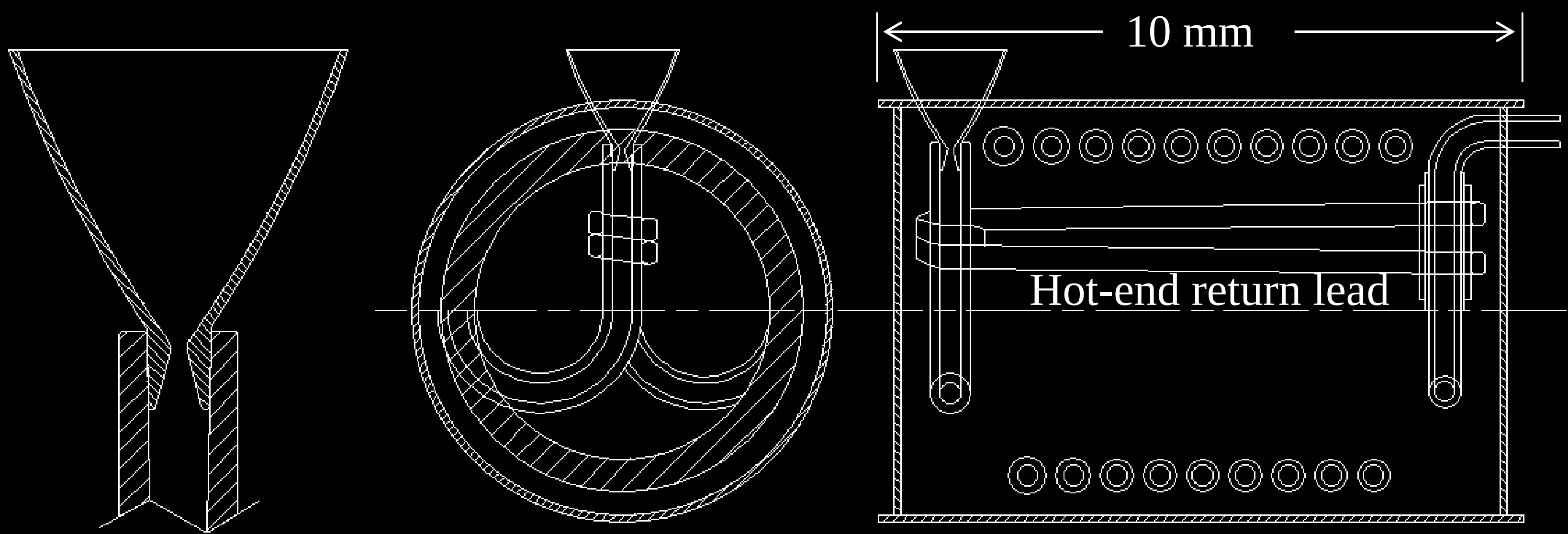


550 kPa piezo pump
23x12.5x12.5 mm

Hot Section Design

How can we get the highest steam temperature for the highest Isp?

1. Use high-temperature materials that don’t oxidize in hot steam!
2. Hot platinum oxidizes in steam slower than higher-melt-temp metals do.
3. Platinum oxide is volatile enough to not condense in the nozzle.
4. Platinum mass <1 gram, so fab cost will far exceed ~$20 Pt material cost.
5. Peak steam temp limited to 1400-1500K by both oxidation & tube creep.
6. Low heater flow volume allows small “minimum impulse bit size.”
7. Helical tube is both resistance heater & temp sensor (~0.3 ohm when hot).
8. “Double-D” laminar flow ~quadruples HX in helical tubing (“Dean #”).



Balance of System Components

Plumbing, actuators, and sensors

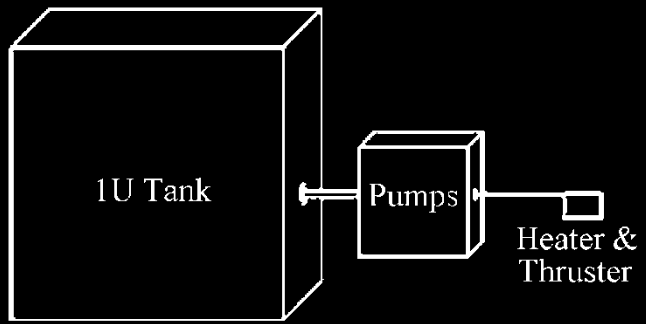
- Lee Company & others have many relevant microfluidics components.

Dedicated microcontroller with power converter

- A standard controller can reduce vulnerability to user software errors.
- It can also downconvert & filter power for a ~8A 2.5V heater circuit.

Optional 2-axis gimbal (or 3 separate thrusters?)

- 10mN resistojet thrust is enough that aim errors need steering correction.
- Either use 3 thrusters straddling CG, or be able to aim a single thruster.
- Gimbal lets thruster go outside cubesat envelope, reducing heat soakback.



Conclusions

1. Many Cubesat missions may benefit from on-board propulsion.
2. Water is a benign propellant with good volumetric impulse.
3. Steam resistojets of ~5-20W power may often be competitive.
4. A platinum hot section may allow ~1400K steam and 200 sec Isp.
5. The water tank will often be the main propulsion mass & volume.
6. Pumped-flow resistojets allow lighter tanks & flexible operation.
7. I want to license this design to an existing NewSpace supplier.