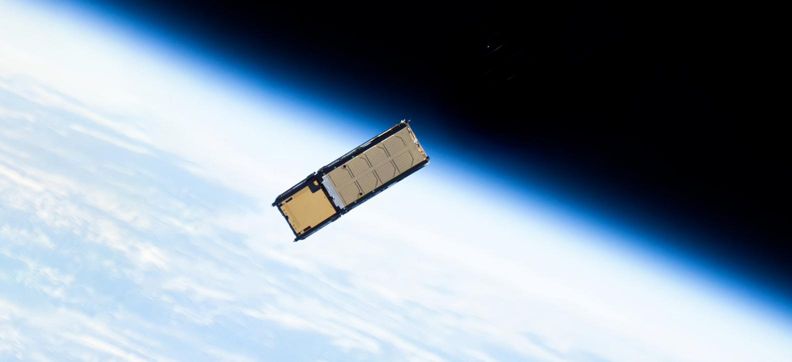
THERMAL ANALYSIS

modeling of piezoelectric pump for single-phase



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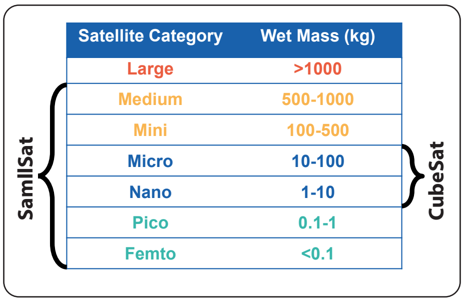
Research conducted by:
Casper Bonnema

For more info please contact:
Sander Elvik
Thermal systems engineer
sander.elvik@demcon.com

Thermal challenges

SmallSats have become increasingly popular due to their lower costs compared to traditional large satellites. The introduction of CubeSats (Figure 1) helped reduce integration costs by offering a modular standard for micro- and nanosatellites. As satellites shrink while maintaining similar performance requirements, their power density increases, making thermal management a key challenge. In space, heat can only be removed via radiation. The miniMPL, developed by Demcon kryoz (Figure 2), is a single-phase cooling system for CubeSats, designed with redundancy, miniaturization, and efficient heat transfer in mind.



Satellite Category	Wet Mass (kg)
Large	>1000
Medium	500-1000
Mini	100-500
Micro	10-100
Nano	1-10
Pico	0.1-1
Femto	<0.1

Figure 1 *Satellite categories.*

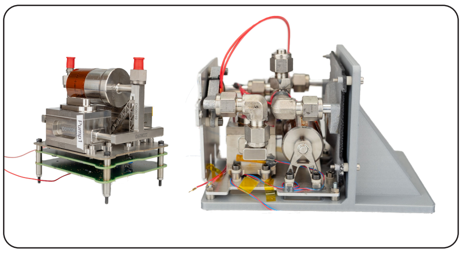


Figure 2 *Demcon kryoz miniMPL.*

Learn more on: kryoz.demcon.com

Single-phase cooling loop

To address these thermal issues, a single-phase cooling loop is proposed (Figure 3), with a piezoelectric pump developed with NLR. This pump uses a vibrating diaphragm with inlet and outlet valves to generate flow (Figure 5). Demcon kryoz developed the miniMPL, pump units are placed in series and parallel for redundancy (Figure 4).

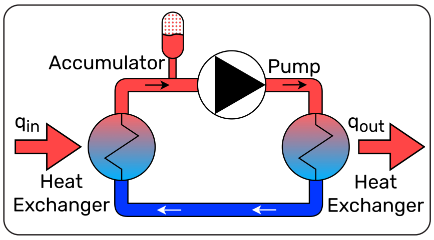


Figure 3 *Schematic of a single-phase cooling loop.*

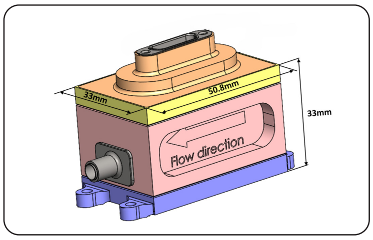


Figure 4 *MiniMPL piezoelectric pump block.*

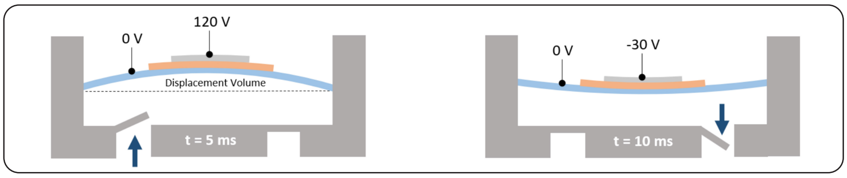


Figure 5 *Pumping cycle of a piezoelectric pump.*

Lumped-Element Model

To understand and optimize the pump's behavior, a Lumped Element Model (LEM) was developed (Figure 6). This reduced-order model captures the dynamics of the hydraulic channels, piezoelectric diaphragms, and the check valves. It combines numerical simulations and experimental data to quantify the flow resistance, diaphragm stiffness, and valve behavior. The model enables transient analysis of the pump's operation under varying conditions.

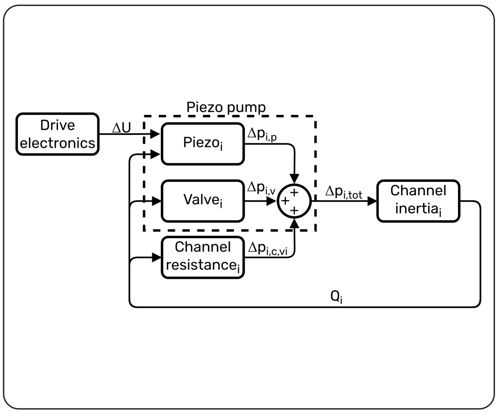


Figure 6 *LEM model overview.*

Quantification of the submodels

The piezoelectric diaphragm model combines empirical stiffness data of the diaphragm (Figure 7.1) and clamping O-rings (Figure 7.2) with its voltage-induced deflection to estimate pressure response. Hydraulic channel resistance is calculated using the Darcy–Weisbach equation and fluid acceleration from Newton's second law. The valve model integrates experimental hydraulic resistance with a hybrid result (Figure 7.3) that merges valve deflection and simulated resistance.

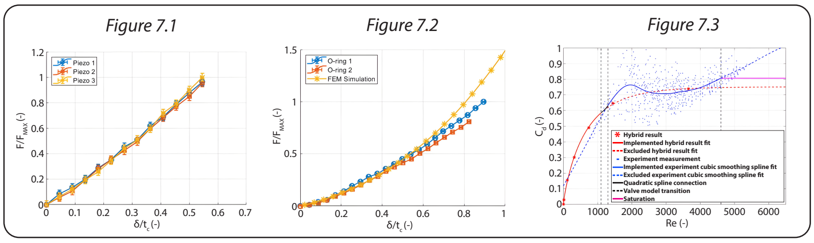


Figure 7 *Valve experiment results.*