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Development of a Miniature Active Cooling System for Space Missions

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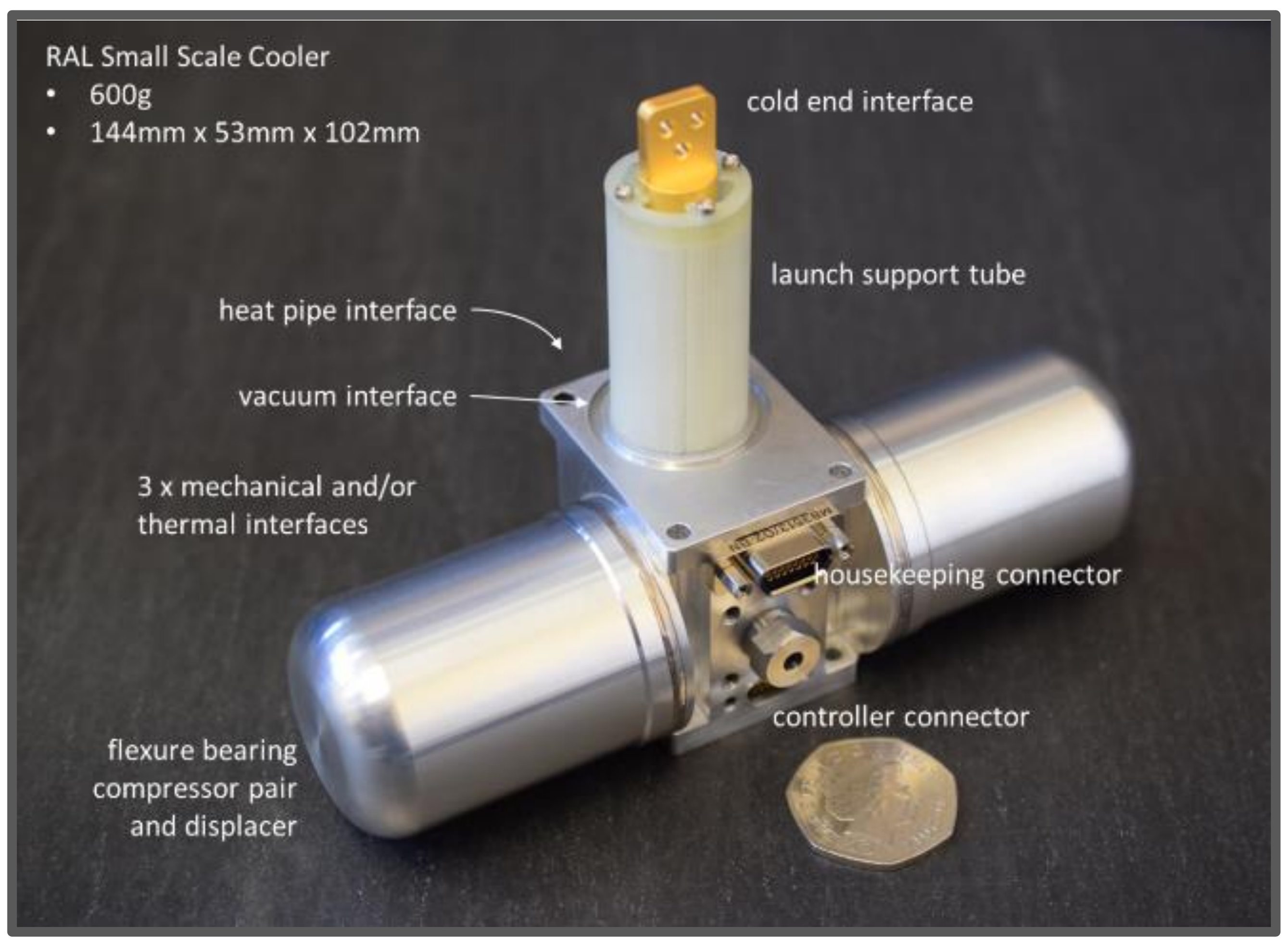
Background

Cryogenic cooling is critical to space exploration. Certain scientific instruments, such as infra-red telescopes, need to operate at extremely low temperatures to produce clear signals. Active cooling is usually only available to large, bespoke science missions. The Cryogenics and Magnetics Group (STFC) have the ambition to provide low-cost, compact coolers for wider use: the Small Scale Cooler (SSC). The project will enable smaller missions to purchase off-the-shelf coolers, expanding the possibilities for future scientific missions. Today, the technology is entering a new design phase, with development led by STFC, along with a consortium of British companies and the European Space Agency.

Isn't Space Already Cold?

The background temperature of Space is a chilly -270°C. However, if the spacecraft has an internal source of heat, such as electronics, the spacecraft's temperature will depend on how much of that heat is radiated into Space. This is largely determined by the size of the spacecraft's radiators. Active cooling systems, such as the SSC, allow instruments to be sufficiently cooled without the need for huge radiators.

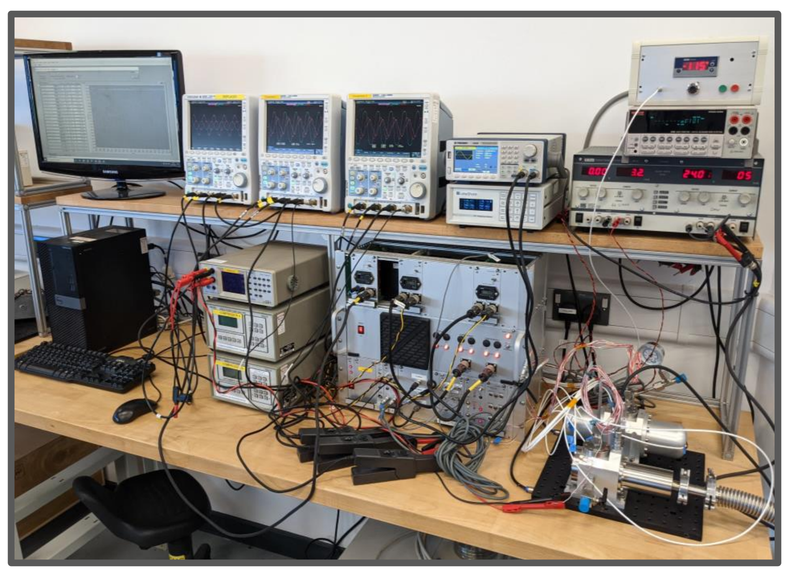


The Small Scale Cooler

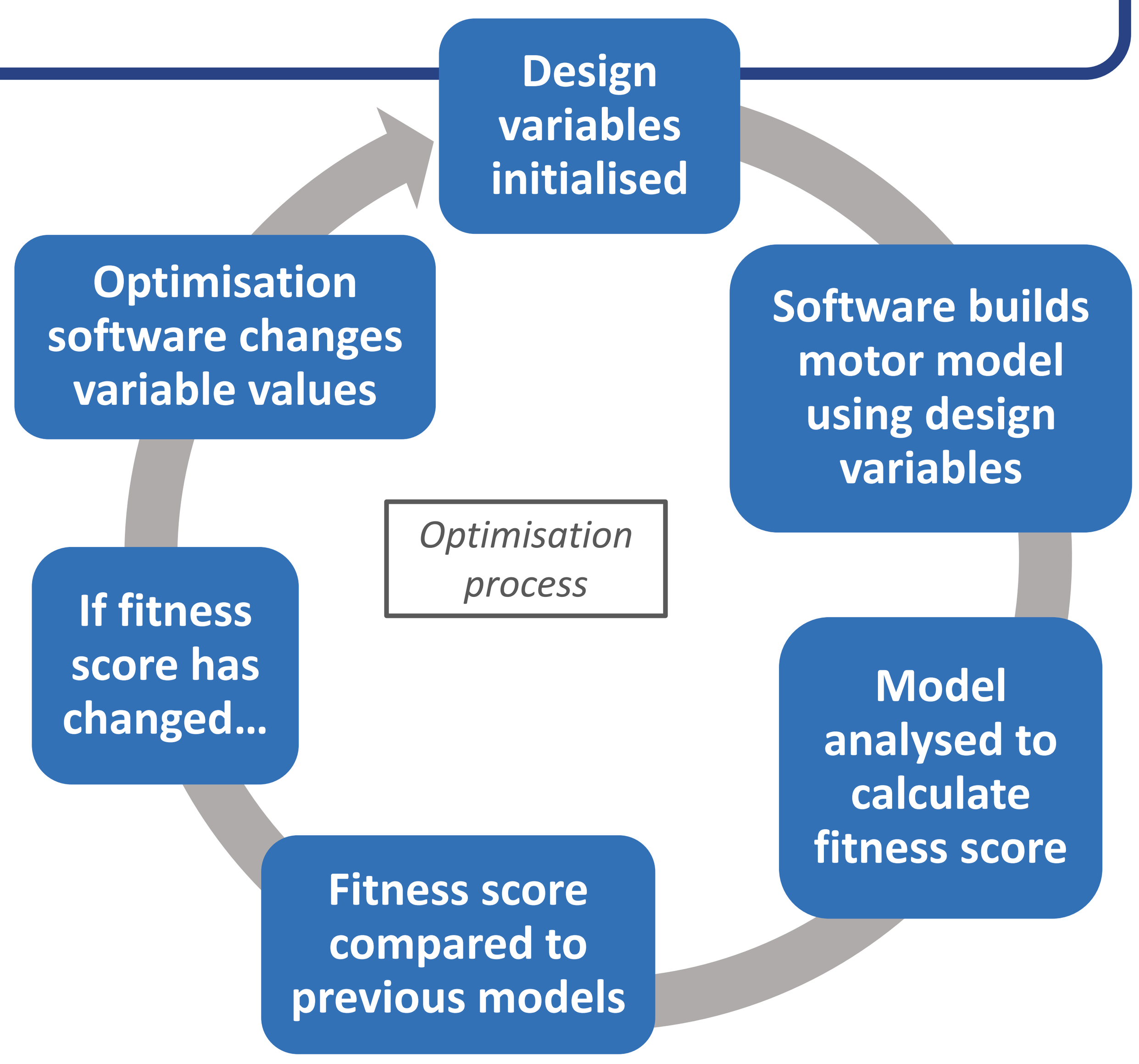
The SSC uses a thermodynamic cycle called the Stirling cycle to produce a cooling effect. Helium gas is cyclically expanded and contracted in different sections of the cooler, which cools down the cold end interface. The pistons are driven by an opposing pair of motors to cancel out vibrations that could contribute to signal noise. The cooler design is bespoke, with many of the parts manufactured in-house to extremely precise standards. Reliability is key when designing coolers for space, as the system cannot be repaired following launch. The finished product will weigh just 600g, and can cool down to nearly -200°C with only 25W of input power.

Optimisation Algorithms

We are currently developing the next version of the design. Several design elements could be adjusted to improve the cooler, but often these elements are interconnected, so changing one may have a negative effect on another aspect of the cooler. Problems like this are best solved using a computer optimisation algorithm, which can quickly cycle through many design variants to find the best one.



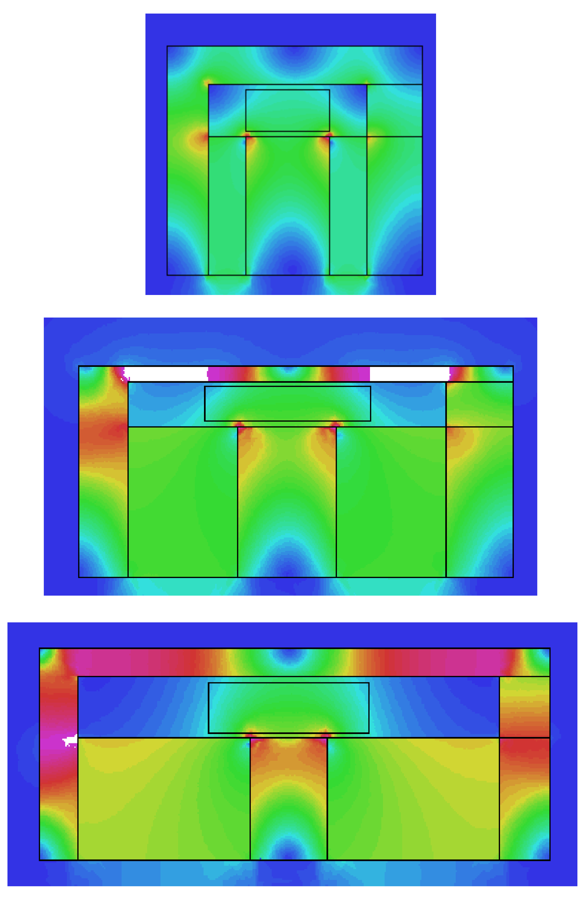
Laboratory system model



Optimisation process

Motor Optimisation

The optimiser software divides a simplified motor model into a fine mesh of points, then does calculations at each point to estimate the complex overall physics (finite element analysis). We use a measure of performance called the fitness function to find the best design, which encompasses factors such as low mass and good electrical efficiency. Each design is ranked according to its fitness score. The best designs can then be analysed further. The analysis is supported by a lab model of the system. The dimensions of the lab cooler are not representative, but the performance can be used to calibrate our thermodynamic and kinematic models.



Optimiser analysis results

Next Steps

The UK already houses world-class satellite manufacturing capabilities, and in 2021 the government announced their vision to be at the global forefront of small satellite launch. The SSC will provide accessible active cooling, enabling a new generation of ambitious small space missions. The SSC is also expected to support numerous terrestrial applications, such as infra-red detection and imaging. With today's unprecedented access to space, the addition of reliable, compact cooling to this landscape will prove revolutionary.

References

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National Space Strategy. HM Government. (2021).

The Group

The Cryogenics and Magnetics Group (Applied Science Division, Technology, Rutherford Appleton Laboratory) are engaged in a wide range of projects, from the development of long-life closed-cycle cooling systems for spacecraft, to superconducting magnet design for particle accelerators.