Thermal assessment of CLIMB - a novel CubeSat mission to the Van Allen Belt

The CubeSat CLIMB is a project of University of Applied Sciences Wiener Neustadt (FHWN). Like FHWN's first project PEGASUS [*1*], also CLIMB is foremost an educational project. There are many students involved in hands-on work on various subsystems with guidance from the professors and industry professionals.

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THERMAL ENGINEER

Recent MSc graduate from the University of Applied Sciences Wiener Neustadt. Involved with the team since late 2017. Through master's thesis built the thermal engineering model for CLIMB and conducted several analyses.

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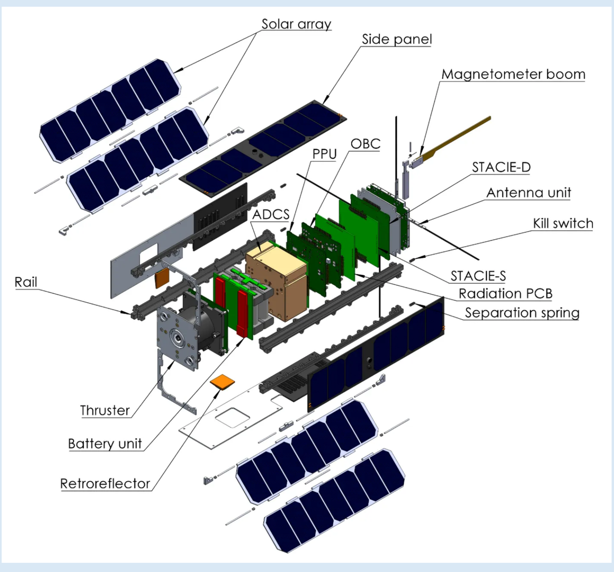
HEAD OF THE CUBESAT PROGRAMME

Head of the Aerospace Engineering department at the University of Applied Sciences Wiener Neustadt, Austria and project manager of the mission CLIMB.

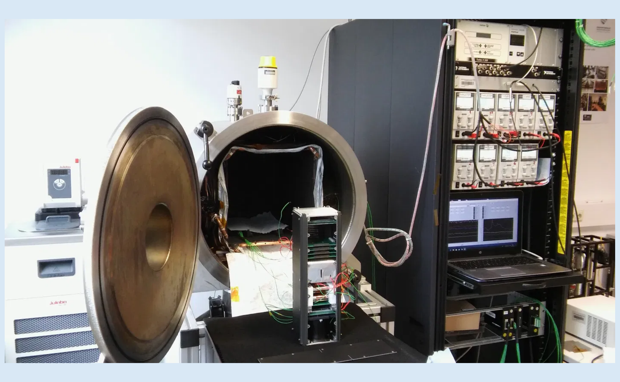
CLIMB mission

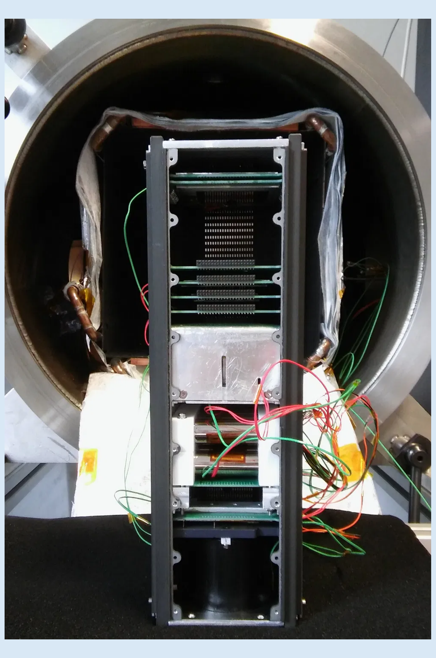
The CLIMB mission will push the envelope of university-led CubeSat missions. Starting from an initial orbit altitude of ~500 km, the satellite will use its IFM (Indium FEEP Multiemitter) [*2*] propulsion system to propel itself to an orbit with an apogee of at least 1000 km, i.e. to within the inner Van Allen Belt [*3*]. Throughout its one year transfer and for a certain time after arriving in the Van Allen Belt, the satellite will measure the accumulated radiation dose and monitor the performance of its subsystems to correlate it with similar tests done during ground testing in radiation facilities. All the subsystems of CLIMB can be seen in the exploded view below.



CLIMB thruster operation

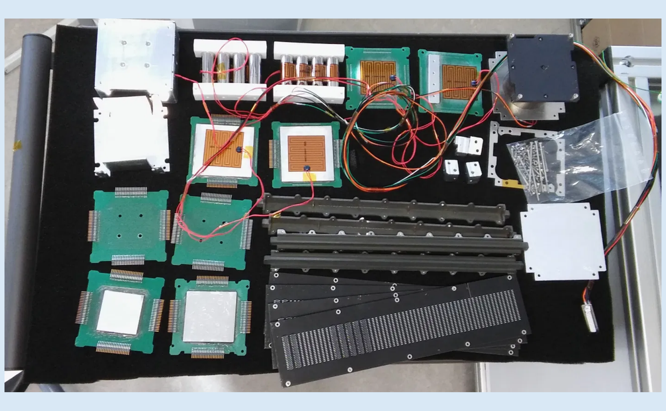
The altitude raising will be nominally done at each perigee for a maximum of 10 minutes at 40 watts of input power. As the power input and the related heat dissipation is significant for a CubeSat (up to 20 W during propulsion mode), a good understanding of the thermal behaviour is needed. For this reason, a comprehensive effort has been made to understand the thermal behaviour of CLIMB consisting of a detailed analytical model (ANSYS) as well as an experimental thermal model of the satellite (see figures below).





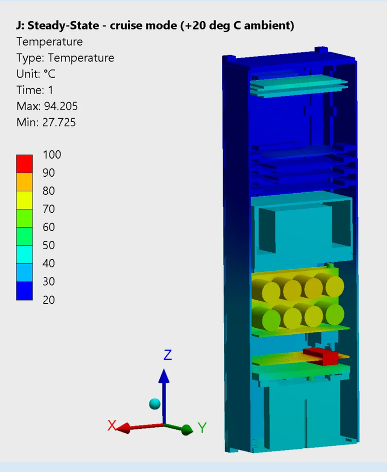
Thermal models

In the physical thermal satellite model, nine individual heaters allowed for a very detailed simulation of the dissipated heat of various subsystems (imaged below) and therefore of the thermal conditions in the satellite.

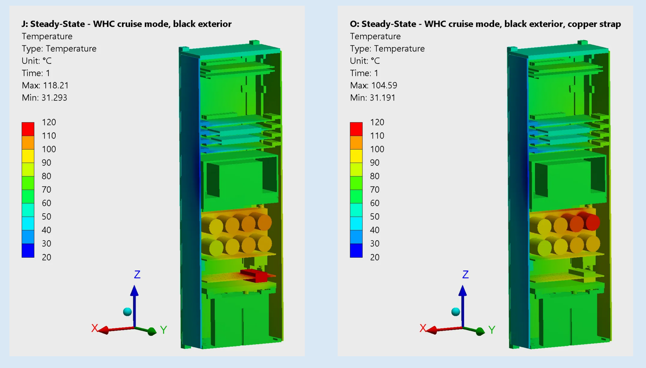


The predictions of the analytical model (one case shown in the figure below) were verified in a thermal vacuum chamber using the thermal satellite model. The correlations were done at several environmental temperatures (-20°C, 0°C, +20°C). In general, a good correlation was achieved between the analytical and physical models. Most of the temperatures were within 5 °C agreement between the models. In the worst hot case and without using a thermal control system, the first iteration of the analytical thermal model predicted the temperatures of the thruster to rise up to +120 °C (as seen below in the figure of the orbital analysis). However, already implementing a simple thermal copper strap between the thruster and the satellite structure in the analytical model showed the temperature decrease of approximately 30 °C.

Analytical predictions: +20 °C environment (Thermal Vacuum Chamber)

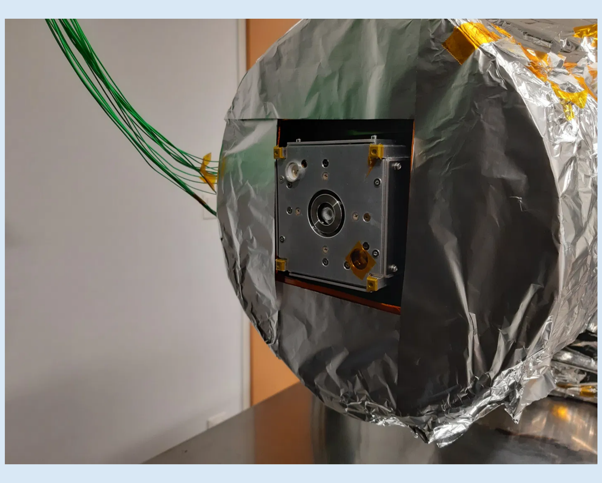


Analytical predictions: Worst Hot Case temperatures (orbit)



Results

In the final step, the thermal model of the thruster was replaced with a flight-like propulsion unit and several tests in a special purpose Thermal Vacuum Chamber (TVC) were conducted. This particular TVC allows to operate the propulsion system during a thermal vacuum test and therefore enables the verification of the thermal prediction in the most demanding operational mode (see photo below). For a +20 °C ambient temperature cruise mode test the temperatures were mostly within 5 °C, comparable with the previous tests. The difference grew larger in 0 °C and -20 °C ambient temperature cruise mode tests (up to 30 °C difference near the thruster).



The discrepancies were mainly due to the slight thermal model design differences and the semi-open thermal shroud design in the TVC (as seen on the photo above). The shroud needed an opening for the thruster plumes to be expelled from. As such, the exterior face of the thruster did not see a temperature controlled shroud surface.

These first tests with the real functional thruster showed the accuracy of the general thermal model and the analytical predictions. Based on these models, it is possible to implement the most fitting thermal control system solution. The options include a combination of thermal straps from the thruster to the structure, thermal shields and phase change material in-between the battery unit and the thruster to reduce the transient temperature peaks. In particular, copper-beryllium springs could be used as a compact thermal strap solution, as used on 3U CubeSat MinXSS-1 [*4*] . The phase change material mini-packs could be used similarly to NASA's 3U IceCube mission [*5*]. For the battery unit PCB design, dedicated coppers layers for heat transfer can be implemented, similarly as in NASA's Mars Cube One design [*6*].

1. *C. Scharlemann, B. Seifert, R. Schnitzer, R. Kralofsky, C. Obertscheider; M. Taraba, T. Dorn, T. Turetschek, H. Fauland, R. Plötzeneder, R. Stockinger, M. Schmid, T. Riel, A. Sinn, G. Janisch, F. Deisl, D. Kohl, B. Lybekk, H. Hoang, E. Trondsen, „PEGASUS – a review of in-orbit operation and obtained results", IAC-18,B4,3,3,x45633, 69th International Astronautical Congress (IAC), Bremen, Germany, October 2018*
2. *D. Krejci, A. Reissner, B. Seifert, D. Jelem, T. Hörbe, P. Friedhoff, and S. Lai, „Demonstration of the IFM Nano FEEP thruster in low earth orbit", in 4S Symposium, Sorrento, Italy, May 2018.*
3. *B. Weimer, C. Scharlemann, A. Reissner , D. Krejci, B. Seifert, „CLIMB: Exploration of the Van Allen Belt by CubeSats", IEPC-2019-805, 36th International Electric Propulsion Conference, , Vienna, Austria, 2019*
4. *J. P. Mason, B. Lamprecht, T. N. Woods, and C. Downs, "CubeSat On-Orbit Temperature Comparison to Thermal-Balance-Tuned Model Predictions", Journal of Thermophysics and Heat Transfer, vol. 32, 2017. DOI: 10.2514/1.T5169.*
5. *M. K. Choi, "Thermal assessment of paraffin phase change material mini-packs on IceCube 3U CubeSat in flight", in 2018 International Energy Conversion Engineering Conference, Cincinnati, Ohio, USA, Jul. 2018. DOI: 10.2514/6.2018-4490.*
6. *E. Sunada and J. Rodriguez, (NASA Jet Propulsion Laboratory, California Institute of Technology), JPL Advanced Thermal Control Technology Roadmap, presentation, Spacecraft Thermal Control Workshop, El Segundo, California, USA: The Aerospace Corporation, Mar. 28, 2017.*

Acknowledgements

The University of Applied Sciences Wiener Neustadt (German: Fachhochschule Wiener Neustadt, FHWN for short) is an Austrian Fachhochschule founded in 1994. It has eight areas of specialization. The main campus is in Wiener Neustadt and two smaller campuses are located in Wieselburg and Tulln (both in Lower Austria). It is Austria's first and largest Fachhochschule for business and engineering, which also includes a master's level aerospace engineering studies in English.

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