University of BRISTOL

DEPARTMENT OF aerospace engineering

Power & Thermal Design of Europa & Ganymede Penetrators

Fiona Hillier, Roderic van Hoof and Lucy Berthoud

The Jupiter Icy Moons Explorer mission (JUICE) has been selected for the L1 launch slot of ESA's Cosmic Vision science programme. It will provide scientific investigations of Jovian moons, including Europa and Ganymede. It has been suggested that the mission could carry penetrator probes to each of these Moons. The probes would be delivered by the spacecraft to impact into the moons' crusts and remain there for one Earth week on Europa and two Earth weeks on Ganymede. The low temperatures experienced and hostile and remote nature of the moons present a serious challenge to the thermal and power systems of the probes.

The purpose of this study was to address and overcome these challenges by arriving at a probe design for each moon which would allow the probes to survive for their mission lifetimes and beyond. This has been achieved in both cases, with the Europa probe surviving for over a year, and the Ganymede probe for 17 days with the option to extend this to over 2 months with an increased power budget.

Ganymede

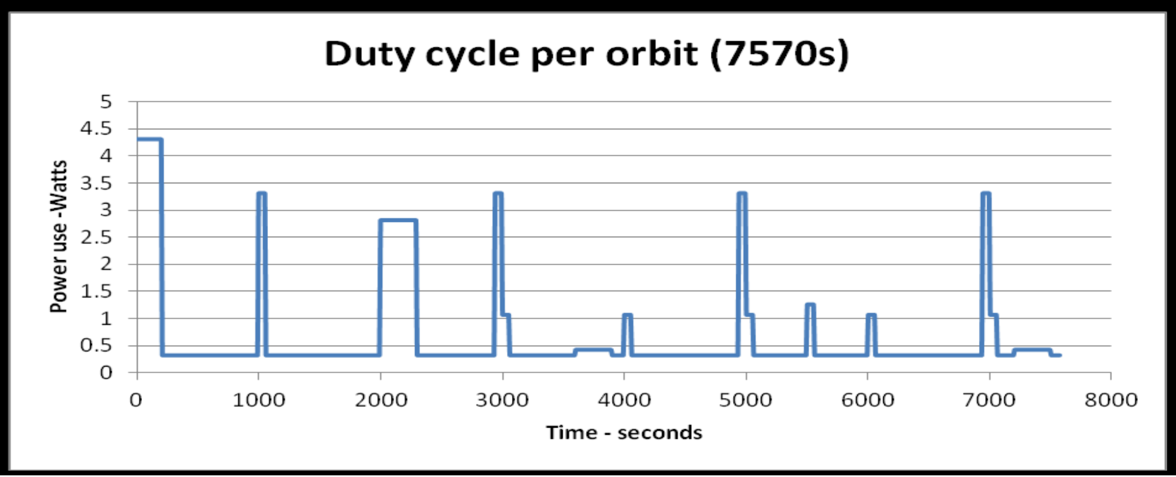
Initial calculations have been performed based on 1D steady state conduction equations. These were undertaken to determine the scope of the problem by calculating the lifetime with minimal thermal protection. The max lifetime was determined to be **1.3 hours**.

Conditions & 1st Steps

Parameter	Ganymede	Europa
Temperature range	70-120K	50-110K
Surface Composition	Water Ice	Water Ice
Radiation	0.08 Sv	5.4 Sv
Current mission lifetime	14 Earth days	7 Earth days
Operating Temp Range	223-323K	223-323K

Europa

Aiming to last for a year, a duty cycle was created using the proposed instruments. This gave an average requirement of 0.63W (6970Wh/Yr at 20% margin).



Trade-offs

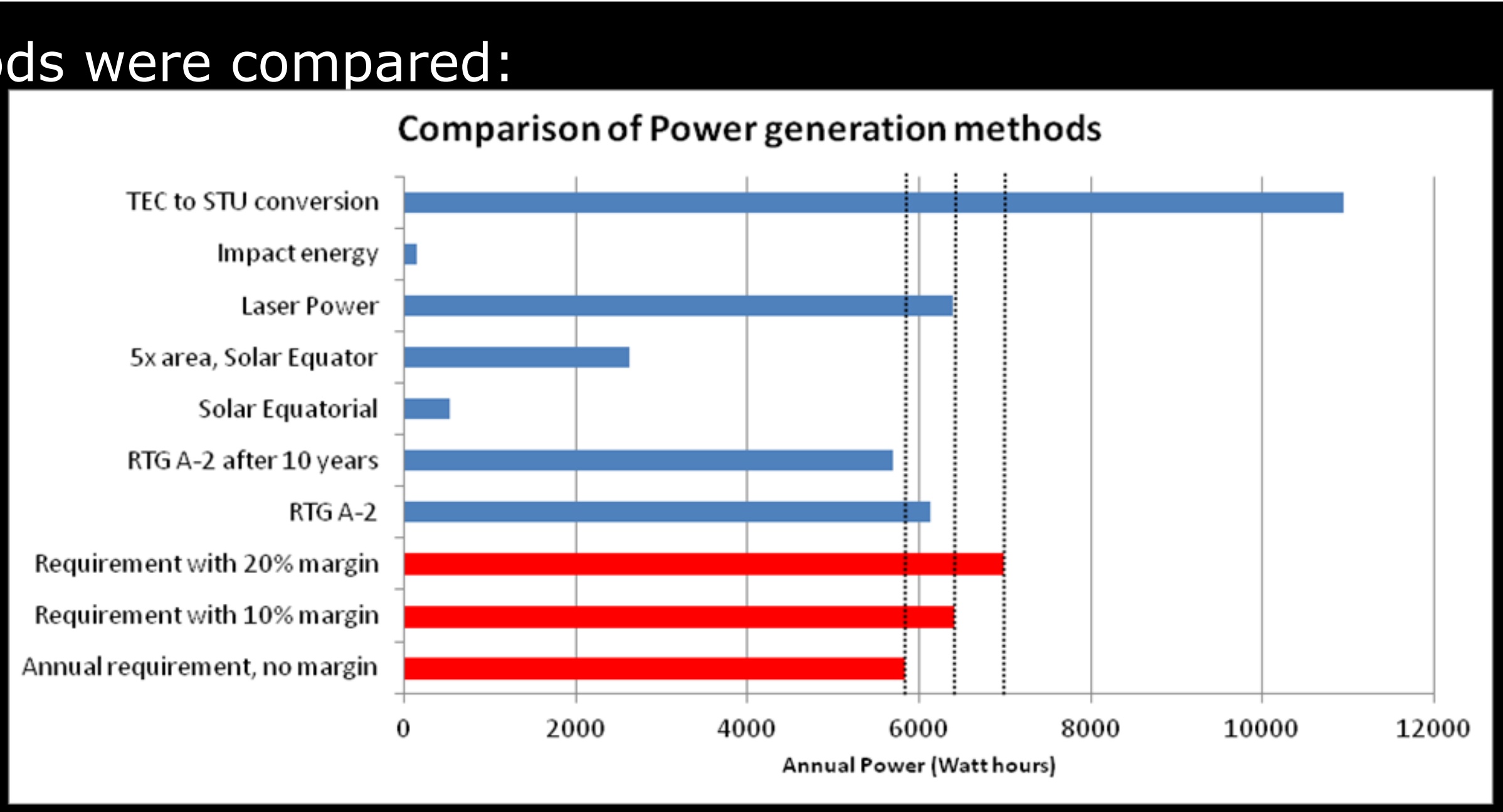
	Insulation	Heater	Vacuum Flask
Pros	No power requirement	Likely to survive	No power requirement
Cons	Calculations show will not survive	High Power requirement	Structural complexity

The vacuum flask concept also offers–

- Low heat loss through conduction
- Possibility to add heater/insulation at later stages

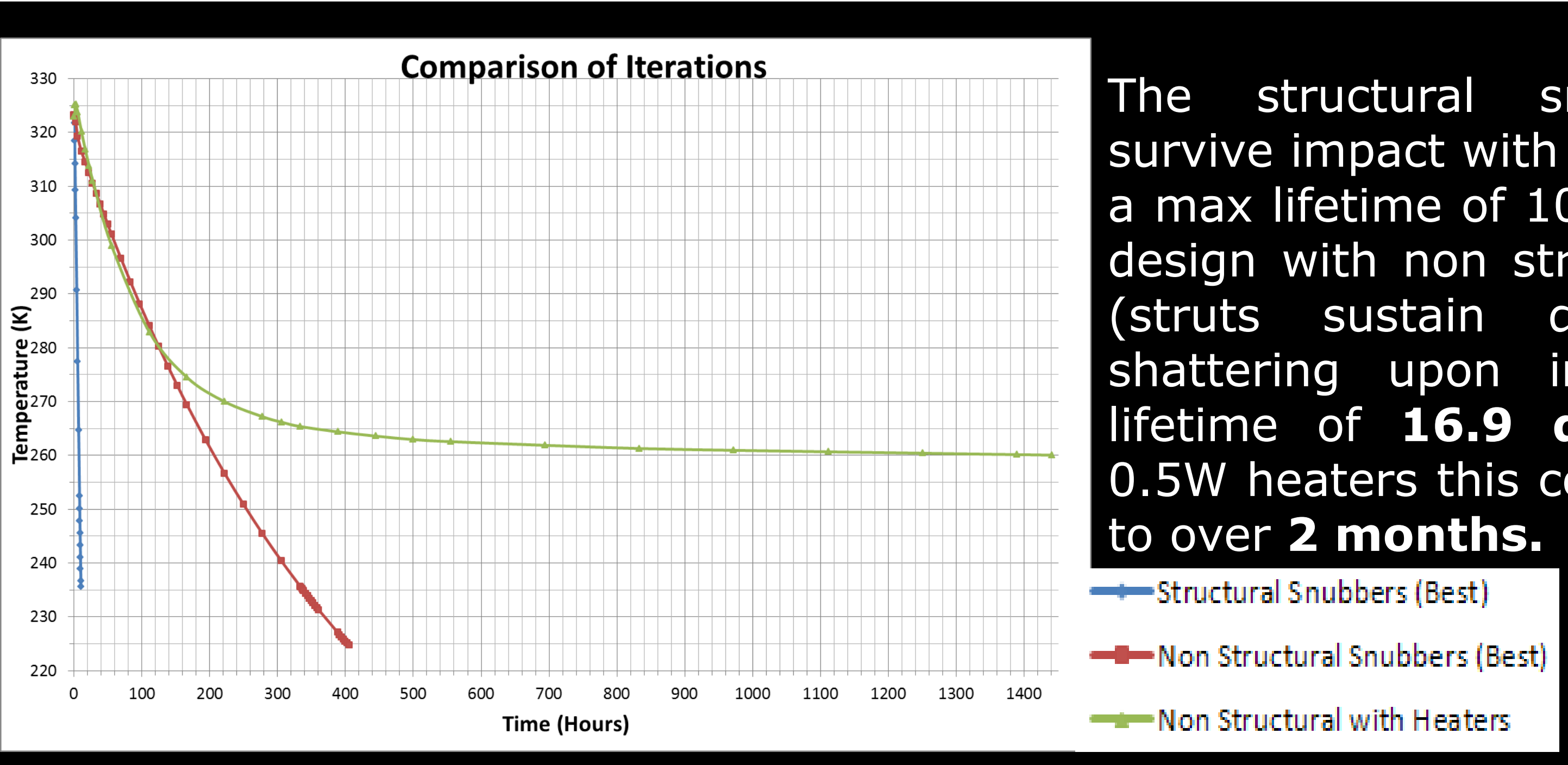
Power generation methods were compared:

- Batteries
- Solar panels
- impact harvesting
- Latent Ice Heat
- Fuel Cells
- Stirling engines
- Laser power beaming
- STU's
- RTG's



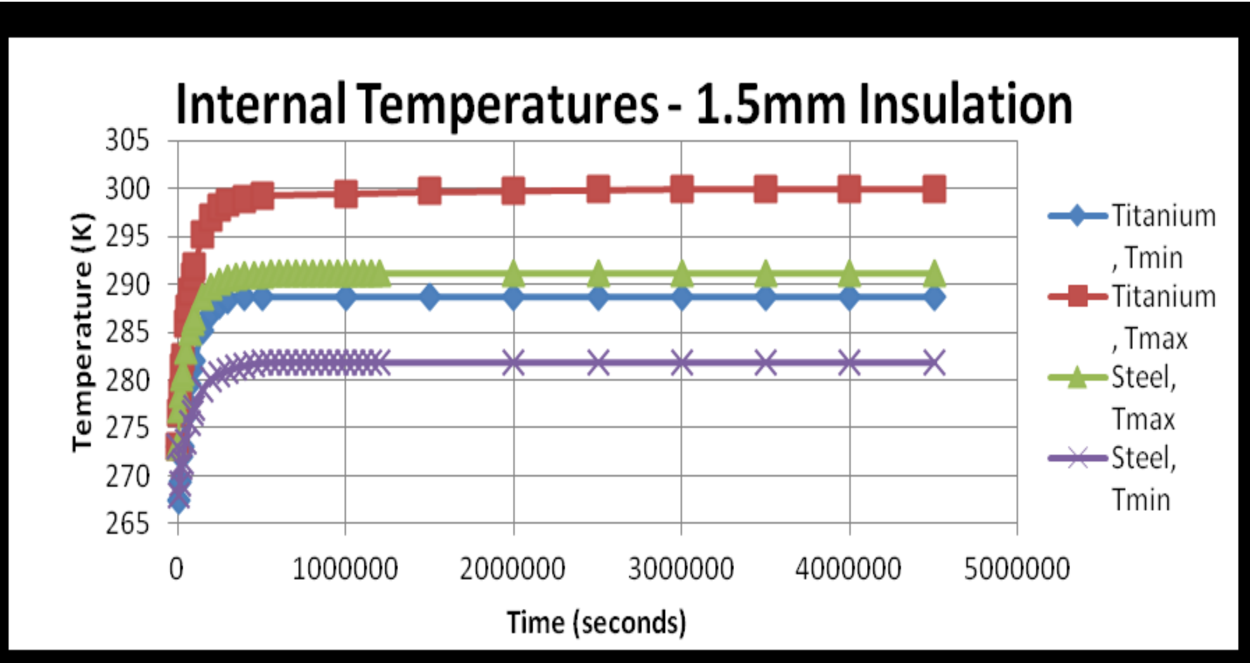
It was decided to use the ***A-2 RTG***, and a ***0.55kg Li-ion*** battery. For a 20% margin, a hibernation system is suggested, gathering data 82% of the time.

Iterations



The structural snubbers (struts survive impact with no damage) give a max lifetime of 10 hours. The final design with non structural snubbers (struts sustain damage without shattering upon impact) gives a lifetime of **16.9 days**. With 2 x 0.5W heaters this could be extended to over **2 months.**

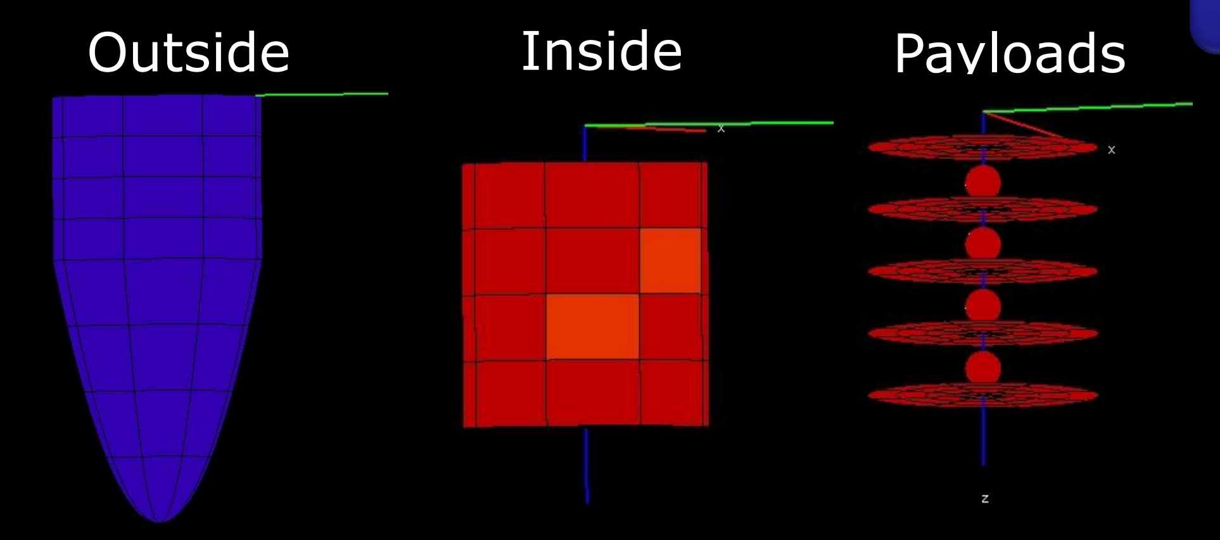
Due to the high heat dissipation of the RTG (17.2W), iterations were required to prevent the probe going outside its operating temperature limits.

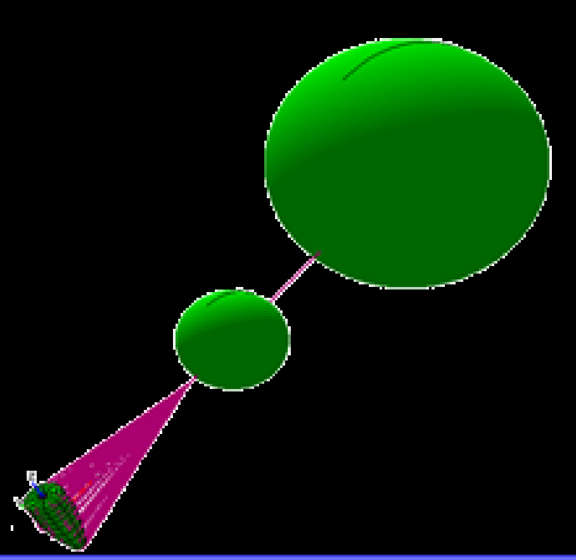


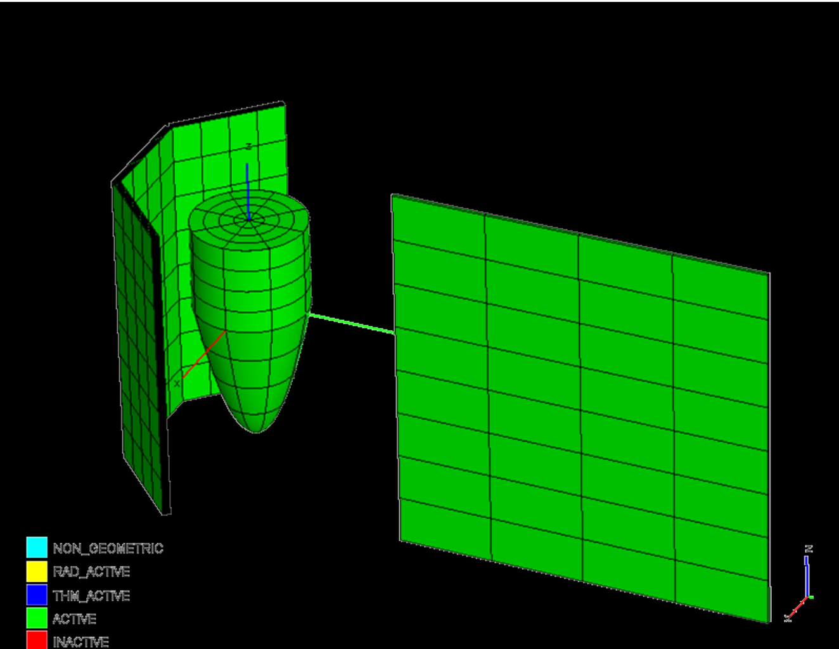
Equilibrium on Europa – 1.5mm insulating foam layer, Titanium Probe.

ESATAN Modelling

The vacuum flask concept has been modelled in ESATAN-TMS. Payloads were modelled as non-geometric thermal nodes and the ice was modelled as a heat sink.





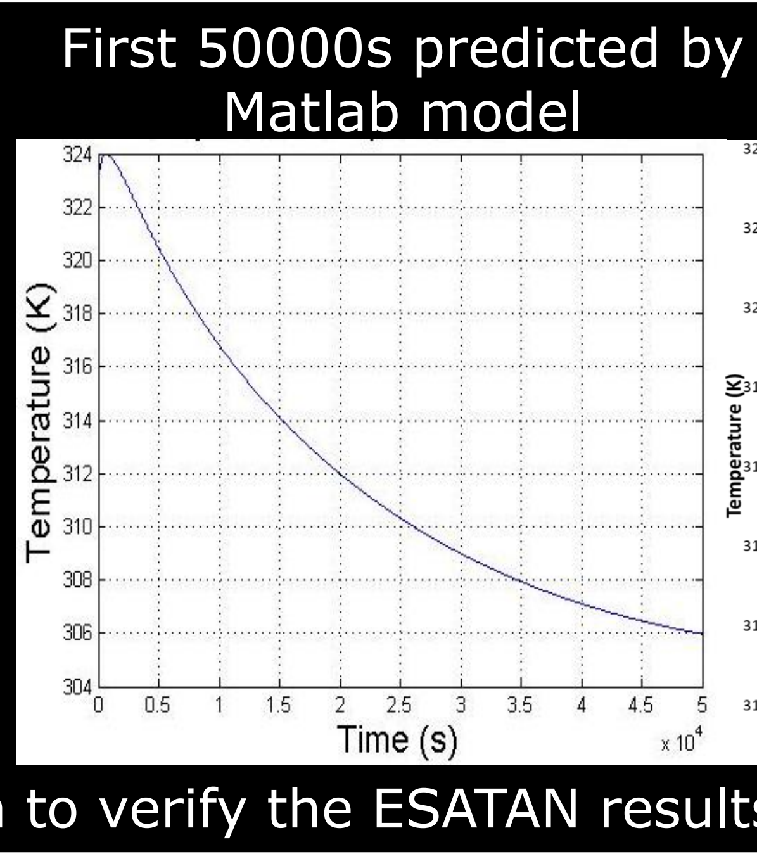


Model Cases	T_{crit}
Europa Pole	Cold – 50K
Europa Equator	Hot – 110K
Deep space cruise	Cold – 3K
Earth orbit	Hot – (unstable)
Earth manufacture	Hot – 293K

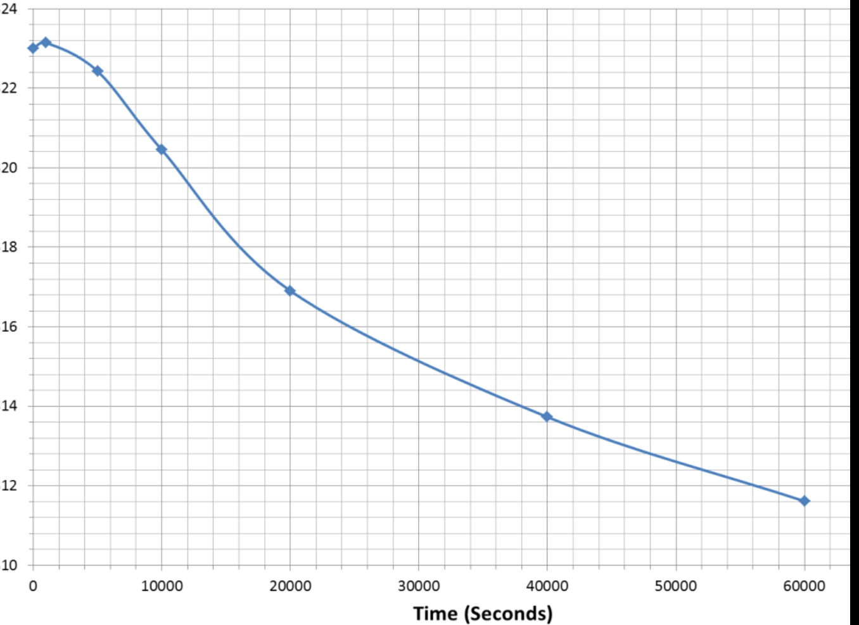
Verification/Results

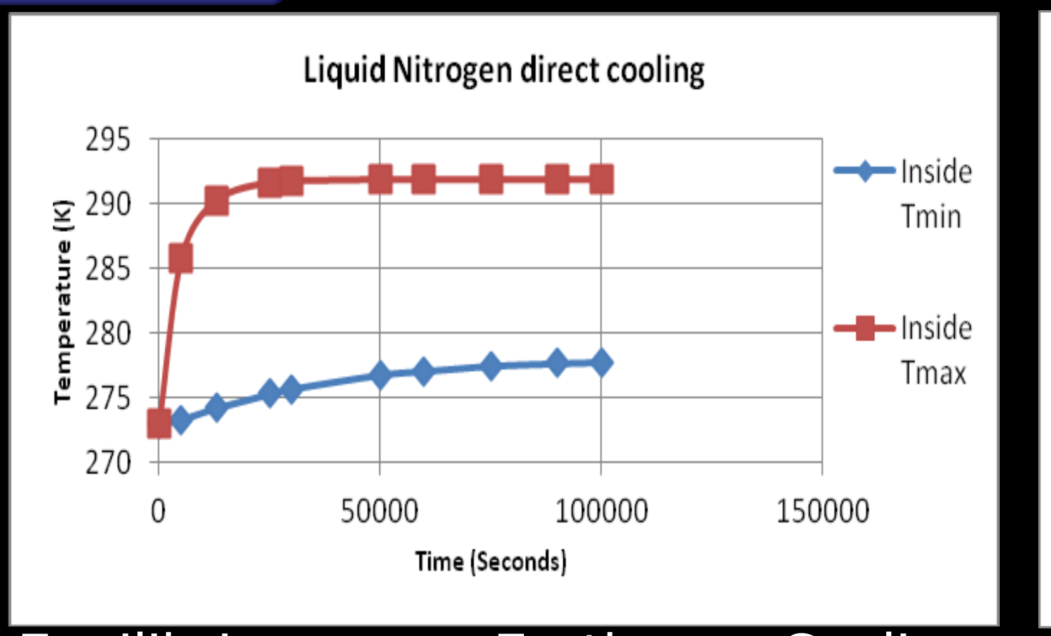
A Matlab model has been constructed from first principles using the 2D transient equations of conduction and radiation to verify the ESATAN results.

First 50000s predicted by Matlab model

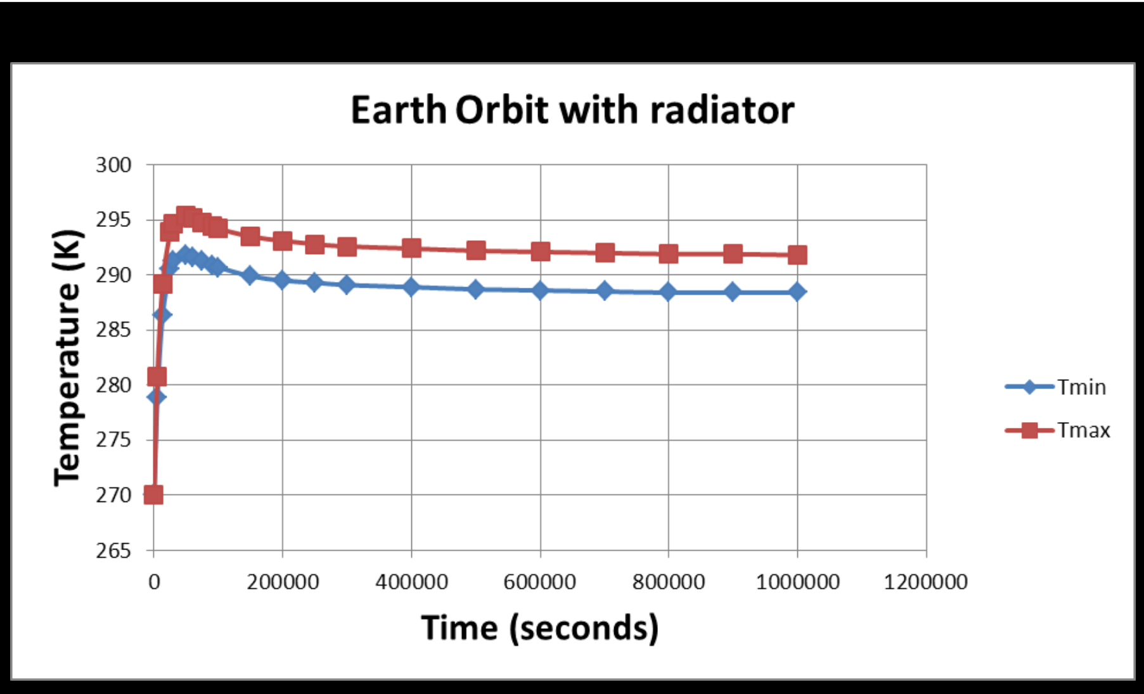


First 60000s predicted by ESATAN model



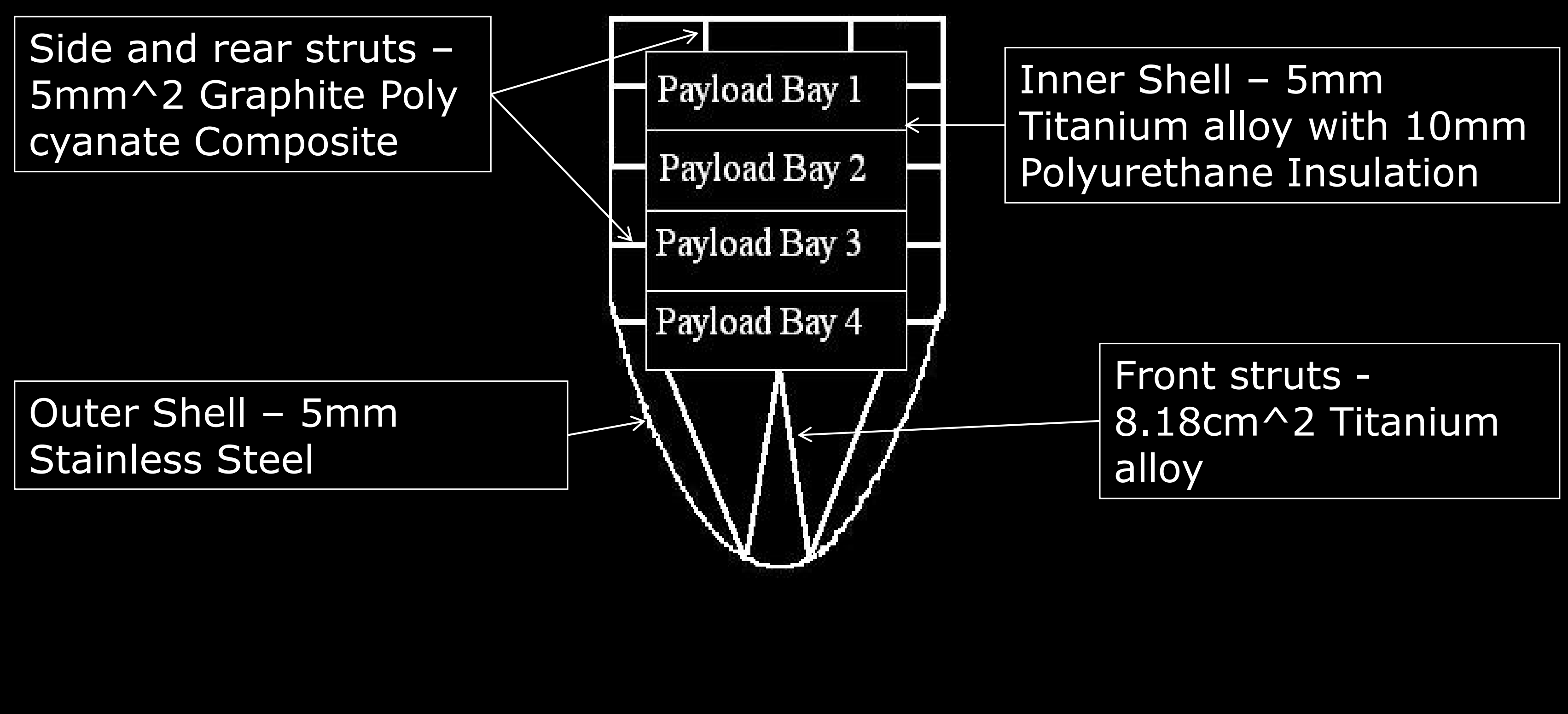


Equilibrium on Earth – Cooling Required



Equilibrium In Earth Orbit – Radiative cooling and a sunshield required.

Final Design



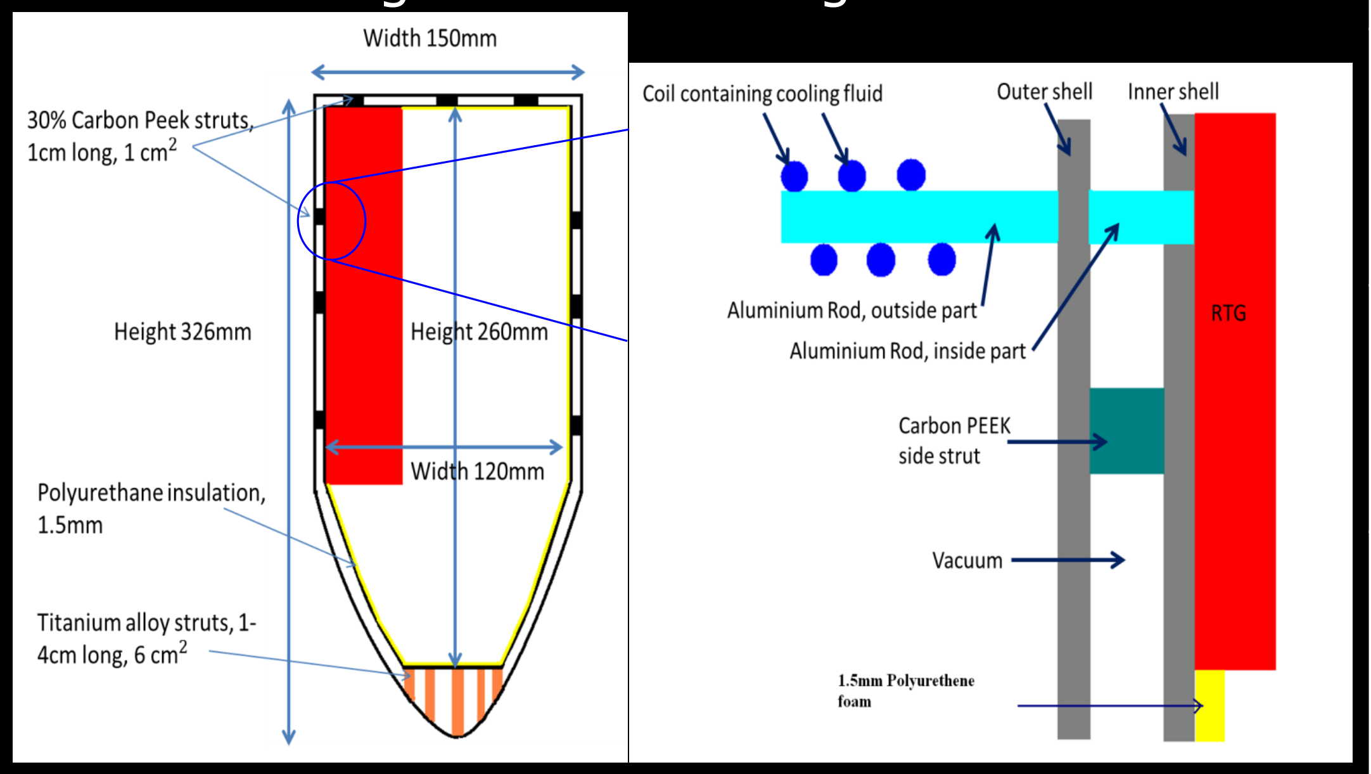
Side and rear struts – 5mm^2 Graphite Poly cyanate Composite

Inner Shell – 5mm Titanium alloy with 10mm Polyurethane Insulation

Outer Shell – 5mm Stainless Steel

Front struts - 8.18cm^2 Titanium alloy

The Heat Transfer on Europa is much greater than any other temperature case, thus an adaptive design was created, making use of a retracting strut contacting a heat sink.



Model Cases	Cooling Method
Earth	Extended Cooling strut + N_2
Earth orbit	Sun Shield + Radiator + Extended Cooling Strut
Deep space cruise	Extended Cooling Strut, Radiator ejected
Europa	Fully Insulated, cooling strut retracted