Heat paths from OSEM to SEI

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1 Introduction

We need to be sure that heating from the current in the OSEM coils, and possibly from the emitter, will no cause excessive temperature rises. This document looks at heat paths from the OSEM to the seismic table and (radiatively) directly to the walls of the vacuum tank, aiming to arrive a single number in W/K linking the temperature rise to the transferred power. Stuart Aston has made a separate study of the effects within the OSEM between the coil and the fixing points.

2 Order-of magnitude calculations

The three principle mechanisms will be conduction through the metalwork, transfer across bolted joints ("contact resistance") and radiation to the walls of the vacuum vessel. In order to establish which effects are important, here are some rough calculations of the size of the effects.

2.1 Conduction

A piece of aluminium alloy 300mm long, 20mm by 20mm (order-of-magnitude for one leg of the structure) has a conductance of

$$C = c \times \frac{a}{l}$$

$$C = 170 \times \frac{0.02 \times 0.02}{0.3}$$

$$C = 0.22 \text{ W/k}$$

So if the OSEM dissipates 10W, there would be a ~45 degree temperature rise along such a piece of aluminium.

2.2 Contact resistance

Maddren and Marschal [1] carried out experiments in vacuum, pushig two aluminium (6061-T6) specimens together and measuring the variation in thermal resistance with clamping force. They give a conductance of around 40 kW/m^{2}K at 355k and 20 kW/m^{2}K at 131K for a 6MPa clamping stress, and varying roughly linearly with clamping stress. Assume 30 kW/m^{2}K at room temperature. A 20mm by 20mm area would then give

$$C = 30{,}000 \times .02 \times .02$$

$$C = 12 \text{ W/k}$$

In this case, 10W would give around a 1 degree temperature rise.

2.3 Radiation

The radiative heat transfer equation for a small body in a large enclosure, where the emissivity of the enclosure is 1, is

$$q = \varepsilon\sigma A(T_1^4 - T_2^4)$$

where q is the heat, ε is the surface emmissivity of the small body, A is it's area, and the Ts are the temperatures of the two bodies

(reference [2])

This may be linearised if the temperature difference is small and

$$T_1^4 - T_2^4 \approx 4T_1^3 \Delta T$$

Considering a body with surface emissivity of 0.05 (typical for aluminium, [2]) and a surface area of 0.3m by 0.3m with 2 sides at around 300K,

$$q = 0.05 \times 5.7^{-8} \times 0.18 \times 4 \times 300^3 \Delta T$$

$$q = 0.05 \text{ W/K}$$

To do the calculation properly we should allow for less than 4pi steradian coverage, and for the emissivity of the vacuum tank. These would both tend to reduce the heat transfer.

On the basis of the simple calculation above, 10W would give a 200 degree rise, or to get a 10 degree temperature rise would need about 0.5W. This can be compared with the estimate from by Ken Strain [3], that we could not rely on radiative cooling to be greater than about 2W from a reaction mass with a 10 degree temperature rise. Similar order of magnitude.

2.4 Combined effect

The contact resistance and the conduction will be in series; the contact resistance is likely to be rather low and so can be ignored. The radiation would tend to short-circuit the conductive route, however the resistance is high and so it can also be ignored.

3 Model

The model is very simple, and consists of the thermal conductance of the tablecloth in series with the structure (figure 1).

I have tried to err of the side of caution by using elements that are if anything less conductive than the real thing.

3.1 Tablecloth

The shape of the tablecloth is quite complex, see figure 2. I approximate the path from a typical OSEM fixing to the tablecloth/structure interface as a piece of aluminium about 6mm by 50mm by 150mm long.

This gives a resistance of

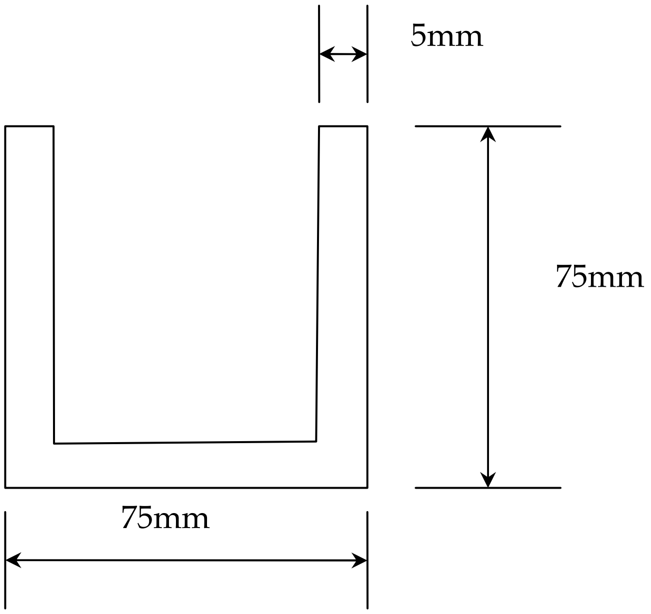
$$R = \frac{l}{a \times k}$$

$$R = \frac{0.15}{.006 \times .05 \times 170}$$

$$R = 3\,\mathrm{K/W}$$

3.2 The structure

The shape of the structure is also complex (figure 3), but for this purpose I have looked at the four vertical legs. Each leg is formed from a U section with a "swiss cheese" part closing the fourth side. Ignoring the "swiss cheese", the section is roughly that shown here:



and the length of each leg is ~ 500mm.

The resistance of a single leg is

$$R = \frac{l}{a \times k}$$

$$R = \frac{0.5}{.005 \times .075 * 3 \times 170}$$

$$R = 2.6\,\mathrm{K/W}$$

3.3 Combined effects

We now have to contend with the fact that some legs will be further away than others as viewed by each OSEM, and that there are twelve OSEMs all together, any of which may be energised. To keep things very simple, I will assume that four of the OSEMs are energised, that they are all equally far from the legs and so each leg carries the same heat load, equivalent to that from one OSEM. To put it another way, four OSEMs are energised and each one “sees” only the most direct heat path to the nearest leg as approximated in the section above. In that case, we can simply add the resistances above to get

$$R = 2.6 + 3 = 5.6\,\mathrm{K/W}$$

So each Watt of heat from an OSEM will lead to about a 5K temperature rise.

4 Refinements

It would be possible to refine the calculations above by doing thermal FEA on the structures but it is not clear how much benefit that work would have. One could then run many cases of different heating in different OSEMs in combination. Again, it is not clear how useful this would be. The thermal resistance of each bolted joint is about 0.1 K/W, so adding them in should not have a big effect.

5 Conclusions

The heat in the OSEMs is expected to be about XXXX, so YYYY.

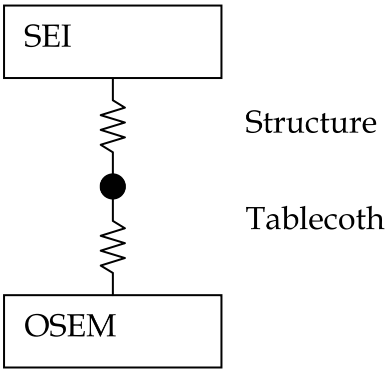


Figure 1. Simplified model of heat transfer paths.

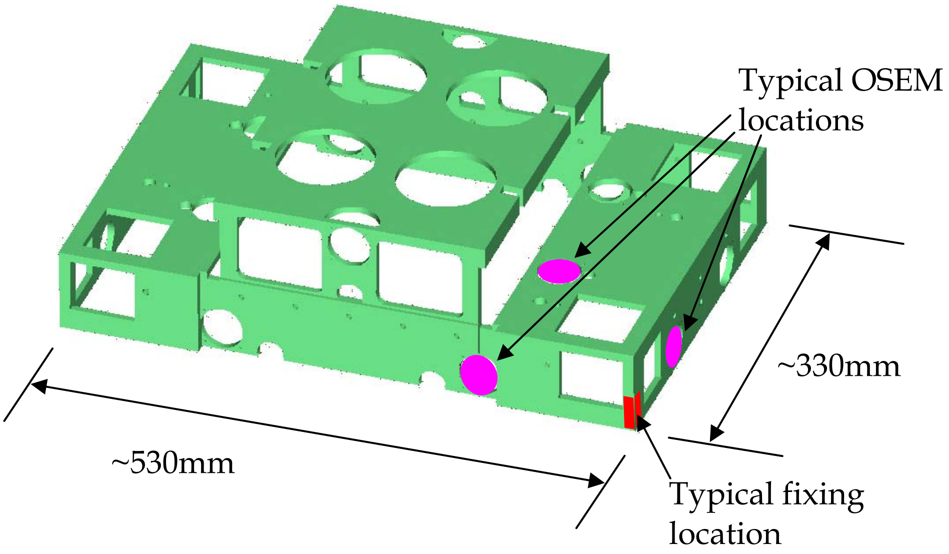


Figure 2 tablecloth (recent design). Wall thickness typically ~6mm

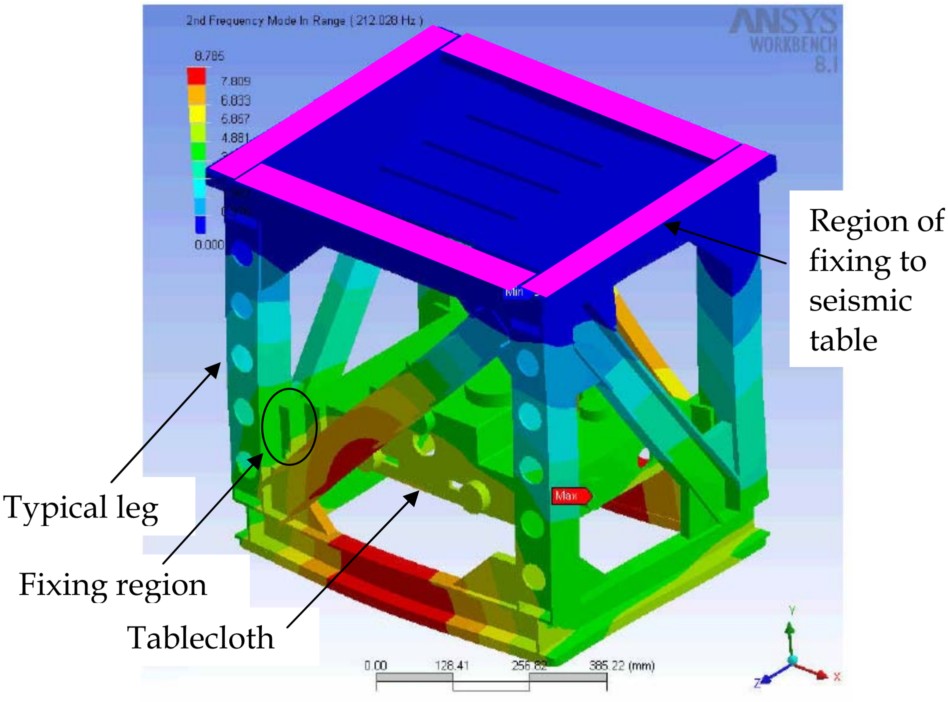


Figure 3. Upper structure of quad suspension with tablecloth in place.

6 References

[1] Maddren and Marschall, J spacecraft and rockets, Vol 32(?) No 3 May-June 1995 page 469
[2] Max Jakob, “Heat Transfer” Wiley and Sons New York, 1949.
[3] Email from Ken Strain, Fri 20/02/2004 17:05. Wide circulation.