

Appendix E

Development of a thermal control system for South Africa's next generation Earth observation satellite

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Abstract

This presentation gives an overview of the work done so far in developing a thermal control system for South Africa's next generation Earth observation satellite. Correlated thermal models of critical major components were developed based on lessons learned from SumbandilaSAT (South Africa's first national satellite). These include amongst others an electronic housing unit and a typical solar panel. In addition, the thermo-optical properties of commonly used coatings and tapes were also measured. The performance of the proposed thermal control system was evaluated using the NXTM Space Systems software. During the evaluation different satellite orientation modes were considered, as well as different mission scenarios. The results show that the suggested thermal control system creates a relatively low, uniform temperature inside the satellite.



Development of a thermal control system for South Africa's next generation EO satellite

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28th European Space Thermal Analysis Workshop



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1. INTRODUCTION

Scope

- Concept development
- Lessons-learned SumbandilaSAT, van der Merwe¹

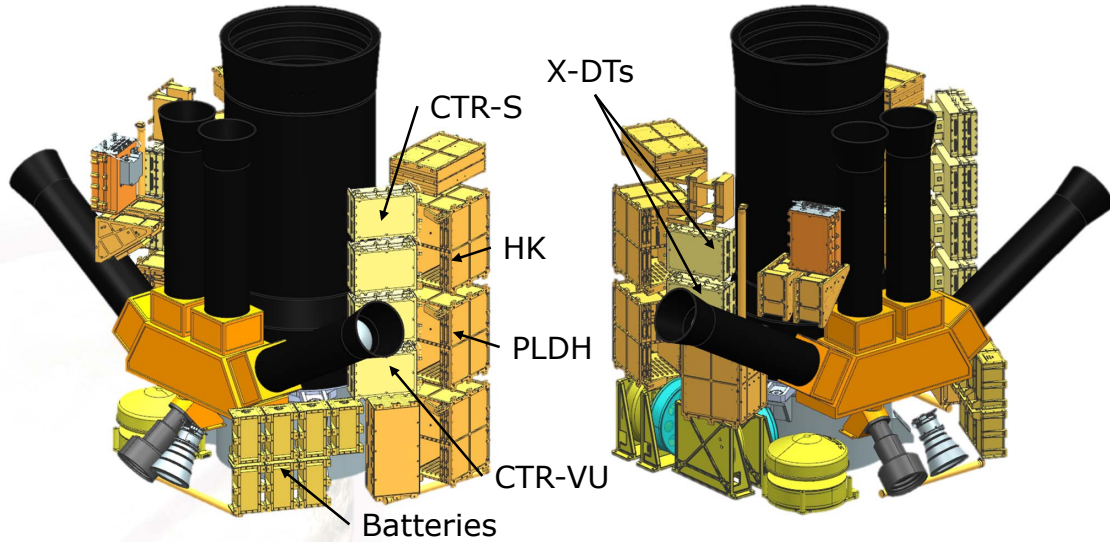
Thermal design challenges

- Batteries: 15-30 °C, uniform temperature field
- Data transmitters: 110 W heat dissipation per transmitter
- CCDs: low operating temperature
- Optical bench: uniform temperature field
- Solar panels: 0-80 °C
- EHU: 0-40 °C



1. INTRODUCTION

Concept layout



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3 of 25

2. ORBITAL HEAT LOAD

Orbit

- Circular Sun-synchronous orbit, 700 km, LTAN 22:30
- Orbit inclination 98.15 °, period 98.6 min

Orbital radiation, Gilmore²

- Solar constant: 1367 W/m²
- Earth IR emission: -18 ° C, 240 W/m²
- Albedo: 30% of incident solar radiative energy, diffuse reflection
- Deep space: 3 K

Beta angle, Chobotov³

- Minimum angle between orbit plane and solar vector
- $\beta = \sin^{-1}(\hat{s} \cdot \hat{n}) = \sin^{-1}[\cos(\delta)\sin(i)\sin(\Omega_{AN} - \Omega_{TS}) + \sin(\delta)\cos(i)]$



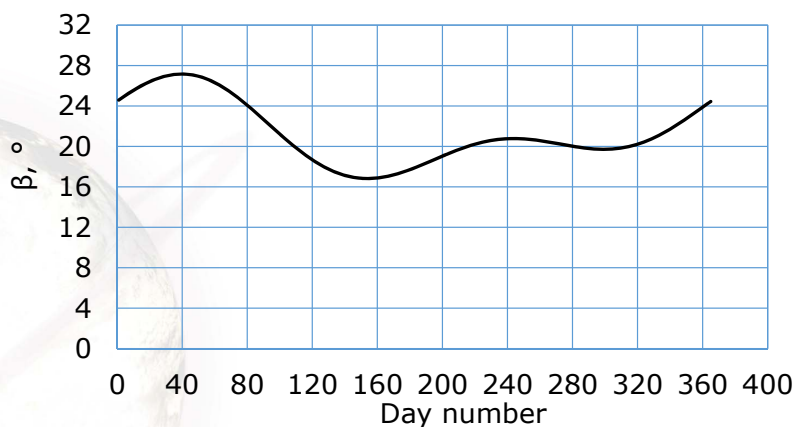
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4 of 25

2. ORBITAL HEAT LOAD

Beta angle

- $\beta = \sin^{-1}(\hat{s} \cdot \hat{n}) = \sin^{-1}[\cos(\delta)\sin(i)\sin(\Omega_{AN} - \Omega_{TS}) + \sin(\delta)\cos(i)]$
- Meeus⁴ algorithm for sun position vector
- $16.8^\circ < \beta < 27.2^\circ$



5 of 25

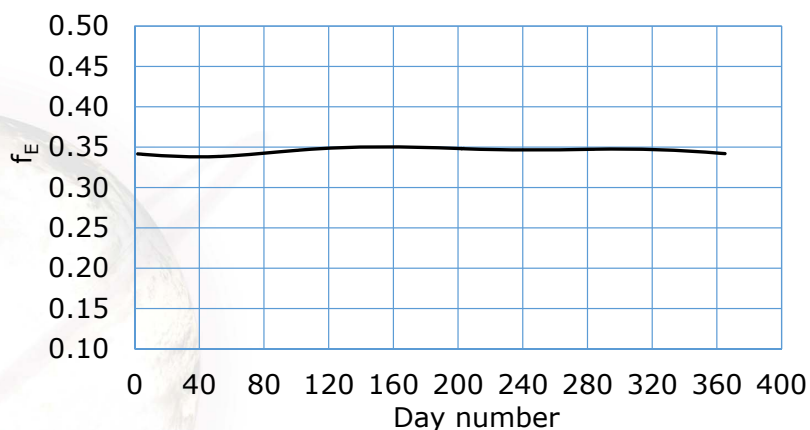


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2. ORBITAL HEAT LOAD

Eclipse fraction

- $\beta^* = \sin^{-1}\left[\frac{R}{R+h}\right], \quad 0^\circ \leq \beta \leq 90^\circ$
- $f_E = \frac{1}{180^\circ} \cos^{-1}\left[\frac{(h^2+2Rh)^{1/2}}{(R+h)\cos\beta}\right], \quad \text{if } |\beta| < \beta^* ; \quad f_E = 0, \quad \text{if } |\beta| \geq \beta^*$



6 of 25



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3. INTERNAL HEAT LOAD

| MC | Coasting, W | Imaging, W |
|------------|-------------|------------------|
| HR CCD | | 6.6 |
| HR EHU | | 5.0 |
| MR CCD | | 8.4 |
| MR EHU | | 5.0 |
| ASF CCD | | 8.4 |
| ASF EHU | | 5.0 |
| ASA CCD | | 8.4 |
| ASA EHU | | 5.0 |
| SWIR CCD | | 8.4 |
| SWIR EHU | | 5.0 |
| X-DT EHU | | 110 each |
| CTR-VU EHU | 4.0 cont. | 4.0 cont. & 20.0 |
| CTR-S EHU | 4.0 cont. | 4.0 cont. & 20.0 |
| RW (each) | 5.0 cont. | 5.0 cont. |
| HK EHU | 15.0 cont. | 15.0 cont. |
| DRS out | | 5.0 transmitting |
| DRS in | | 7.0 imaging |



7 of 25

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4. MISSION SCENARIOS

Mission phases

- Orbit: 14.6 revolution per day
- Coasting: Orbit 1 – 10
- Imaging: Orbit 11 – 12
- Cyclic stability: 10 orbits

Satellite orientation modes

- Least drag (LD)
- Sun-following (SF)
- Imaging (IM)

Coasting phase

- Sun-following (SF)



8 of 25

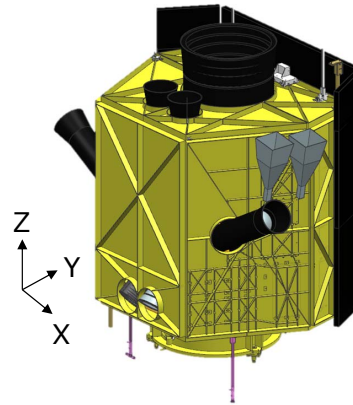
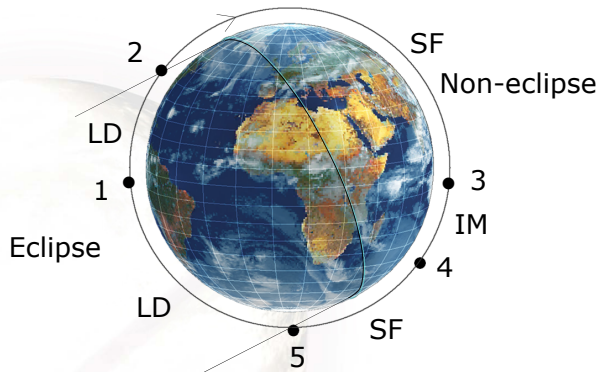
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4. MISSION SCENARIOS

Imaging phase

| Mode | X-axis | Y-axis | Z-axis |
|------|--------------------|--------------------|----------------|
| LD | | Align orbit normal | Nadir pointing |
| SF | Align orbit normal | Sun pointing | |
| IM | | Align orbit normal | Nadir pointing |

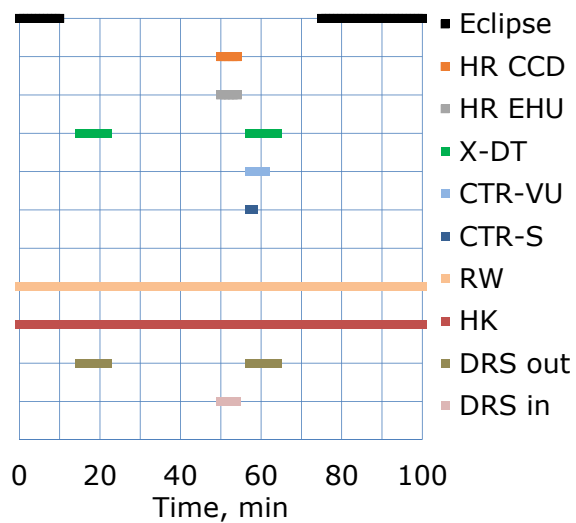
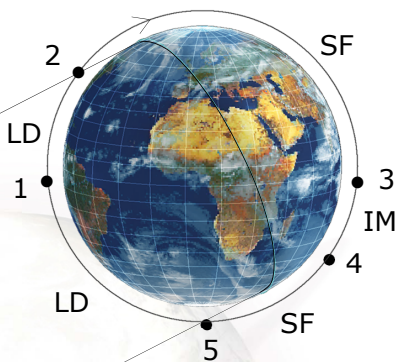


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9 of 25

4. MISSION SCENARIOS

Imaging phase: MCs switching sequence



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10 of 25

5. PROPOSED TCS

High heat dissipating MCs

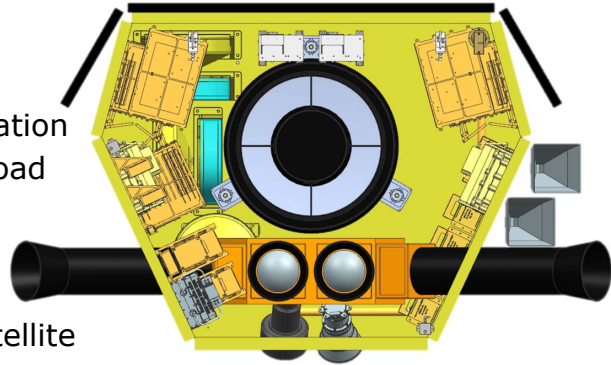
- Use primary structure as radiator, good thermal contact
- Strategic placing: external area with low solar irradiation and high IR emission

Batteries

- Batteries: area of low fluctuation in orbital and internal heat load

Thermal isolation

- Solar panels: prevent temperature gradients inside satellite
- Optical payload: ensure stable, uniform temperature



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11 of 25

5. PROPOSED TCS

Materials

| Component | Coating | Material |
|-------------------|---|-----------------------------|
| Solar panels | Graphite epoxy, $\epsilon = 0.85, \alpha = 0.93$ | Al honeycomb, bare CF skins |
| Optical baffles | Black Z306, $\epsilon = 0.87, \alpha = 0.95$ | CF epoxy (25% vol.) |
| Rest of satellite | Alodine®, $\epsilon = 0.15, \alpha = 0.08$ | Al 6082 - T6 |



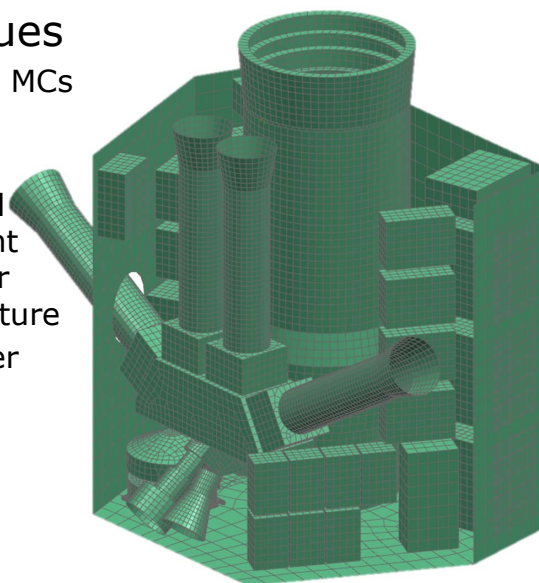
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12 of 25

6. THERMAL MODEL

Assumptions and techniques

- Perfect thermal contact between MCs and primary structure
- Grey-body radiation, $\alpha=\epsilon$
- All EHUs modelled as thin-walled boxes (zero temperature gradient over wall thickness), similarly for optical baffles and primary structure
- Heat loads applied uniformly over EHU



Performance evaluation

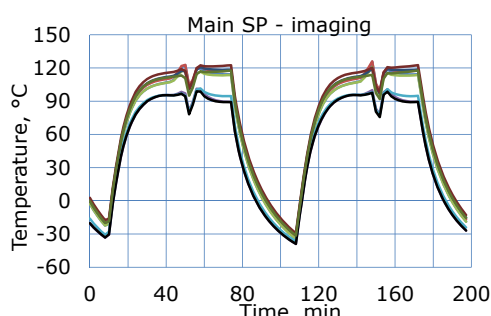
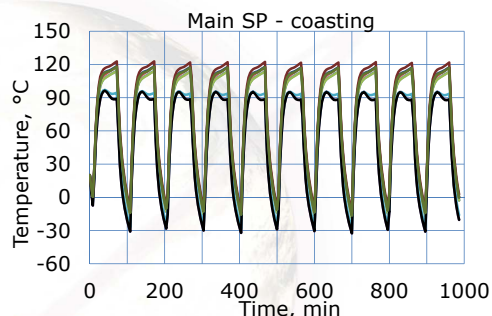
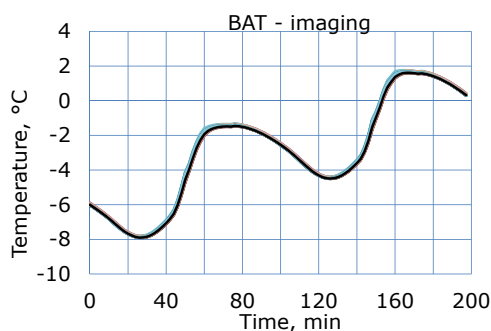
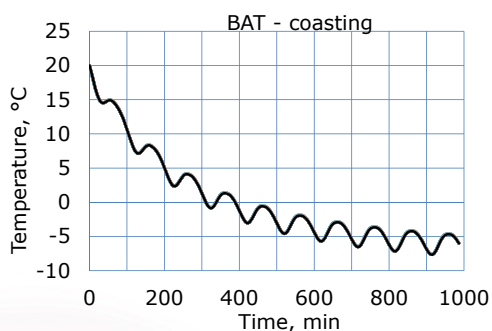
- Two mission phases
- Two beta angles: 16.8 °, 27.2 °



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13 of 25

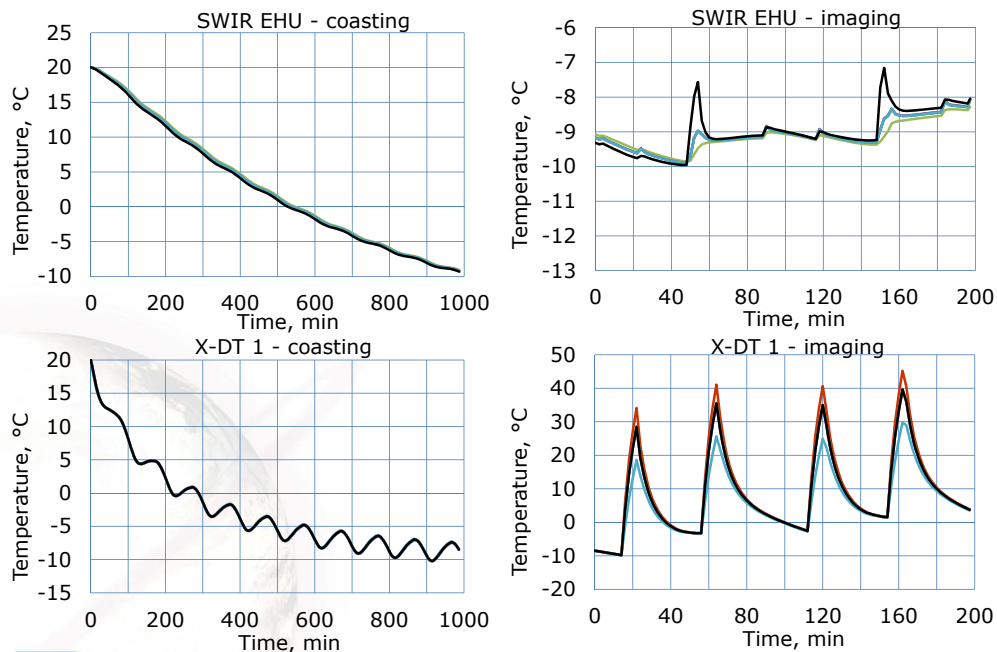
7. PERFORMANCE OF TCS



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14 of 25

7. PERFORMANCE OF TCS



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15 of 25

7. PERFORMANCE OF TCS

X-DTs

- Coasting: low nominal temperature mainly due to absence of internal heat loads; -10.3 °C to -7.3 °C
- Imaging: Temperature jump 40 °C due to 110 W internal heat load; -9.9 °C to 45.2 °C

Optics

- CCDs not modelled hence EHU response is used
- Coasting: Don't reached cyclic stability
- Imaging: Temperature jump less than 7.5 °C

Solar panels

- Coasting: side -45 °C to 68 °C; main -30 °C to 121 °C
- Imaging: side -50°C to 78°C; main -38 °C to 133 °C



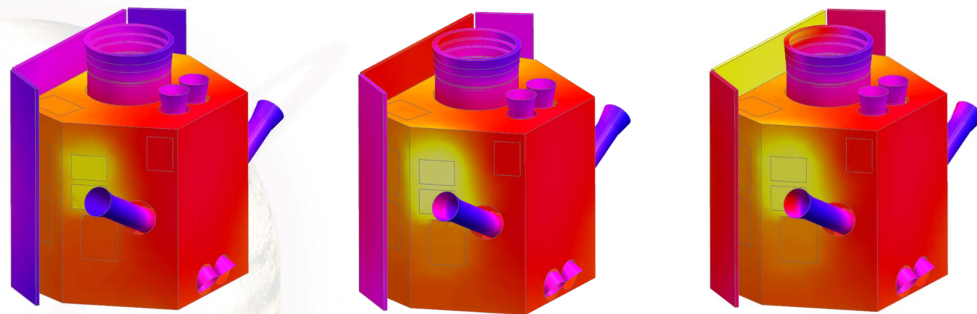
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16 of 25

7. PERFORMANCE OF TCS

General

- Satellite experiences uniform orbital heat load
- Hot and cold condition mainly due to mission scenarios
- The suggested TCS seems to create a relatively low uniform temperature inside satellite
- More internal heat loads will be incorporated in the future which will probably increase the temperature



17 of 25

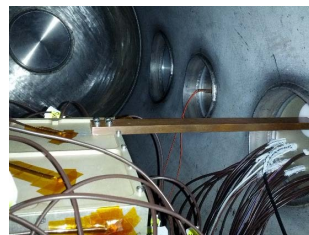
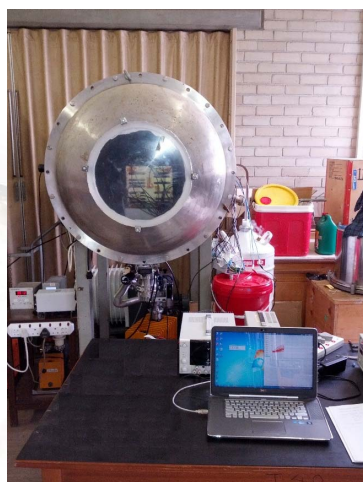


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8. EXPERIMENTAL WORK

EHU

- EHUs modelled as thin-walled boxes
- Thermal model comparison: thermal vacuum test



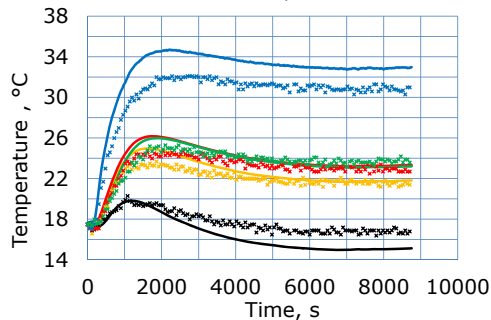
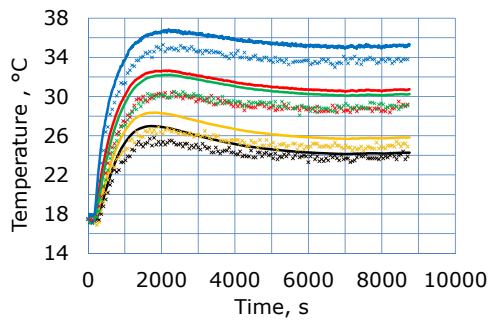
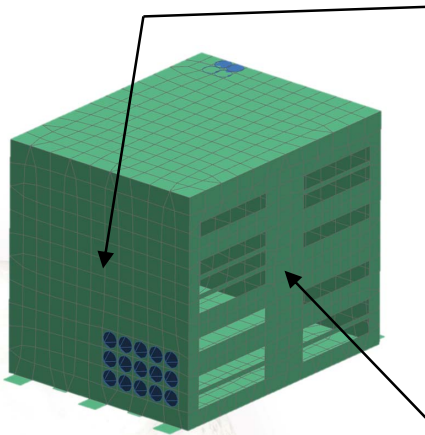
18 of 25



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8. EXPERIMENTAL WORK

EHU



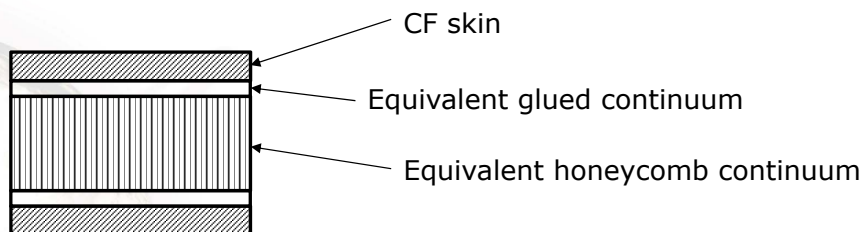
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19 of 25

8. EXPERIMENTAL WORK

Solar panels

- Effective thermal conductivity models: Swann and Pittman⁵, Gilmore, Daryabeigi⁶ (modified Swann and Pittman model: glued interfaces and CF sheets)
- Expanding effective model to an equivalent continuum (k, ρ, c_p) similar to Liu⁷: 3D, orthotropic, transient conduction
- Thermal model still under investigation results look promising

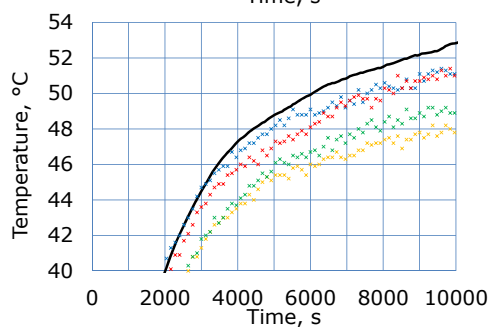
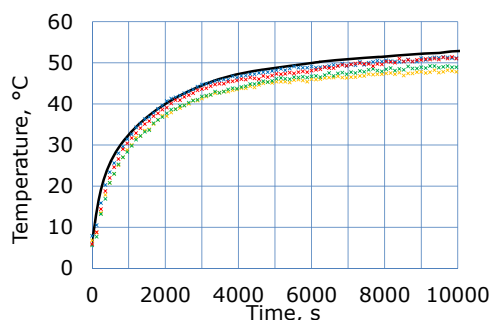
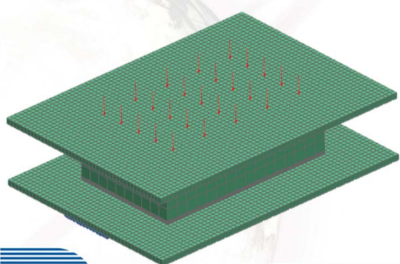


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20 of 25

8. EXPERIMENTAL WORK

Solar panels



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21 of 15

8. EXPERIMENTAL WORK

Thermo-optical measurements

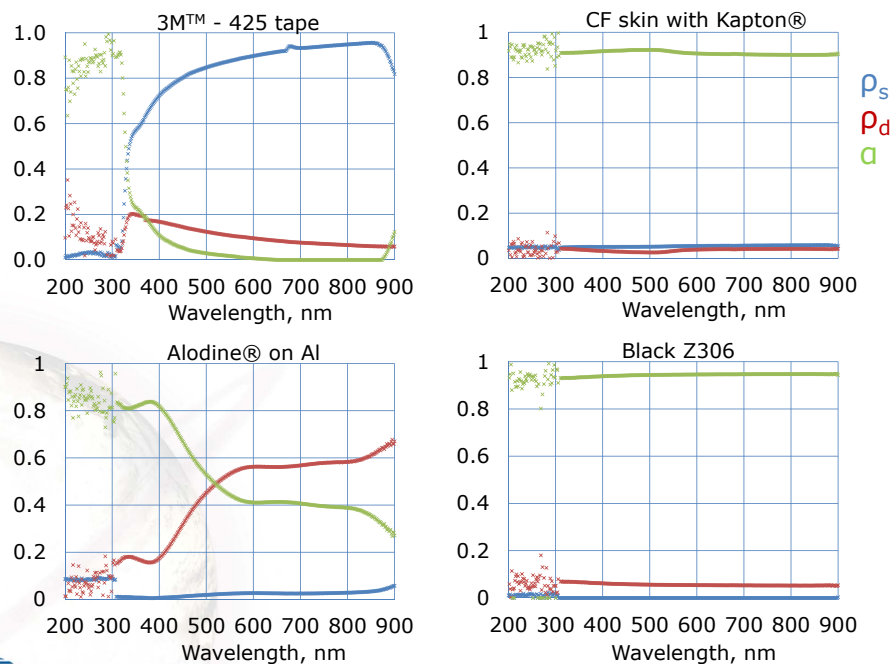
- Physics Department of the University of the Western cape using a Varian Cary 1/3 spectrophotometer
- Spectral values: hemispherical averaged and specular reflectivity (measured), hemispherical averaged absorptivity (indirect)



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22 of 25

8. EXPERIMENTAL WORK



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23 of 25

9. Conclusion

TCS

- Relatively low uniform temperature inside the satellite
- Future work: update thermal model and adjust TCS where needed

Experimental work

- EHU thermal model shows good comparisons with measured data
- Similarly for the SP thermal model
- Thermo-optical test results shows good comparison with published data
- Future work: Complete SP thermal model, expand and refine thermo-optical databases



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24 of 25

9. References

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25 of 25

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