Appendix J

Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

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Abstract

A thermal analysis was performed in support of the power analysis for the MTM wing of the Bepi Colombo mission. At 14 points in the mission the power and maximum incidence angle were requested. The temperature of the MTM solar array wing of the Bepi Colombo mission is highly dependent on the angle of incidence, especially when the space craft is close to the sun. As a result, small deformations due to thermal warping and production will have an effect on the temperature of the solar panels. These need to be accounted for in the analysis.
In a traditional approach these angles would be reflected directly into the ESATAN model. This would drastically increase the modelling effort and would in addition also require an extensive amount of manual iterations to find the worst case scenario with respect to the temperatures of the panels.
In order to save both time and to create flexibility a tool was constructed to find the maximum temperature per panel at these points in the mission for all solar array pointing and deformation angles without having to perform a new thermal analysis or remodelling.
Four different pointing parameters were considered. These different parameters were combined in a single equivalent solar aspect angle of the solar panel.
115 thermal cases were run in total. This resulted in a maximum temperature for all panels that could be interpolated as a function of the equivalent solar aspect angle.

Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

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24 October 2017

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Presentation content

- Introduction
  - Mission and analysis objective
- Rotations influencing solar aspect angle
- PVA efficiency
- Thermal model
- Thermal modelling approach
- Results
- Tool Description
- Conclusion

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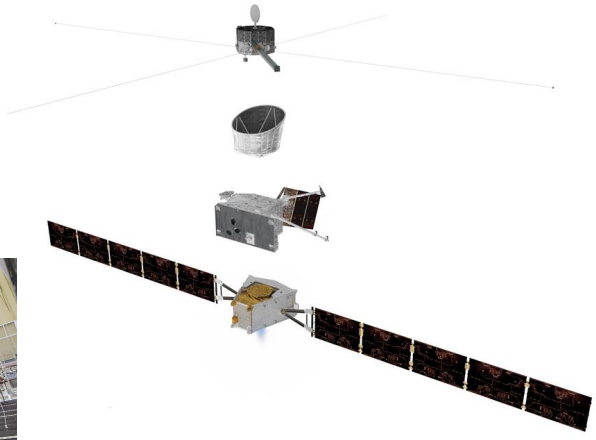
BepiColombo Mercury Transfer Module Solar Array

- Mission to Mercury
- Closest sun approach 0.3 AU
- Wingspan > 30m



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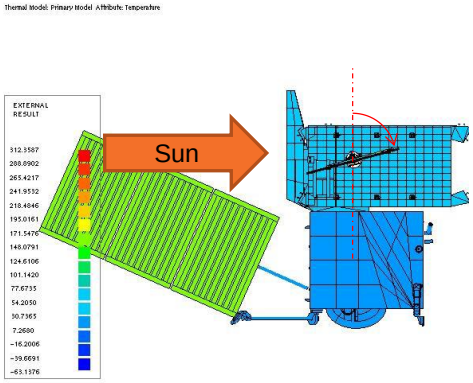
BepiColombo MTM SA Thermal approach

- Shielding on all exposed parts
- Panel 1 always operational
- Panels offpointing near sun



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Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Analysis Objective

Client side request:

- Determine:
  - Loaded PVA hotspot temperature
  - Unloaded PVA hotspot temperature
  - Allowable limit pointing angle
    (in unloaded conditions)
- For 14 power cases
- Taking into account misallignements

Case	Day	ESH [hrs]	Sun [AU]	Distance
1	277.2	6046		1.1946
2	345.5	7218		1.1286
3	477.2	10400		0.8836
4	832.5	18249		0.7500
5	855.9	19583		0.6429
6	1224.0	26877		0.3946
7	1367.6	30345		0.3072
8	1519.1	33114		0.5412
9	1650.3	38085		0.6100
10	1780.6	42061		0.5955
11	1901.6	45494		0.5829
12	2408.3	63819		0.3842
13	2516.1	68174		0.3136
14	2553.2	70683		0.4621

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Analysis Objective

Problem:
- Possibility of future changes
- Large amount of cases (for every possible angle)

Solution: Develop a tool and approach based on beta angle

Advantages:
- Robust for future requests
- Applicable to multiple situations (e.g. power or thermal calculations)
- Easy optimisation of pointing angle

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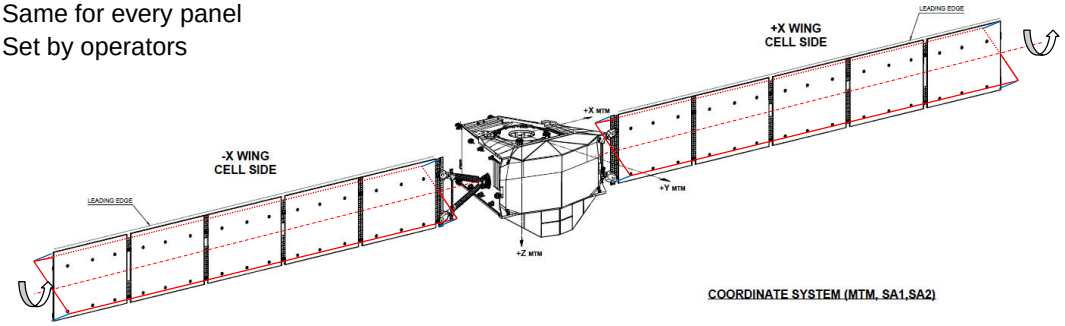
Rotations influencing the Solar Aspect Angle

SA Pointing angle:

- X-axis rotation
- Same for every panel
- Set by operators



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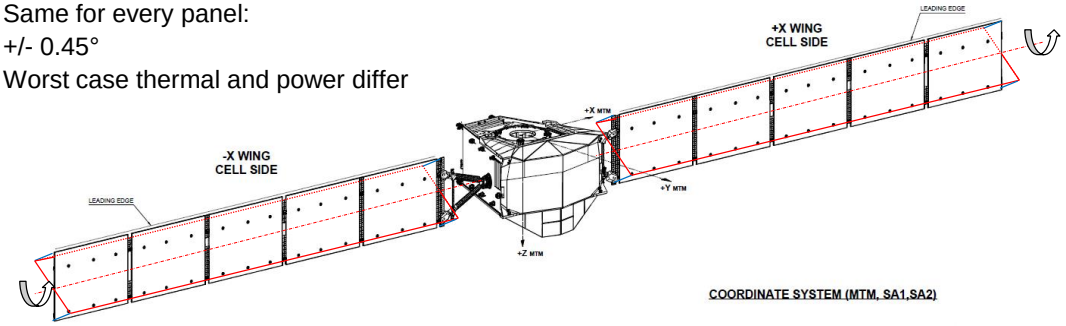
Rotations influencing the Solar Aspect Angle

SA Pointing uncertainty:

- X-axis rotation
- Same for every panel:
- +/- 0.45°
- Worst case thermal and power differ



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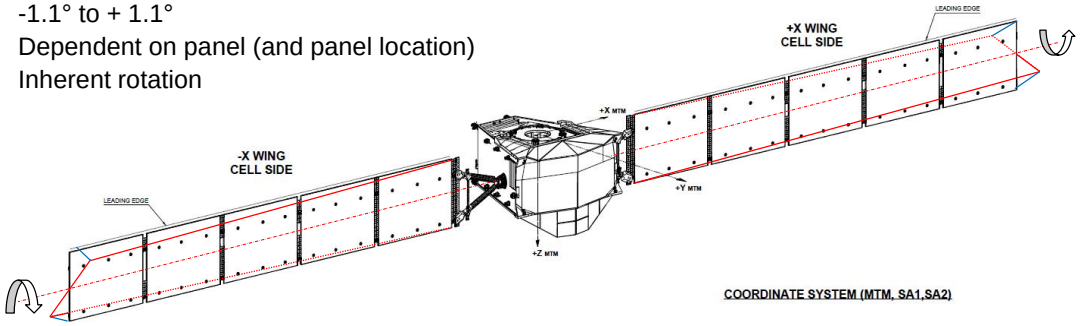
Rotations influencing the Solar Aspect Angle

Panel warp due to manufacturing:

- X-axis rotation
- -1.1° to + 1.1°
- Dependent on panel (and panel location)
- Inherent rotation



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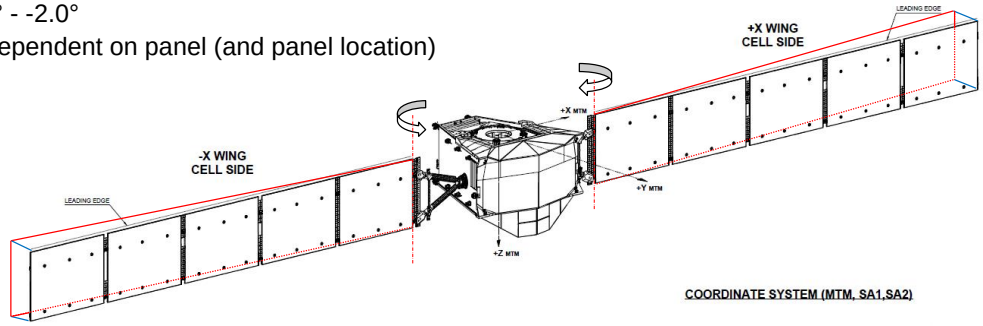
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Rotations influencing the Solar Aspect Angle

Thermal deformation due to temperature gradient:

- Y/Z-axis rotation
- 0° - -2.0°
- Dependent on panel (and panel location)



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Rotations influencing the Solar Aspect Angle

Rotations included in thermal model:
- SA pointing angle

Rotations not included in thermal model:
- SA pionting uncertainty
- Panel warp
- Thermal deformation

Beta angle:

$$\beta = \text{acos}\{\cos(SAA_{nom} + SAA_{uncertainty} + warp) \cdot \cos(deform_{thermal})\}$$

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PVA efficiency

PVA efficiency dependent on:
- Mission time (cell degredation)
- Panel temperature (T)
- Solar flux (I)

$$\eta_{PVA} = (c_{IdT} \cdot I + c_{TdT}) \cdot T + (c_I \cdot I + c_T)$$

Where c_{IdT}, c_{TdT}, c_I and c_T are coefficients determined for every power case based on client data.

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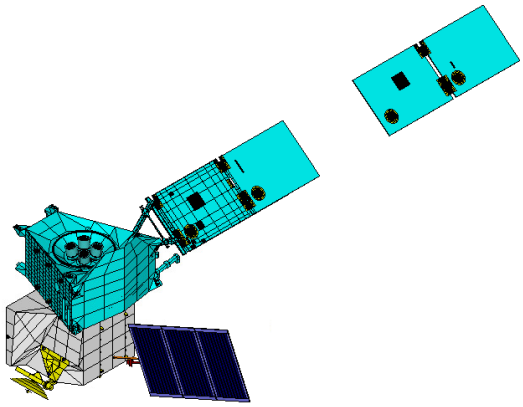
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Thermal Model

- Esatan-tms r5
- Adapted from thermal analysis model
- Single pointing axis

- Contains:
  - 1 (of 2) wings
  - 4 (of 5) panels
  - Details for hotspots:
    - Diodes
    - Harness clusters
    - Hold down structure



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Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Thermal modelling approach Solar Distance > 0.62 AU

Approach:

1. Predict the hotspot temperature for every power case for panel 1, 2 and 5 with SAA 0.0°
2. Predict hotspot temperature for all panels.

Assumption:

- At SAA 0.0°C small rotations have a negligible effect.

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Thermal modelling approach Solar Distance < 0.62 AU

Approach:

1. Predict the hotspot temperature for every power case for panel 1, 2 and 5 at min. 10 different SAA around a nominal estimate of the limit SAA.
2. Predict the temperature response of all panels, as function of the SAA angle.
3. Calculate the limit nominal pointing angle for every panel quadrant based on warp, panel deformation and SA pointing uncertainty.

Assumptions:

- Wing 1 and 2 have similar temperature and temperature response (conservative)
- Hot spot temperatures panels 3 and 4 can be interpolated.

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Temperature fit

Every solar panel element can be fitted to:

$$T_{hotspot} = A \cdot \cos(\beta) + B$$

Where:

- A,B are determined by fitting analysis results
- $\beta = \text{acos}\{\cos(SAA_{nom} + SAA_{uncertainty} + warp) \cdot \cos(deform_{thermal})\}$

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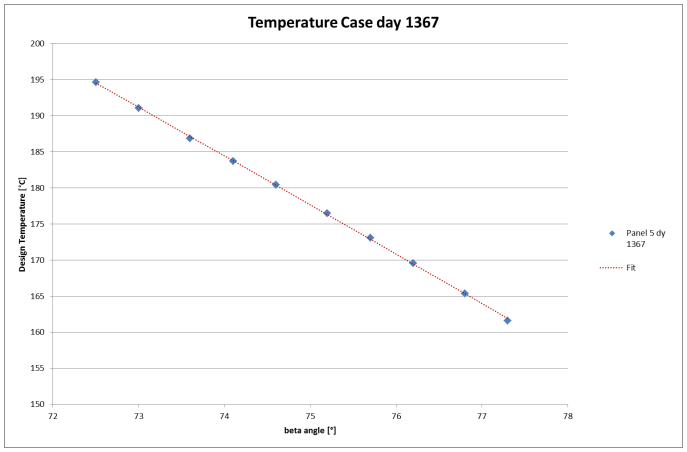
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Analysis results



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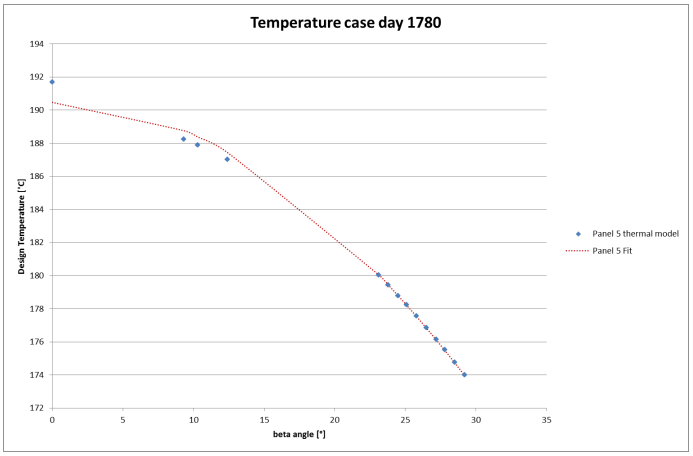
Analysis results



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Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Tool

- Excel based
- Uses analysis results as basis
- Robust
- Flexible for future client requests

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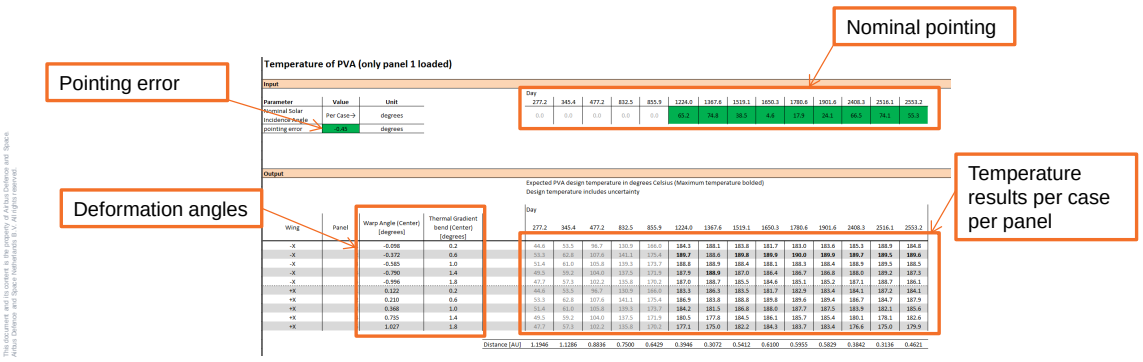
Tool
Temperature calculations



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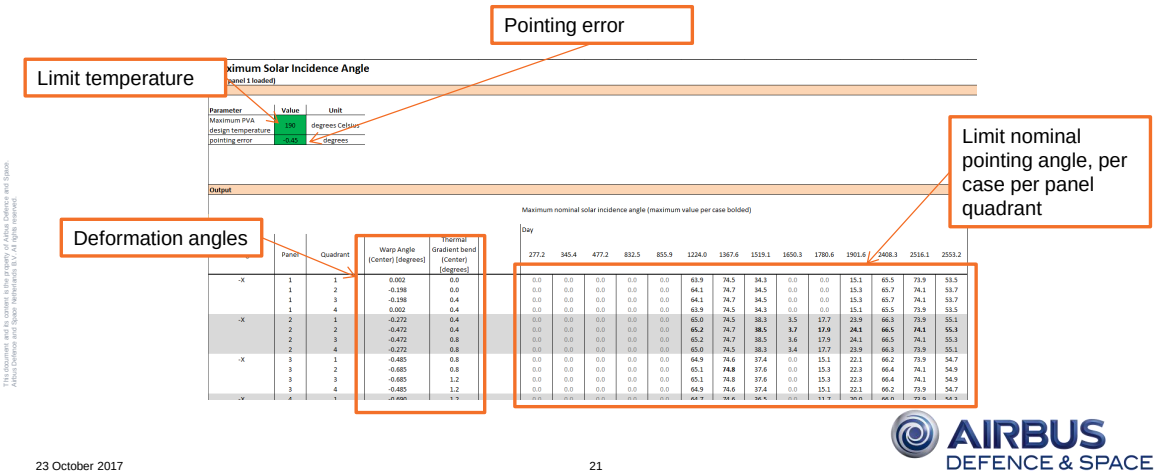
Tool
pointing calculations



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Conclusion

- An extensive thermal analysis was performed to find PVA temperatures
- A tool was developed to summarize result

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