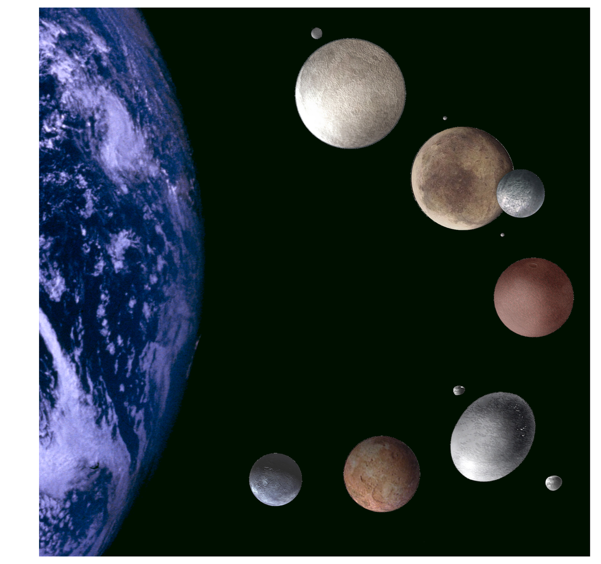
Design and validation of an articulated solar panel for CubeSats



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Abstract

- CubeSats missions more and more demanding
- Current designs mostly limited to surface mounted solar cells
- Additional potential by deployable solar panels like in large satellites
- Further enhancements possible by proposed articulated solar panels
- Successfully validated prototype to vibrational loads during launch phase

Motivation

- Increasing power demands on small satellites
- Currently increase of solar cell area by deployable solar panels with fixed angle
- Proposed further improvements by adjusting solar panels for an optimized sun-incident angle

Subsystems

- Release Mechanism
  - Required for releasing panel from locked configuration during launch
  - Simple, light, small and reliable mechanism required
- Articulation Mechanism
  - Proposed to increase the efficiency of solar cells
  - Rotation of deployable solar panels in one or more degrees of freedom
  - Simple, light and reliable mechanism required
- Type of Solar Cells
  - Comparison of solar cells regarding costs, availability and achievable efficiency
- Control Mechanism
  - To adjust the attitude of the solar panels to achieve optimal sun-incident angle
  - Electronic controller embedded in on-board data handling systems preferable

Environmental Challenges

- Launch Environment
  - Large vibrational load during rocket launch
  - Risk of physical destructions by loosening of mechanical joints (e.g. screw connections)
  - Risk of physical destructions by not improper locking of the solar panel and mechanical oscillations
- Orbital Environment
  - Cyclic changes of temperatures during one orbit
  - Induced stress on mechanical components by differences in thermal expansion
  - Vacuum environment
  - Outgasing of mechanical components
  - Particle radiation
  - Degradation of applied materials

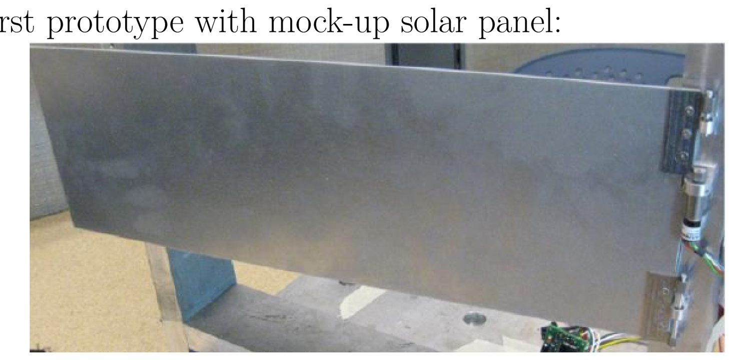
Problem Statement

- Additional available energy: 12 Wh at AM0 by articulated solar panels
- Output voltage between 16 and 20 volts
- Embedded torque coil including interface
- Temperature sensor at back side of panel
- Possibility to print antenna circuit on or within the array substrate without degradation of array performance
- Electrical interface for antenna, torque coil, power and temperature sensor
- Size:
  - 10x30x0.6 cm (placed completely outside of spacecraft) for a deployed solar array
  - 10x30x1.6 cm for an articulated solar array
- Mass: 182.5 gram
- Compliance to the launch loads specified in NASA GEVS
- Compatibility with on-orbit temperatures
- Compatibility of thermal expansion / contraction of all materials used

Conceptual Design

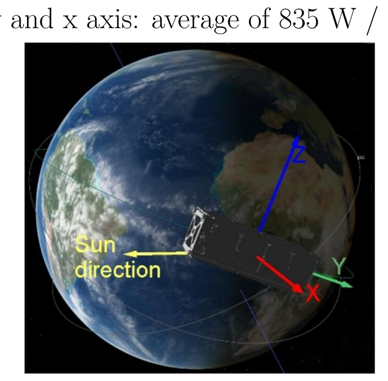
- Hinge design with stepper motor enhanced by planetary gears for larger available torque and higher precision of sun-incident angle
- Attachment of solar panel by wire which is cut by heat winding
- Ultra Triple-Junction solar cells for highest efficiency
- Electronic controller for calculation of control signal to stepper motor
- CAD drawing of proposed mechanism:

- Constructed first prototype with mock-up solar panel:



Refined Specification

- Estimated Solar Cell Area: 0.058 m^2
- Improvements by articulated Solar Panels:
  - Fixed mounting parallel to +x panel: average of 286 W / m^2 per year
  - Additional rotation around y axis: average of 817 W / m^2 per year
  - Additional rotation around x axis: average of 496 W / m^2 per year
  - Additional rotation around y and x axis: average of 835 W / m^2 per year



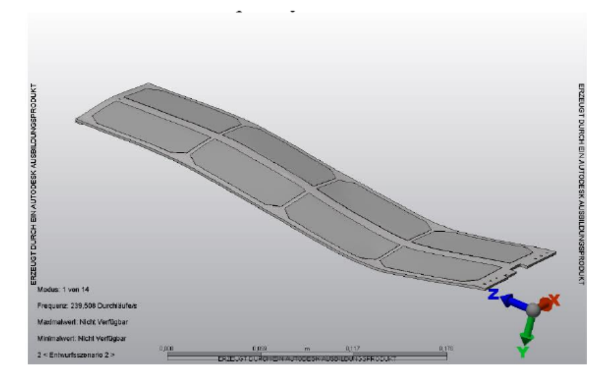
- Assembly of Solar Arrays:
  - 8 solar cells
  - Two solar panels
- Thermal Expansion:
  - Maximum of 0.05 mm of mismatch due to differences in thermal expansion for a temperature difference of 161 K

Evaluation and Testing of the proposed Solution

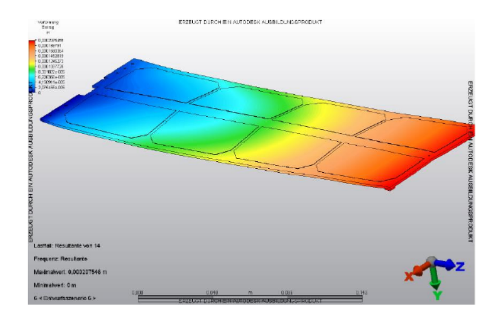
- Classical numerical vibration analysis
  - First step: sine survey (modal analysis), required to find oscillatory modes of analyzed system
  - Right end of solar panel fixed
  - First ten calculated fundamental modes:

Mode number	Frequency
1	239.5 Hz
2	297.3 Hz
3	353.5 Hz
4	399.5 Hz
5	522.8 Hz
6	648.8 Hz
7	848.5 Hz
8	1041.9 Hz
9	1107.4 Hz
10	1246.0 Hz

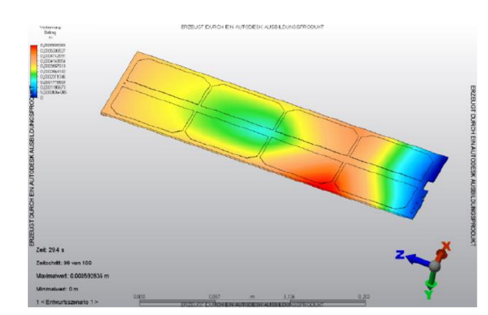
  - First mode found in model analysis at approximately 240 Hz:



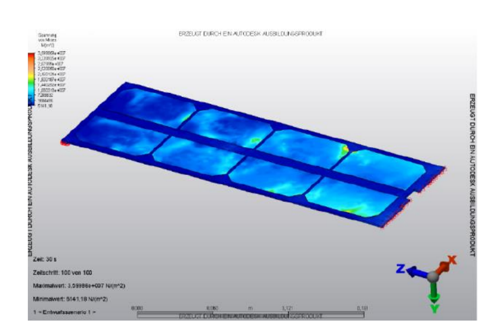
  - Second step: classical analysis with constant excitation
  - Resulting deflections:



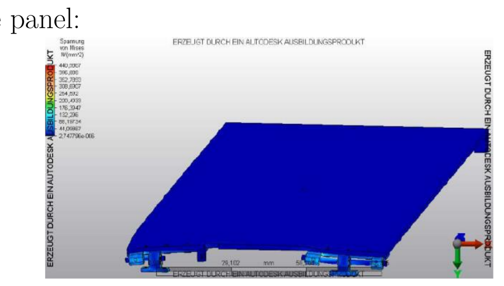
- Analysis with randomly dynamically changing load to reflect launch conditions more realistically
  - Power density function of oscillations as input
  - Resulting deflections:



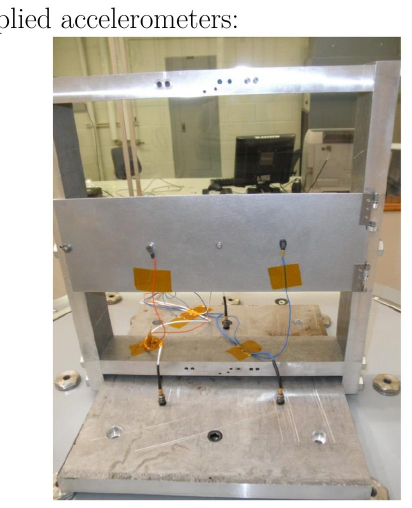
  - Resulting mechanical stress:



- Numerical analysis of thermal expansion
  - Temperature changes between 0 °C and 83 °C
  - Resulting stress in whole panel:



  - Largest stress of 440 N / mm^2 within attachments ⇒ potential need to shift from Aluminum to Steel
- Experimental vibration tests performed at Space Dynamics Lab of Utah State University
  - Experimental setup with applied accelerometers:



  - Power Spectrum Density for random vibration test:

Frequency (Hz)	Qualification ASD Level (G^2 / Hz)
20	0.026
20 - 50	+ 6 dB / octave
50 - 800	0.16
800 - 2000	- 6 dB / octave
2000	0.026
Overall	14.1 G_{rms}

  - First detected resonance frequency: 240 Hz

Conclusion and Future Work

- Large improvements by adding one degree of articulated degree of freedom
- Validated feasibility of proposed design
- Consistent results from numerical and experimental vibrational analysis
- Further tests for outgasing, particle radiation

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References

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- Höhn P., Design, construction and validation of an articulated solar panel for CubeSats. 2010.