Recent Advances in the Construction of Solar Arrays for CubeSats

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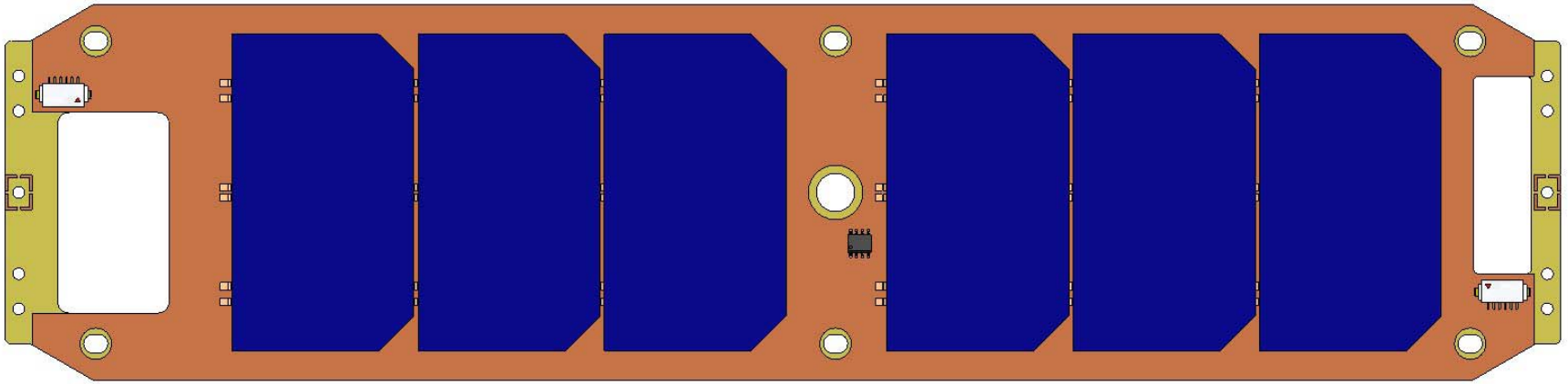
Pumpkin, Inc.

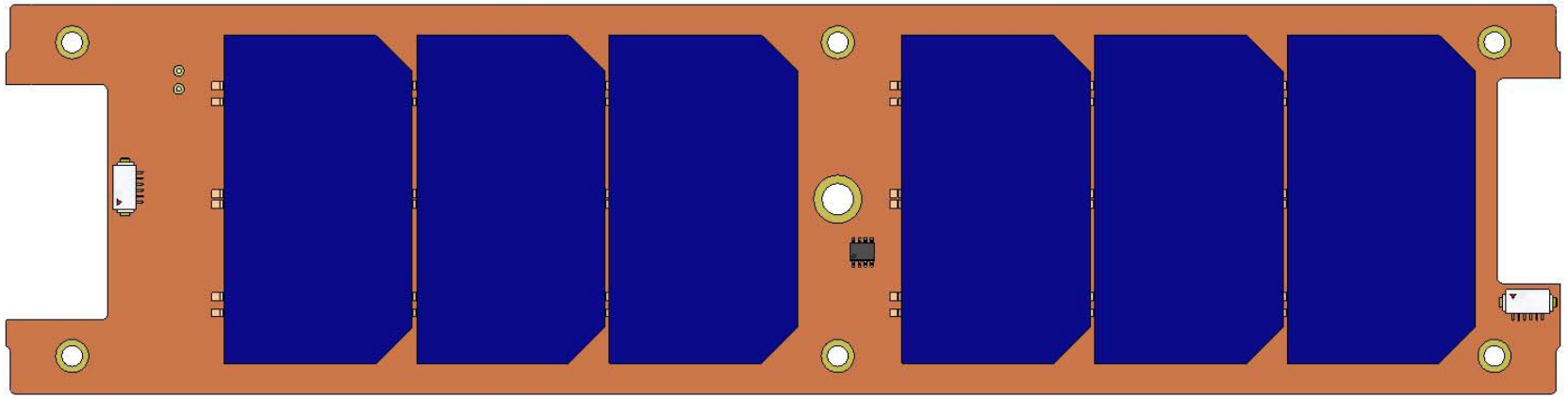
Outline

- SOA Solar Panels
- CubeSat Mechanical Constraints
- Kapton®+Adhesives-based Approach
- Next-generation Expectations
- Array Design – Mechanical
- Array Design – Solar Panels
- Results
- 56W Solar Array for CubeSats
- Conclusion

SOA Panels

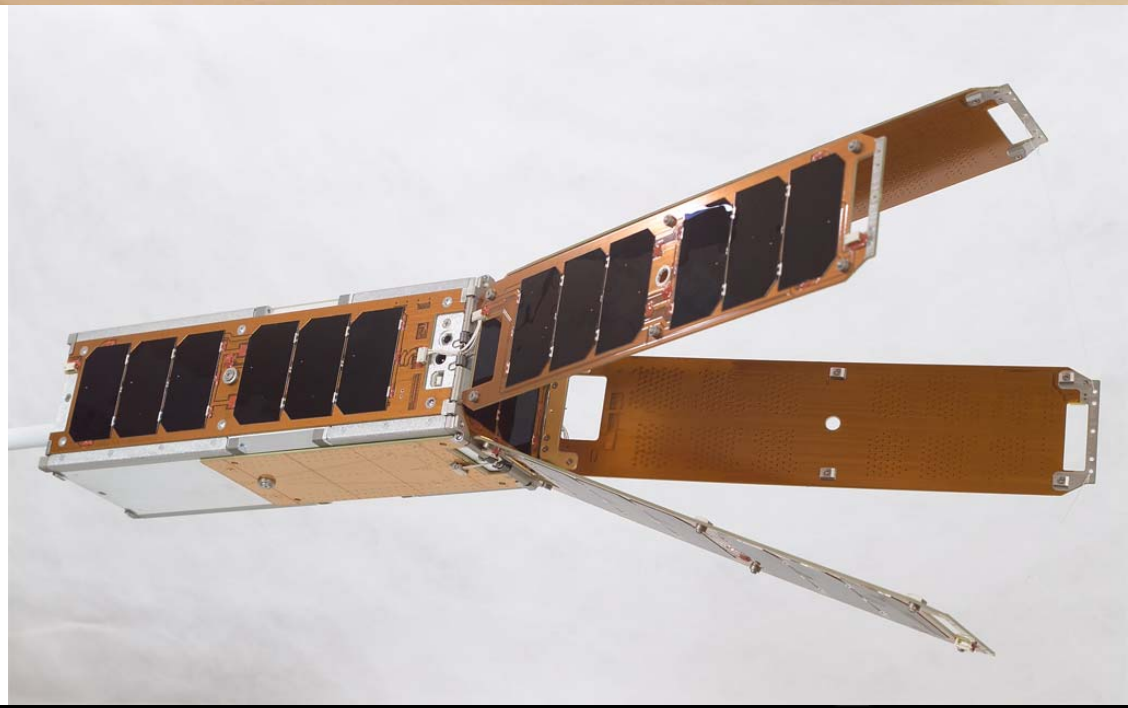
- Fixed 3U: 6-, 7- & 8-UTJ-cell panels
- Deployable 3U: 6-UTJ-cell panels





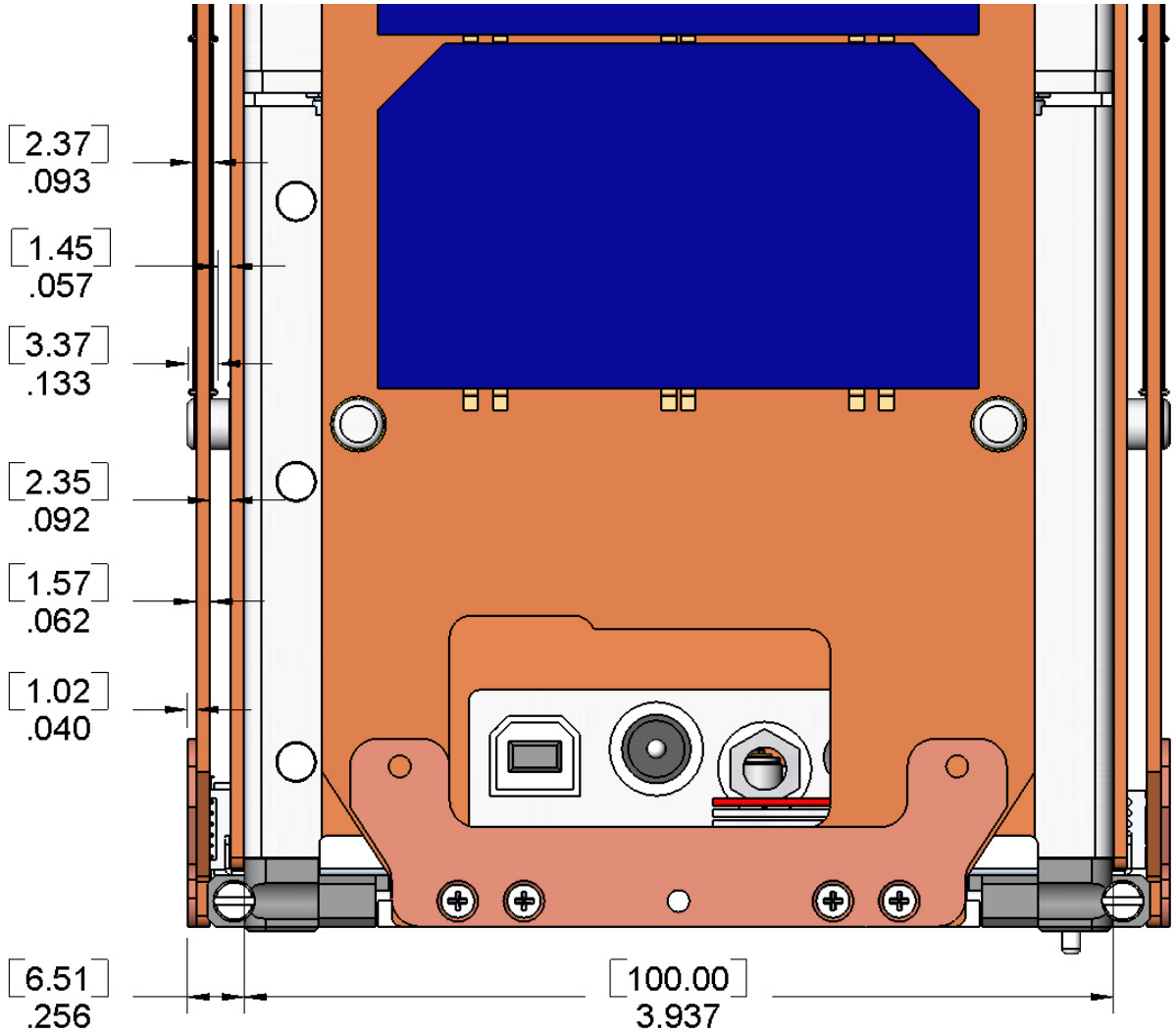
SOA Panels

- Pumpkin's MISC 2 has 3U-size fixed and deployable solar panels
- Each panel has six 40x70mm UTJ solar cells, utilizing conventional solar cell attachment techniques



CubeSat Mechanical Constraints

- Typical 1.6mm (0.062”) PCBs leave precious little room for solar cells on three available faces given P-POD’s 6.5mm available height outside 100x100mm CubeSat cross-section



Kapton®+Adhesive-based Approach

- Aerospace Corp's approach with NuSil®
  - Overview
    - One-sided Kapton® adhesive to insulate from base material (Al)
    - Two-sided NuSil® adhesive to attach solar cell
    - Adhesive thicknesses and cutouts chosen for maximal flatness of cell
    - Conductive epoxy to connect cells
    - Post-assembly thermographic analysis to ensure no air bubbles, etc.
  - Benefits
    - Highly configurable
    - Rapid, non-messy assembly
    - Cure time required only for epoxy (short)
  - Drawbacks
    - NuSil® is expensive
    - Rework options are limited
  - Does not address solar cell string and array wiring issues

Next-generation Expectations

- Need (much) more power than Colony I's 15W OA
- Restricted mass allocation for panels / **arrays**
- Redundancy in array wiring
- Need arrays NOW
- UTJ or better cells
- Thermal issues
- Cost-sensitive

- *Need more power*
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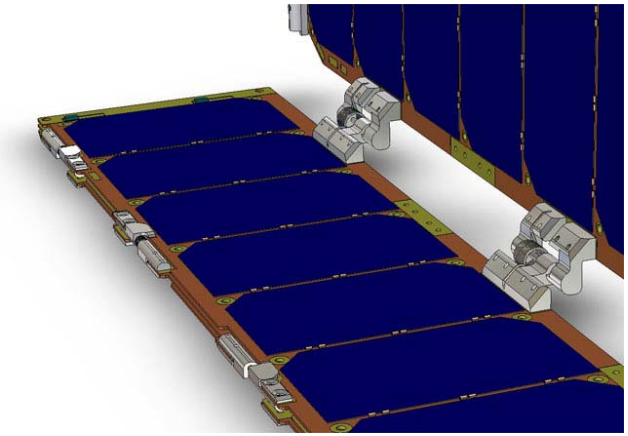
Array Design - Mechanical

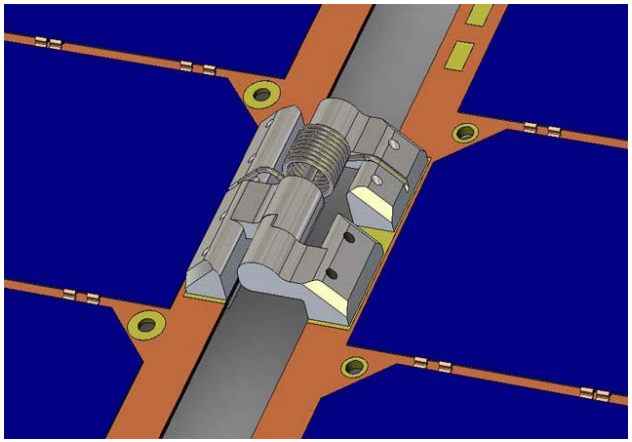
- Conventional technologies found to be best fit
- Small-scale moving parts
- Finishes and coatings are critical
- PCBs are foundation of panels, in large part due to the simplicity of wiring through a PCB-based approach, and because of copper's excellent thermal conductivity
- System-based approach – assemble each array from Pumpkin catalog of components, with standard, semi-custom or custom PCBs
- Except for screws and pins, every mechanical component (hinge, spring, etc.) is a Pumpkin design
- Presents an interesting mechanical puzzle

Array Design - Mechanical

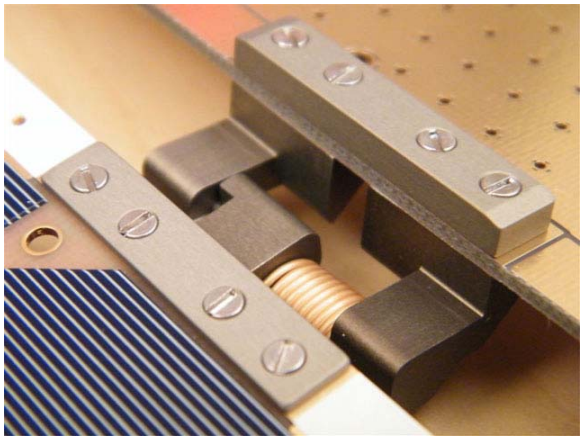
- Center panel
  - Hinged to CubeSat via CubeSat Hinge™
  - Deploys at user-specified angle (45º to 190º)
  - Routes power from all panels into EPS via harness(es)
  - For typical CubeSat applications, connects to winglet panels on either side via 90º hinge + torsion spring



Stowed



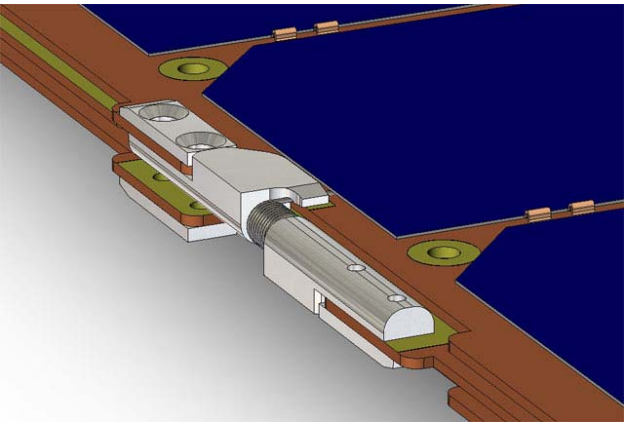
Deployed



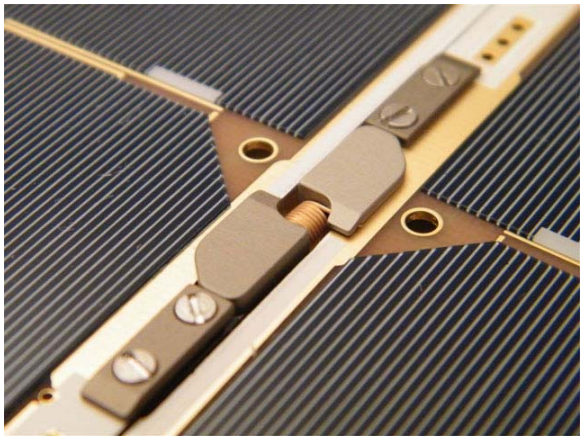
Deployed

Array Design - Mechanical

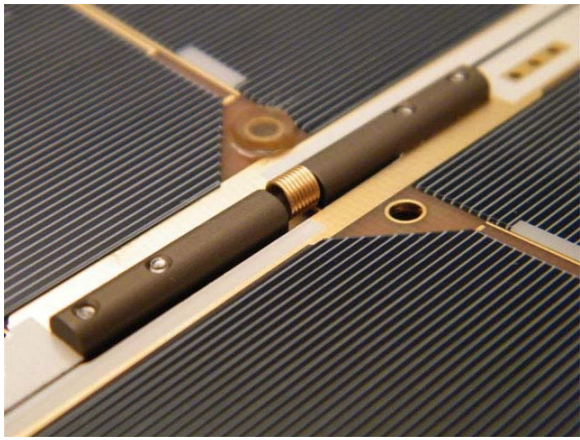
- Winglet panel(s)
  - Three types – left, right, and ambidextrous
  - When stowed, winglets are stacked on top of each other (long-edge binding) … when deployed, they open into a single plane (fanfold)
  - Each winglet panel connects to its neighbor(s) via multiple 180º hinges + torsion springs
  - Same panel and hinges for underfolder or overfolder configuration



Stowed



Deployed – underfolder



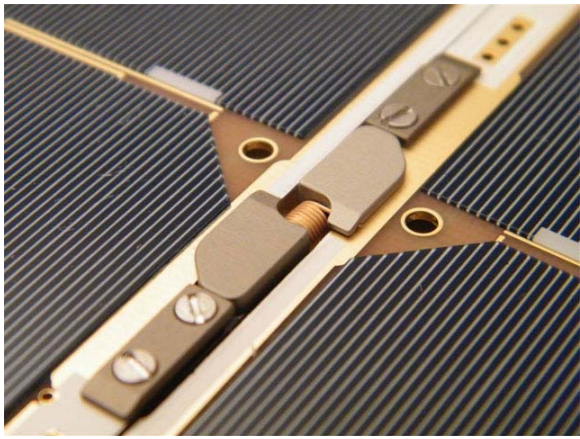
Deployed - overfolder

Array Design – Solar Panels

- Modified version of Aerospace Corp technique used to apply cells to panels – uses NuSil and conductive epoxy
- Additional use of Kapton® tapes for UV shielding, dark side radiator, etc.
- PCB material is Copper-clad FR4-type in applicable thickness (<< 0.062”)
- Copper layout carefully controlled for maximum thermal transfer (“sea of vias”), minimum warping through temperature extremes, hard points for hinges and spacers, etc.
- Cell packing:
  - Eight cells per panel – $$$
  - Seven or six cells per panel – much more economical

Array Design – Solar Panels

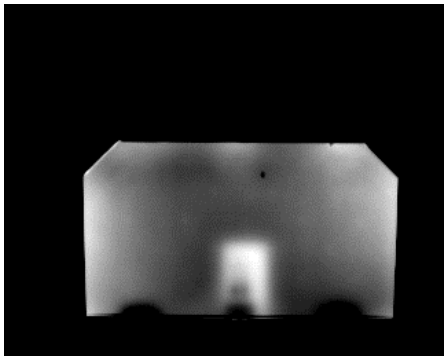
- Eight series-connected 40x70mm UTJ cells per panel
- Blocking diodes on each panel permit wire-OR'd power distribution within 8S*N*P arrays
- Panels are electrically interconnected via hinge springs (no cabling required)
- Redundancies:
  - Four blocking diodes per array (2 hot, 2 cold)
  - Two springs per string terminal (2 "+", 2 "-")
  - Redundant array output terminals (2 "+", 2 "-")
  - Additional redundancies in the copper layers
  - Optional redundant inter-panel wiring pads
  - Additional contact redundancies in the winglet hinges
- Conservative design safety factors

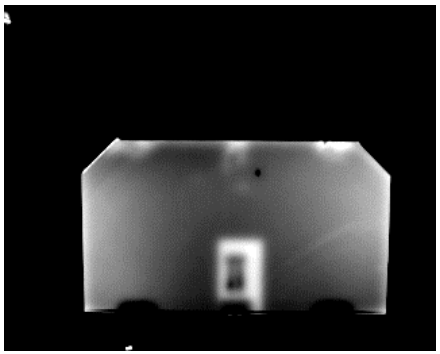


Hinge spring also carries current across panels

Results

- 56W array designed, developed and delivered in under 90 days – represents three generational design iterations
- 56W array delivers expected power in terrestrial (sol) tests
- Panels tested and passed at Pumpkin: –40ºC to +140ºC
- Array tested to mission profile and accepted by customer
- Thermographic testing reveals no trapped voids, etc.

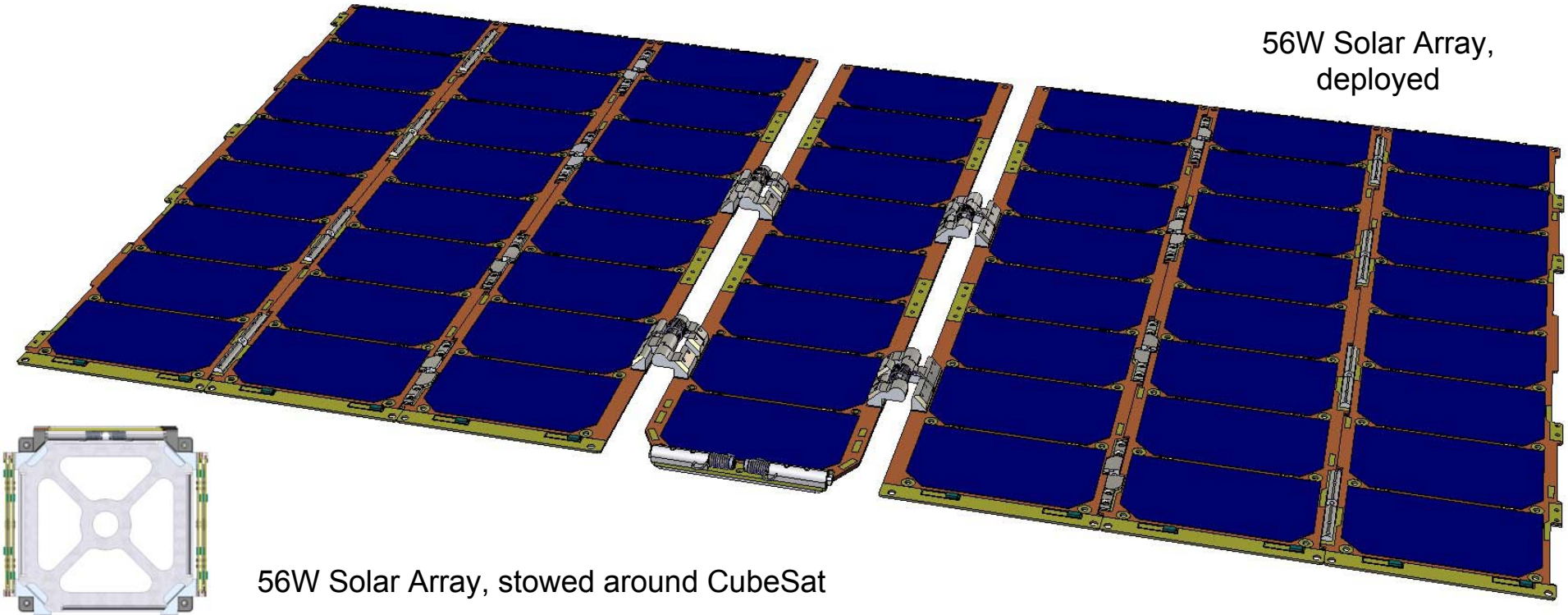




- Panel production, test & validation time: 1 cell/technician-hr

56W Solar Array for CubeSats

- 56W EOL power from 8S7P solar array configuration
- Three winglets per side, and 0.062” side panels fit, too.
- All seven panels aligned to same normal, within 5º (2º typical)

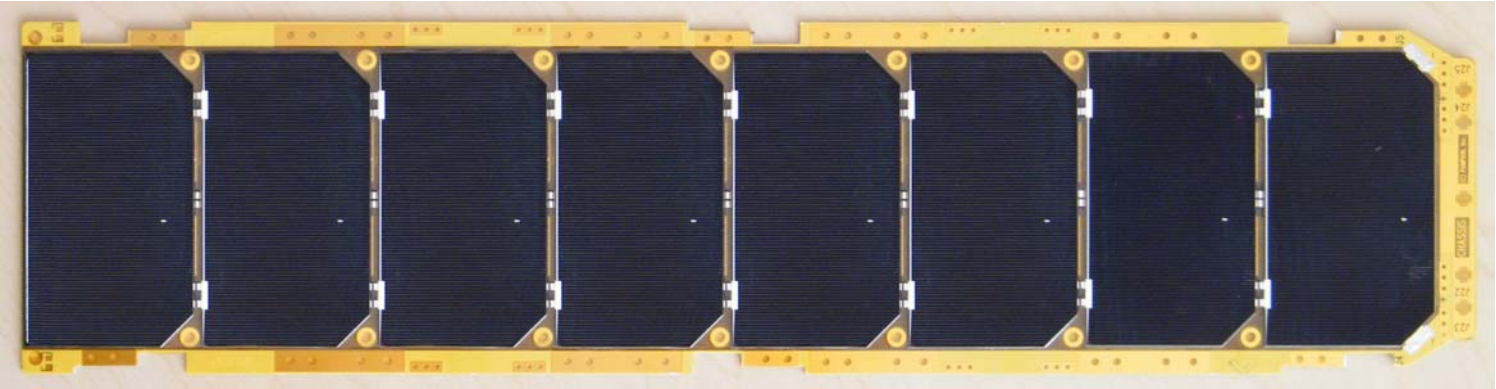


56W Solar Array, deployed

56W Solar Array, stowed around CubeSat

Conclusion

- Pumpkin's collection of solar array hardware permits a wide range of hinged solar array configurations beyond those illustrated here (e.g., "puddle-jumper" 3U nadir-pointing configuration)
- Pumpkin can deliver solar panels and solar arrays using these assembly techniques on short order – not only for CubeSats



8-UTJ-cell panel for 3U-size CubeSats

- Special thanks to the Aerospace Corp., esp. Petras Karuza, David Hinkley and Siegfried Janson

Q&A Session

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Appendix

- Speaker information
  - Dr. Kalman is Pumpkin's president and chief technology architect. He entered the embedded programming world in the mid-1980's. After co-founding Euphonix, Inc – the pioneering Silicon Valley high-tech pro-audio company – he founded Pumpkin, Inc. to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He is the creator of the Salvo RTOS and the CubeSat Kit. He holds several United States patents. He is a consulting professor in the Department of Aeronautics & Astronautics at Stanford University and directs the department's Space Systems Development Laboratory (SSDL). Contact Dr. Kalman at aek@pumpkininc.com.
- Acknowledgements
  - Pumpkin's Salvo, CubeSat Kit and MISC customers, whose real-world experience with our products helps us continually improve and innovate.
- CubeSat Kit information
  - More information on Pumpkin's CubeSat Kit can be found at http://www.cubesatkit.com/. Patented and Patents pending.
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