# Compact Telescoping Array (CTA)

## Advancement from Concept to Reality

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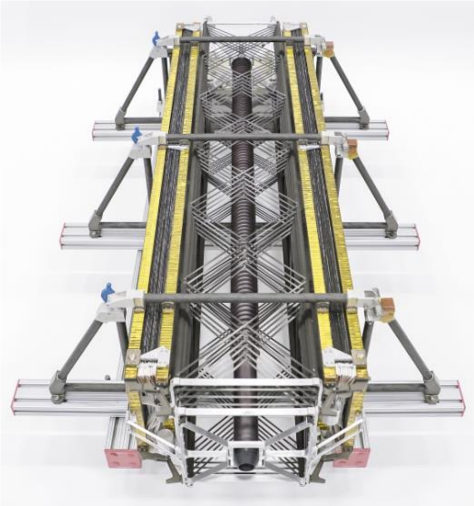
# Overview of Topics

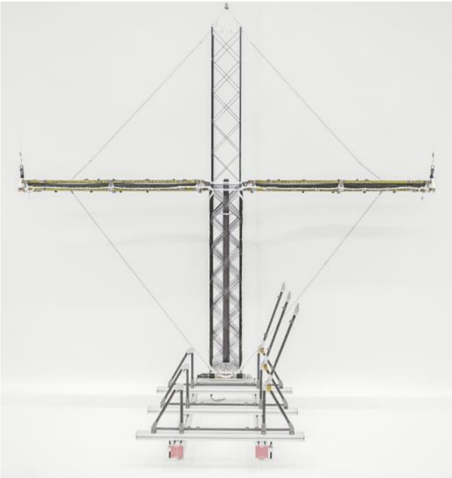
- CTA overview – concept of operation
  - Deployment sequence
- Review of development activities
  - TRL 8 achieved by multi-unit miniature telescoping boom (flight units delivered)
    - CTA uses same drive mechanism, same detents, etc.
  - AFRL "Gen2" EDU thermal deployments, vibration tests
- CTA benefits for missions under consideration
  - Multi-manifest launch configurations need ultra compact volume and short extents
  - High power in small s/c bus
  - Deep space – large PV area for low intensity operation
  - Landers
    - Lunar – self-supported vertical deployment for polar lander, full alpha tracking
    - Mars – horizontally-deployed via support legs (R. Pappa, et al)

# CTA Operation

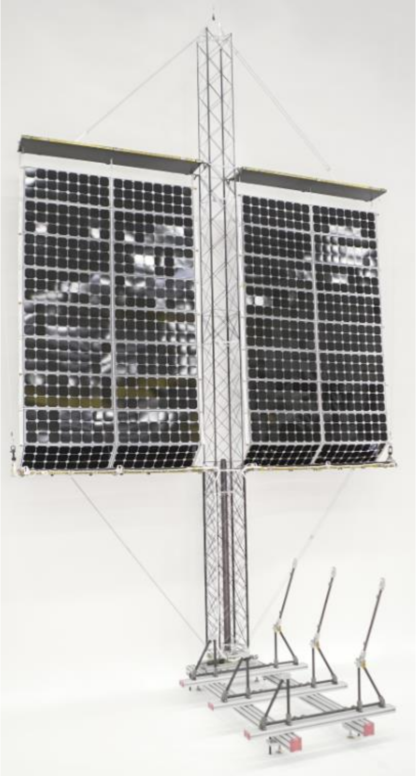
## Deployment Sequence



Stowed



Root and blankets staged



Blankets unfurling

Deployed

# CTA Prototypes - Comparison

| Item | Gen1 (NASA) | Gen2 (AFRL) | Flight |
|---|---|---|---|
| Launch Cradle | n/a | High fidelity prototype, manually released (bolted) | Use custom tubes, release actuators |
| Root Staging | n/a | Flight-like | (no change) |
| Blanket Staging | Manually released (pull pin) | Manually released (pull pin) | Use release actuators |
| Blanket | Sheet metal "frames" tied to blanket tapes | Composite SPM frames, mesh substrate, individual cell simulators (2 SPMs have actual cells) | Gen3 SPM design with live CICs |
| Electrical Harness | n/a | mechanically represented (flex on blanket, round on panels) | Custom flex harness |
| Panel Stays | Flexible cords | Articulated rods | (no change) |
| Mast | High fidelity prototype | High fidelity prototype (flight-like) | Minor design refinements |
| Testing Performed | Ambient functional | Ambient functional, thermal functional, stowed vibration | Ambient functional, thermal functional, stowed vibration, electrical |

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# CTA (& Related) Activities

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| | Lead (partner) | Funding, Title | Time-frame | Key Activities | TRL Advancement |
|---|---|---|---|---|---|
| Completed | AD (NGIS) | NASA, CTA Phase 1 SBIR | 7/15 - 12/15 | CTA system modeling, CAD & FEA, scaling & model correlation studies. Focused on large (>30kW) systems. | TRL 3 (no hardware built) |
| Completed | AD (NGIS) | AFRL, CTA Phase 1 SBIR | 8/15 - 5/16 | CTA system modeling, CAD & FEA, scaling & model correlation studies. Focused on affordability and modularity for commercial systems. | TRL 3 (no hardware built) |
| Completed | AD (NGIS) | NASA, CTA Phase 2 SBIR | 6/16 - 12/17 | CTA EDU, key functional aspects less root hinge and tiedowns. Ground offloaded deployments only. | TRL 4, by laboratory demonstration of high-fidelity prototype system hardware. |
| Completed | AD (NGIS) | AFRL, CTA Phase 2 SBIR | 3/17 - 9/18 | CTA EDU, adding root hinge, tiedowns. **Vibration and thermal testing.** | **TRL 5+** by demonstration of high-fidelity system (less PV) |
| Completed | NGIS (MOLLC) | NASA, EESP PFC-CTA Base & Option 1 Phases | 10/16 - 4/18 | Point Focus Concentrator: Pointing, thermal, system performance, etc. High fidelity prototypes & test hardware development tested in relevant envts. | TRL 5-6 of photovoltaic aspects of concentrator array |
| Completed | MOLLC (SolAero) | NASA, Phase IIE | 10/16 - 4/17 | 25X Point Focus lens developed, including lens tooling. Lens samples delivered to NASA. | TRL 4 of Point-focus Fresnel lenses for optical concentration |
| Completed | MOLLC (SolAero) | NASA, CCRPP | 9/17 - 4/18 | Cell optimization for high concentration including heat spreaders. NGIS is "investor" via EESP Option 1 & 2. | TRL 4 of PV optimized for high optical concentration |
| Completed | NGIS (NASA LaRC) | NASA, CIRAS (Tipping Point) | 10/16 - 10/18 | In-flight assembly technology demonstration program. Prototype CTA wing built to validate robotic installation and deployment. | TRL 4-5 of mechanical platform suitable for in-space assembly |
| Current | NGIS (commercial) | (proprietary) | 6/18-ongoing | CTA for multi-unit & constellation spacecraft | Design for manufacturability and PV accommodation |
| Current | NGIS | IR&D | 11/18-ongoing | Refinement of SPM design, environmental testing of PV populated SPMs, mast design refinements & testing | TRL 6 of telescoping truss TRL 6 of populated SPMs |
| Current | NGIS | AFRL ASSISTT | 11/18-ongoing | SPM mfg scale-up; incorporation of refined design into full-system prototype | TRL 6 of full CTA wing (including populated SPMs) |
| ated | NGIS (commercial) | (proprietary) | 9/16 - 9/18 | Miniature composite telescopic mast system EDUs, PDR/CDR, **multiple flight units** | **TRL 8 of miniature telescopic mast system** |

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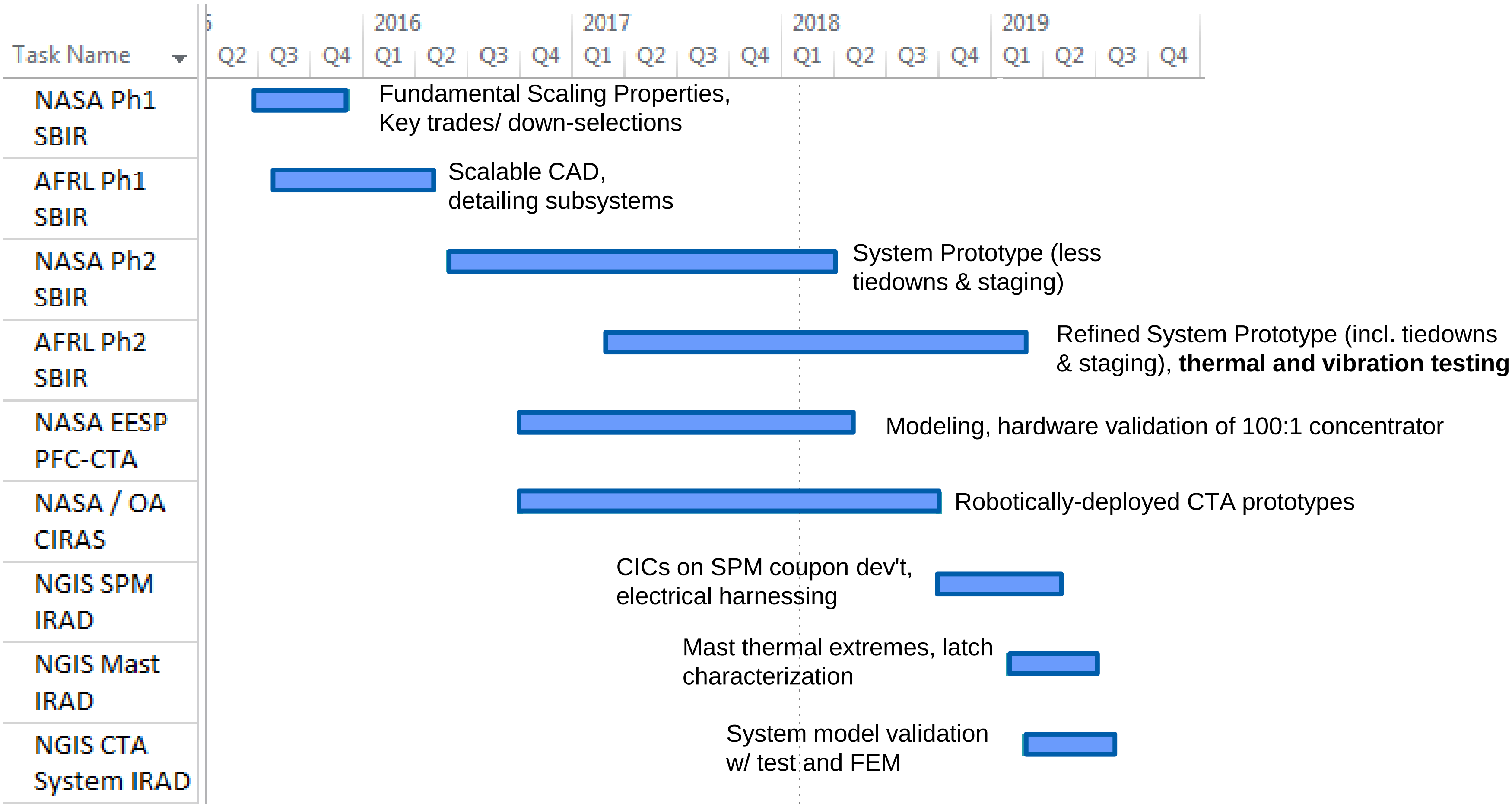
# Activities and Accomplishments

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# CTA Advantages – Structural Efficiency

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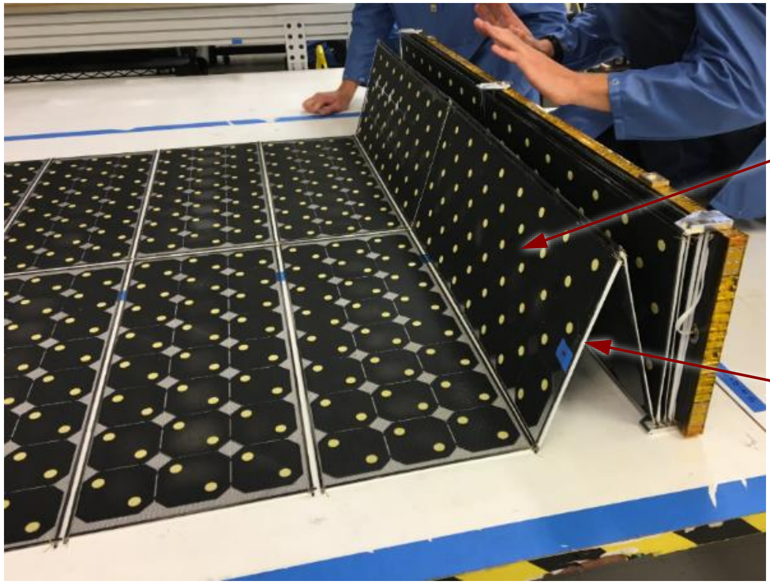
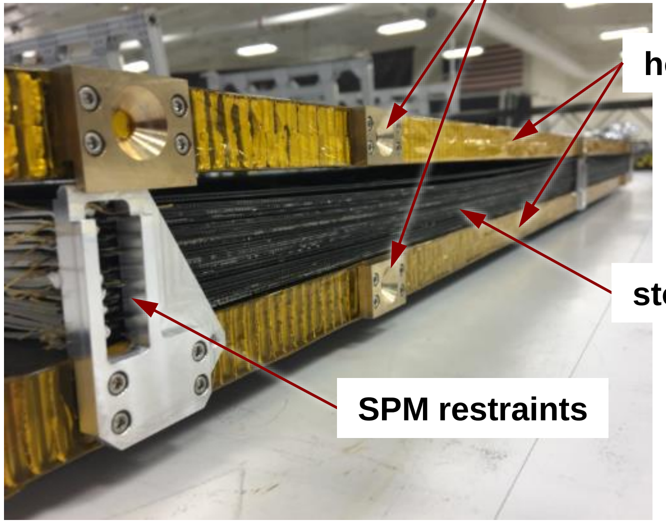
- Wing is deployed and supported by an **optimized, high modulus** carbon fiber **central lattice truss**

- Truss avoids challenges associated with alternative structures:
  - Thin shells, subject to defects and buckling
    - Structural optimum (EI/mass) is a large diameter, thin-walled tube which cannot be fabricated thin enough to be optimal, and suffers buckling limitations
  - Material tradeoffs for strain capability
    - Elastic tubes use standard modulus carbon, isotropic layup. E = 12-15 msi
    - CTA truss uses unidirectional, high modulus fiber. E = 32 msi
  - Creep issues (temperature, storage life limitations)
    - Elastic deployables are highly strained; **CTA truss is always un-strained**
  - Need for a separate standoff (“yoke”) structure
    - Most array designs require a separate beam with hinges; **CTA’s yoke is integral**
  - Bending loads in blanket spreader beams
    - CTA’s stays **eliminate bending loads** which drive spreader volume and mass
  - Stowed loads driving structural design
    - CTA makes dual use of blanket end support beams for **compact stowage** & **efficient blanket stack containment**

# Blanket Assembly



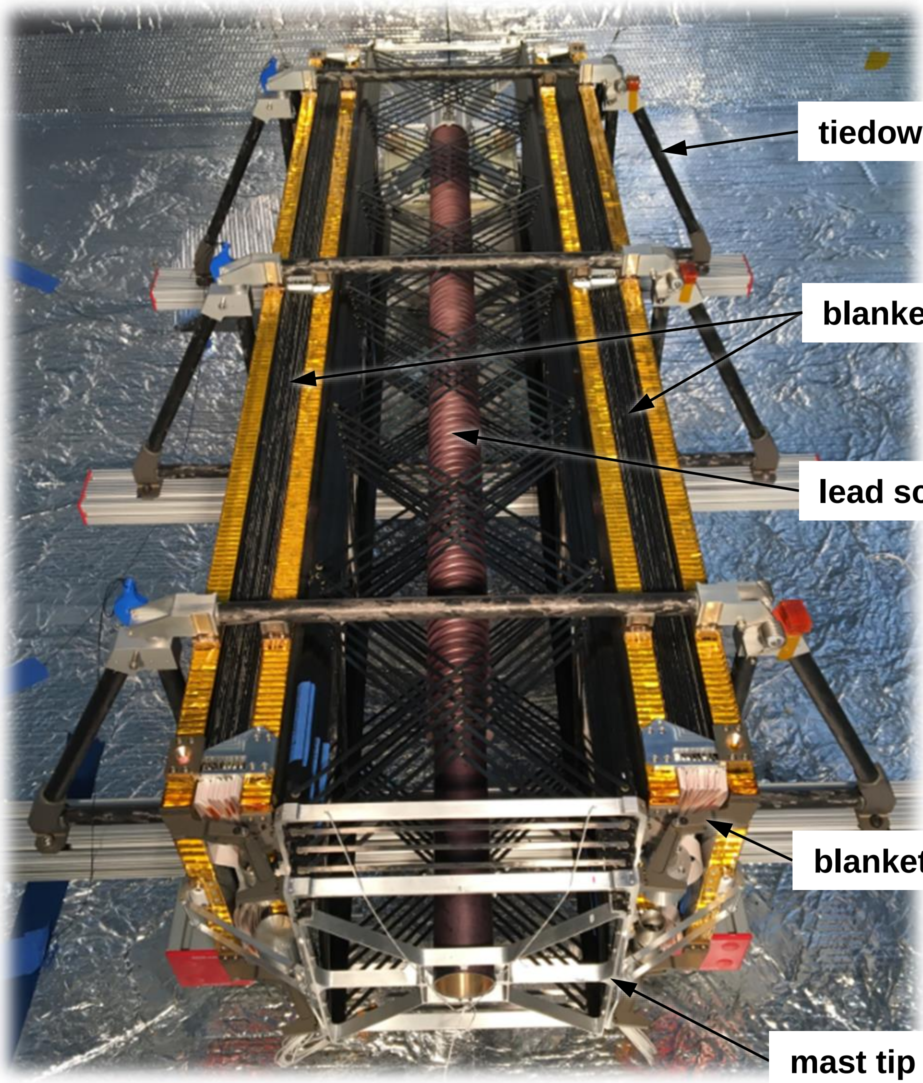
# Blanket Assembly

flat flex cable harness, 4 places

SolAero CICs (fragility indicators) 2 SPMs only

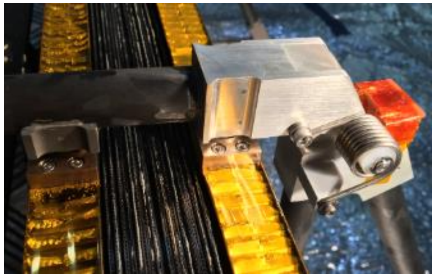
All other “cells” are painted aluminum mass simulators

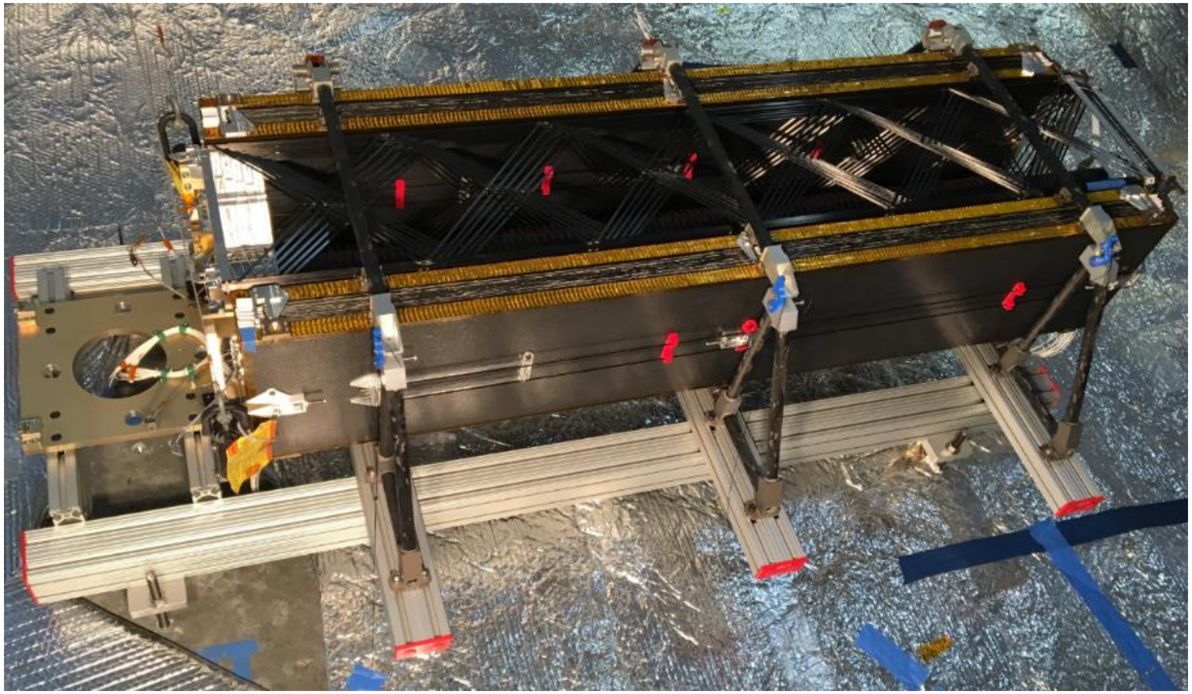
# Wing Assembly

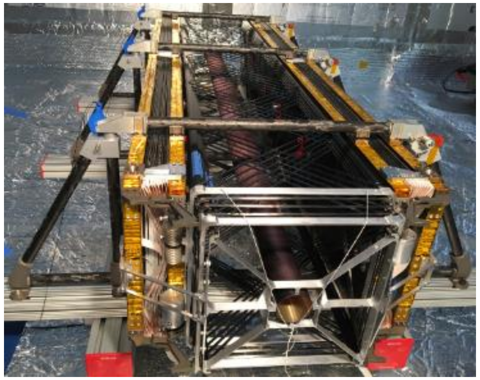


# Launch Cradle

- Cradle includes cup-cone constraints between stanchions and panels
- Cradle arms spring out upon release, allowing wing to stage out 90°



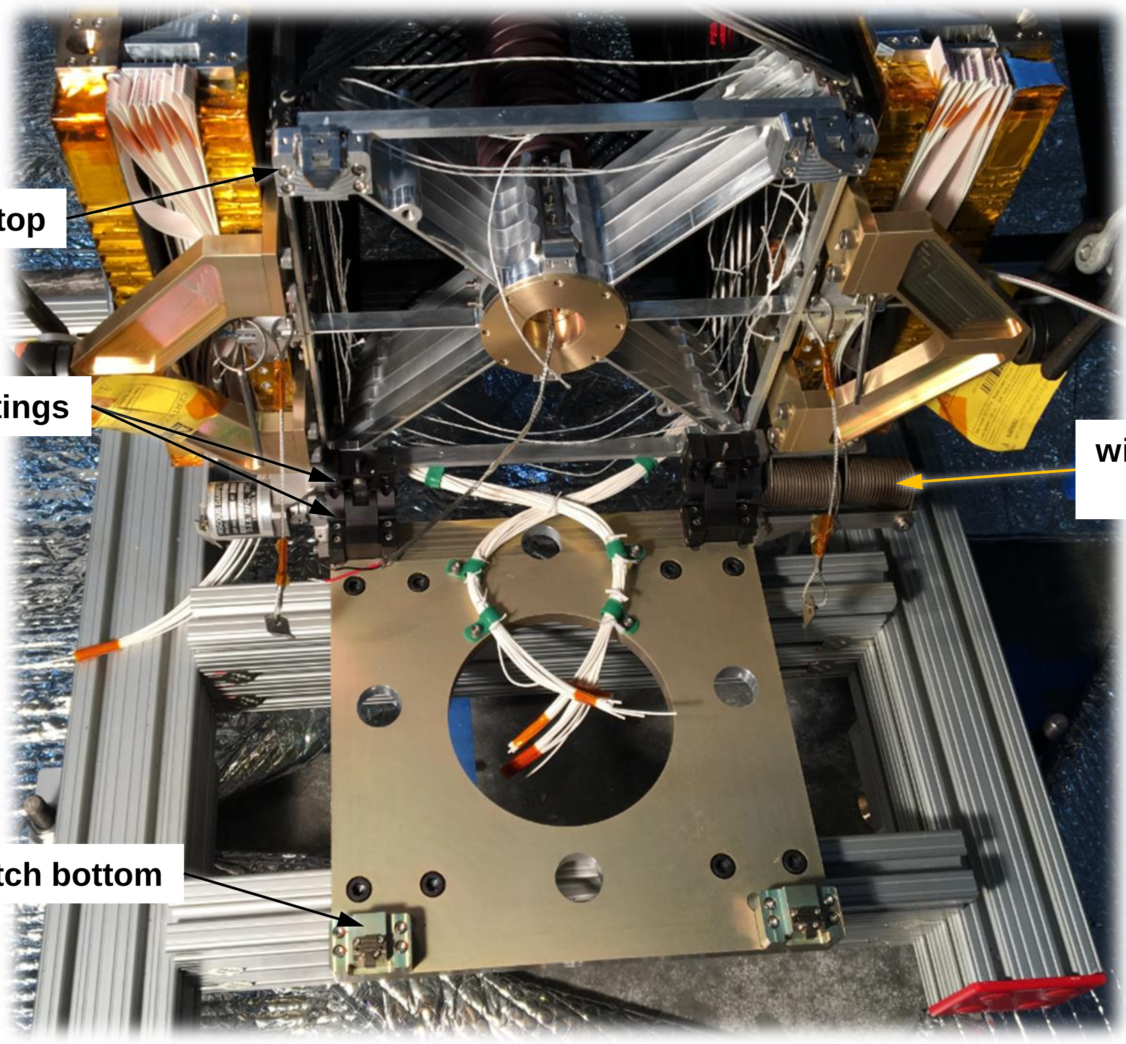




# Root Hinge

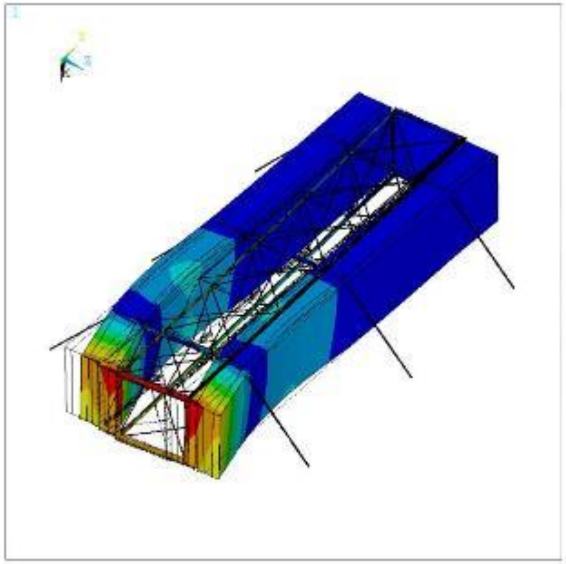
Spring/ damper, latching root hinges are modified vs. GeoStar 3

(for wide footprint)



# Stowed FEA

- First mode predicted 68 Hz
  - (panel bending)
- Vibration testing demonstrated >100 Hz first mode
  - FEM smeared blanket mass is conservative
  - SPM frames contribute significant bending stiffness



# Wing Testing (cont'd)

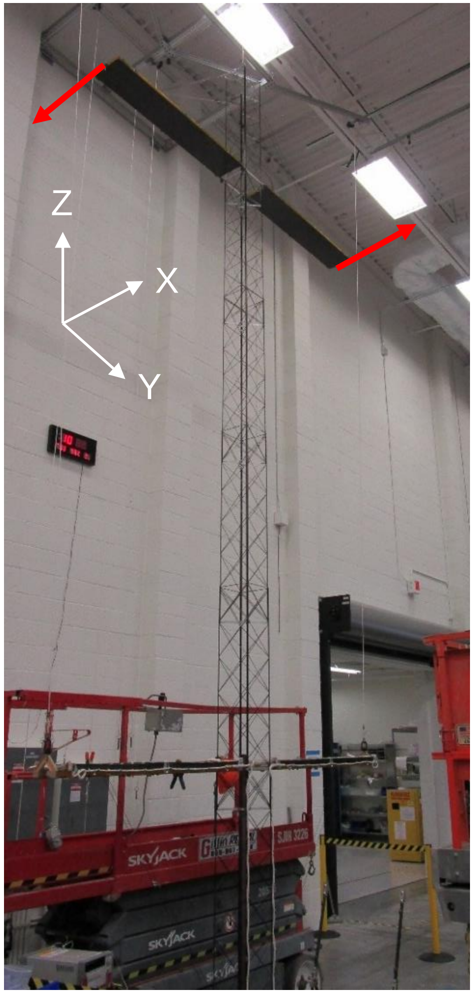
- Thermal deployments
  - Full deployments at hot (+60°C)
    - Result: full deployment success
  - Full deployments at cold (-50°C)
    - Result: full deployment success

**THERMAL TEST CHAMBER**
**NGIS Goleta CA**
**16' x 16' x 28'**

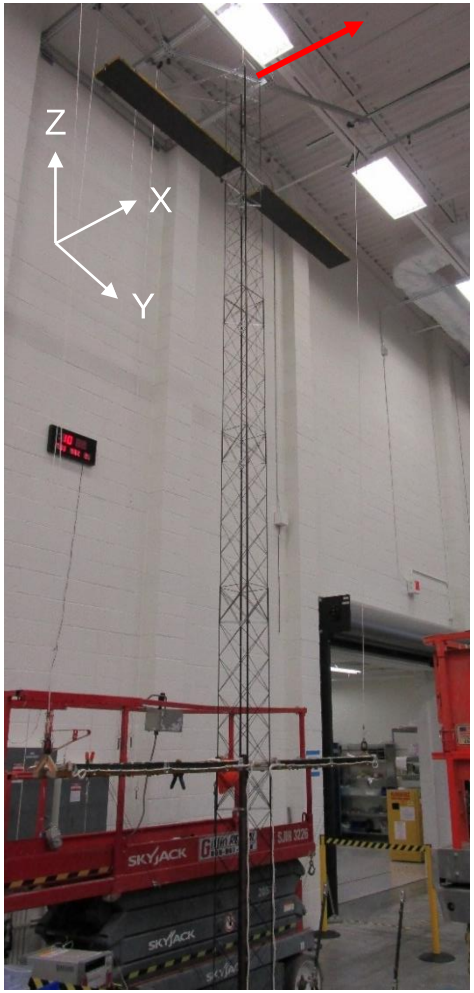
# Stiffness Testing

- Gen2 mast measured with blanket retracted
  - Tip lateral stiffness
  - Top blanket torsion stiffness
- Results compared with FEA and closed-form predicts
- Discrepancies noted; sources of compliance identified and targeted for design refinement and/or further testing

Torsion Load, -Z




Lateral Tip Load, +X

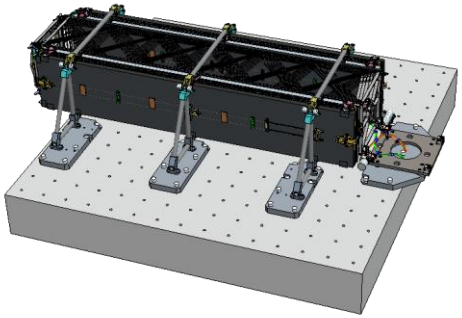


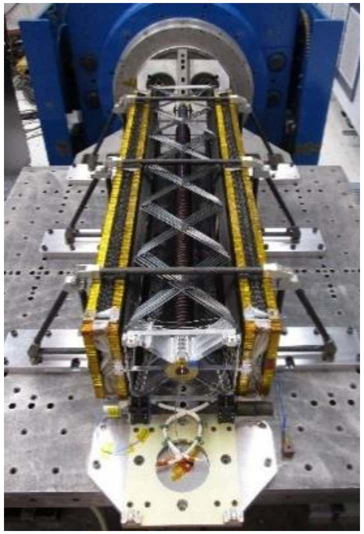
# Vibration Testing

- Test details
  - Full level sine sweep prior to random
  - Random Spectrum per GEVS, with notching to limit response per MAC (18 g's)
  - X-axis ~9 g's RMS
  - Y-axis ~10 g's RMS
  - Z-axis ~9 g's RMS
  - 60 sec duration
  - Increment loading, -12/-9/-6/-3/0 dB with inspections between
  - 0.5g sine sweep before RV and after full level

**sine sweep**

| Freq (Hz) | G's |
| --- | --- |
| 5-60 | 6 |
| 60-100 | 4 |
| Sweep | 4 oct/min |

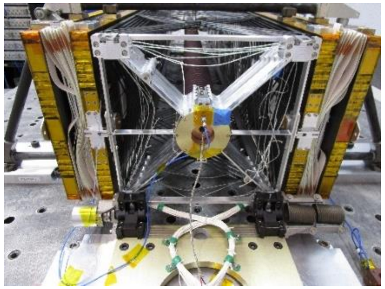




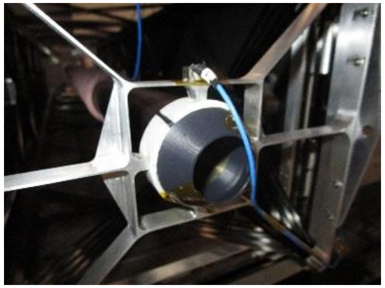
**STOWED VIBRATION TEST SETUP**

# Vibration testing – observations

- Pre and post low level vibe overlays match well, no frequency shifts
- Successful demonstration of stowed / launch configuration
  - SPM shear restraint tabs were damaged during full level sine sweep in the X-axis
    - Previously known issue, refined SPM design addresses
  - Lead screw tip snubbing – reduce clearance for more consistent response at tip bulkhead
    - Previously known issue, new tip bulkhead design addresses



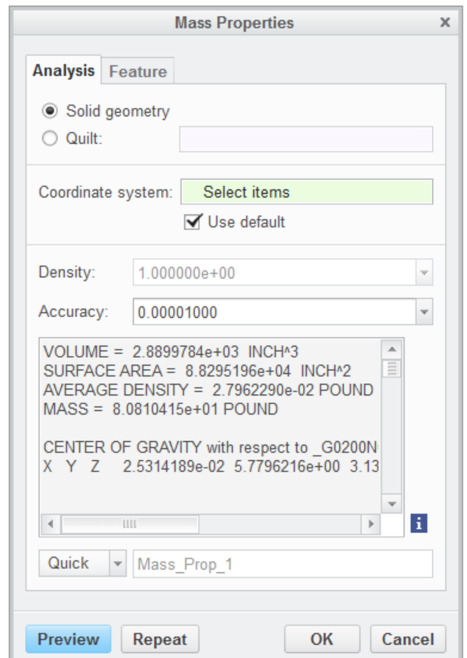
*VIBRATION SETUP - ROOT*



*LEAD SCREW TIP PADDING*

# Gen2 EDU wing weight

- As built: 81.89 lbs
- Per CAD: 80.81 lbs
- CAD within 1.3% of actual
- Weights include 3.9 lb “GSE” root plate and design concessions for cost/schedule
- See following for adjustments

# Mass Breakdown

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- EDU is approx. 18% heavier than a “flight-optimized” wing of that size
  - Minimal impact due to cost/schedule limitations
- CTA design (validated by EDU hardware) projected to achieve 156 W/kg with a 1.1 kg/m2 PV blanket

| System Mass Elements (kg) | Gen2 EDU | "Flight" (6 bay) | "Flight" (12 bay) | EDU vs. Flight Comment | 12 bay Flight comment |
|---|---|---|---|---|---|
| PV Blanket | 14.8 | 14.8 | 33.7 | EDU included 1.3 kg/m2 blanket (conservative SoP) | 1.1 kg/m2 for optimized PV |
| Electrical harness | 2.0 | 2.0 | 9.7 | No change - EDU construction "flight-like" | No change |
| Mast | 3.0 | 2.8 | 5.4 | No change - EDU construction "flight-like" | No change |
| Blanket Panels | 6.3 | 2.8 | 2.8 | EDU panels were COTS CFRP; flight will be custom | No change |
| Top Panel Hinge | 0.1 | 0.1 | 0.1 | No change - EDU construction "flight-like" | No change |
| Bottom Panel Hinge | 0.4 | 0.4 | 0.5 | No change - EDU construction "flight-like" | No change |
| Lead Screw & Motor | 2.2 | 1.8 | 1.8 | Flight will be lightweighted (thinner walls) | No change |
| Mast Root Hinge | 0.8 | 0.8 | 0.8 | No change - EDU construction "flight-like" | No change |
| Stays | 0.3 | 0.3 | 0.3 | No change - EDU construction "flight-like" | No change |
| Launch Cradle | 3.8 | 2.8 | 2.8 | EDU tubes were COTS CFRP; flight will be custom | No change |
| Total Wing Mass* | 33.7 | 28.6 | 57.8 | | |
| | | | | | |
| Mast root plate | 1.8 | 0.0 | 0.0 | EDU was solid aluminum; flight is application-specific | |
| | | | | | |
| Wing BoL power (kW, AM0) | 3.3 | 3.3 | 9.0 | | |
| W/kg | 98 | 115 | **156** | (6 bay wing metrics are for reference only) | |

* Mast root plate excluded; EDU had solid aluminum “GSE” plate

# Configuration Flexibility

- CTA benefits for missions under consideration
  - Multi-manifest launch configurations need ultra compact volume and short extents
  - High power in small s/c bus
  - Deep space – large PV area for low intensity operation
  - Landers
    - Lunar – self-supported vertical deployment for polar lander, full alpha tracking
    - Mars – horizontally-deployed via support legs (R. Pappa, et al)

- Launch cradle configuration
  - Standard cradle
  - Skewed cradle

- Staging options
  - Root hinge (standard)
  - Yoke
  - Beta joint

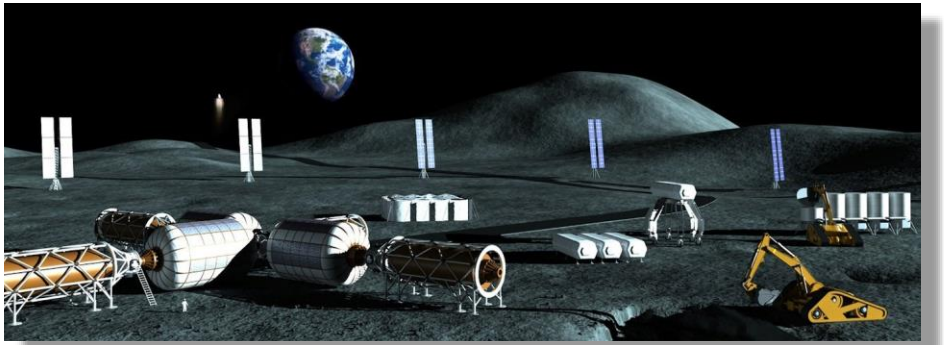

*Photo credit NASA*

# Acknowledgements

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