A Sampler Of Aerospace Research At NASA Langley

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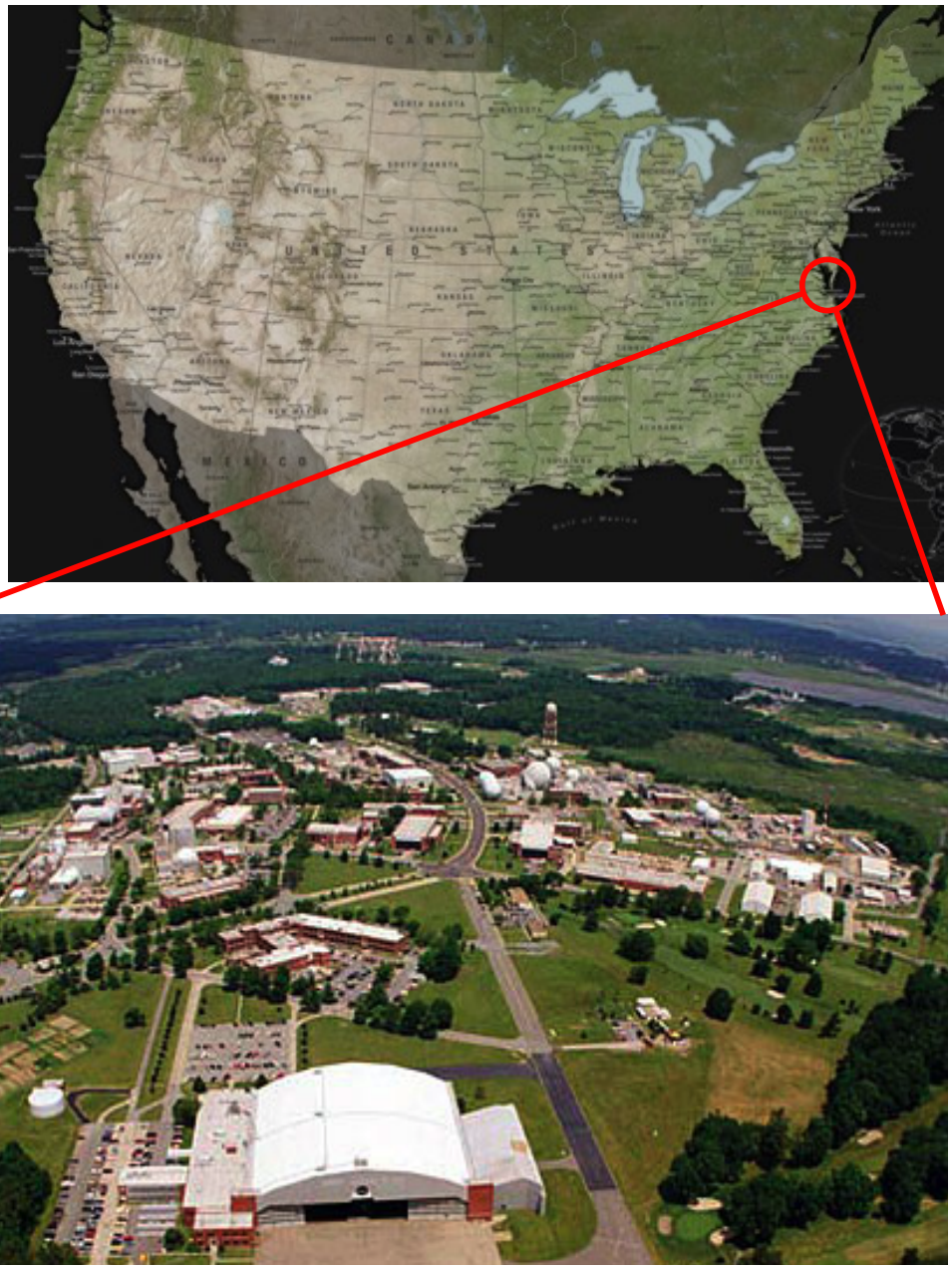
Langley Research Center - Who Are We?

- N.A.C.A. chartered in 1915 for "… *the scientific study of the problems of flight with a view to their practical solution* …"
- First US civilian aeronautics research lab, founded 1917.
- Approx. 1700 Civil Servants and 1700 contractors.
- Located in Hampton, Virginia, 130 miles SSE of Washington, D.C.
- Work is approx. 1/3 each: Space, Aeronautics, and Earth sciences.



N.A.C.A. Langley - On The Frontiers Of Aviation

- Variable Density Tunnel used to characterize airfoils (1921).
- Weick awarded Collier Trophy for development of low-drag cowlings for air-cooled radial engines (1929).
- Rapid expansion of N.A.C.A. and LMAL during WW2; cadre moved to form Ames and Lewis (now Glenn) centers.
- Drag clean-up, 6-series NLF airfoils, compressibility research, etc. supporting the US war effort.
- Collier Trophies awarded to Stack for supersonic theory (1947) and slotted-throat supersonic wind tunnel (1951), Whitcomb for area rule (1955).
- Stack led team developing a piloted hypersonic research aircraft concept (1954), built and flown as the X-15.
- Langley-led team at HQ planned early man-in-space activities (mid-1958), later renamed as Project Mercury.
- Faget designed Mercury capsule, LES (1958).

NASA Langley - Into The Space Age

- Gilruth led Space Task Group to implement Project Mercury (1958); Original 7 trained at LaRC; *Right Stuff*, *Hidden Figures*.
- Houbolt was key advocate of LOR mode for Apollo (1962).
- Whitcomb (area rule) also developed supercritical wing (1965) and winglet (1976) concepts; all three widely used now.
- Mars Viking project mgmt. and system integration (1976).
- Space Shuttle TPS tile adhesion (1979); LDEF (1984), ACCESS (1985), SILTS (1986), LITE (1994) STS payloads.
- Challenger (1986), Columbia (2003) investigations and RTFs.
- EDL analyses for Mars rovers (1997, 2004, 2012, 2021).
- Supported NTSB on AA587 composite tail failure (2001).
- Led X-43A Hyper-X scramjet; Mach 7 and 10 flights (2004).
- Supported ESAS, CxP; Ares I-X, led Orion LAS (2005-2012).
- Supporting Orion, SLS; leading X-57, X-59, X-66A research.

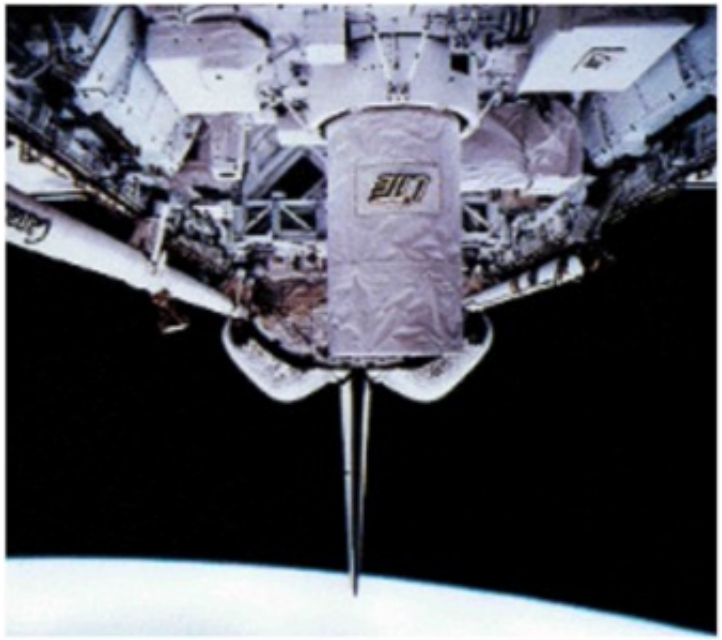
My Background

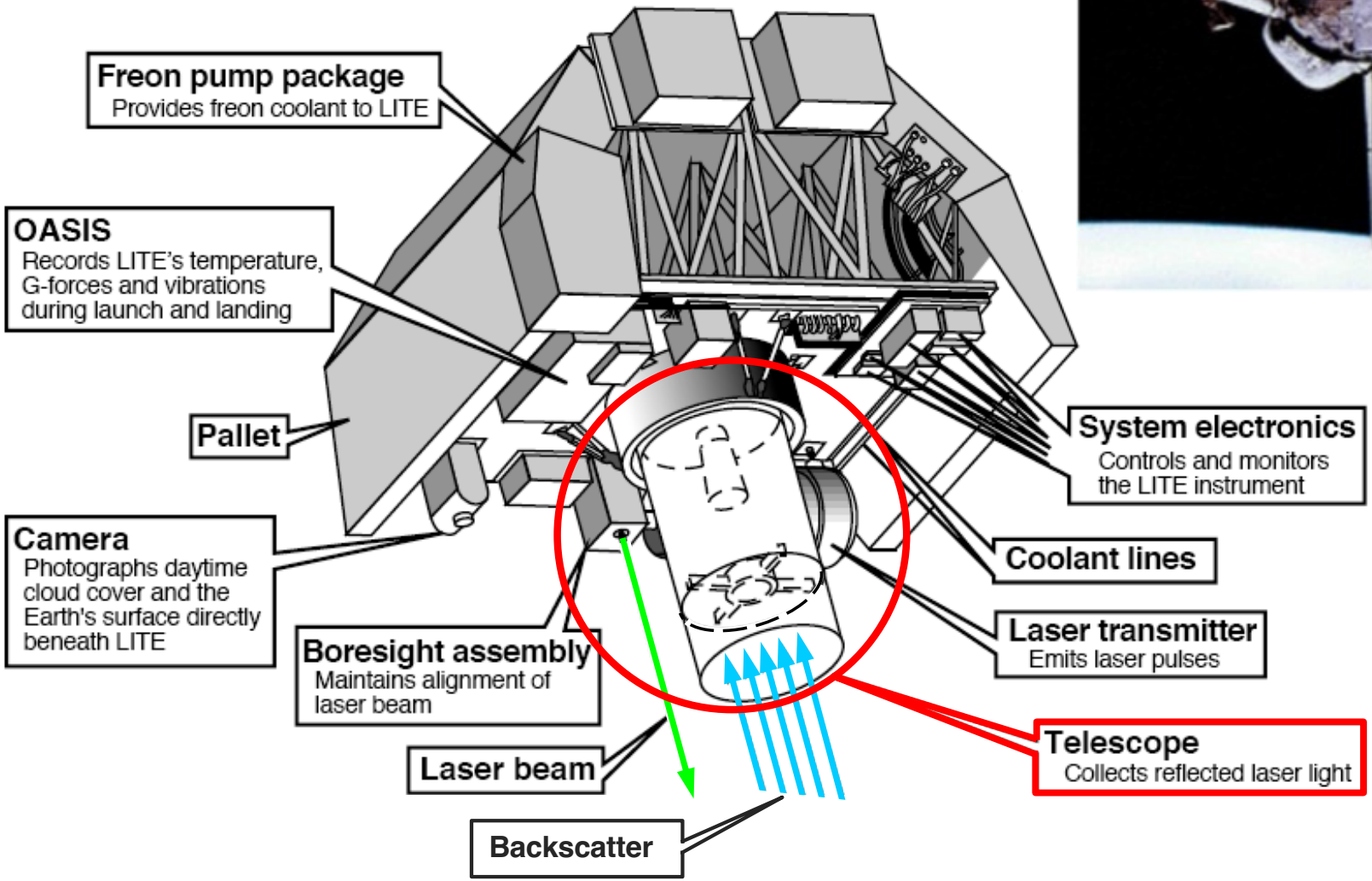
- BS in Aeronautical and Astronautical Engineering, Purdue University (1988)
- MS in Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign (1990)
- PhD in Aerospace Engineering, Delft University of Technology, The Netherlands (2006)
- Started in NASA Langley's co-operative education program (1985-1987)
- 23 years structures research, 7 years space systems analyses, 8 years science mission evaluations
- The following examples are all drawn from my experiences.

LITE Shuttle Flight Experiment



Lidar ("optical radar") remote sensing atmospheric science payload flown on STS-64 (Sept. 1994).







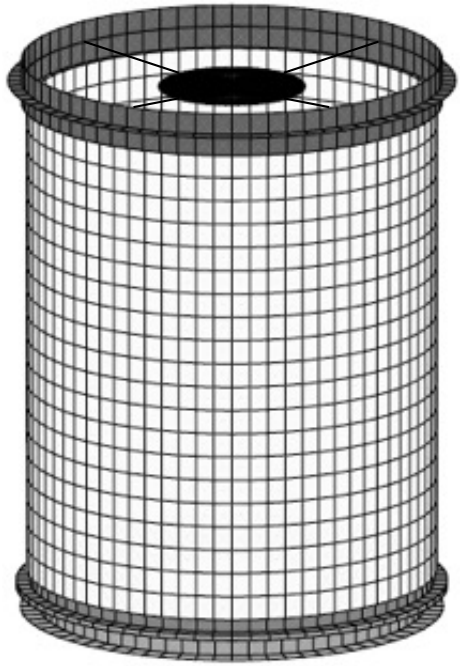
LITE Telescope Simulator Design-Analysis-Test

Goal: Design a structure that replicates the mass properties and structural dynamics of the existing flight telescope.

Mass props est'd with hand calcs, but shell structural dynamics require FEA since freqs are $\sim \sqrt{k/m}$.



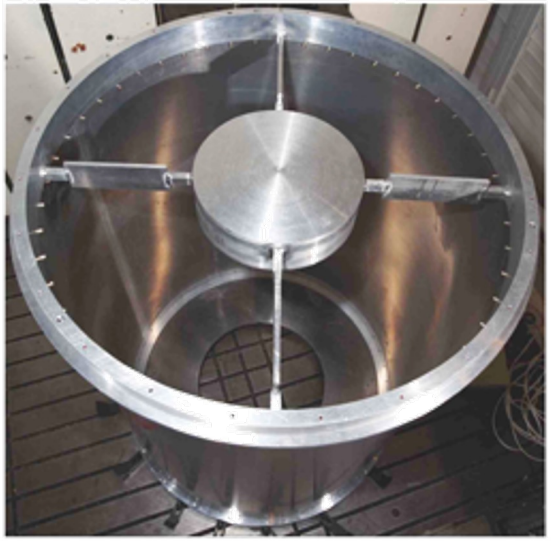
Flight telescope



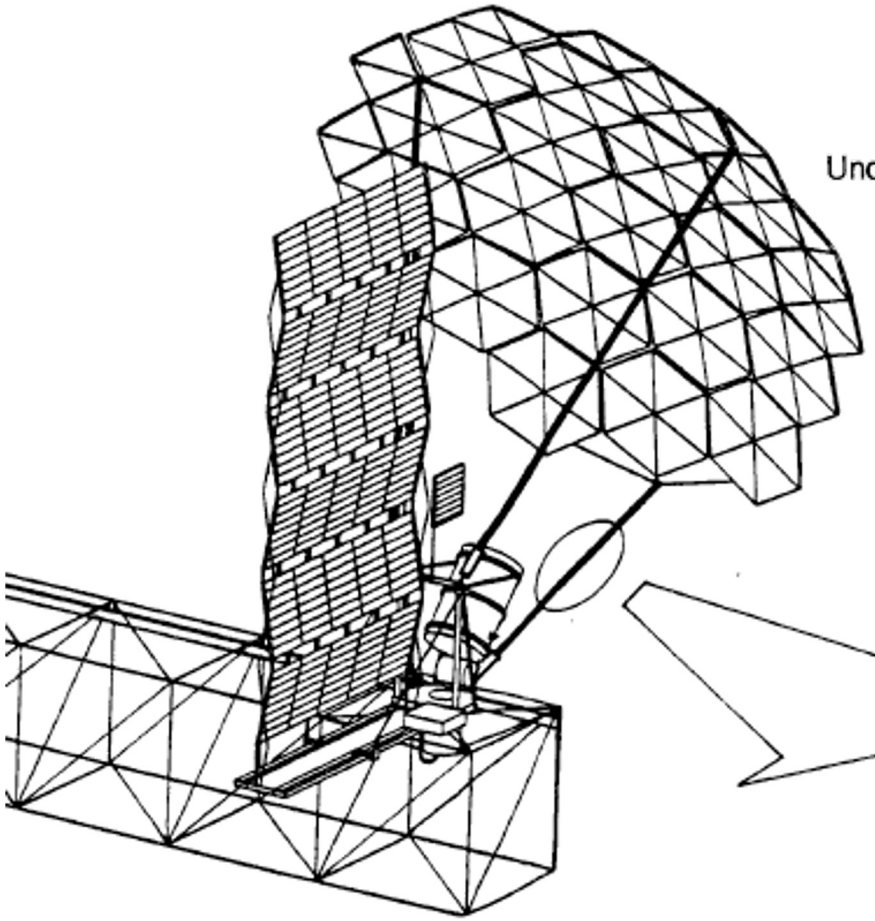
FE model

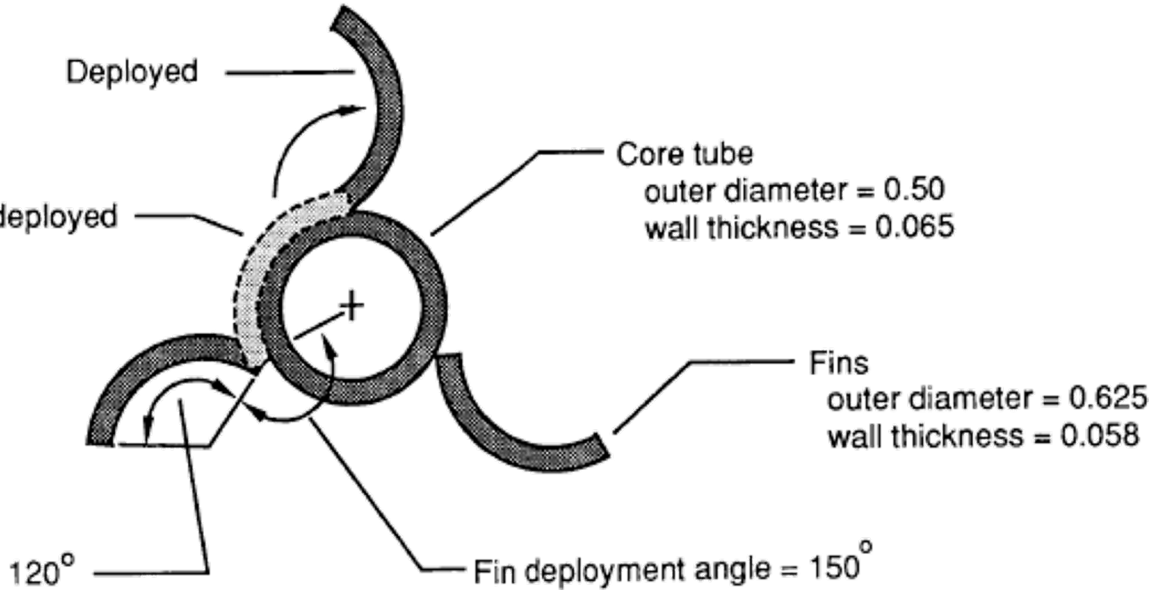
Performance Metric	Telescope (measured)	Simulator (predicted)	Simulator (measured)
Mass, lbs	359.9	359.2	--
CM, in.	21.0	20.7	--
I_{xx}, I_{yy}, lb-in^2	203,600	219,833	--
I_{zz}, lb-in^2	94,050	92,046	--
f_1, Hz - 2mt	***18.5***	***18.3***	71.4
f_2, Hz - 2mz	47.7	48.9	43.5
f_3, Hz - 1xb	61.0	76.6	71.3
f_4, Hz - 1yb	65.0	76.6	74.2

Simulator

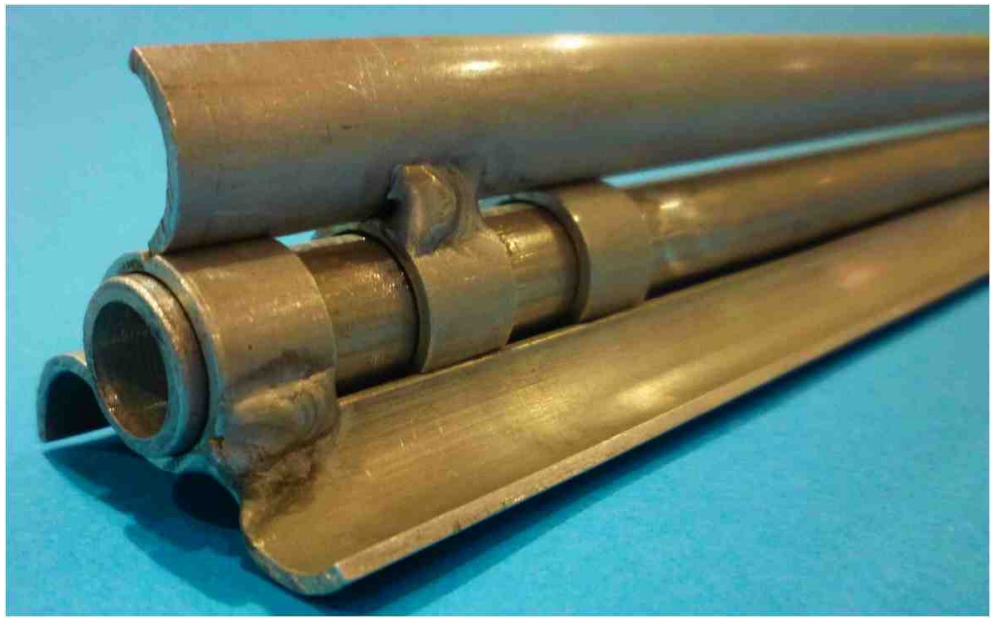


Laterally-Stiffened Deployable Strut Concept



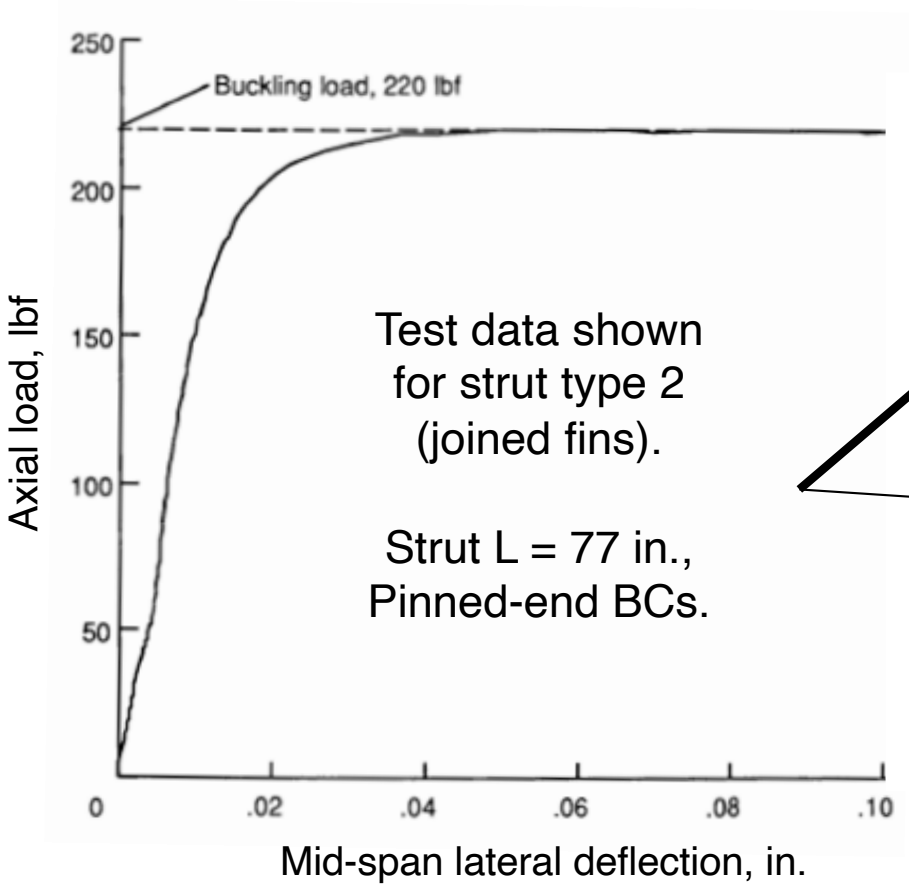


Goal: Evaluate buckling performance of deployable strut concept.



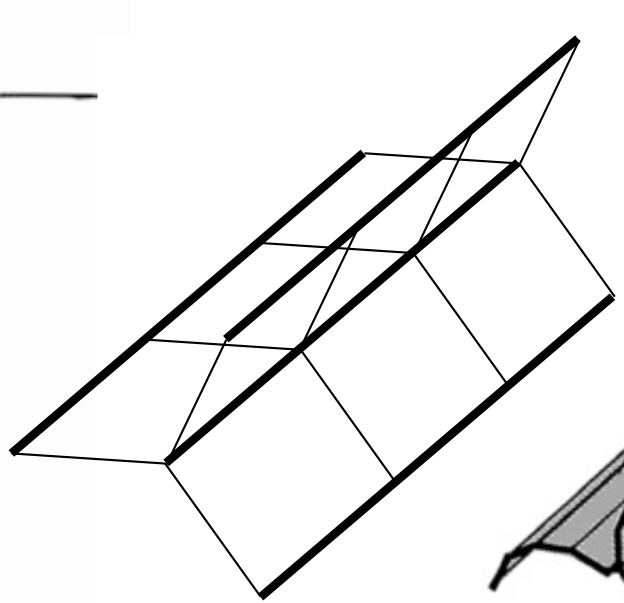
Strut type 1 (independent fins) shown

Stiffened Strut Buckling Tests And Analyses



Test data shown for strut type 2 (joined fins).

Strut L = 77 in., Pinned-end BCs.



Beam FE model

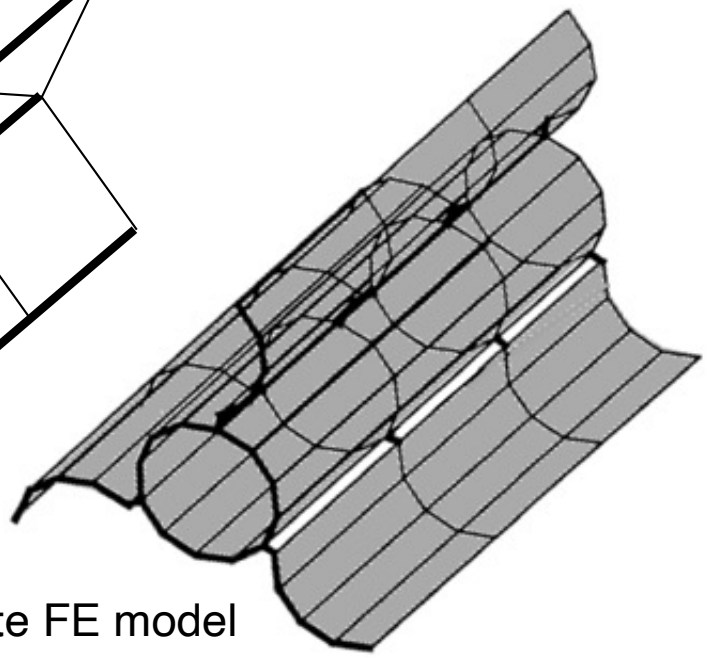
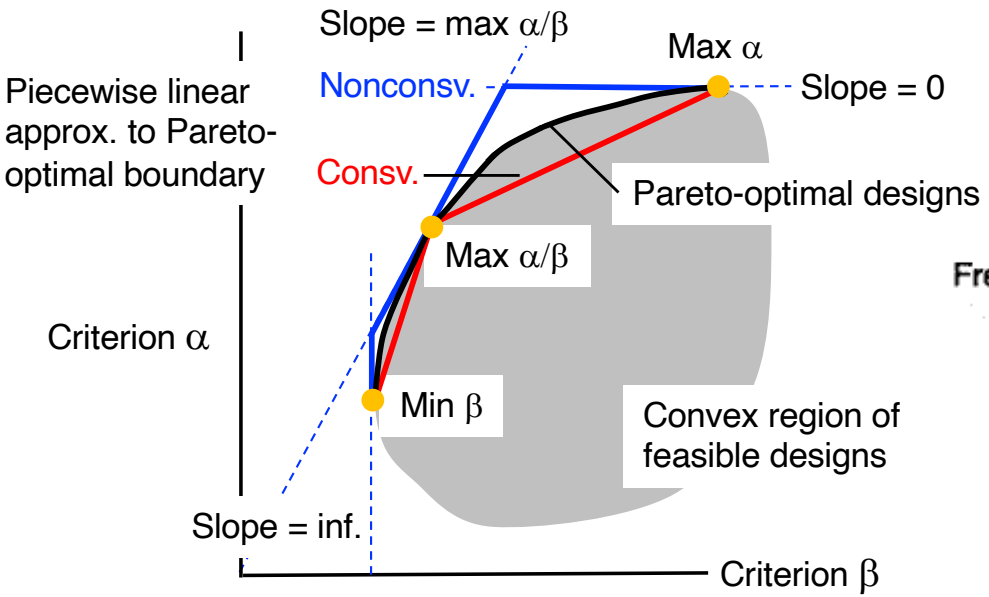


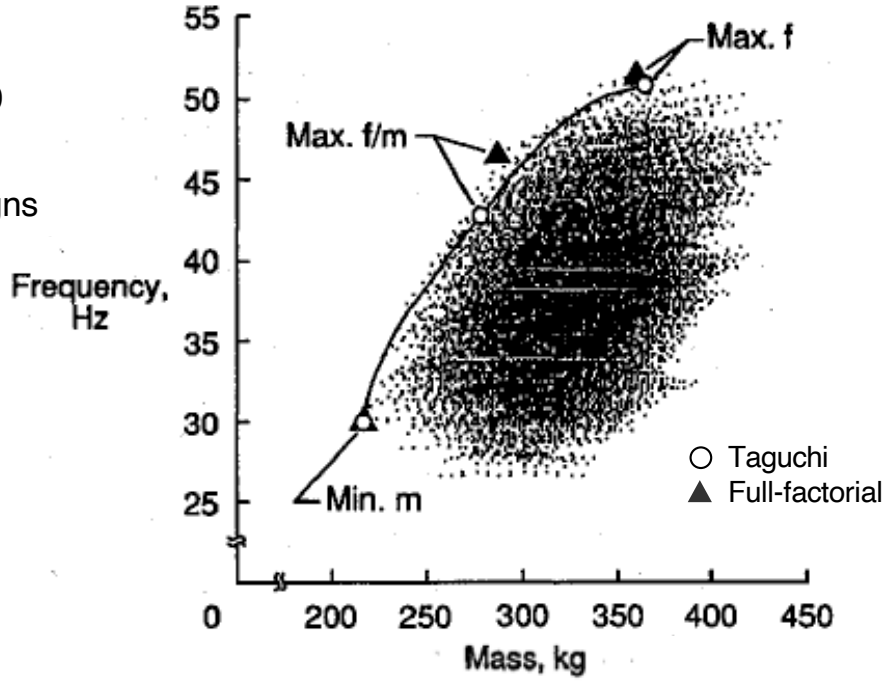
Plate FE model

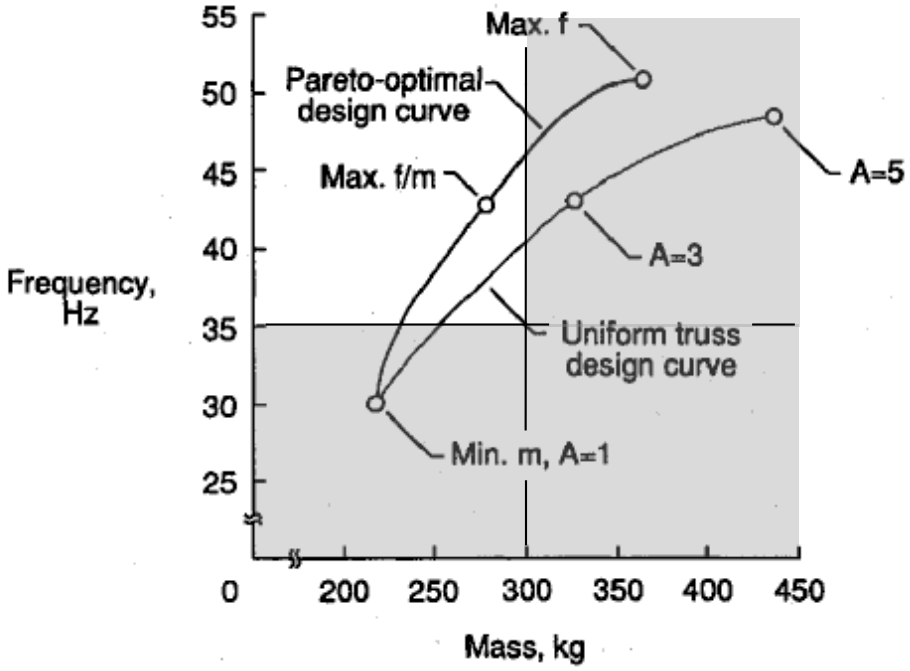
Buckling load, lbf, from -

Strut type	Euler theory	Beam FE model	Plate FE model	Average test
Core tube	36.2	38.5	36.2	38.4
1	59.9	58.0	59.3	63.2
2	---	222.6	260.2	222.0
3	299.7	256.5	289.9	283.0

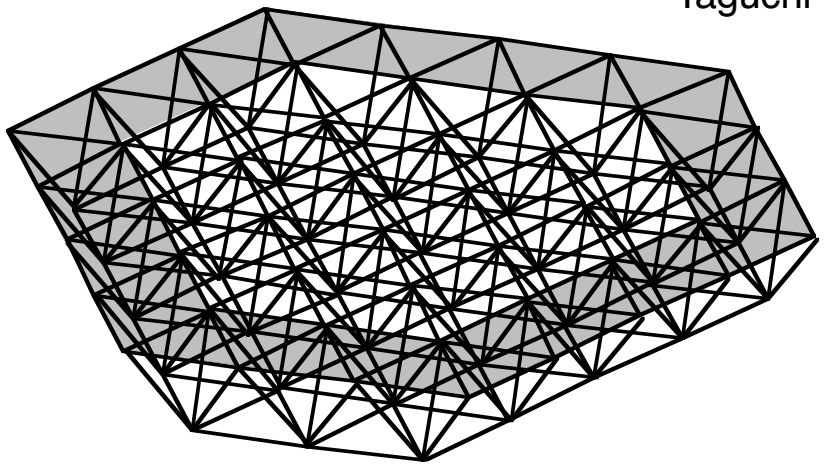
Multicriterion Design Of 3-Ring Truss



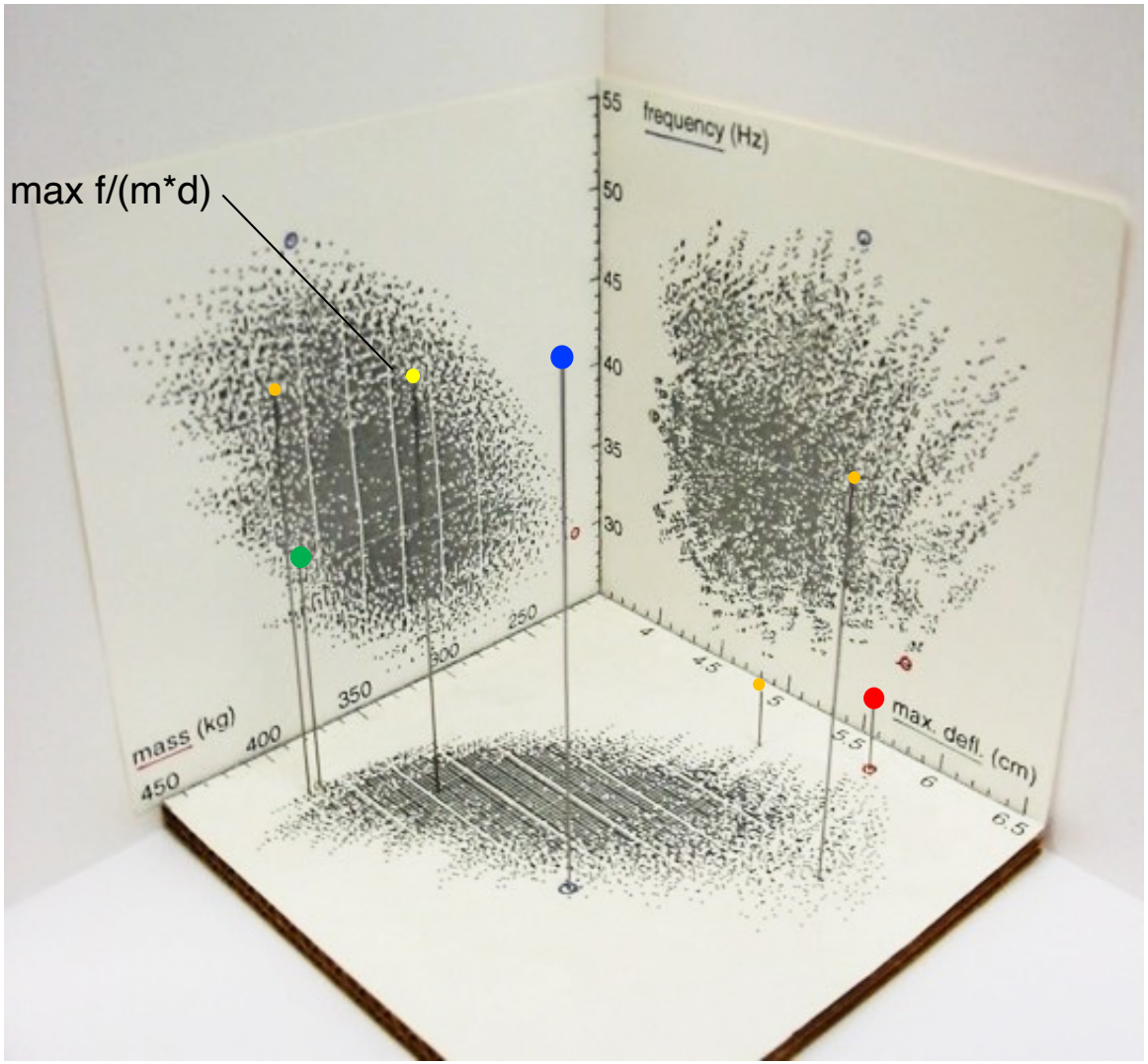




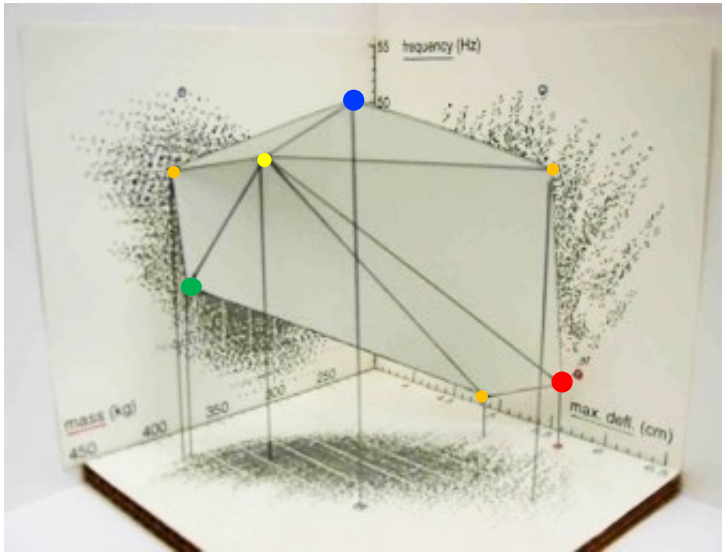
315 struts arranged into 9 groups with 1, 3 or 5 x nominal strut area. Near-optimal designs obtained using Taguchi methods.



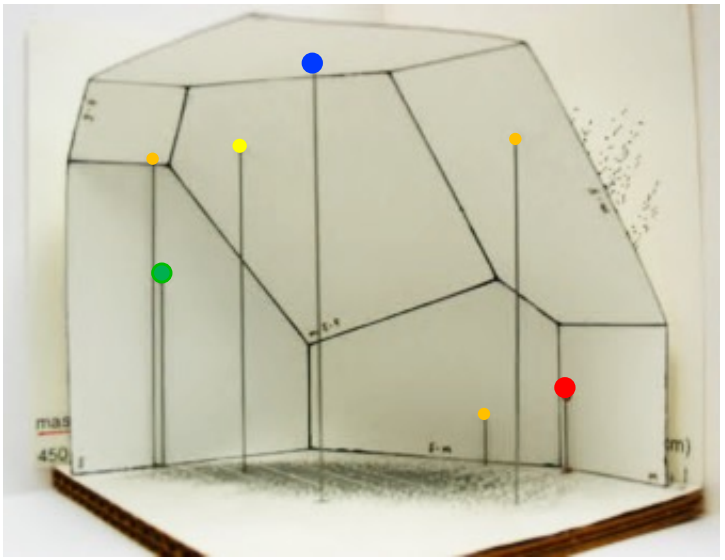
Methodology Extended Graphically To 3 Criteria



Now include maximum deflection of truss platform under free vibration as criterion. 7 key points on Pareto surface identified.



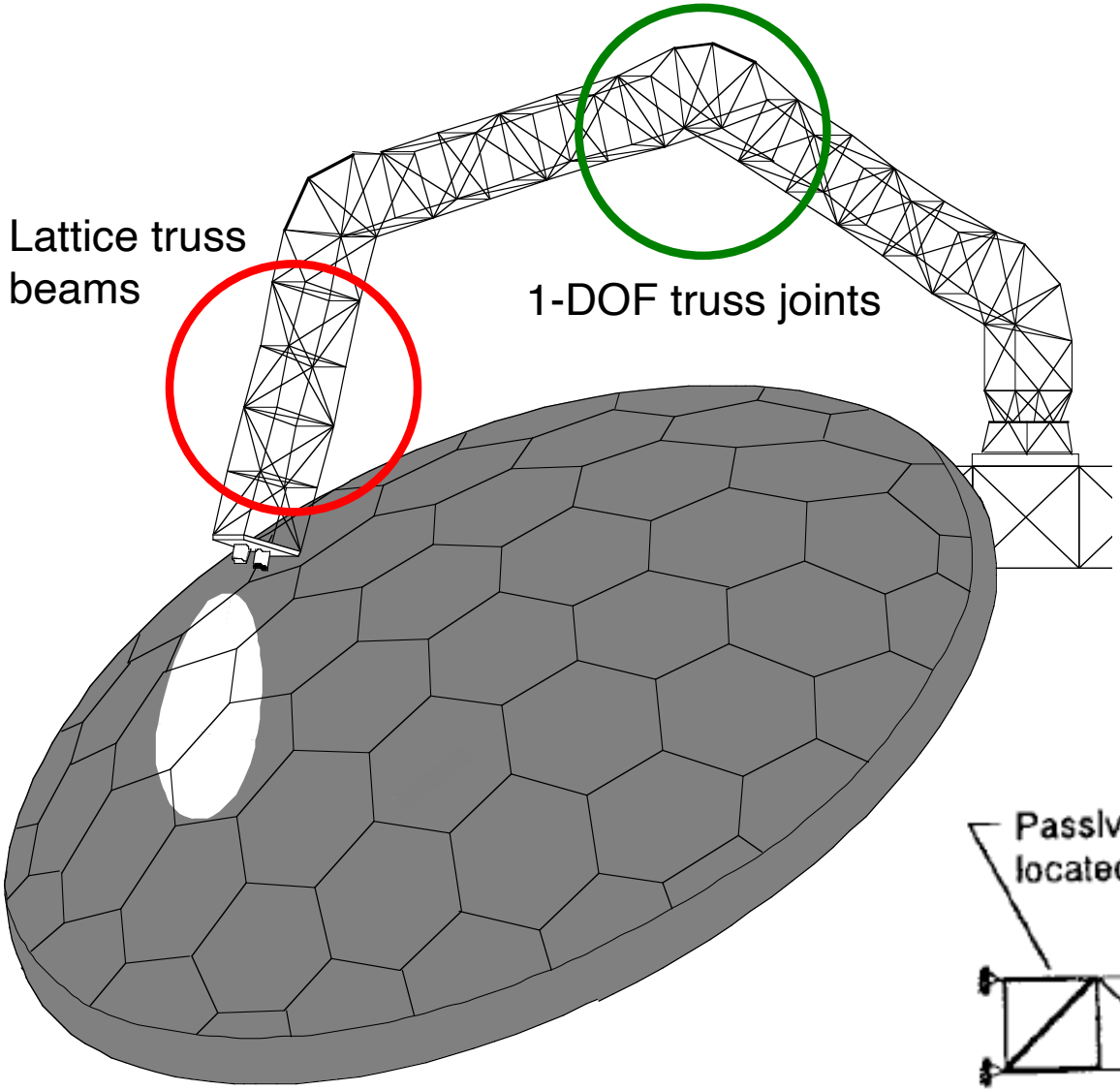
Conservative Pareto surface



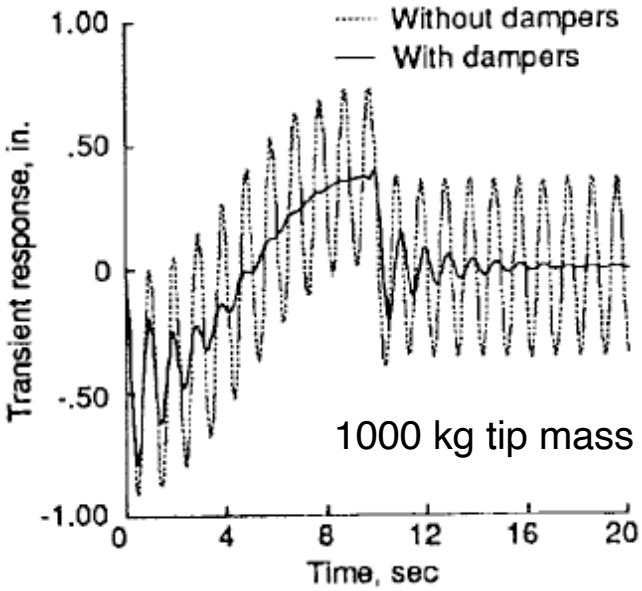
Nonconservative Pareto surface

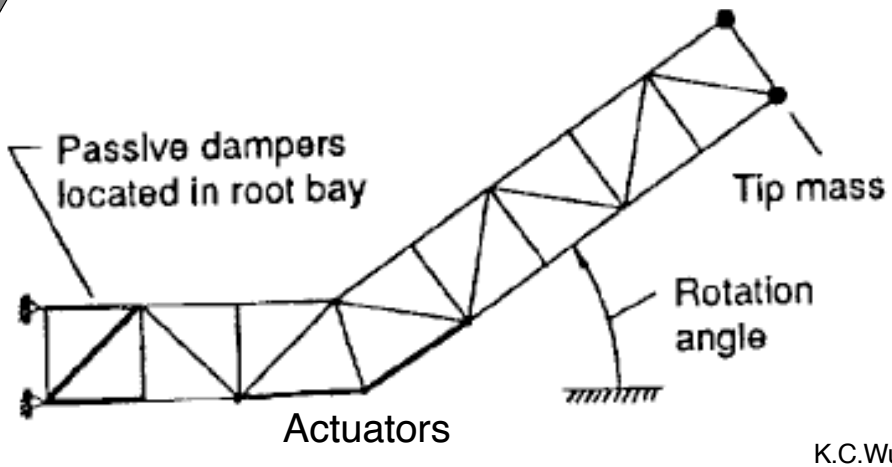
Articulated-Truss Space Crane Testbed

Goal: Simulate crane structural response to large-angle motions and inertial loads.

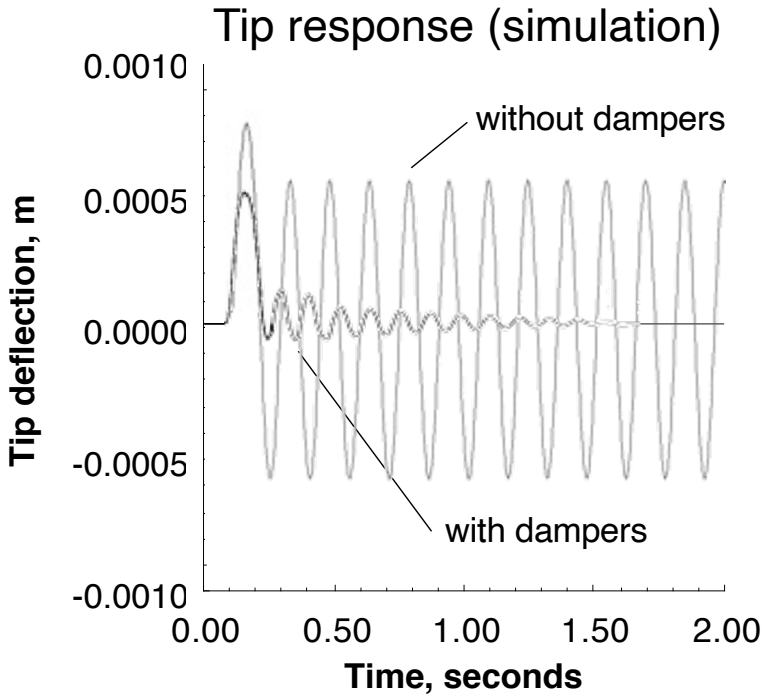


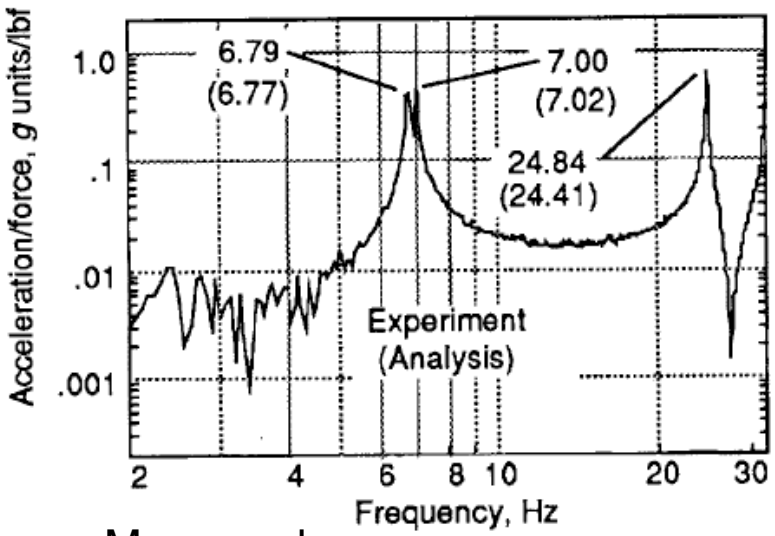
2-D Slew Simulation
(1 radian in 10 s)





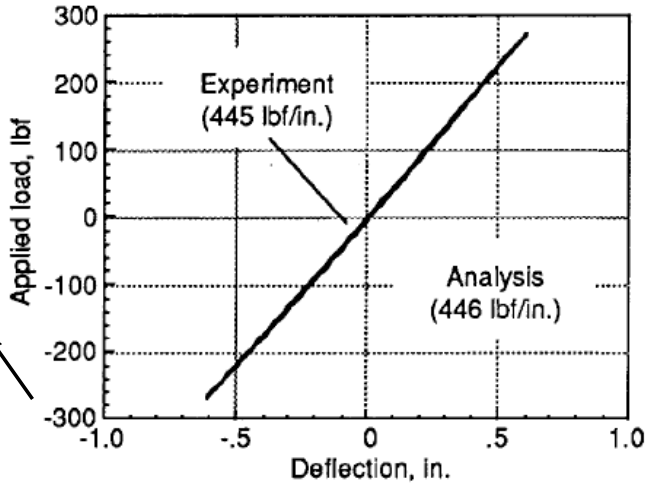
Truss Beam Tests And Analyses With Damping



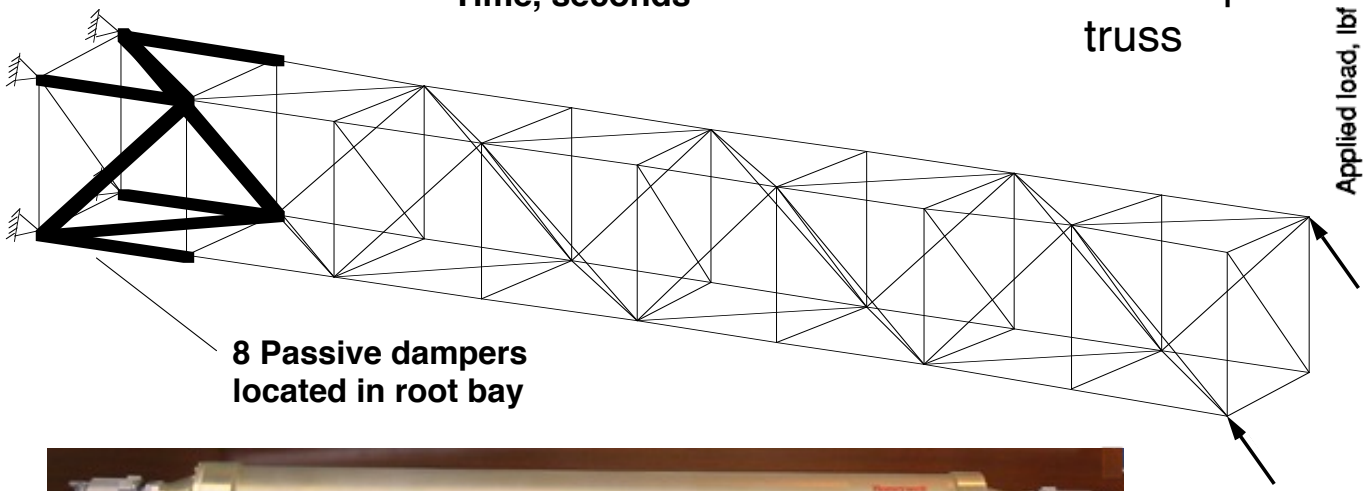


Modal survey

Measured response of undamped truss



Static response

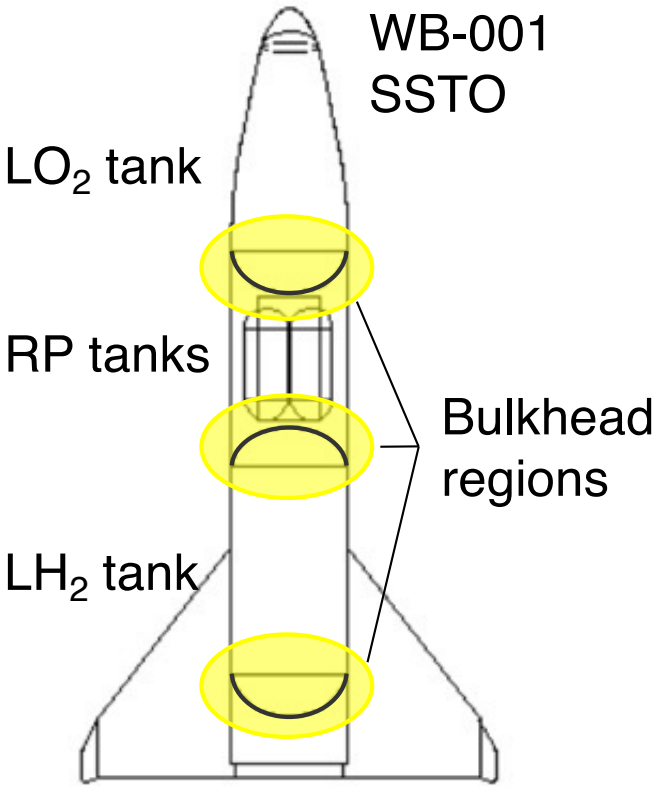


Impulse loads applied at beam tip in simulation.



Honeywell D-Strut passive dampers

Propellant Tank Bulkhead Shape Optimization



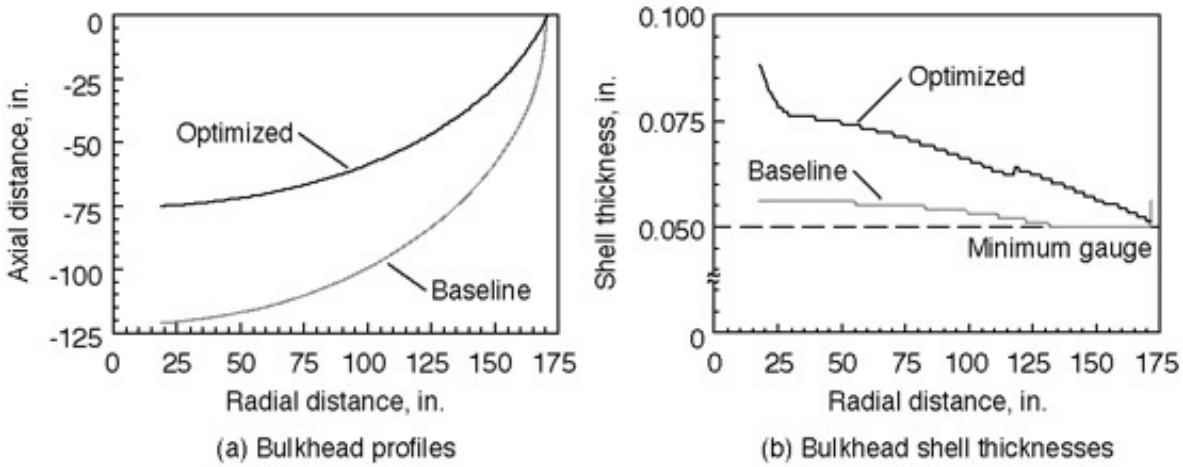
Assess vehicle weight reduction resulting from tank bulkhead shape variation.

1 lb structure ~ 4 lbs vehicle dry mass, 40 lbs wet mass

Baseline vehicle with ellipsoidal bulkheads
- Vehicle dry weight = 200,679 lbs
- Vehicle length = 185.8 ft

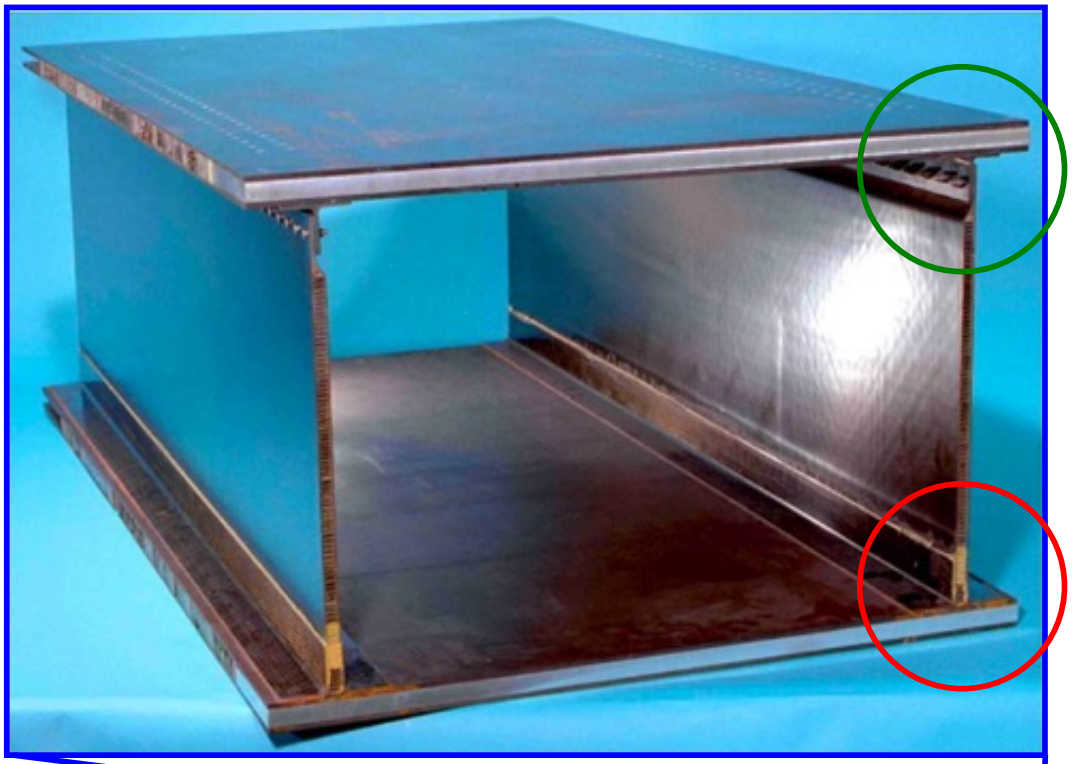
Design from structural-level optimization
- BH region weight reduction = 1083 lbs
- Vehicle weight reduction = 4365 lbs
- Vehicle length reduction = 1.4 ft

Design from vehicle-level optimization
- BH region weight reduction = 1234 lbs
- Vehicle weight reduction = 5129 lbs
- Vehicle length reduction = 1.8 ft



Baseline and optimized designs for aft LH2 bulkheads (vehicle-level analysis)

HSR Gr/BMI Sandwich Wing Box Analysis

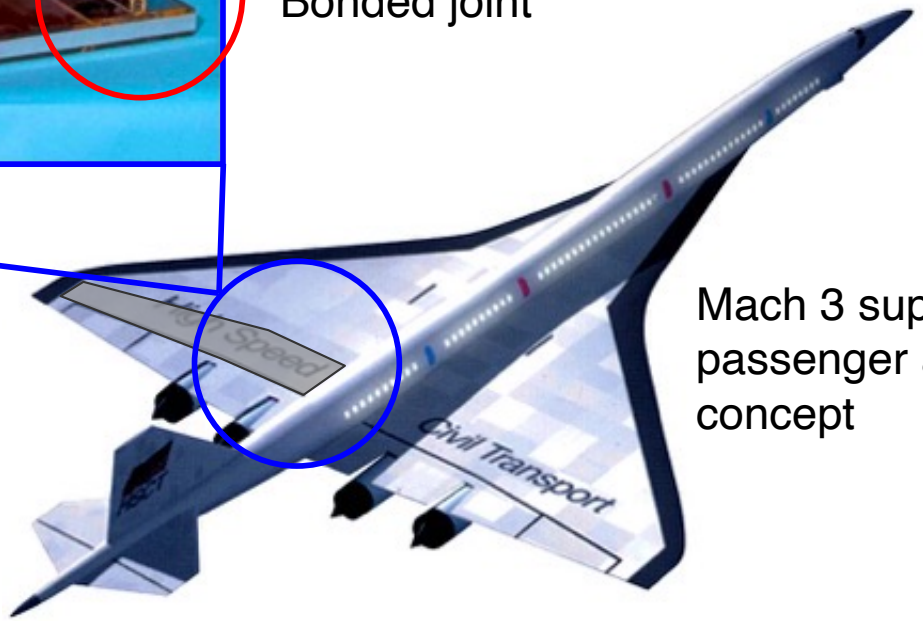


Bolted joint

Wing skins and shear webs are IM7/5260 graphite/toughened BMI composite face sheets (12 to 28 plies) over Ti-honeycomb cores (0.5 to 1.0 in. thickness).

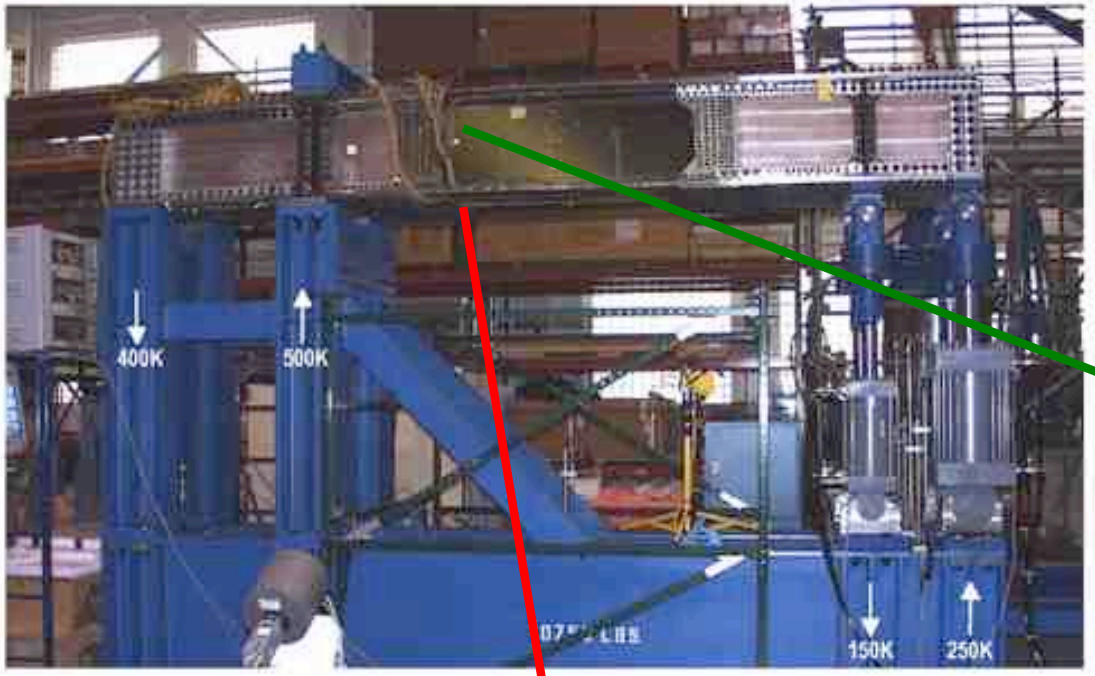
Bonded joint

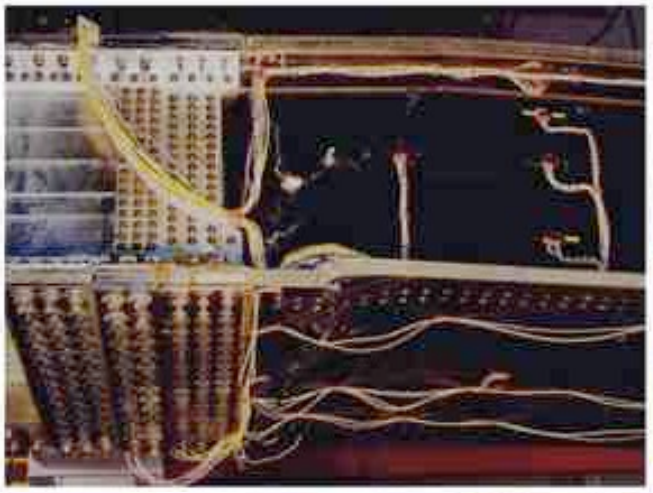
64 in.-long wing box built by Northrop Grumman and tested at NASA LaRC. Skin running loads from 3.75g subsonic pull-up case range from 10 to 20 klb/in., with uniform 2.5 klb/in. shear in webs.



Mach 3 supersonic passenger aircraft concept

Wing Box Tested To Failure In 4-Point Bending

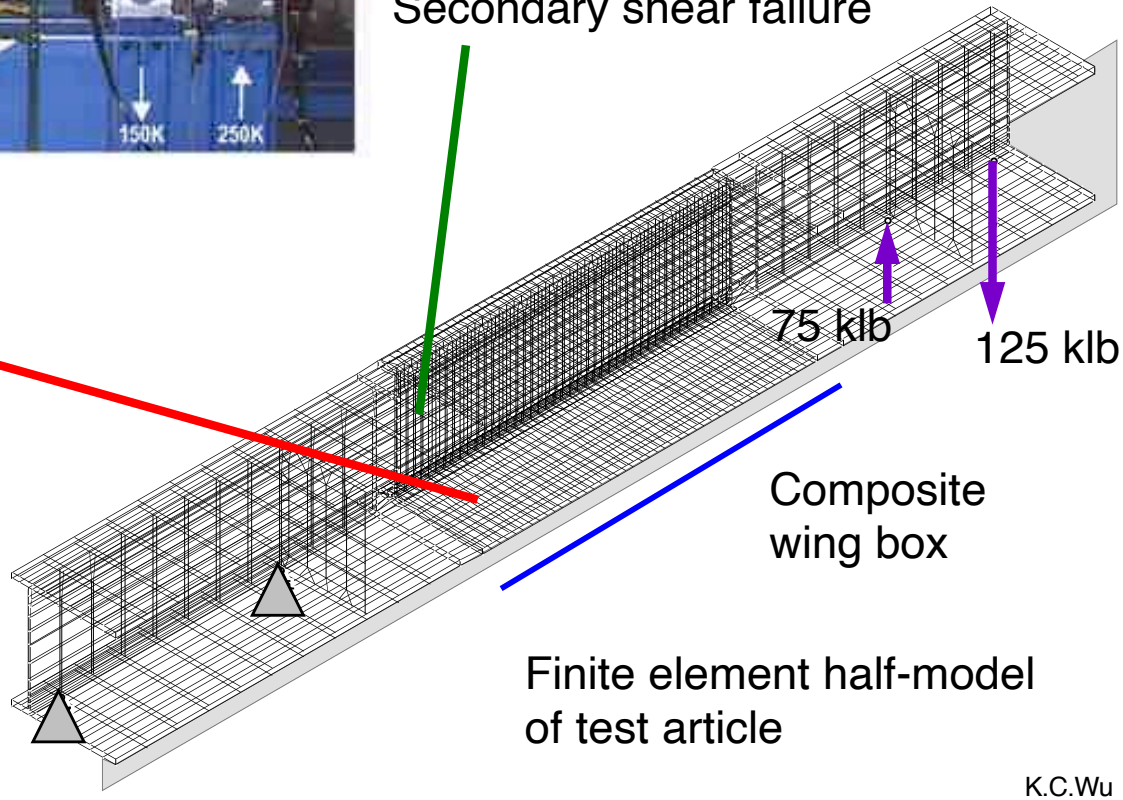




Secondary shear failure



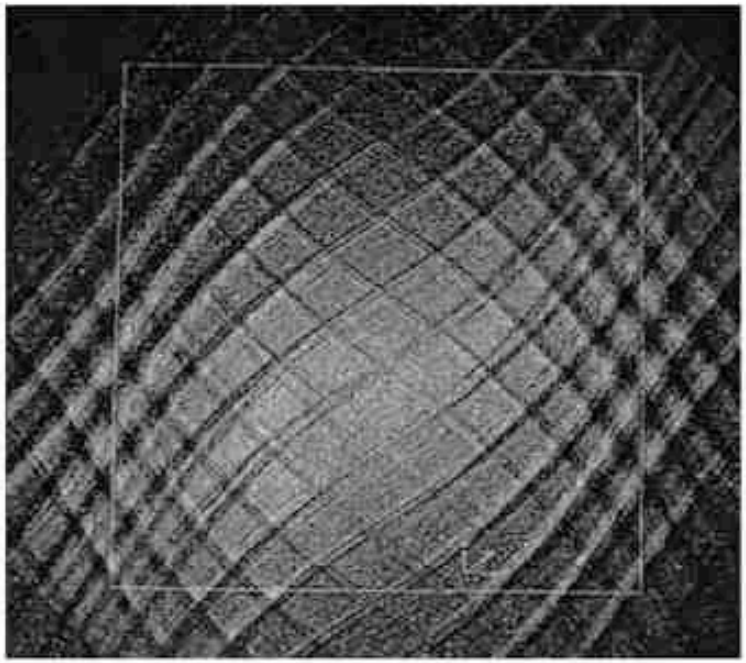
Primary compression failure



Composite wing box

Finite element half-model of test article

Tow-Steered Composite Panels (PhD Thesis)





Panel with overlaps

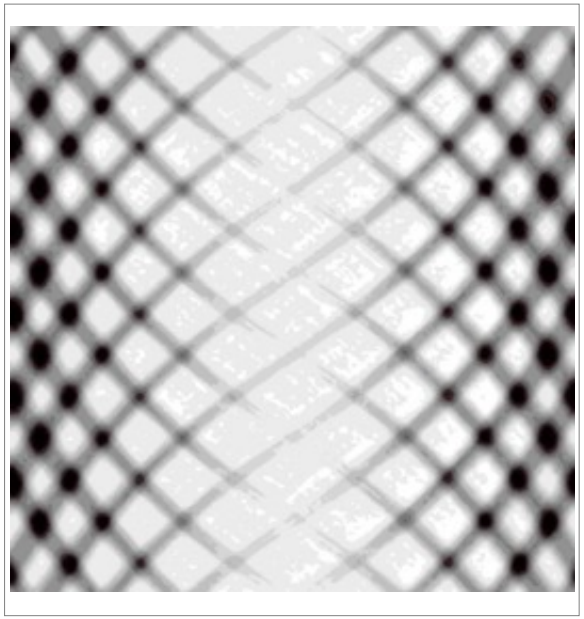
All 24 tows placed during each pass of the FPS for 100% tow overlaps.

Panel without overlaps

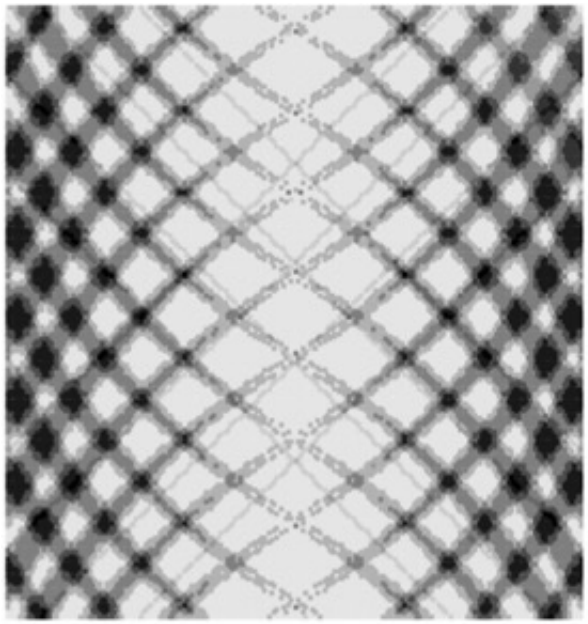
Cut/restart capability of FPS used to eliminate tow overlaps during fabrication.

- Both $[\pm 45/(\pm \Theta)_4]_s$ layups, with 16 variable stiffness plies.
- Conventional $[\pm 45]_{5s}$ panel also fabricated as a baseline.
- 0.00765 in.-thick AS4/977-3 graphite-epoxy prepreg tows.

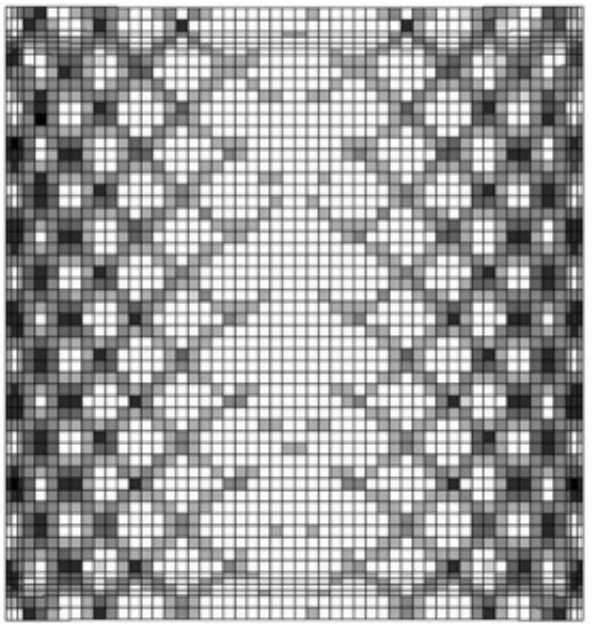
Panel With Overlaps Laminate Thicknesses



Measured



Predicted

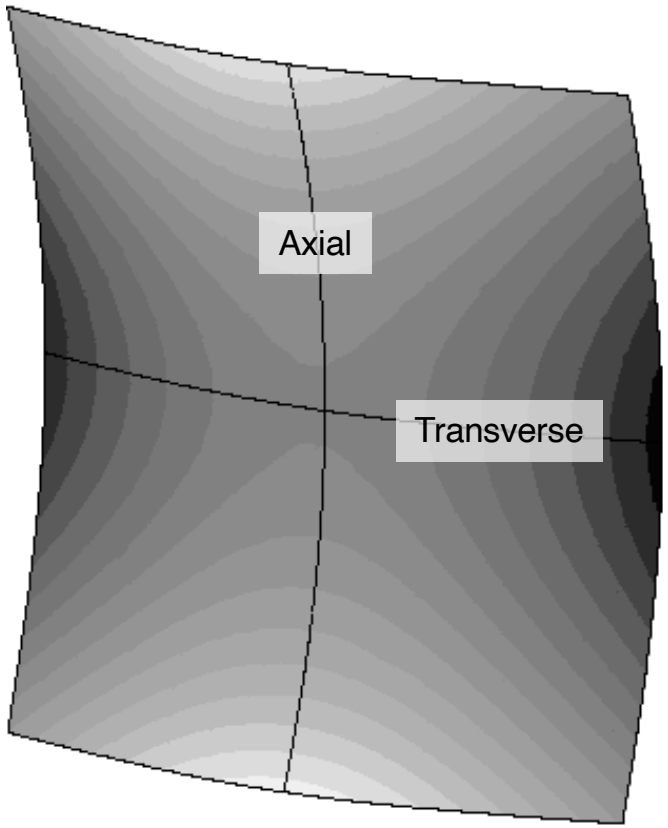


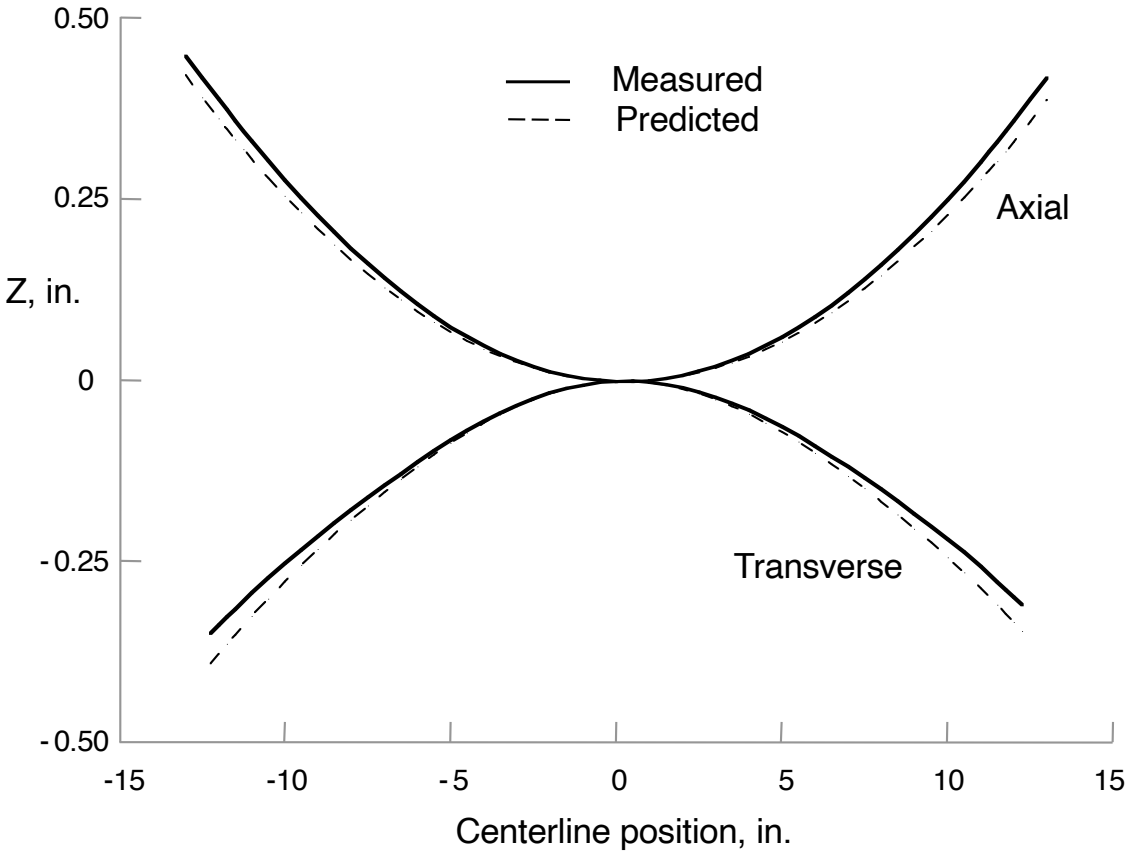
Discretized FEM

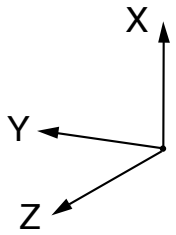
- Measured panel thickness determined from surface surveys of cured panel using high-precision CMM.
- Predicted and discretized panel thicknesses computed using ACRAPLACE data from panel manufacturer.
- Each finite element has a uniform laminate thickness (integer number of plies) with a unique layup.

Measured And Predicted Cured Imperfections

Panel with overlaps tool surface measured at RT. Max. Z = 0.450 in., min. Z = −0.347 in.







Predicted shape from geom. nonlinear FE analysis, ΔT = −280 deg. F to RT. Max. Z = 0.422 in., min. Z = −0.389 in.

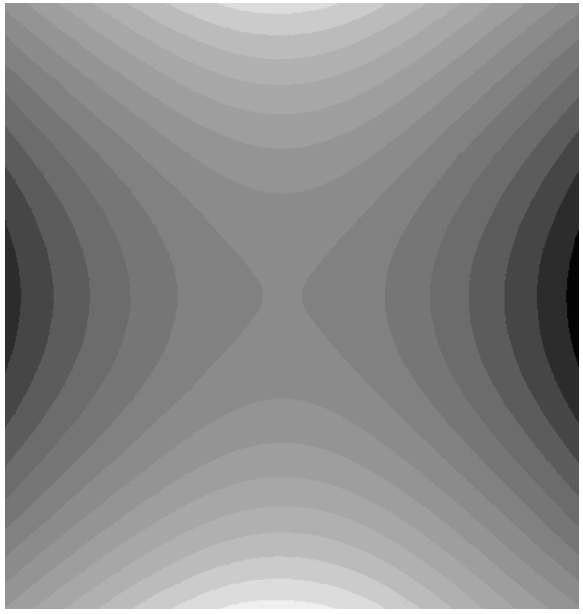
Test Fixtures Reduce Manufacturing Imperfections

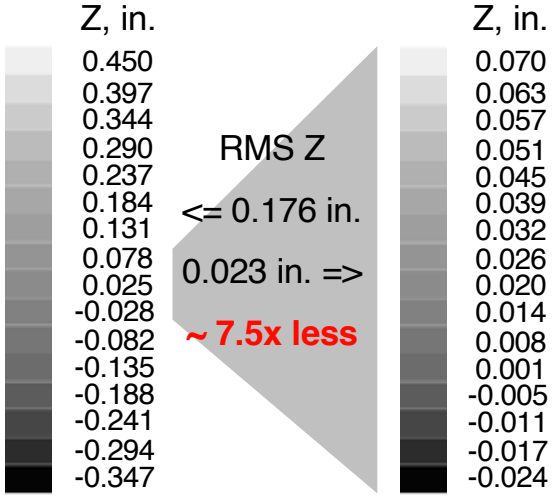
Panel with overlaps and attached test fixtures

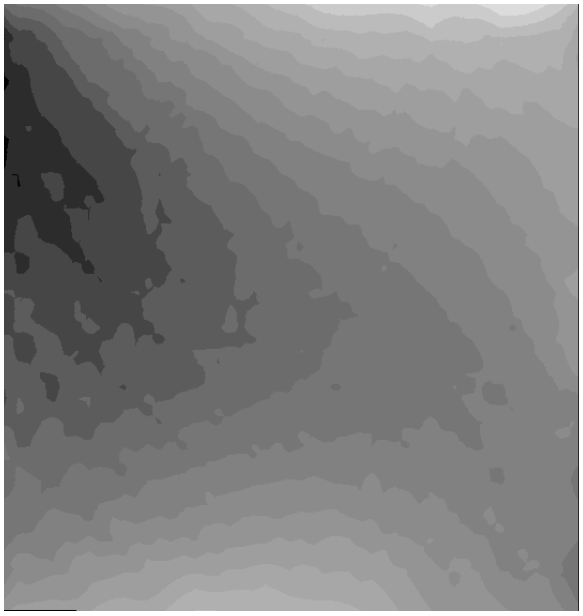


Much smaller imperfections for panel with test fixtures installed.

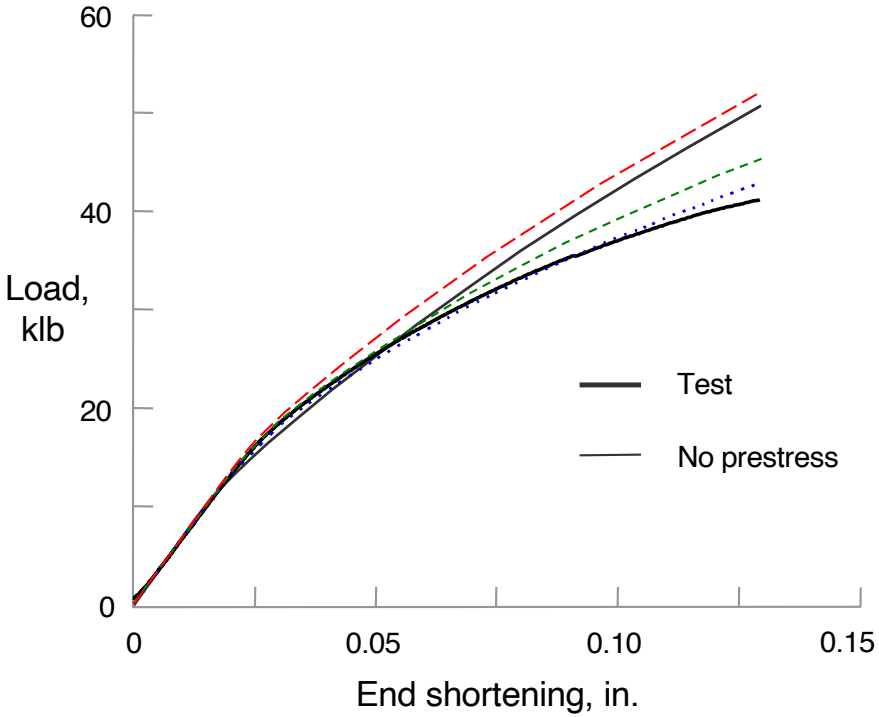
Very large geometric imperfections for cured, unfixtured panel.



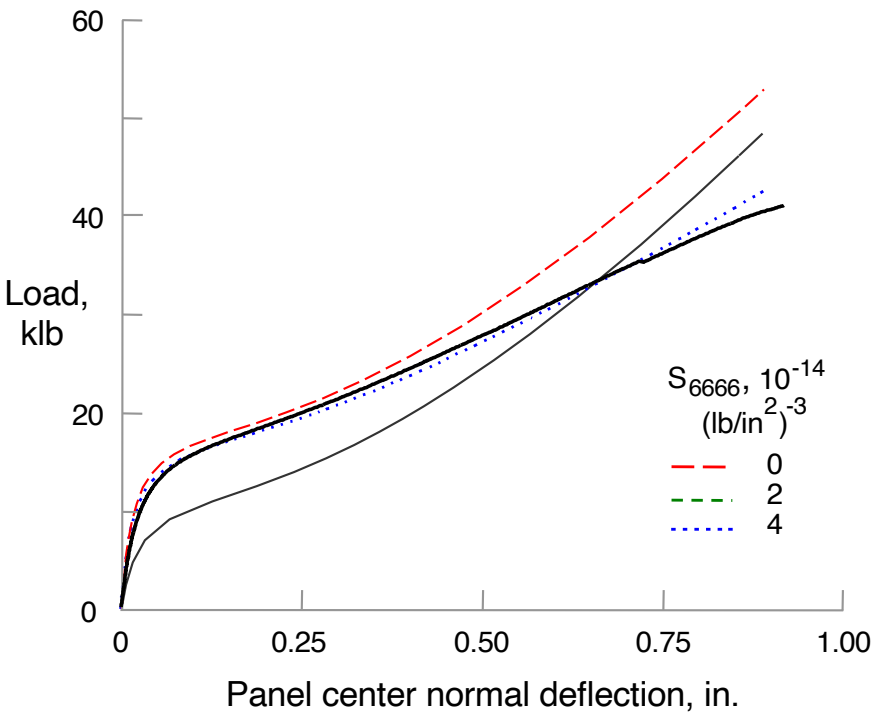




Measured And Predicted Displacements



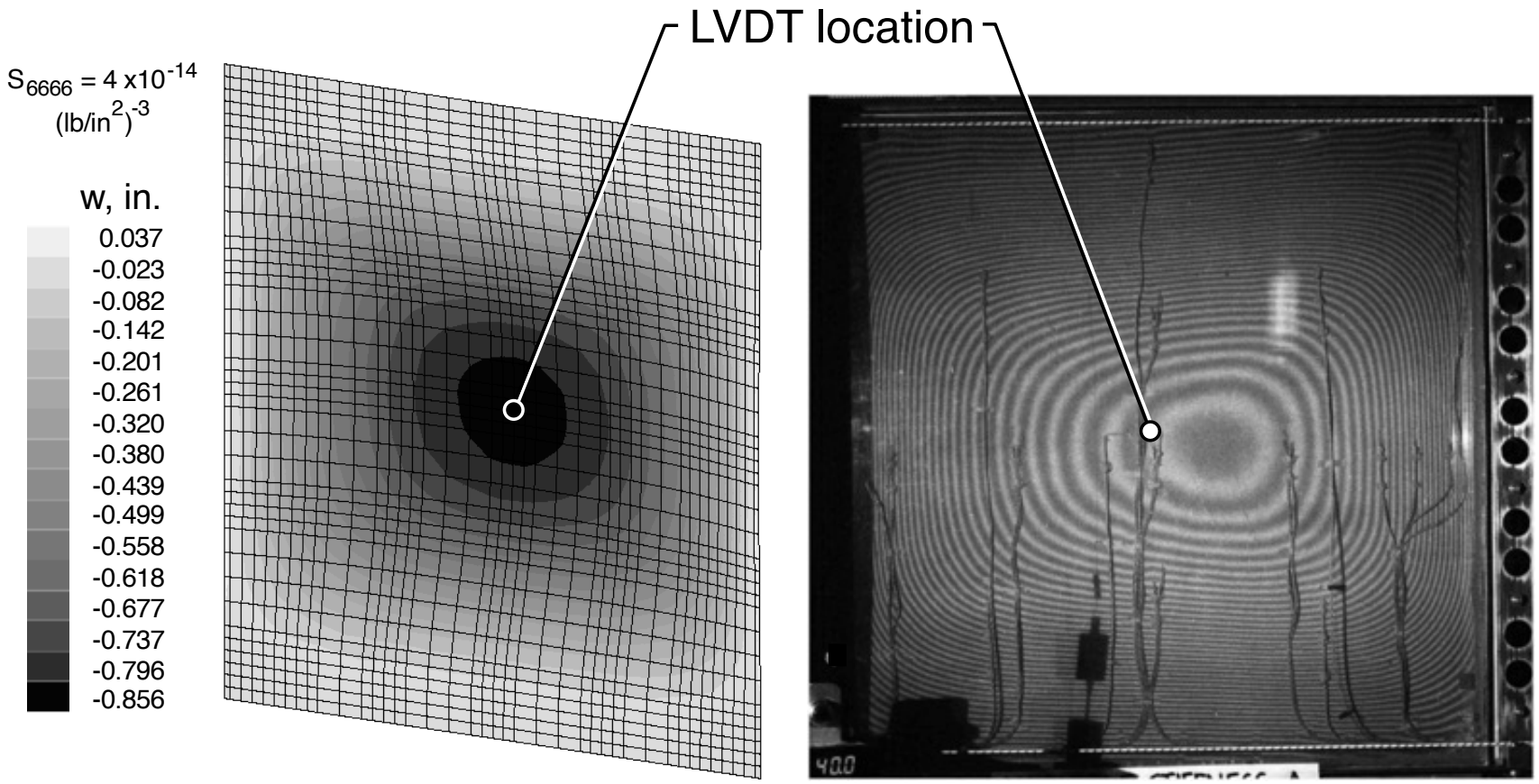
Load vs. end shortening



Load vs. normal deflection

- Analyses with geometric and material nonlinearities including mechanical prestresses from edge straightening.
- Very good prebuckling correlation between analyses and test.
- Best postbuckling correlation for $S_{6666} = 4 \times 10^{-14} (lb/in^2)^{-3}$ up to global failure at 0.130 in. applied end shortening.

Measured And Predicted Normal Deflections

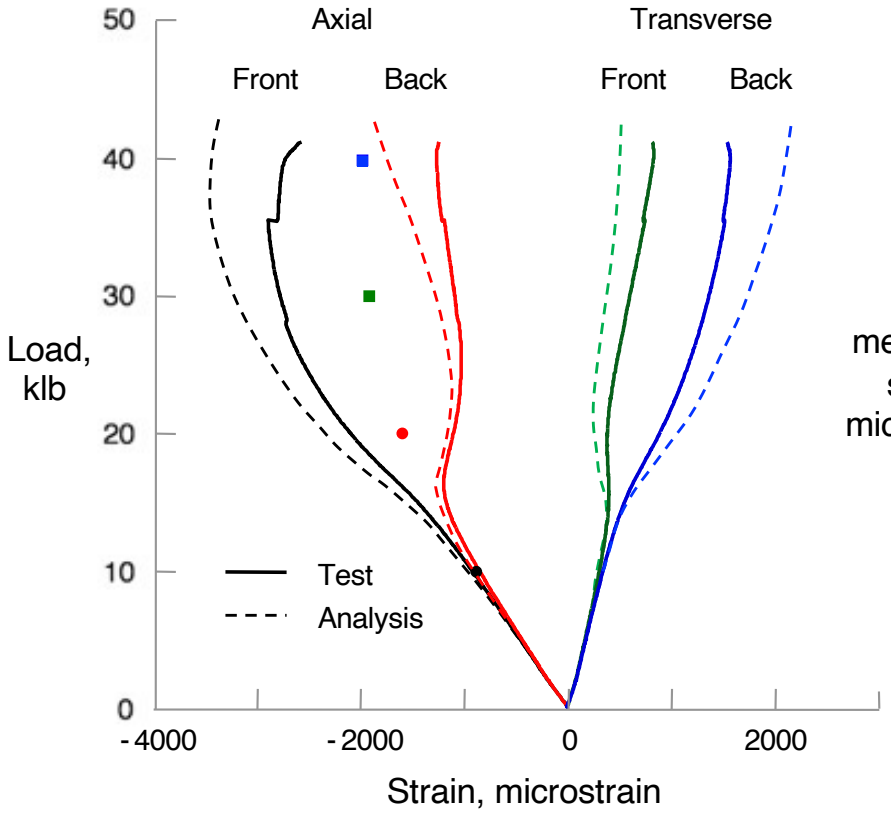


Predicted deflection contours

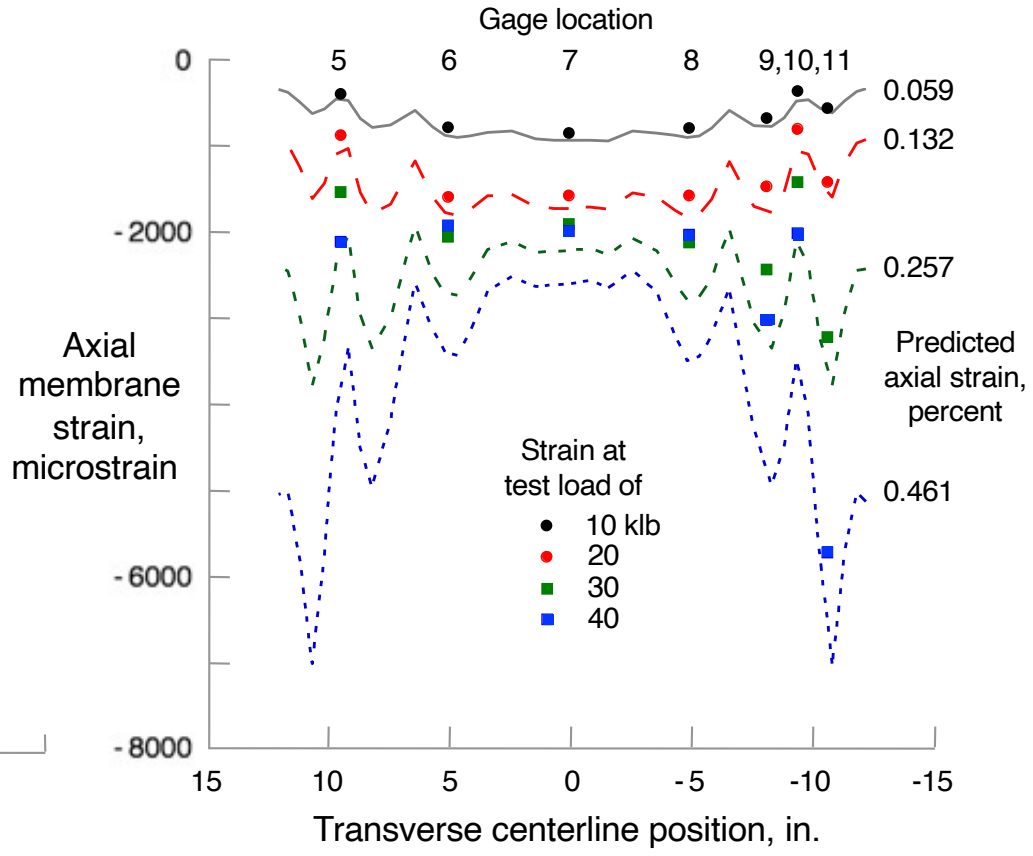
Photo of test shadow moiré

- End shortening = 0.120 in., or 0.461 percent applied strain.
- Compressive load = 41.1 klb analysis, 40.0 klb test.
- Panel center deflection = – 0.856 in. analysis, – 0.869 in. test.

Measured And Predicted Strains



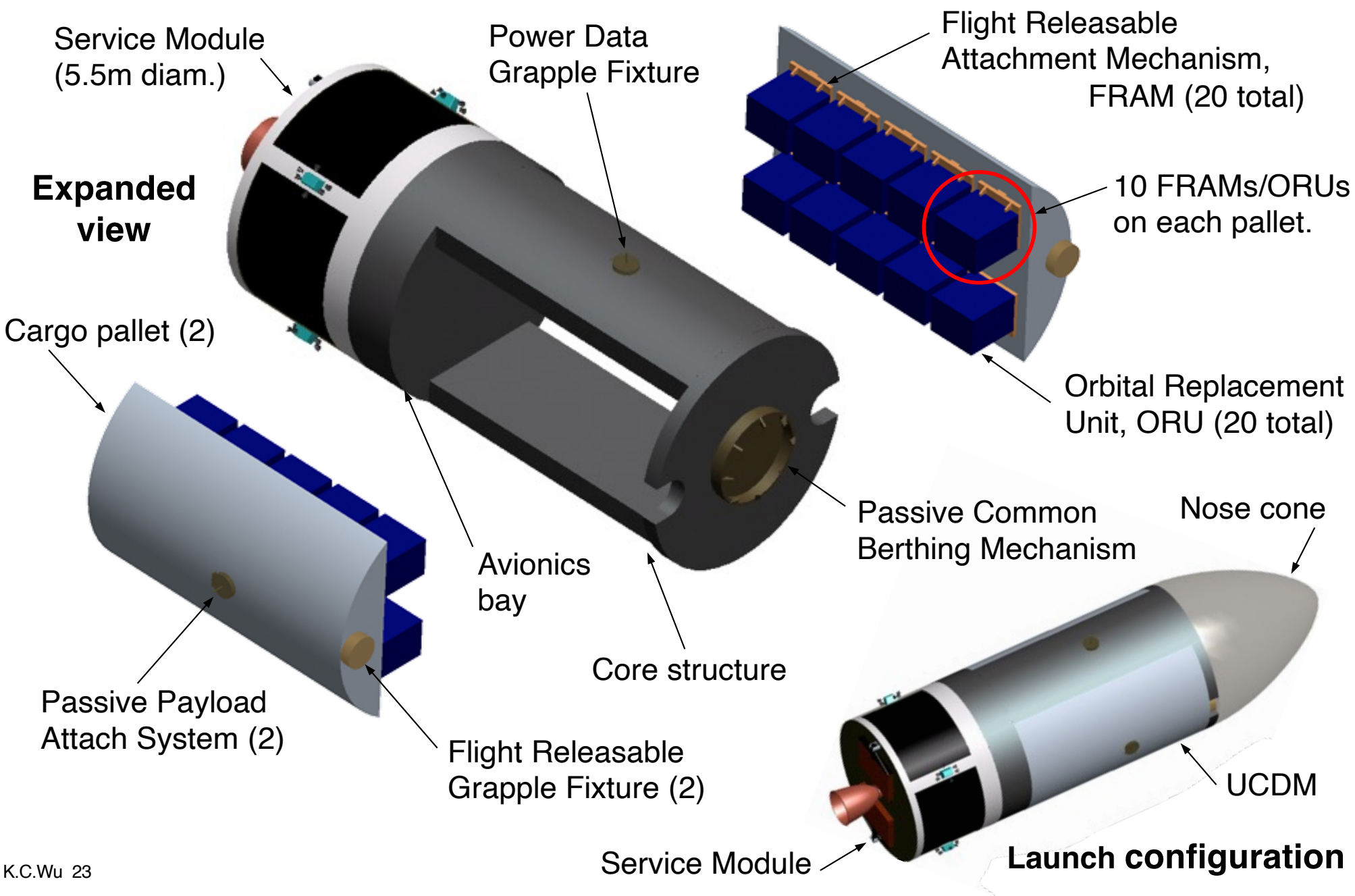
Load vs. panel center strain



Membrane strain vs. position

- Analysis results shown for $S_{6666} = 4 \times 10^{-14} (lb/in^2)^{-3}$.
- Fair to very good correlation between analysis and test.
- Large variations in membrane strain across tow overlaps.

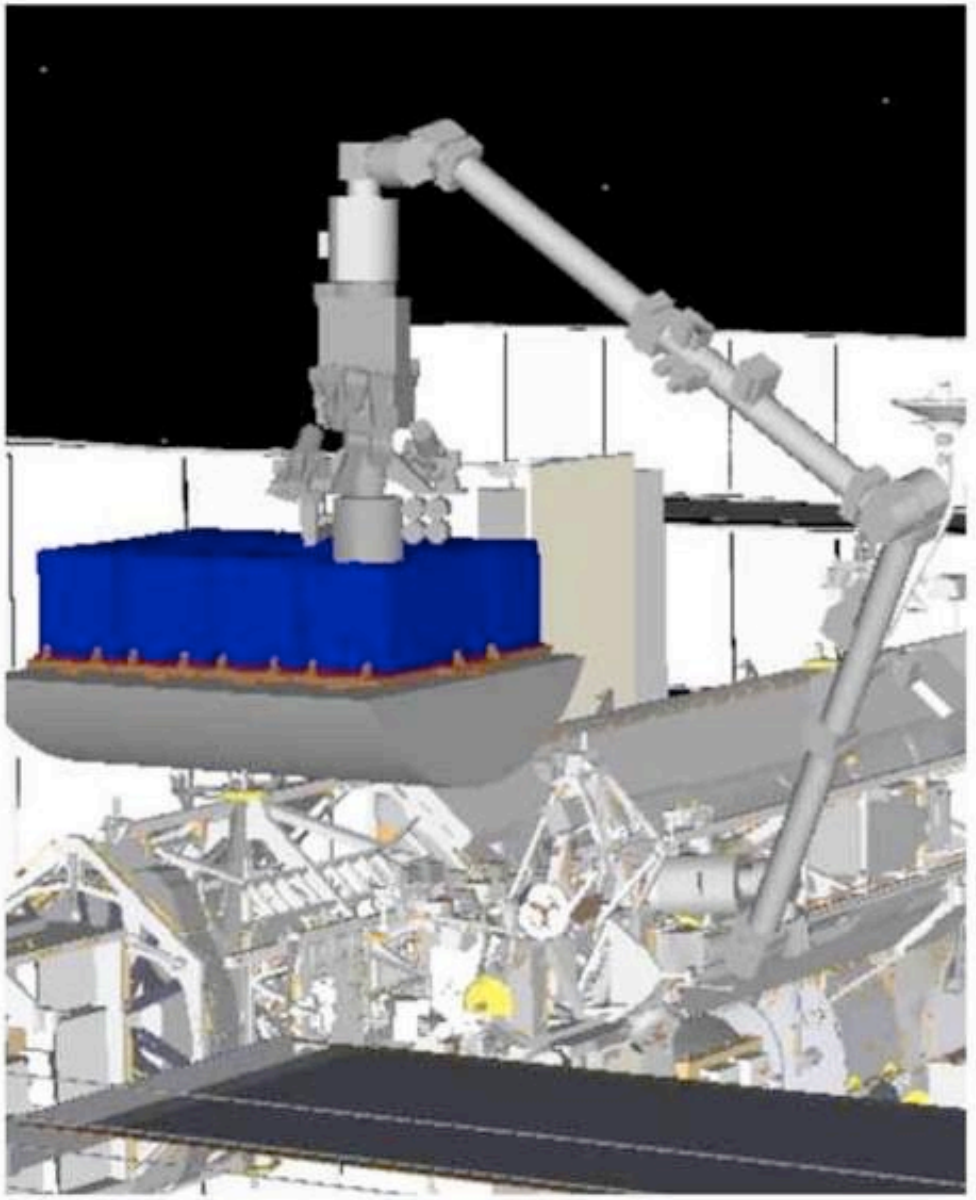
Cargo Delivery Vehicle For ISS Resupply



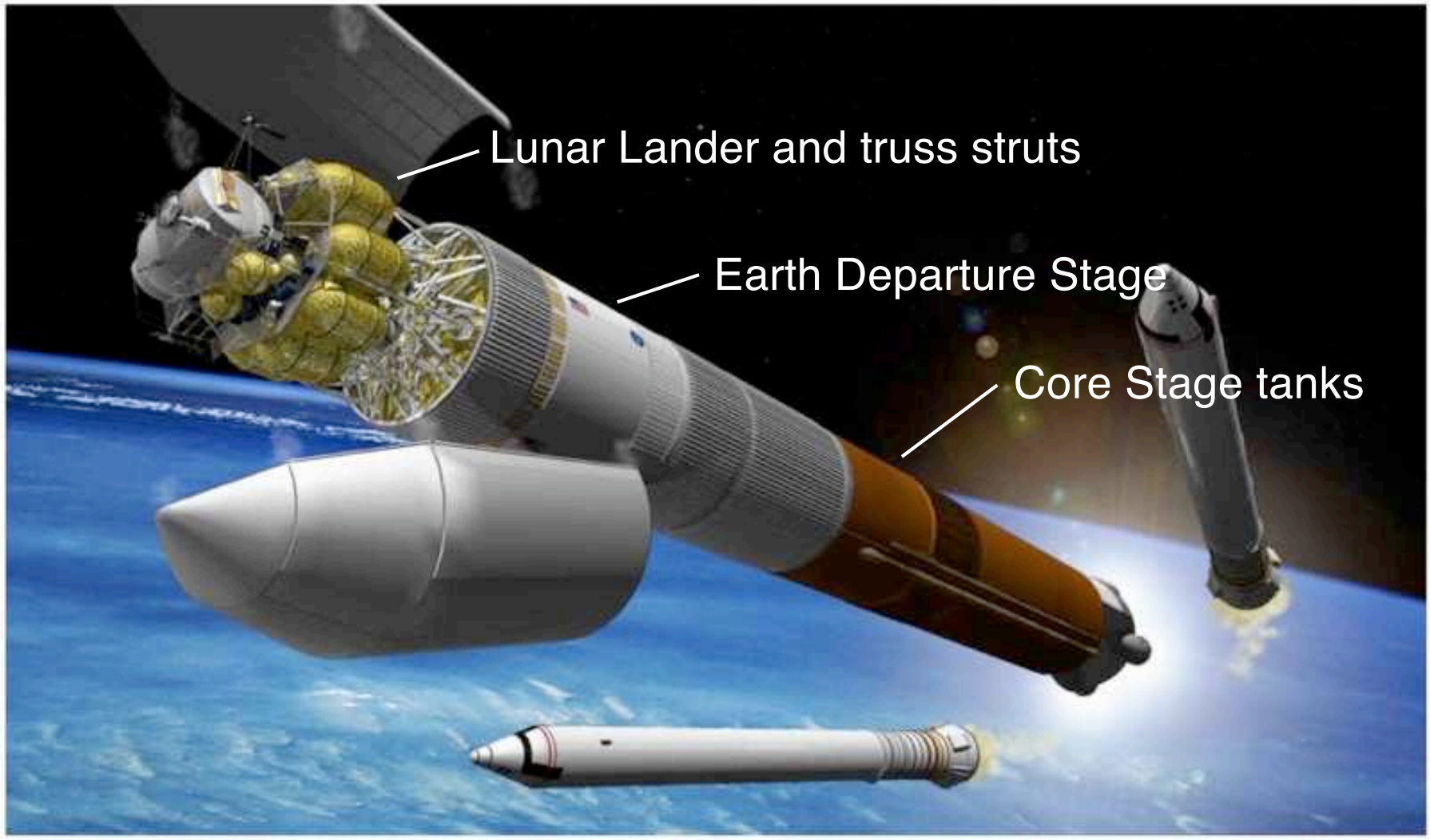
UCDV Launch On CLV



EVR Operations On ISS



Support For NASA's Constellation Program



Ares V heavy-lift launch vehicle with Altair lunar lander payload shown.

Alternate Earth Departure Stage Concepts

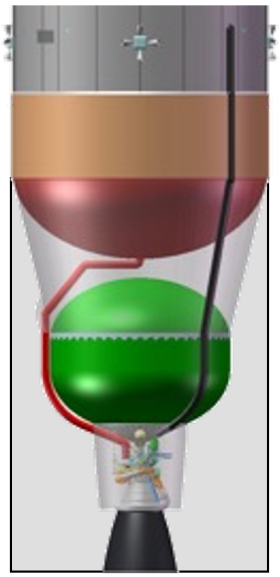
Drop tanks in alternate concepts contain:

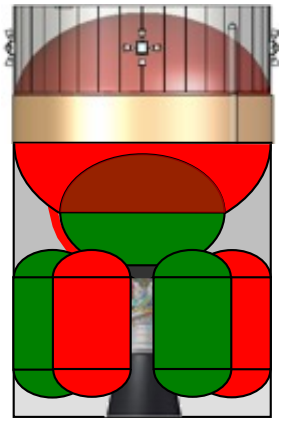
A - all Ascent LO_2 and 1/3 TLI LH_2

B - all Ascent LO_2

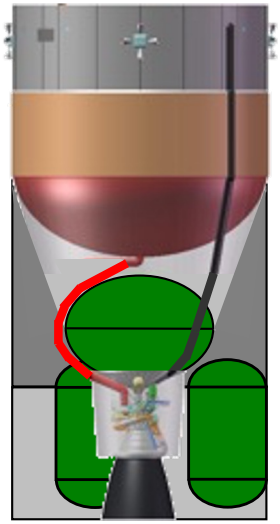
C - all Ascent prop (mod. Ares I US)

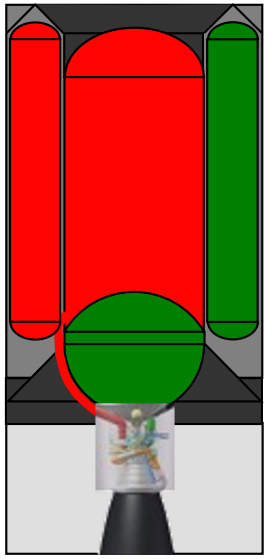
54 M/T to LEO payload req't





(***# drop tanks***)

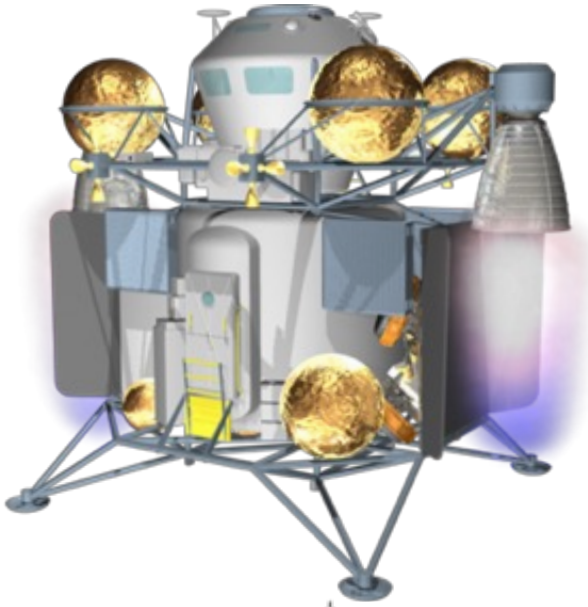


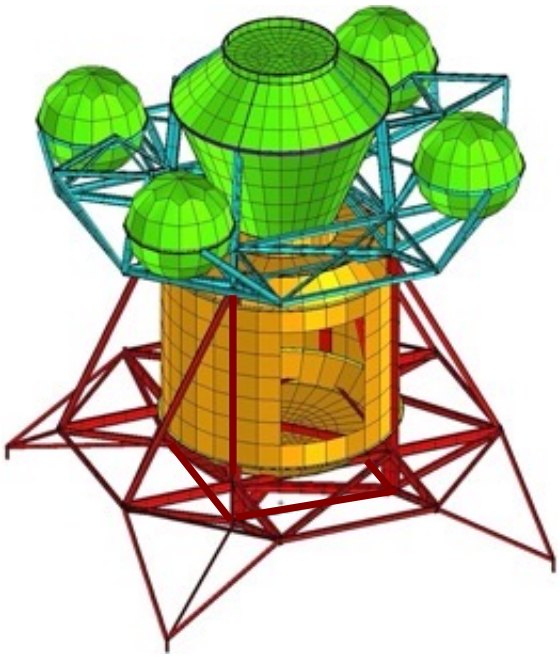


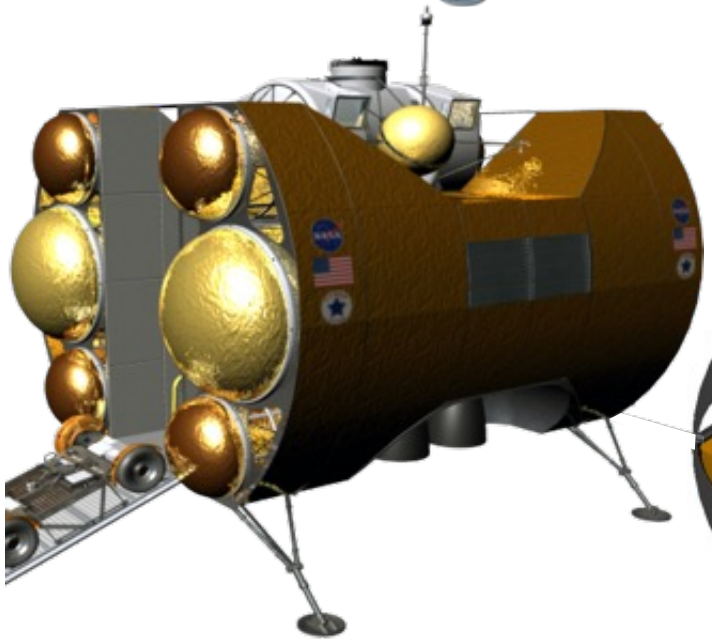
	Baseline	**A** (*3+3*)	**B** (*3*)	**C** (*3+9*)
Overall length, m (ft)	22.2 (72.9)	16.4 (53.9)	20.4 (66.9)	21.6 (70.8)
Total I/S length, m (ft)	15.4 (50.5)	10.7 (35.0)	13.6 (44.6)	19.8 (64.9)
TLI+drop tank I/S dry mass, M/T (klb)	22.6 (49.9)	*TBD*	16.4+9.0 (36.0+19.8)	*TBD*
LEO payload, M/T (klb)	**49.8** (109.7)	*TBD*	**51.2** (112.6)	*TBD*
Δpayload, M/T (klb)	---	*TBD*	+1.3 (+2.9)	*TBD*
Deficit, M/T (klb)	**–4.2** (–9.3)	*TBD*	**–2.9** (–6.4)	*TBD*

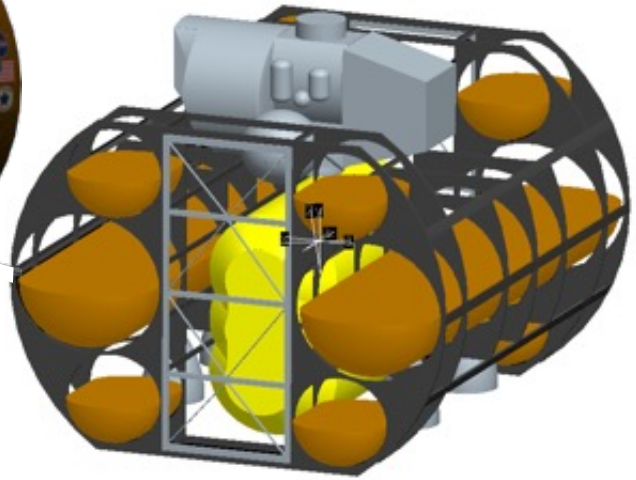
Still doesn't close, but getting better!

Structures For Lunar Lander Concept Vehicles









Developed during CxP/APO LLPS Phase 2 study (2006).

DASH Lander

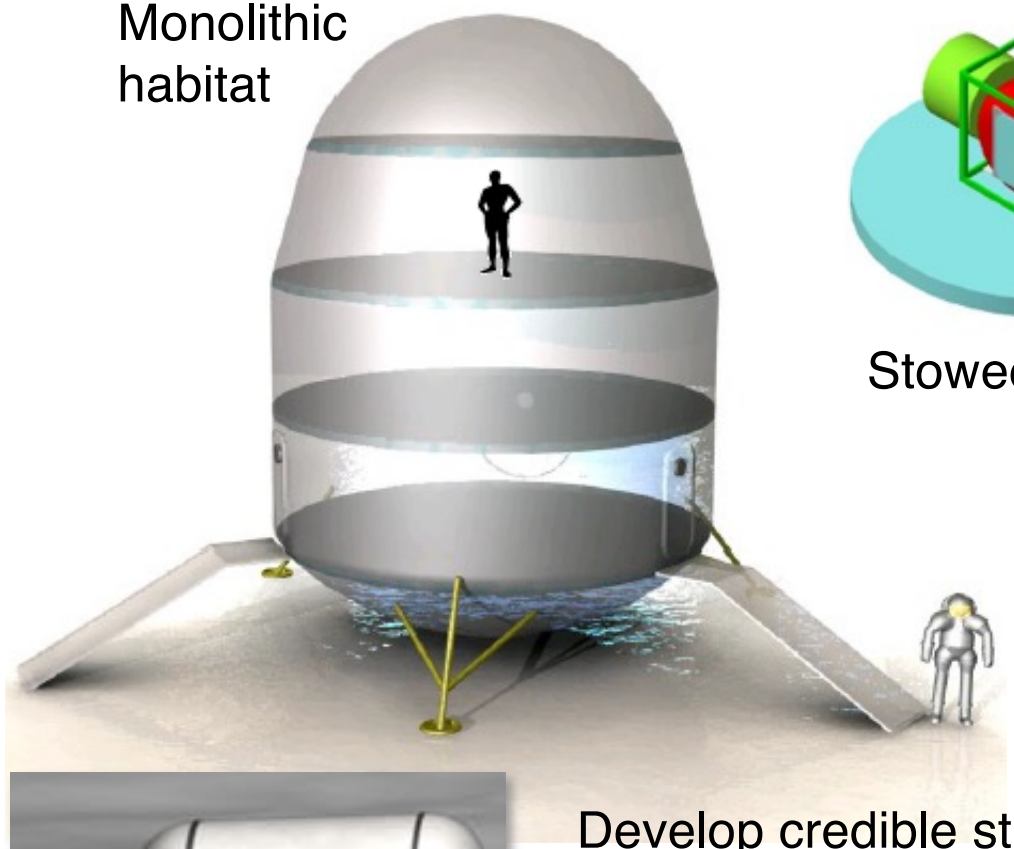
Split ascent, surface stages. Separate LOI/LDI stage. Common truss platforms. Integral landing gear. Truss-mounted engines. Design adaptable for cargo. Inflatable airlock/alcove provided.

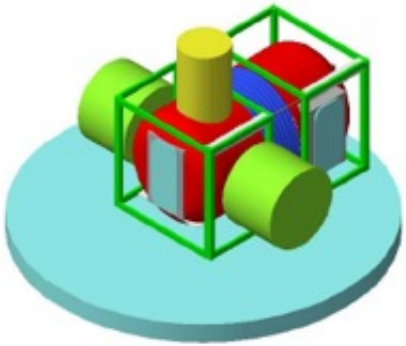
Horizontal Lander

Split ascent, surface stages. Semi-monocoque airframe. Apollo-like landing gear. Large bay in center for easy unloading of cargo modules. Different launch/TLI load axes result in mass penalty.

Lunar Surface Habitat Structures Sizing

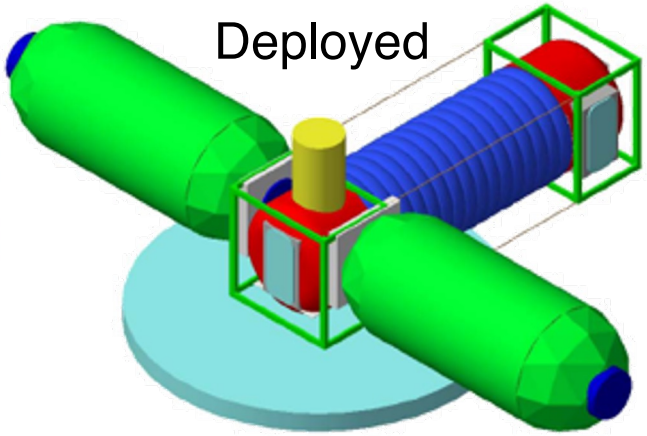
Monolithic habitat





Stowed habitats

Deployed



Inflatable habitat demo



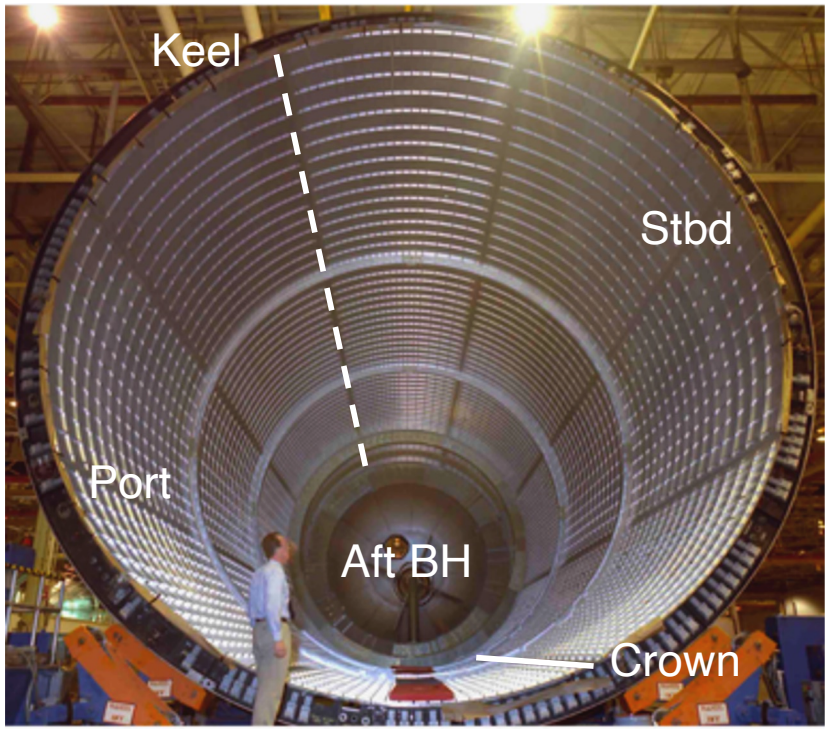


Rover with habitat

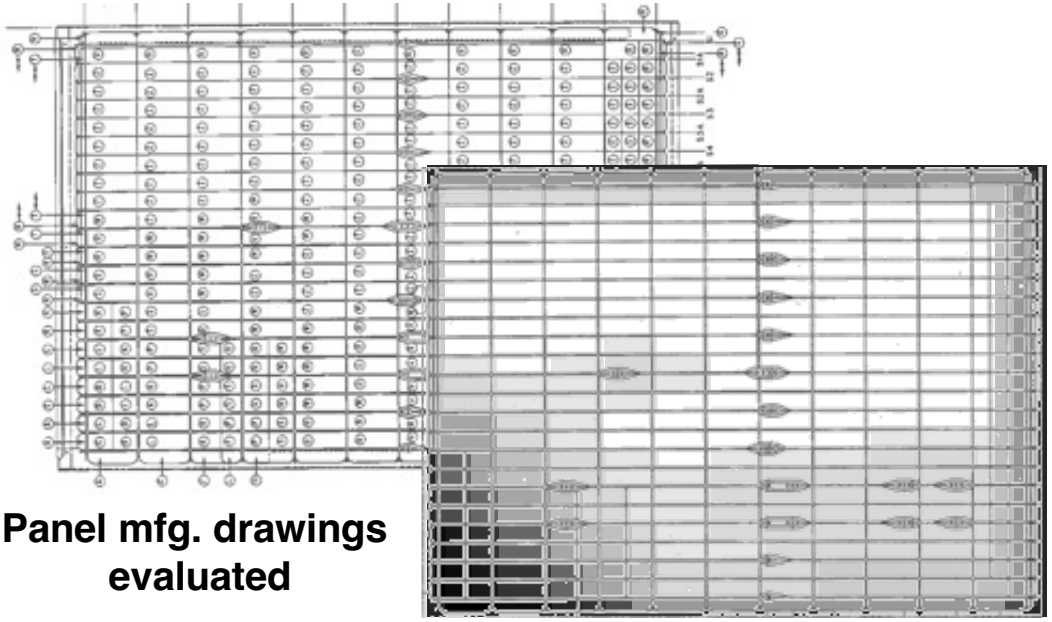
Develop credible structural mass estimates for composite, metallic, and inflatable lunar habitats.

Physics-based (barrel $t = p*R/\sigma$), hybrid analytical-empirical (inflatables), or empirical (fittings, hatches and windows) sizing.

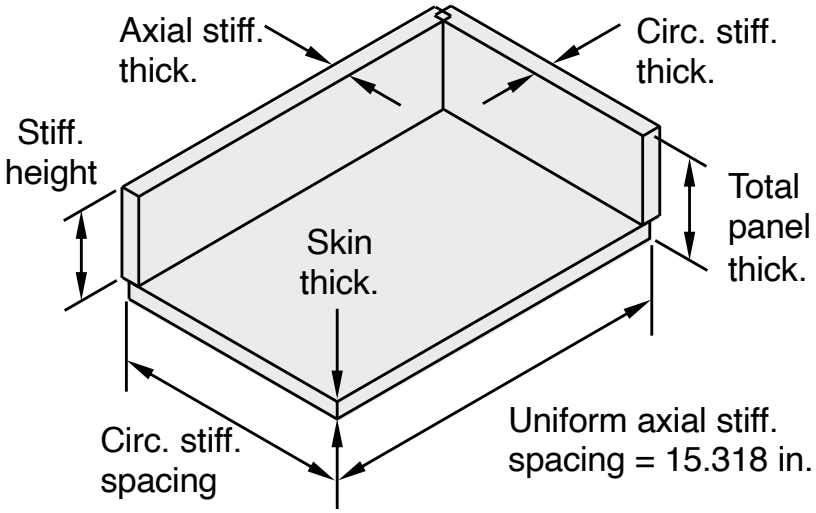
Non-Optimum Factors For Launch Vehicle Design



Lockheed Martin



Panel mfg. drawings evaluated

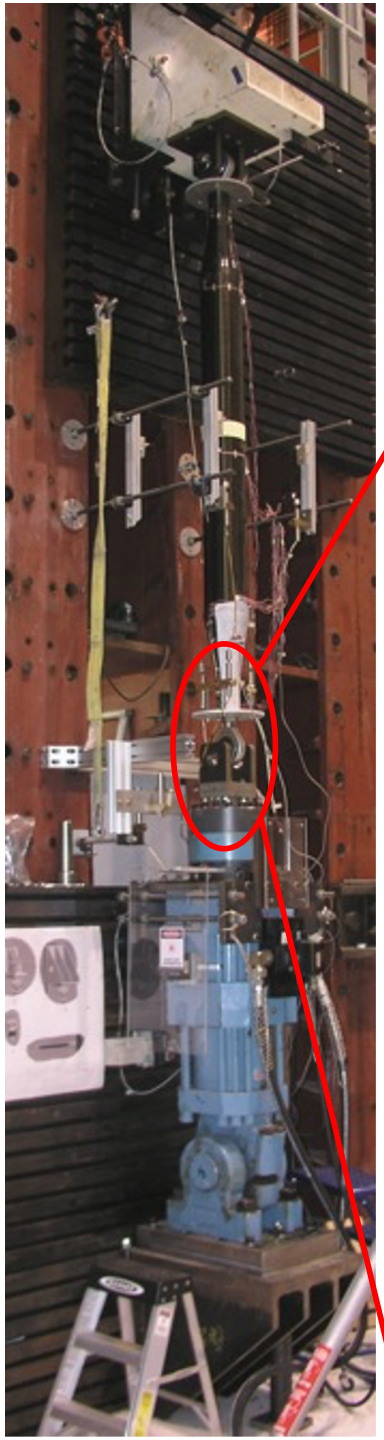


Orthogrid unit cell weights predicted using panel hardware minimum dimensions

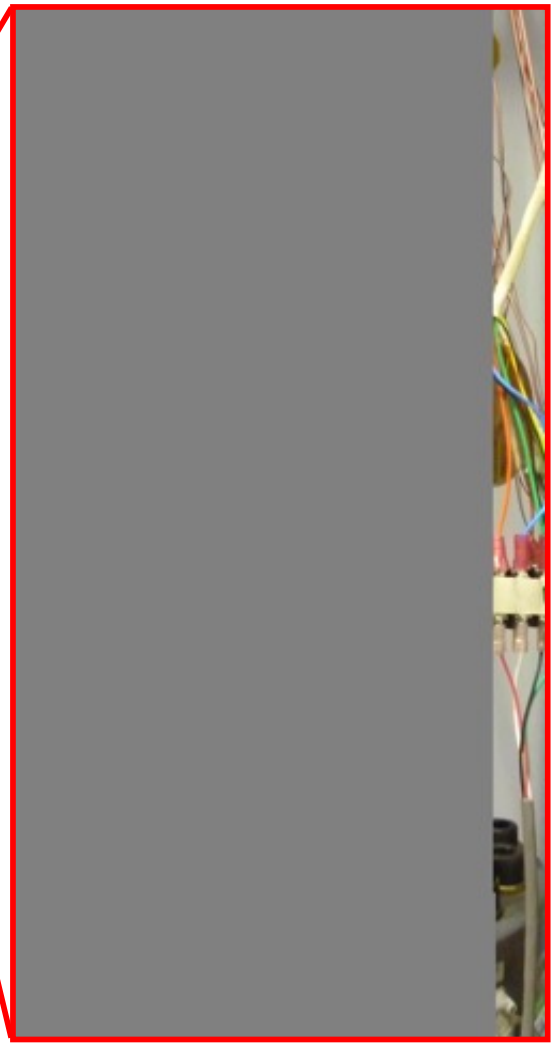
1.10/1.16	1.08/1.14	1.42/1.44	1.48/1.54
1.04/1.04	1.05/1.04	1.48/1.48	1.32/1.33
1.03/1.03	1.02/1.02	1.02/1.02	1.12/1.12
1.03/1.03	1.03/1.03	1.02/1.02	1.09/1.09

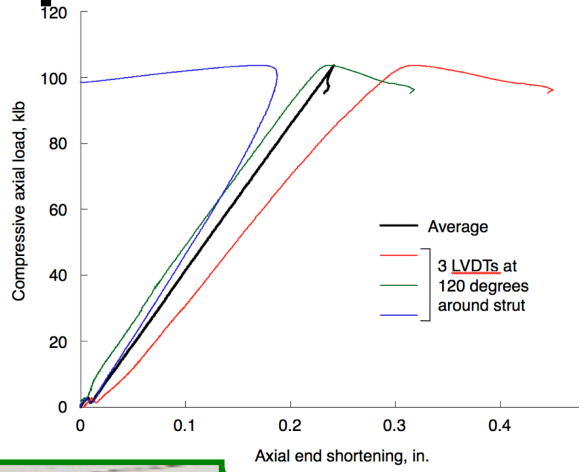
Non-opts = actual / predicted panel weights

Highly Loaded Composite Struts Testing



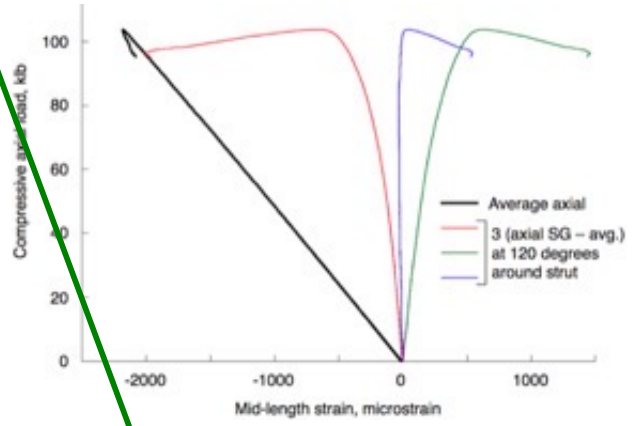
10 struts tested to failure
60 to 127 inches length
2 to 120 klb compression

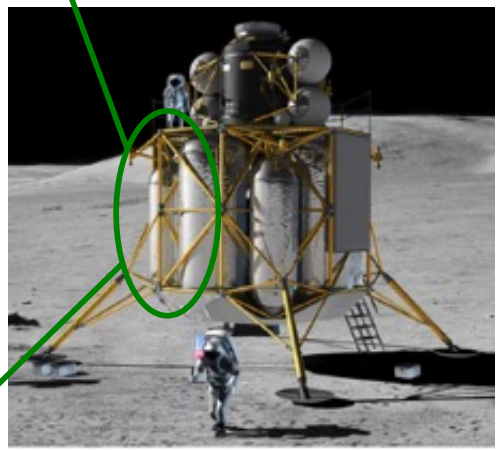




Measured deflections and strains from test

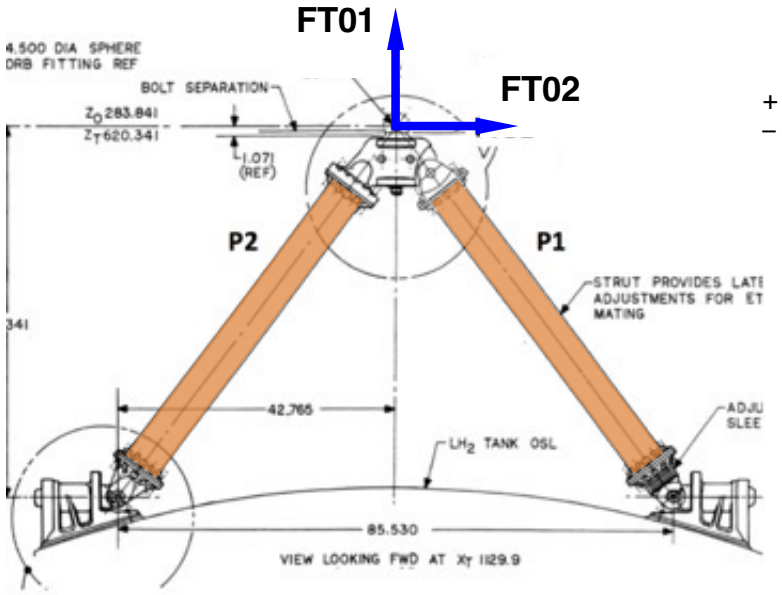




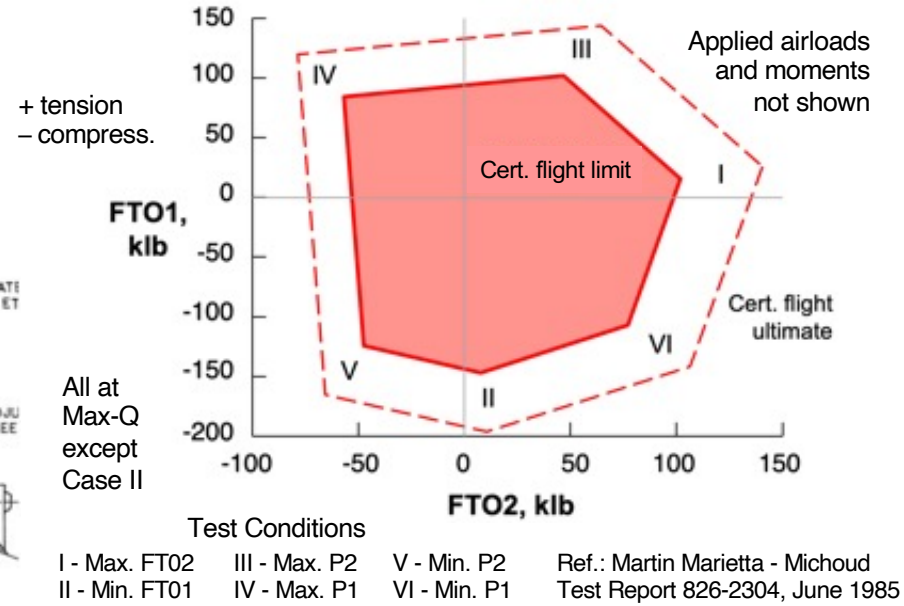


Space Shuttle Forward Bipod Loads Capability





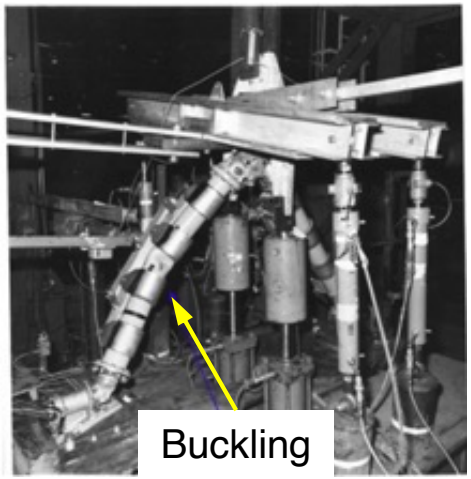
STS – forward bipod location circled in red



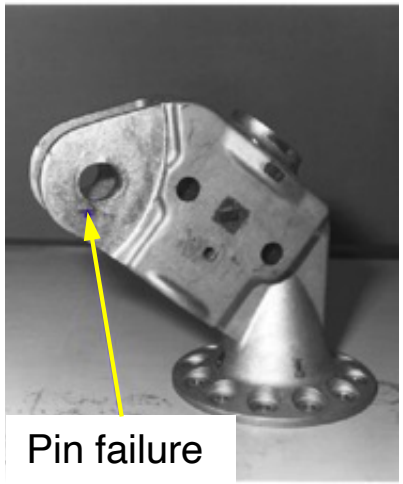
Program-certified loads envelope



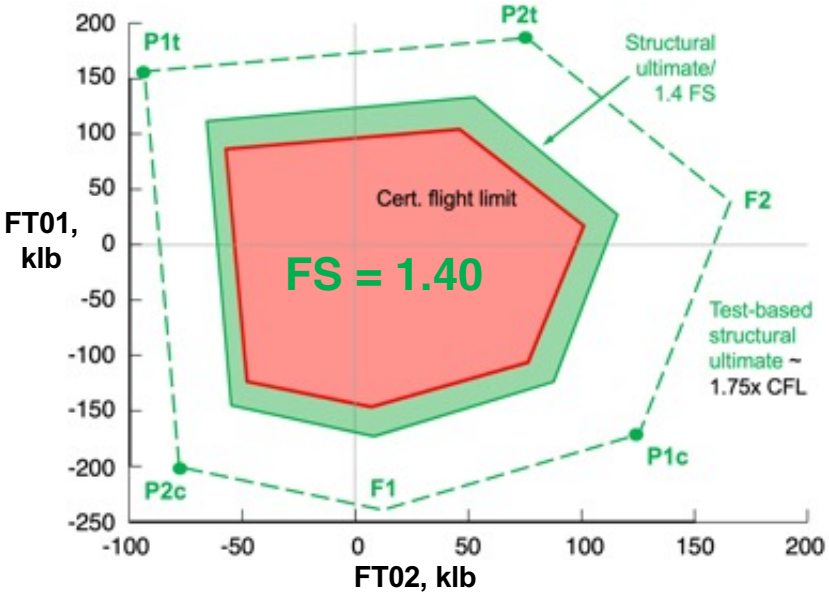
Compression



Tension



Tests performed to determine capabilities

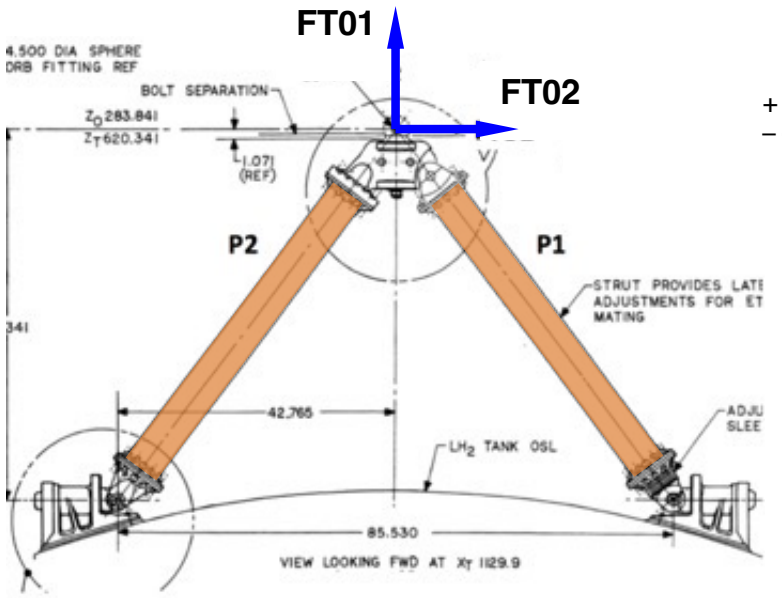


Expanded loads envelope from hardware-based capabilities

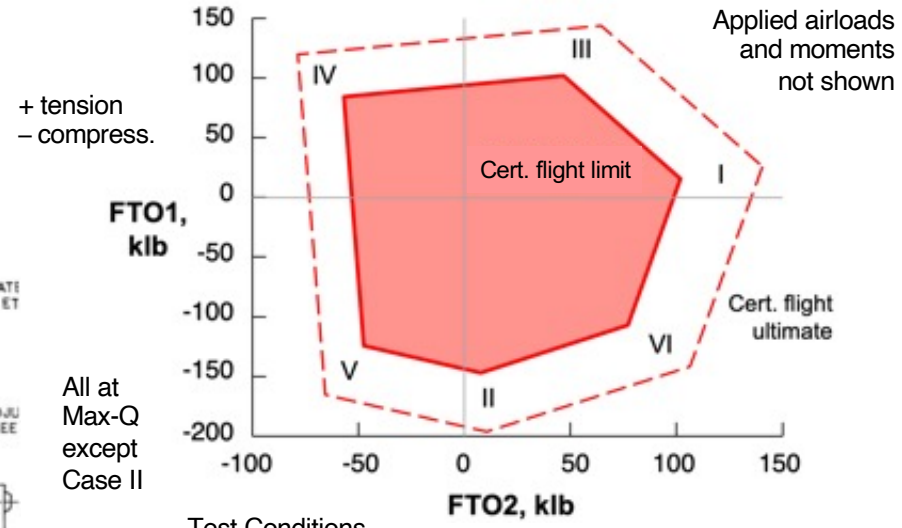
Side-mount SDHLV – higher mass and loads than STS

Additional Capability Available - *IF*…





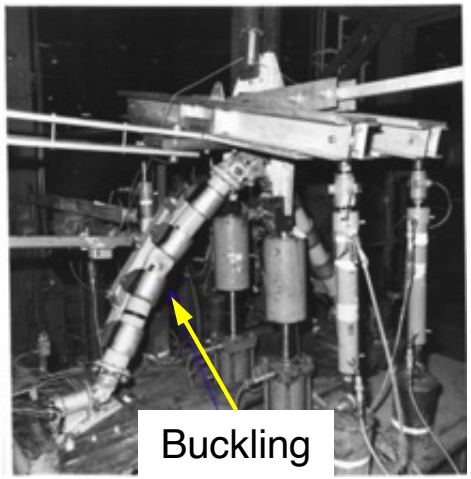
STS – forward bipod location circled in red



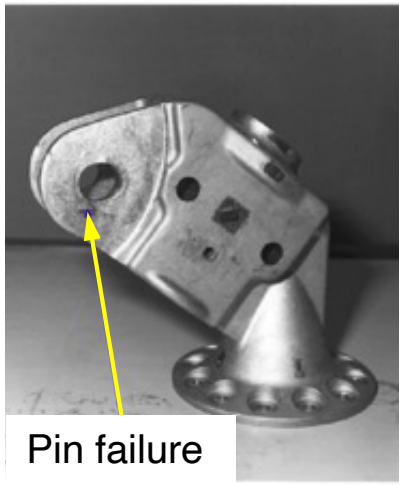
Program-certified loads envelope



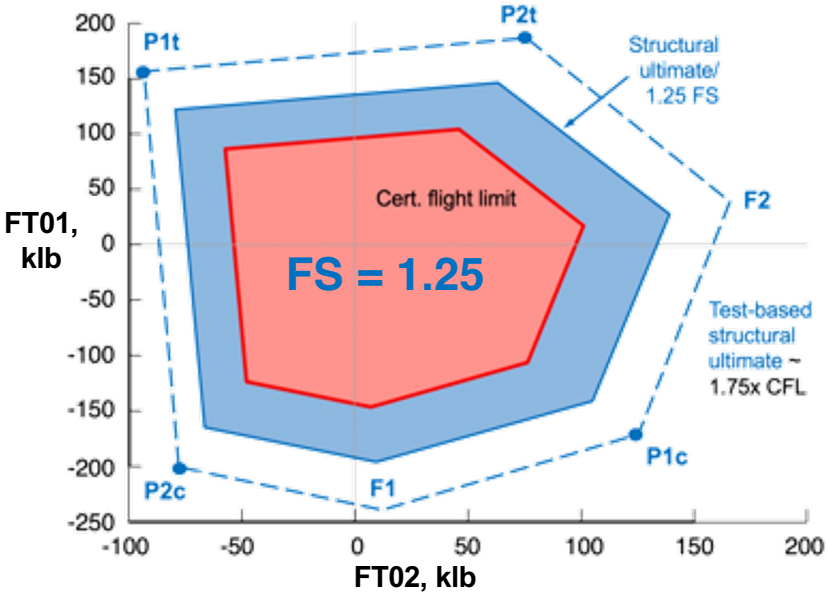
Compression



Tension



Tests performed to determine capabilities



Additional capability using reduced safety factor

Side-mount SDHLV – higher mass and loads than STS

NASA Kennedy Space Center - April 2010



Space Shuttle *Atlantis* - STS-132

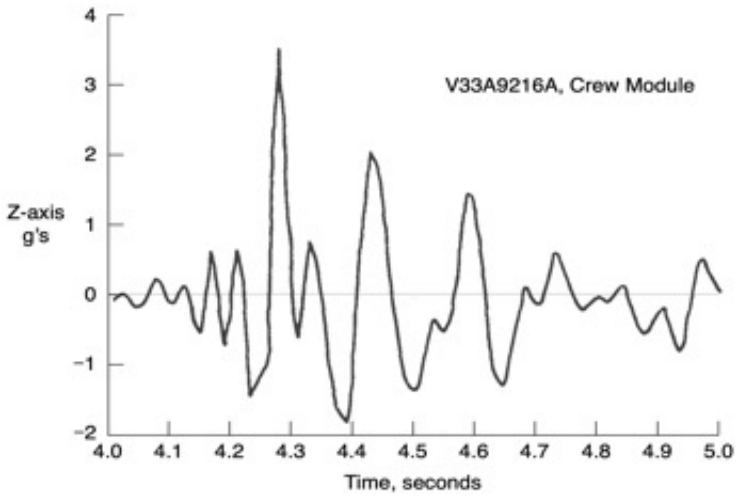




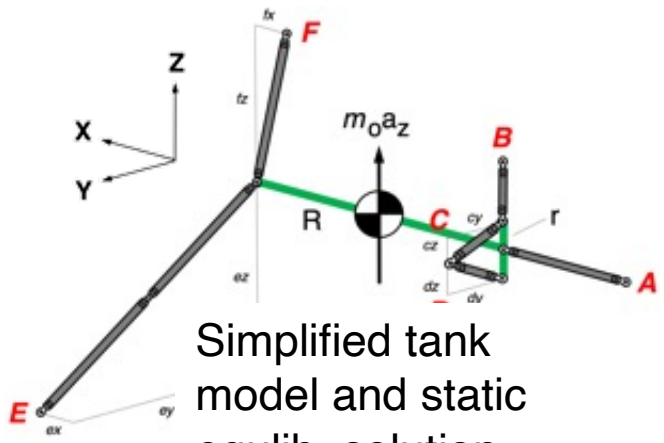
STS-1 Fwd RCS Strut Failure Analyses



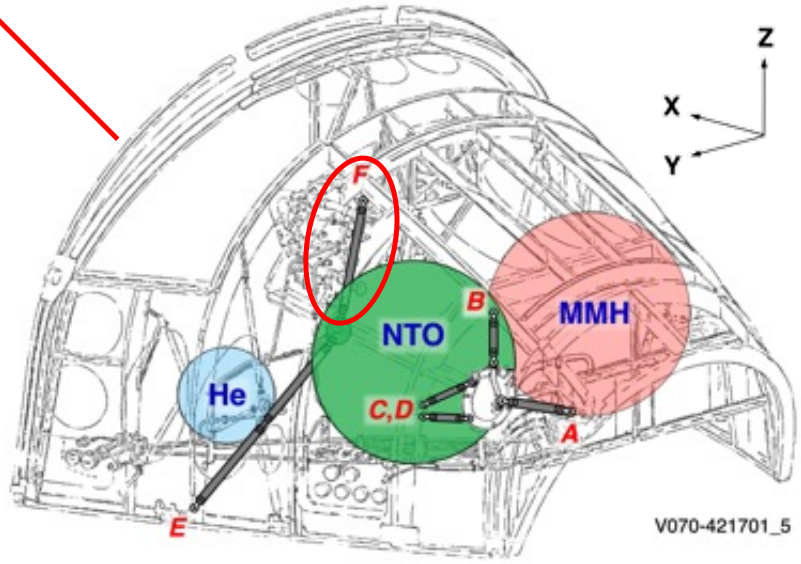
First launch - with crew!
12 April 1981



High dynamic Z-load at SRB ignition



Simplified tank model and static equlib. solution



Failed *Strut F* in Forward RCS Module found during post-flight inspection at KSC

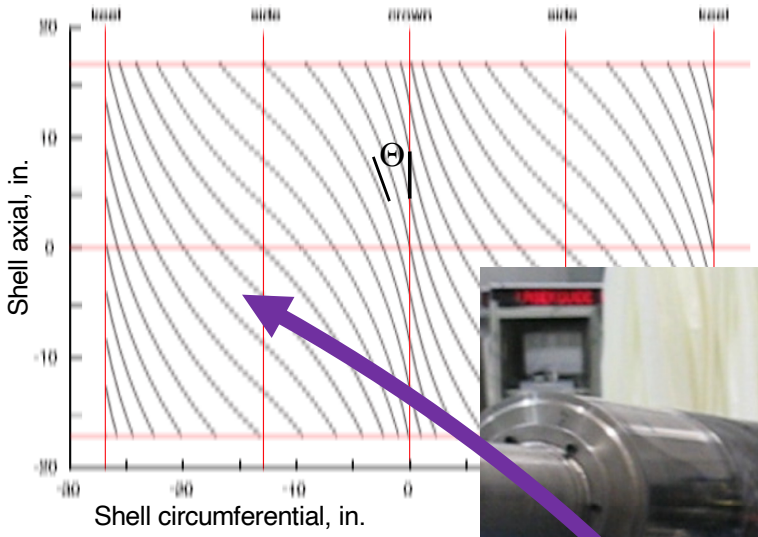
Compute Euler **buckling, bending**, and **first yield** of *Strut F*

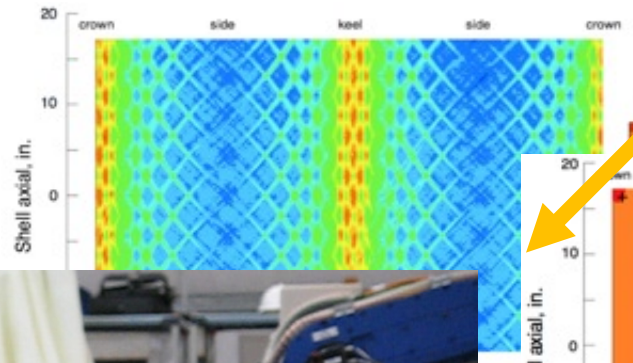
Further analyses suggest **possible failures** of two other struts at liftoff

JSC Director Kraft
"We just became infinitely smarter."

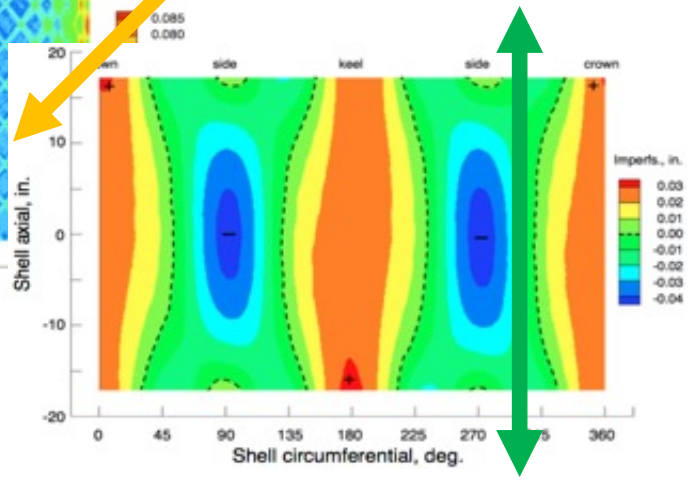


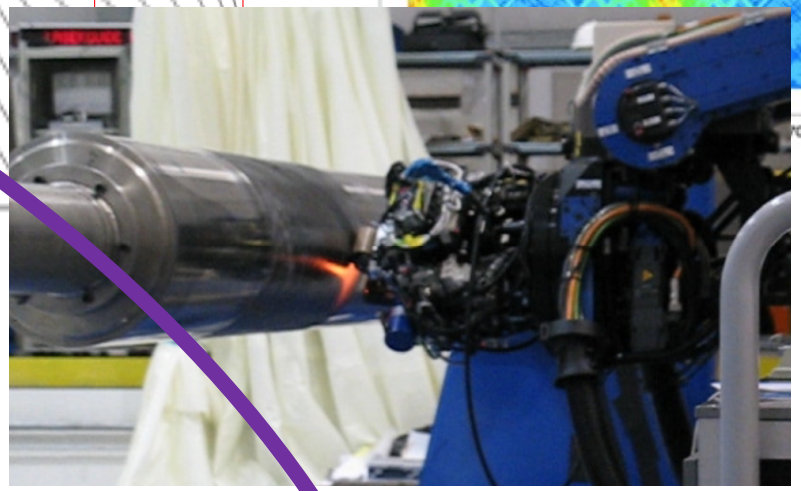
Advanced Composite Tow-Steered Shells





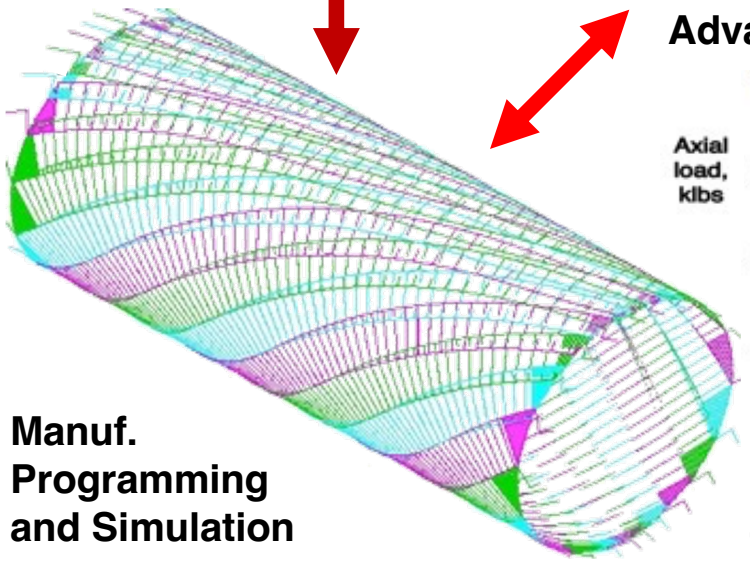
Characterization of As-Manufactured Shells





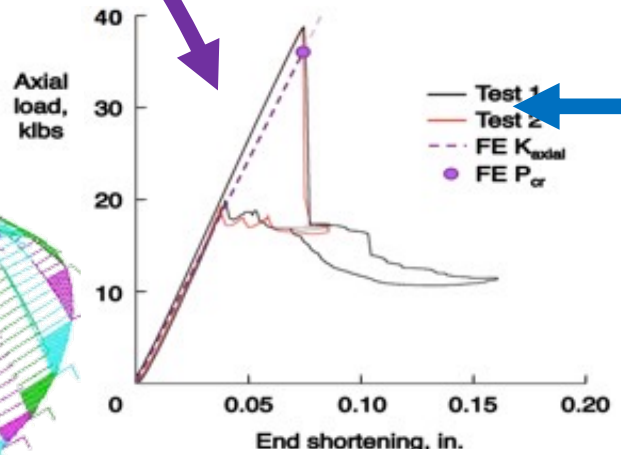
Structural Concepts, Design and Analyses

Structural Analyses with Nonlinearities

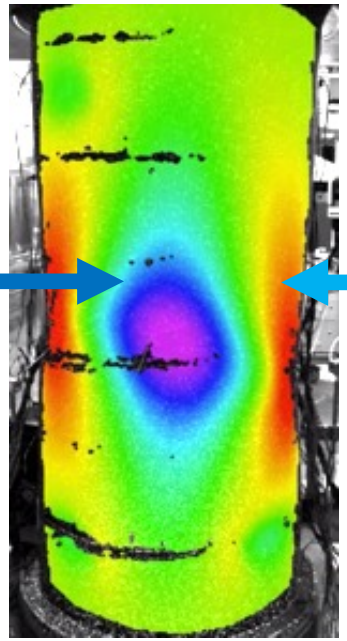


Manuf. Programming and Simulation

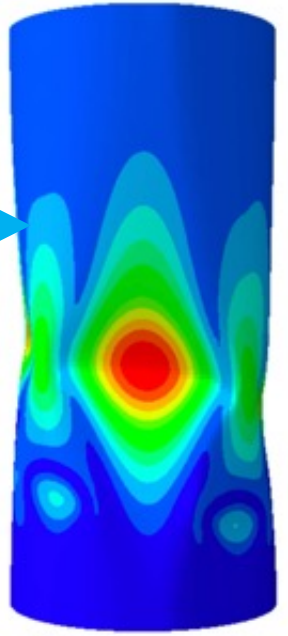
Advanced Manufacturing



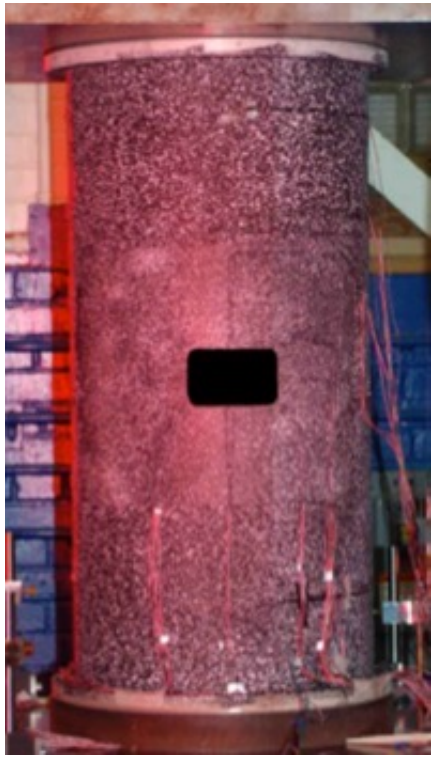
Test-Analysis Correlation



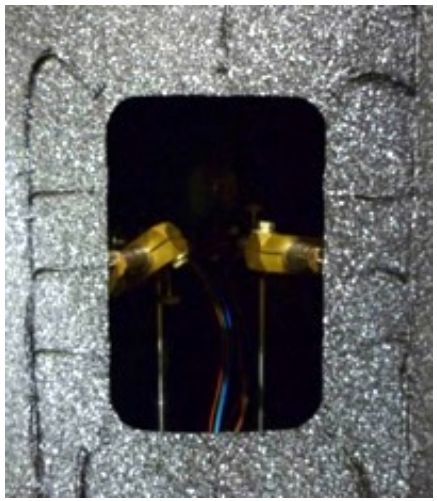
Testing



Additional Tow-Steered Shells Research

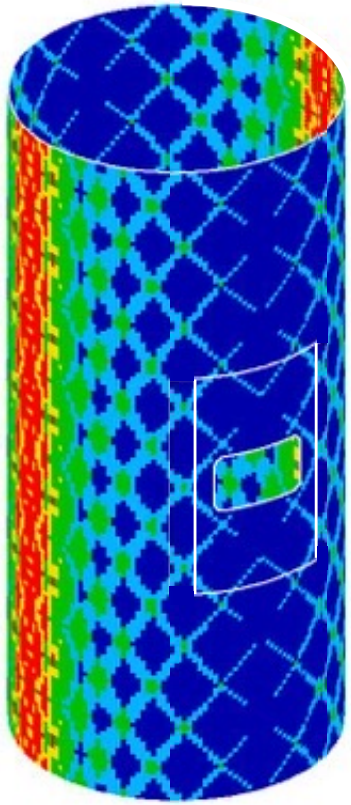


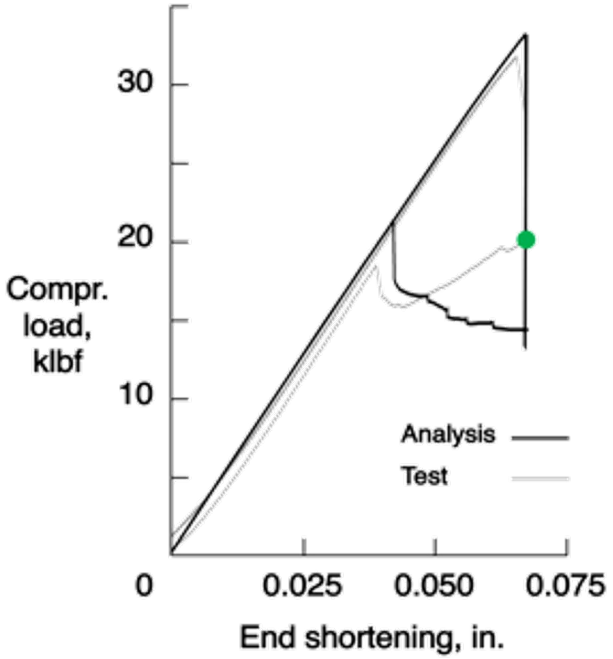
Small Cutouts



Large Cutouts

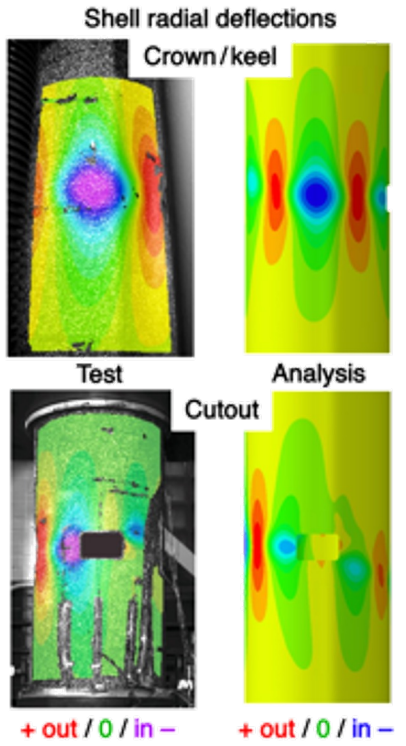
FE Models Updated with Cutouts

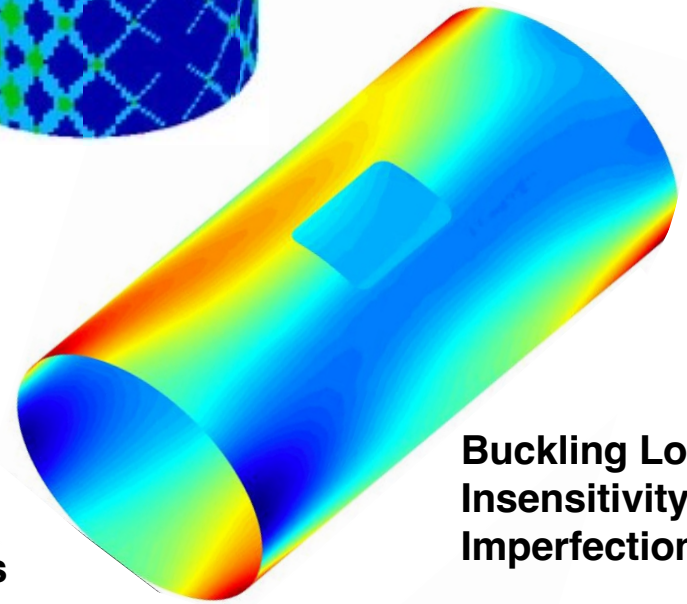




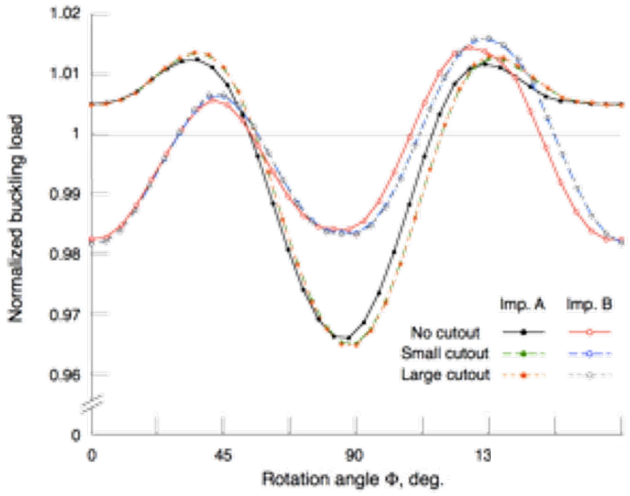
Compression Tests and Correlation with FEA

Digital Image Correlation at Stable Postbuckling



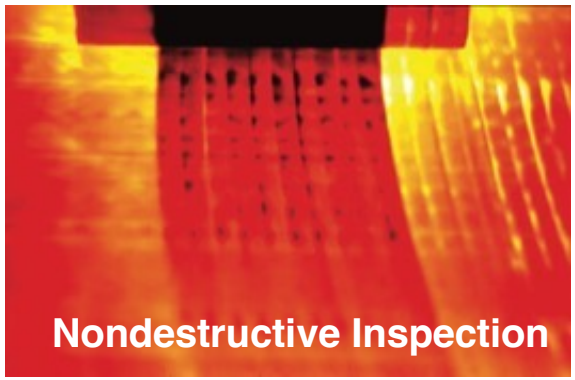


Buckling Load Insensitivity to Imperfections

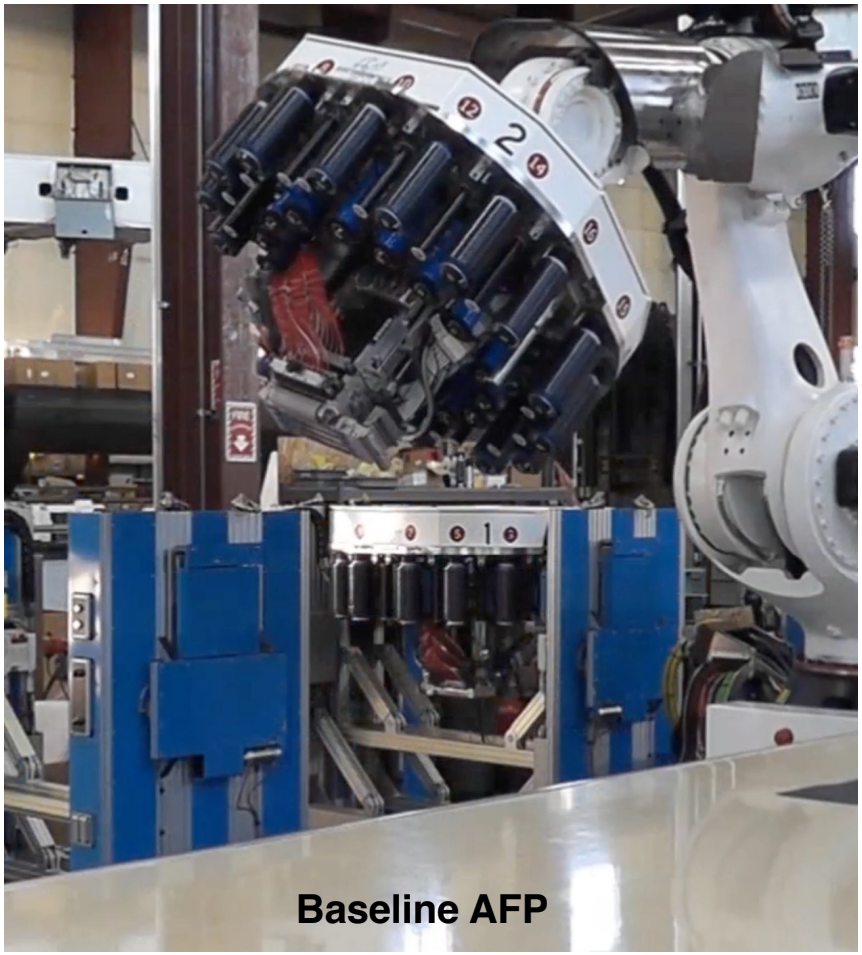


LaRC Advanced Composites Manufacturing

Integrated Structural Assembly of Advanced Composites









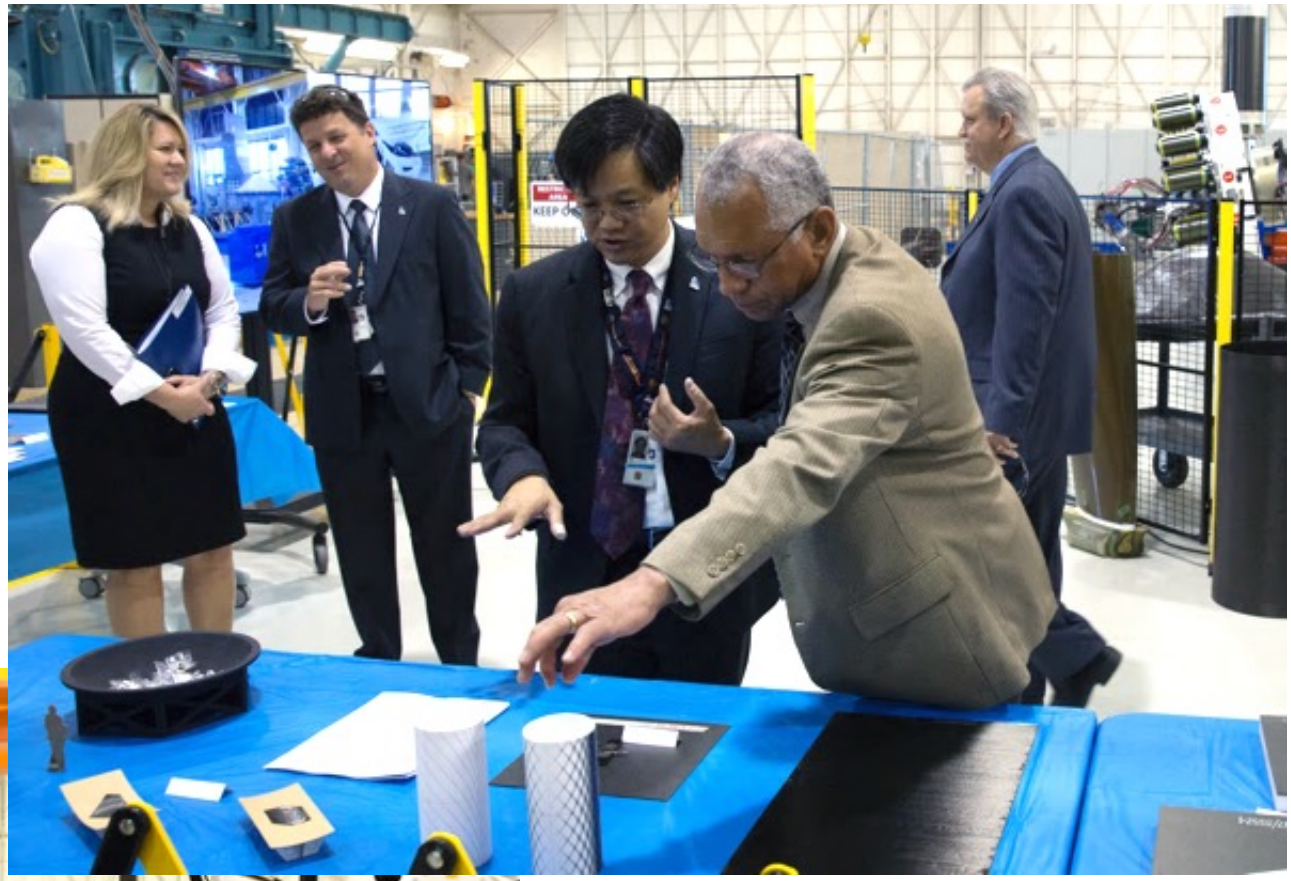


A robot-based system that utilizes multiple end effectors to develop and evaluate next generation composite materials, processes, structural concepts, manufacturing, and inspection techniques

ISAAC Is Operational!



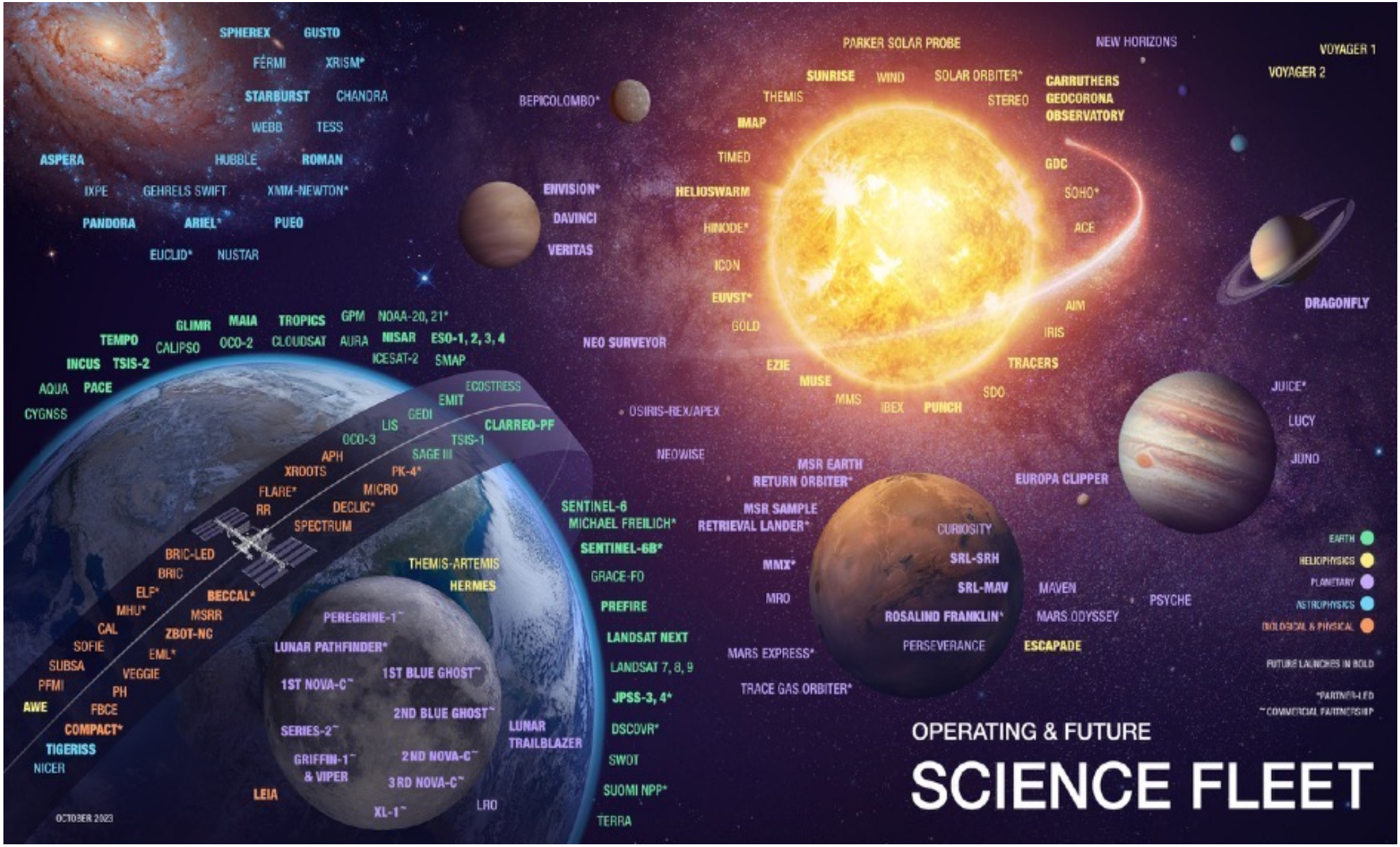
Charlie Bolden
NASA Administrator
May 2015





Dava Newman
NASA Deputy Admin.
June 2015

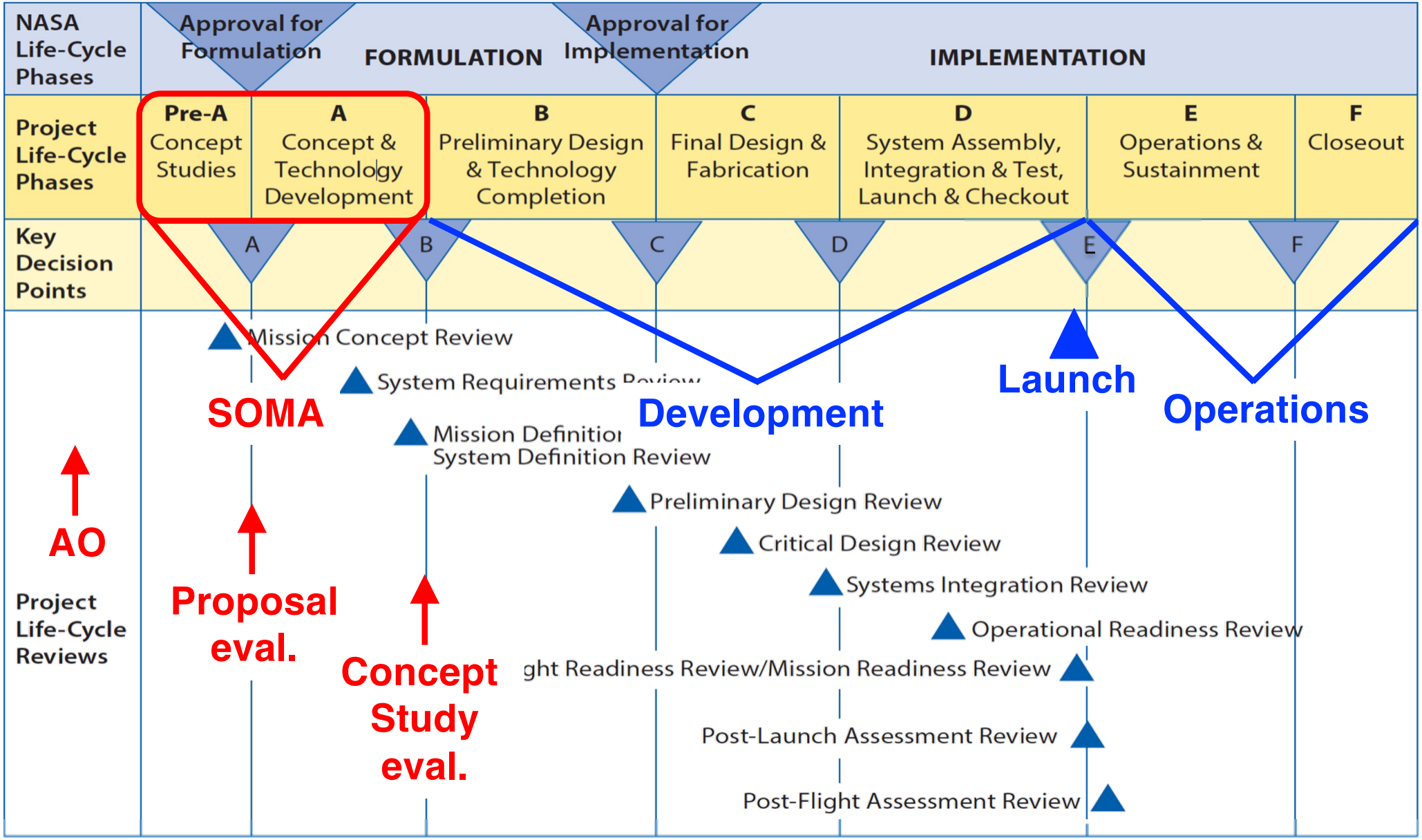
NASA Science Missions In Development And Operations



Science Office For Mission Assessments

- SOMA supports the Science Mission Directorate (SMD) at NASA Headquarters in the acquisition of future Earth- and space-science missions and instruments. SOMA is located at the NASA Langley Research Center.
- Announcements of Opportunity (AOs) are used to solicit proposals for Principal Investigator (PI)-led, competed Missions. The PI is responsible for their mission's scientific, technical, and programmatic success.
- SOMA works with SMD Program Scientists to develop AOs, and leads the Technical, Management, and Cost (TMC) evaluations of pre-Phase A proposals and Phase A Concept Studies received in response to the AO solicitations.
- Mission budgets range from approximately $30M (Missions of Opportunity) up to $1B (2023 Astrophysics Probe).

Simplified NASA Project Life Cycle

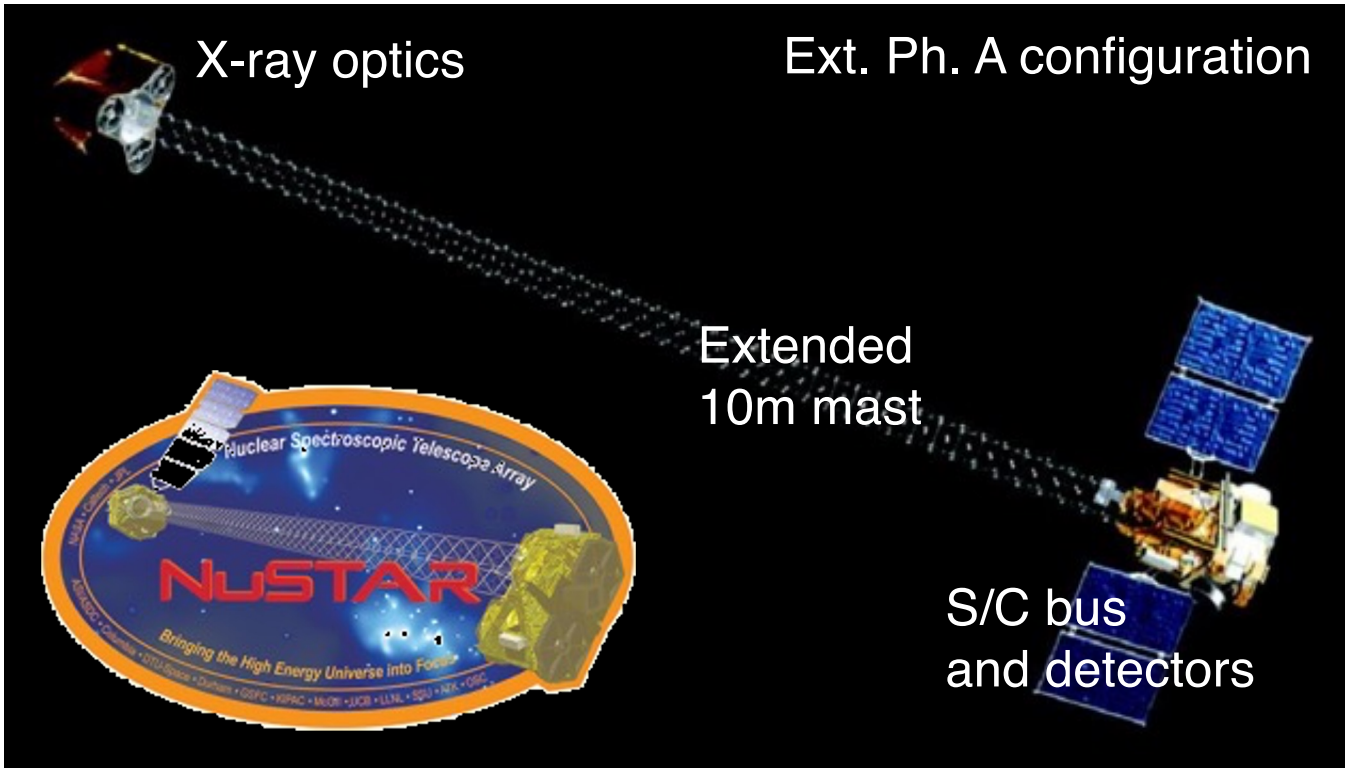


NuSTAR Extended Phase A Study (2005-2007)

Nuclear Spectroscopic Telescope ARray (*NuSTAR*)

- Three focusing hard X-ray (6-80 keV) telescopes with a 10-meter deployable mast.
- Astrophysics Small Explorer (SMEX) mission cost-capped at $120M (FY2003 AO).
- Caltech Principal Investigator, with JPL project management and systems engineering.
- Launched on Pegasus XL in June 2012 - and still operational in 2024!

To reduce mast deployment failure risk, **additional strut** recommended for kinematic stability of mast interface to X-ray optics module.





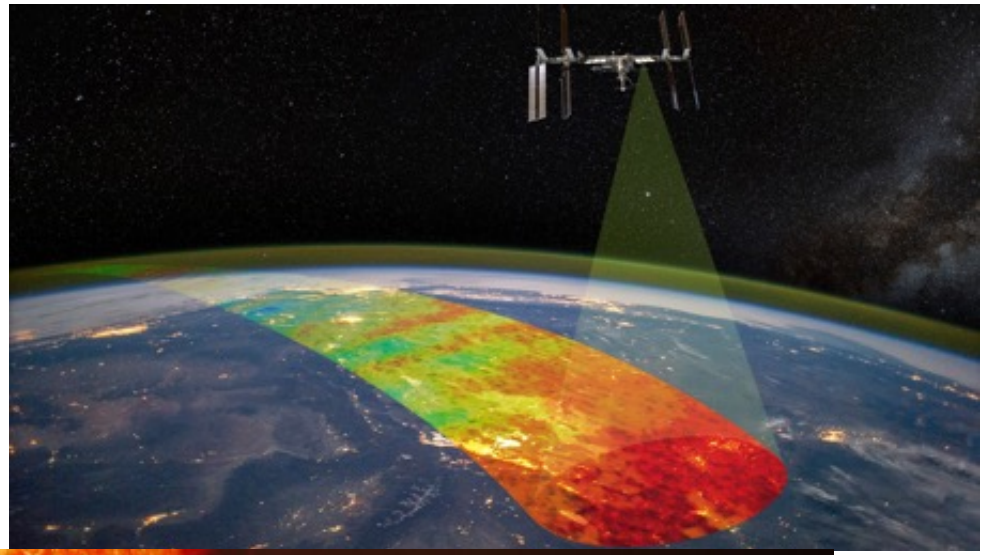
Adjustment mechanism truss and mast bay model

2016 Heliophysics Mission Of Opportunity (MO)

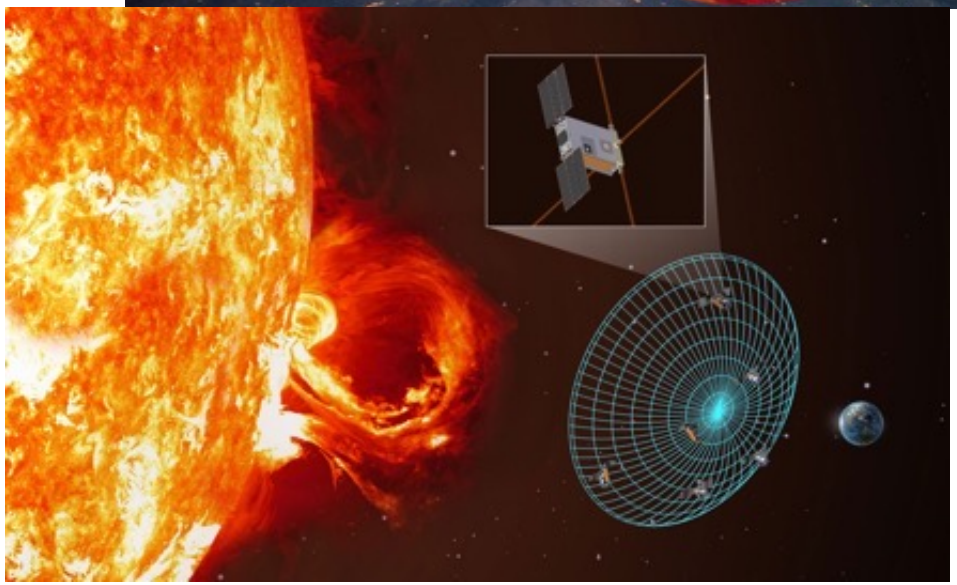
- AO development began in late 2015; $55M FY17 cost cap.
- 2 MOs down-selected by SMD in Feb. 2019 and March 2020, and funded for dev. and flight.

  - *AWE* (Utah State Univ.) ISS instrument to study atmospheric gravity waves; ***launched Nov. 2023!***

  - *SunRISE* (U.Michigan) 6, 6U CubeSat radio interferometer to study solar particle storms; planned 2024 launch.



NASA/USU



NASA/JPL

2016 Heliophysics Small Explorer (SMEX)

- AO development began in late 2015; $165M FY17 cost cap.
- 2 SMEXes down-selected by SMD in June 2019, and funded for development and flight.

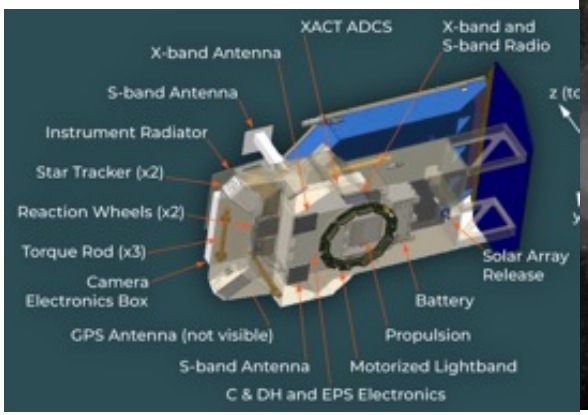
➢ *TRACERS* (U.Iowa)
2 s/c studying Sun-Earth magnetic field interactions.

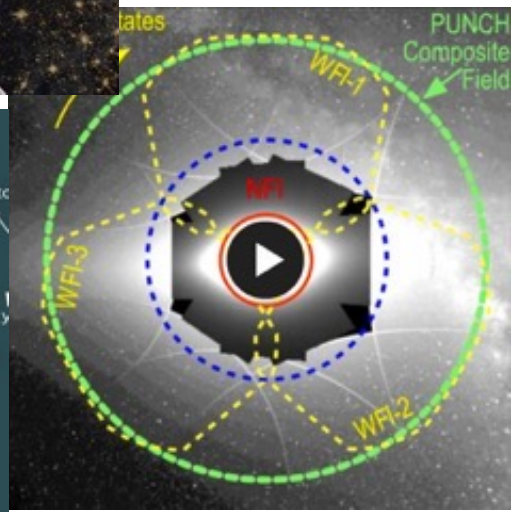
➢ *PUNCH* (SwRI)
4 s/c imaging corona and solar wind.

➢ Planned 2025 launches.



NASA/U.Iowa



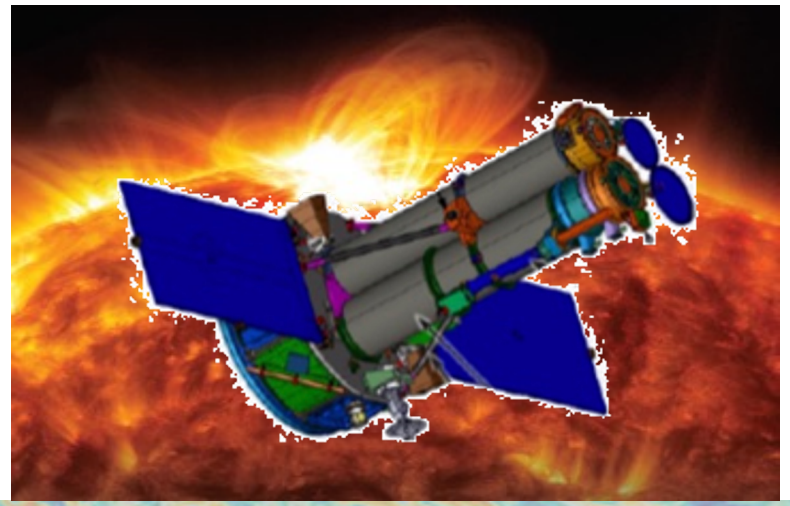


NASA/SwRI

2019 Heliophysics Medium-Class Explorer (MIDEX)

- AO development began in early 2019; $250M FY19 cost cap.
- 2 MIDEXes down-selected by SMD in February 2022, and funded for development and flight.

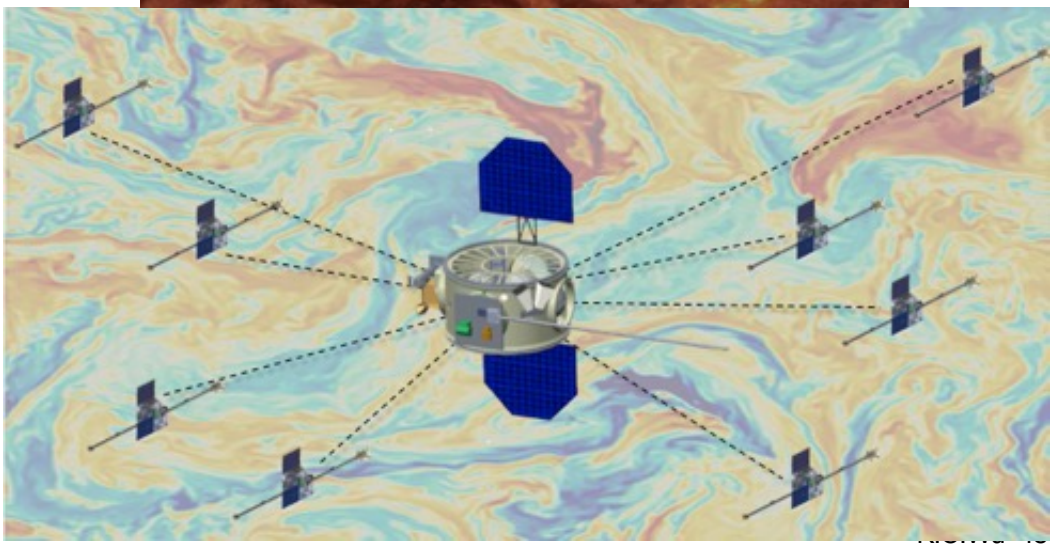
➢ *MUSE* (Lockheed Martin), Multi-slit spectrograph and EUV imager to study the Sun's corona.



NASA/ Lockheed Martin

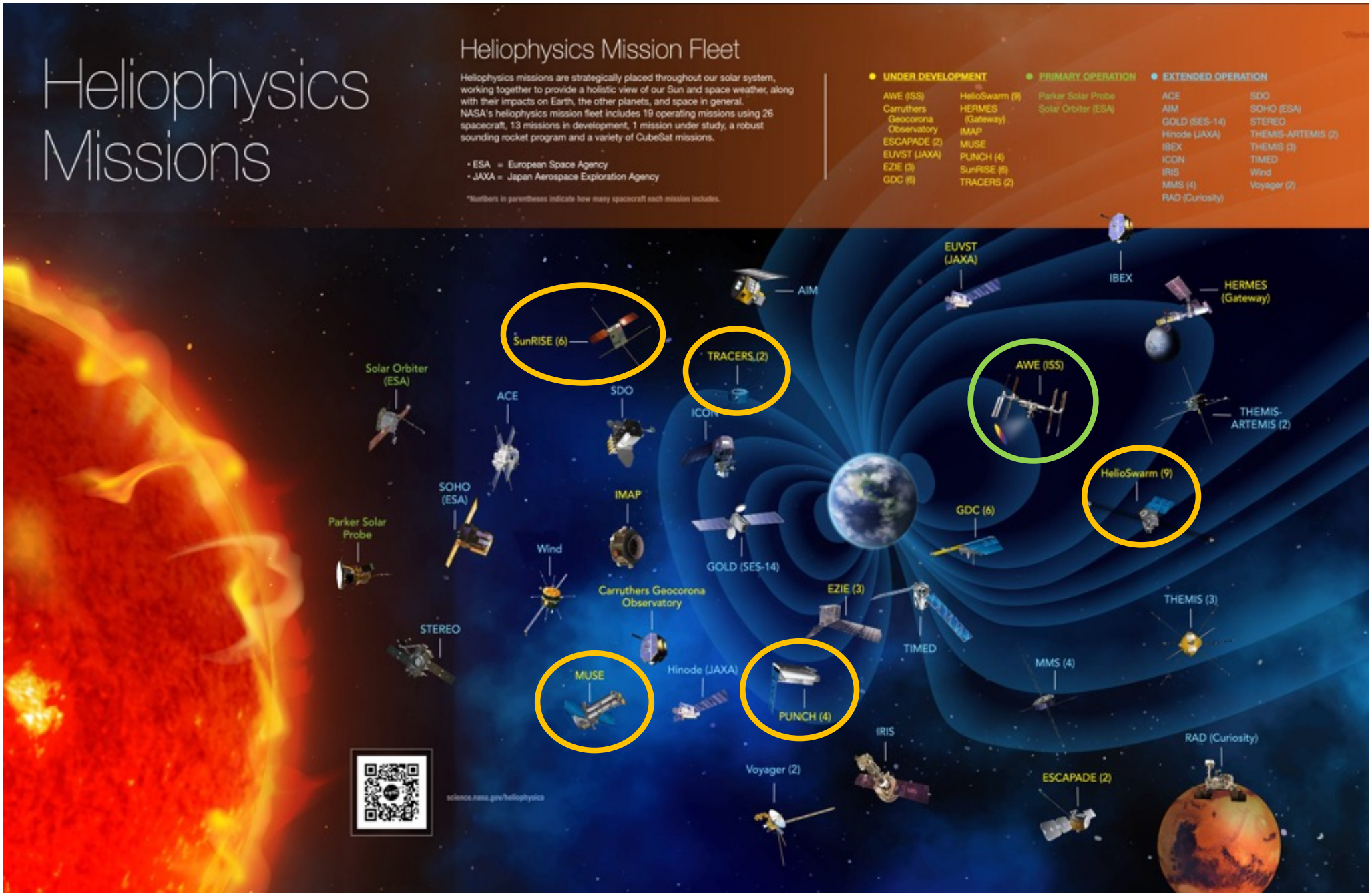
➢ *HelioSwarm* (U.NH), 9 s/c to study multiscale solar wind turbulence.

➢ Planned launches in 2027 and 2028.



NASA/U.NH

Heliophysics Missions In Development And Operations

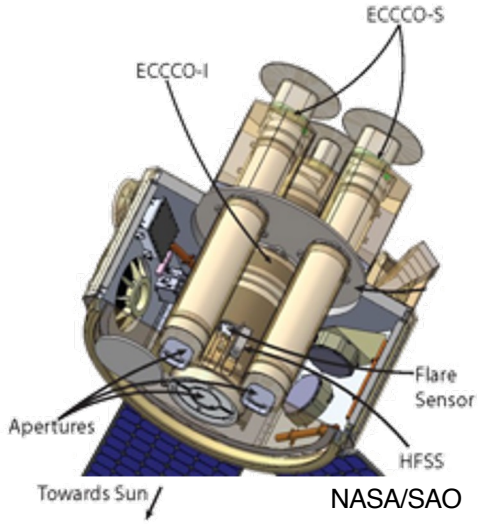


2022 Heliophysics Small Explorer (SMEX)

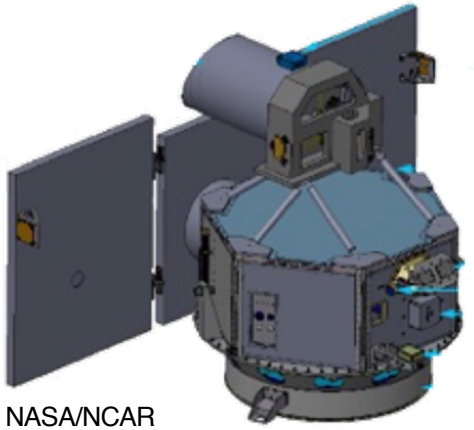
- AO development began in late 2021, and released in September 2022; $150M FY22 cost cap.
- 4 missions selected by SMD in September 2023 for NASA-funded Concept Studies ($2M each).

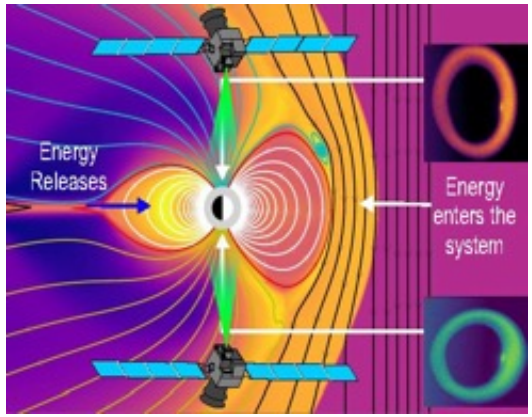
- *CINEMA* (Dartmouth); 9, 12U CubeSats to study Earth's magnetotail.
- *CMEx* (NCAR) to study the Sun's magnetic field.
- *ECCCO* (SAO) to study the Sun's corona and CMEs.
- *MAAX* (U.Michigan) to study Earth's M-I electrodynamic coupling.





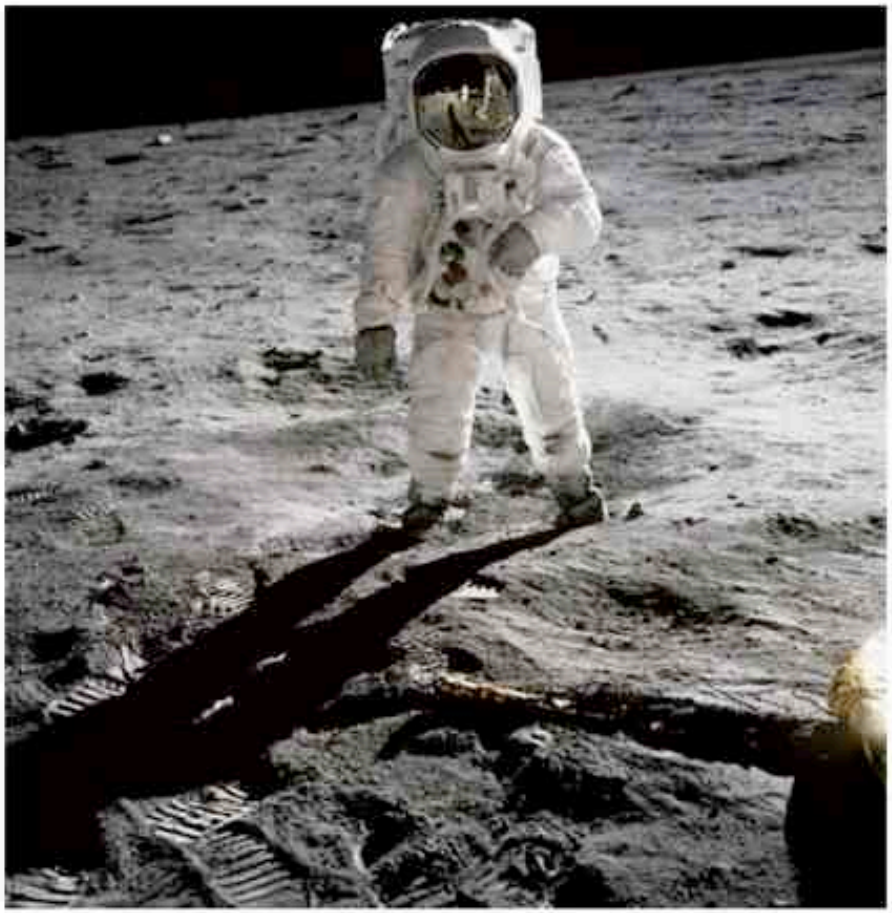
NASA/SAO


NASA/NCAR



NASA/U.Michigan

Our Next Giant Leap(s)…



The Moon - 1969, 203X?



Mars - 20XX?