TriTruss Packaging and Deployment Trade Study

Julia Cline, Lauren Raffanello, Kyongchan Song, Brace White, Gillian McGlothin, John Dorsey, Bill Doggett
Structural Mechanics & Concepts Branch, NASA Langley Research Center, Hampton, VA

and

Iok Wong, Rounak Mukhopadhyay
National Institute of Aerospace, Hampton, VA

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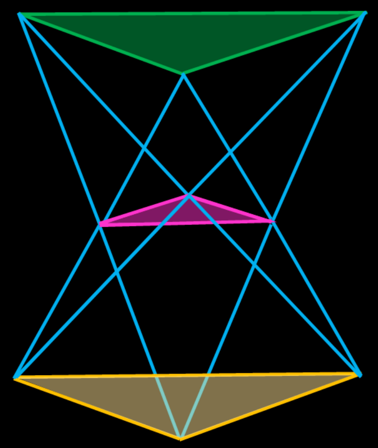
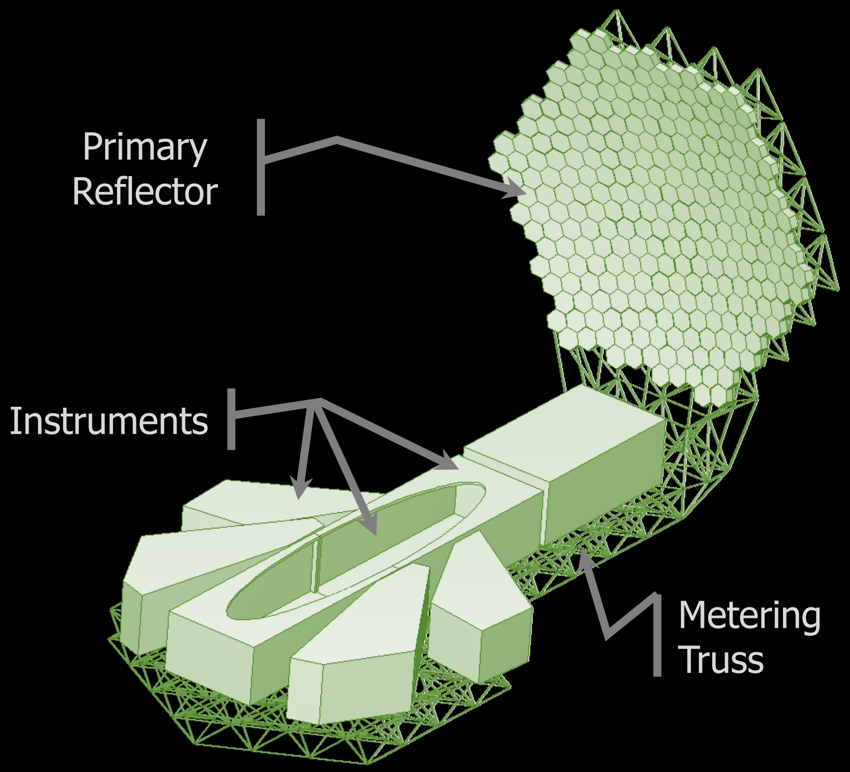
The trade study objective is to develop novel packaging and deployment (P&D) strategies for TriTruss modules used to assemble the foundational truss structure of an In-Space Assembled Telescope (iSAT) with a 20-m diameter primary reflector.

Presentation Agenda
- Review the TriTruss module and geometry
- Summarize the iSAT Trade Study
- Introduce the ongoing TriTruss P&D trade study
- Discuss proposed P&D concepts and phase 1 down select
- Discuss ongoing work

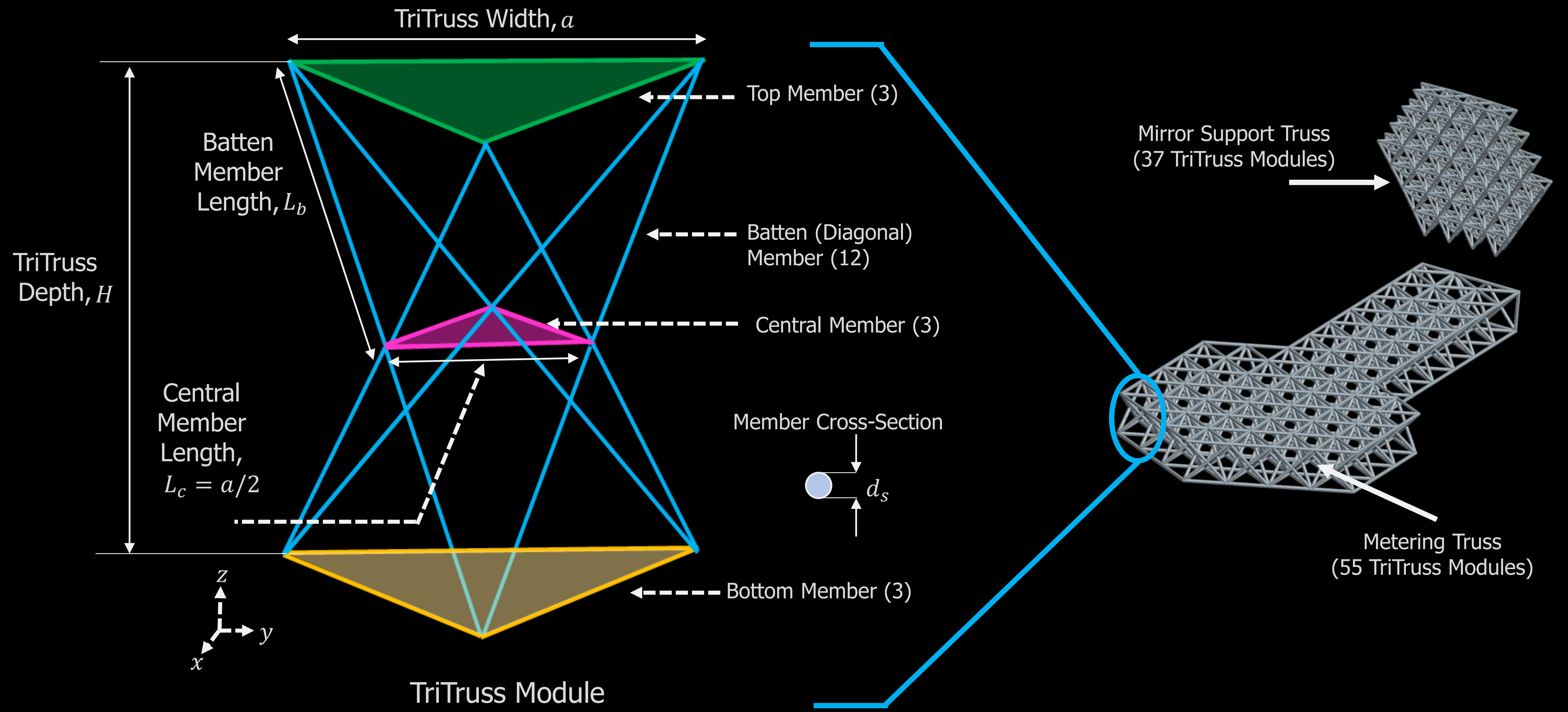


TriTruss Module

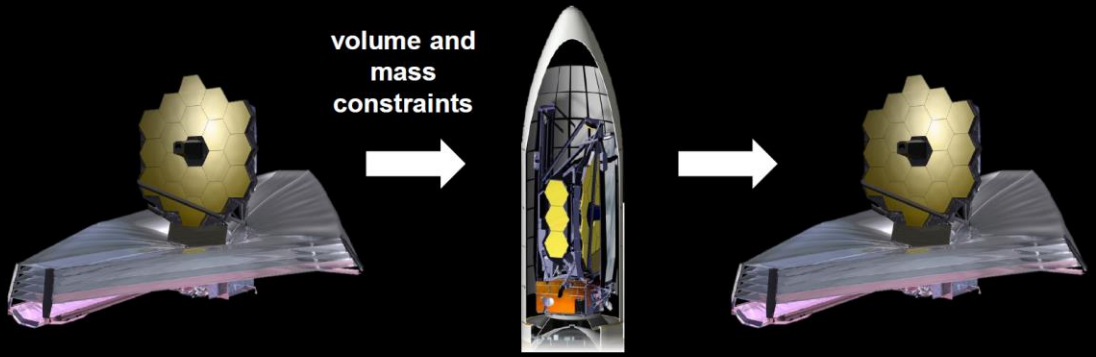


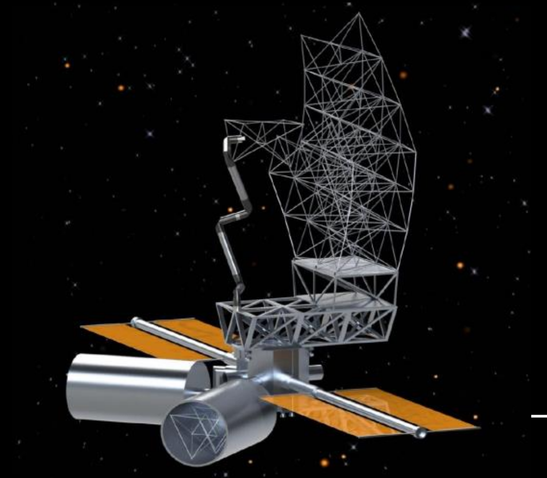
Concept for an iSAT

The TriTruss is a novel deployable modular truss that can be used to assemble the foundational truss structure of persistent assets (PA).



The 2019 iSAT trade study concluded that robotic in-space assembly (iSA) of modular components is necessary to enable large aperture (>15-m primary reflector diameter) space telescopes.

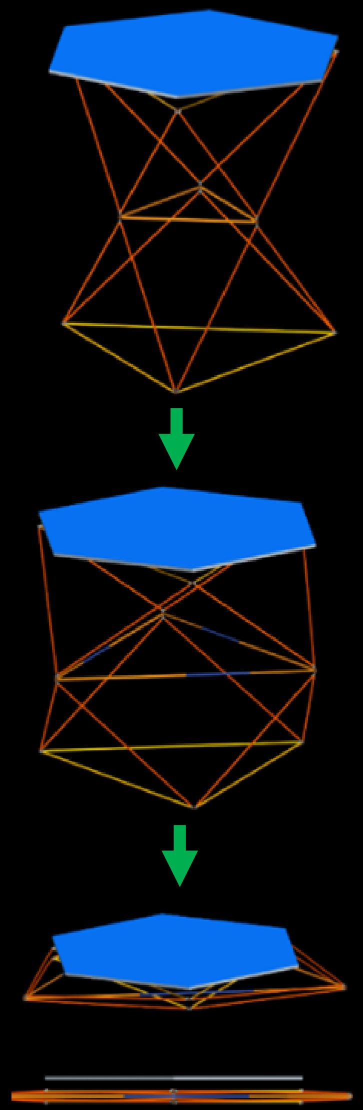


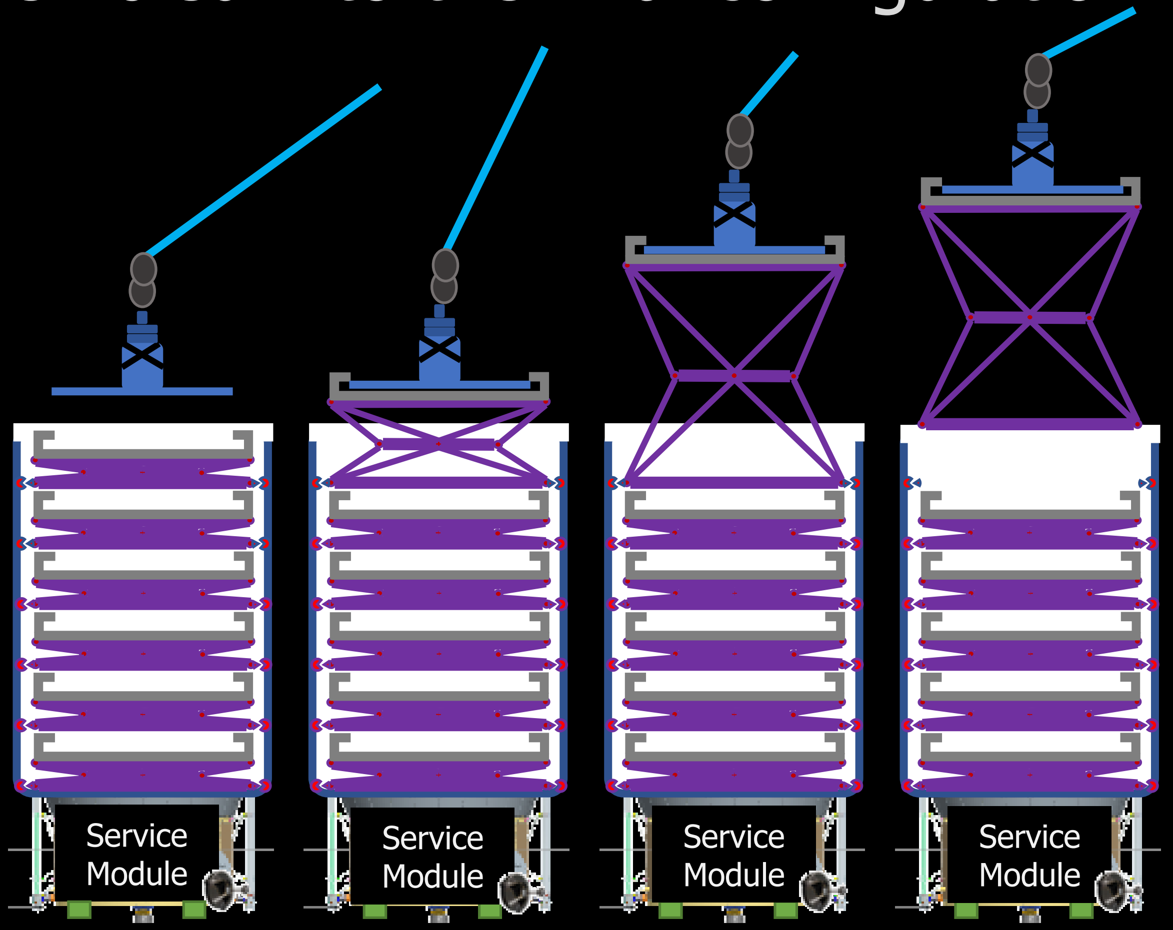


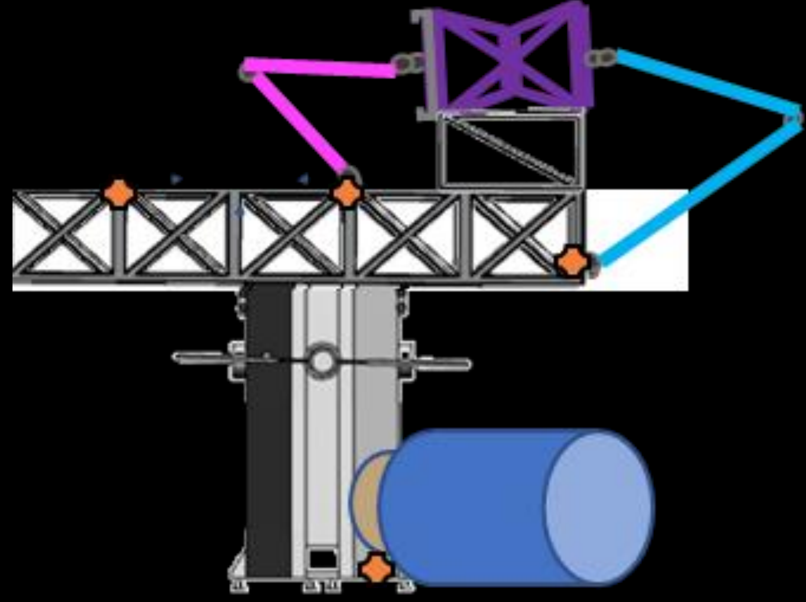
Conventional Approach - James Webb Space Telescope	New PA Paradigm - iSAT
Mirror diameter = 6.5 m	Mirror diameter = 5 m to >15 m
Entire structure assembled on Earth, packaged for launch, and deployed on-orbit	Modular components packaged for launch, structure assembled on-orbit using robotic agents
Deployment includes 20 sequential events, 40 deployable structures and 178 release mechanisms	Significantly reduced deployment complexity
Constrained based on fairing (mass and volume)	Launch vehicle constraints reduced – multiple launches
Cannot be serviced or upgraded to extend mission duration	Designed to be serviced and upgraded to extend mission duration

TriTruss modules were baselined as the structural element for the foundational structure of the iSAT.

TriTruss modules are packaged for launch, deployed on orbit and robotically assembled into the final configuration.







Specific Concepts of Operations (ConOps) for P&D of TriTruss modules were not explored during the iSAT trade study.

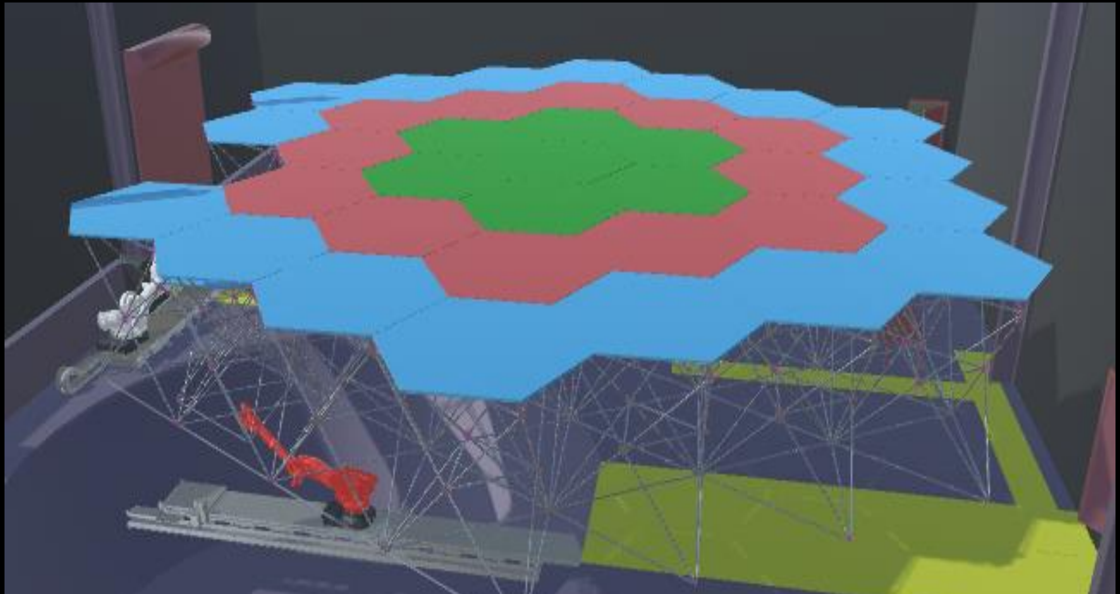
Unifying assumptions are used to bound the trade study.

Overall Trade Study Purpose
Develop and evaluate options for P&D of TriTruss modules that can be designed, fabricated and tested as part of the Precision Assembled Space Structure (PASS) project. PASS will demonstrate autonomous assembly of a 3-ring, 20-meter class, doubly curved iSAT mirror backbone structure in an end-to-end ground demonstration.

Three-Phased Approach
Phase 1: Understand the kinematics of packaging and deployment of novel P&D strategies

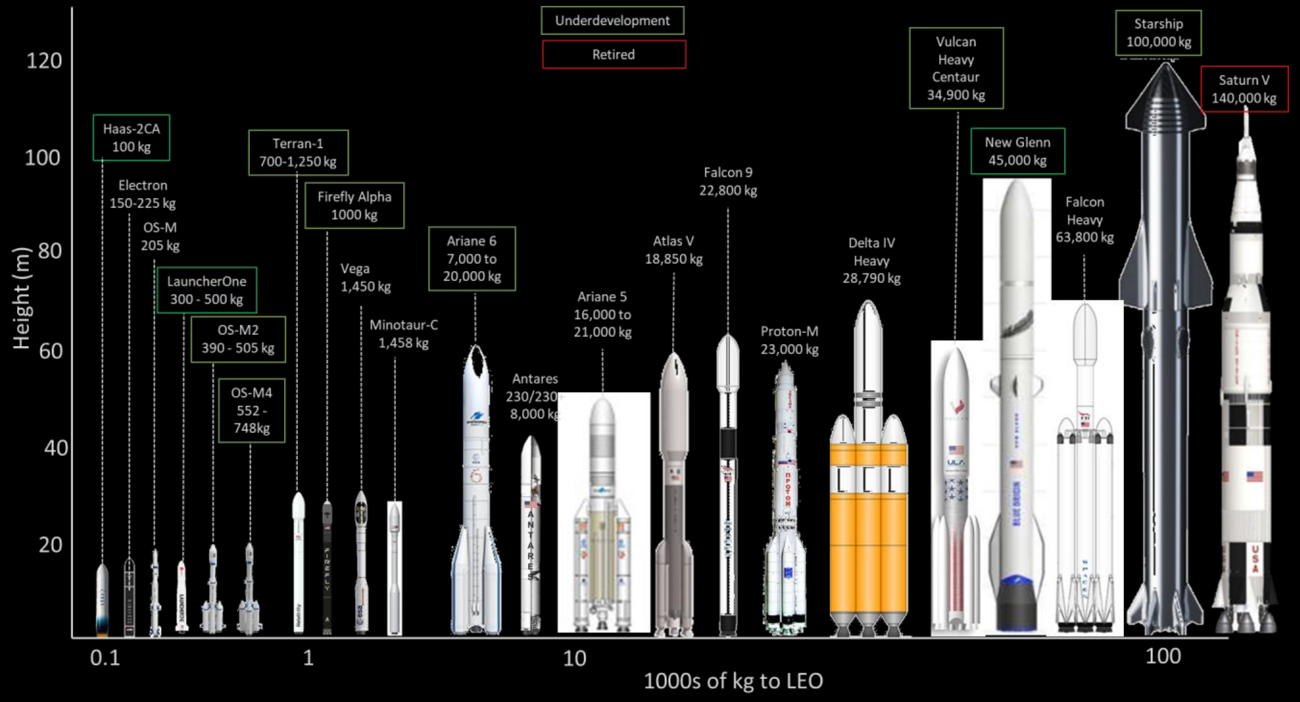
Assumptions
- Robotic assembly (no extra vehicular activity)
- Multiple arms available
- One way deployment
- Deployment using either internal strain energy members or robotic assist
- TriTruss geometry is H/a = 1
- TriTruss modules connected using multi-nut

Constraints
- Fairing size: 4.6-m interior working diameter


Simulation of PASS 20-m class mirror truss structure

An ideal P&D strategy would package efficiently, be geometrically versatile with low mechanical and deployment complexity.

- Efficient packaging with sufficient geometric versatility to be launch vehicle independent
- Ability to integrate subsystems or utilities prior to launch if required
- Stiff and lightweight structure with low joint complexity and component modularity
- Kinematically simple deployment concept accomplished robotically using a minimum number of specialized tools



Multiple low cost commercial launch options

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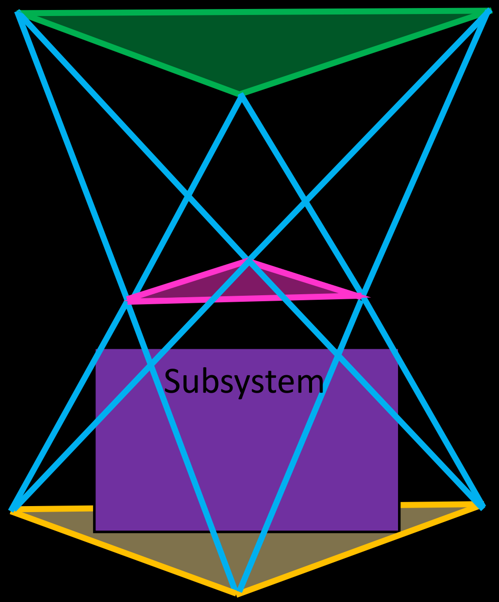
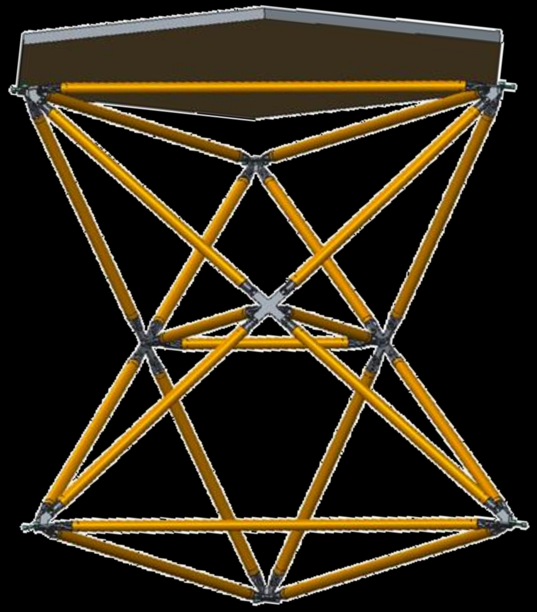


Subsystem integration


Mirror raft integration

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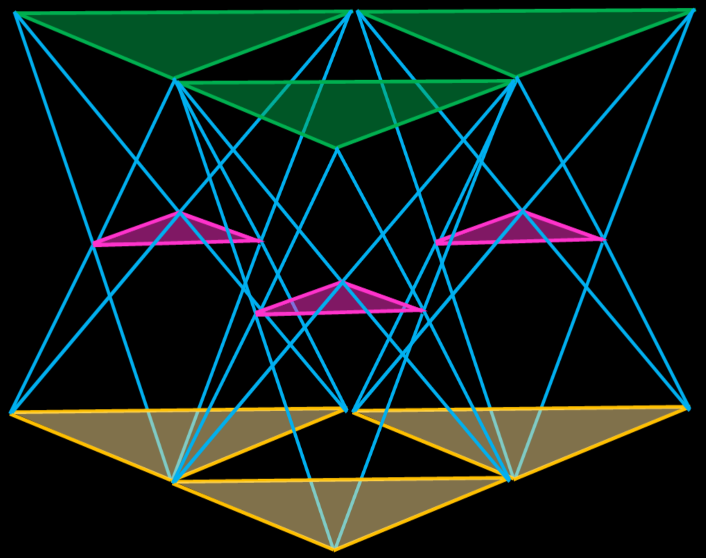

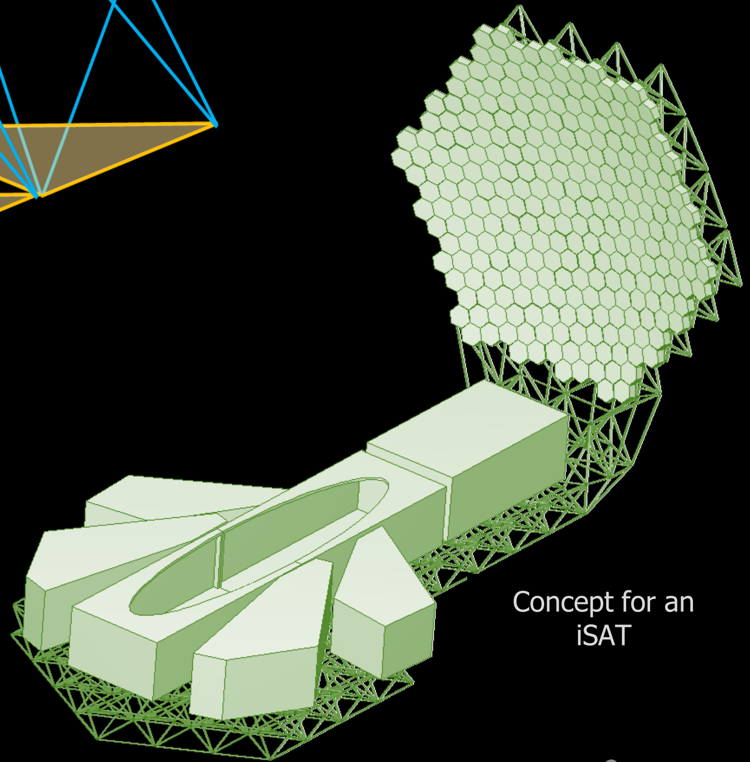

Concept for an iSAT

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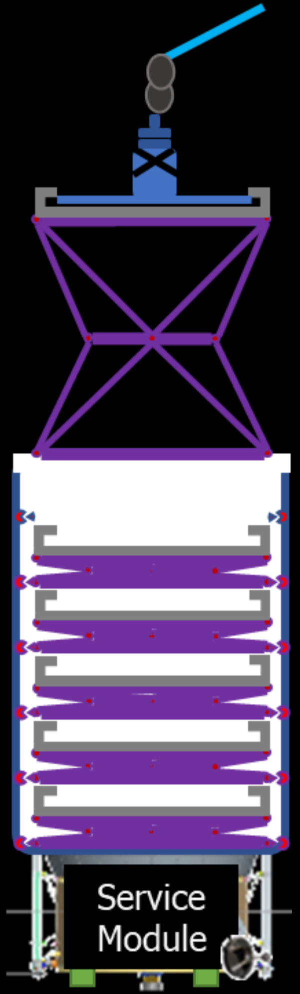
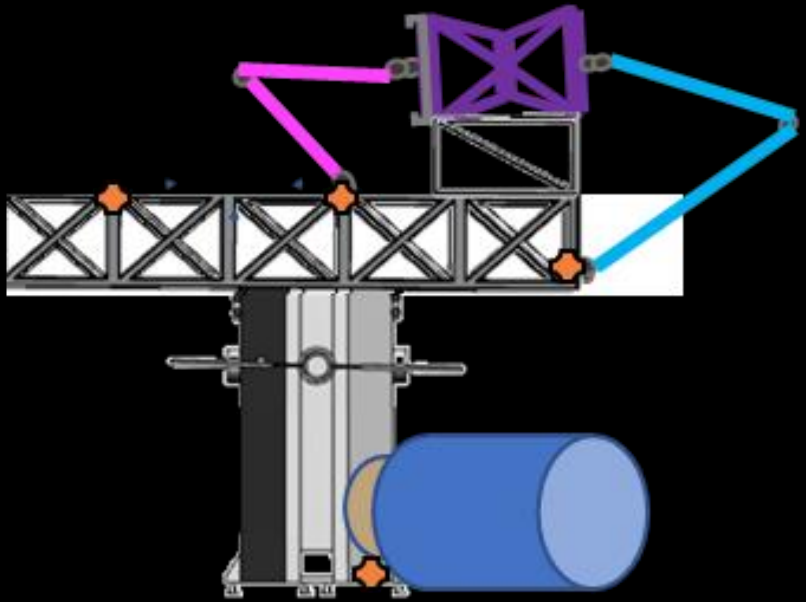




The ideal P&D strategy defines the evaluation metrics used in the trade study.

Packaging Efficiency

- Dimensions/shape of packaged module
- Modules per fairing
- Number of launches to assemble structure

Mechanical Complexity

- Joint kinematics
- Degrees of Freedom (DOFs)
- Types of members used

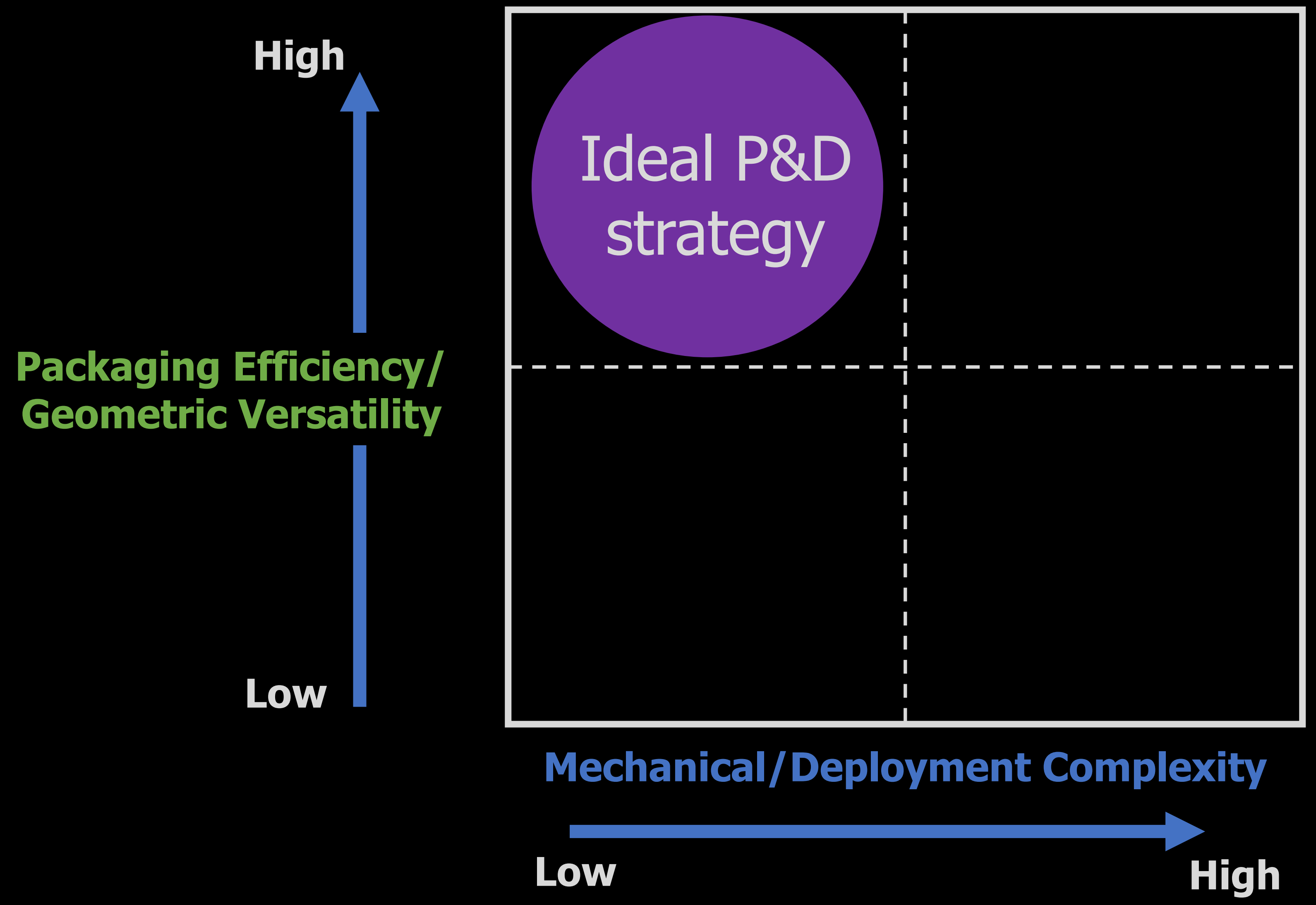
Geometric Versatility

- Partial and full module collapse
- Subsystem and utility integration pre-launch
- Mirror raft integration

Deployment Complexity

- Deployment ConOps
- Robotic assistance required
- Additional support infrastructure required

The ideal P&D strategy values high packaging efficiency and geometric versatility and low mechanical and deployment complexity.



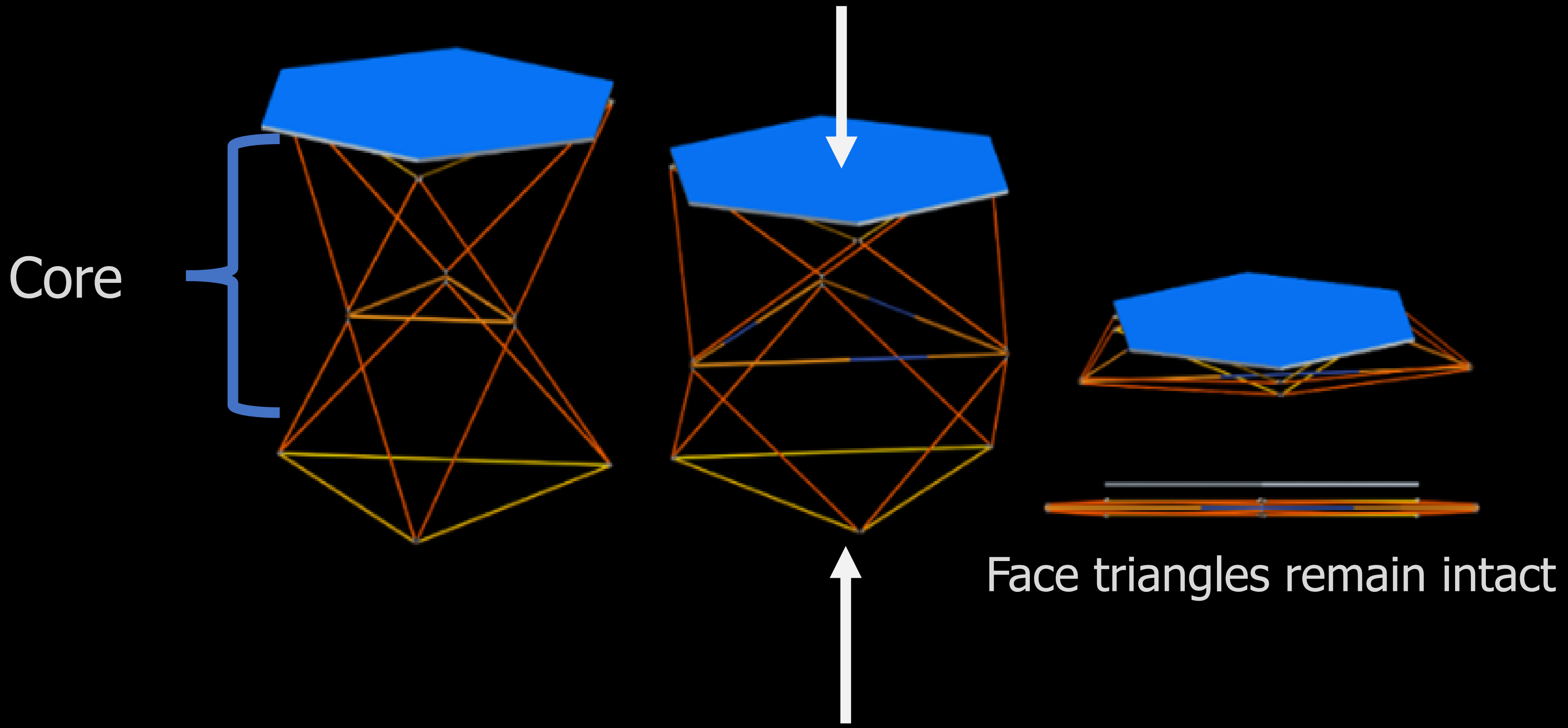
Weighting Scale

Scale	Packaging Efficiency and Geometric Versatility
Low	1 point
Medium	3 points
High	5 points

Scale	Mechanical and Deployment Complexity
Low	5 points
Medium	3 points
High	1 point

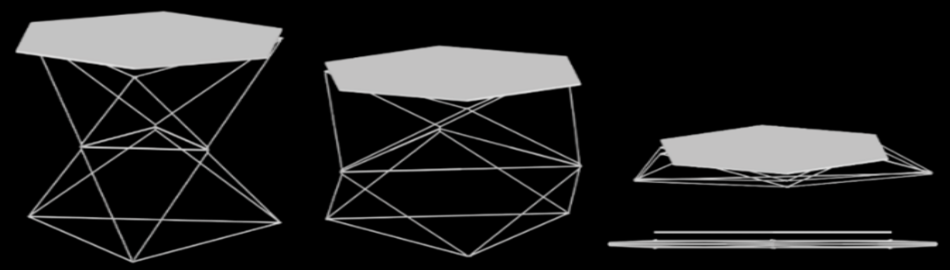
P&D strategies fall into three categories: Core Collapse.

Core Collapse

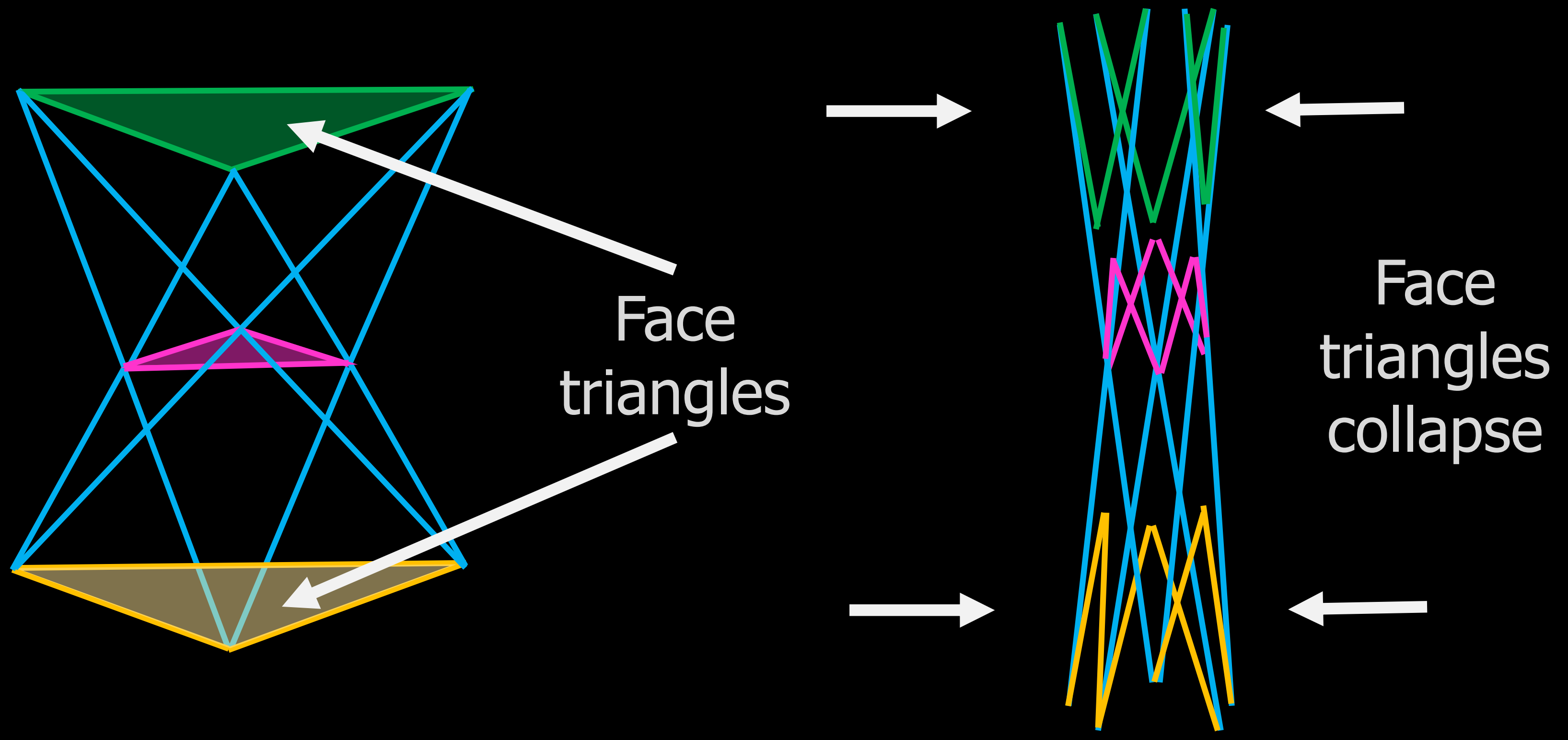


P&D strategies fall into three categories: Face Collapse.

Core Collapse

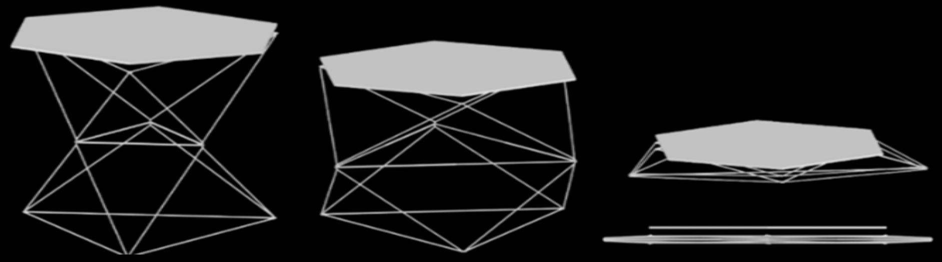


Face Collapse

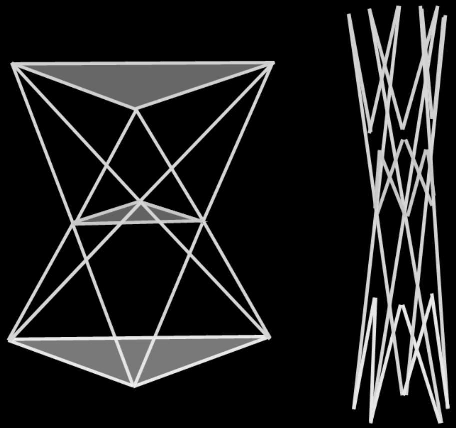


P&D strategies fall into three categories: Erectable Structures.

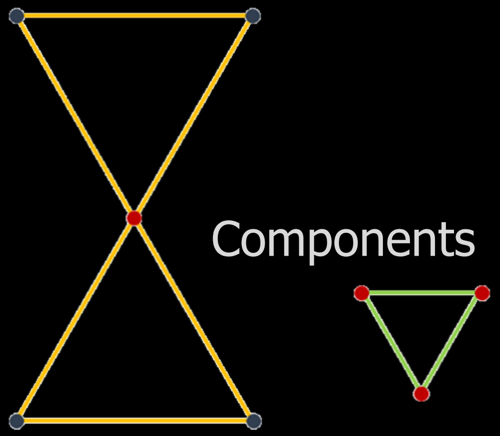
Core Collapse



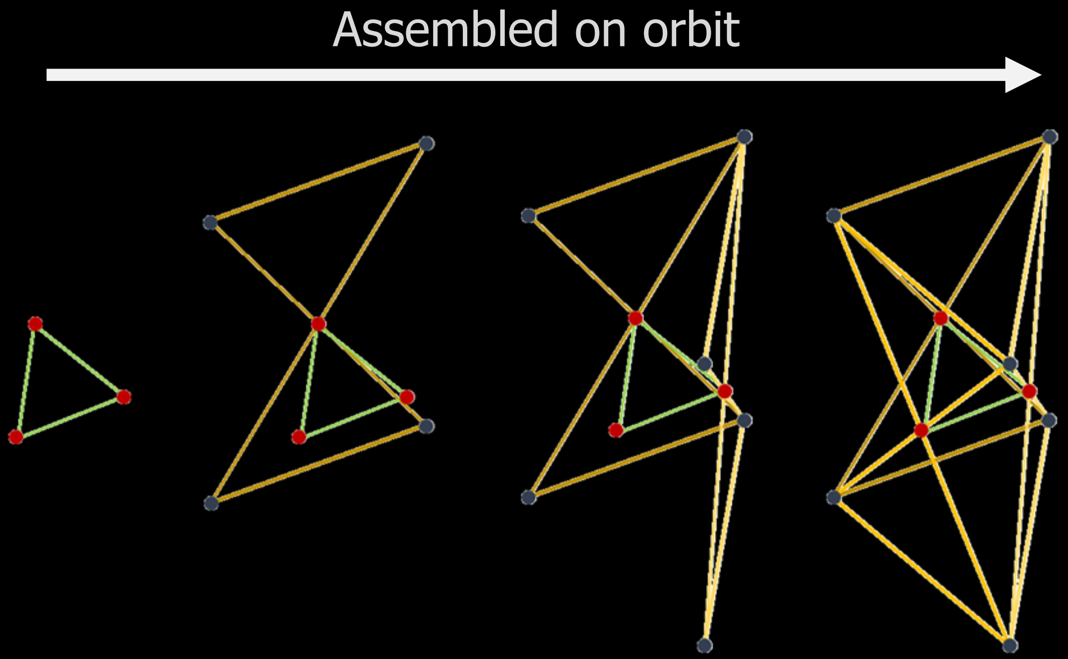
Face Collapse



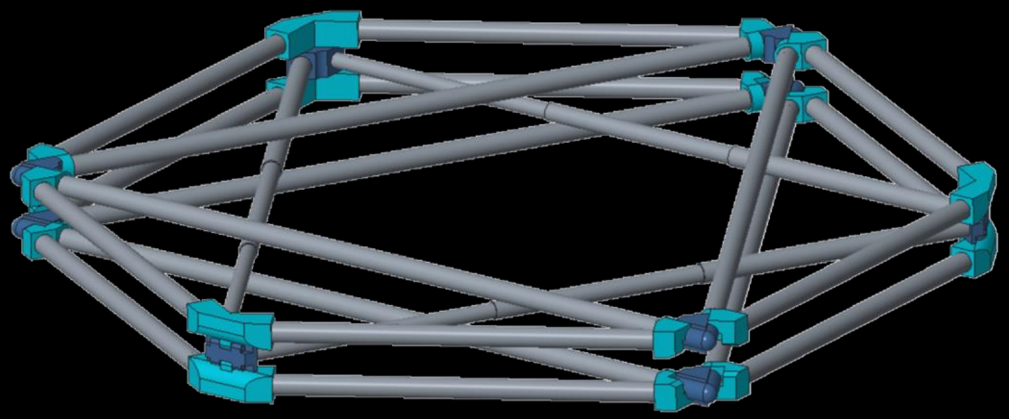
Erectable Structures



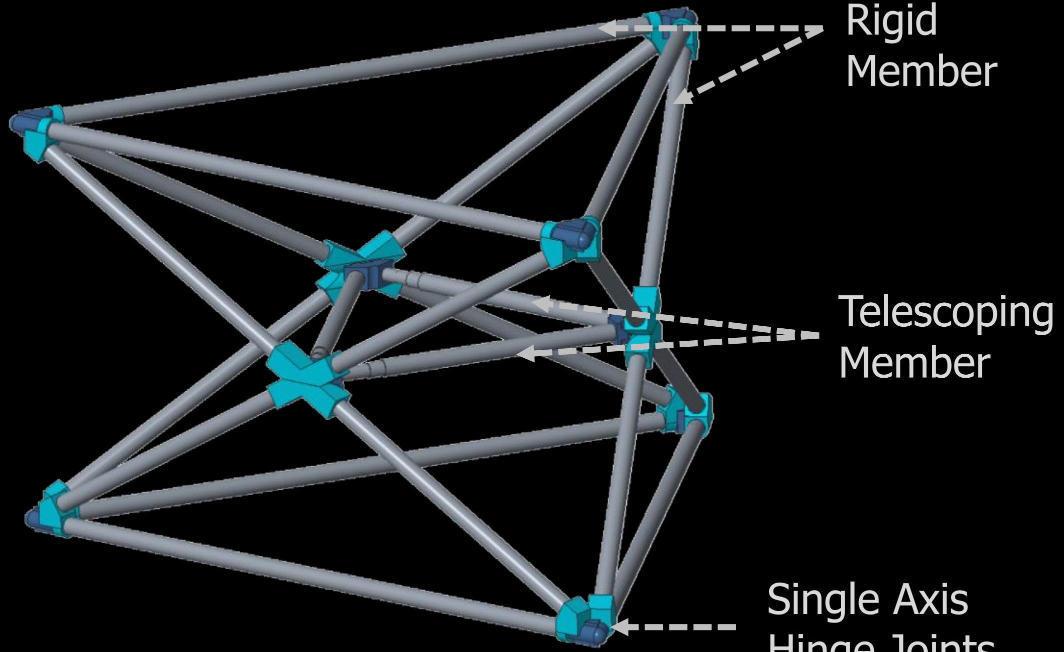
Components



The “Telescoping Middle TriTruss” has telescoping members in the central triangle that lengthen to allow the TriTruss to collapse



Packaged Configuration

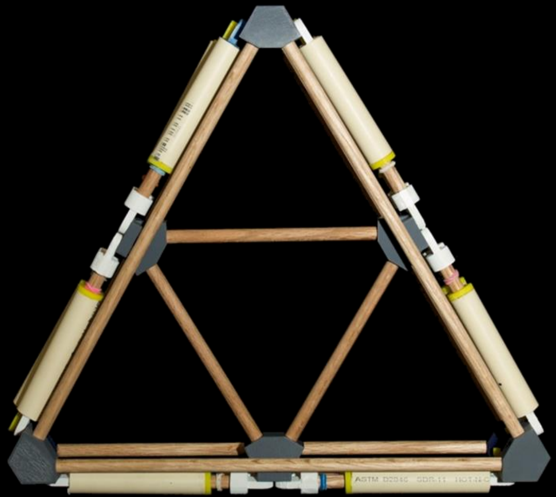


Deployed Configuration

Features:

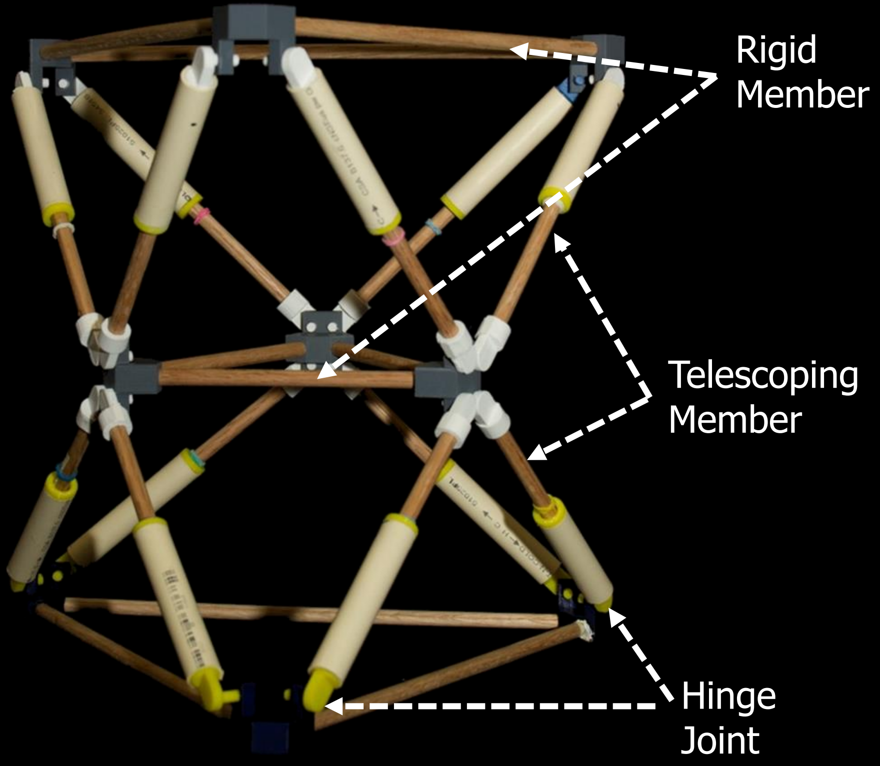
- Compact hexagonal packaged shape
- Limited to $H/a = \sqrt{3}/3$ to meet fairing diameter requirement
- Full package only; mirror raft can be integrated
- 18 hinge joints and 3 telescoping members

The “Telescoping Diagonal TriTruss” has diagonal telescoping members that shorten to allow the TriTruss to collapse.



Packaged Configuration

Partial Packaging

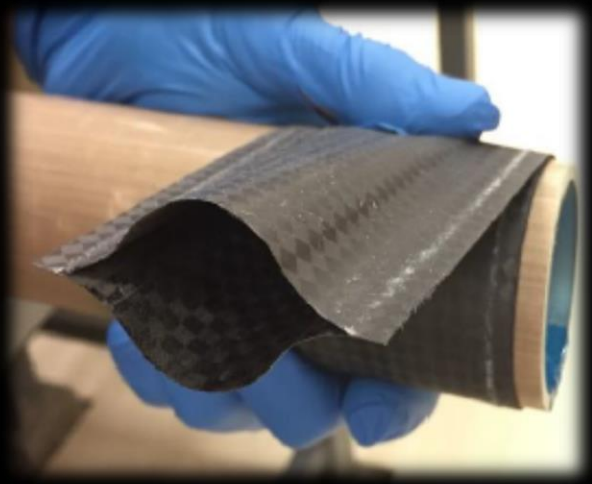


Deployed Configuration

Features:

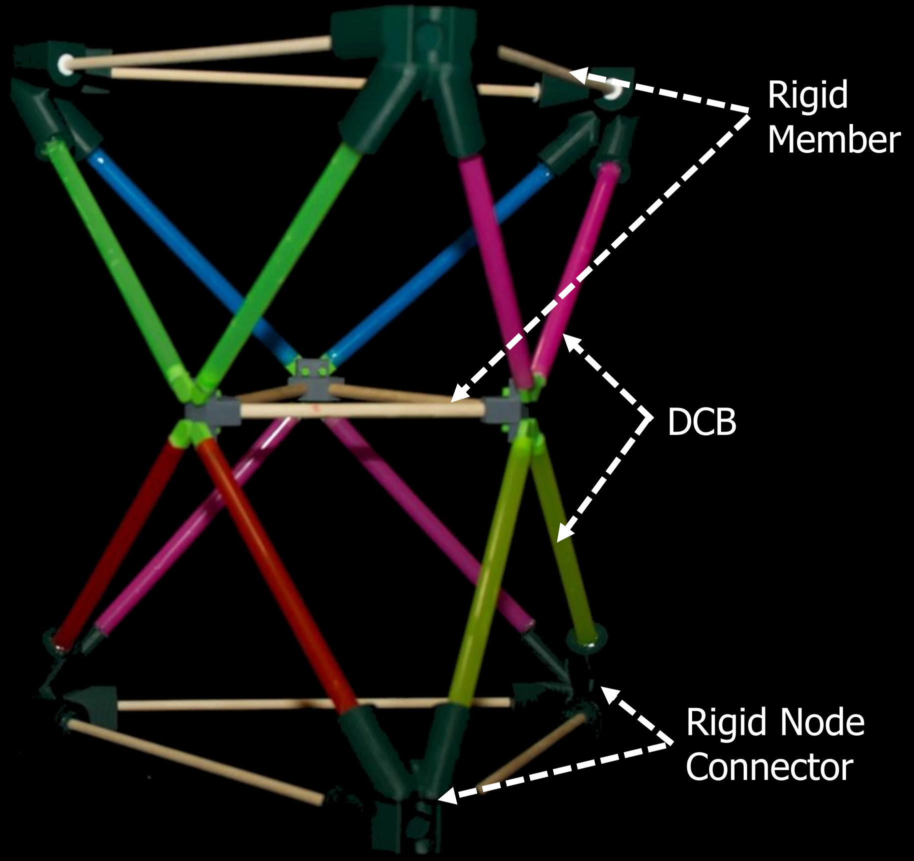
- Compact triangular packaged shape
- Full and half package; mirror raft can be integrated
- Optional spring in telescoping member to deploy
- 24 hinge joints and 12 telescoping members

The "Collapsible Cross-section TriTruss" is based on Deployable Composite Boom (DCB) technology, where the diagonal members can fold into the packaged shape.



DCB are thin-walled composite structures, developed at NASA LaRC, that can roll/fold flat.

Packaged Configuration

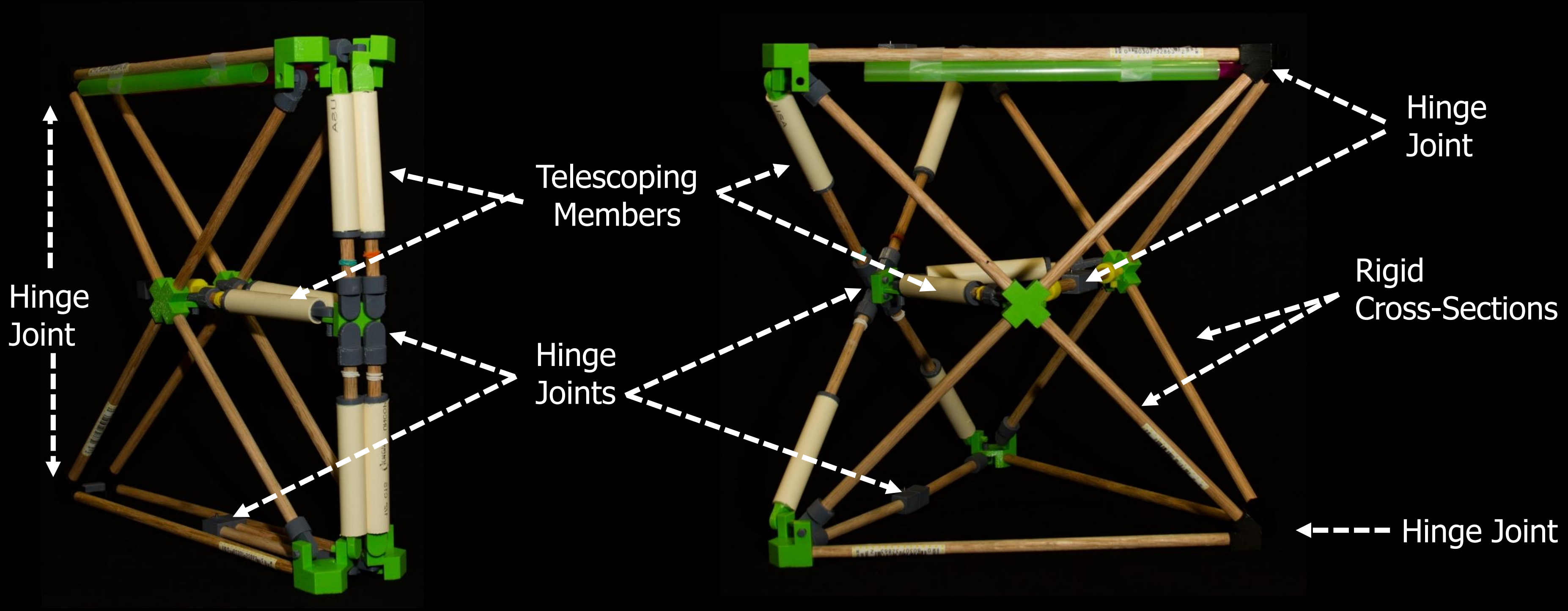


Deployed Configuration

Features:

- Compact triangular packaged shape
- Full and half package; mirror raft can be integrated
- Low node connector complexity
- Analysis required to ensure stiffness required can be achieved using DCB

The "Side Fold" TriTruss has hinges and telescoping members that allow one side of the TriTruss to fold inward.



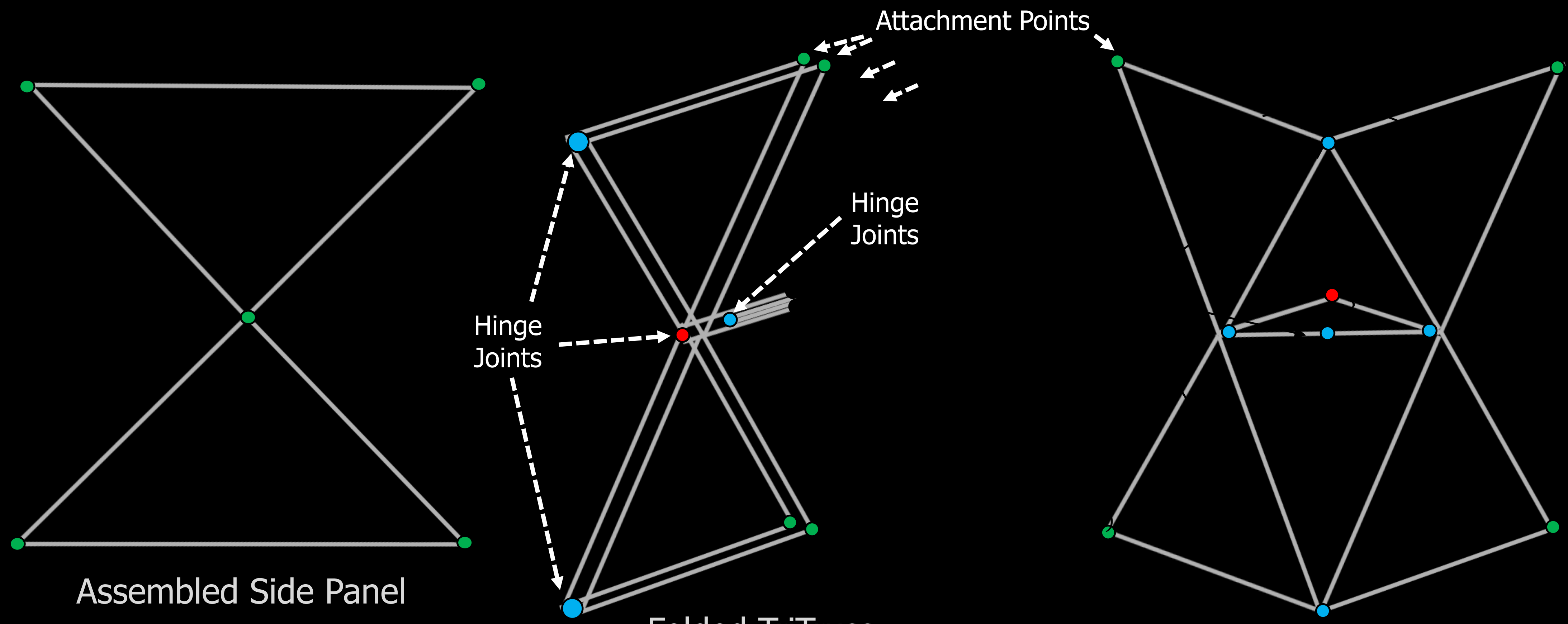
Packaged Configuration

Deployed Configuration

Features:

- Compact rectangular packaged shape with triangular cut-out
- Full package only; mirror raft cannot be integrated
- 15 hinges; 6 telescoping members

A semi-erectable variant of the “Side Fold” TriTruss would have an assembled side panel that is attached on-orbit, eliminating the telescoping members from the original design.



Assembled Side Panel

Folded TriTruss

Deployed Configuration

Packaged configuration

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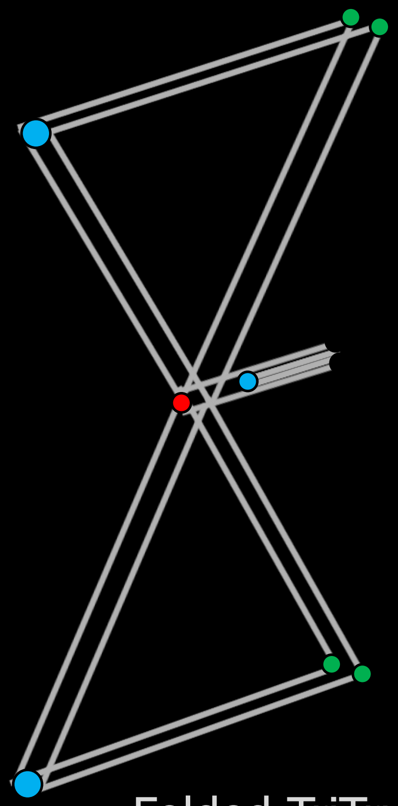
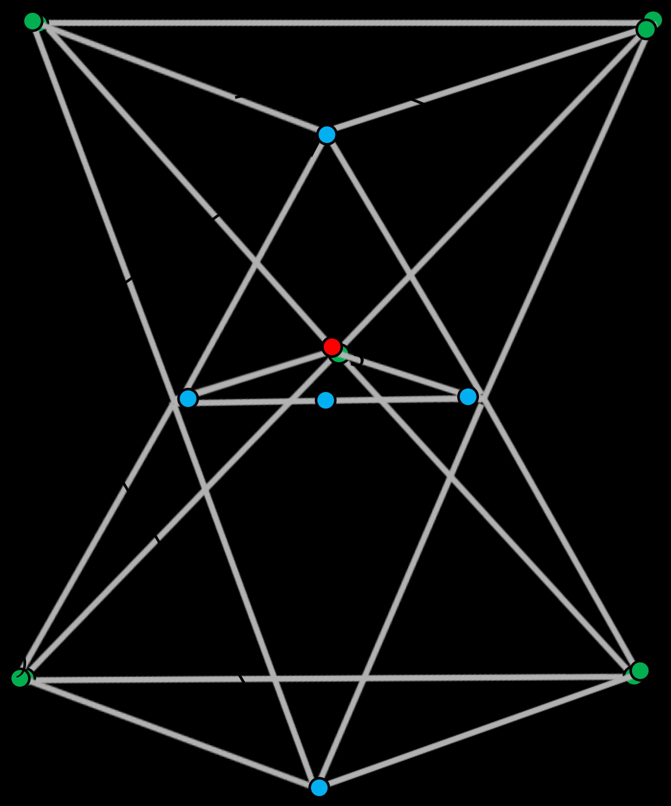


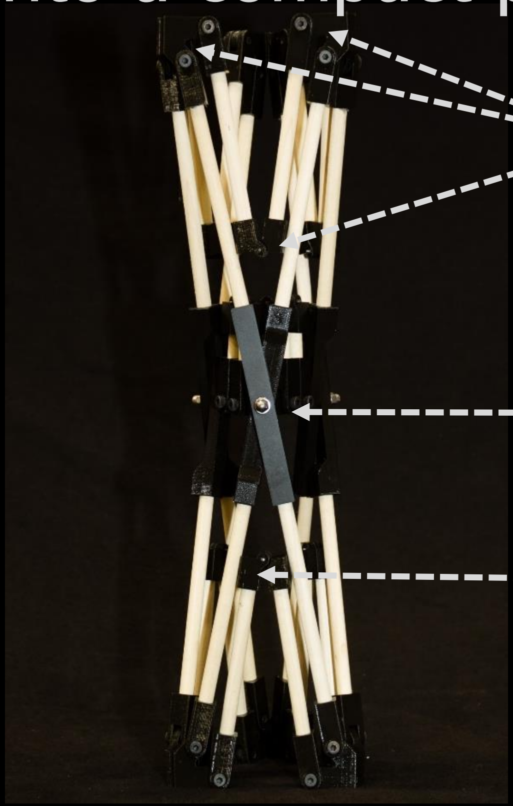
Folded TriTruss

Packaged Configuration

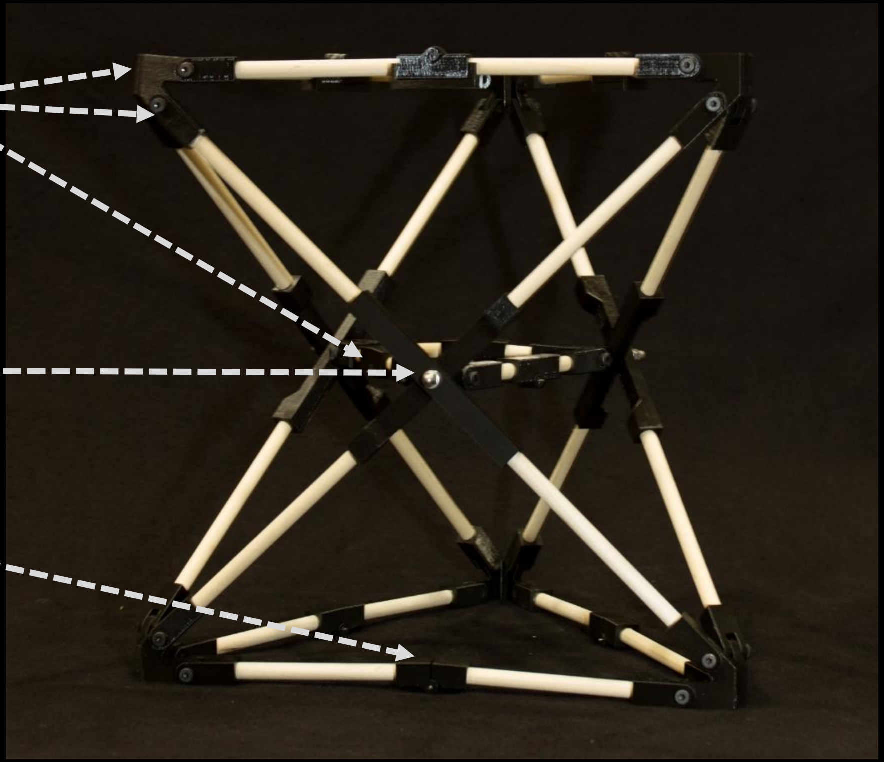


Deployed Configuration

The "Camping Chair" TriTruss has multiple hinge joints that fold the TriTruss into a compact package.



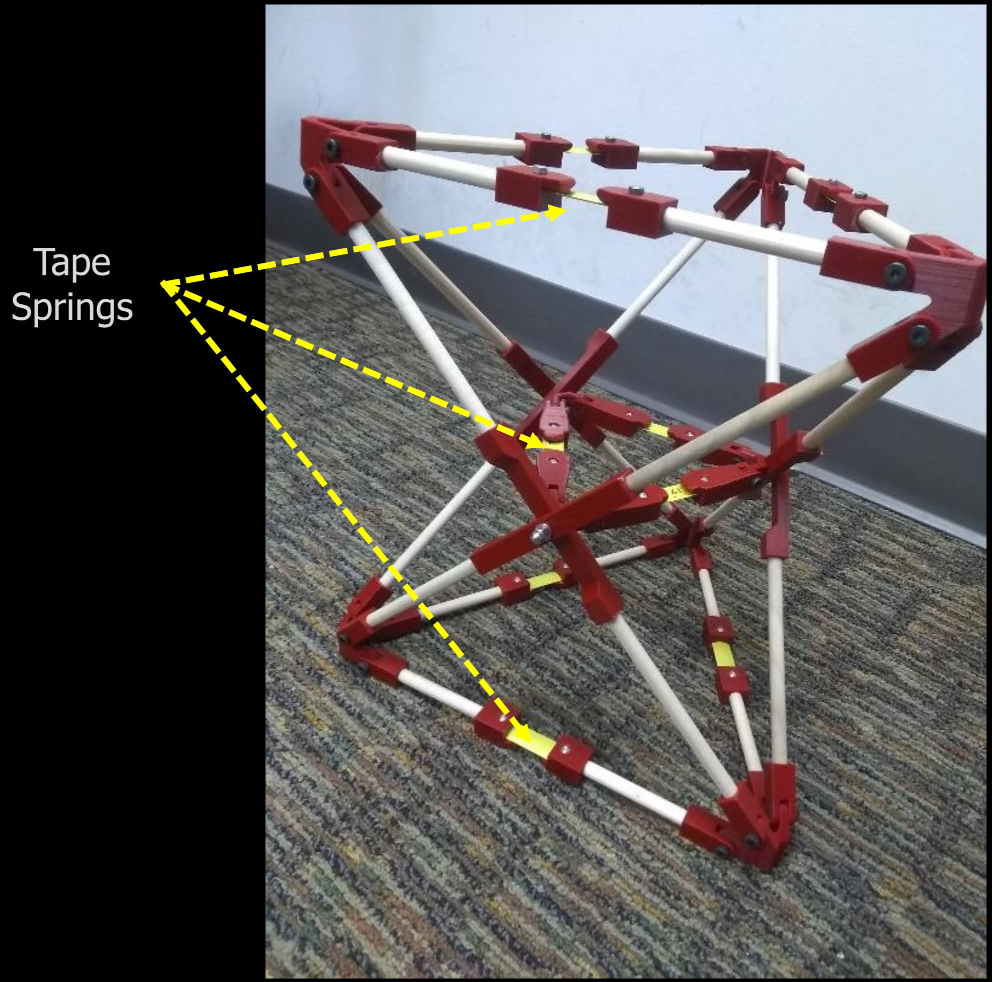
Packaged Configuration



Deployed Configuration

Features:
- Very compact packaging
- Full package only; mirror raft cannot be integrated
- 42 hinges

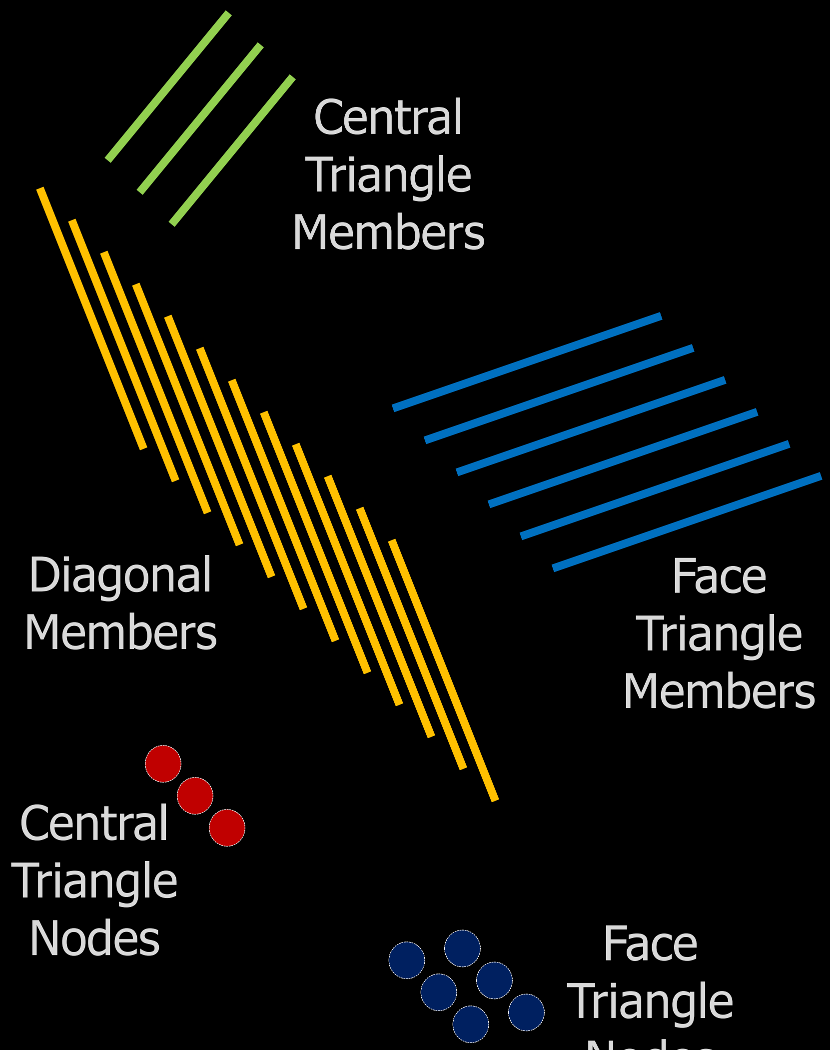
A variant of the "Camping Chair" TriTruss replaces the hinge joints with composite tape springs, allowing the TriTruss to deploy under internal strain energy.



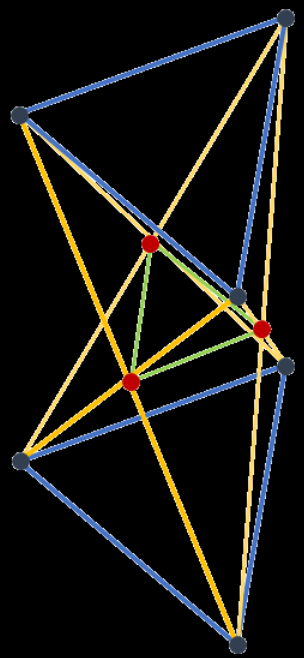
Deployed Configuration

Strain Energy Deployment

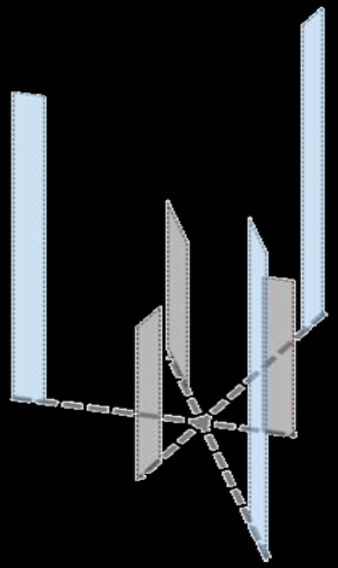
A “Fully erectable” TriTruss is launched in components and fully assembled on orbit.



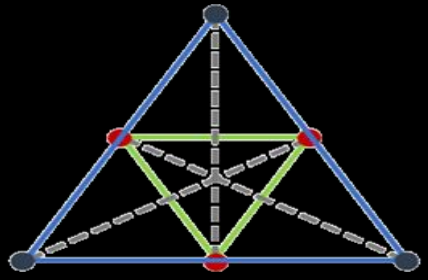
Components



Assembled Configuration

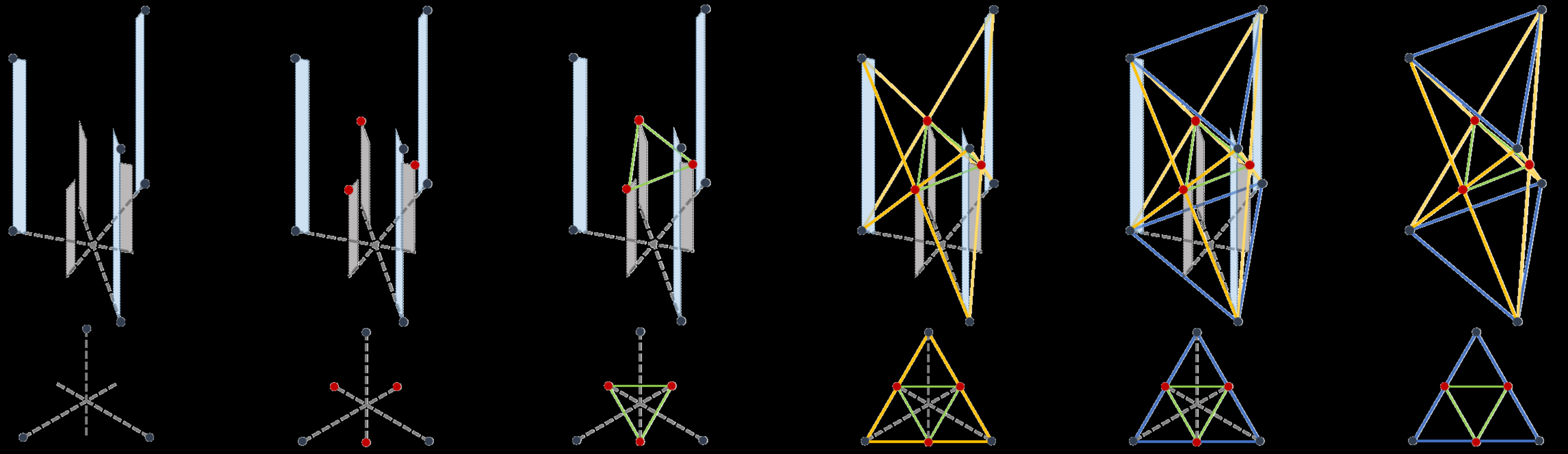


Concept for an Assembly Jig



TriTruss (Top Down View) on Jig

A "Fully erectable" TriTruss is launched in components and fully assembled on orbit by robotic agents.

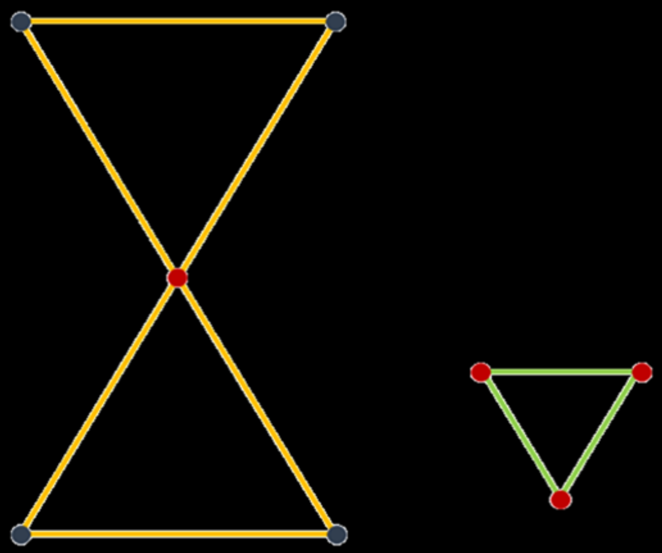


1. Secure Face triangle nodes on jig	2. Secure central triangle nodes on jig	3. Attach central triangle members	4. Attach diagonal triangle members	5. Attach face triangle members	6. Remove TriTruss from jig

Features:

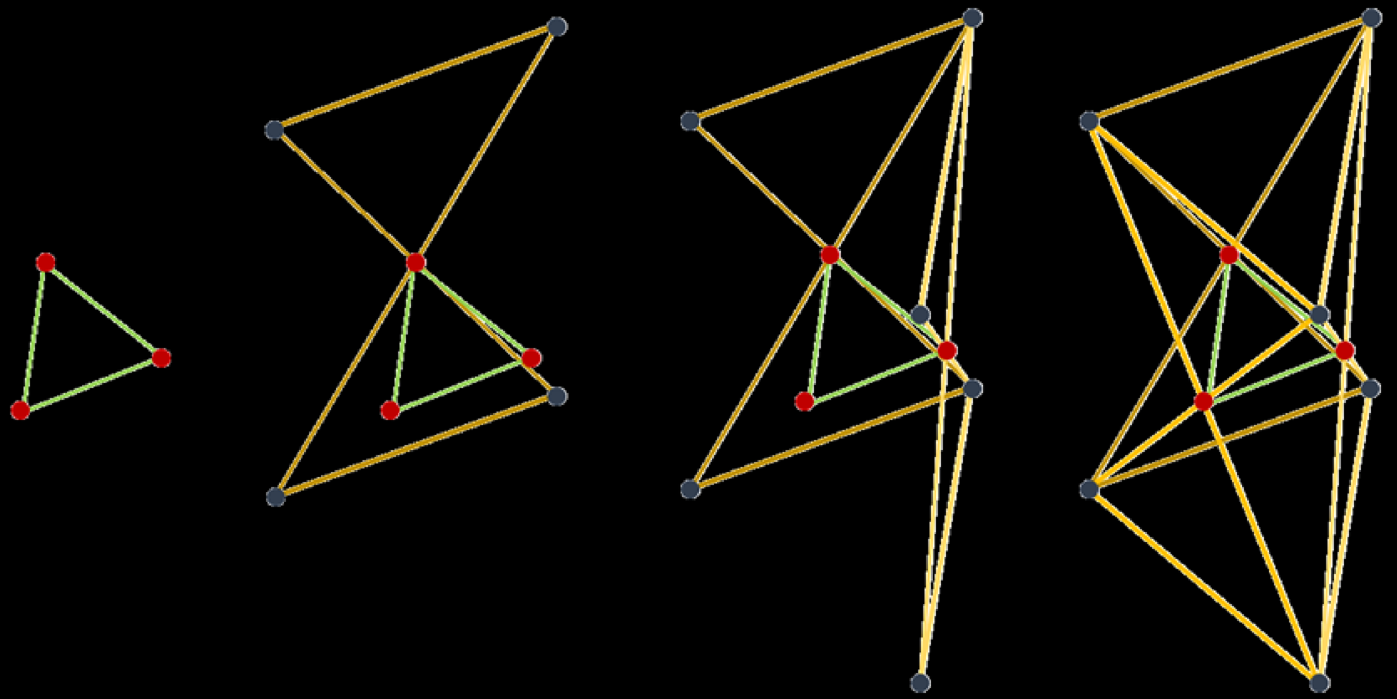
- Maximum packaging efficiency
- Subsystems cannot be integrated prelaunch
- DOF not required at nodes
- Requires a jig and end-effectors to grapple nodes and members

A “Semi Erectable” TriTruss has preassembled panels and central triangle subcomponents that are assembled on orbit by robotic agents.



Side Panel (3)   Central Triangle

Subcomponents Packaged
for Launch

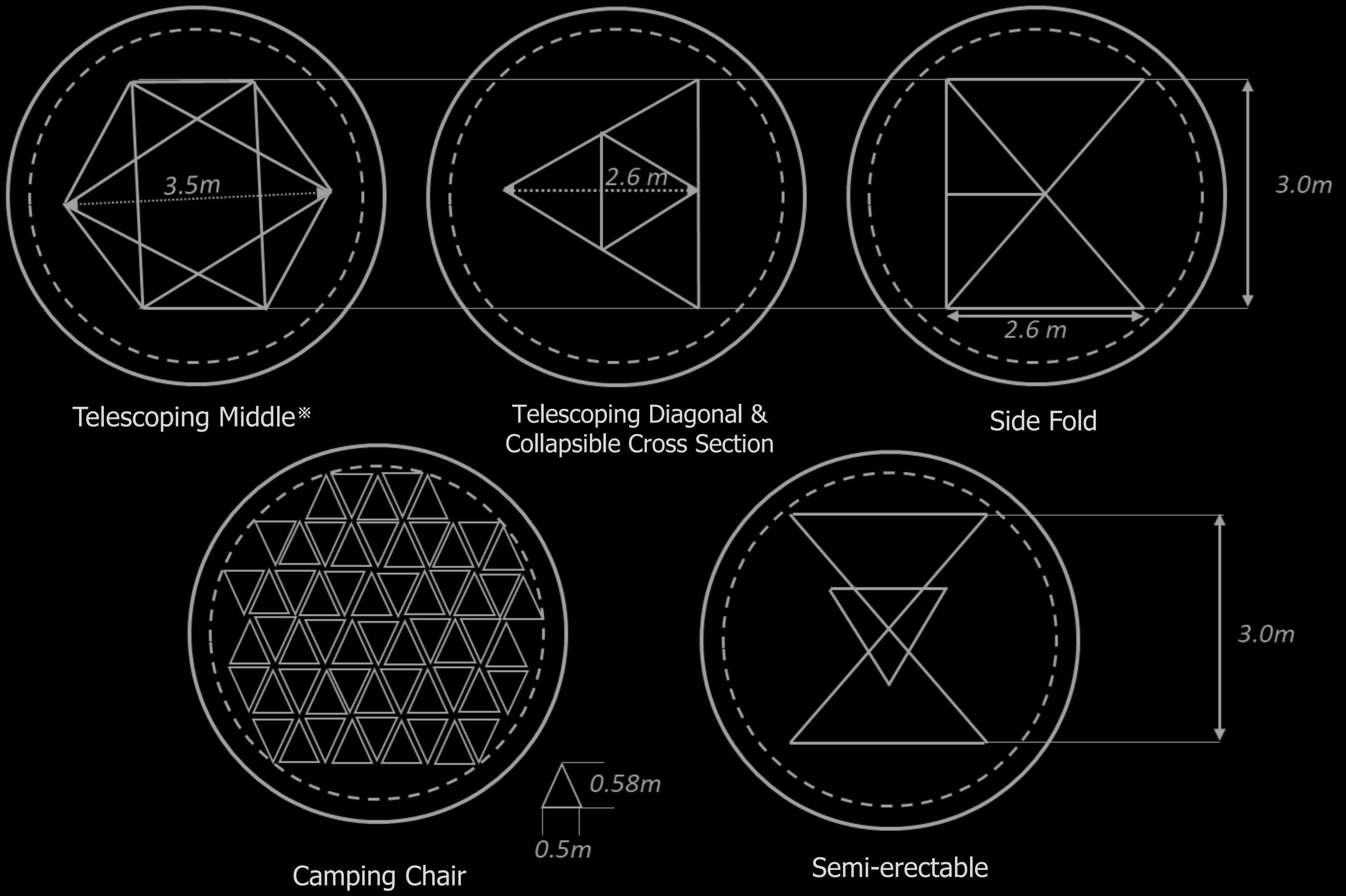


Assembly Steps (Jig is removed for clarity)

Features:

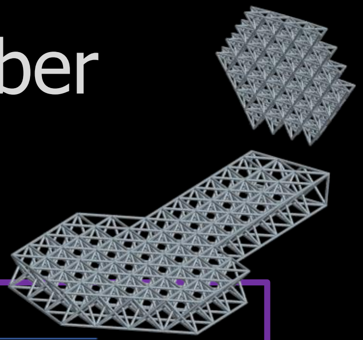
- Compact packaging
- Subsystems cannot be integrated prelaunch
- DOF not required at nodes
- Requires a jig and end-effectors to grapple nodes and members

The packaging shape in a 4.6-m working diameter fairing for each concept indicates potential packing density.

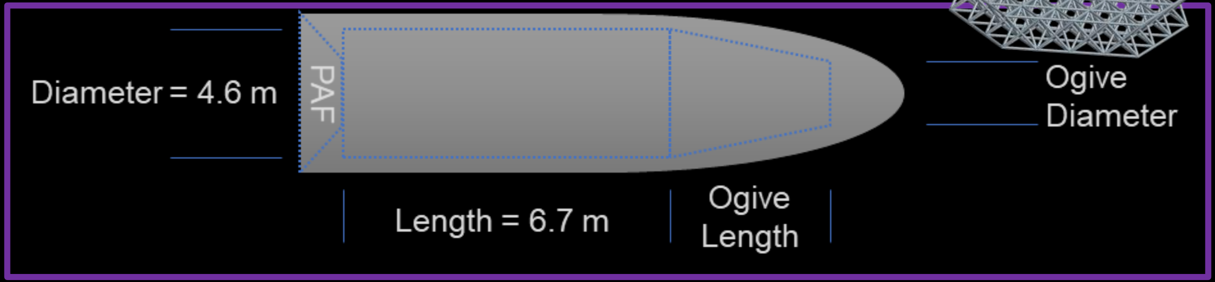


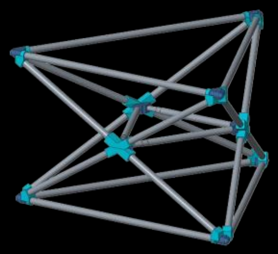
※the geometry presented is for an H/a = $\sqrt{3}/3$ TriTruss as H/a=1 will exceed the working diameter of the fairing

The packaging efficiency can be estimated as to the number of launches to assemble the foundational structure (92 TriTruss modules).



Falcon Heavy Fairing Dimensions



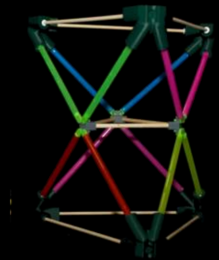


Telescoping Middle

(31 TriTruss modules per launch)

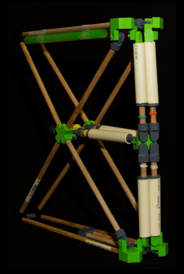
Telescoping Diagonal

(31 TriTruss modules per launch)

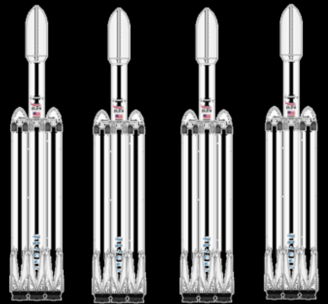


Collapsible Cross Section

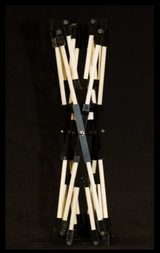
(31 TriTruss modules per launch)



Side Fold

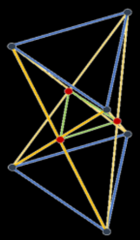


(24 TriTruss modules per launch)



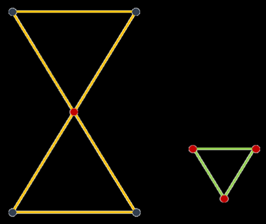
Camping Chair

(118 TriTruss modules per launch)



Fully Erectable

(686 TriTruss modules per launch)†



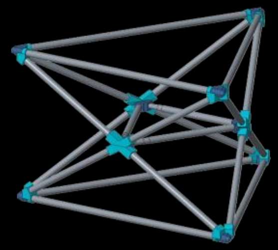
Semi Erectable

(31 TriTruss modules per launch)†

†Does not represent the optimal packaging scheme

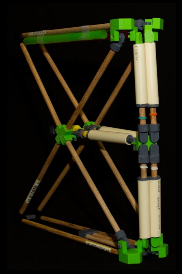
The overall packaging efficiency is assessed to be highest for the Camping Chair and Fully Erectable P&D concepts.

LOW



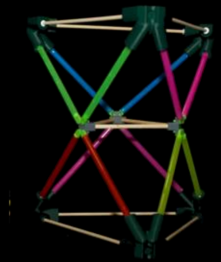
Telescoping Middle

MEDIUM

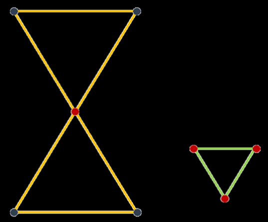


Side Fold

Telescoping Diagonal

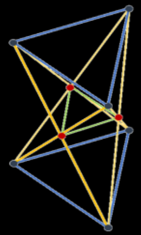


Collapsible Cross-Section

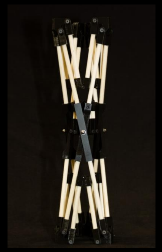


Semi Erectable

HIGH

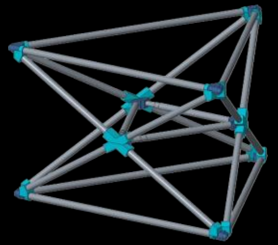
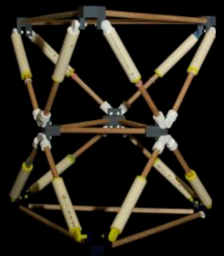
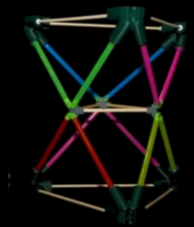
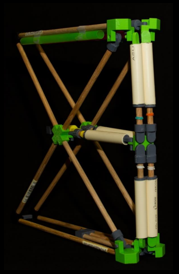
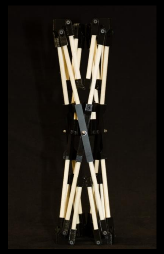
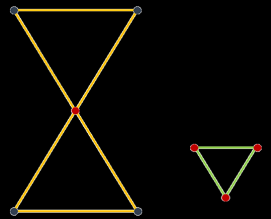
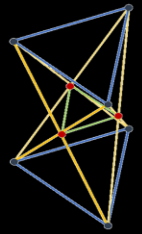


Fully Erectable



Camping Chair

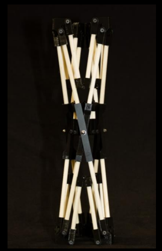
The versatility metric is assessed by looking at packaging, and integration of mirror rafts and subsystems and verification of module performance prior to launch.

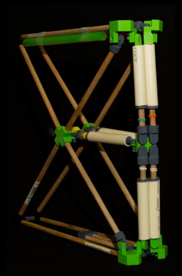
	Telescoping Middle	Telescoping Diagonal	Collapsible Cross Section	Side Fold	Camping Chair	Semi Erectable	Fully Erectable
Partial Package	No	Yes	Yes	No	No	N/A	N/A
Fully Package	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Integration of Mirror Prelaunch	Yes	Yes	Yes	No	No	No	No
Integration of Subsystems Prelaunch	No	Yes	Yes	No	No	No	No
Verify Module Prior to Launch	Yes	Yes	Yes	Yes	Yes	No	No

The overall versatility is assessed to be highest for the telescoping diagonal and collapsible cross section P&D concepts.

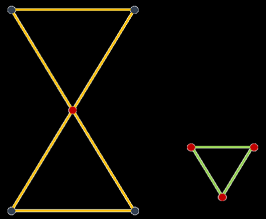
LOW



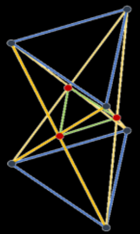
Camping Chair



Side Fold

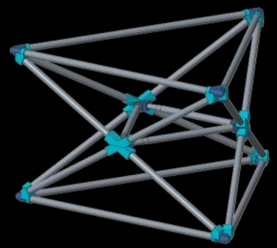


Semi Erectable



Fully Erectable

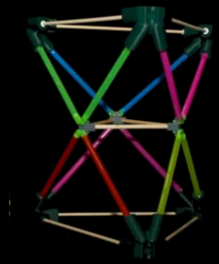
MEDIUM



Telescoping Middle

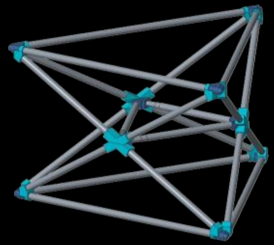
HIGH

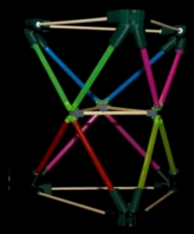
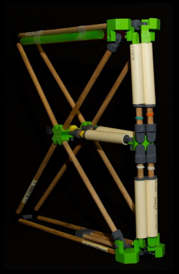
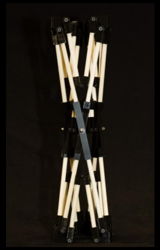
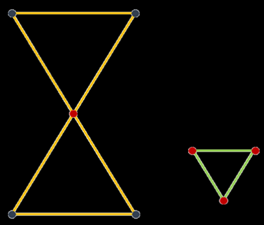
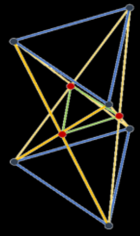
Telescoping Diagonal



Collapsible Cross Section

The mechanical complexity is assessed by looking at degrees of freedom (DOF), and the types of members required to enable packaging.

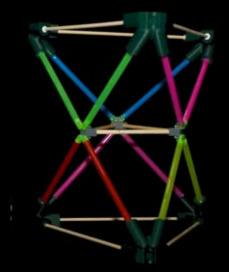


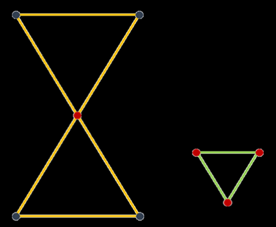
	Telescoping Middle	Telescoping Diagonal	Collapsible Cross Section	Side Fold	Camping Chair	Semi Erectable	Fully Erectable
Joints Required	Hinges	Hinges	Connecting joints only	Hinges	Hinges, Scissor joints	Connecting joints only	Connecting joints only
DOF	18 rotational 3 translational	24 rotational 12 translational	none	11 rotational 6 translational	42 rotational 0 translational	none	none
Telescoping Members	Central Triangle (3)	Diagonal members (12)	No	Diagonal and middle triangle (6)	No	No	No
Strain Energy Members	No	Optional Spring in diagonals (12)	Diagonal members (12)	Optional Spring in diagonals (4)	Optional tape spring hinges (42)	No	No

The overall mechanical complexity is assessed to be highest for the telescoping diagonal and lowest for the collapsible cross section and erectable P&D concepts.

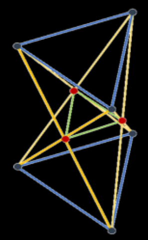
LOW



Collapsible Cross Section

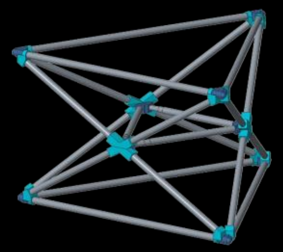


Semi Erectable

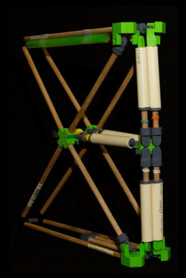


Fully Erectable

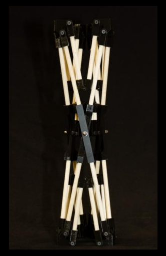
MEDIUM



Telescoping Middle



Side Fold

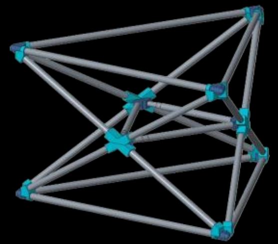


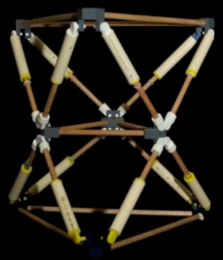
Camping Chair

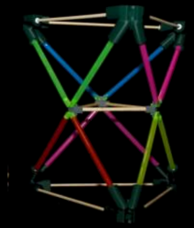
HIGH

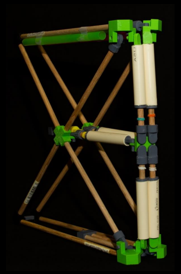
Telescoping Diagonal

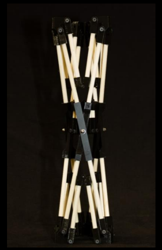
The deployment complexity is assessed by the steps required to deploy (or assemble) the TriTruss module on orbit, canister design and infrastructure needed for assembly.

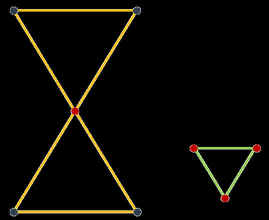

Telescoping Middle

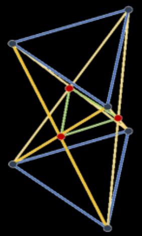

Telescoping Diagonal


Collapsible Cross Section


Side Fold


Camping Chair


Semi Erectable

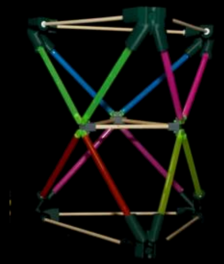

Fully Erectable

- Deployables
  - Robotic deployment: apply force to deploy or control strain energy member release
  - Canisters to hold TriTruss modules in place during launch
  - Additional infrastructure not required

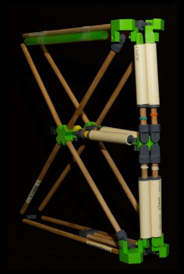
- Erectables
  - Robotic assembly
  - Canisters to organize and store components
  - Assembly infrastructure (jigs, etc.) required for assembly

The overall deployment complexity is assessed to be highest for the erectable P&D concepts and lowest for the deployables.

LOW

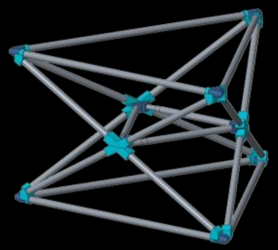


Collapsible Cross Section

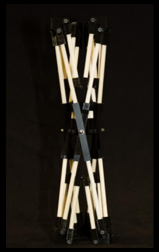


Side Fold

Telescoping Diagonal

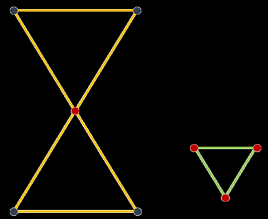


Telescoping Middle

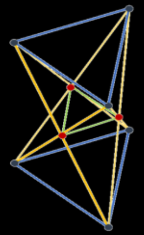


Camping Chair

HIGH

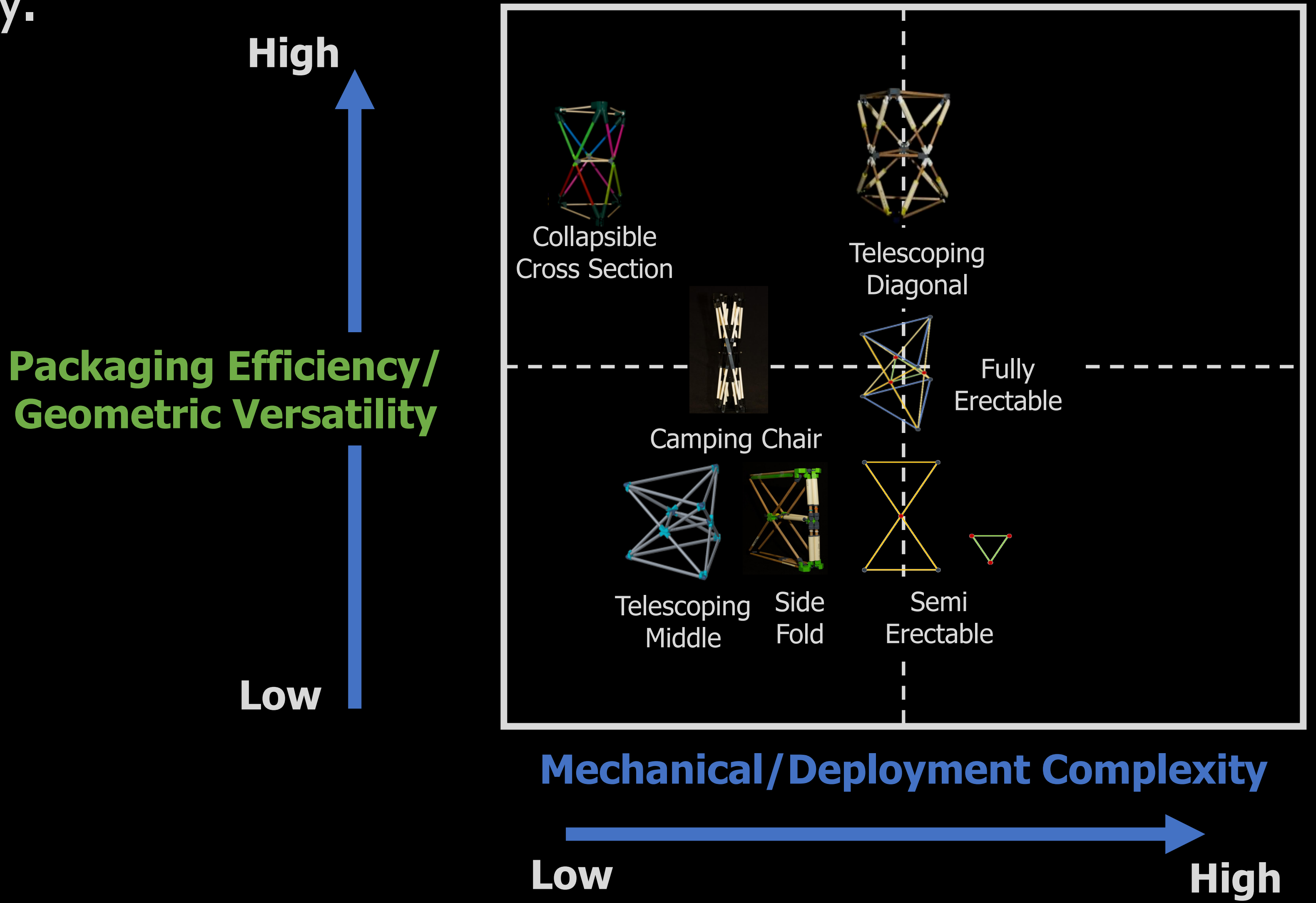


Semi Erectable

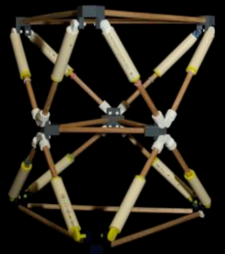


Fully Erectable

Comparing the P&D concepts shows that the collapsible cross-section, telescoping diagonal and camping chair are closest to the ideal P&D concept established at the onset of the trade study.

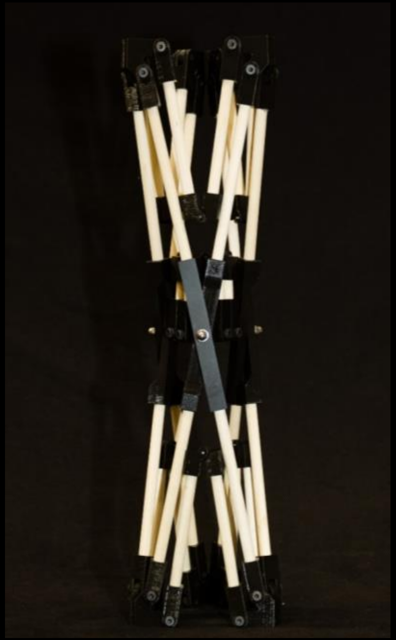


P&D concepts are selected for further refinement and evaluation in the next phase of the trade study.

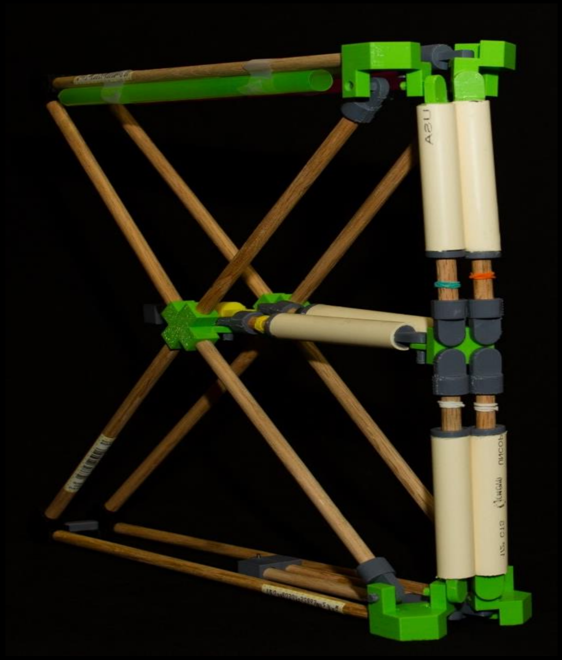


Telescoping Diagonal

Collapsible Cross Section



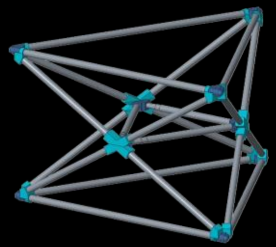
Camping Chair



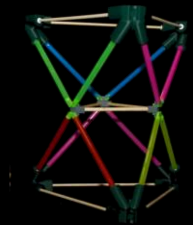
Side Fold

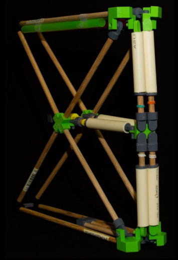
The ongoing trade study investigated concepts for P&D of TriTruss modules for on-orbit assembly of a 20-m class iSAT.

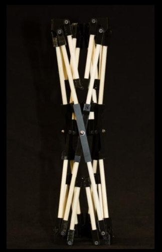
- Evaluated 7 concepts (5 deployable; 2 erectable) to understand the kinematics of packaging

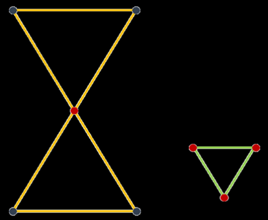

Telescoping Middle

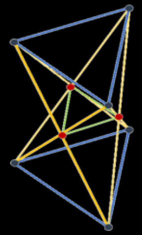

Telescoping Diagonal


Collapsible Cross Section

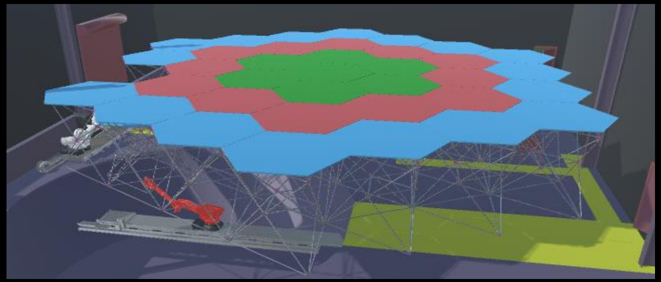

Side Fold


Camping Chair


Semi Erectable


Fully Erectable

- Down selected to three concepts for future study and evaluation
- Phase 2
  - Refine TriTruss design; build scale models; expand on deployment concepts
- Phase 3
  - Recommend a TriTruss and accompanying P&D concept to build, test and evaluate as part of PASS Project



Thank you for watching : TriTruss Packaging and Deployment Trade Study

Julia Cline, Lauren Raffanello, Kyongchan Song, Brace White, Gillian McGlothin, John Dorsey, Bill Doggett

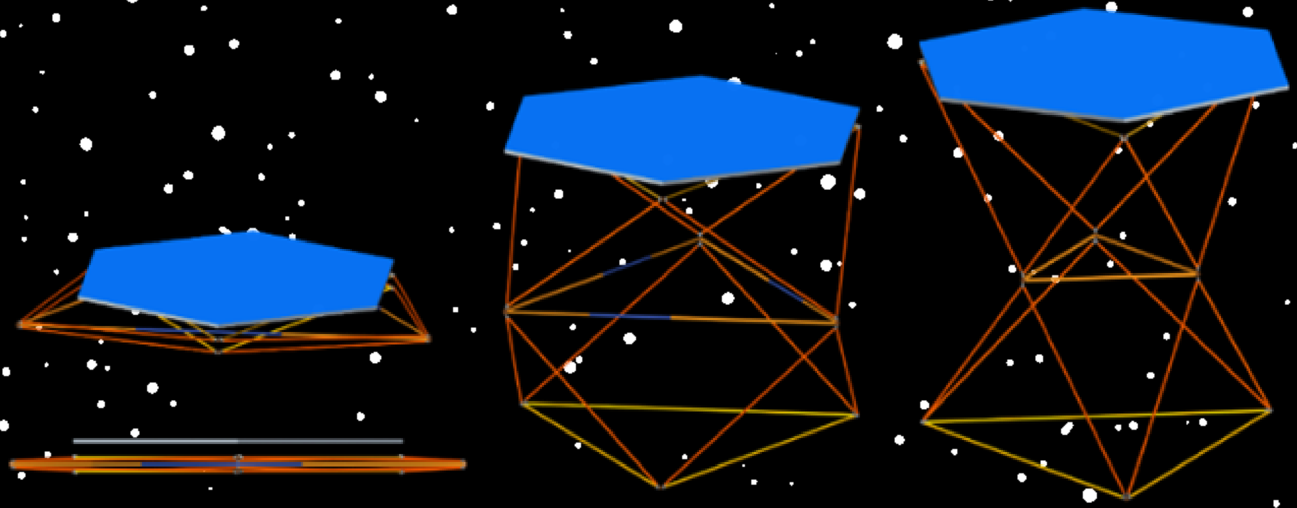
Structural Mechanics & Concepts Branch, NASA Langley Research Center, Hampton, VA

and

Iok Wong, Rounak Mukhopadhyay

National Institute of Aerospace, Hampton, VA

We look forward to the Question and Answer (Q&A) session at the 2020 AIAA ASCEND Virtual Conference 16-18 November 2020



Notional TriTruss Packaging and Deployment Strategy