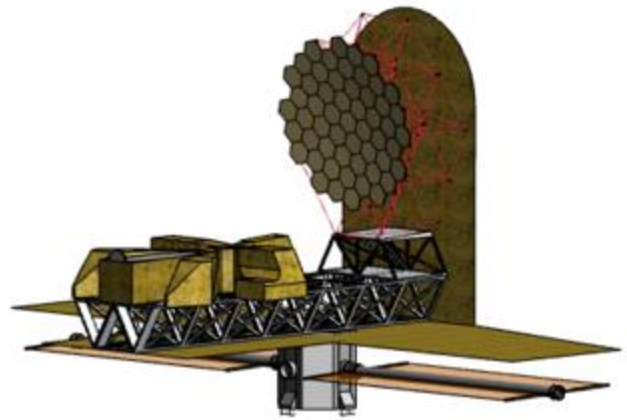
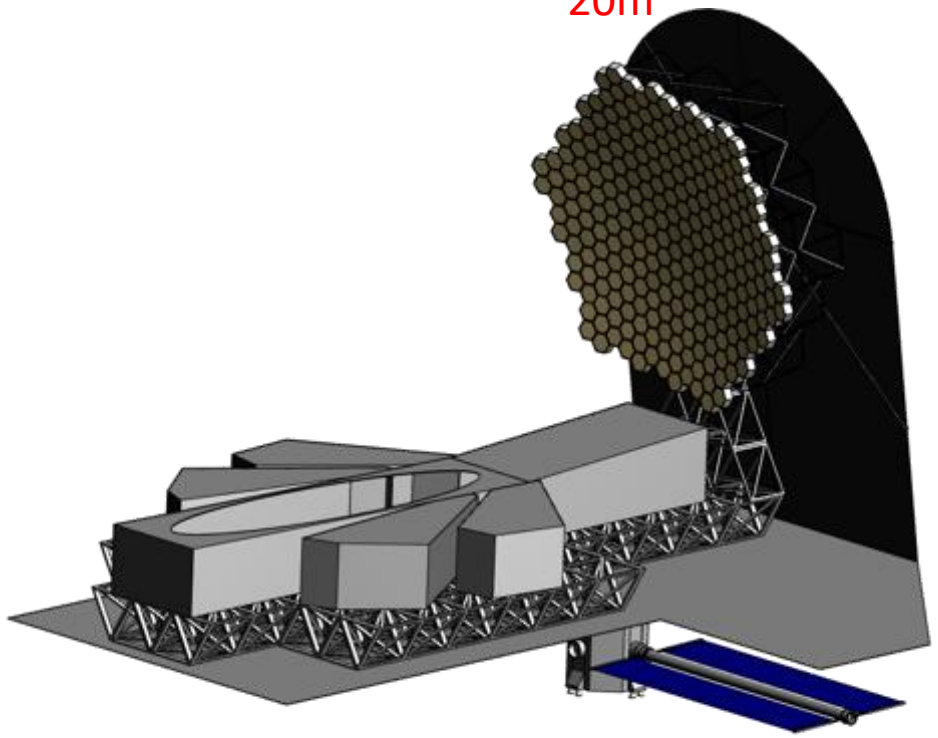
Notional ISAT Concept of Operations

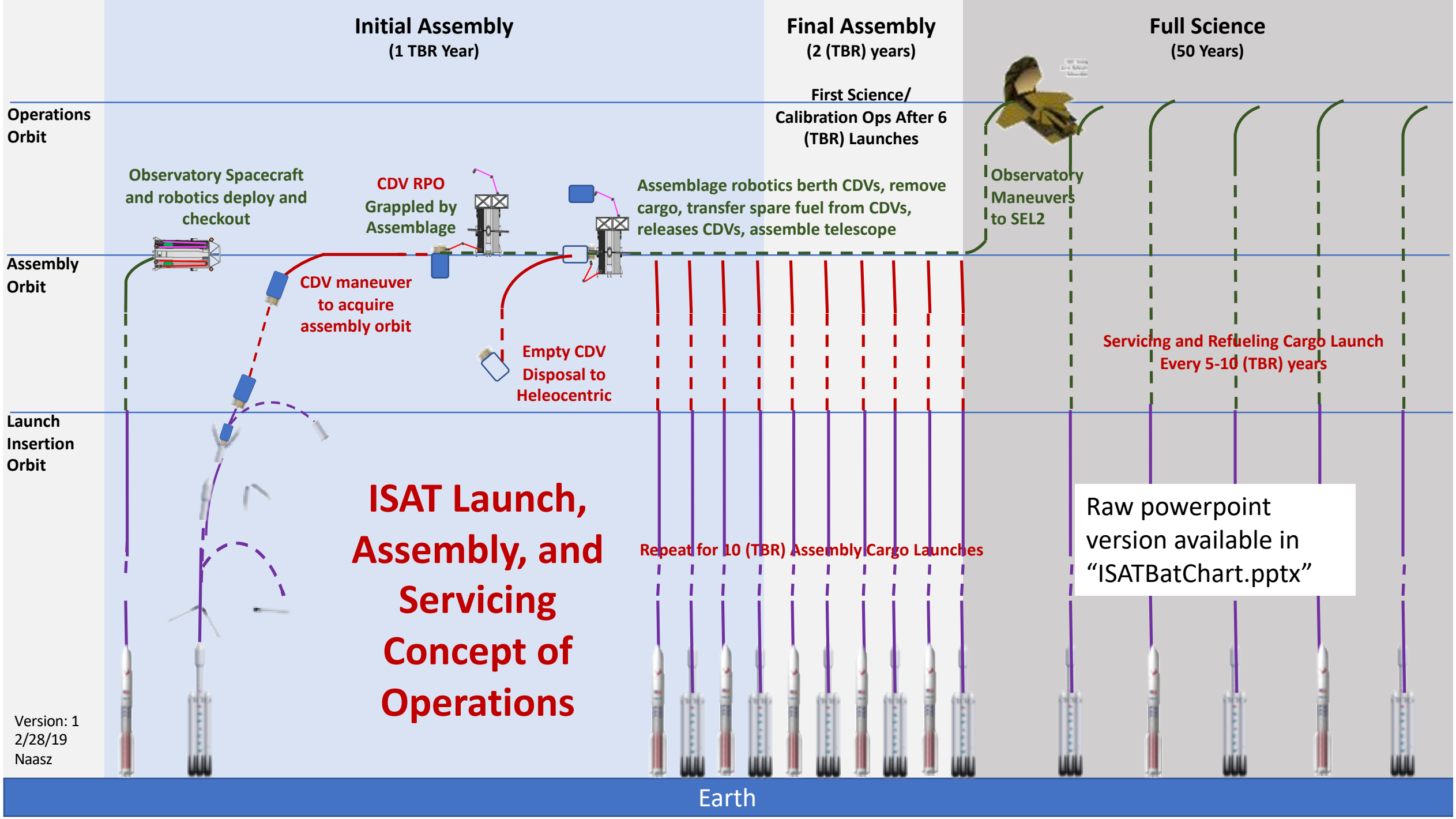
Bo Naasz
4/2/2019

10m



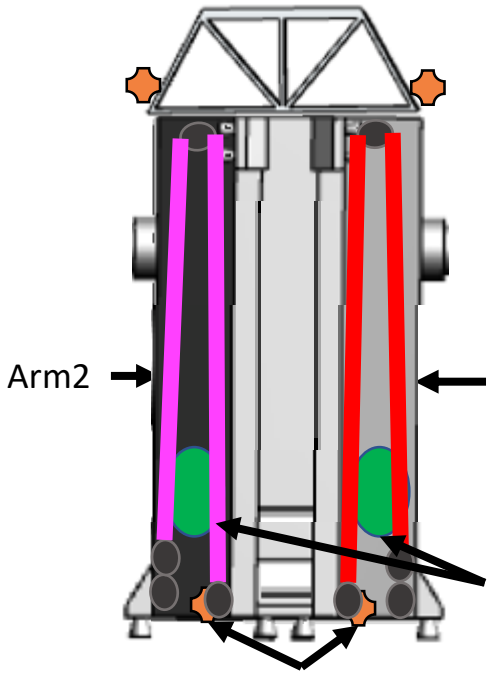
20m




Initial Assembly
(1 TBR Year)
Final Assembly
(2 (TBR) years)
Full Science
(50 Years)
Operations Orbit
Assembly Orbit
Launch Insertion Orbit
First Science/ Calibration Ops After 6 (TBR) Launches
Observatory Spacecraft and robotics deploy and checkout
CDV RPO Grappled by Assemblage
Assemblage robotics berth CDVs, remove cargo, transfer spare fuel from CDVs, releases CDVs, assemble telescope
Observatory Maneuvers to SEL2
CDV maneuver to acquire assembly orbit
Empty CDV Disposal to Heleocentric
Servicing and Refueling Cargo Launch Every 5-10 (TBR) years
ISAT Launch, Assembly, and Servicing Concept of Operations
Repeat for 10 (TBR) Assembly Cargo Launches
Raw powerpoint version available in "ISATBatChart.pptx"
Version: 1
2/28/19
Naasz
Earth

Launch Configurations (Spacecraft and Cargo)

Spacecraft w/ Robot Arms: Launched on high reliability launcher (probably with some room up top for some trusswork or adapter)



Cargo: Remaining hardware delivered in several commercial Launches, Transported to Assembly orbit by disposable **Cargo Delivery Vehicles (CDVs)**

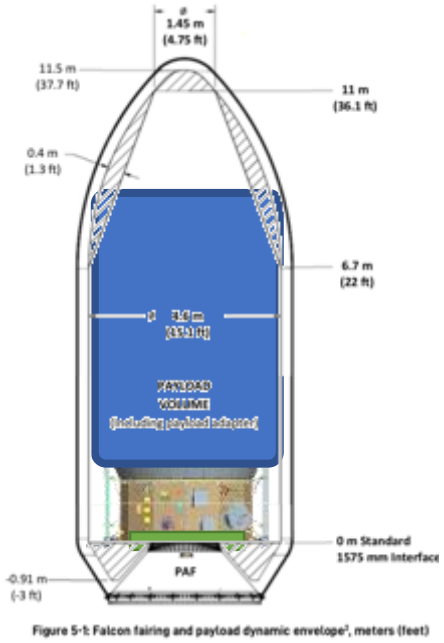
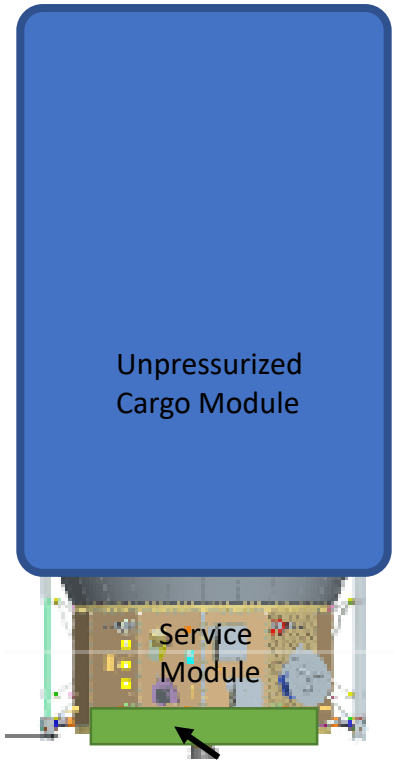


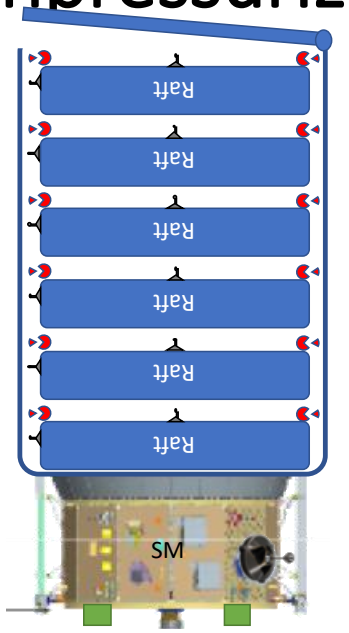
Figure 5-1: Falcon fairing and payload dynamic envelope², meters (feet)

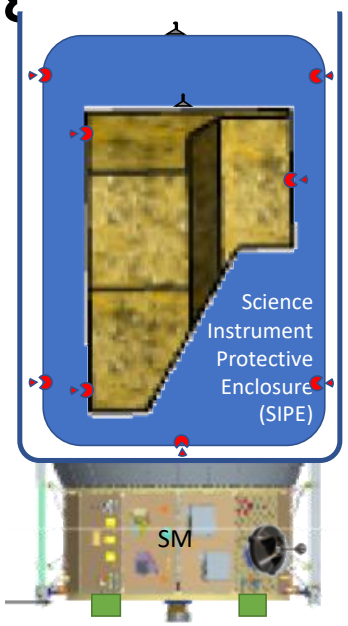
Unpressurized Cargo Module
Service Module
Cargo Delivery Vehicle

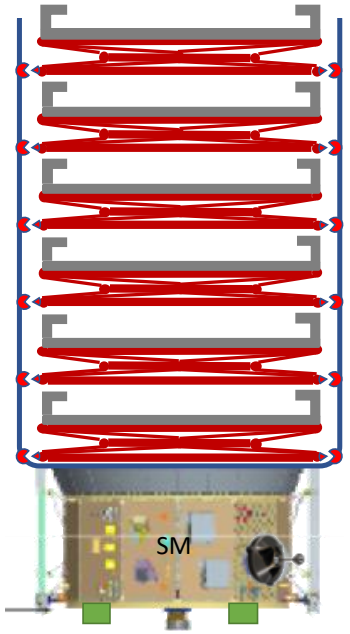


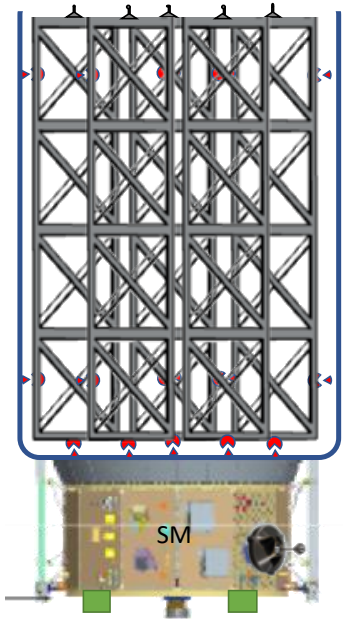
Berthing Features (Passive Half?)

Notional CDV with multi-purpose, disposable, unpressurized cargo carrier



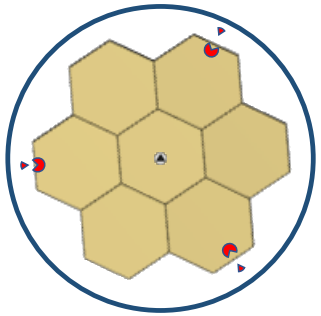






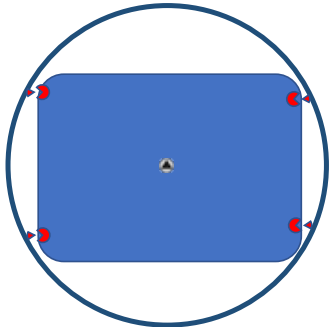
Key
- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

Falcon Heavy shown



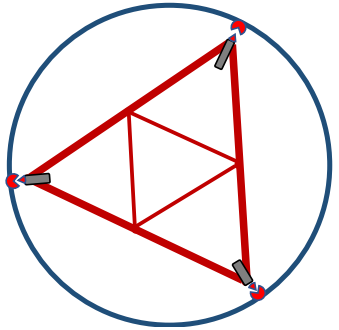
Mirror Raft Transport

- Three point mount on each raft
- 6 (TBR) Rafts per launch
- Robot actuated door



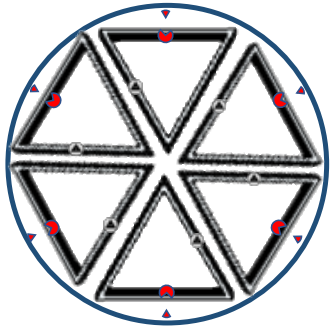
Science Instrument Transport

- Instruments delivered in SIPES
- SIPES launch mounted to Cargo Carrier
- Robotically moved to temp stowage on OTE
- 1 (TBR) SI per launch = 5 Launches



Tri-Truss Transport

- Attach similar or identical to mirror rafts
- Trusses deployed by arm prior to release from Carrier
- TBD Tri-Trusses per launch

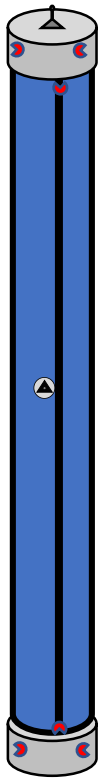


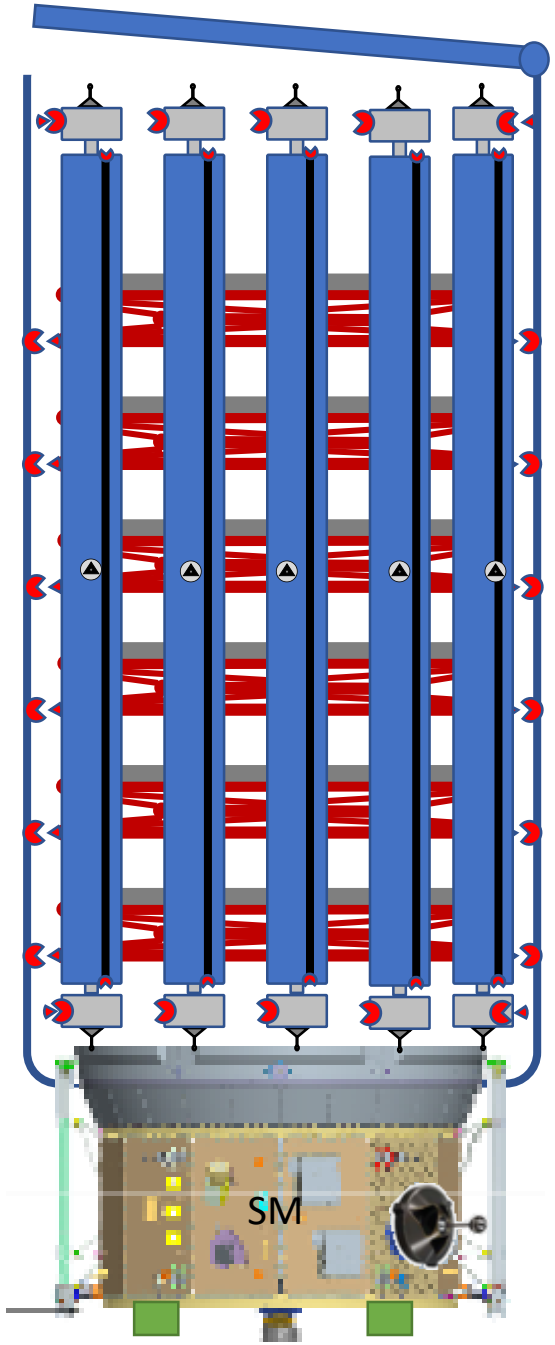
Metering Truss Transport

- TBD (6?) ~6m trusses per launch = TBD Launches
- Attach points around perimeter of carrier and at top of each truss

Sunshade Transport

(with tri-truss)





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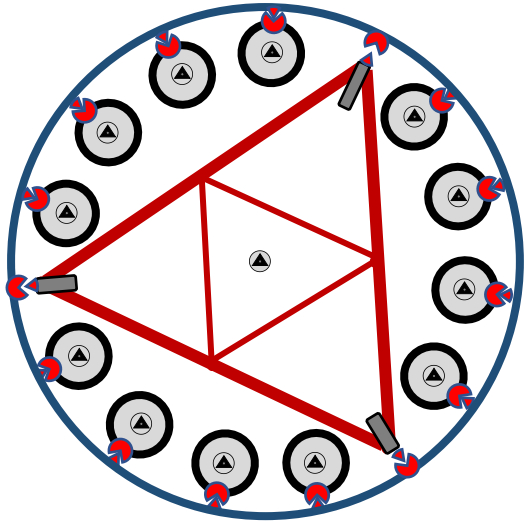
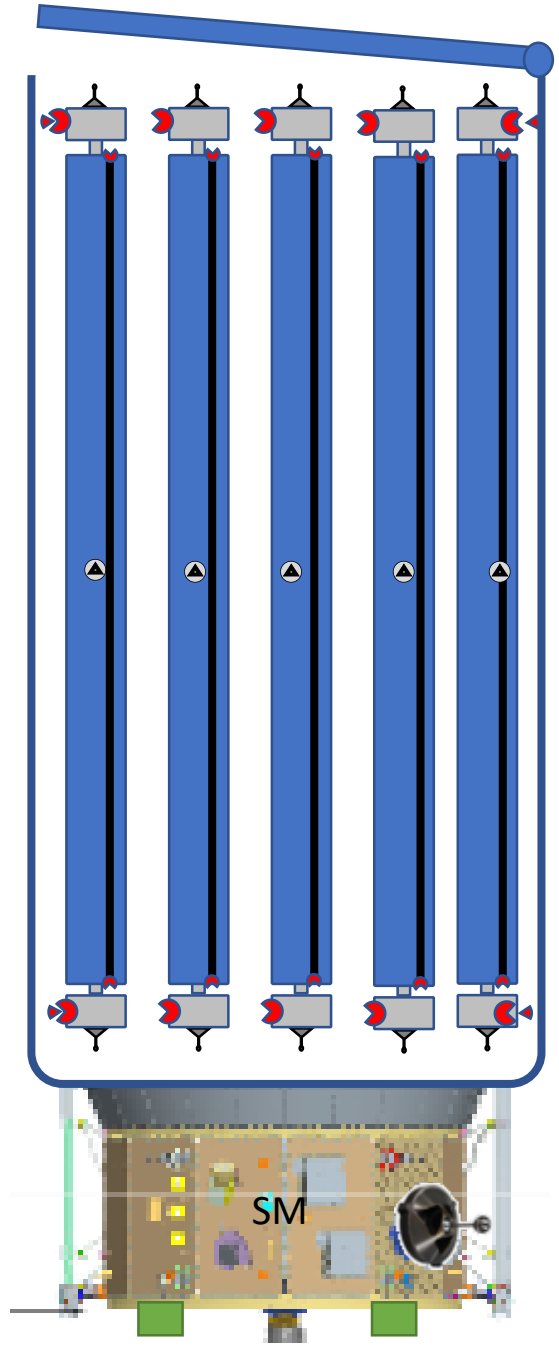
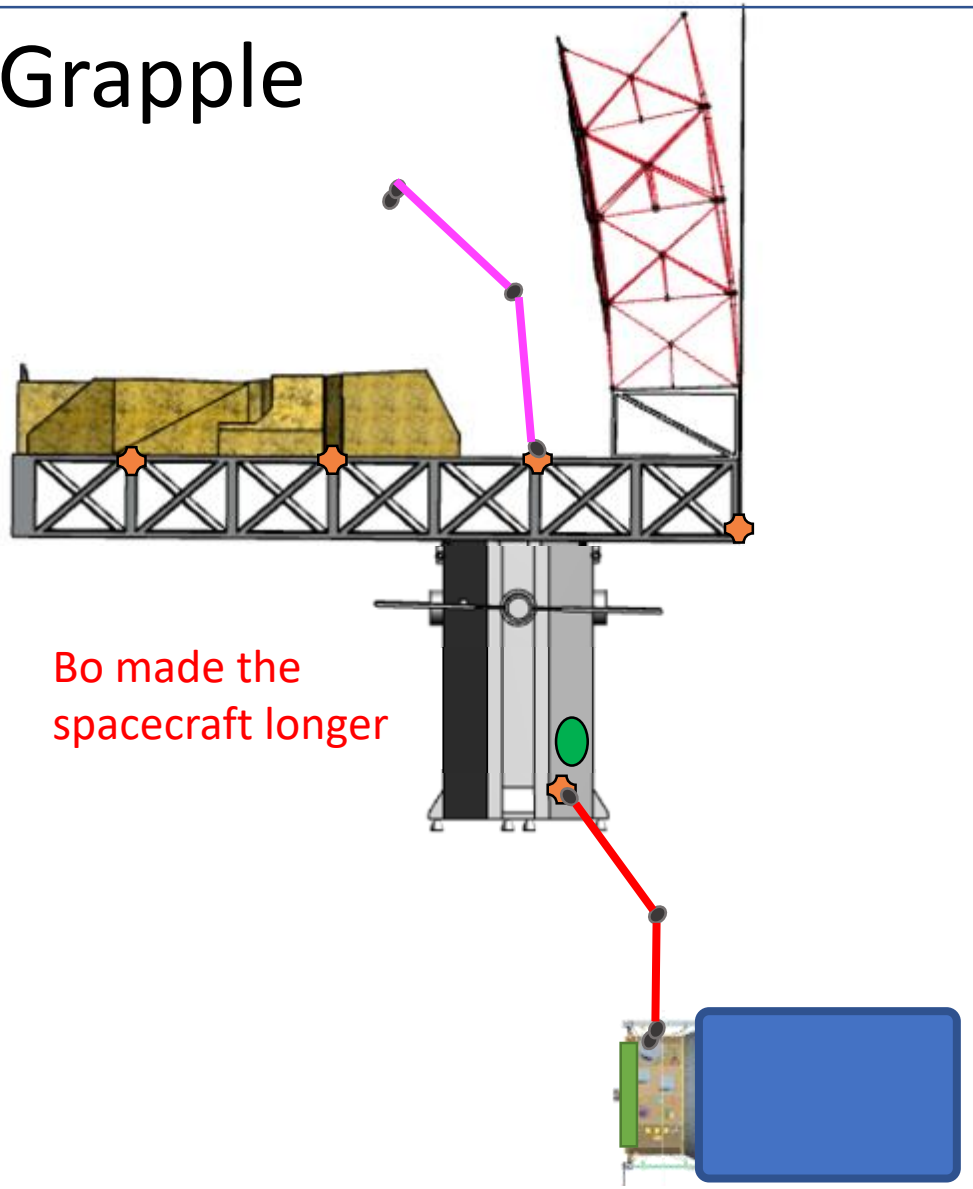




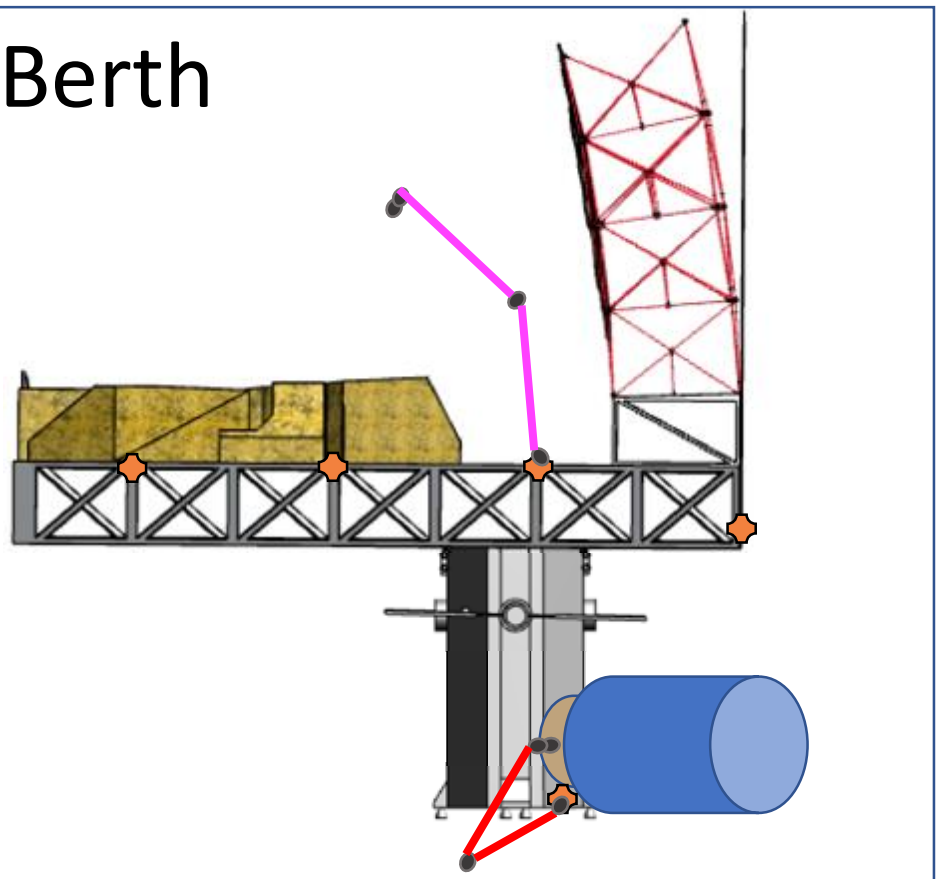
Cargo Delivery Vehicle Capture (Grapple and Berth)

Grapple



Bo made the spacecraft longer

Berth



NOTE: 10m Telescope shown, replace w/ 20m when available

NOTE 2: This graphic is not intended to imply an assembly sequence

Key

- Grapple/Grasp Feature
- Passive Berthing Feature
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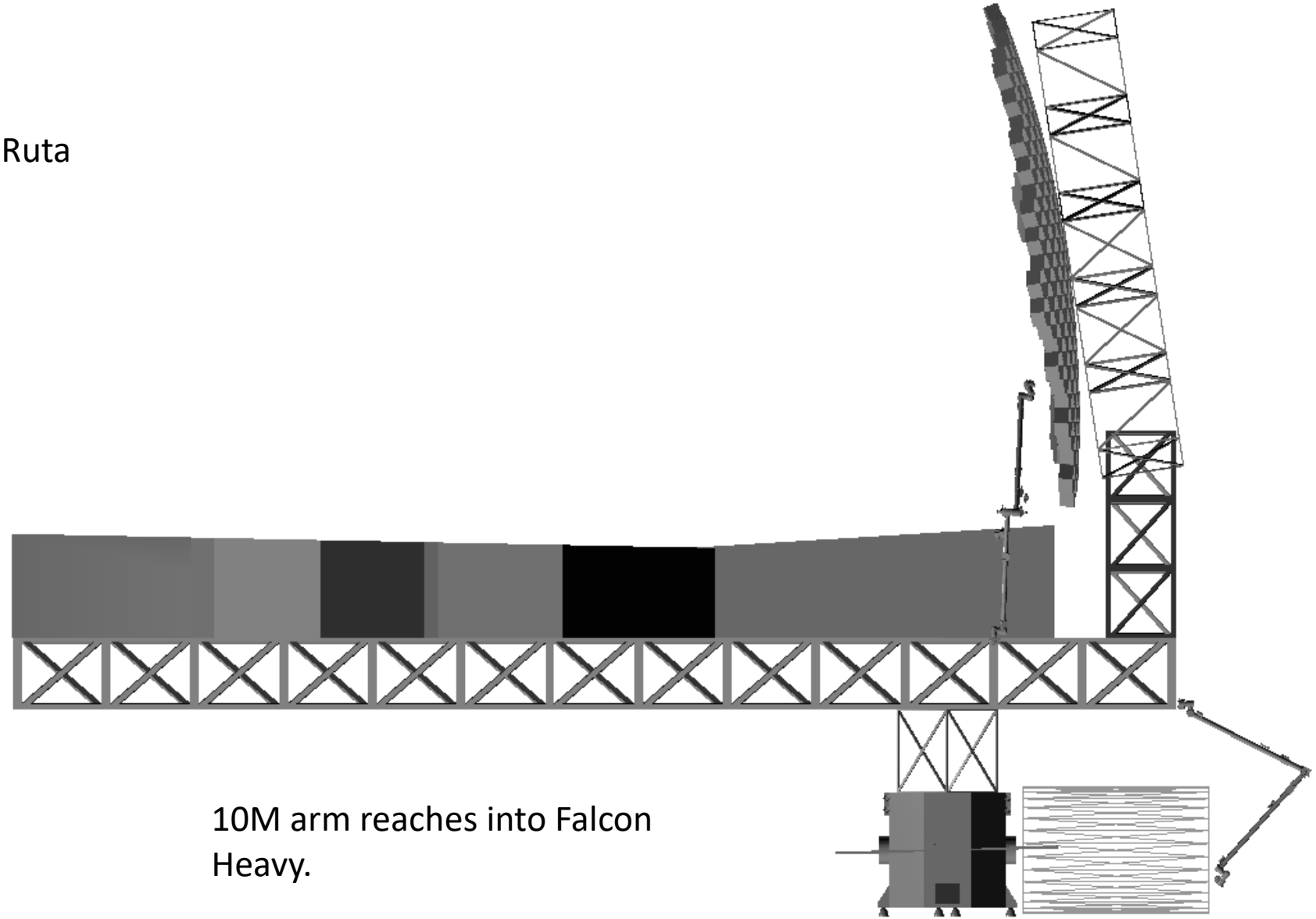
From Ken Ruta

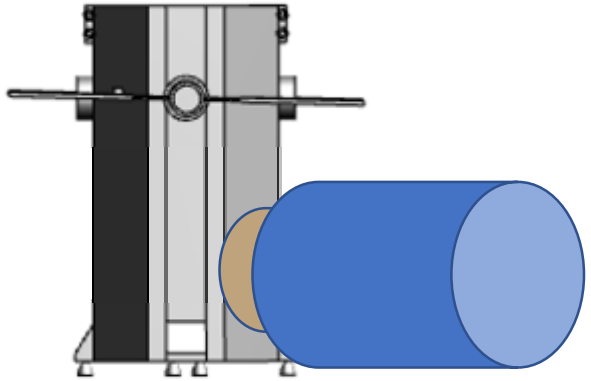


10M arm reaches into Falcon Heavy.

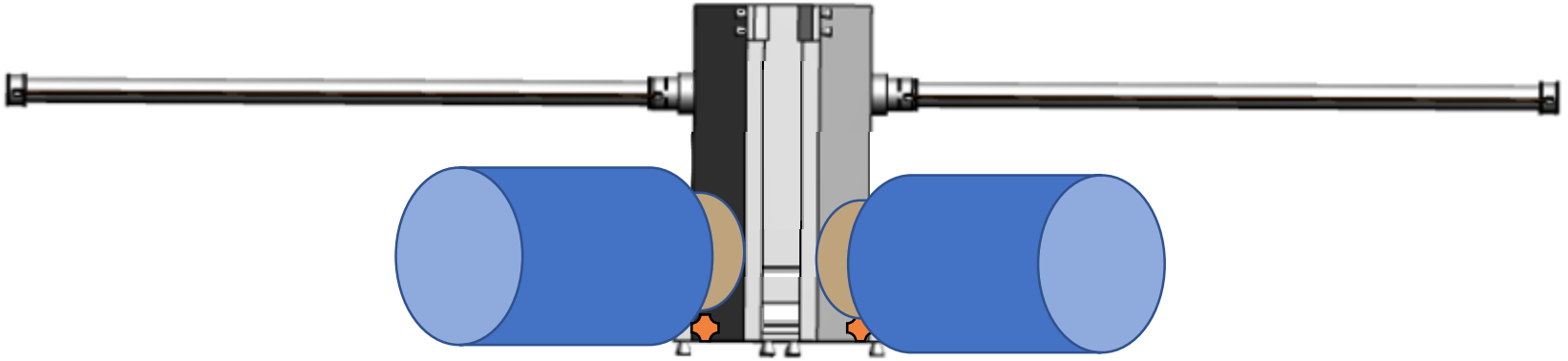
20m telescope shown

Option to provide two (2) Visiting Vehicle berthing locations

Side View



Back View



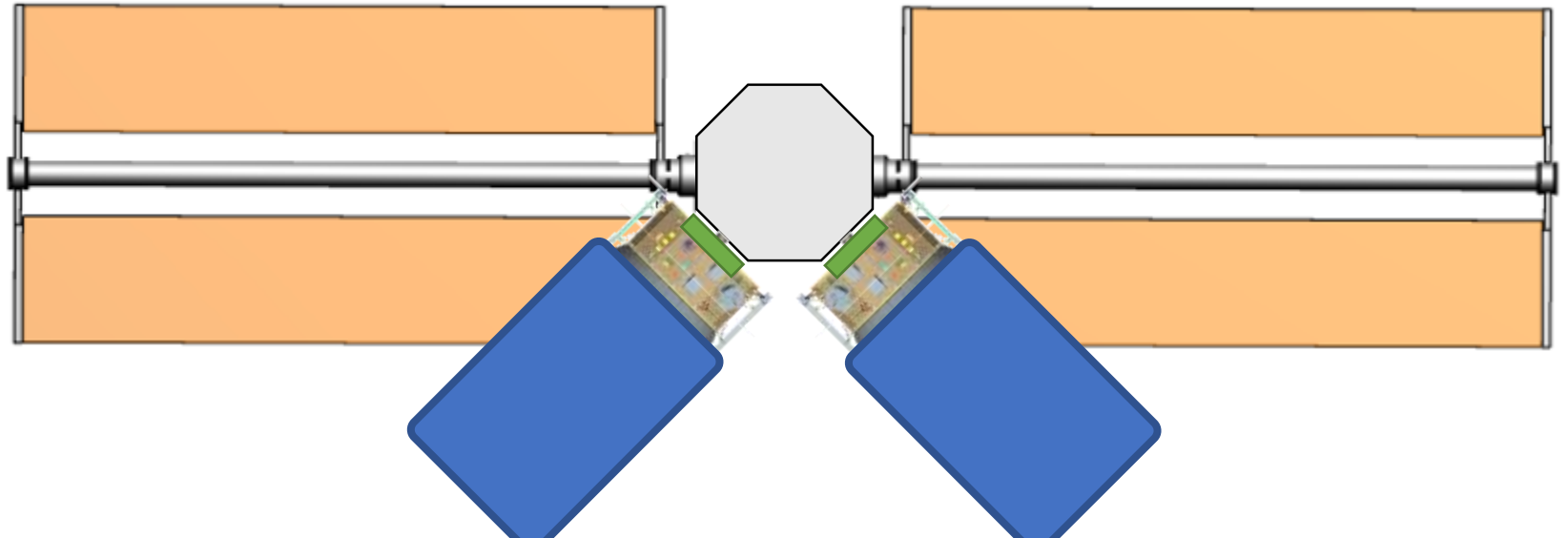
Trades:

1. 1 or 2 VV berthing ports?
2. All on SC, or some on OTE?
3. Active mechanisms on the visiting vehicles (limited life) or spacecraft (need fewer, so less $)
4. Type of interface between spacecraft and OTE (docking/berthing, other)

Question:

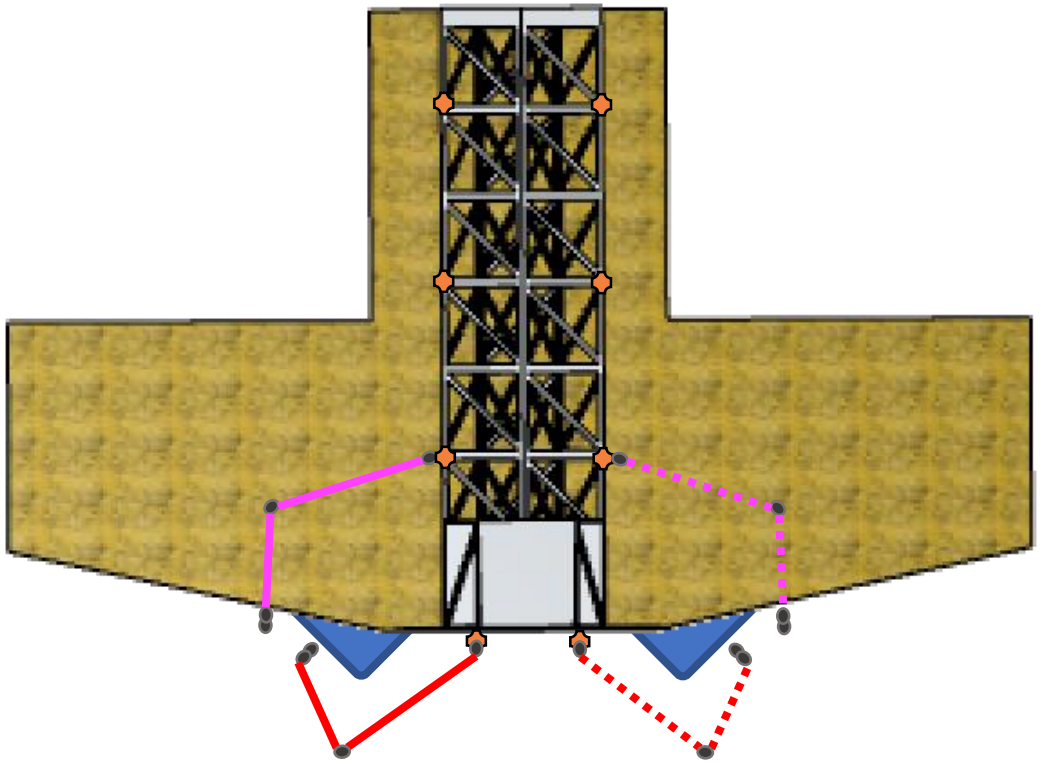
How does spacecraft survive 30-50 years? Recommend wholesale replacement of spacecraft and arms – need to draw up that conops. Probably means we need spacecraft to dock to OTE

Bottom View

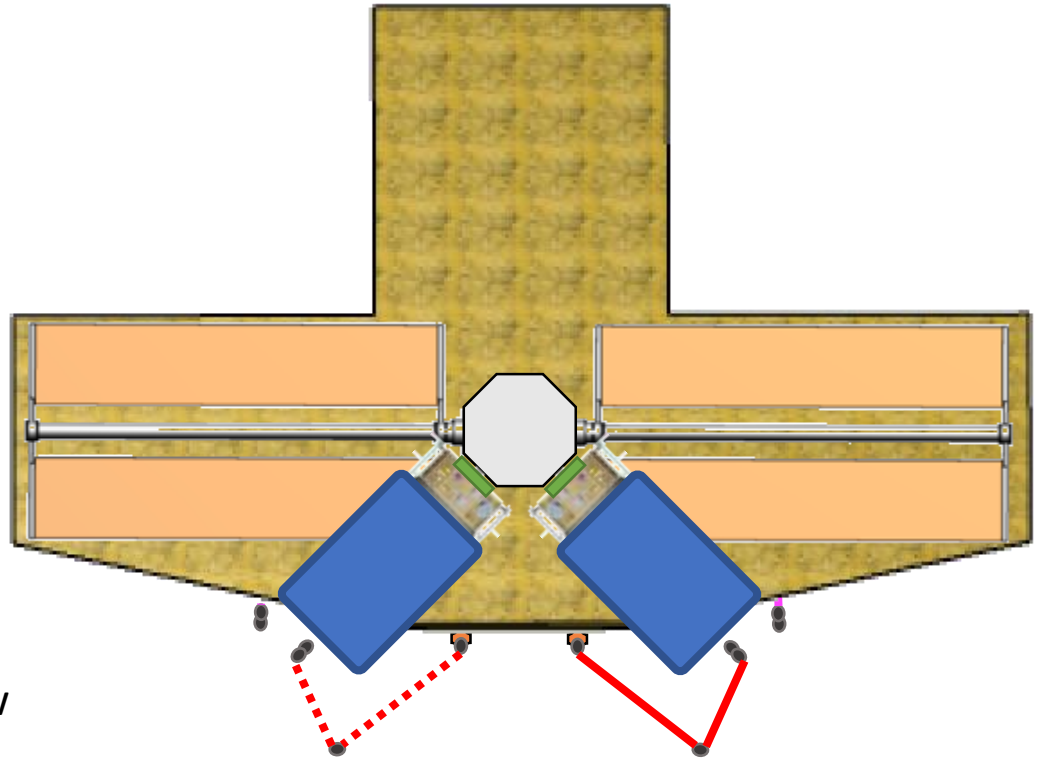


Option to provide two (2) berthing locations

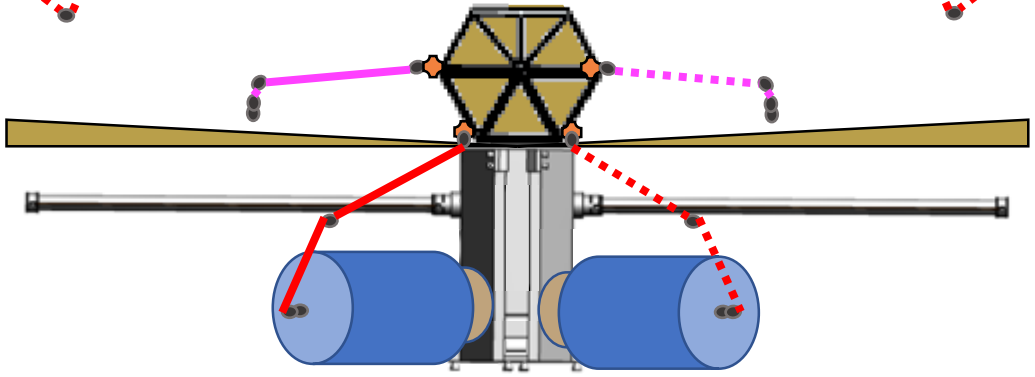
Top View



Bottom View



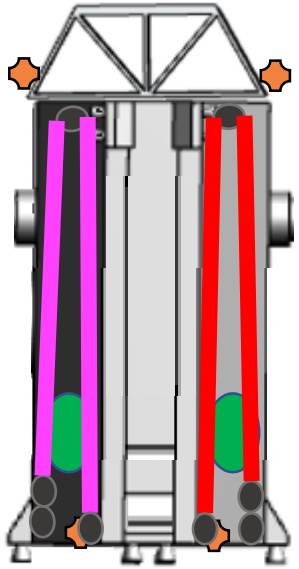
Back View



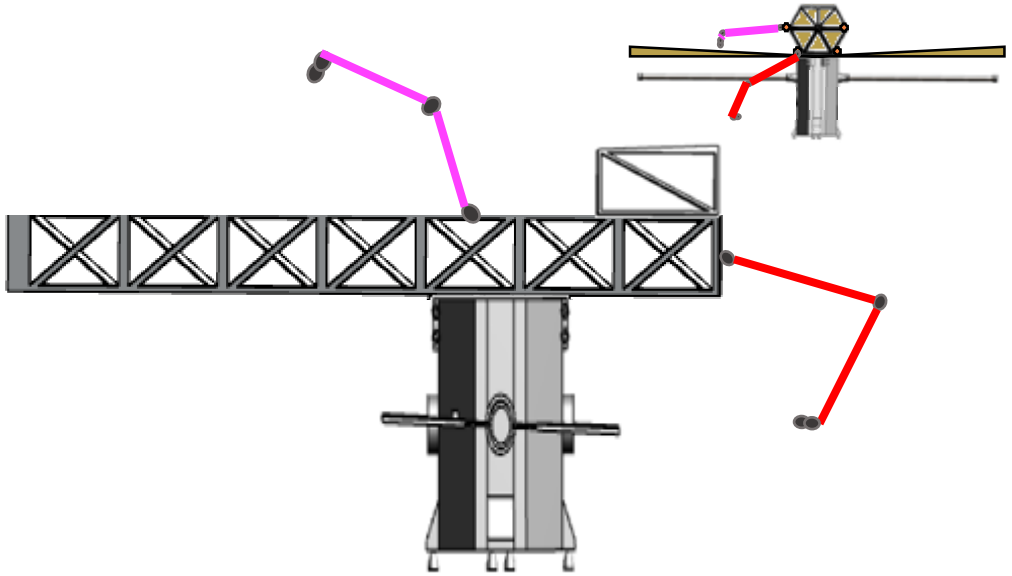
Assembly Sequence

Notional iSAT Assembly Sequence

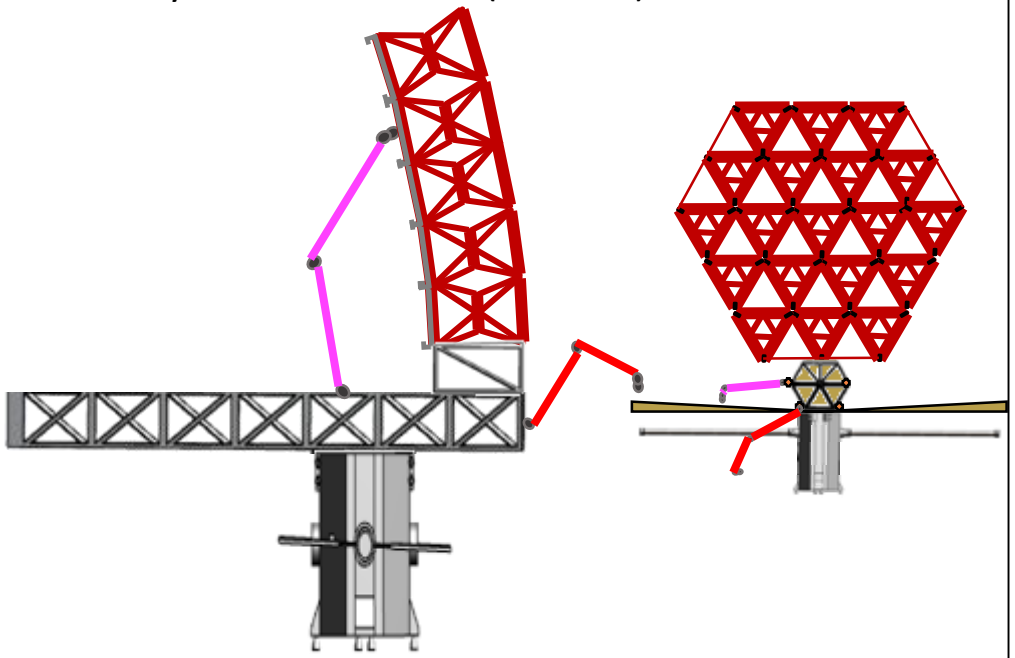
1. Spacecraft, arms, truss adapter



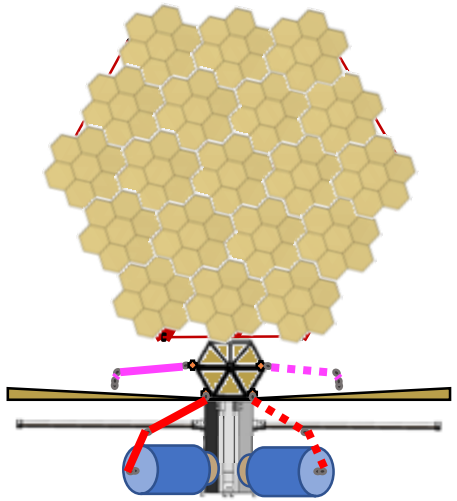
2. Metering Truss and bottom sunshade



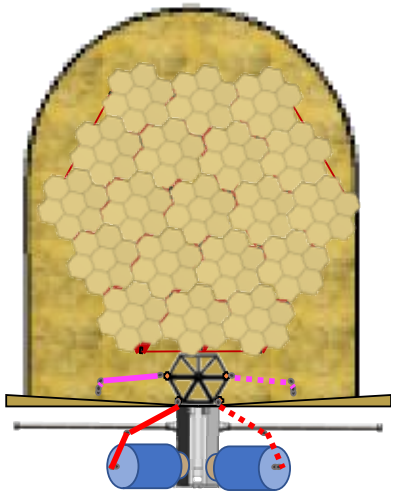
3. Primary mirror structure (tri-truss)



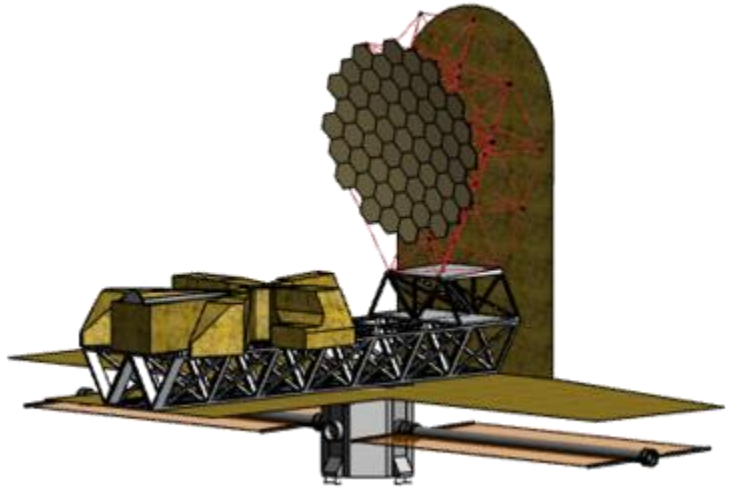
4. Secondary, Metrology, Mirror Rafts



5. Primary (upper) sunshade



6-?. Science instruments



Early Science Assembly Sequence

1.Spacecraft + Robots (Launch 1)
2.Transition Structure (Launch 1)
3.Metering Truss (Launch 2)
4.Metering Sunshade (Launch 2)
5.PM Tri-truss (would we need to assembly the entire PM structure?) (Launch 3)
6.Secondary Mirror and Verification System (Launch 4)
7.Aft Optics (Launch 5)
8.1xMirror Raft (Launch 6)
9.PM Sunshade (Launch 6)
10.SI1 (Launch 6 or 7)

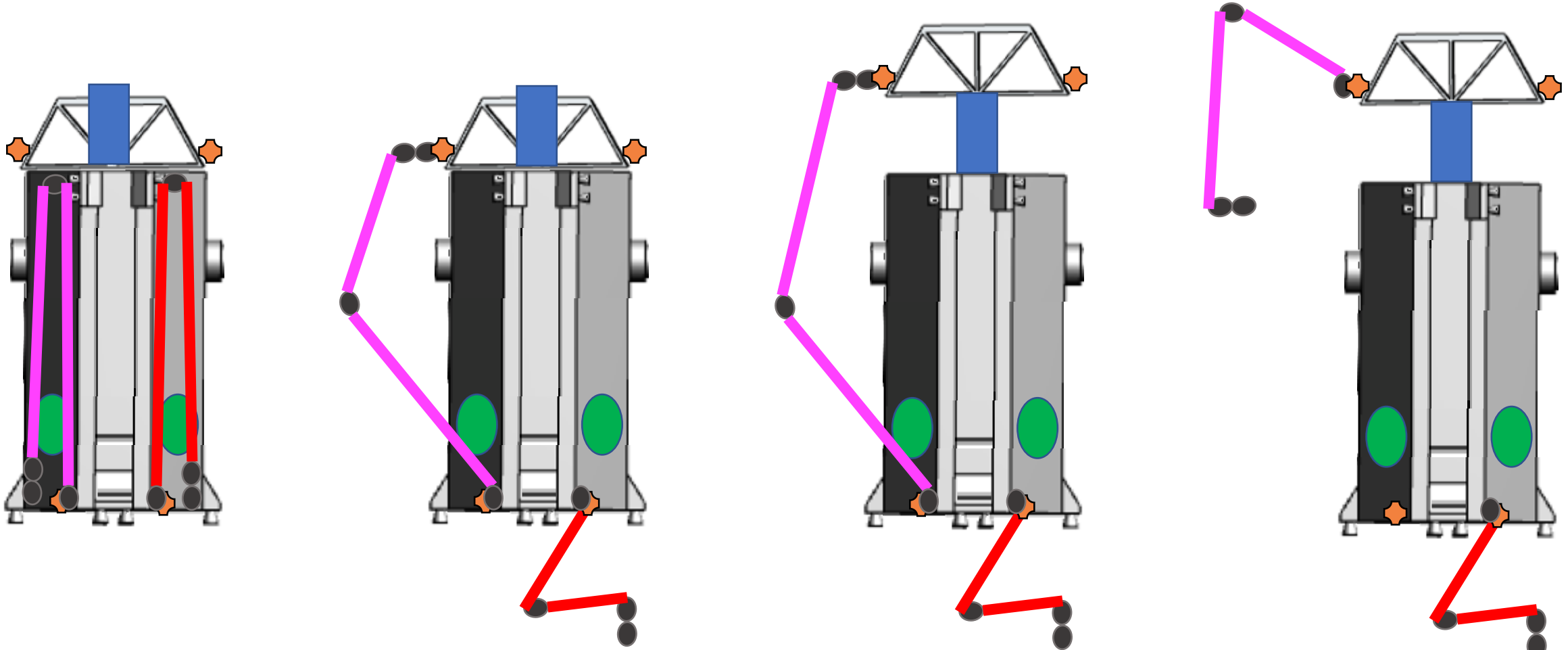
First Science here

11.Remaining Tri-Truss (assume it all went up on launch 5)
12.Remaining Mirror Rafts (Launches 7-9)
13.Remaining Science Instruments (Launches 10-12)

Spacecraft Launch, Deploy, Initial construction

Spacecraft prepares for 1st Cargo delivery

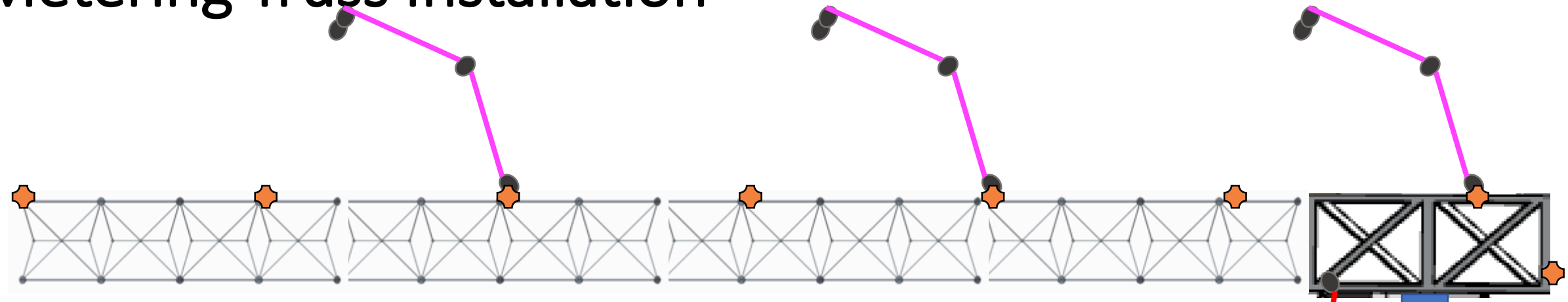
Not clear what this is yet, perhaps some configuration of the SC to OTE interface



Metering Truss Installation

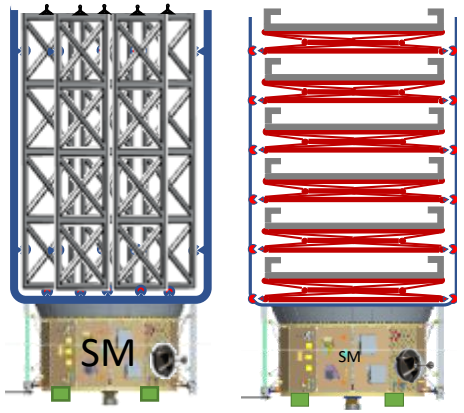
Metering Truss Installation

Metering Truss: TriTruss Option



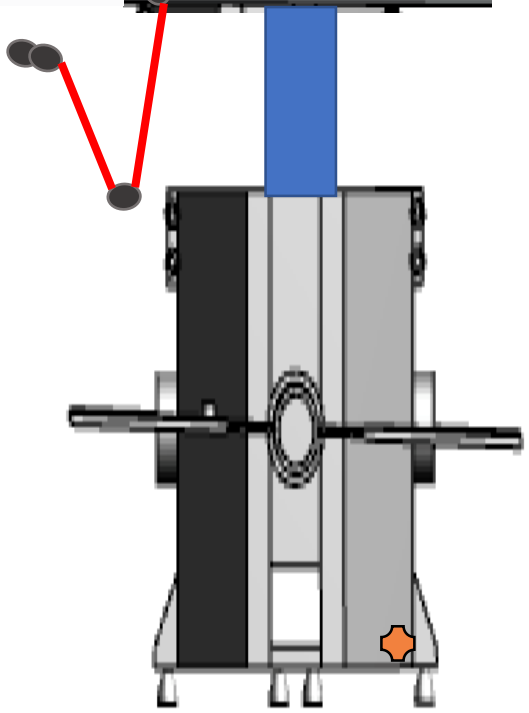
Questions:

1. Are we using tri-truss or pre-assembled truss or deployable truss?
2. Can we use a longer fairing than shown and launch in bigger pieces?
3. Is the spacecraft attached directly to metering truss as Rudra's graphics show, or is there some kind of truss adapter the joins spacecraft to trusses?
4. What launches with the spacecraft?
5. For now, assume this assembly is similar to the tri-truss assembly



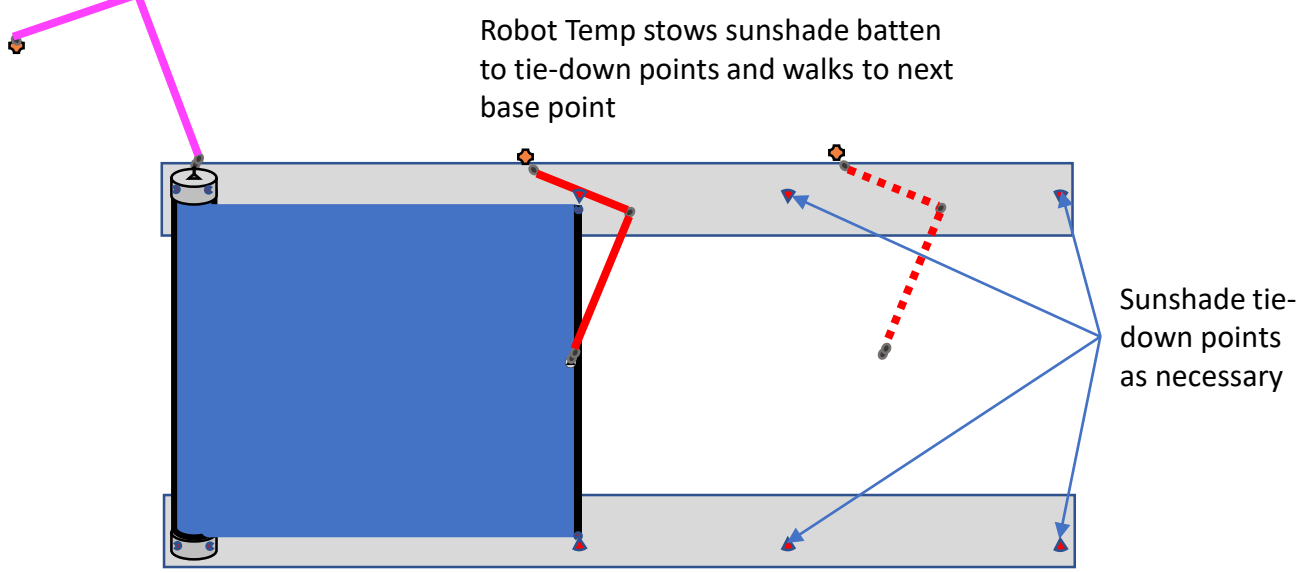
Metering Truss Transport

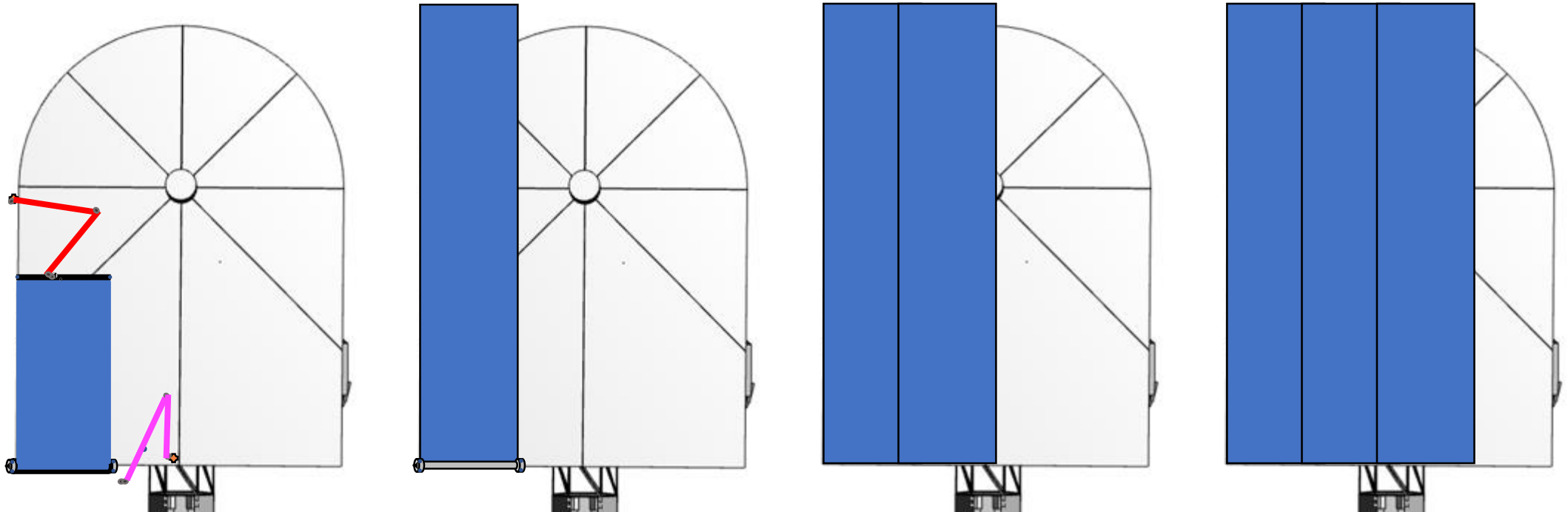
- TBD (6?) ~6m trusses per launch = TBD Launches
- Attach points around perimeter of carrier and at top of each truss



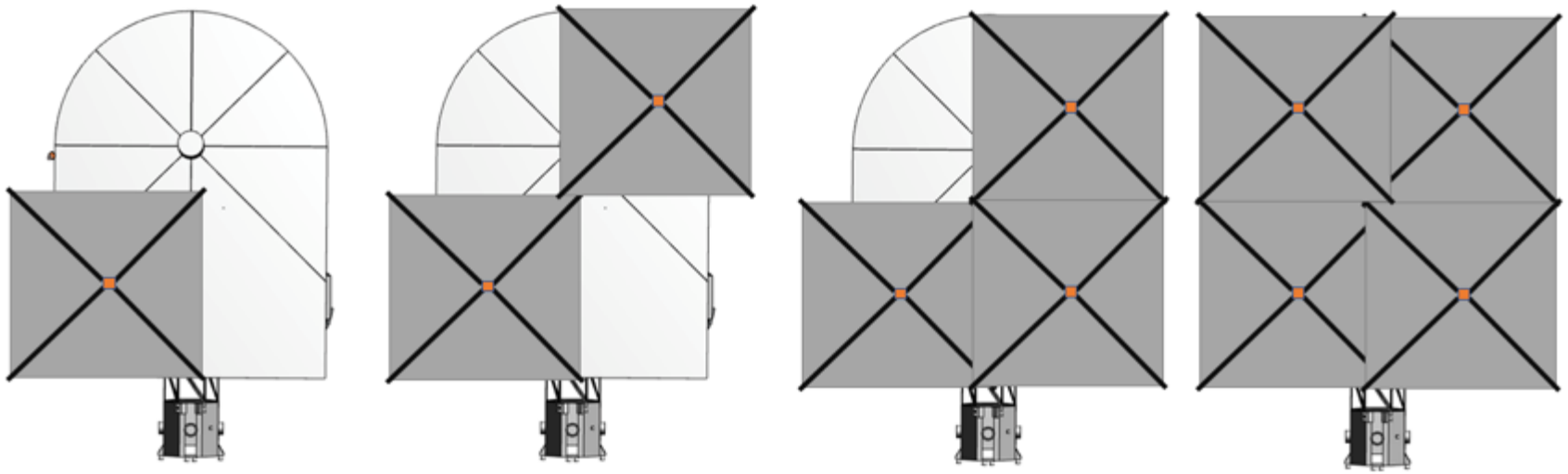
Metering Truss Sunshade Installation

Sunshade deployment

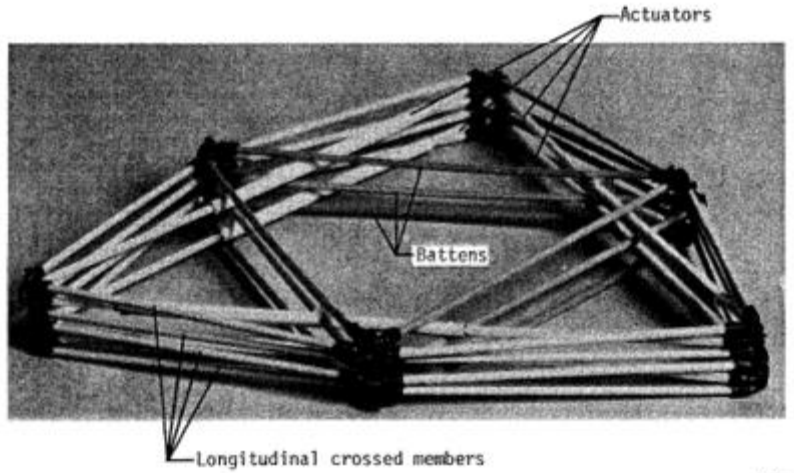




Solar sail derived version

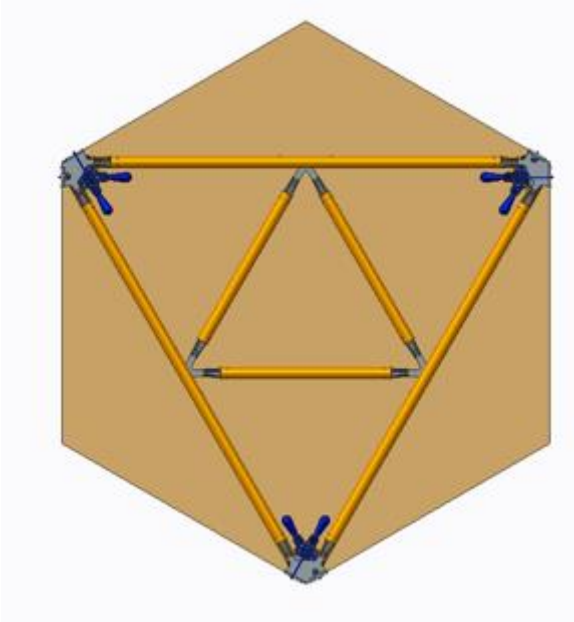


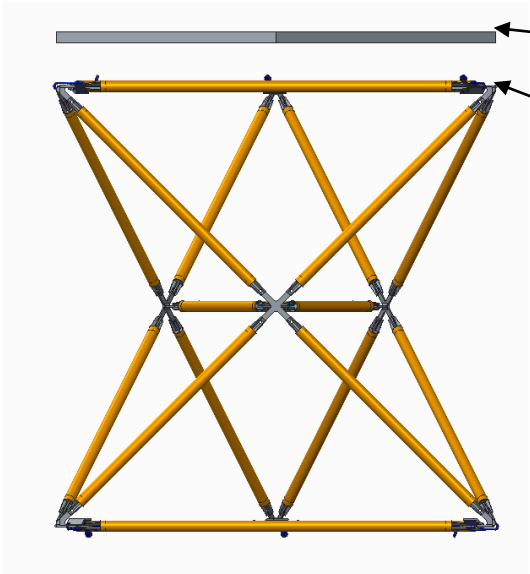
Tri-Truss Unload and Installation



L-85-48

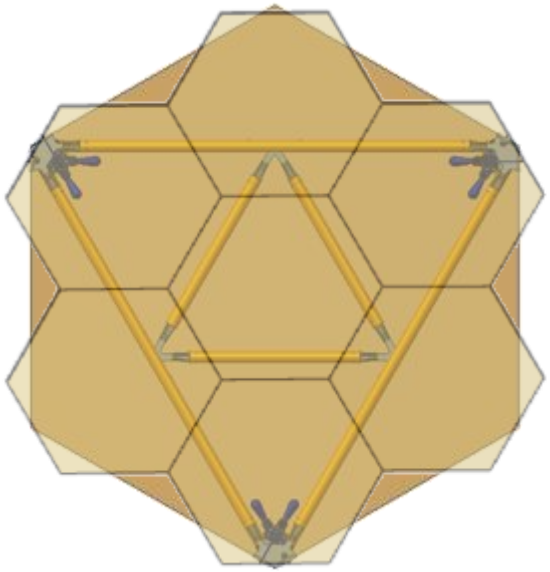
Figure 2. Conceptual model of controllable geometry truss beam structure in packaged configuration.

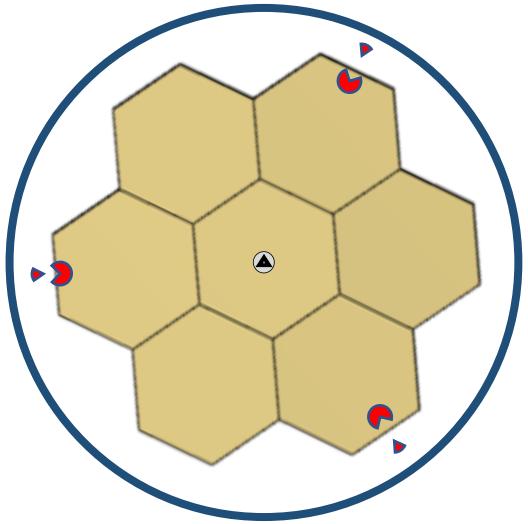


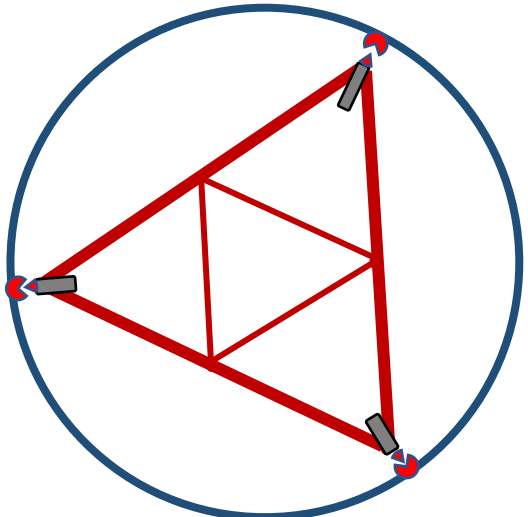


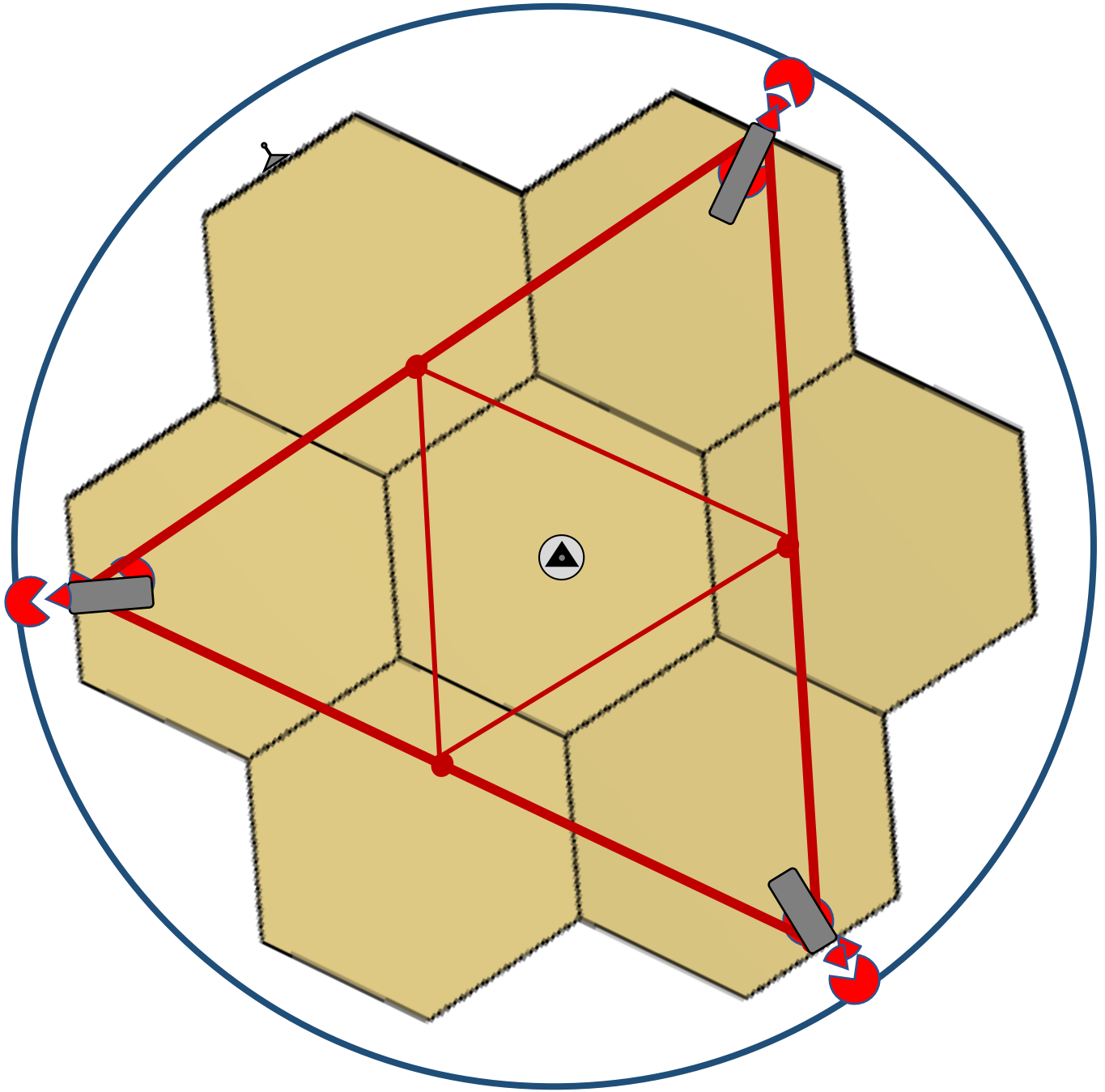
Mirror Raft

TriTruss Top Surface

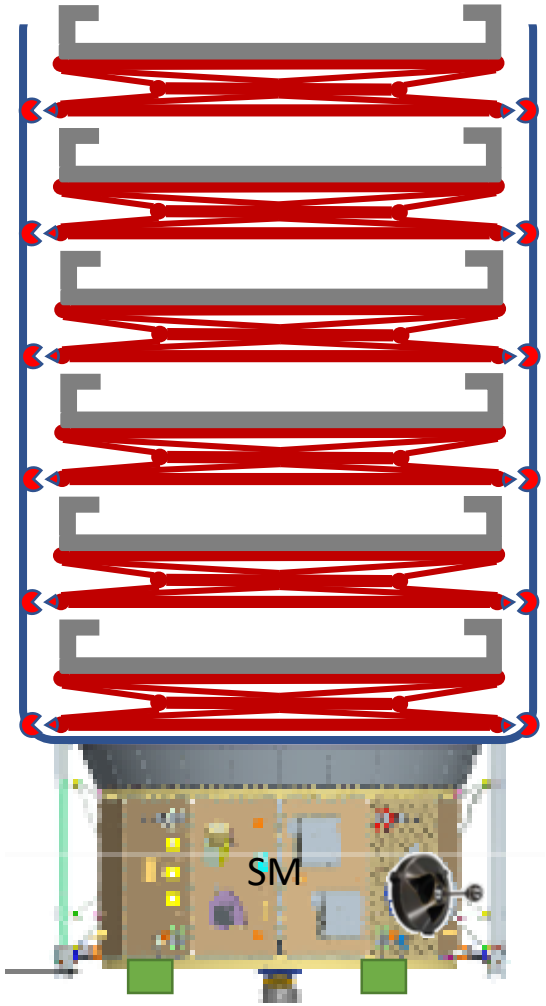






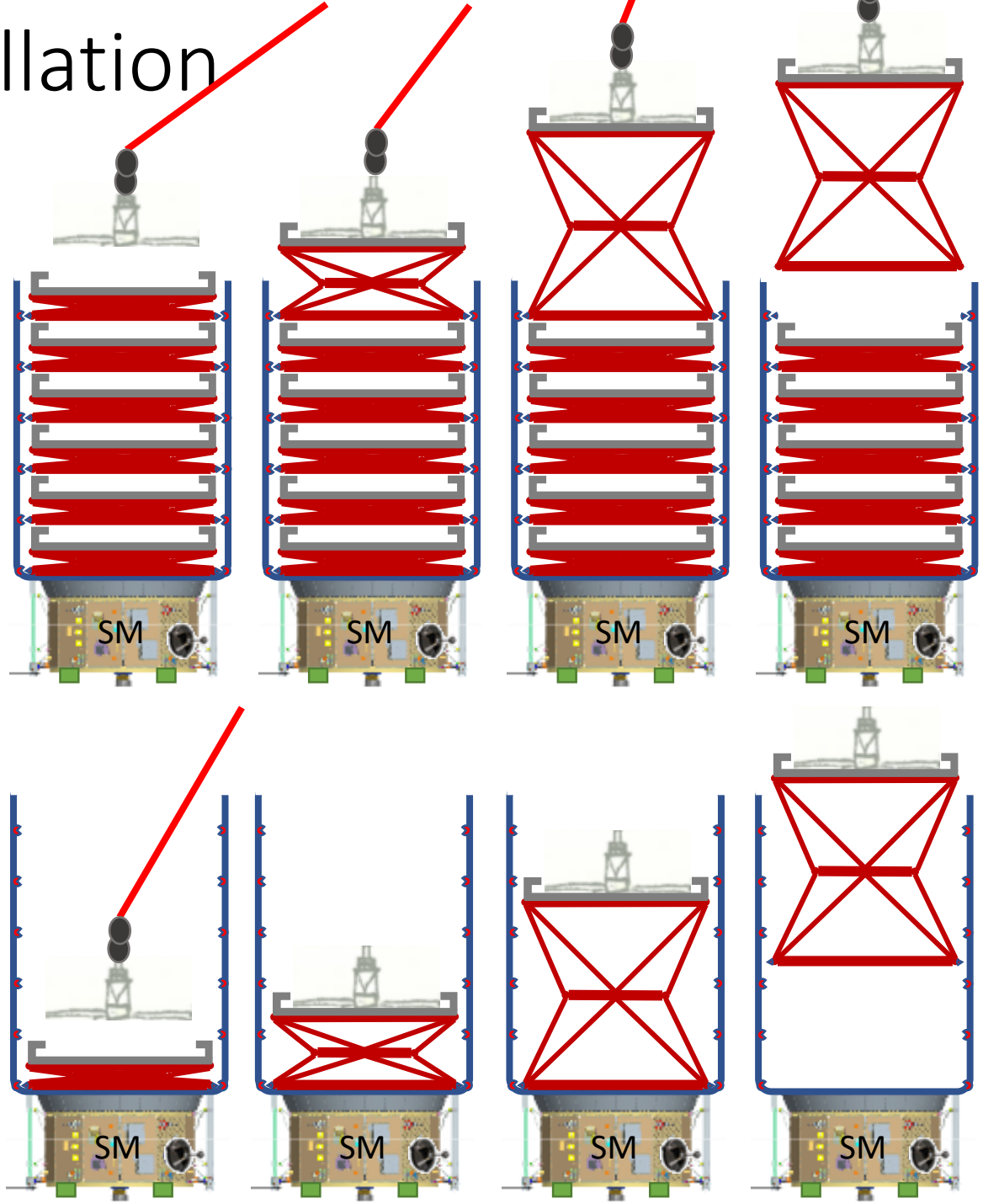


Tri Truss Installation



Tri-Truss Transport

- Attach similar to mirror rafts
- Trusses deployed by arm prior to release from Carrier
- TBD Tri-Trusses per launch



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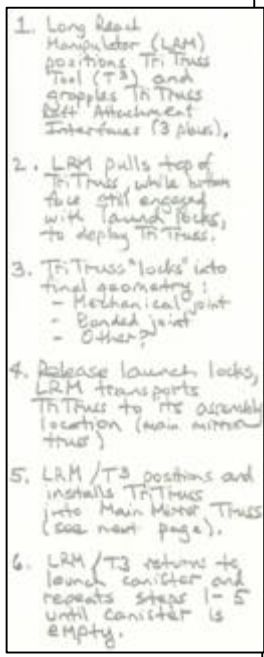
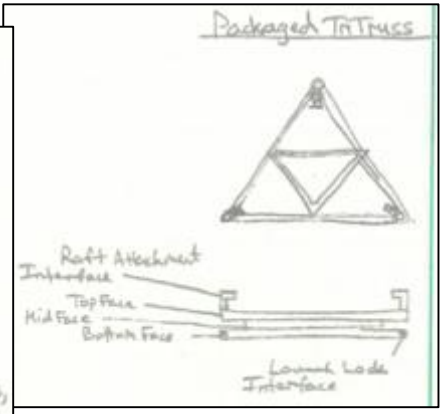
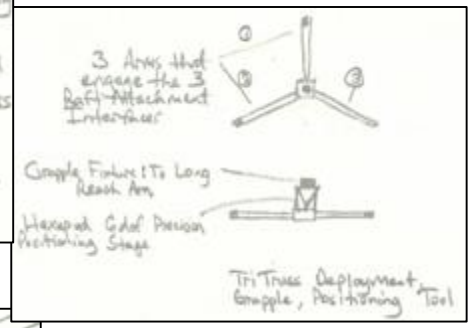
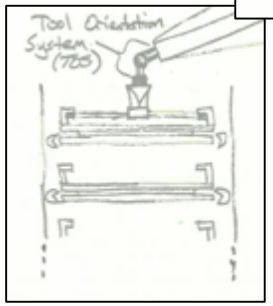
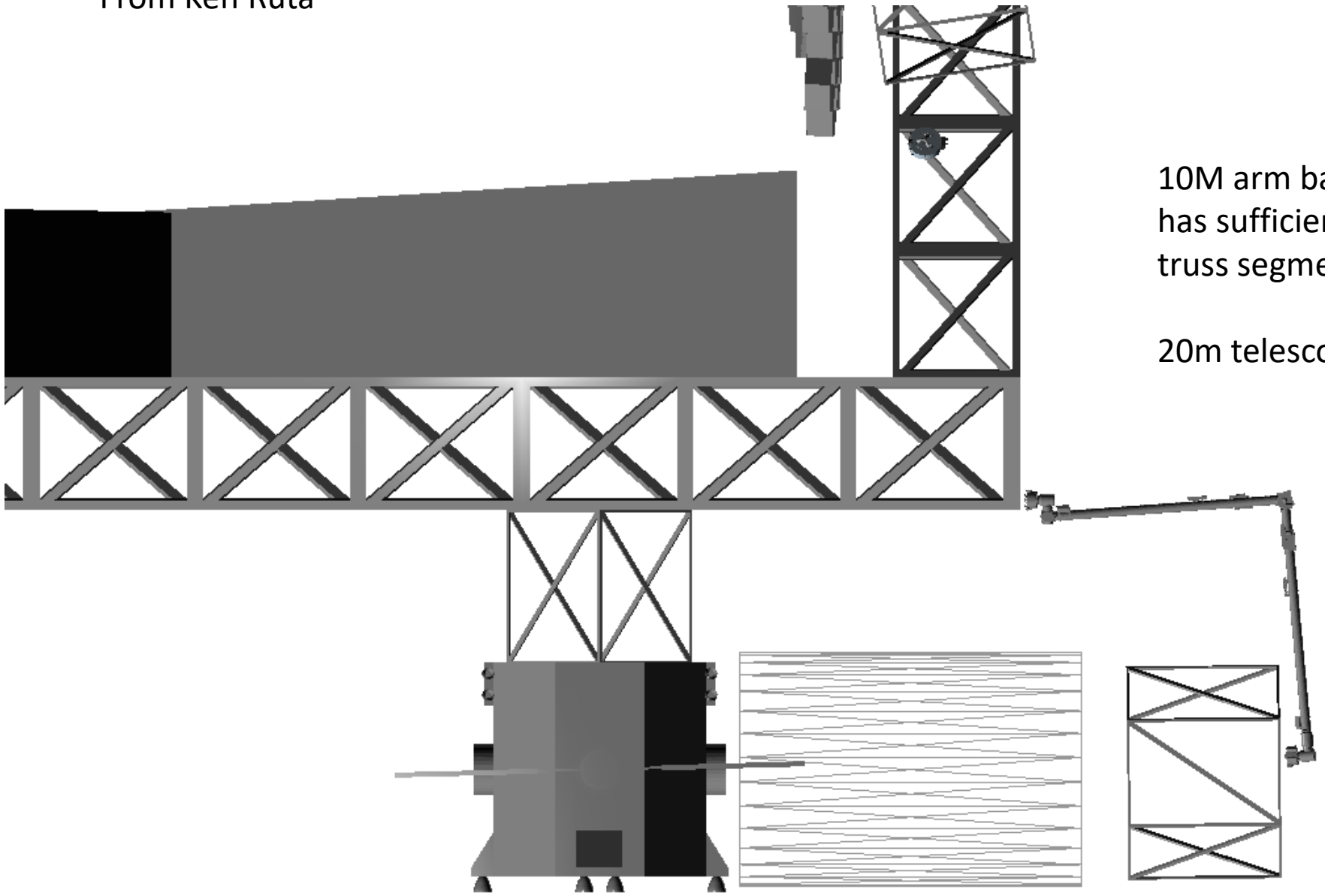








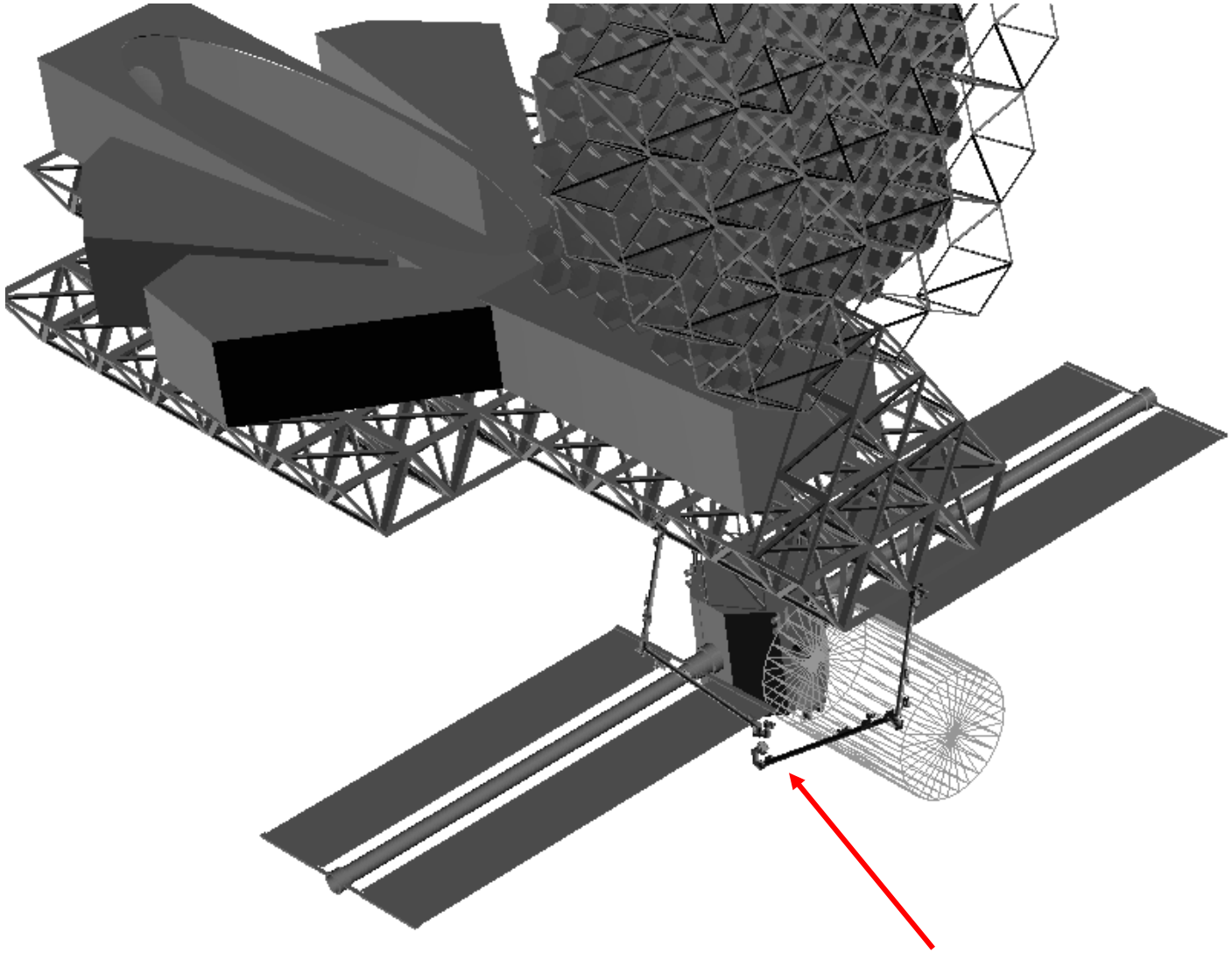
From Ken Ruta



10M arm based on metering truss has sufficient reach to retrieve Tri-truss segments from Falcon Heavy.

20m telescope shown

From Ken Ruta

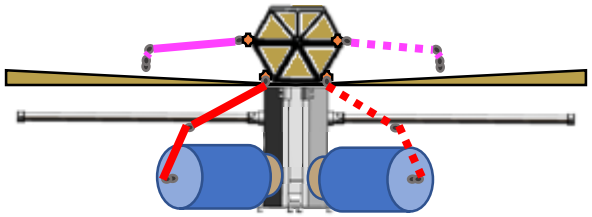


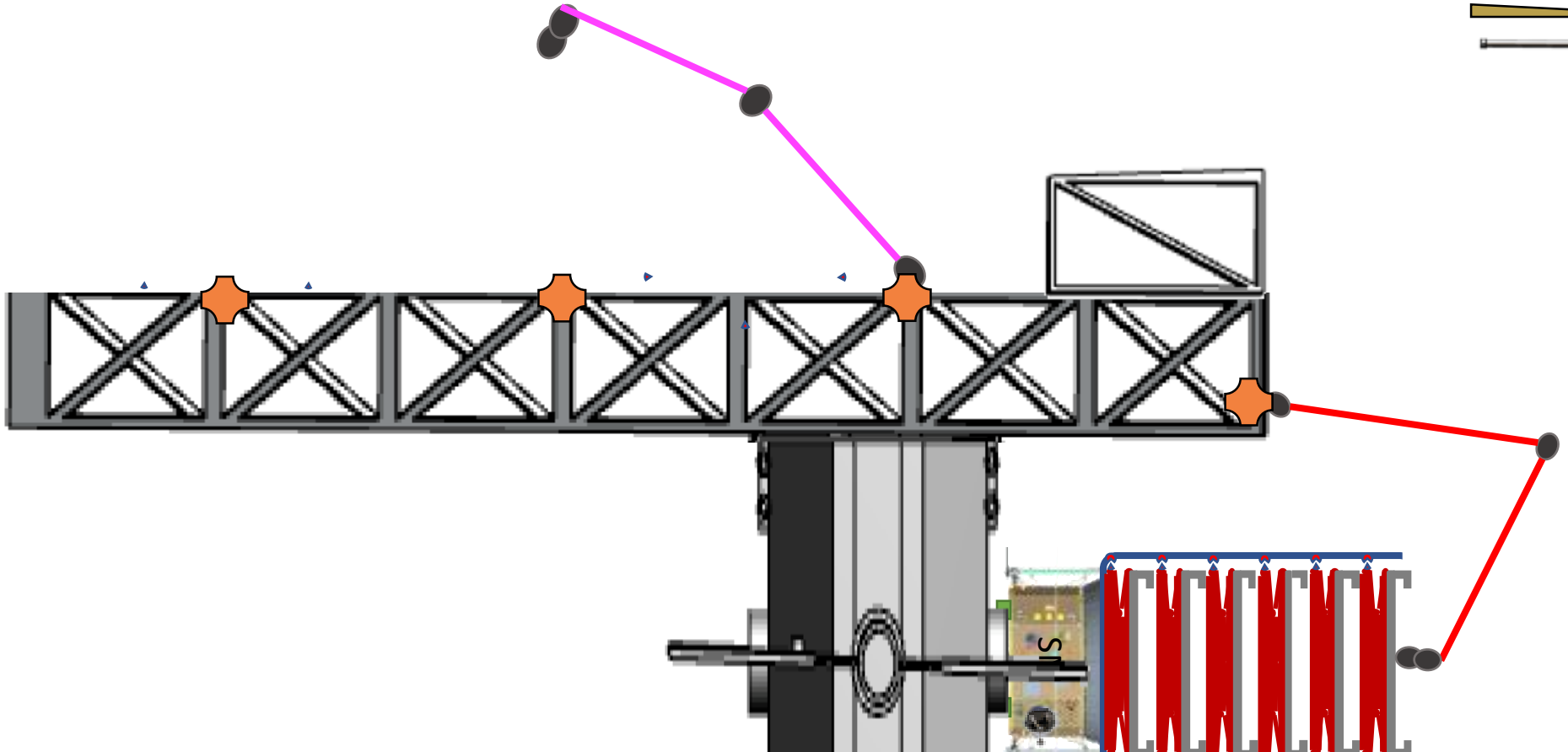
Two 10M arms have enough reach to perform handoffs

20m telescope shown

Tri-Truss Unload Sequence

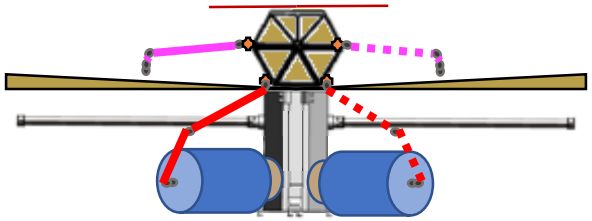
1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)

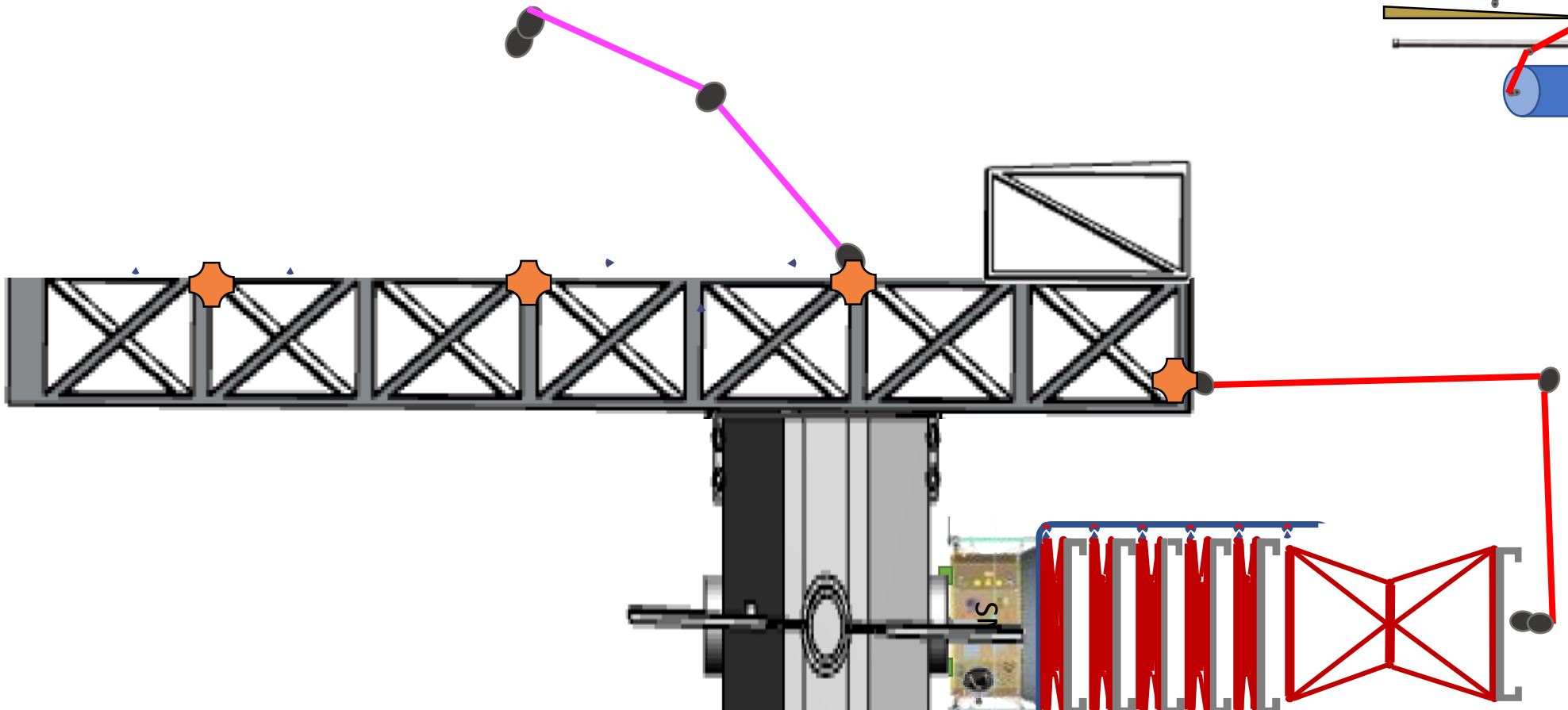




Tri-Truss Unload Sequence

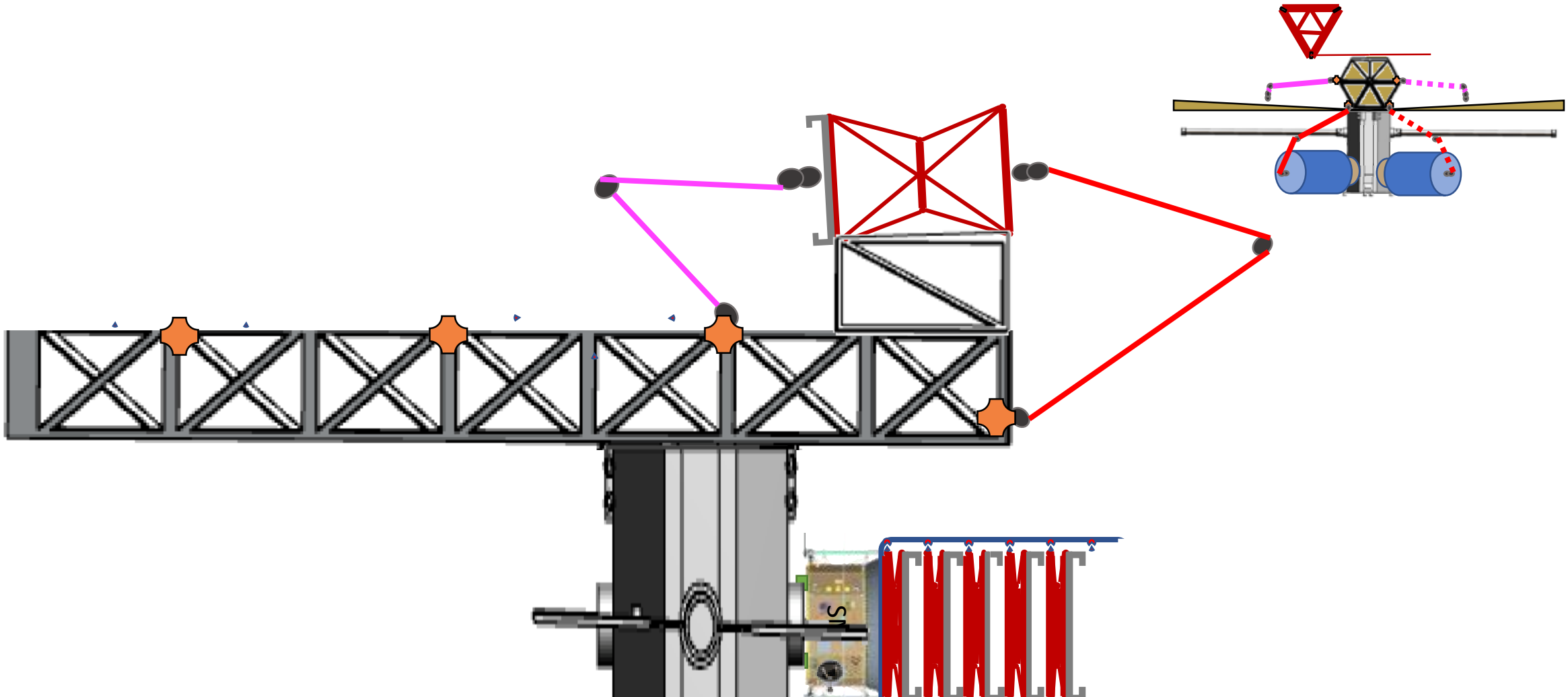
1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks





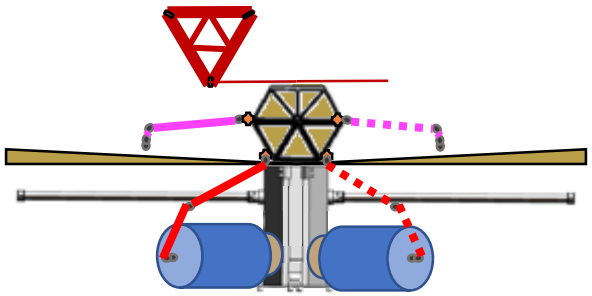
Tri-Truss Unload Sequence

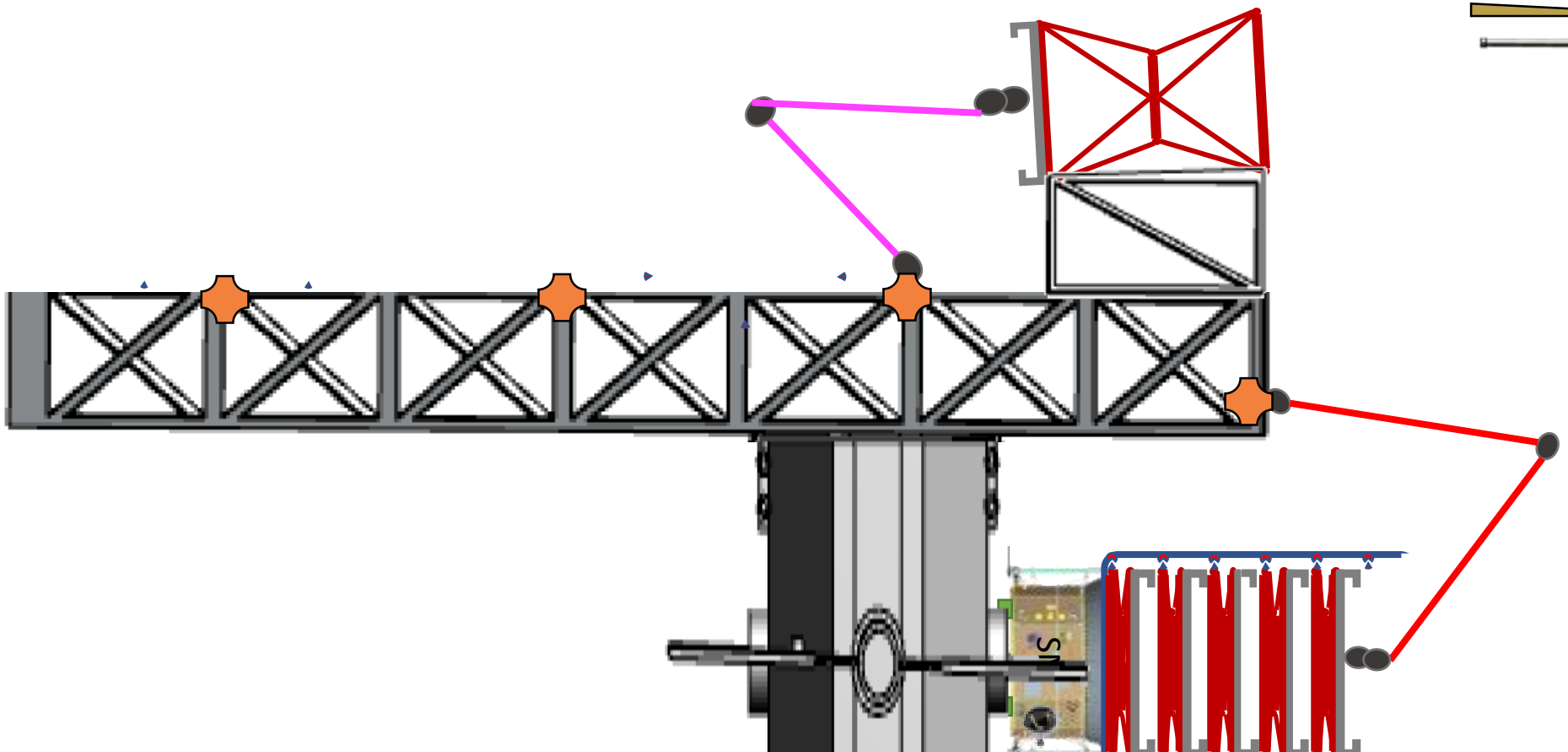
1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks
3. Arm 1 hands off or installs first tri-truss



Tri-Truss Unload Sequence

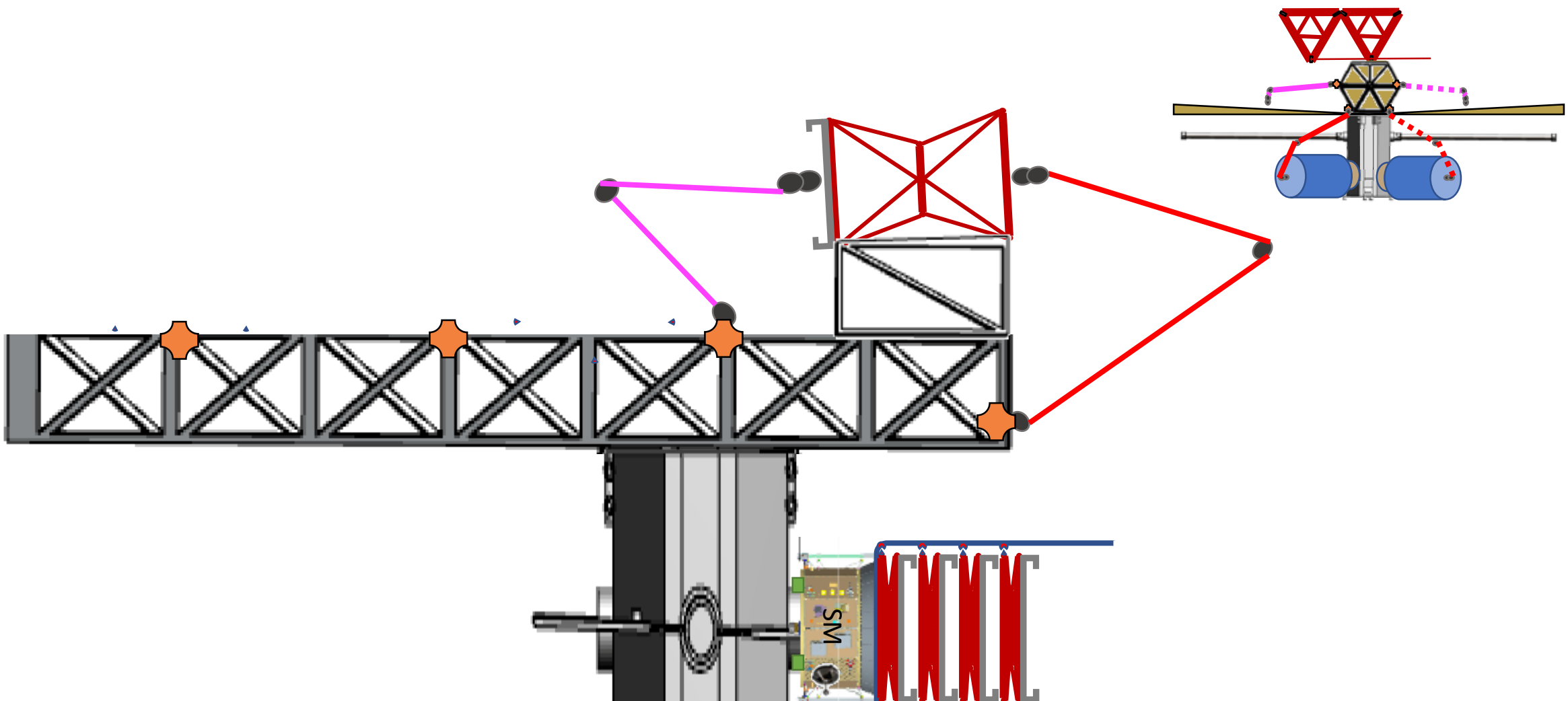
1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks
3. Arm 1 hands off or installs first tri-truss
4. Arms continue deploying and installing tri-truss load





Tri-Truss Unload Sequence

1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks
3. Arm 1 hands off or installs first tri-truss
4. Arms continue deploying and installing tri-truss load



Tri-Truss Unload Sequence

1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
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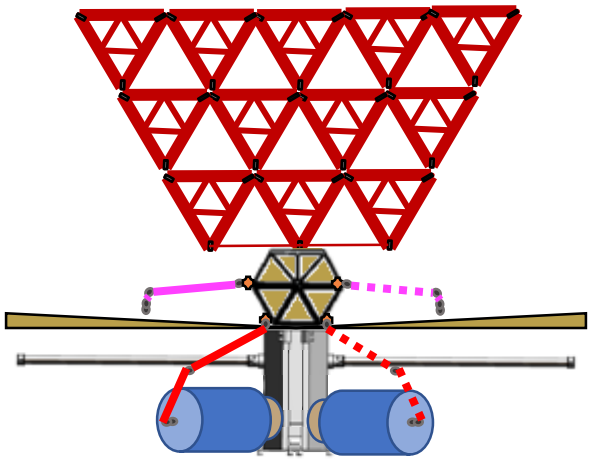
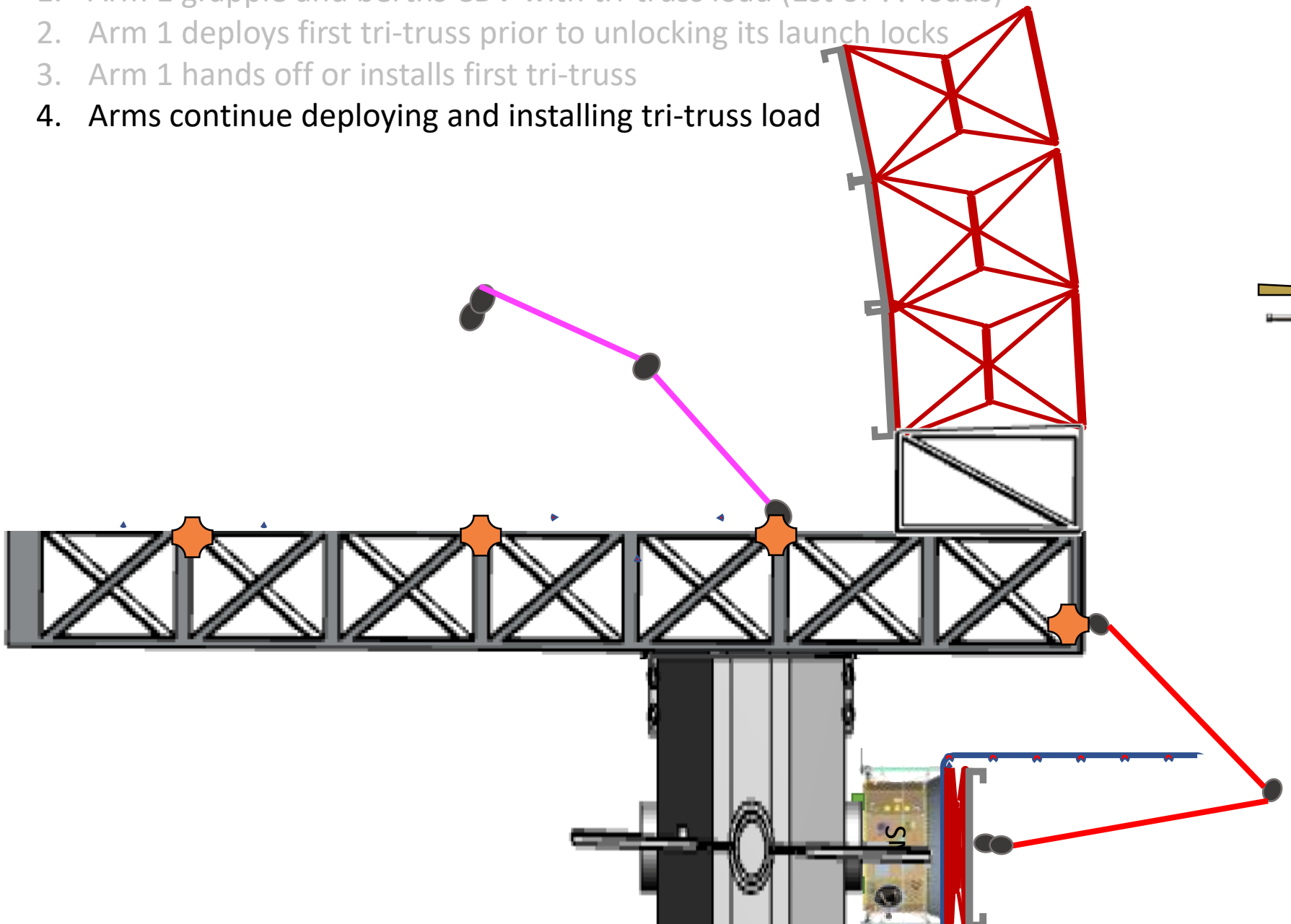
4. Arms continue deploying and installing tri-truss load





Tri-Truss Unload Sequence

1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks
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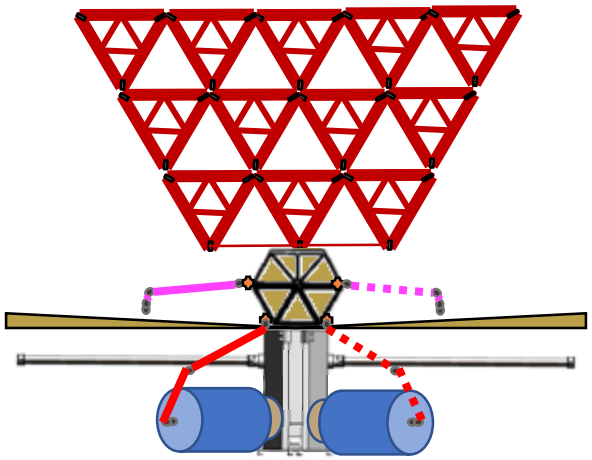
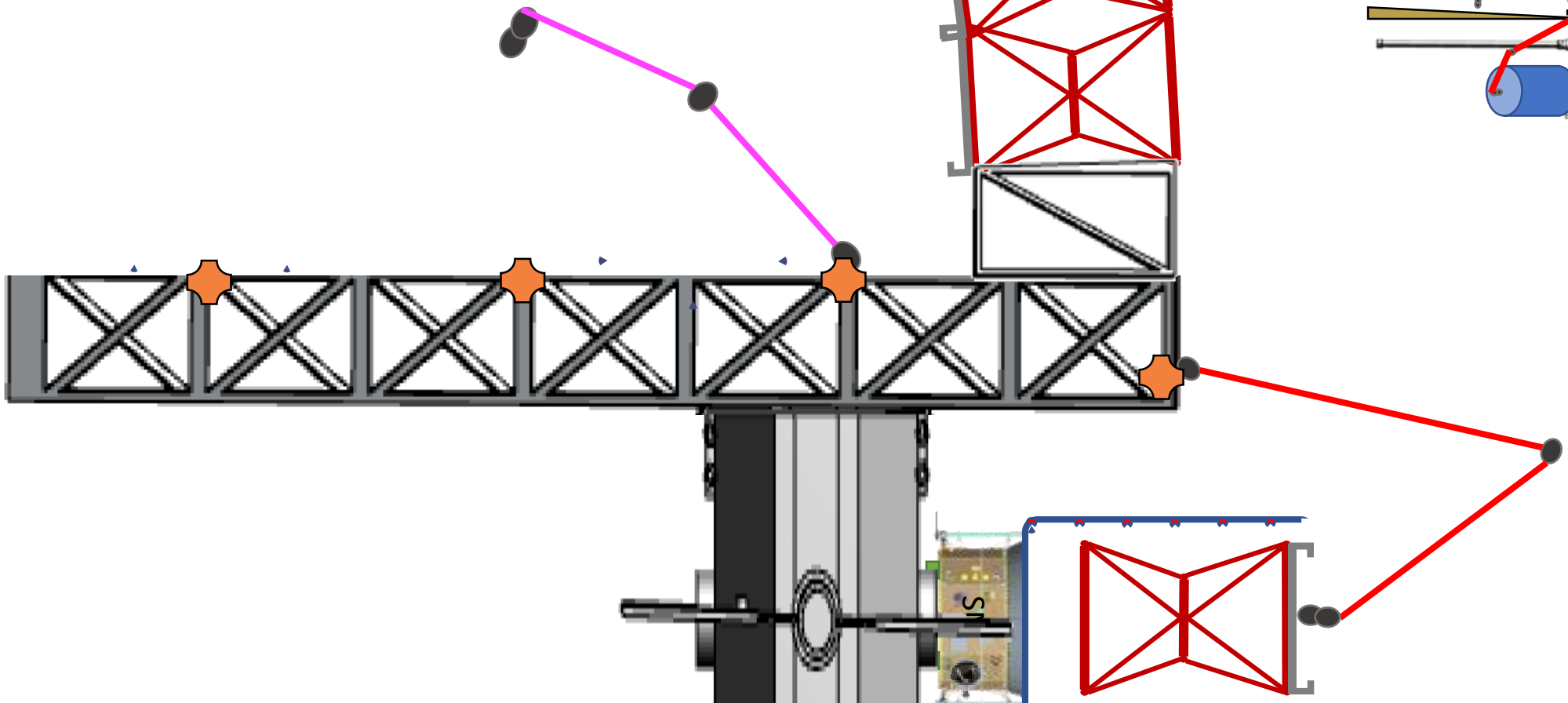
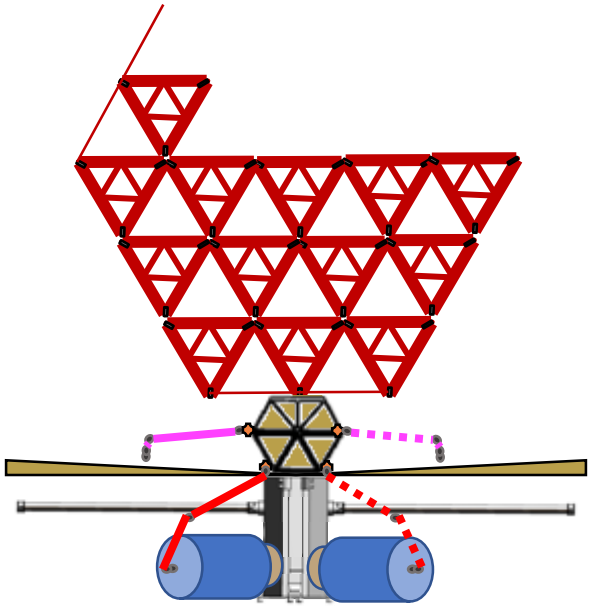
4. Arms continue deploying and installing tri-truss load

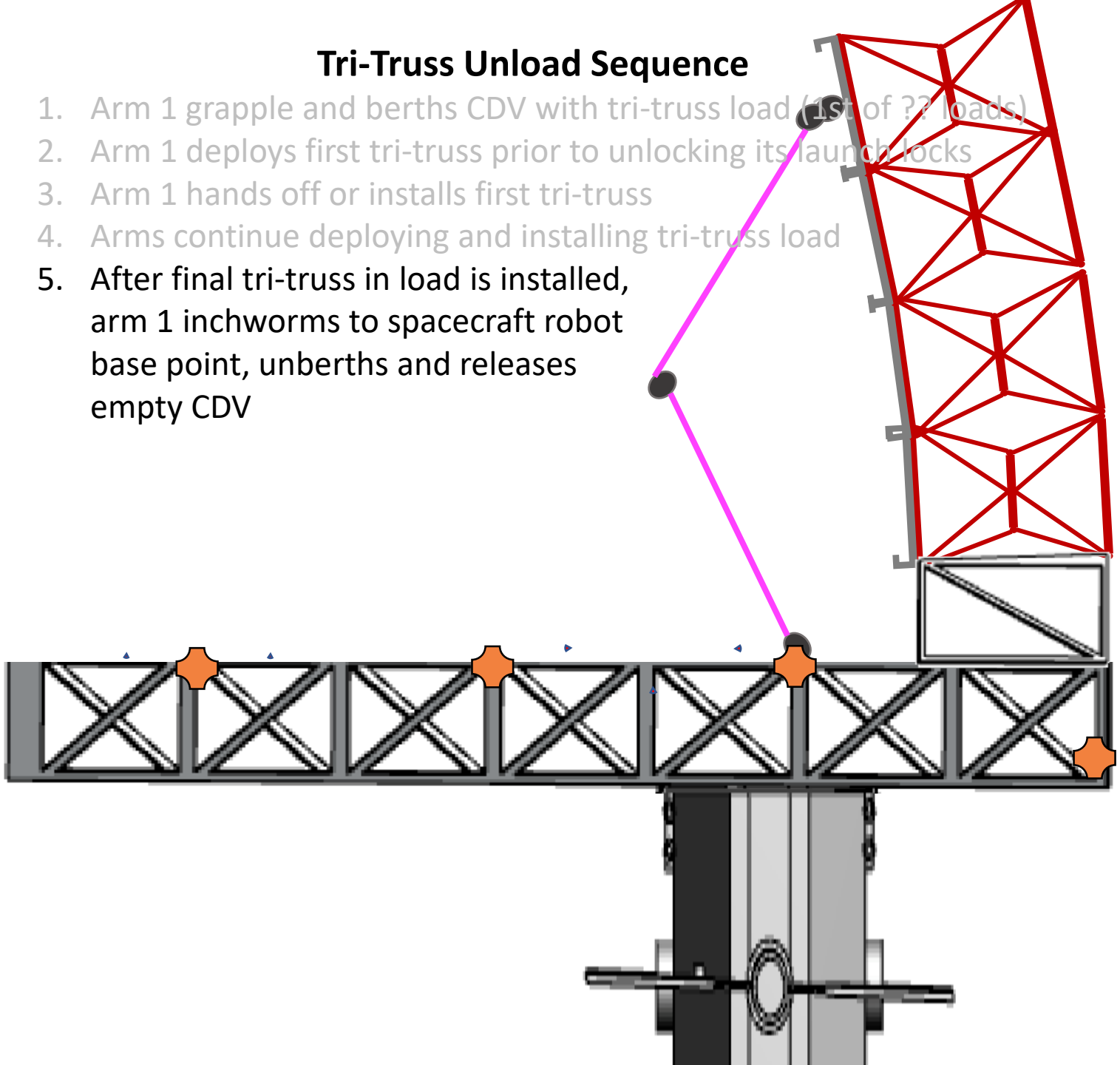




Tri-Truss Unload Sequence

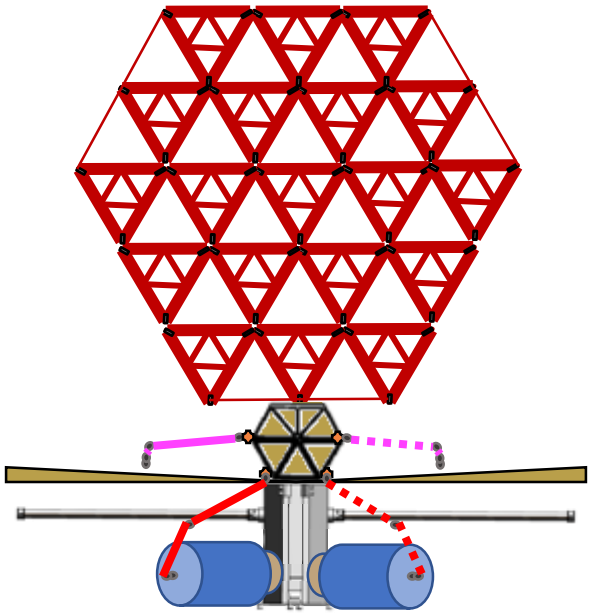
1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks
3. Arm 1 hands off or installs first tri-truss
4. Arms continue deploying and installing tri-truss load
5. After final tri-truss in load is installed, arm 1 inchworms to spacecraft robot base point, unberths and releases empty CDV

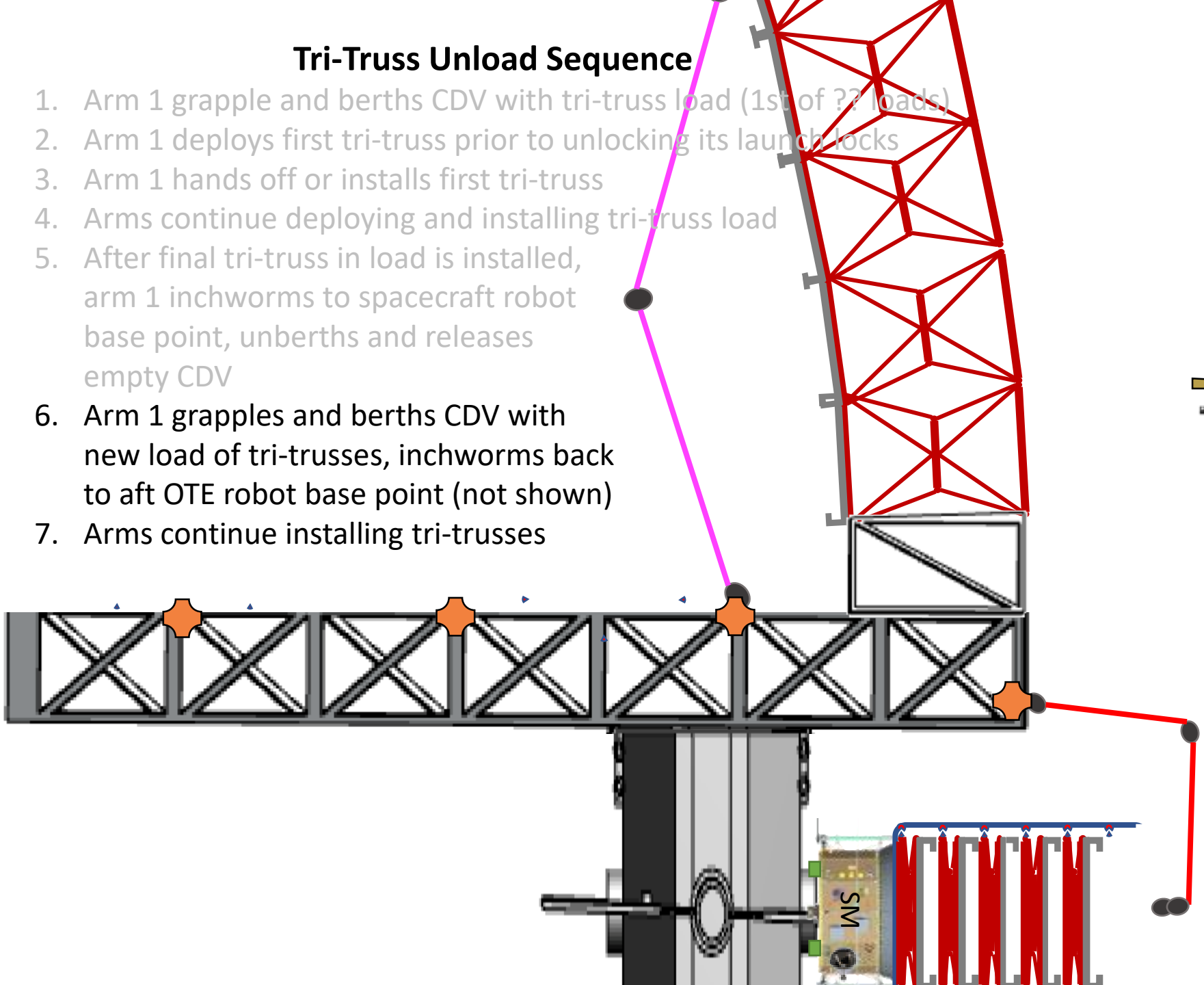




Tri-Truss Unload Sequence

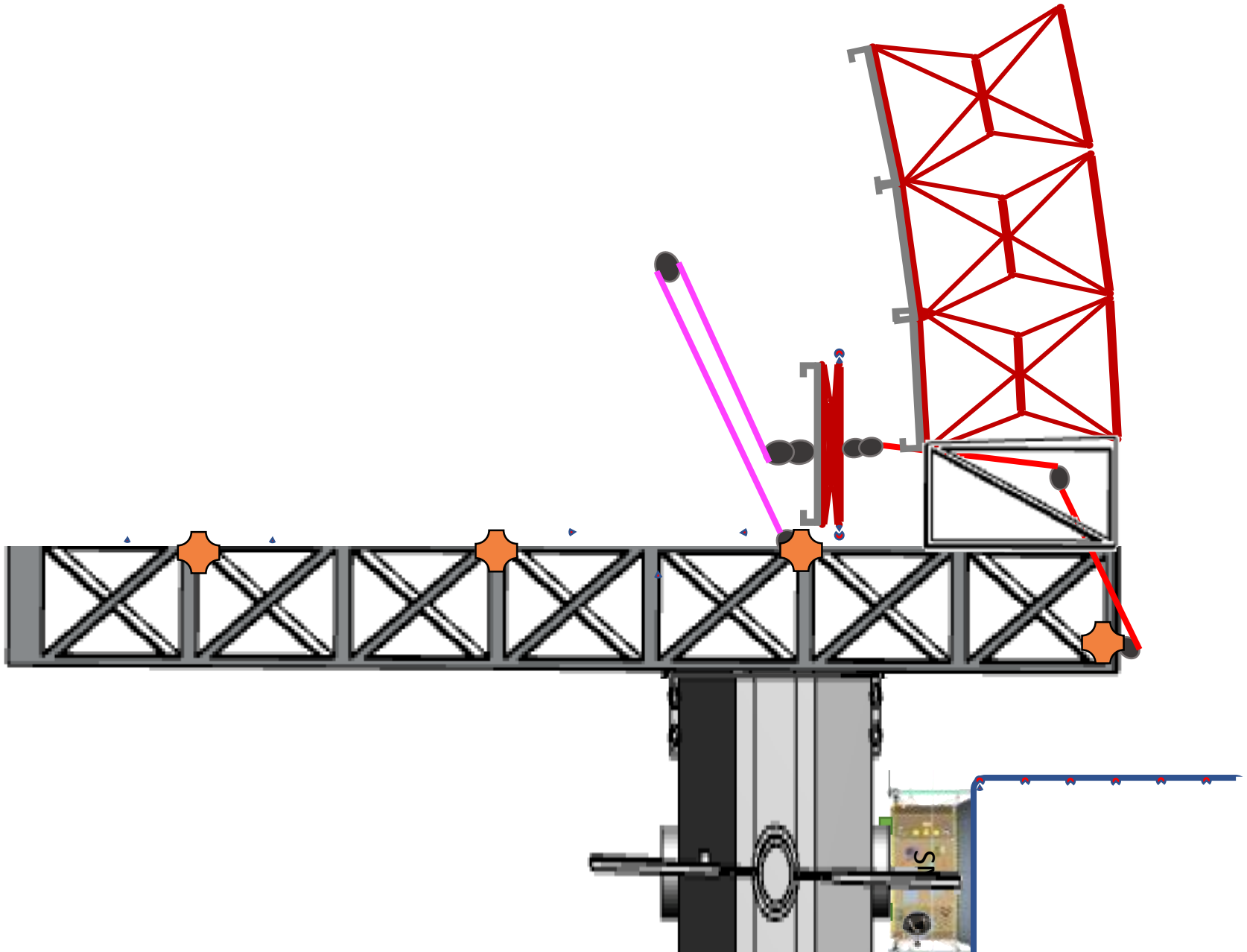
1. Arm 1 grapple and berths CDV with tri-truss load (1st of ?? loads)
2. Arm 1 deploys first tri-truss prior to unlocking its launch locks
3. Arm 1 hands off or installs first tri-truss
4. Arms continue deploying and installing tri-truss load
5. After final tri-truss in load is installed, arm 1 inchworms to spacecraft robot base point, unberths and releases empty CDV
6. Arm 1 grapples and berths CDV with new load of tri-trusses, inchworms back to aft OTE robot base point (not shown)
7. Arms continue installing tri-trusses

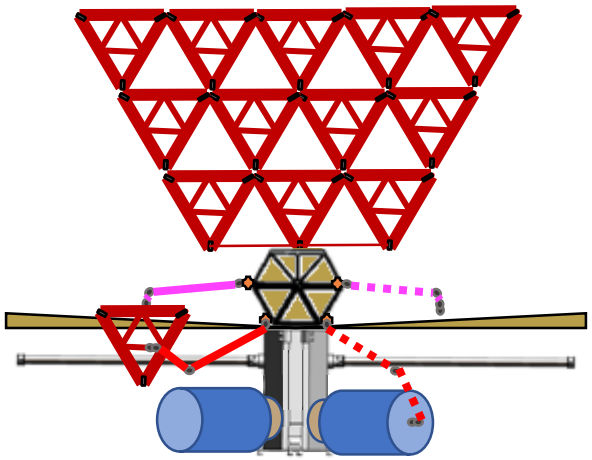




Alternative Tri-Truss Unload Approach

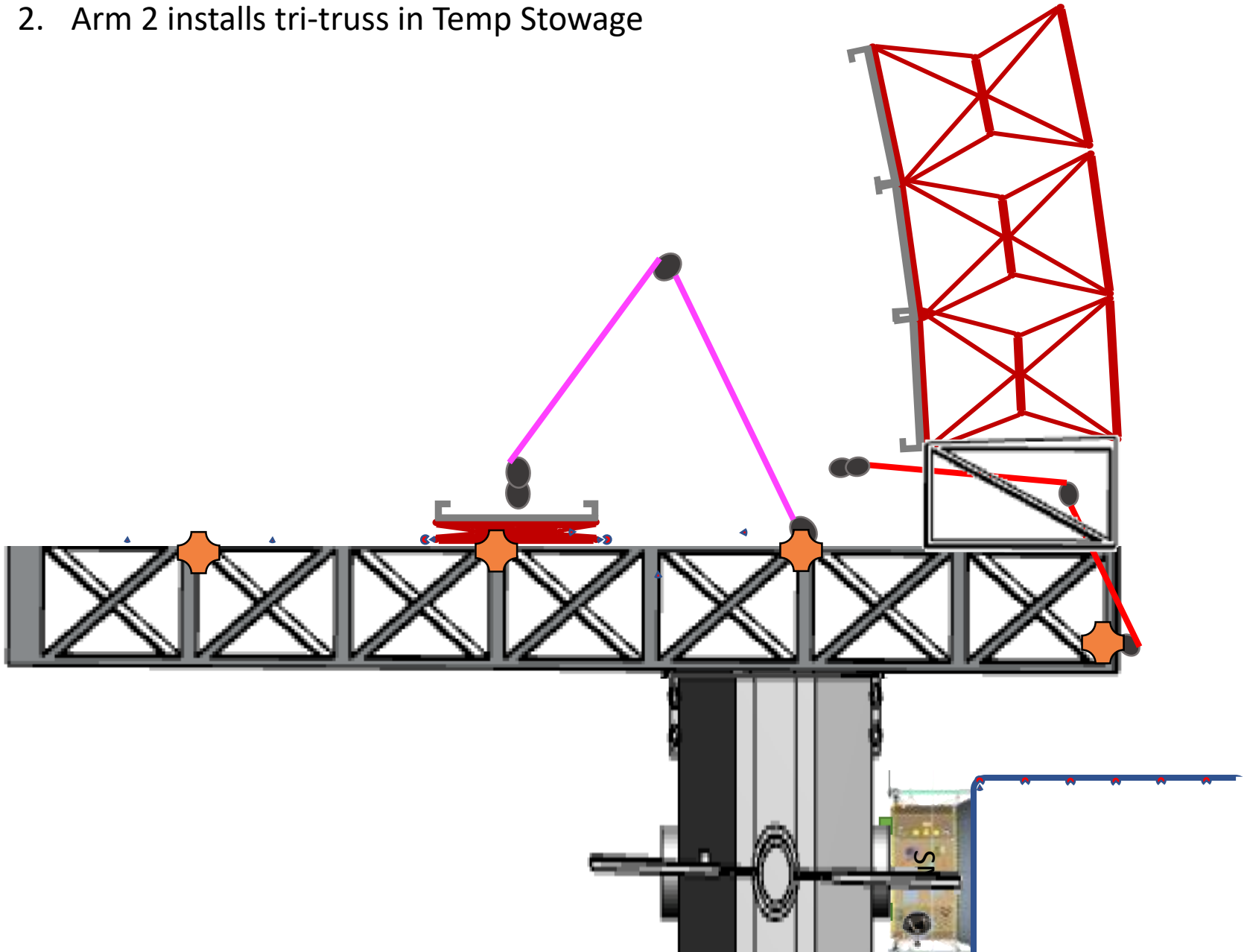
1. Arm 1 hands off un-deployed tri-truss to arm 2

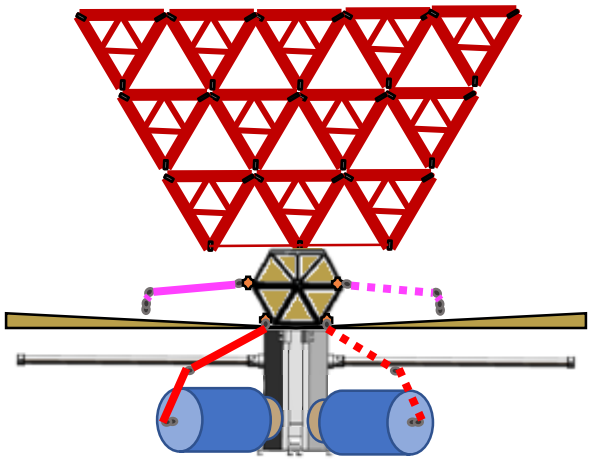




Alternative Tri-Truss Unload Approach

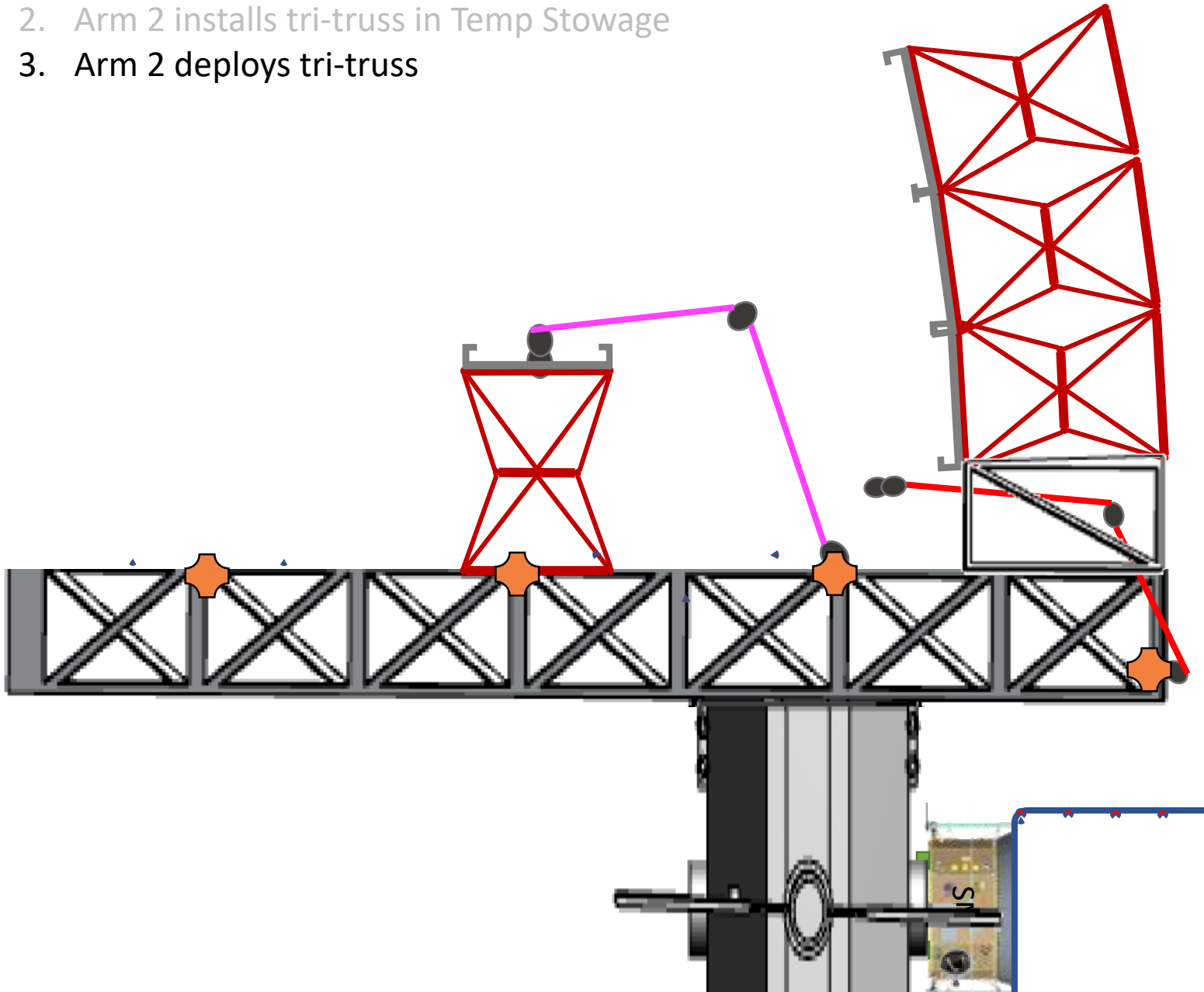
1. Arm 1 hands off un-deployed tri-truss to arm 2
2. Arm 2 installs tri-truss in Temp Stowage

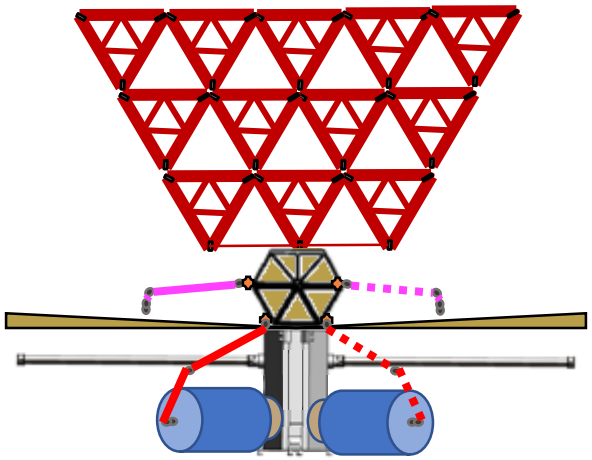




Alternative Tri-Truss Unload Approach

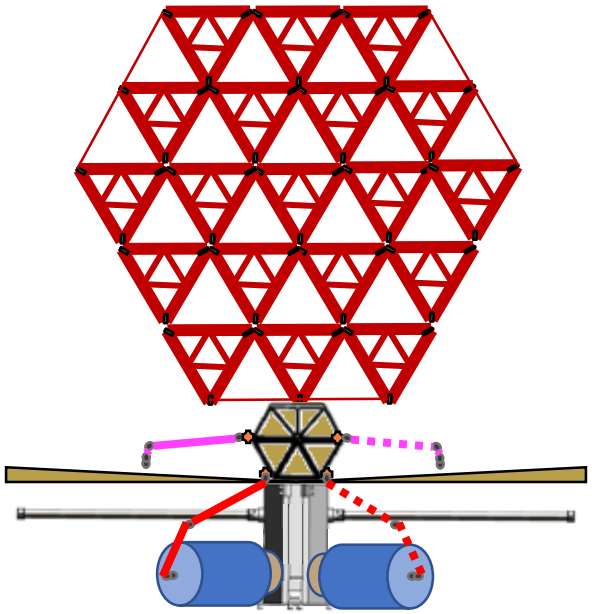
1. Arm 1 hands off un-deployed tri-truss to arm 2
2. Arm 2 installs tri-truss in Temp Stowage
3. Arm 2 deploys tri-truss





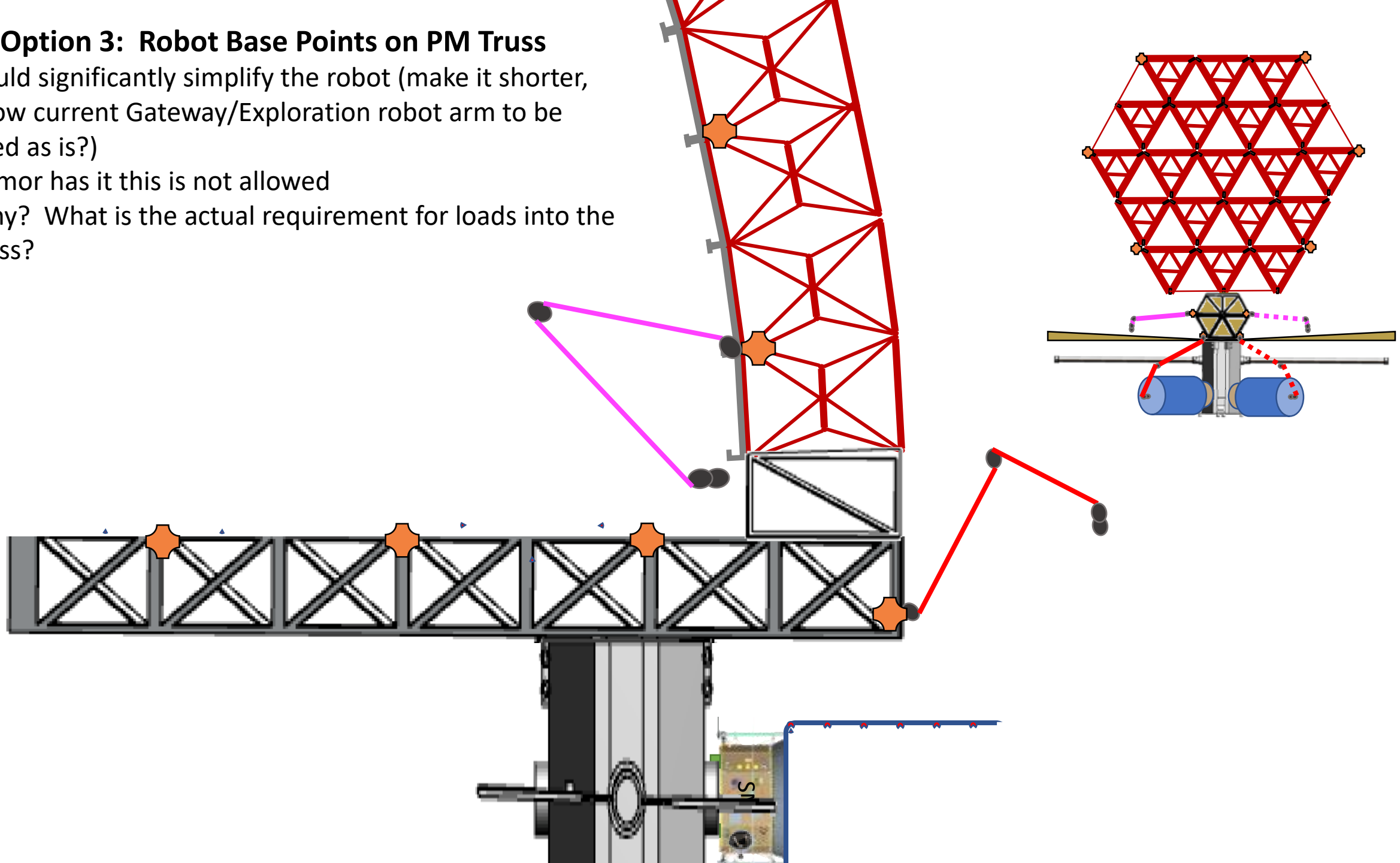
Option 2: Alternative Tri-Truss Unload Approach

1. Arm 1 hands off un-deployed tri-truss to arm 2
2. Arm 2 installs tri-truss in Temp Stowage
3. Arm 2 deploys tri-truss
4. Arm 2 installs tri-truss



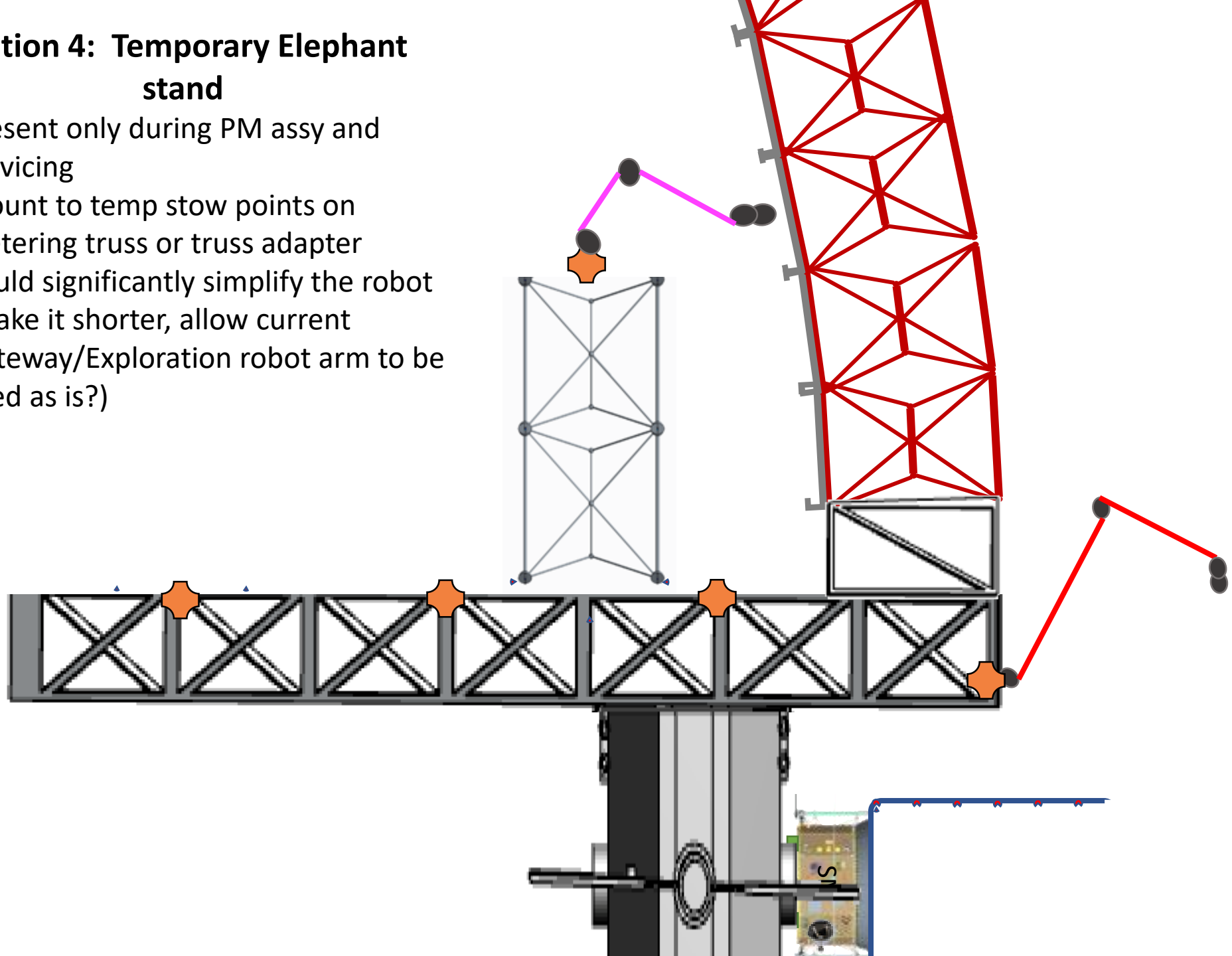
Option 3: Robot Base Points on PM Truss

- Could significantly simplify the robot (make it shorter, allow current Gateway/Exploration robot arm to be used as is?)
- Rumor has it this is not allowed
- Why? What is the actual requirement for loads into the truss?



Option 4: Temporary Elephant stand

- Present only during PM assy and servicing
- Mount to temp stow points on metering truss or truss adapter
- Could significantly simplify the robot (make it shorter, allow current Gateway/Exploration robot arm to be used as is?)



Option 5: Long Reach Arm holding smaller arm

Questions:

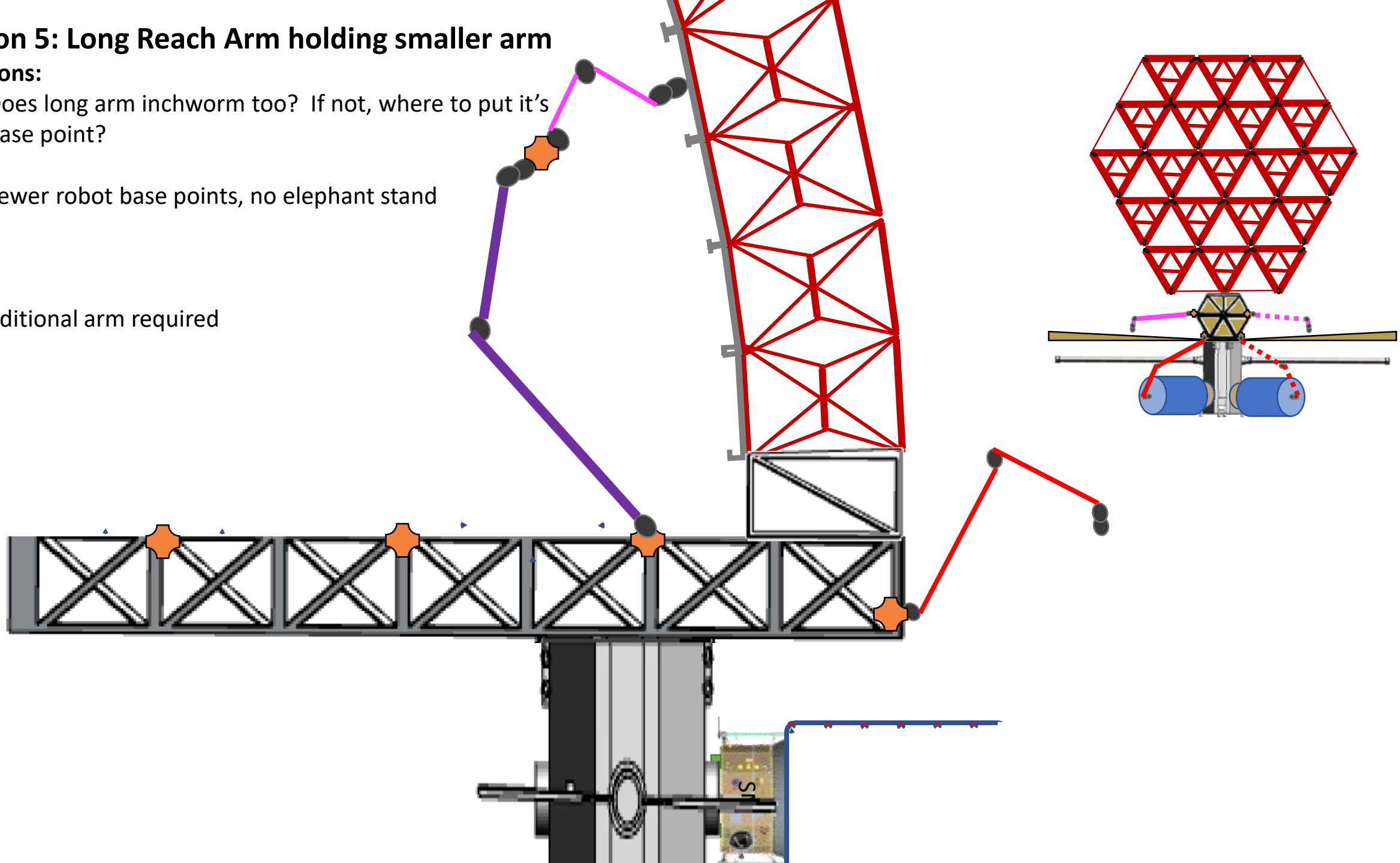
1. Does long arm inchworm too? If not, where to put it's base point?

Pros:

1. Fewer robot base points, no elephant stand

Cons:

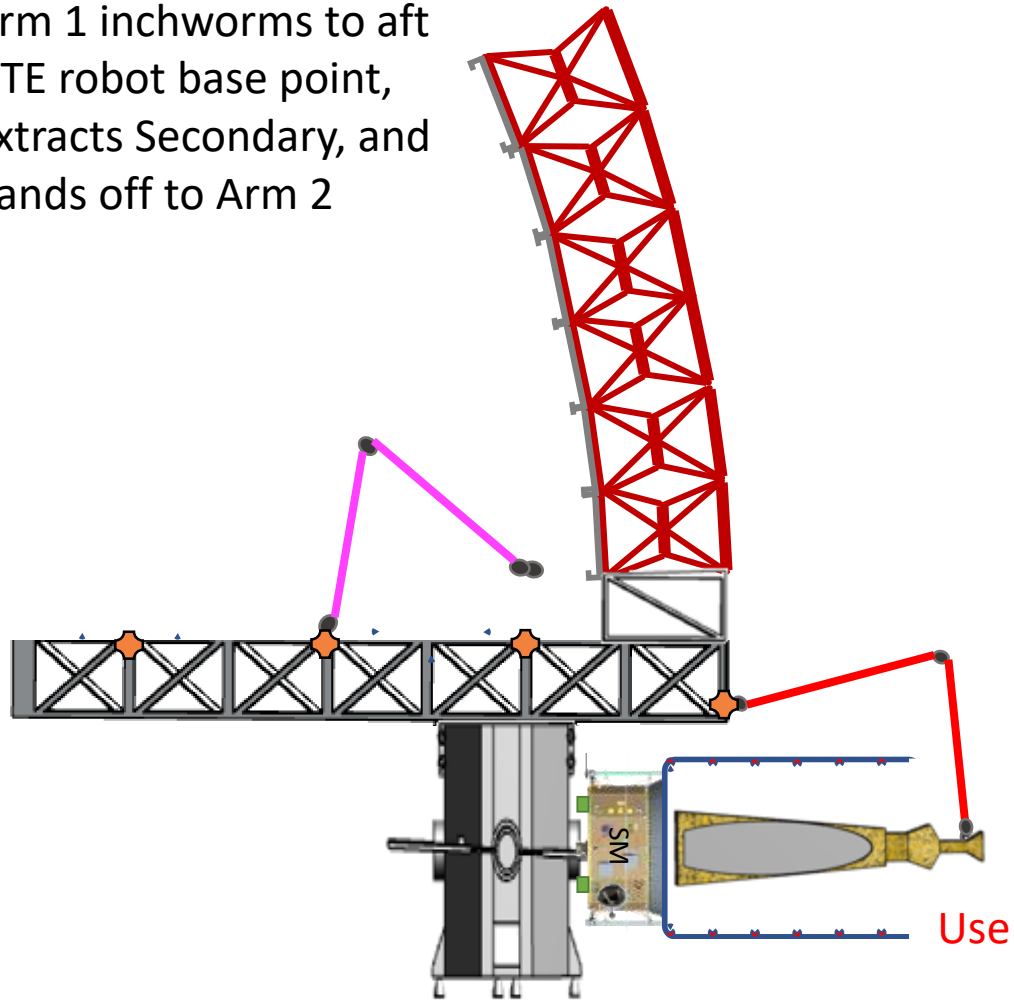
1. Additional arm required



Secondary and Metrology System Installation

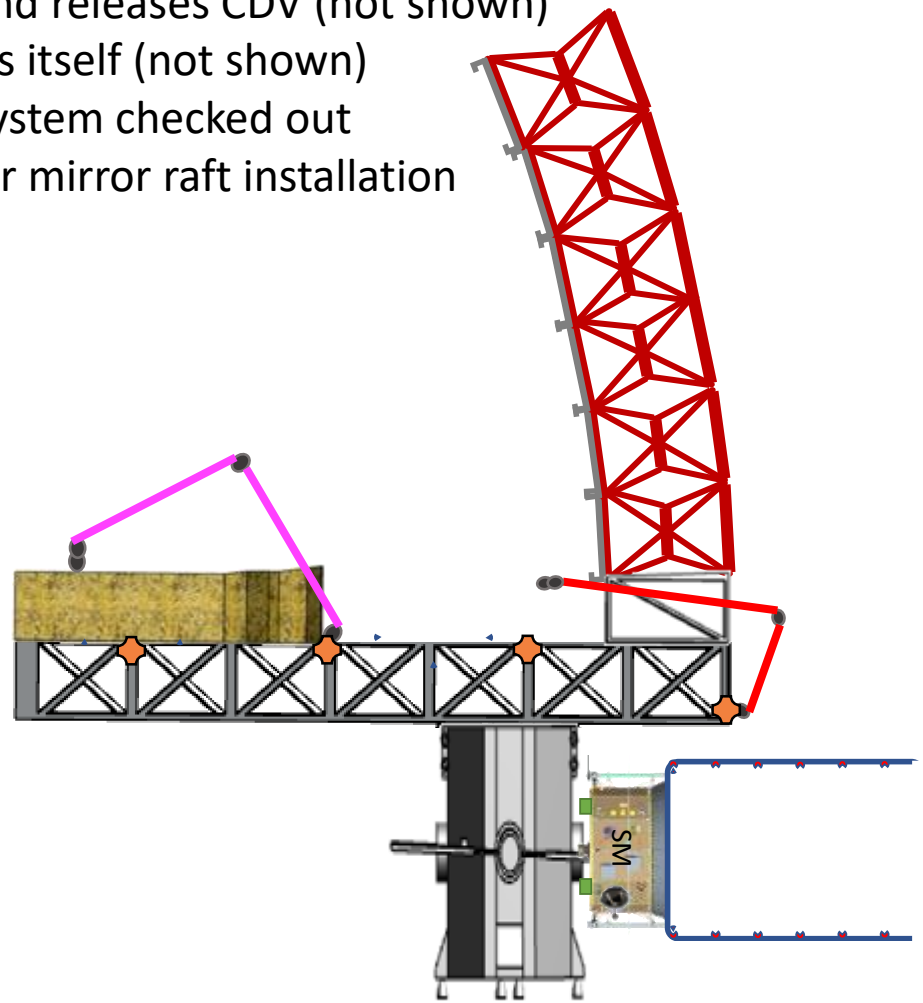
Secondary and Metrology System Installation

1. Arm 1 grapples and berths CDV with Secondary/Light Box (not shown)
2. Arm 1 inchworms to aft OTE robot base point, extracts Secondary, and hands off to Arm 2

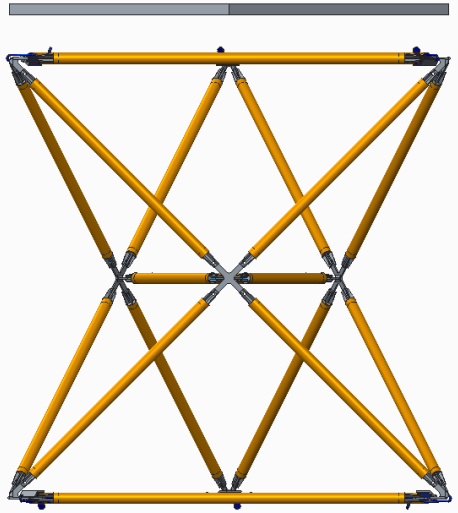


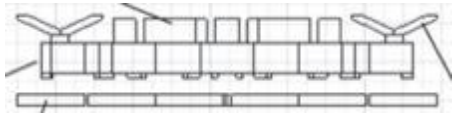
Use longer fairing

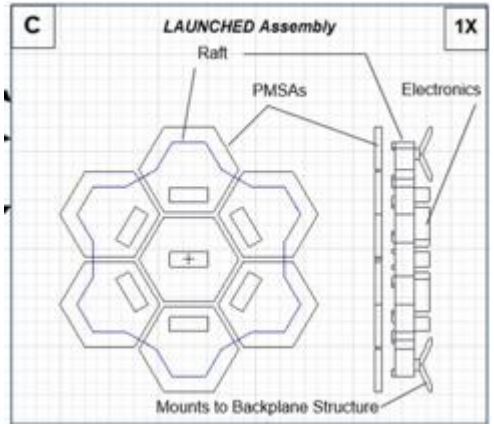
3. Arm 2 installs Secondary/Light Box
4. Arm 1 inchworms to spacecraft aft robot base point, unbearths and releases CDV (not shown)
5. CDV disposes itself (not shown)
6. Metrology system checked out and ready for mirror raft installation

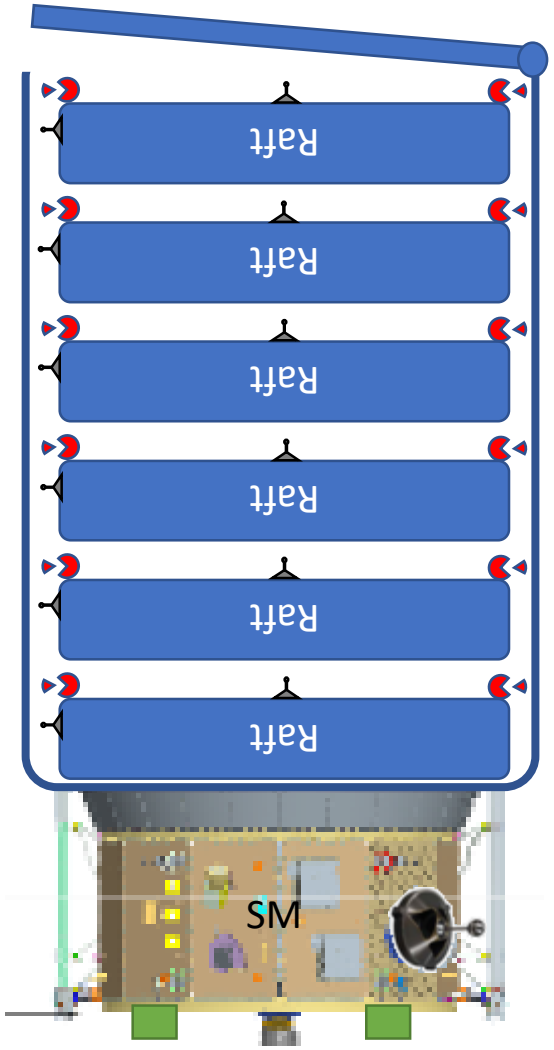


Mirror Raft Unload and Installation



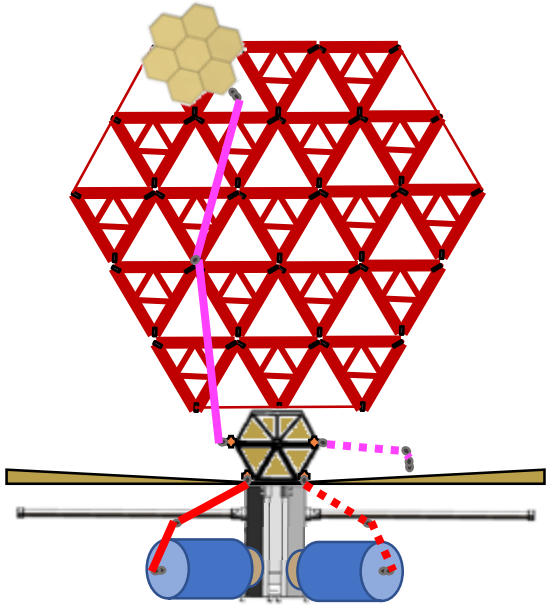
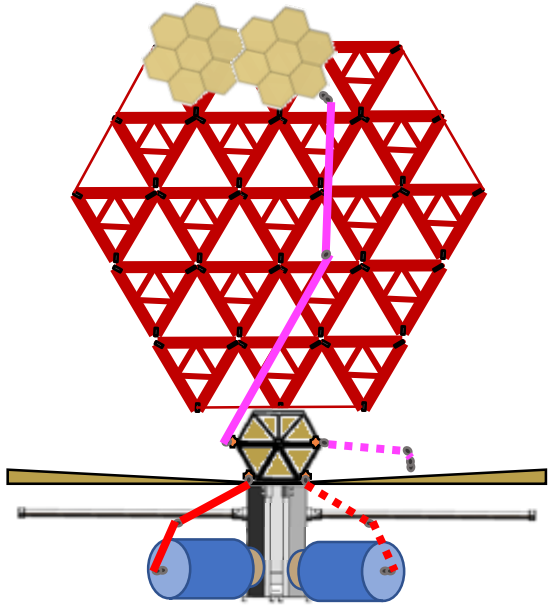
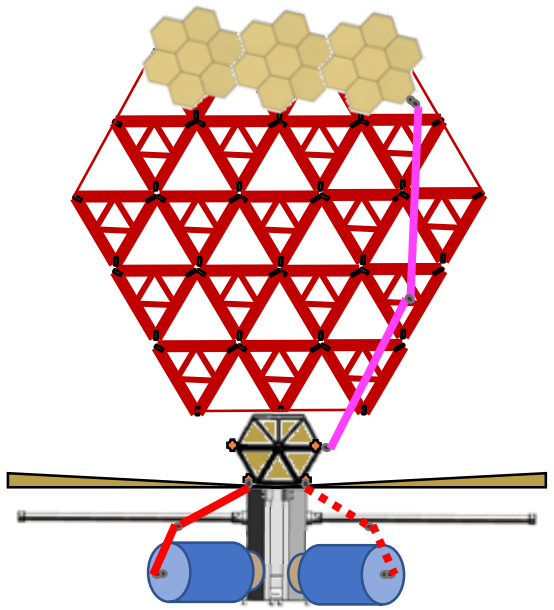
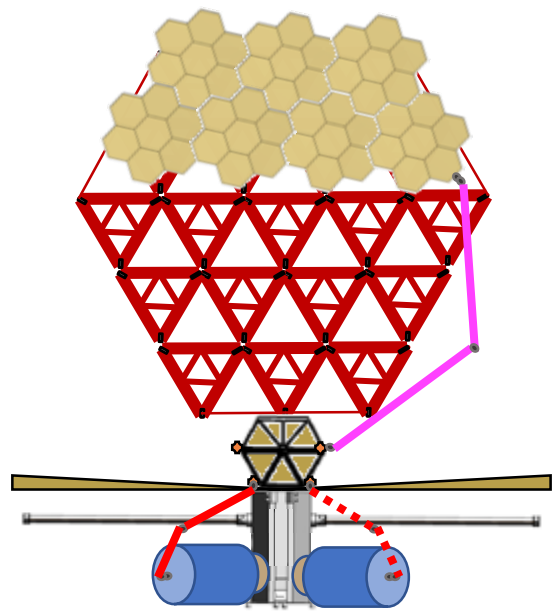
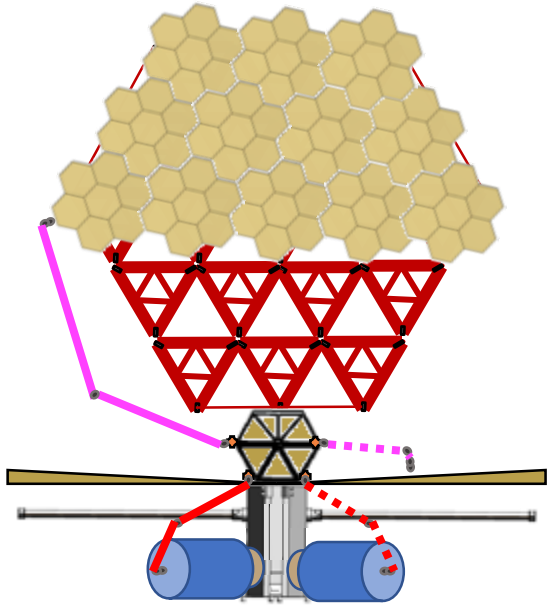
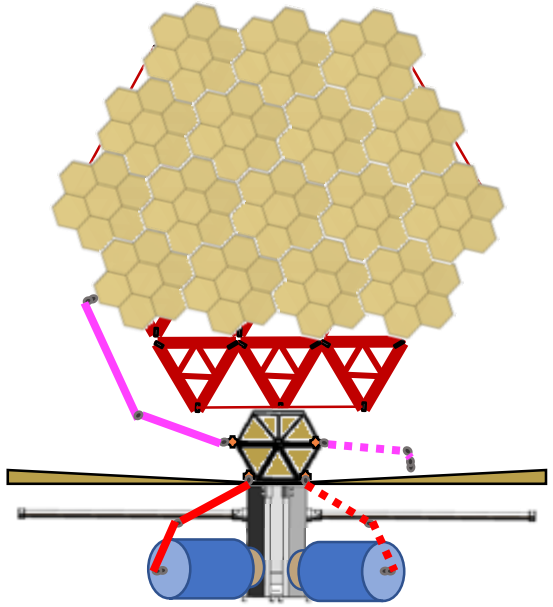
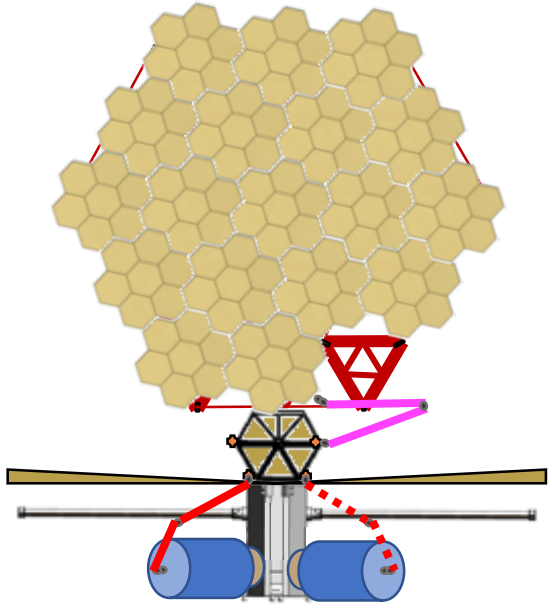
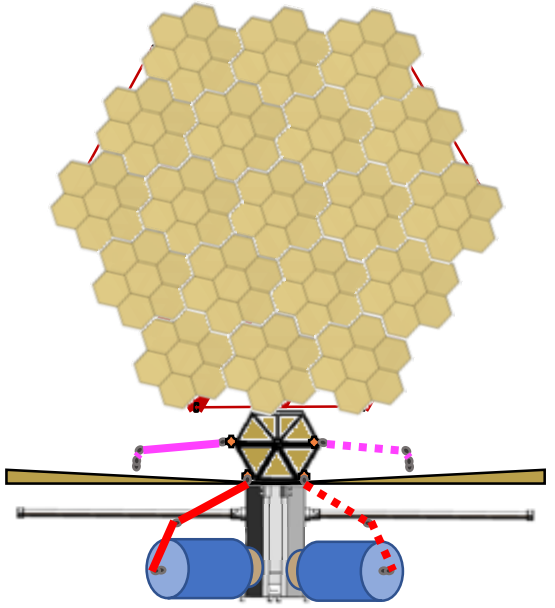






Mirror Raft Transport

- Three point mount on each raft
- 6 (TBR) Rafts per launch
- Robot actuated door

Raft mating sequence option 1:

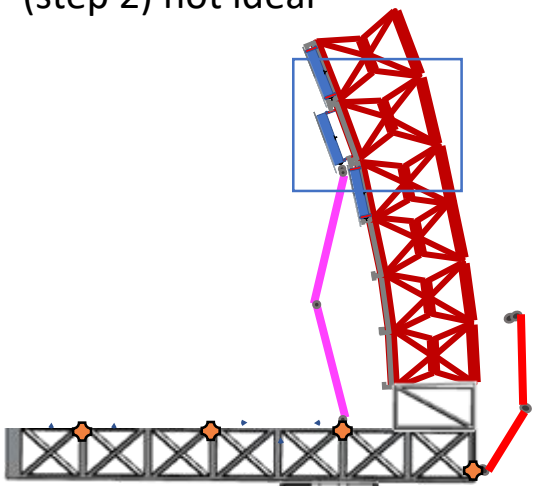
1. Arm aligns raft to truss-mounted passive mating features
2. Arm couples raft to features on truss (including power to raft)
3. Arm retracts
4. Mechanisms in raft draw raft into fully attached position

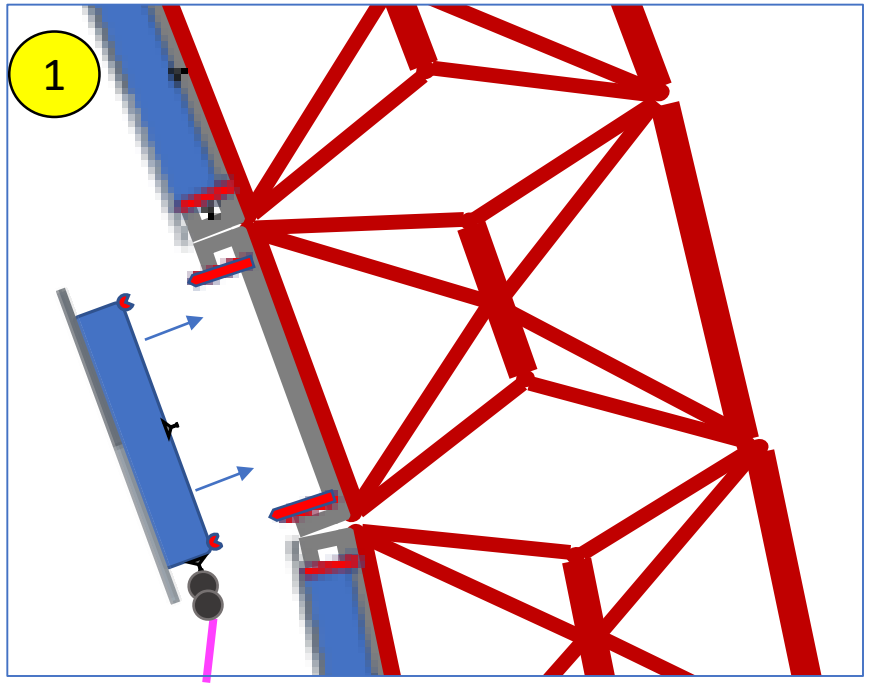
Pros:

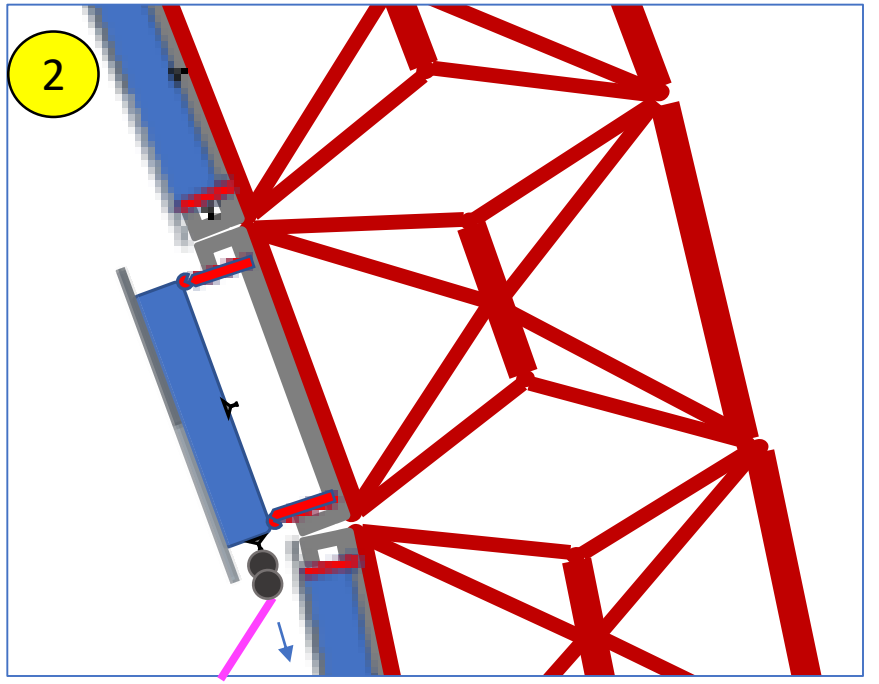
1. Allows installation and replacement (servicing) in any order

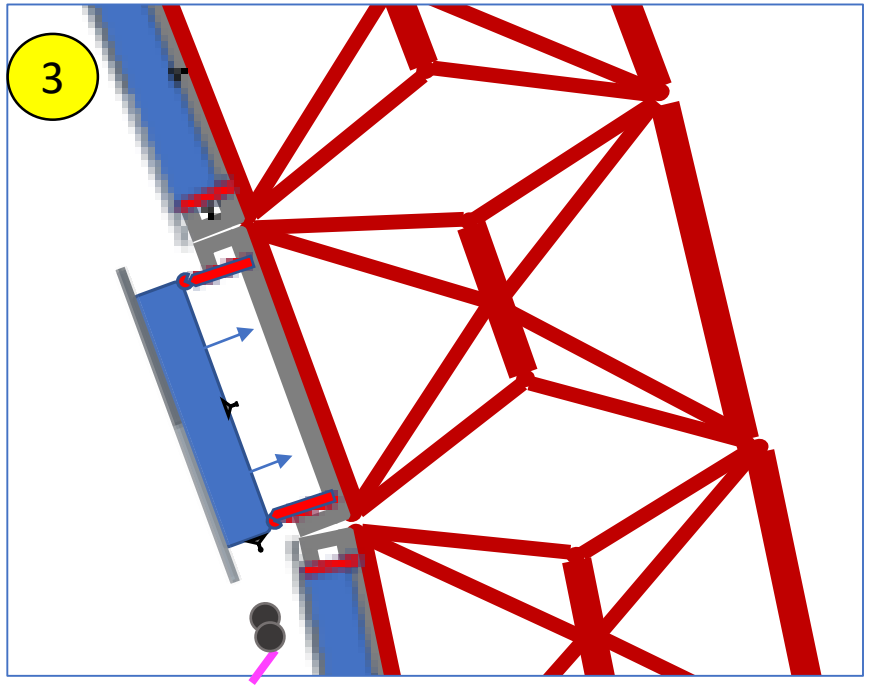
Cons:

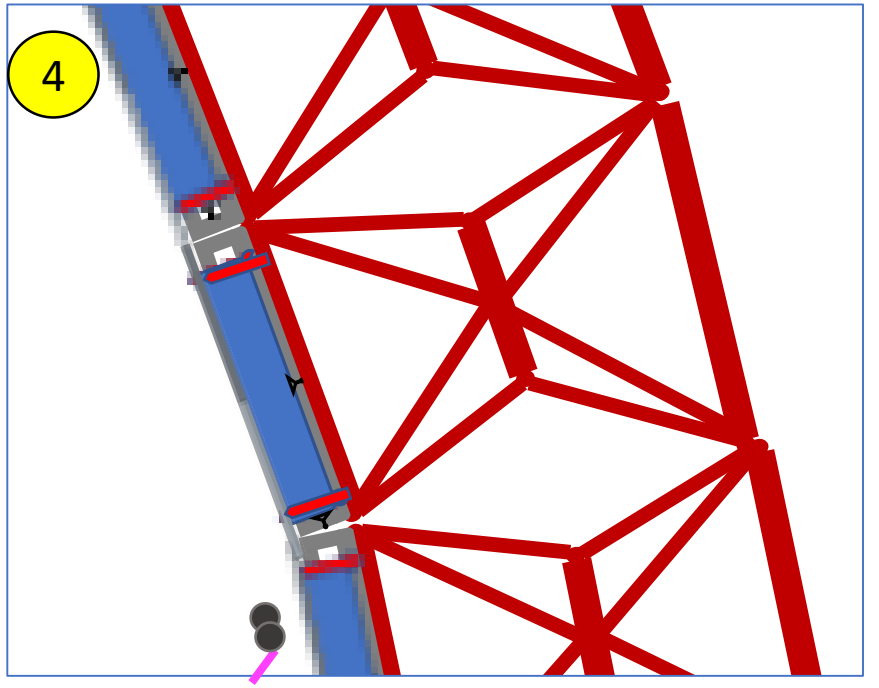
1. requires mechanism in raft that could fail (consider robot override of that mechanism, requires access from behind but ***only in*** **anomaly**)
2. Power to raft in intermediate state (step 2) not ideal











Raft mating sequence option 2:

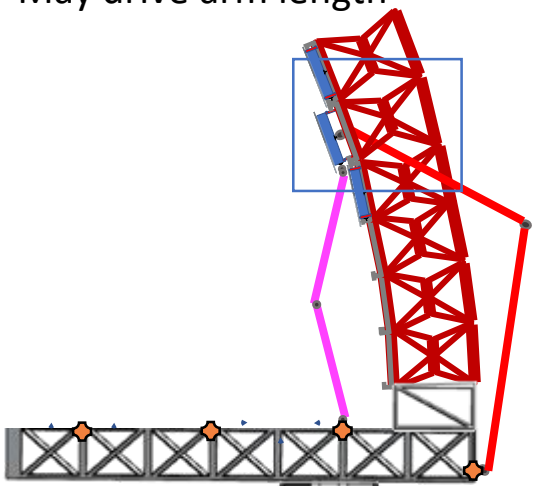
1. Arm 1 aligns raft to truss-mounted passive mating features
2. Arm 2 couples raft from behind
3. Arm 2 pulls raft into place, drives coupling mechanisms

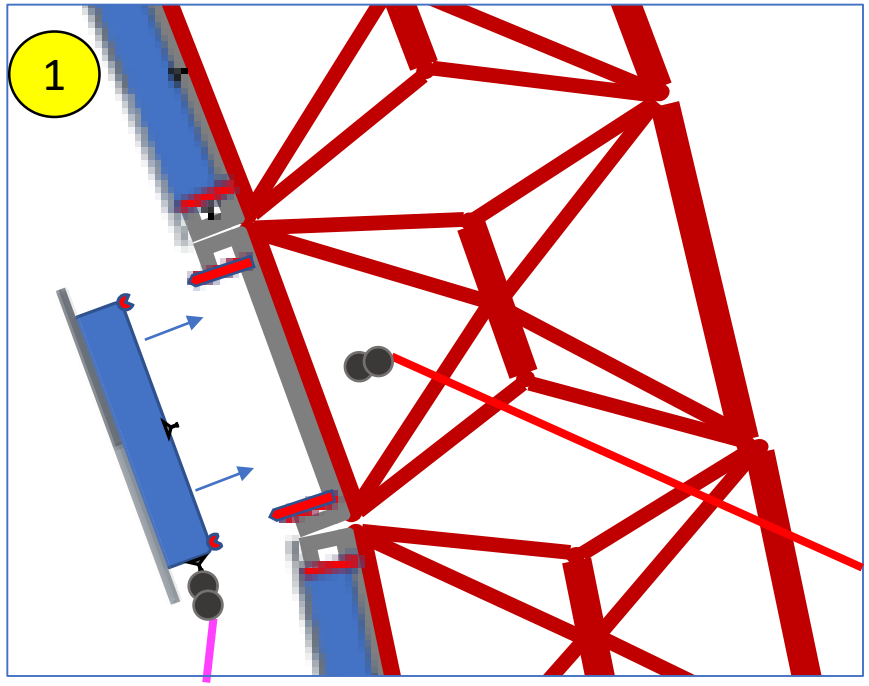
Pros:

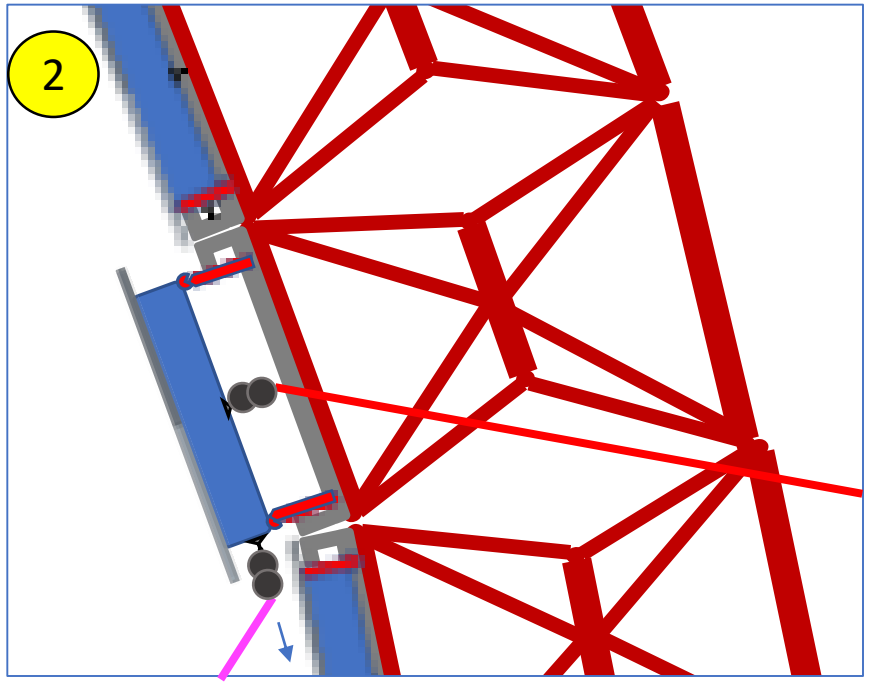
1. Purely robotic actuated mechanism in raft
2. Allows servicing

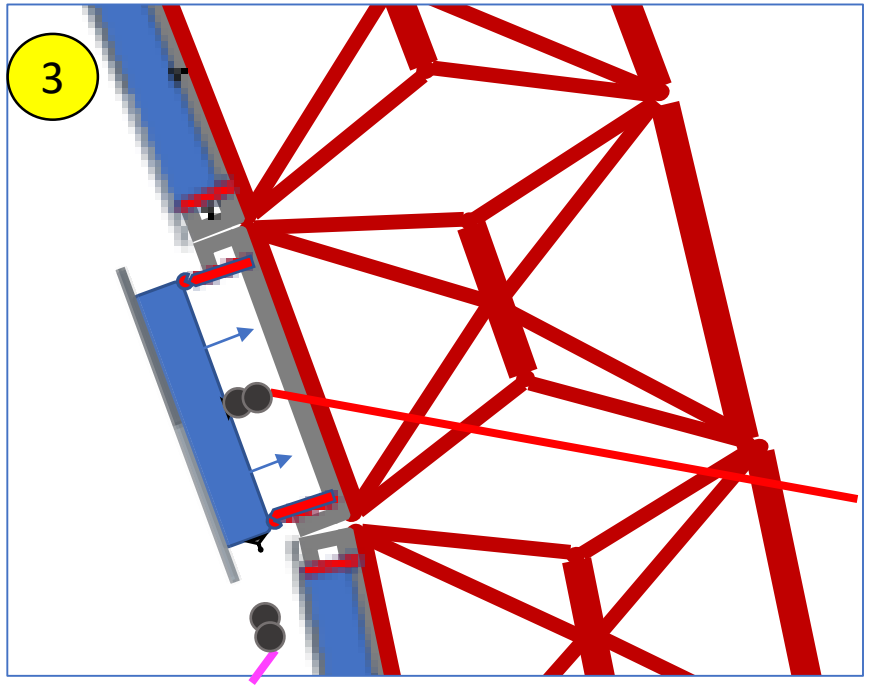
Cons:

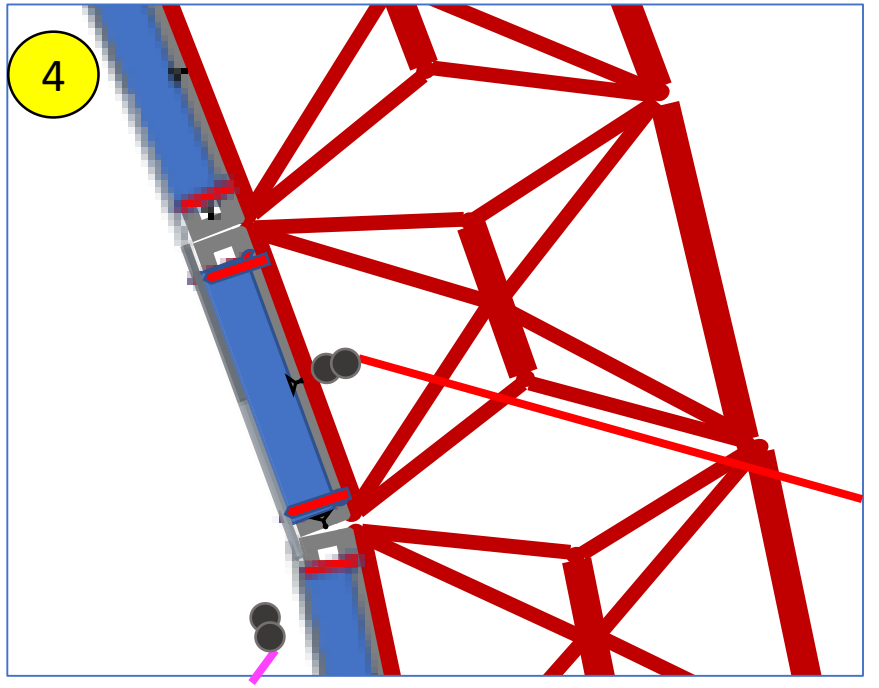
1. Requires removal of aft sunshade in ***nominal*** servicing scenario
2. Robot reach through truss may be difficult (but would be required by option 1 in some form, too)
3. May drive arm length











Raft mating sequence option 3:

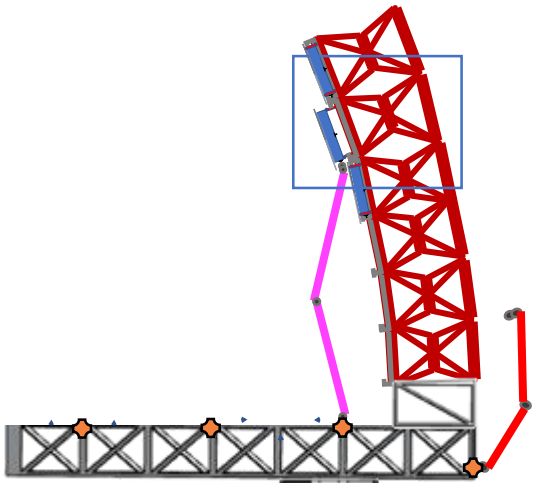
1. Arm 1 aligns raft to truss-mounted passive mating features
2. Arm 1 drives mechanism to mate
3. Arm 1 releases raft

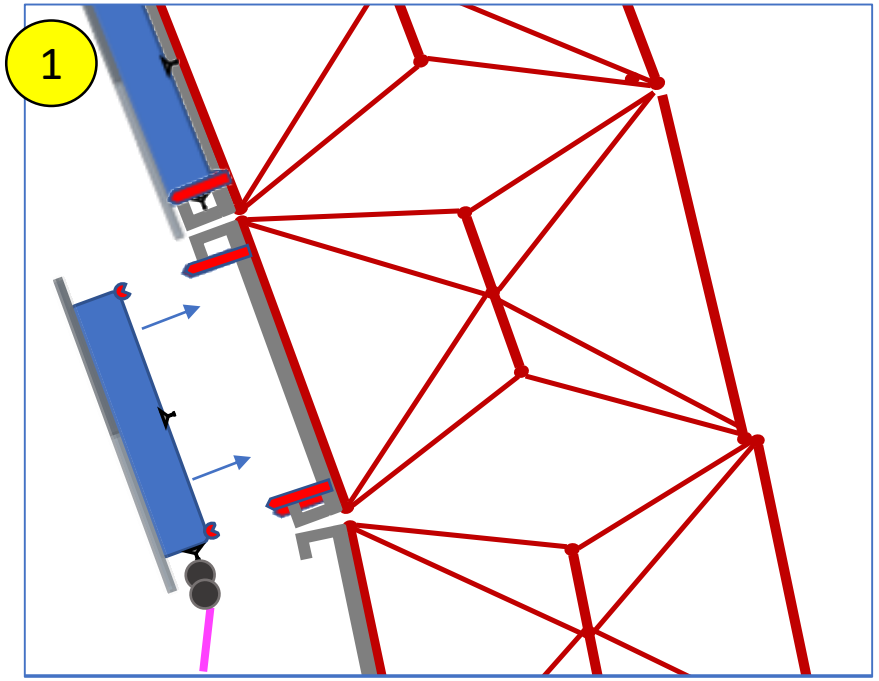
Pros:

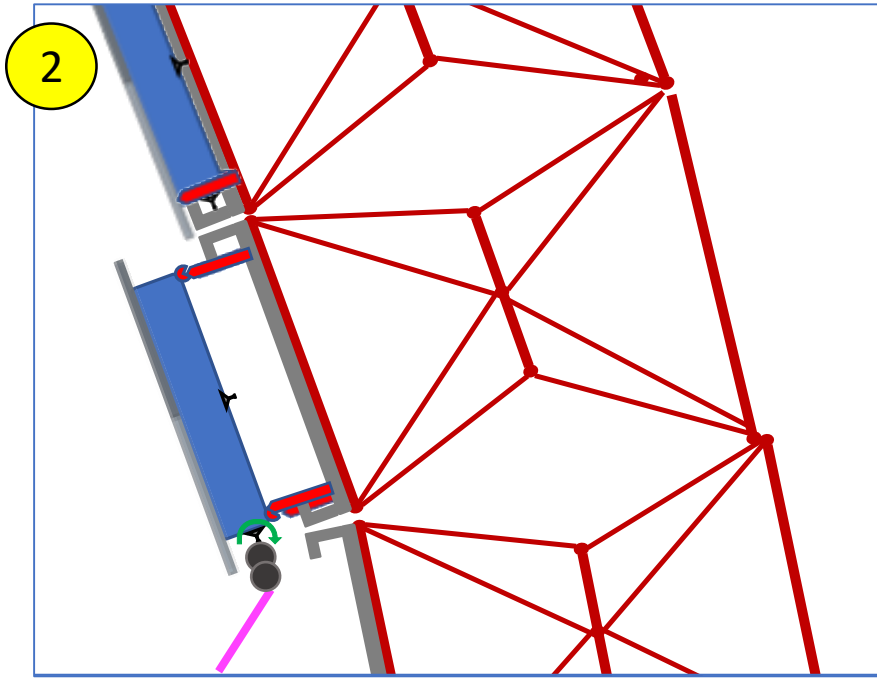
1. Purely robotic actuated mechanism in raft (simplifies raft design)

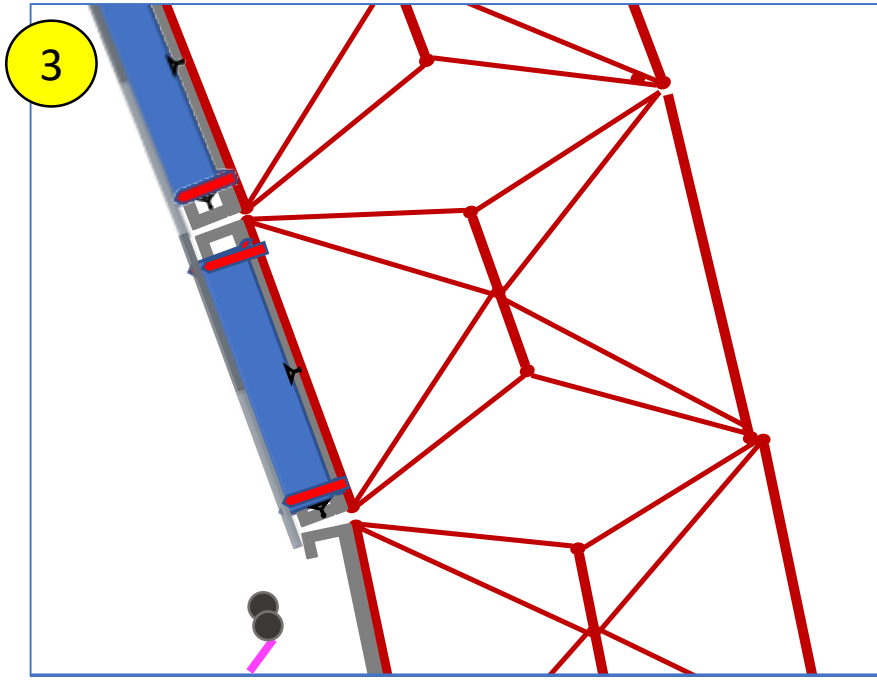
Cons:

1. Servicing inner rafts requires removal, temp stow of additional rafts)



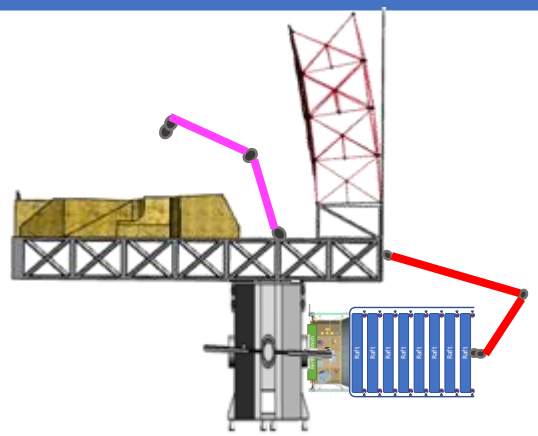
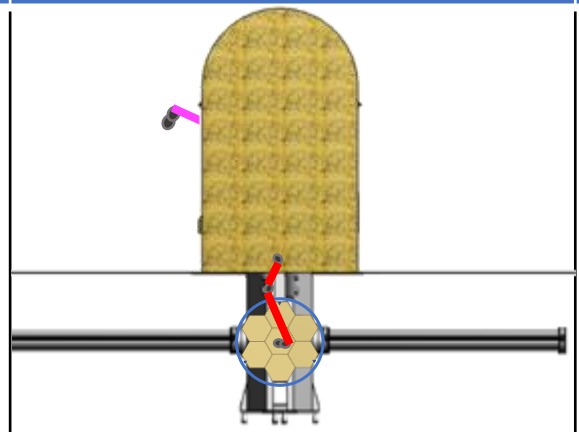
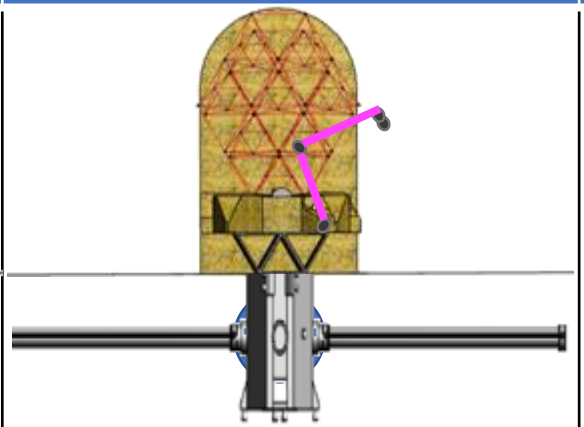
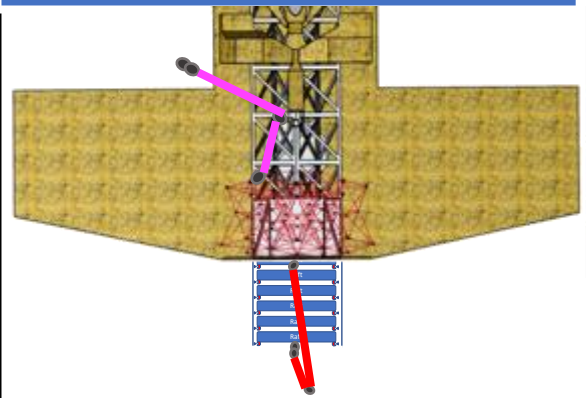
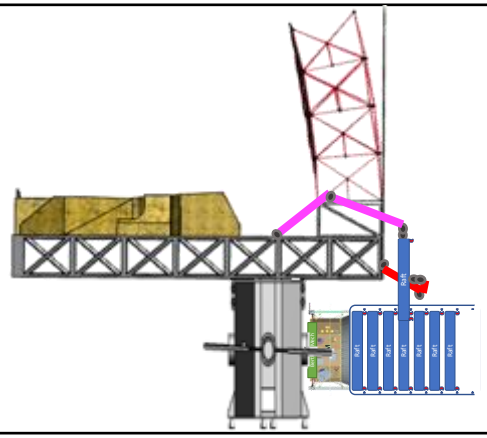
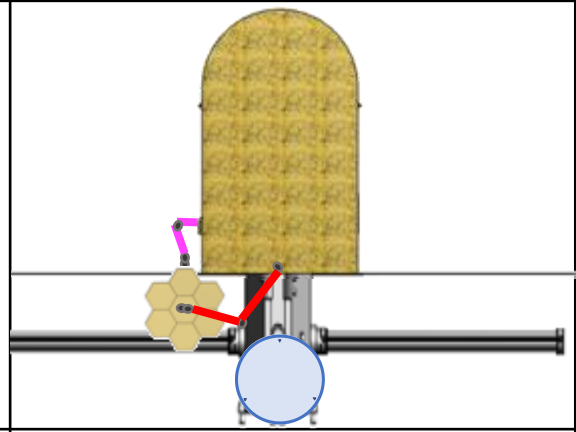
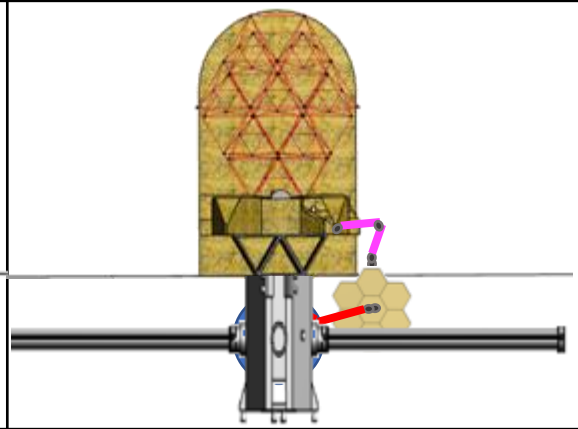
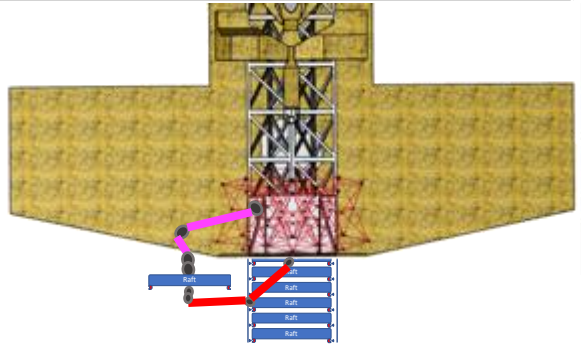
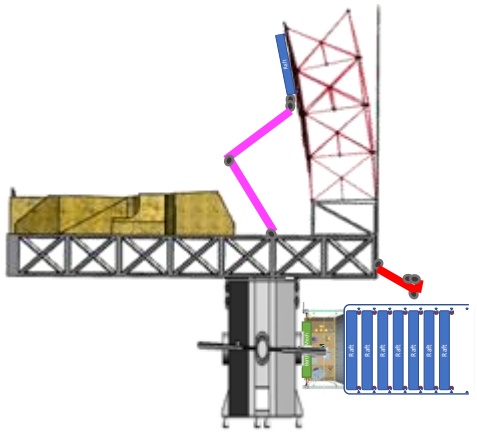
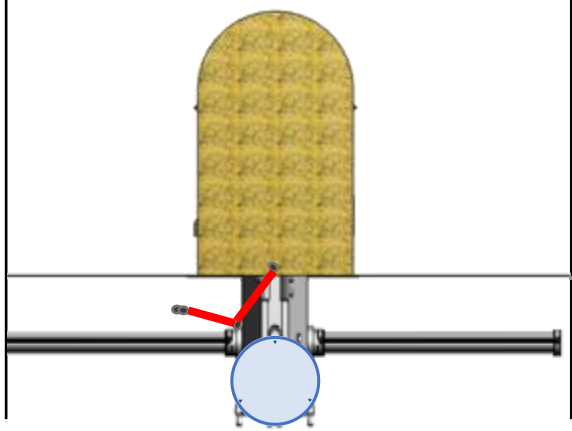
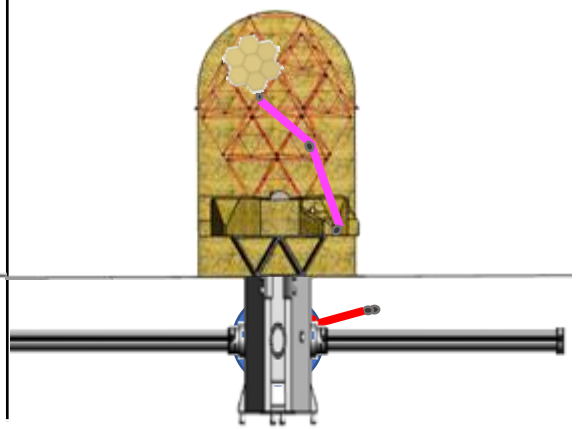
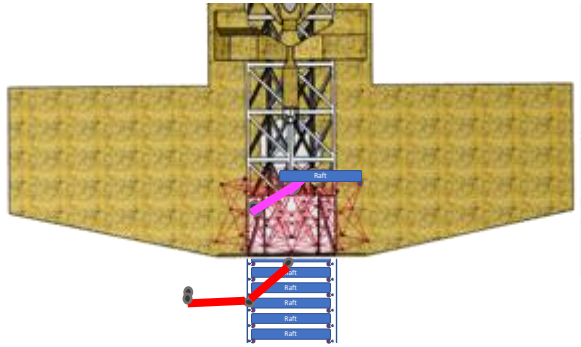






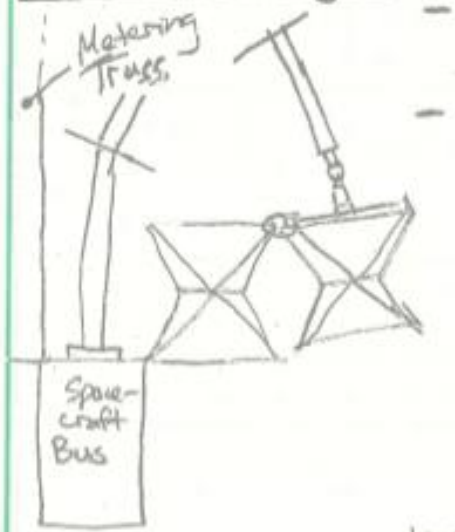
NOTE: 10m Telescope shown, replace w/ 20m when available

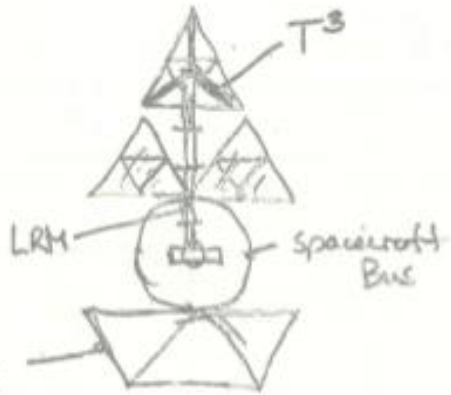
Mirror Raft Unload Sequence

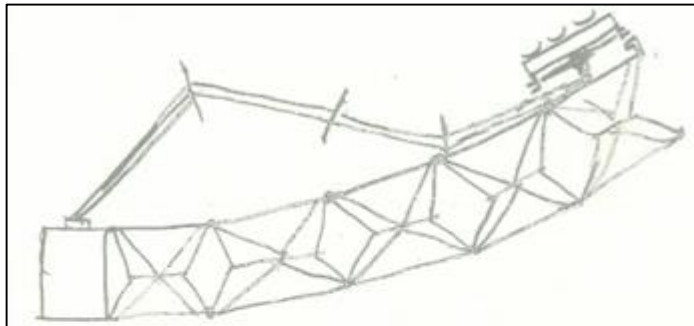
Step	Side View	Back View	Front View	Top View
1				
2				
3				

TriTruss Assembly : Use spacecraft Bus as Assembly Platform?

- T^3 in combination with the TDS or LRM would perform insertion and capture for each module
- T^3 or separate tool would lock joints.

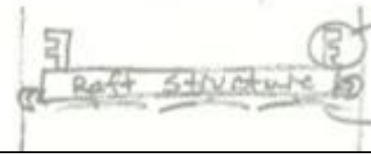




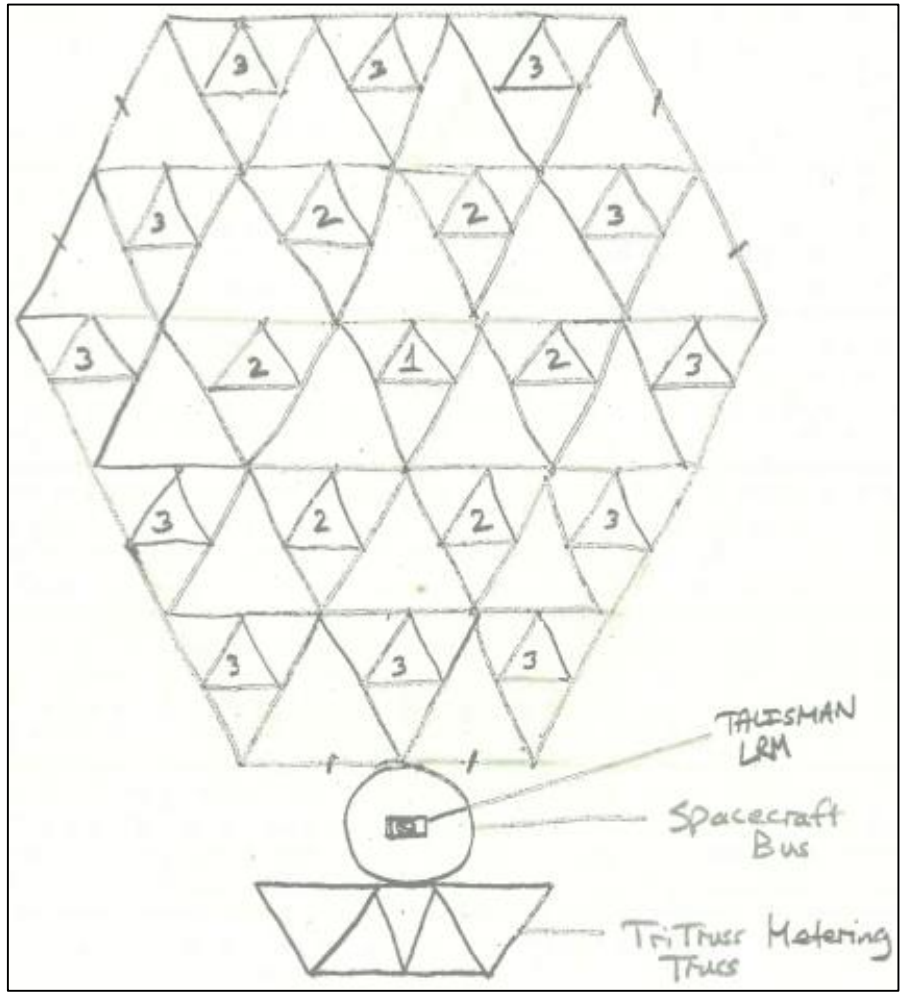


- Thought is to begin panel insertion at the point farthest from the spacecraft bus and begin moving in towards bus.
- For side insertion, shown above, looks like LRM and T^3 clebrances will have to be mitigated.
- Side insertion does seem like it would make subsequent rafts easy to install and minimize possibility of collision between raft that is being installed and those already in place.

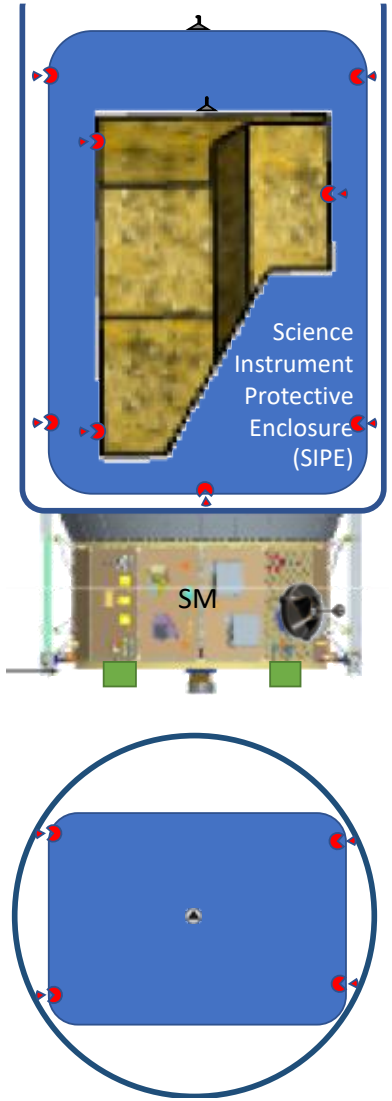
Packaged Mirror Rafts



Raft Side of the TriTruss-to-Raft Connector (3 locations



Science Instrument Unload and Installation

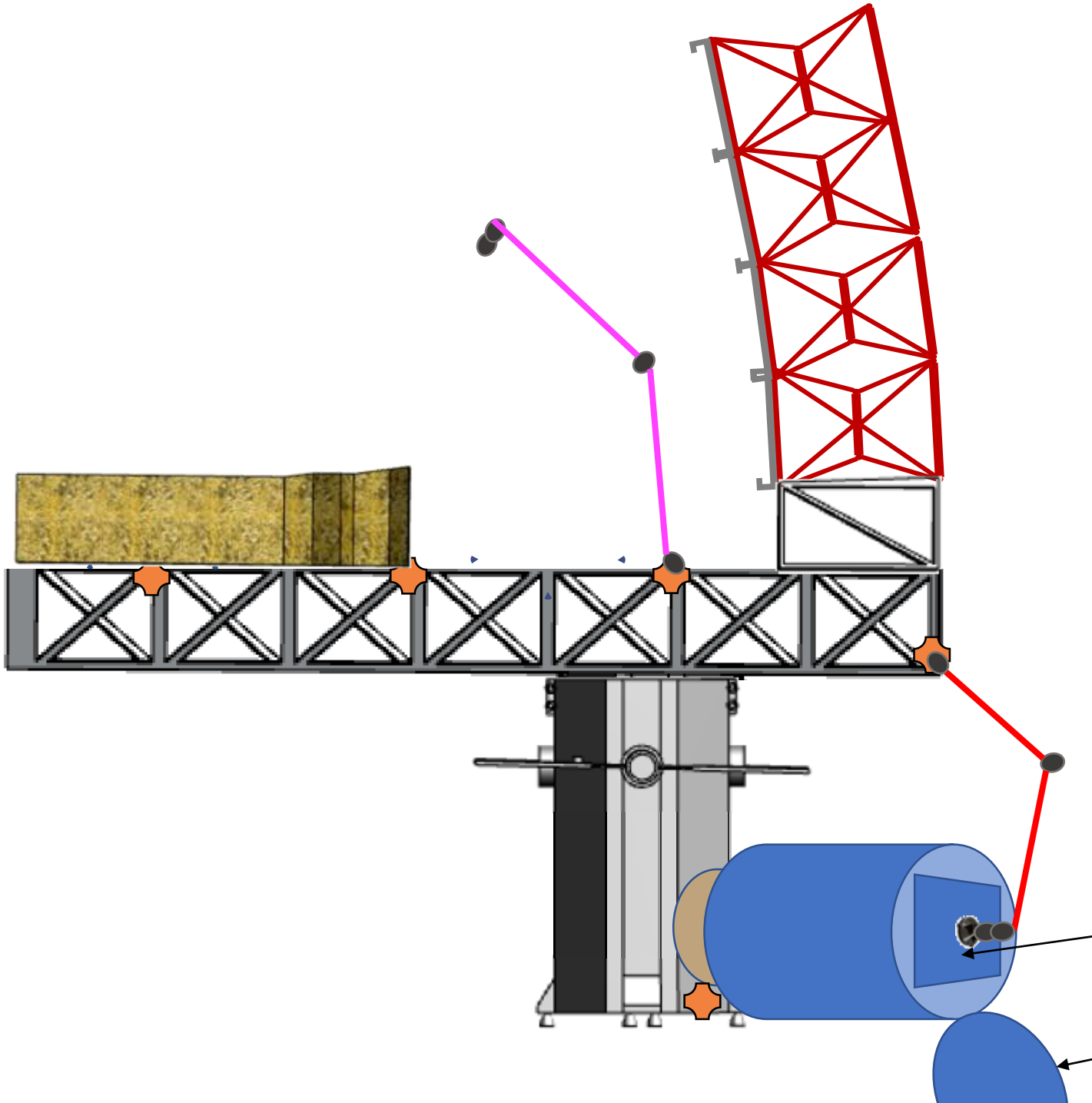


Assumptions:
CDV provides survival heater power to SIPE,
robot provides heater power to SIPE during translation,
SIPE temp stow location provides heater power to SIPE,
robot provides heater power to instrument,
robot must ensure no direct sun on SI, etc.

Science Instrument Transport

- Instruments delivered in SIPES
- SIPES launch mounted to Cargo Carrier
- Robotically moved to temp stowage on OTE
- 1 (TBR) SI per launch = 5 Launches

SI Unload Sequence

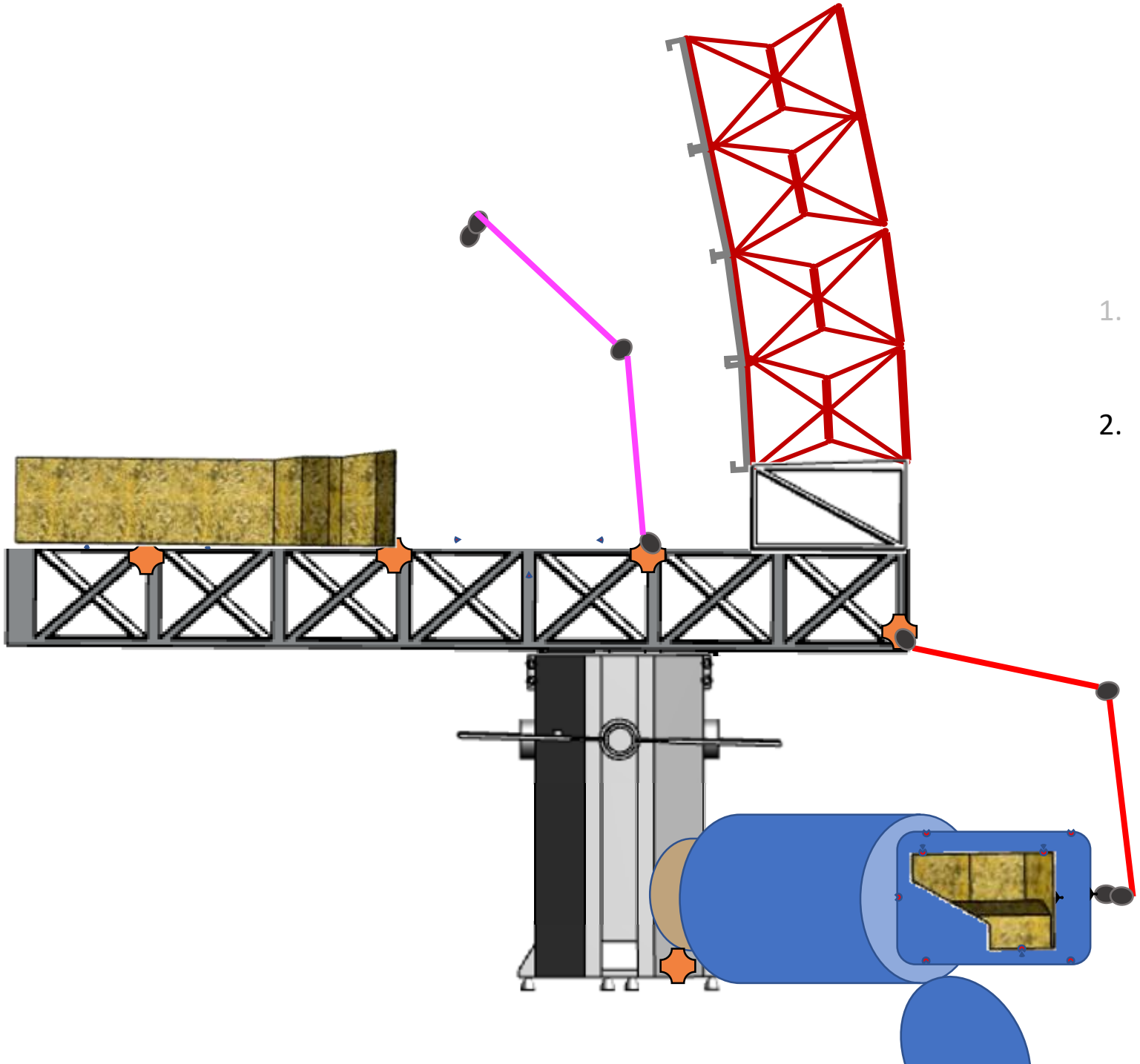


Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock/Temp Stow
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle

SI Unload Sequence

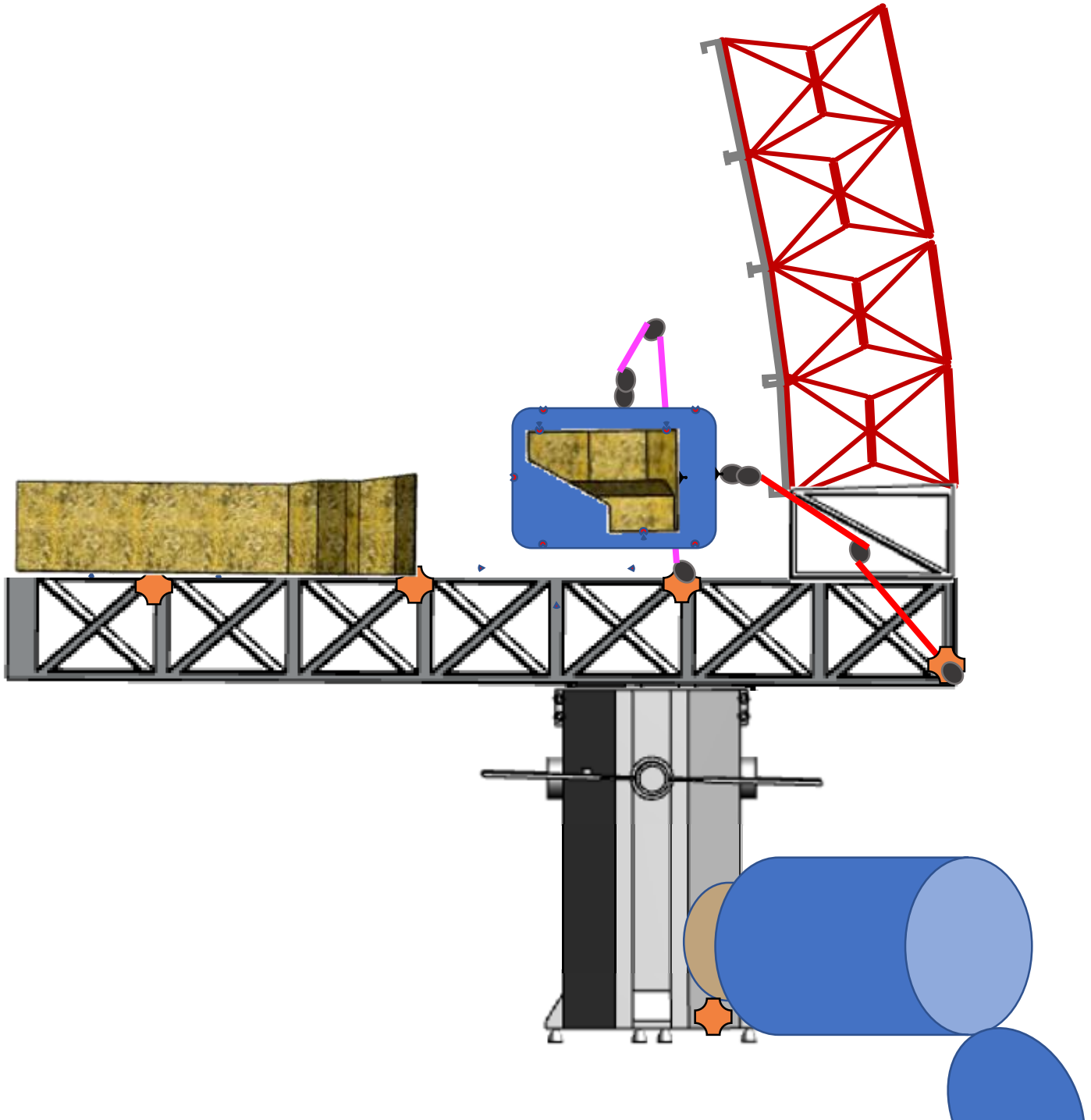


Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle

SI Unload Sequence

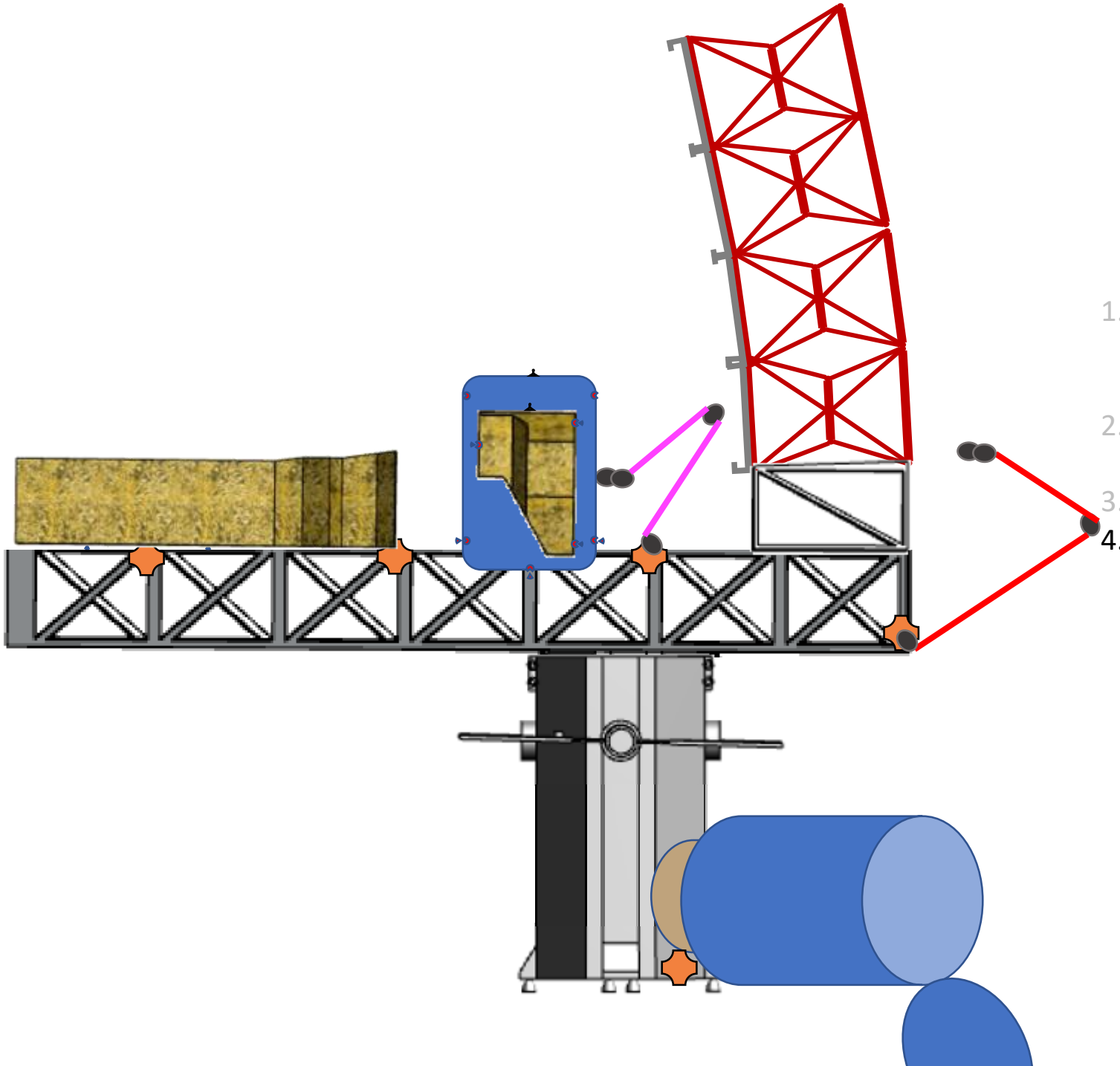


Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle
3. Robot 1 hands off SIPE to Robot 2

SI Unload Sequence

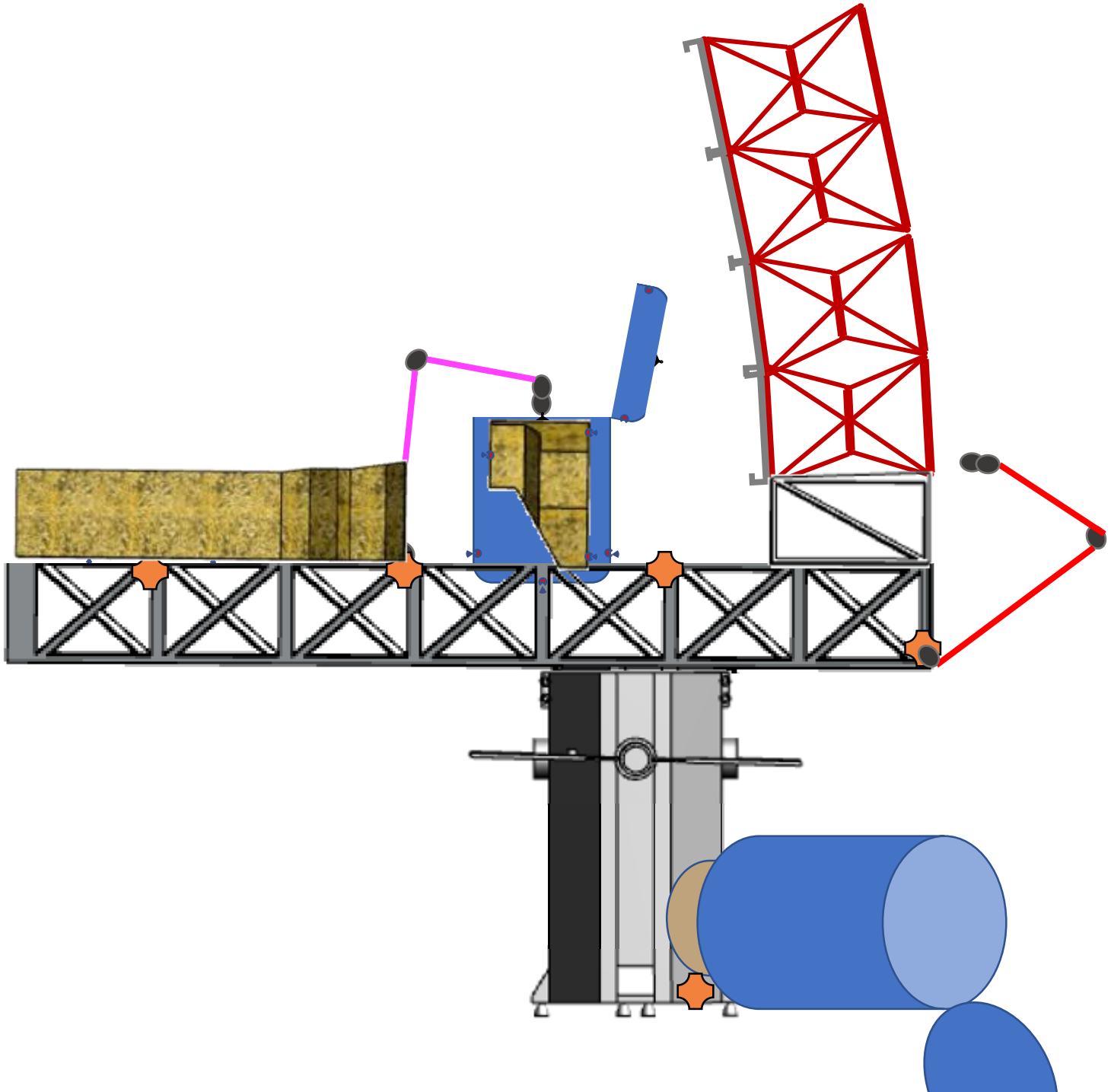


Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle
3. Robot 1 hands off SIPE to Robot 2
4. Robot 2 Temp Stows SIPE on metering truss

SI Unload Sequence

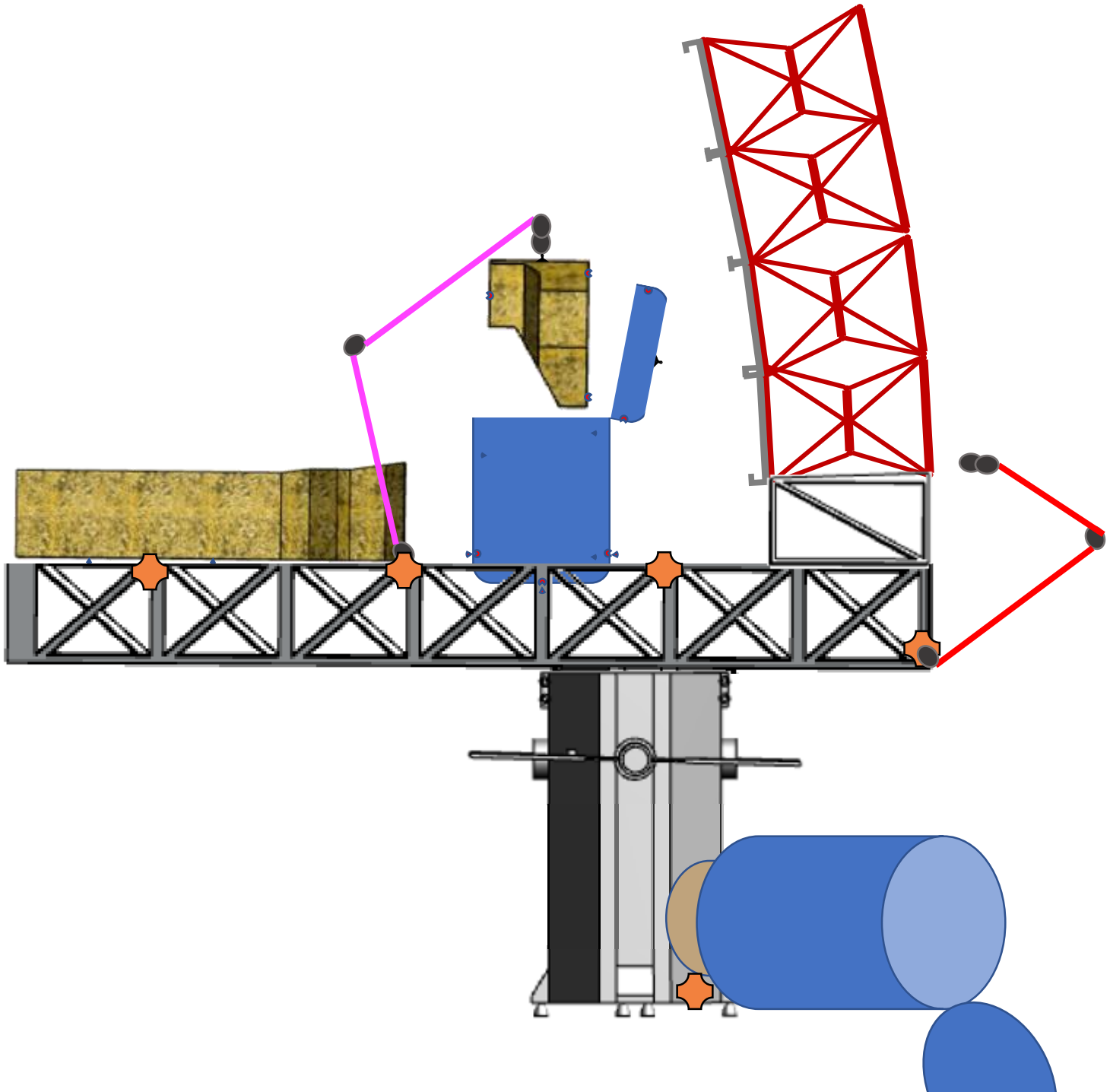


Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle
3. Robot 1 hands off SIPE to Robot 2
4. Robot 2 Temp Stows SIPE on metering truss
5. Robot 2 inchworms to SI install robot base point, SIPE opens

SI Unload Sequence

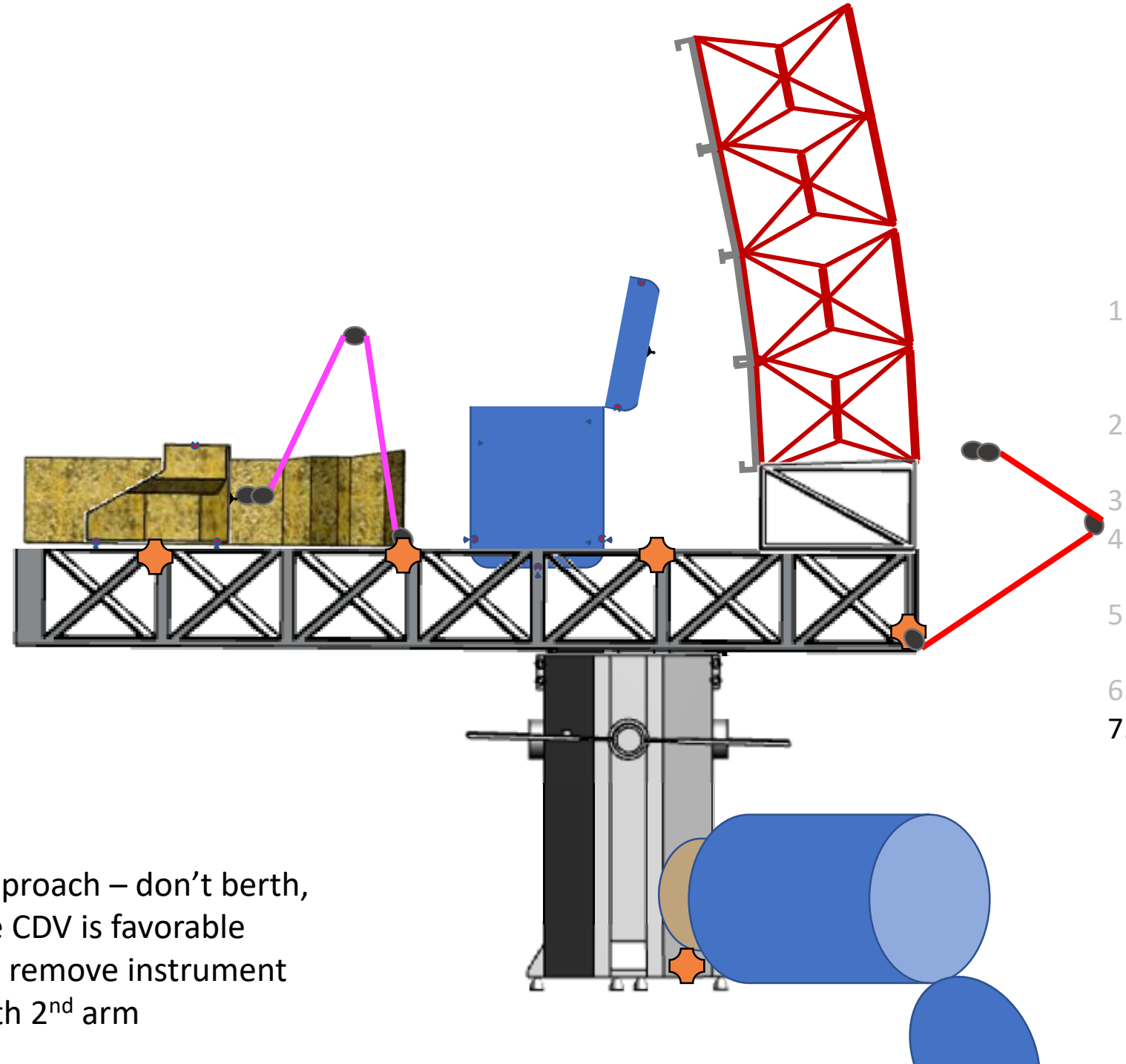


Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle
3. Robot 1 hands off SIPE to Robot 2
4. Robot 2 Temp Stows SIPE on metering truss
5. Robot 2 inchworms to SI install robot base point, SIPE opens
6. Robot 2 removes SI from SIPE

SI Unload Sequence



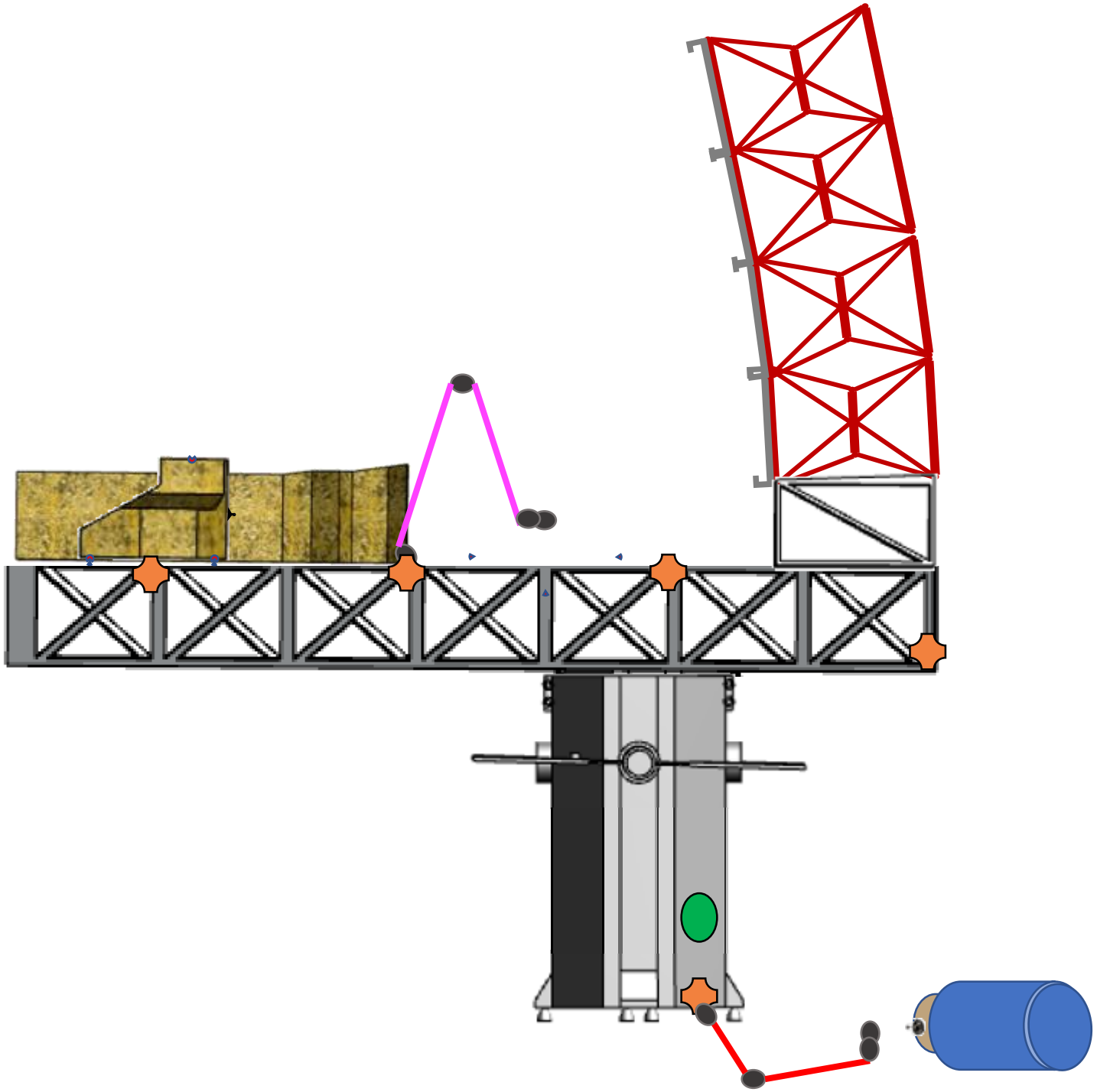
Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle
3. Robot 1 hands off SIPE to Robot 2
4. Robot 2 Temp Stows SIPE on metering truss
5. Robot 2 inchworms to SI install robot base point, SIPE opens
6. Robot 2 removes SI from SIPE
7. Robot 2 installs SI

Alternate approach – don't berth, just hold the CDV is favorable location and remove instrument (no SIPE) with 2nd arm

SI Unload Sequence



Key

- Grapple/Grasp Feature
- Passive Berthing Feature
- Active Berthing Mech
- Launch Lock
- Tri Truss Tool
- Robot Base Point

1. Robot 1 grapples and berths Cargo Delivery Vehicle with, inchworms to robot base point on aft OTE (not shown)
2. Robot 1 removes SIPE from Cargo Delivery Vehicle
3. Robot 1 hands off SIPE to Robot 2
4. Robot 2 Temp Stows SIPE on metering truss
5. Robot 2 inchworms to SI install robot base point, SIPE opens
6. Robot 2 removes SI from SIPE
7. Robot 2 installs SI
8. Robot 2 closes SIPE, hands off empty SIPE to Robot 1 (not shown)
9. Robot 1 re-installs SIPE in CDV, inch-worms to spacecraft aft robot base point, unberths and releases CDV
10. CDV departs to disposal w/ SIPE

Repeat for remaining SIs