MAFSA

Mars Autonomous and Foldable Solar Array

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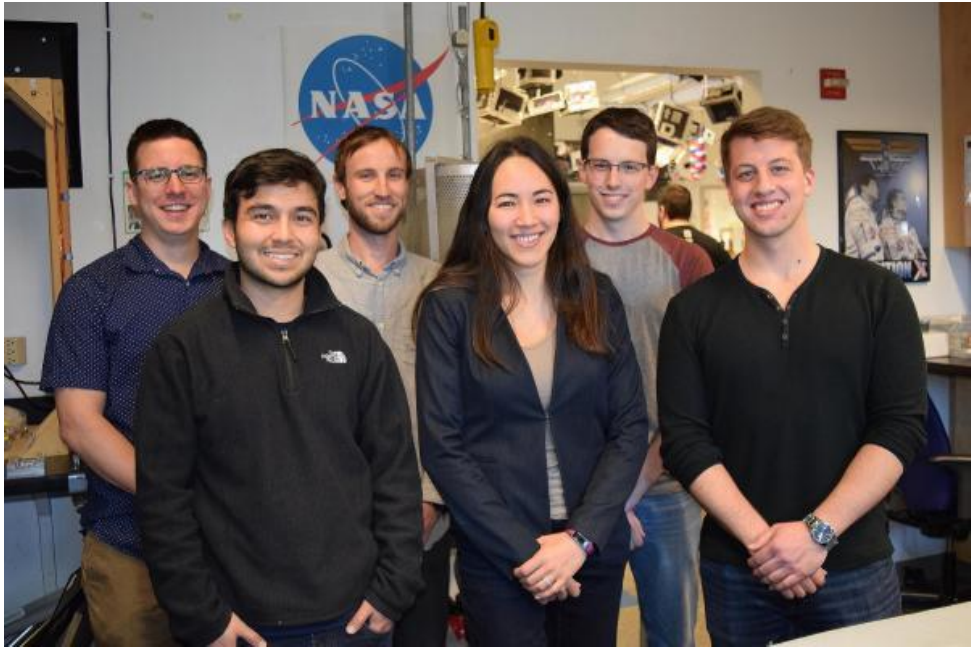
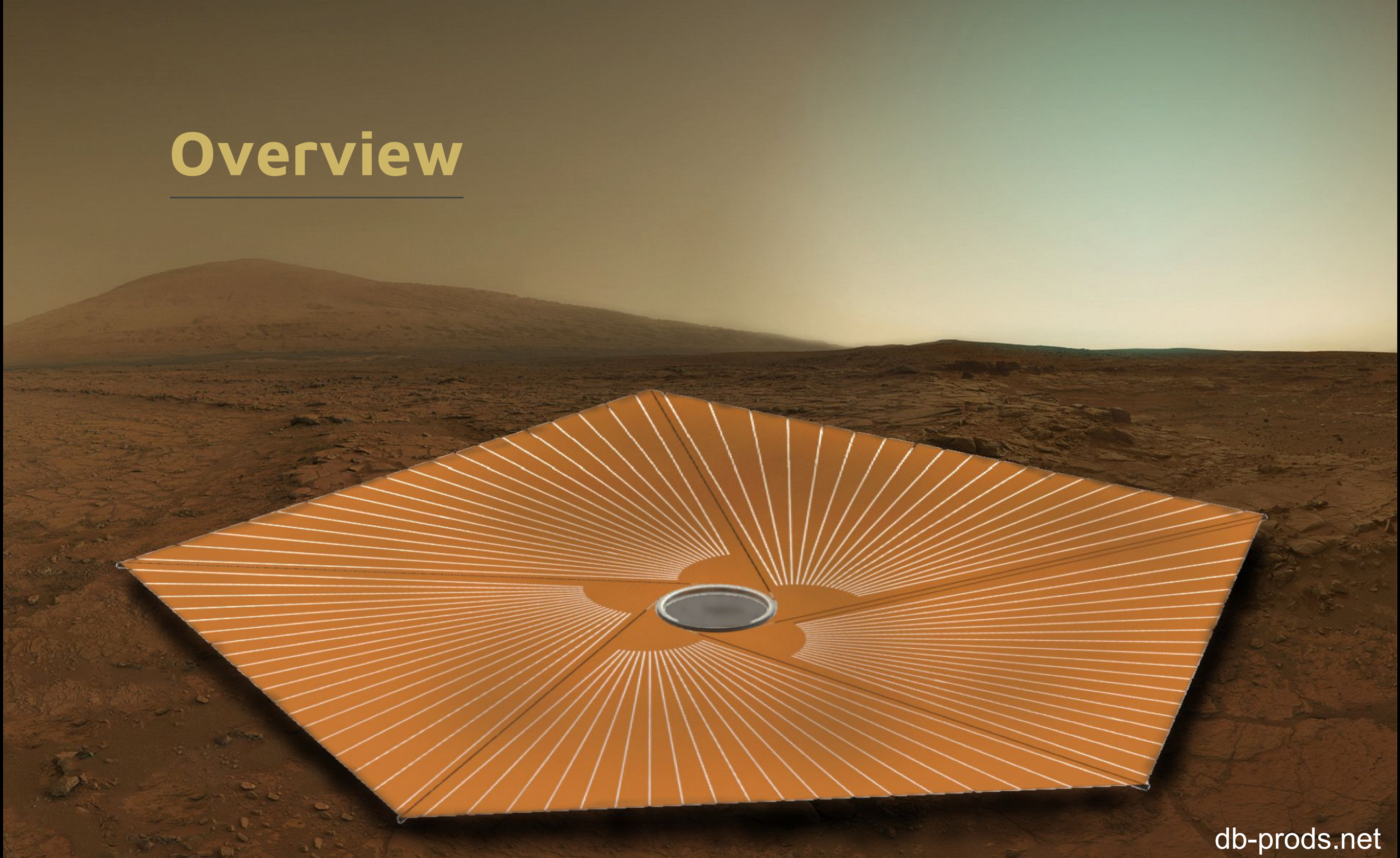


Overview



Problem Description

- Mass - 1500 kg

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- Volume - 10 m^3

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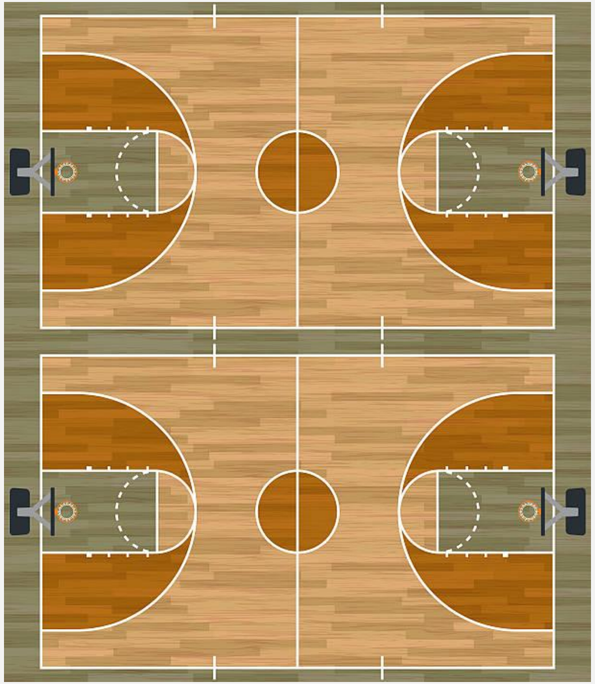
- Mass - 1500 kg
- Volume - 10 m^3
- Photovoltaic area - 1000 m^2
- Operational environment
  - 0.5m obstacles
- Dust mitigation



Motivation for Design

- Rigid booms
    - Telescoping
    - Foldable
    - Combination
- Small lander sized arrays
- Elaborate cabling systems
- Oddly shaped modules

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  - Large ring inflated around the lander
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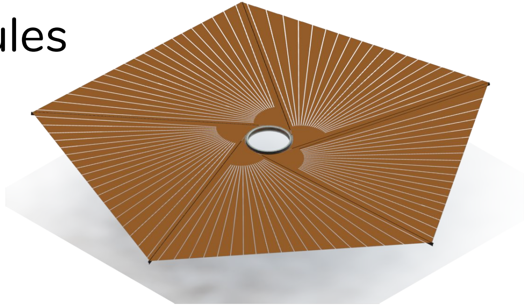


booms

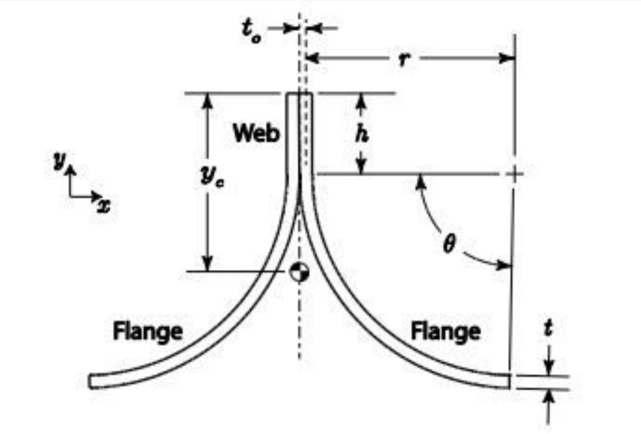
Dimensions

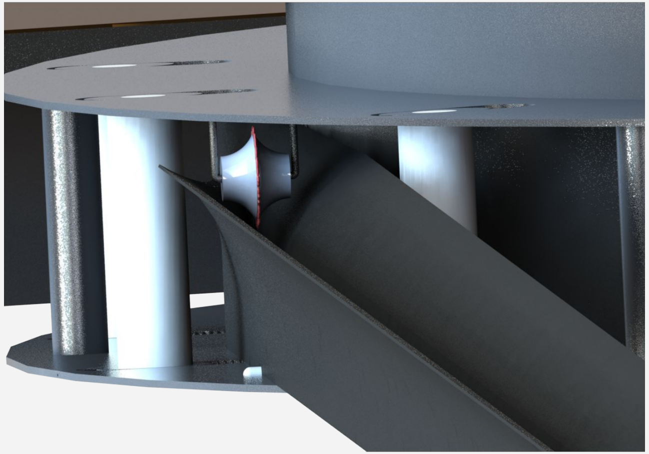
Required:

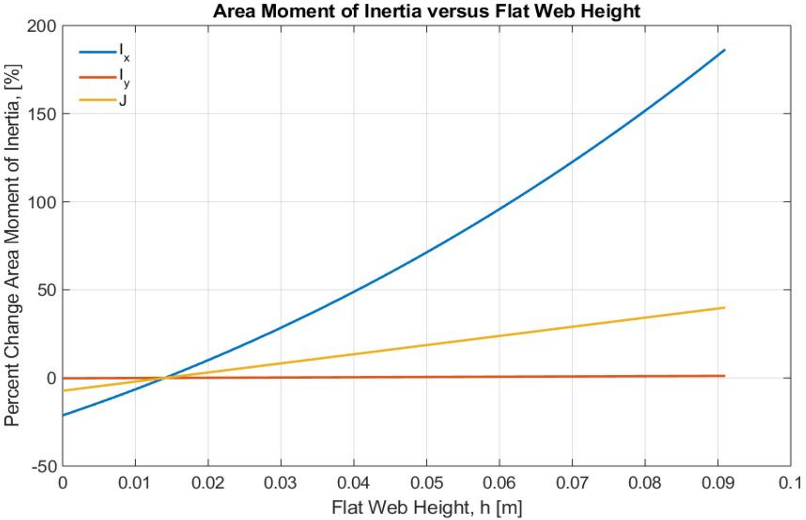
- 20+ meters long
- Support 500 kg of solar array
- Stow within the lander

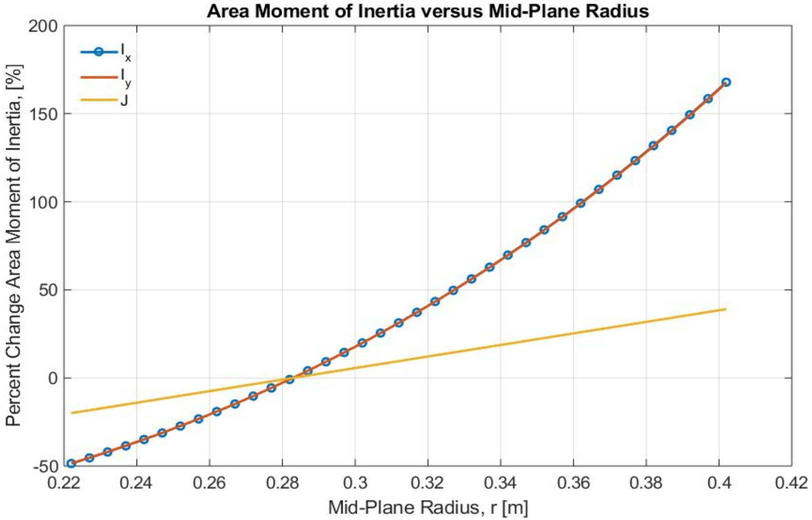
Triangular Rollable and Collapsable (TRAC) Booms:

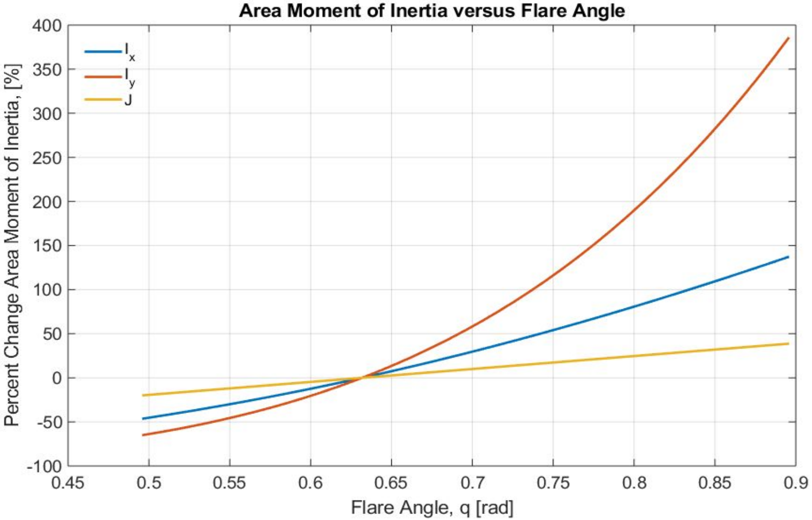
- Invented by Air Force Research Lab, developed by Roccor
- High ratio of cross-section inertia to packaged height

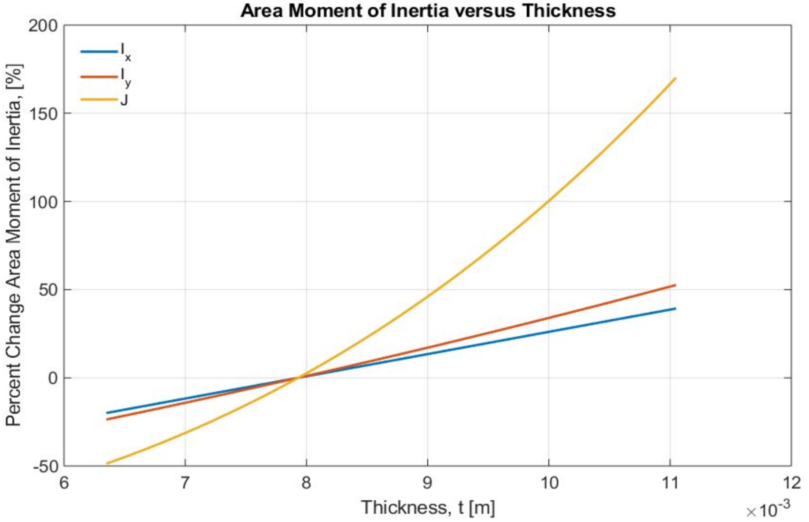





Area Moment of Inertia versus Flat Web Height
I_x
I_y
J
Percent Change Area Moment of Inertia, [%]
Flat Web Height, h [m]
200
150
100
50
0
-50
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1


Area Moment of Inertia versus Mid-Plane Radius
I_x
I_y
J
Percent Change Area Moment of Inertia, [%]
Mid-Plane Radius, r [m]
200
150
100
50
0
-50
0.22
0.24
0.26
0.28
0.3
0.32
0.34
0.36
0.38
0.4
0.42


Area Moment of Inertia versus Flare Angle
I_x
I_y
J
Percent Change Area Moment of Inertia, [%]
Flare Angle, q [rad]
400
350
300
250
200
150
100
50
0
-50
-100
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9


Area Moment of Inertia versus Thickness
I_x
I_y
J
Percent Change Area Moment of Inertia, [%]
Thickness, t [m]
200
150
100
50
0
-50
6
7
8
9
10
11
12
×10⁻³

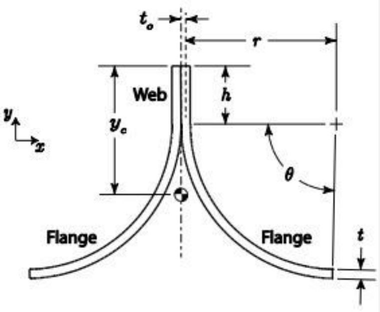
Structural Performance

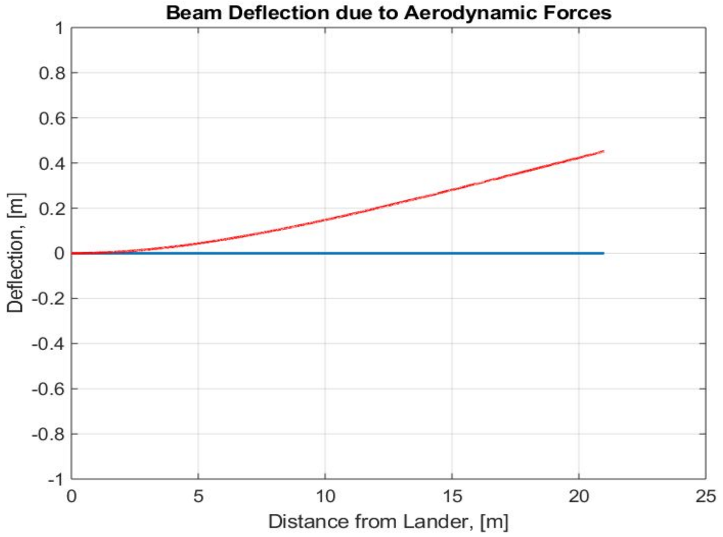
Dimensions:

h = 1.4 cm, Web height
r = 28 cm, Mid-plane radius
q = 36°, Flange flare angle
t = 8 mm, Thickness

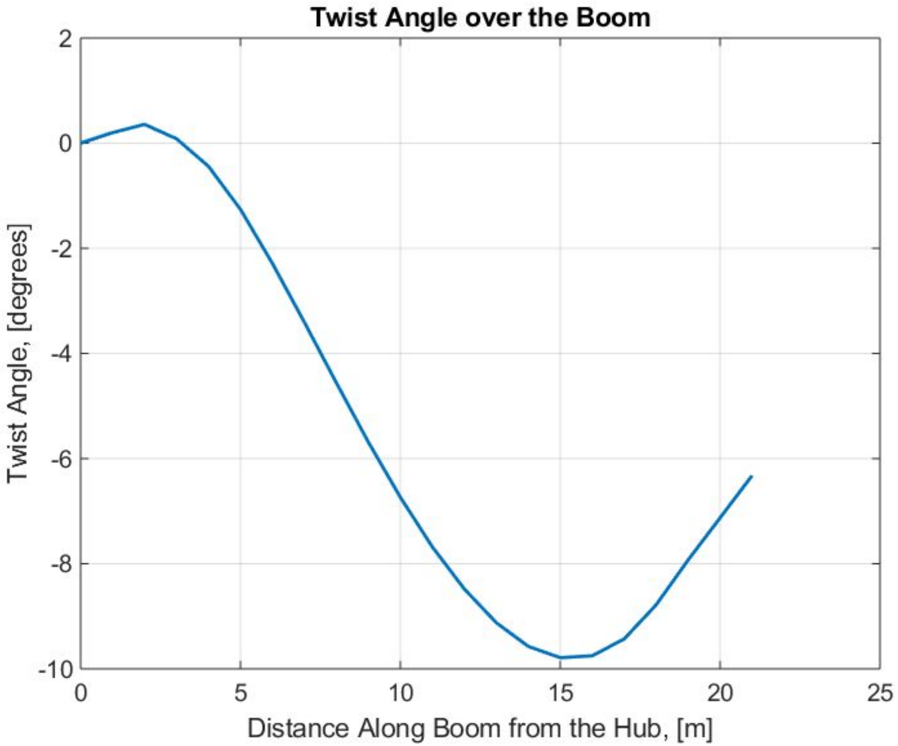
Stiffness:

$EI_x = 1.3 \times 10^6\ Nm^2$
$EI_y = 3.3 \times 10^5\ Nm^2$
$GJ = 320\ Nm^2$





Structural Performance



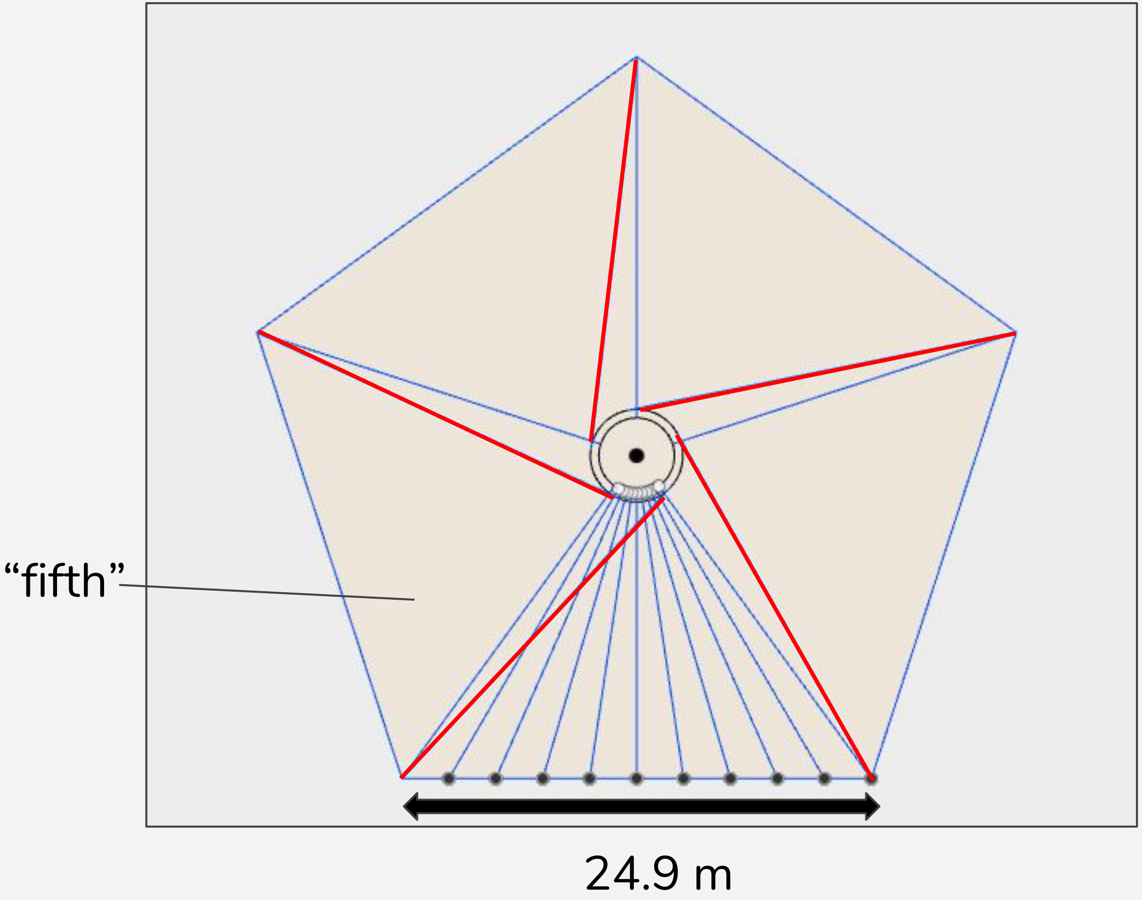
- Max Bending Stress:
  - X: 67 MPa
  - Y: 119 MPa
  - Limit: 1800 MPa
- Axial Buckling Load:
  - 1435 N
- Wrapping Strain
  - X: 0.4%
  - Y: 1.4%
  - Limit: 1.9%

array

Geometry

Array and “fifth”

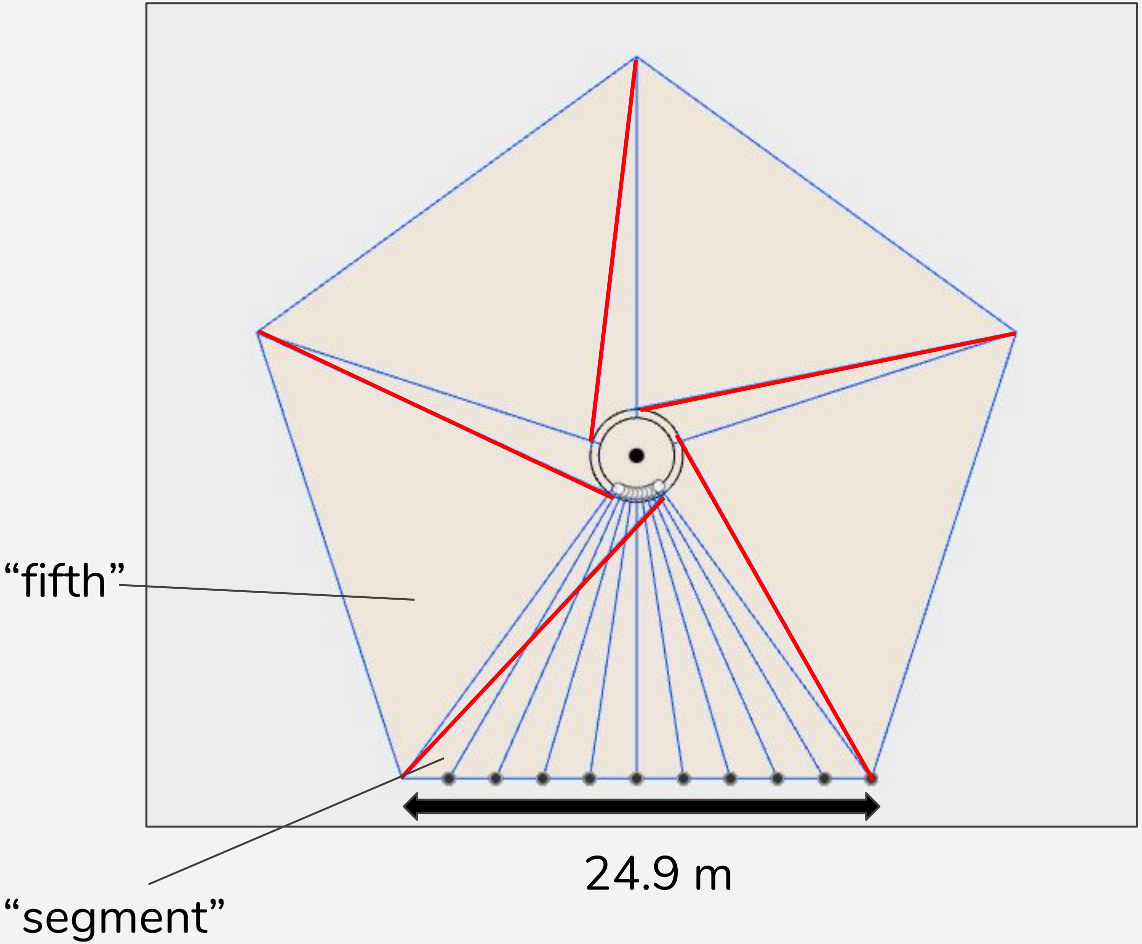
- 1040 m^2 area
- 508 kg array mass
- 130 kW max power



Geometry

Segments

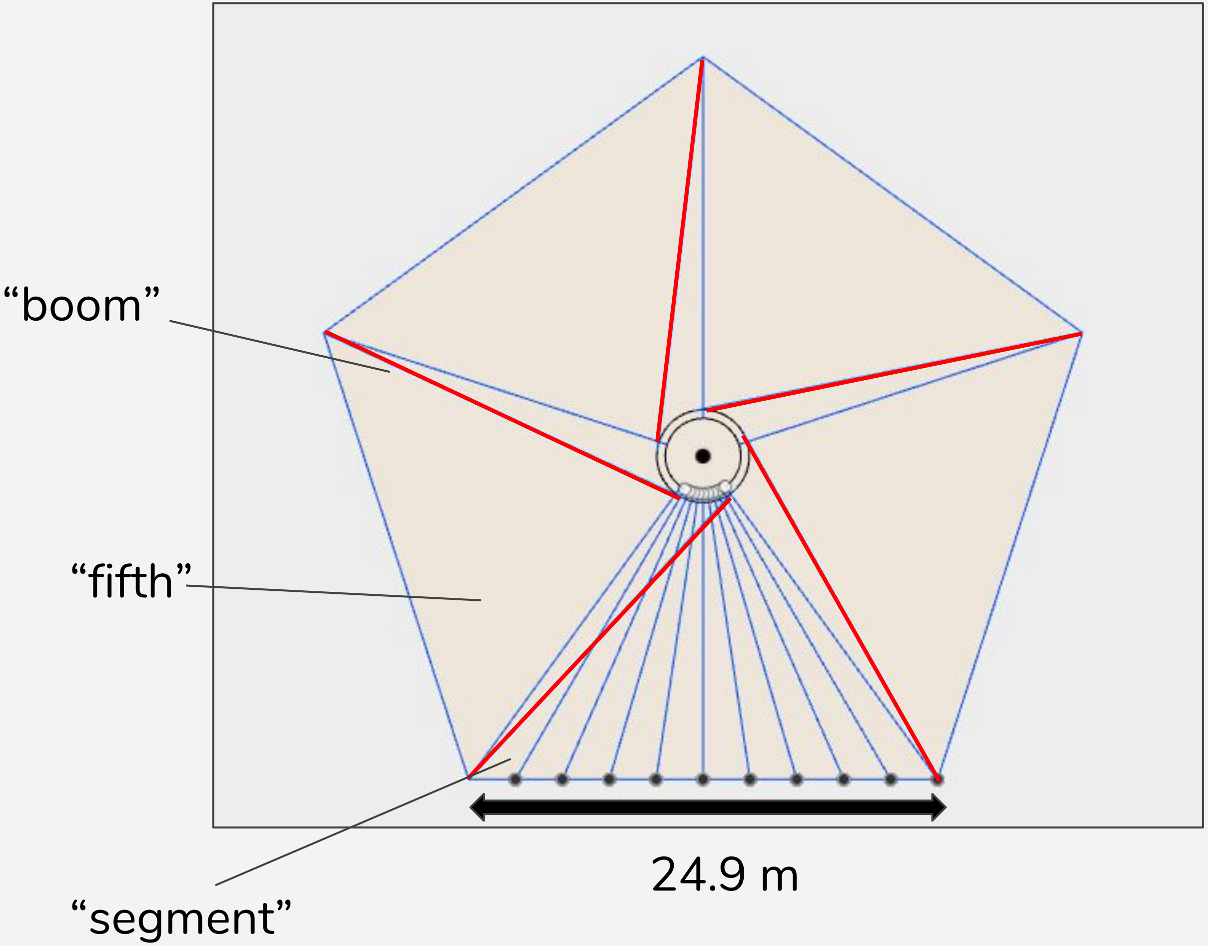
- 80 segments per fifth
- 2.5 m^2 segment area
- 30 cm segment lengths



Geometry

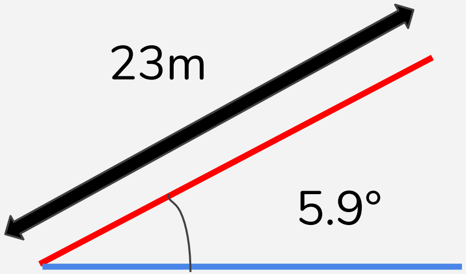
Booms

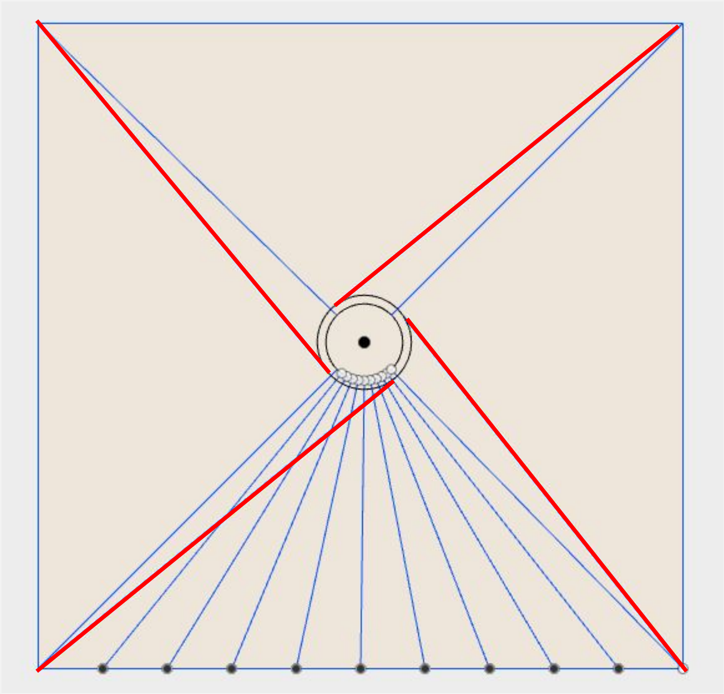
- 21 m booms
- 626 kg total mass



Geometry

Previous Design





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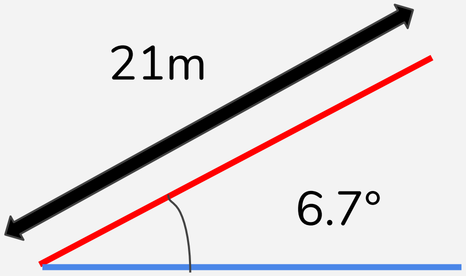

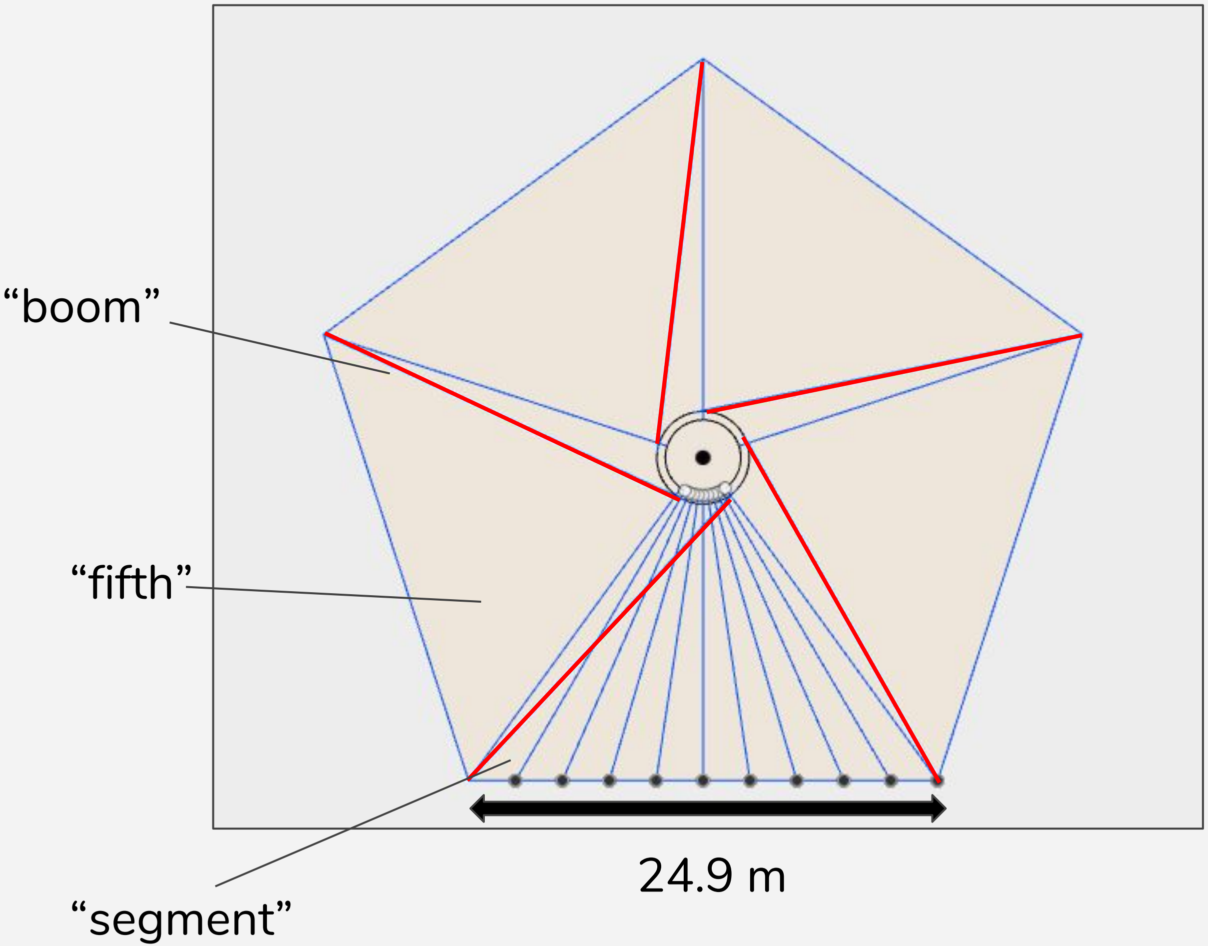

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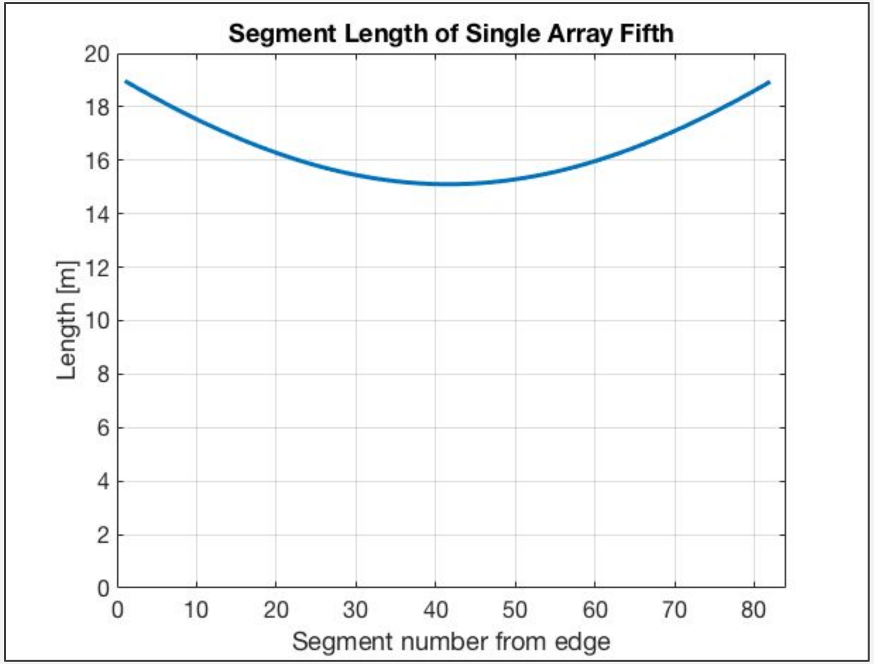
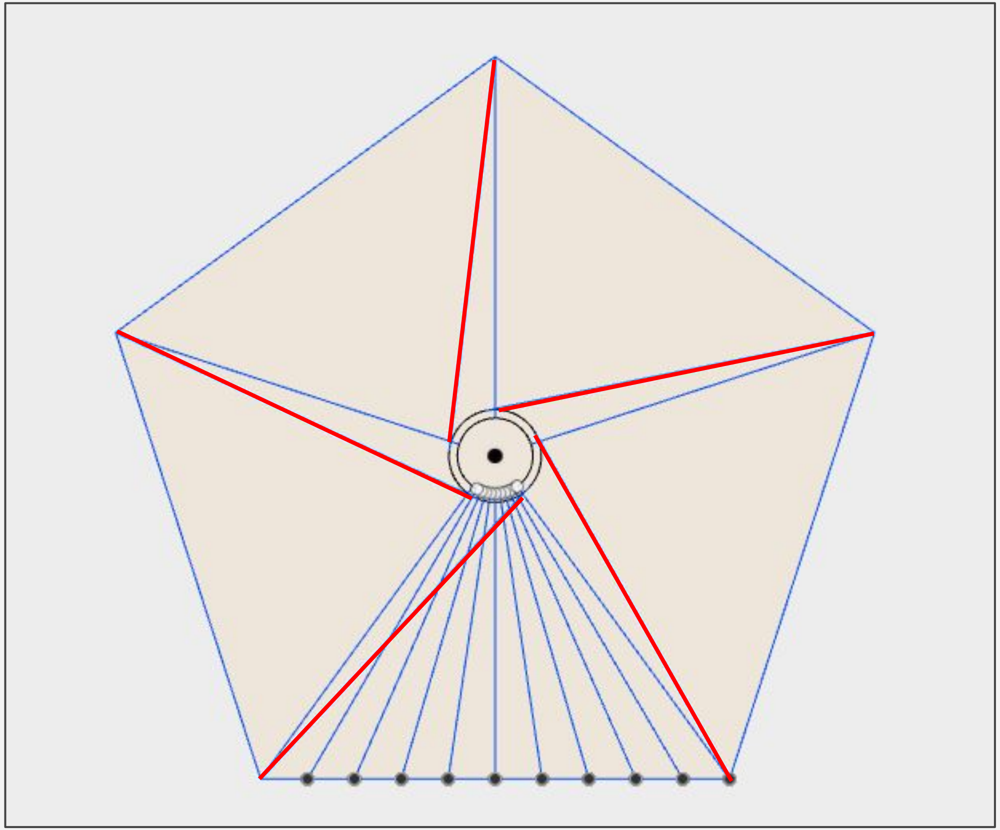
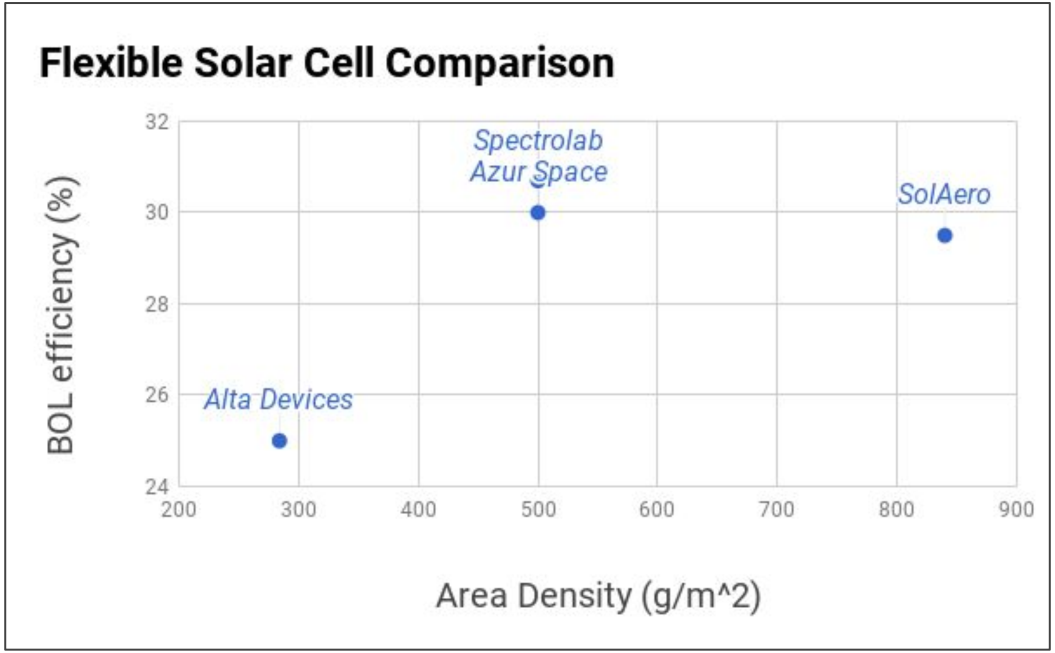


Segment Length of Single Array Fifth
Length [m]
Segment number from edge
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80



Solar Cells

XTJ Prime from Spectrolab



- Chose bounds for area density based on mass of other MAFSA components
- Highest efficiency valued over lower area density

Solar Cells

XTJ Prime from Spectrolab

DuPont Kapton PV9100
Series flexible substrate

255 μm

- 26.7% EOL
- 27.4 cm^2 cell area
- 2.85 V_{mpp}
- 6.7 $mA/cm^2{}_{mpp}$

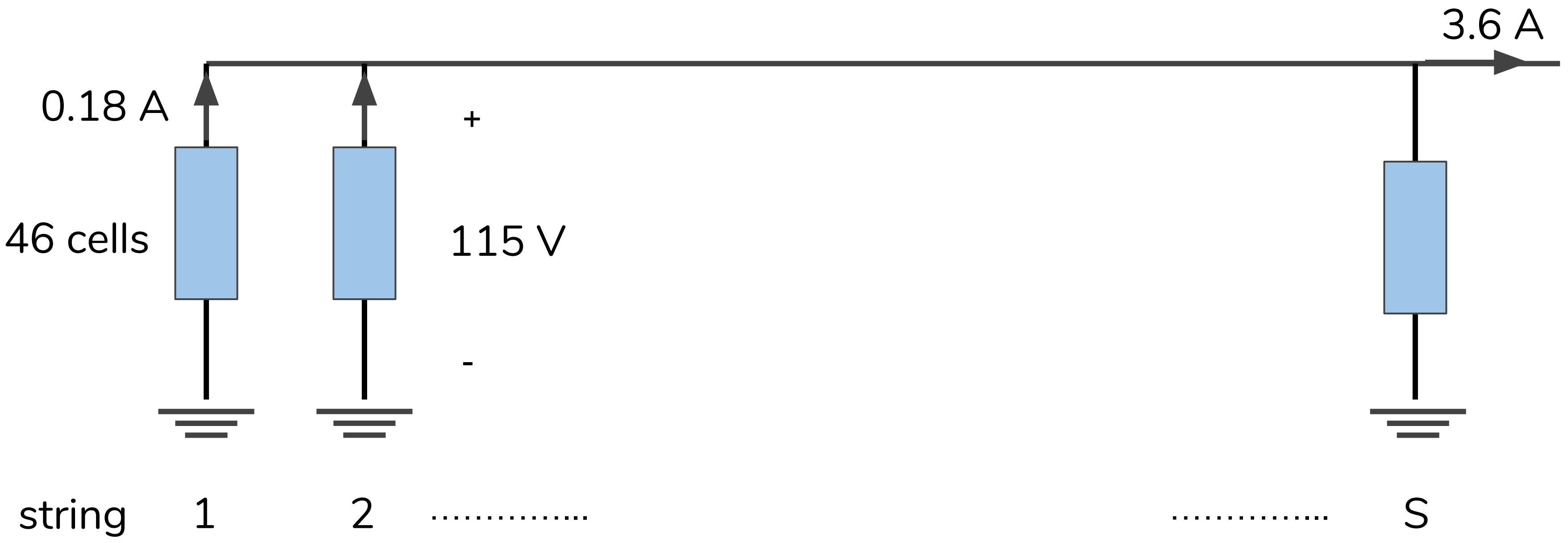
6.91 cm

3.97 cm

Electrical System

Segment at MPP

S = 20

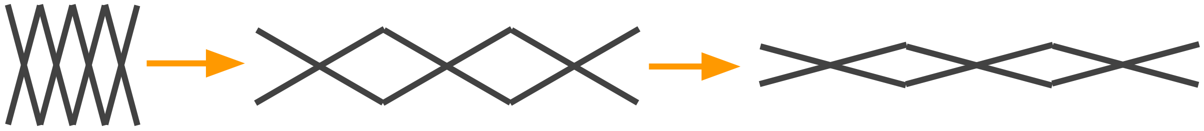


Electrical System

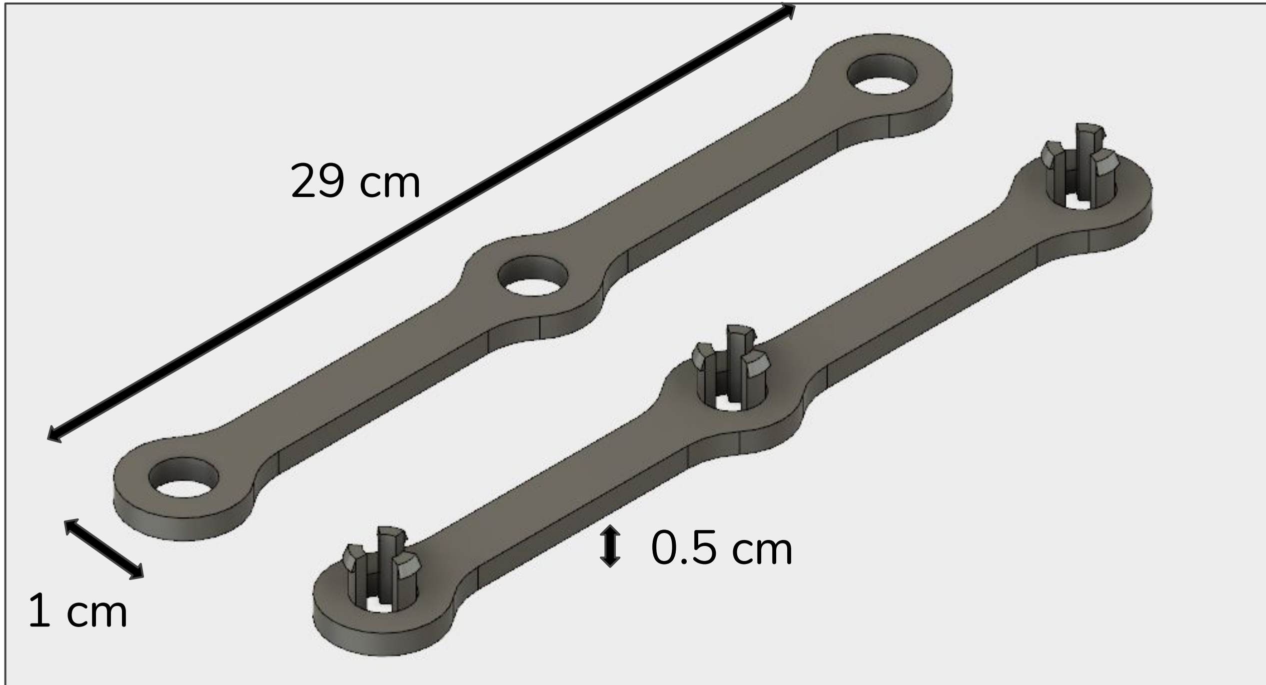
Array fifth at MPP

N = 80

Grating

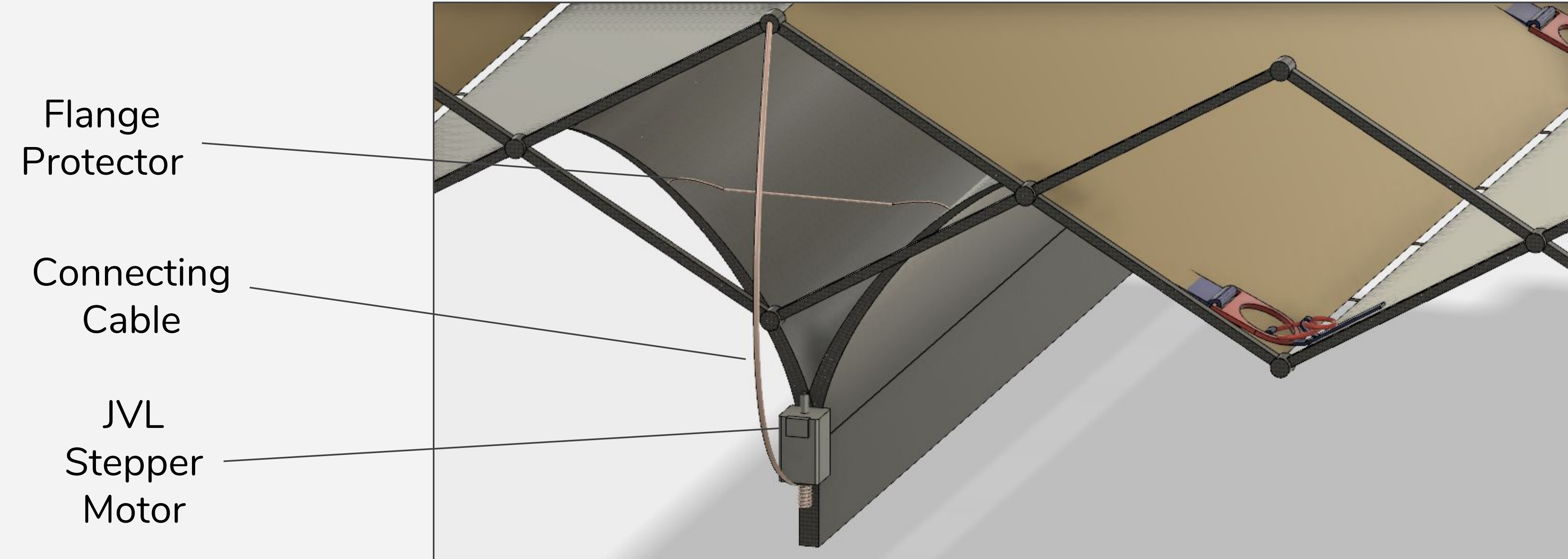


- Carbon fiber
- Snap to assemble
- 17.7 kg total mass

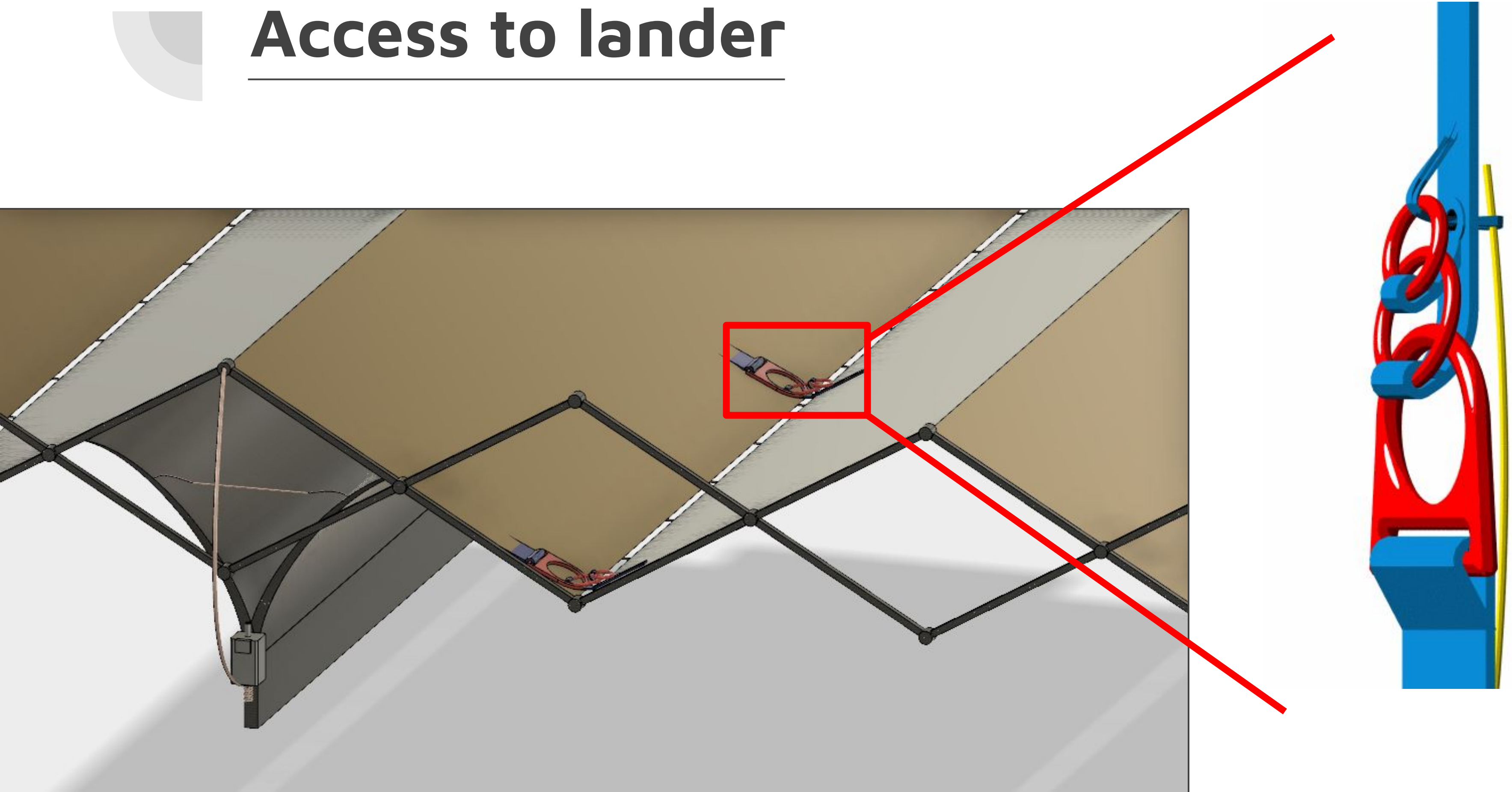


Array to Boom

Attachment mechanism



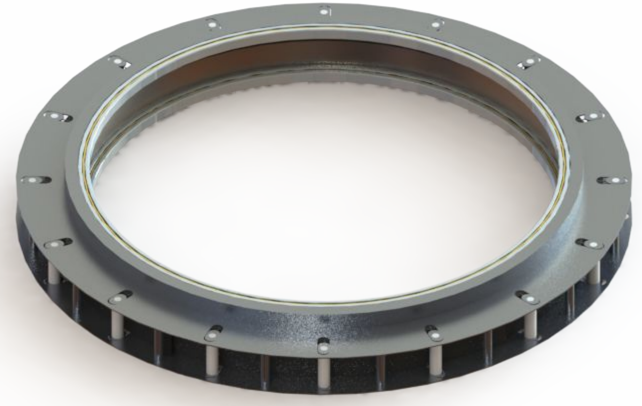
Access to lander

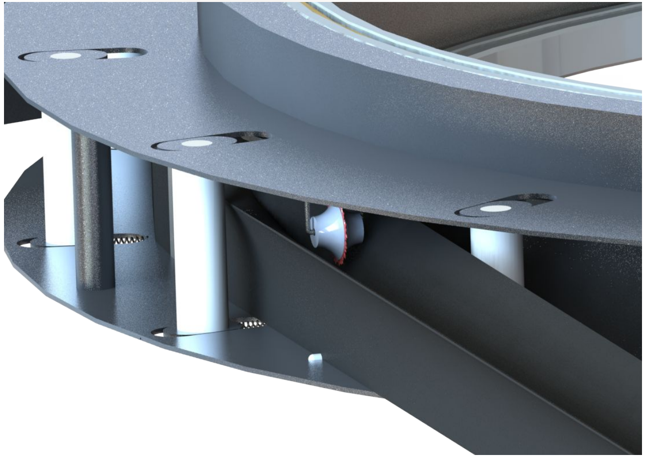


hub

Components

- Lower hub cylinder
- Upper hub cylinder
- Fixed plates - base and middle
- Guide rollers
- Boundary rollers
- Dust/contaminant brush
- Central bearings

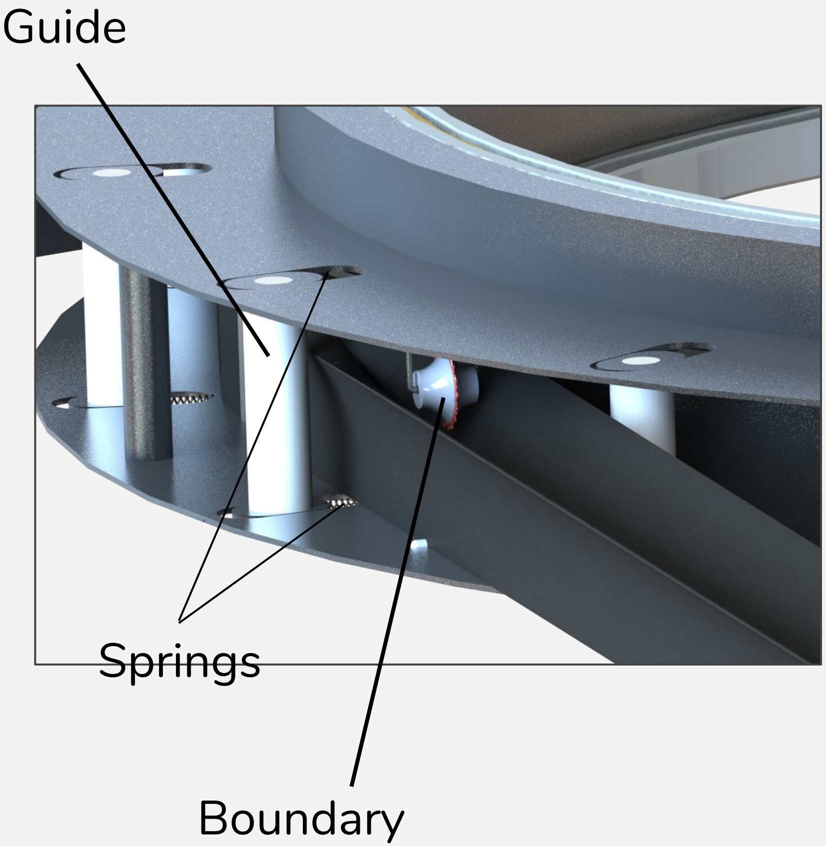




Rollers

- Guide rollers
  - Rotate
  - Force booms inward

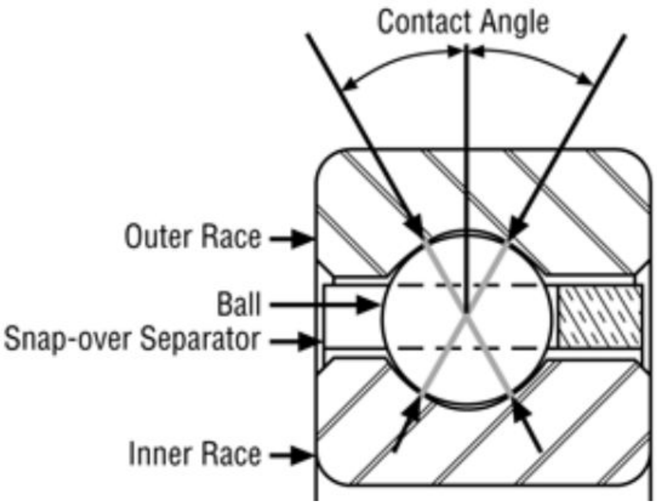
- Boundary rollers
  - Open boom flange
  - Clear contaminants



Bearings

Kaydon NG series, Type X

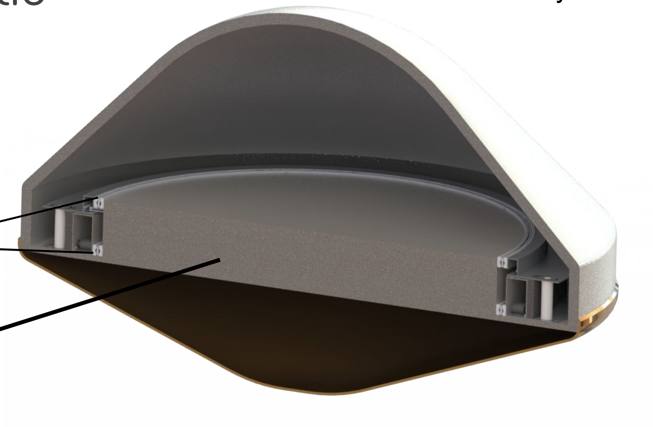
- Lightweight
- Durable
- Appropriate radius to height ratio



kaydonbearings.com

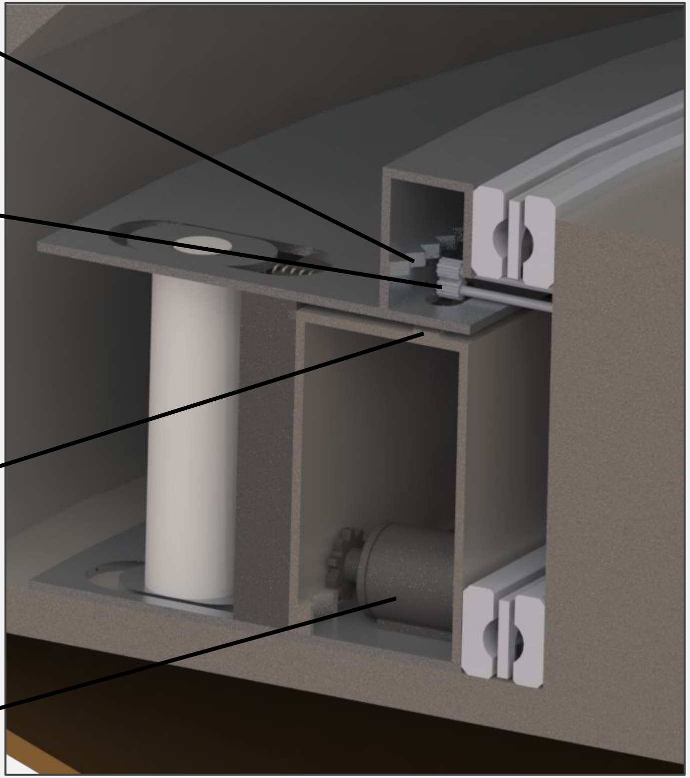
Kaydon Bearings

Central shaft fixed to lander



Gears

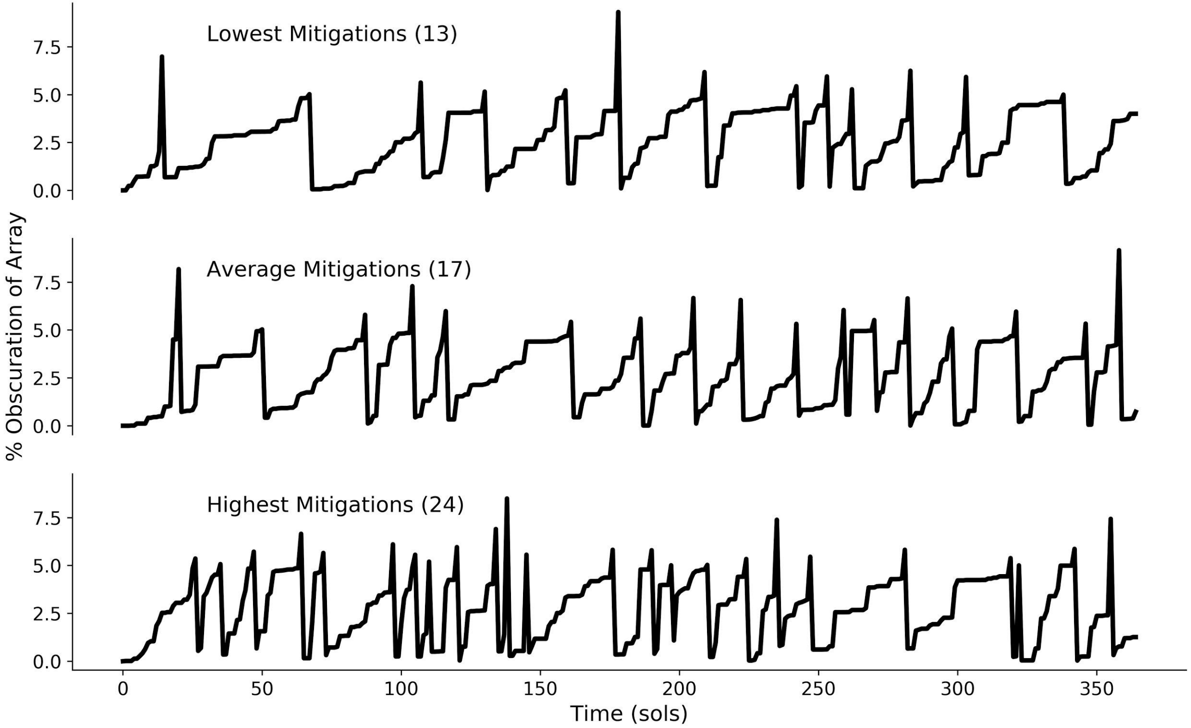
- Hub sections deploy at different rates
- Motor operates both sections simultaneously



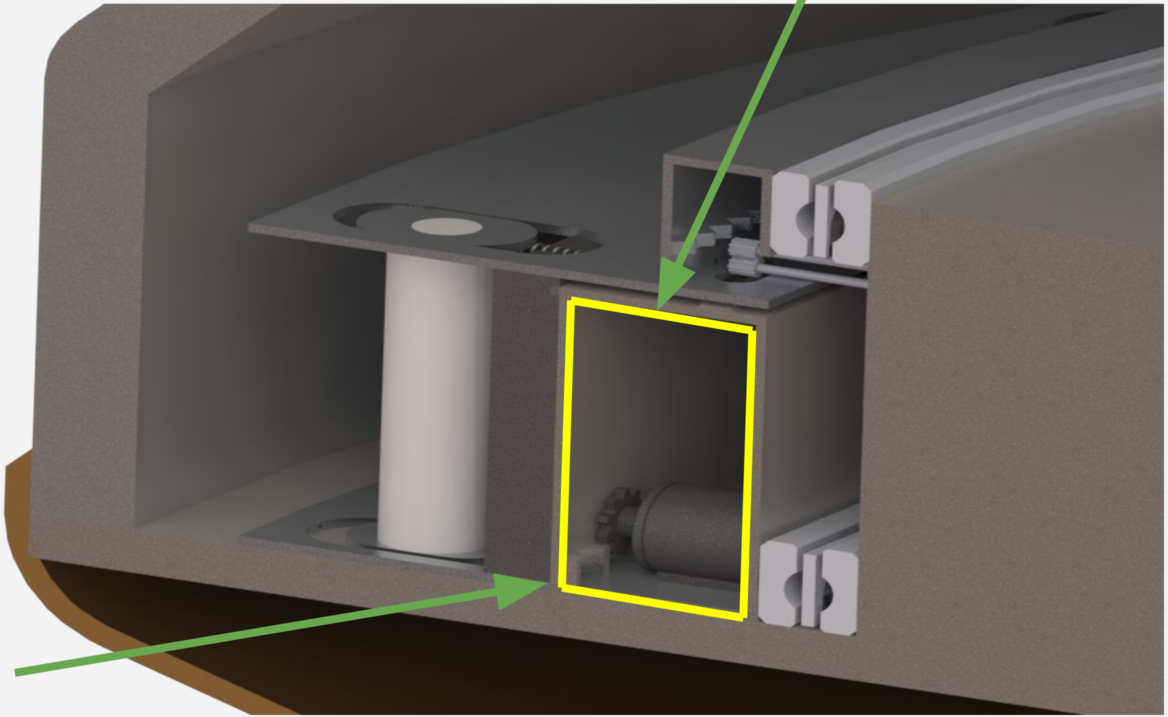
dust

Dust Accumulation

- Sampled from gamma distribution of obscuration rates:
  - **Mean: 0.29%**
- Dust removal **after 5% obscuration**
  - Balance between power production and mechanical operation



Dust Mitigation (Hub)



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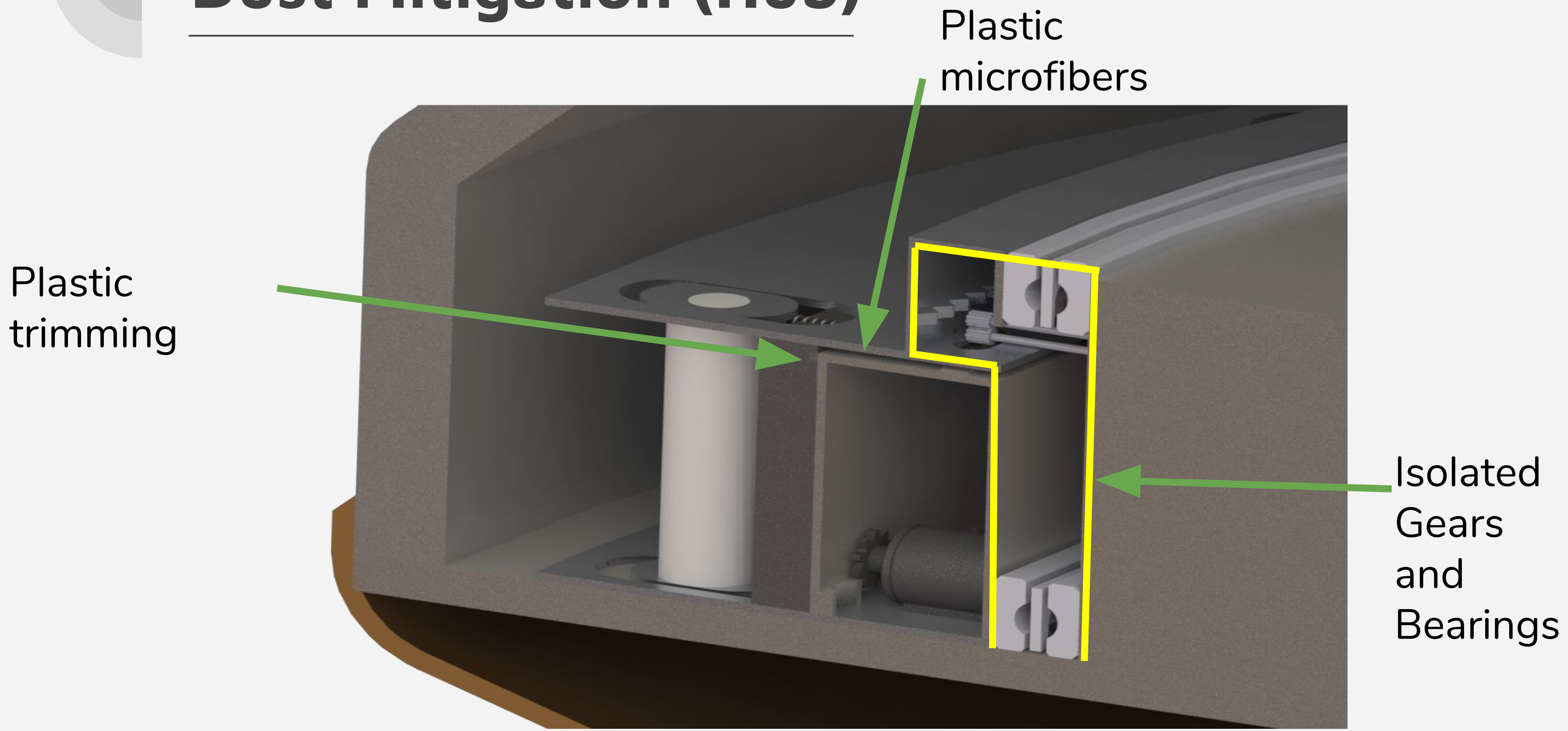
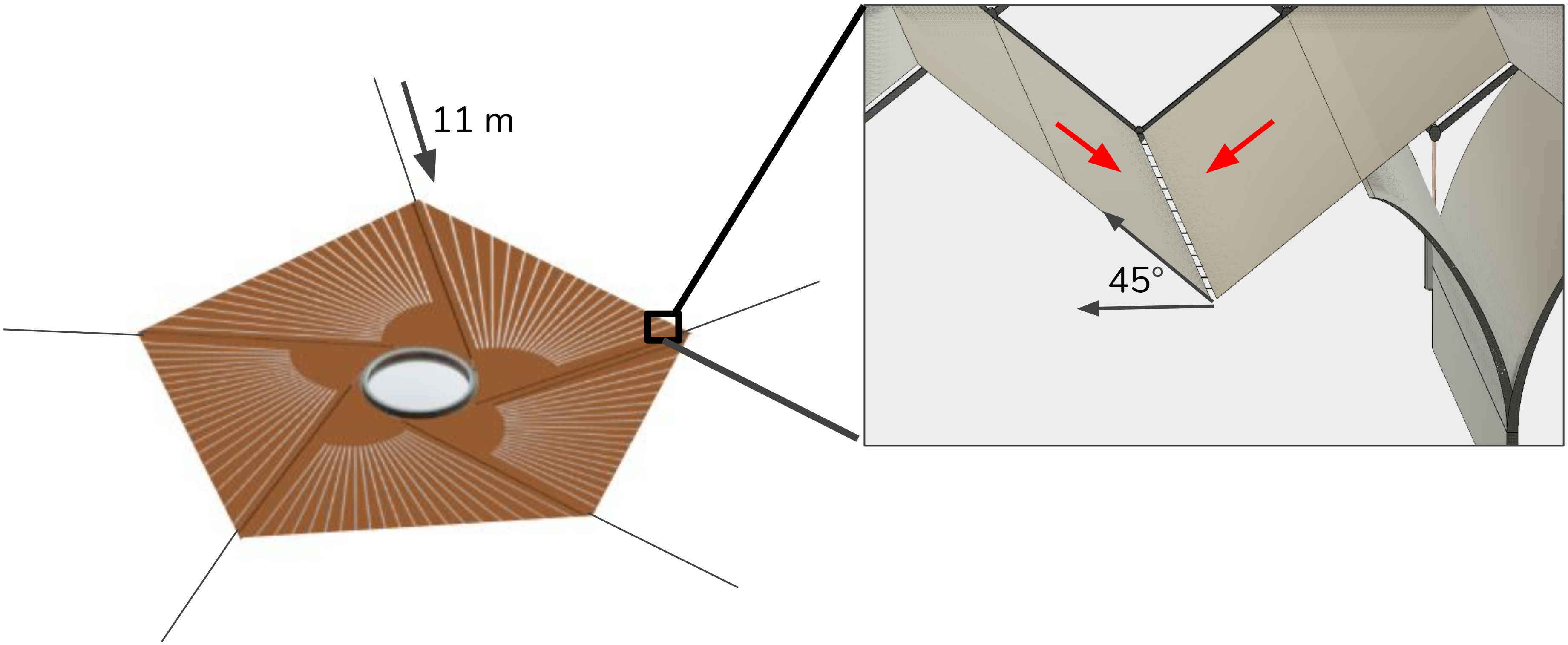
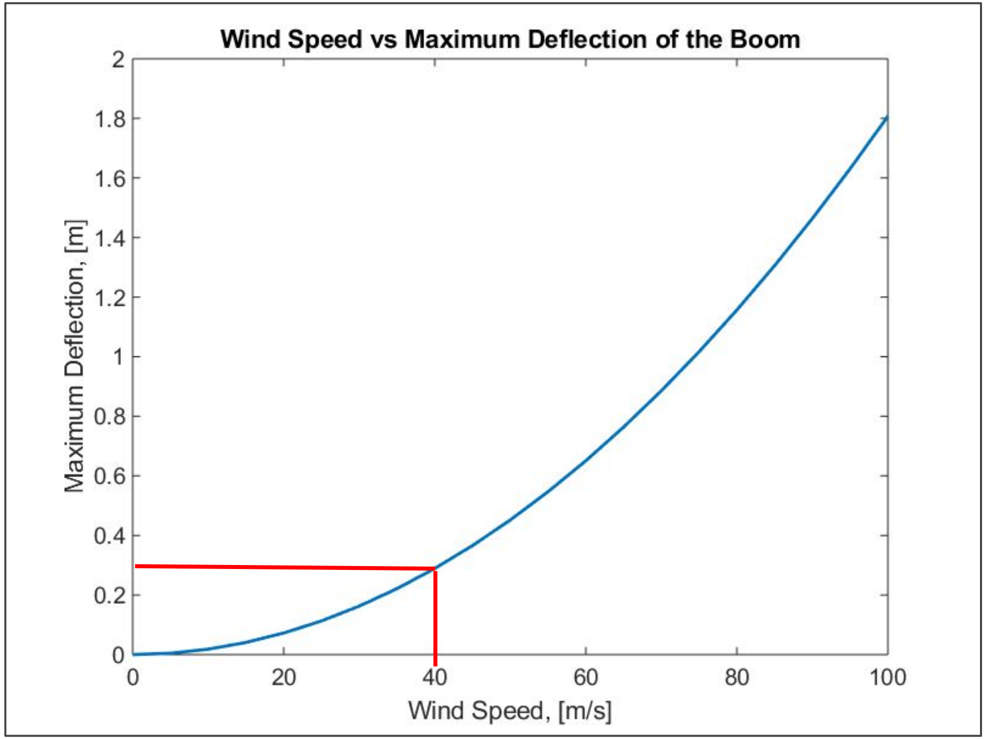


Dust Mitigation (Array)



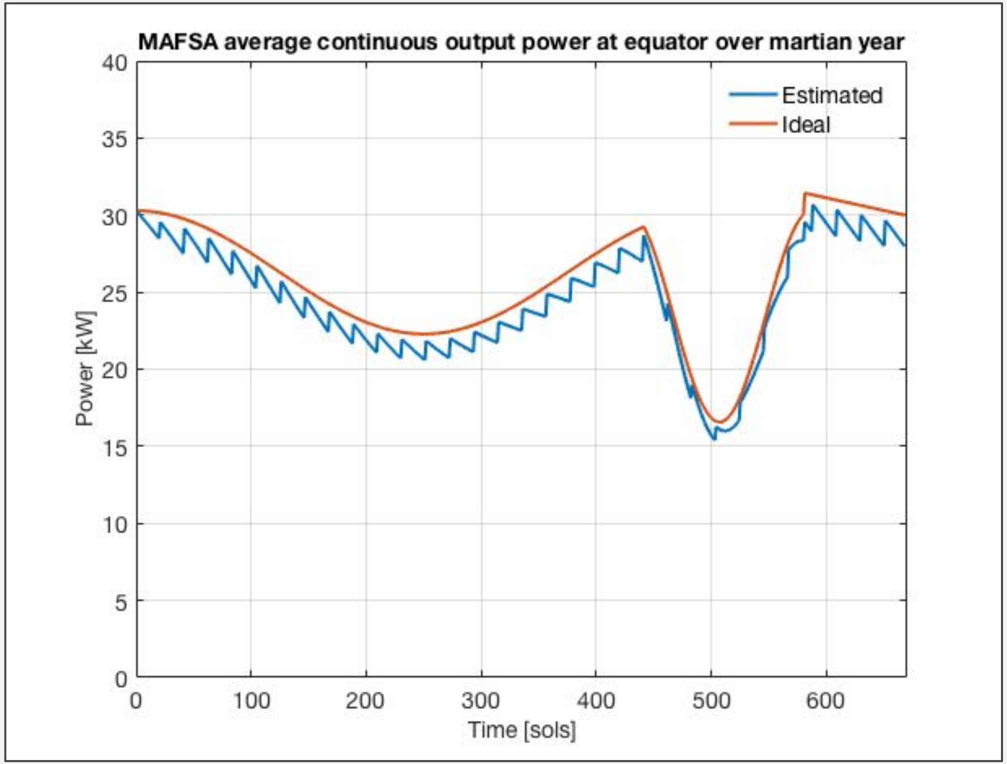
Storm Mitigation

- Two Scenarios:
  - **Winds > 40 m/s (rare)**
    - Complete retraction of array
  - **Winds < 40 m/s** (0.3 max deflection)
    - Array remains deployed



Power Generation

- **With 21 sol dust removal…**
  - Year-averaged energy loss from ideal case due to dust: **4.7%**.



risk

Risk Matrix

1. Motor failure (while deployed)
2. Motor failure (while retracted)
3. Impact of boom with Martian debris
4. Dust build up on solar array
5. Dust intrusion into mechanical parts
6. Martian Dust Storms

Likelihood

5	4,6	5			
4					
3					
2				3	
1				1	2
	1	2	3	4	5

Consequence

Mitigation Strategies

1. Motor failure (while deployed)
    a. Careful selection of driving motors and modification to minimize dust intrusion
2. Motor failure (while retracted)
    a. Careful selection of driving motors and modification to minimize dust intrusion
3. Impact of boom with Martian debris
    a. Careful landing site selection and highly accurate landings
    b. LiDAR or similar system
4. Dust build up on the solar array
    a. Regular dust mitigation every 21 days
5. Dust intrusion into mechanical parts
    a. Rubber o-rings to seal the ball bearings
    b. Brush dust from booms
6. Martian Dust Storms
    a. Fully retract MASFA during high wind storm events

Margins

Component	Mass (kg)	Volume (m^3)
Solar Array	508	0.23
Array Grating	22.1	0.012
Booms	626	0.352
Hub	134	0.05
Hub Motors	63.5	0.042
Stepper Motors	4	0.0002
Bearings	110	0.287
Total	1463.2	1.73
Allocated Total	1500	10.0
Margin	32.4	8.31

future

Boom Analysis and CFD

- Detailed characterization of structural performance
  - Non-linear FEA models
  - Analysis of coupled response to loading
- Array folding during deployment and retraction
- Laminate design for the booms
- CFD to analyze the interaction between the wind and the structure
  - Pressure variation along the booms
  - Aero-elastic effects

thank you

extra slides

Deployable Leg