Manufacturing of Cold-Welded Assemblies COSMIC Capstone Challenge – Track 1

Outbrief

Embry Riddle Aeronautical University

April 13, 2026

Keven Duong, Kimo-Mark Hesse, Cordelia Kohuth, Daniel Mount, Ela Ozatay, & Manan Patel

Advisors: Dr. Kaela Martin, Dr. Dawn Armfield

Mentor: Sara Mitran

The organizational structure of MOCA is presented below.

Team Lead

Cordelia Kohuth

Co-Team Lead

Kimo-Mark Hesse

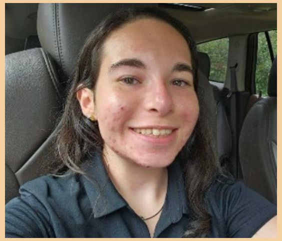
Mechanical Lead

Manan Patel

Electronics Lead

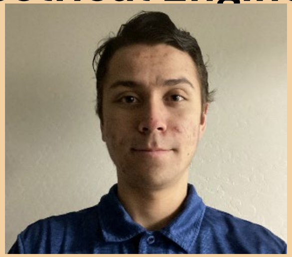
Daniel Mount

Controls Software Lead



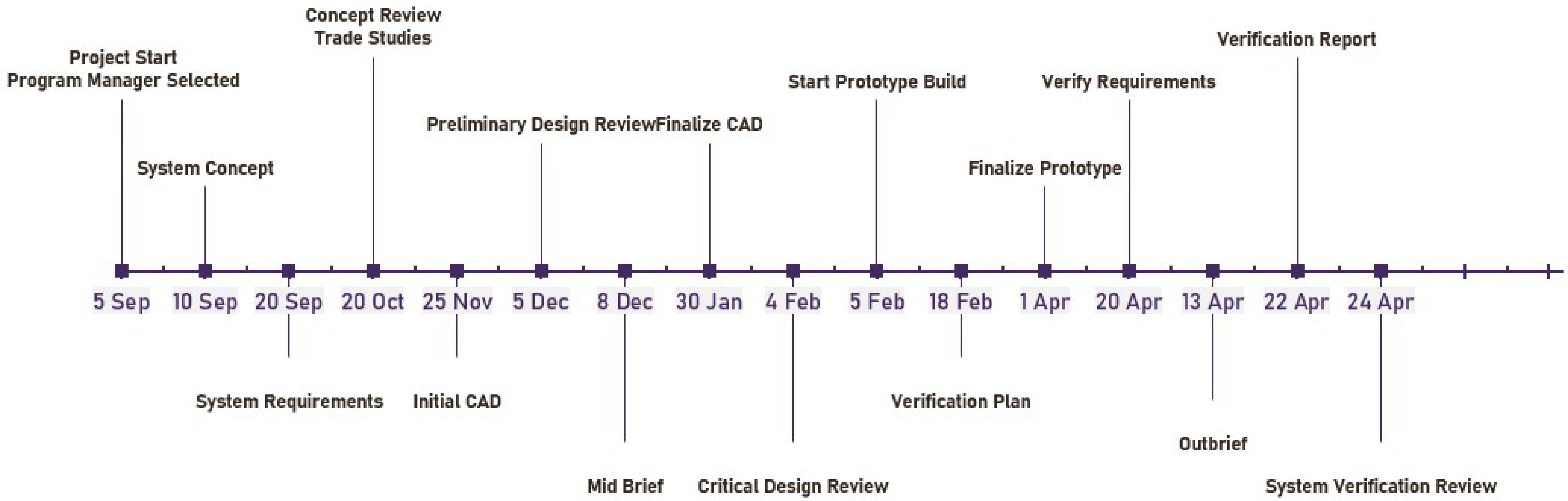
Ela Ozatay

Electrical Engineer

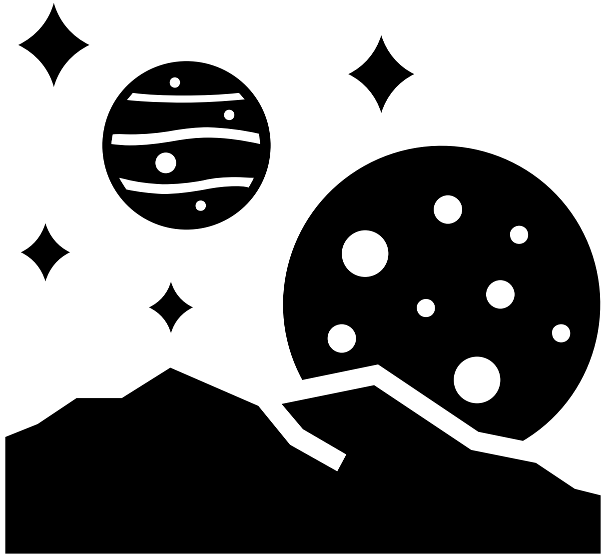


Keven Duong

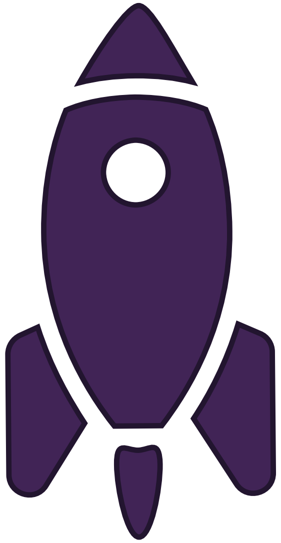
MOCA utilized a timeline to organize tasks and remain on schedule.



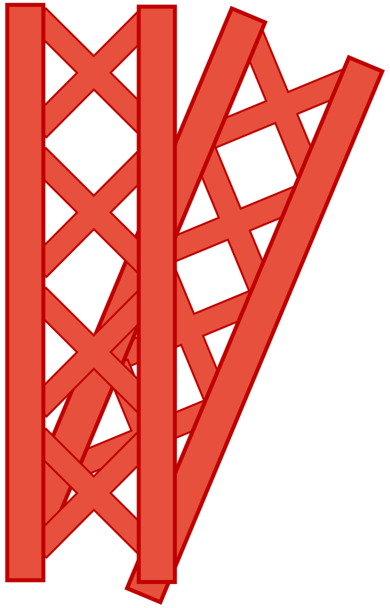
MOCA will support future space exploration by providing major benefits.



Space Exploration



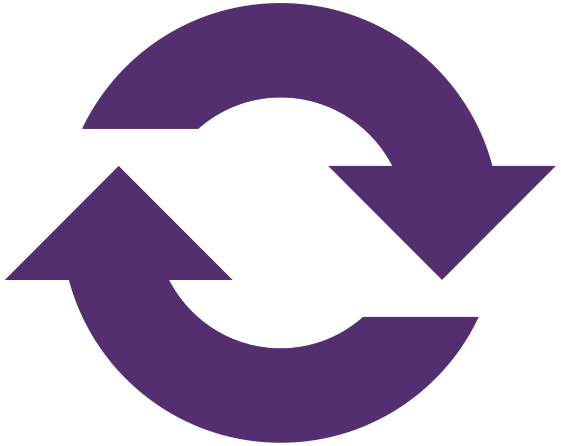
Reducing Launches



Building Large Structures

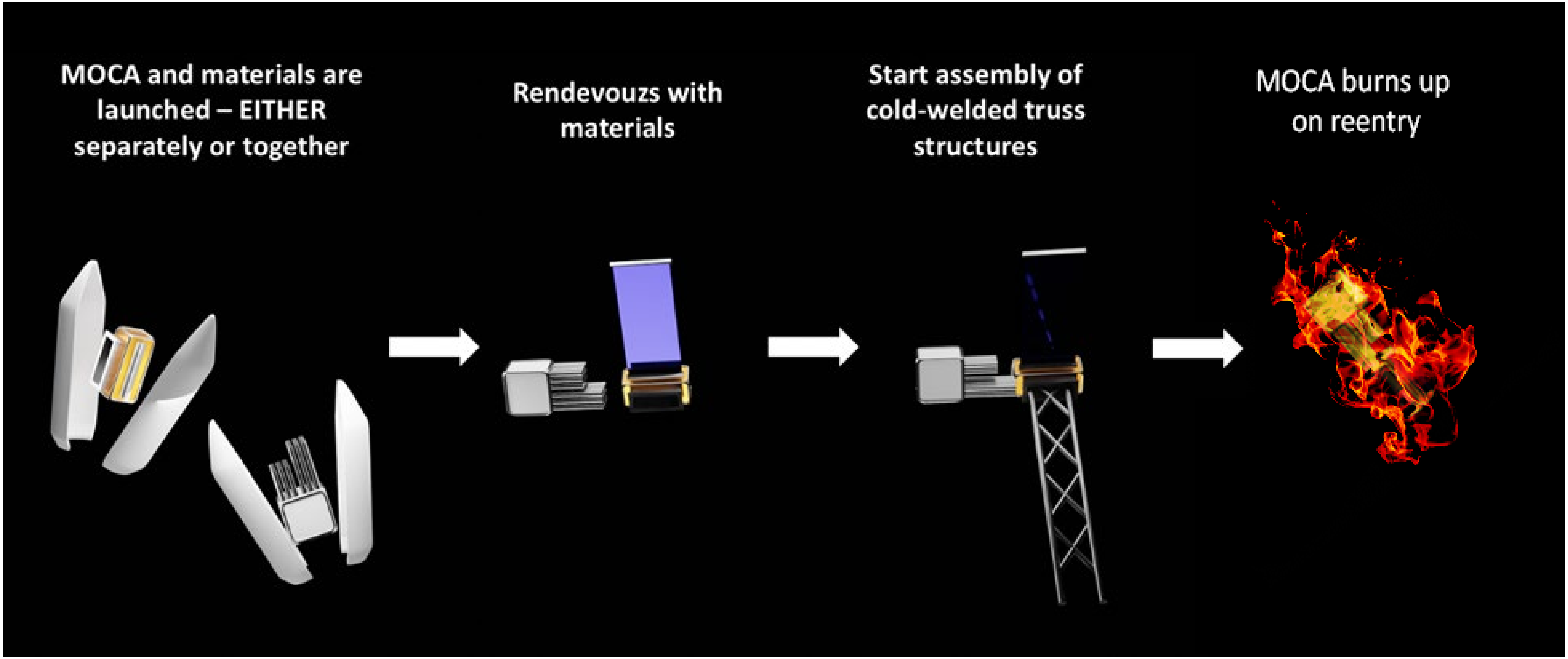
MOCA will provide a viable solution by following these two objectives.

Cold Welding

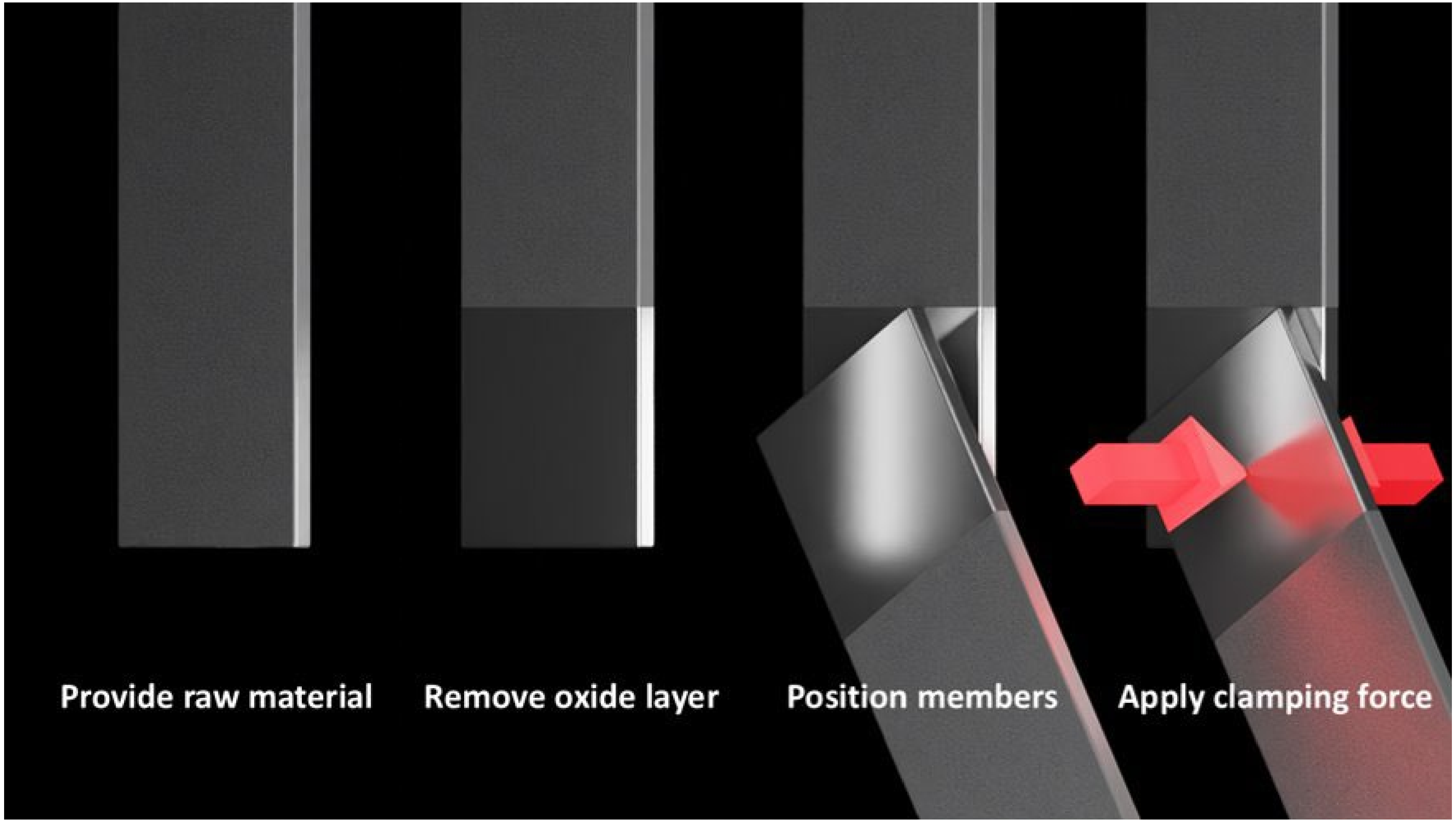


Repeatability

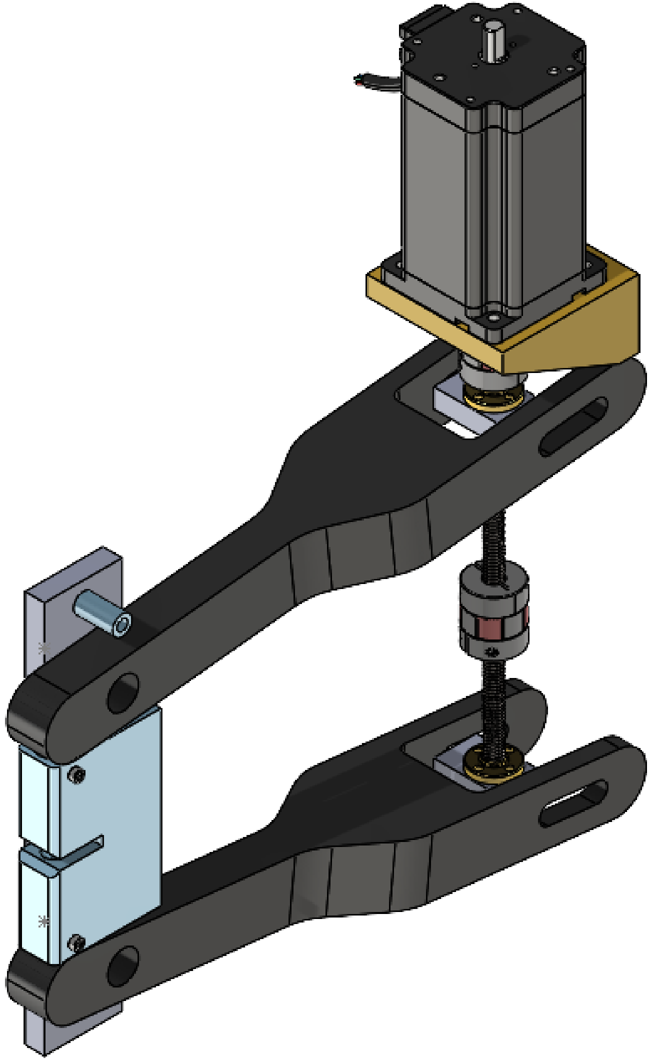
MOCA developed a concept of operations for constructing large space structures.

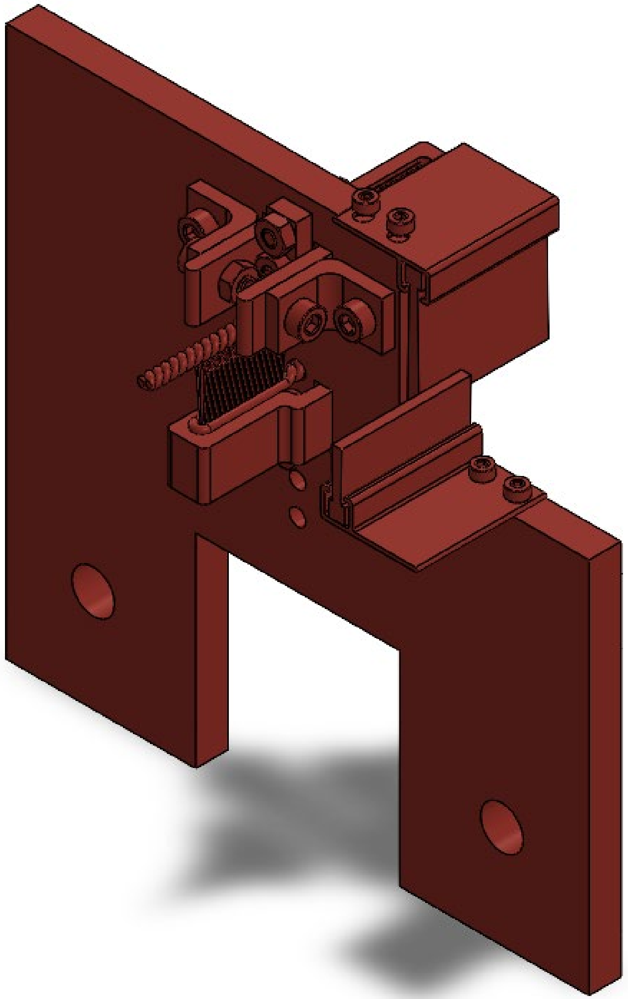


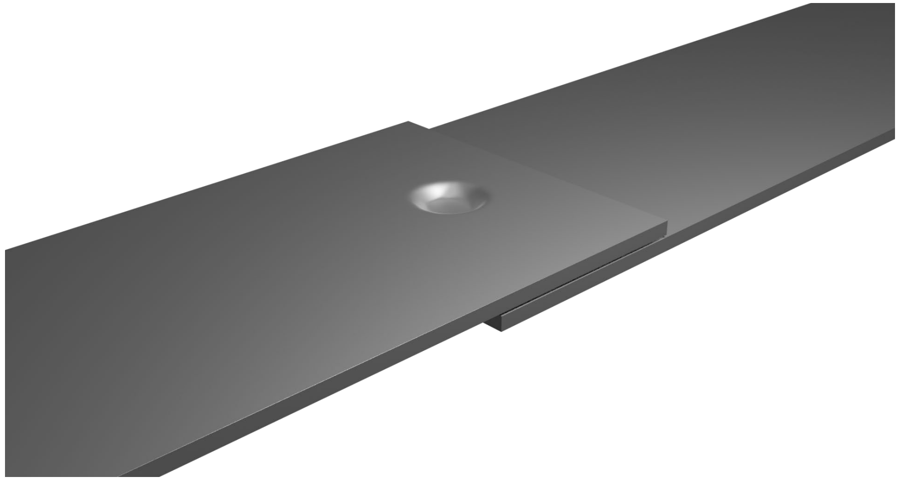
MOCA developed a method of joining two Aluminum members using cold welding.



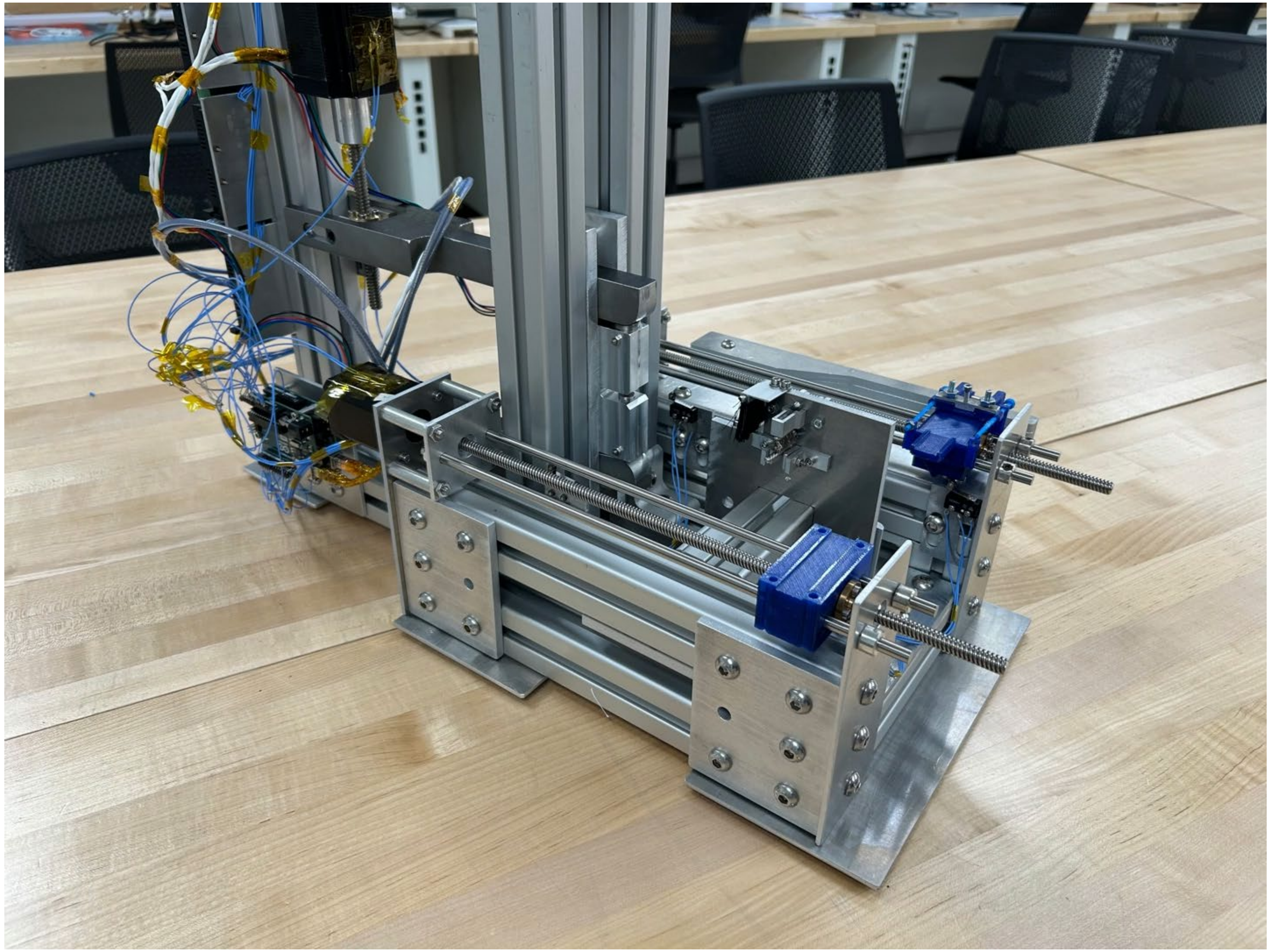
Three main trade studies controlled the direction of the design.



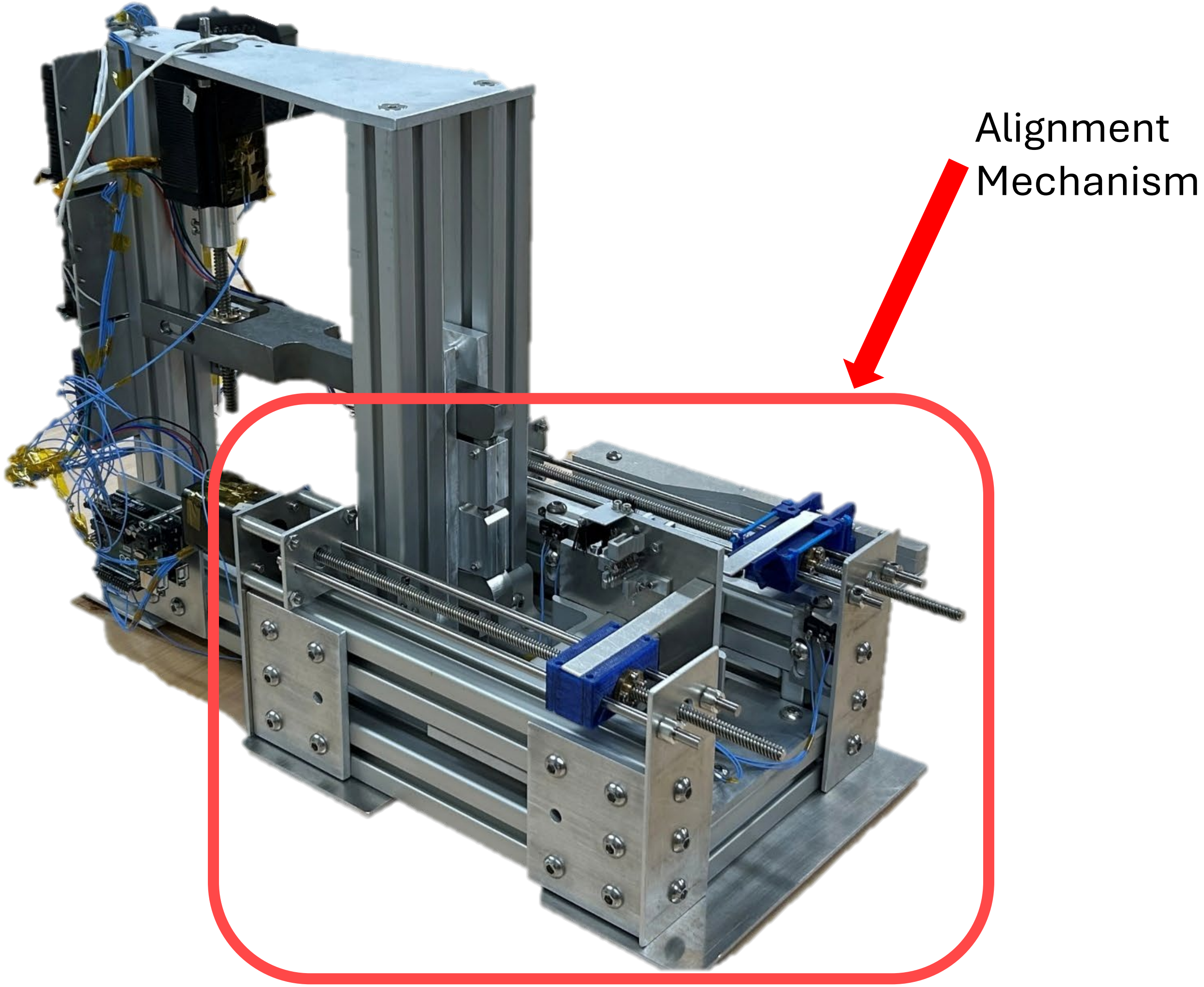




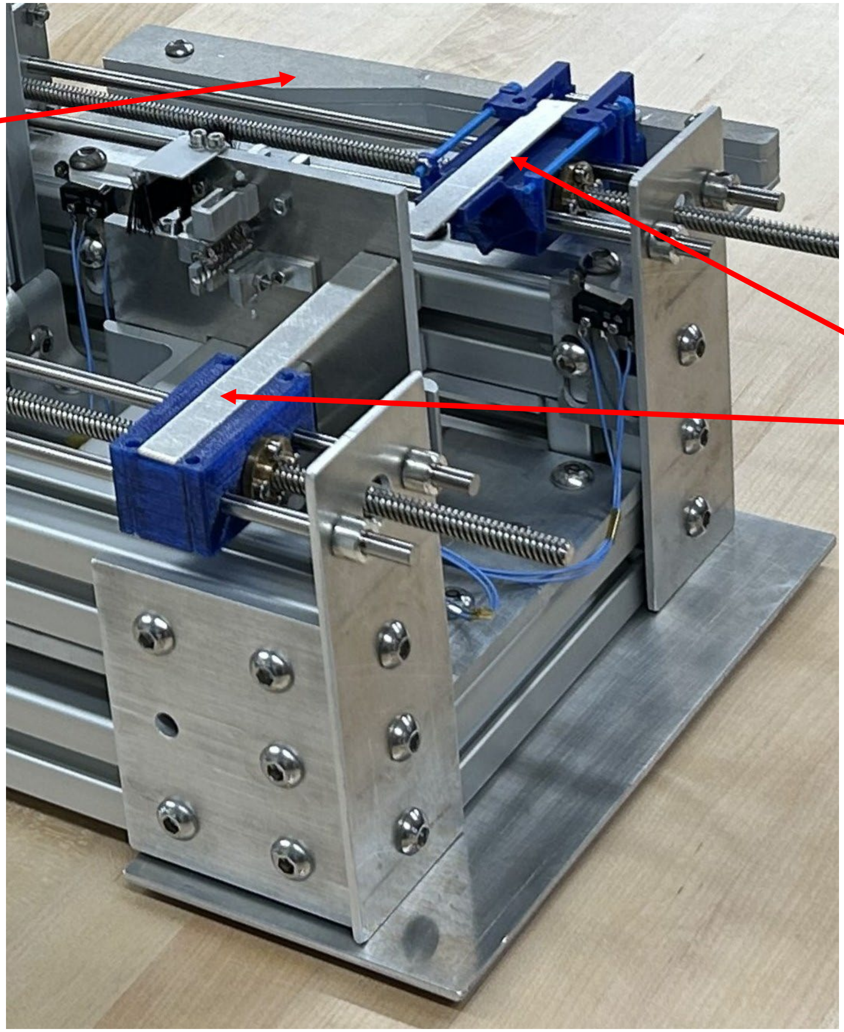
MOCA developed a system to perform the concept of operations.

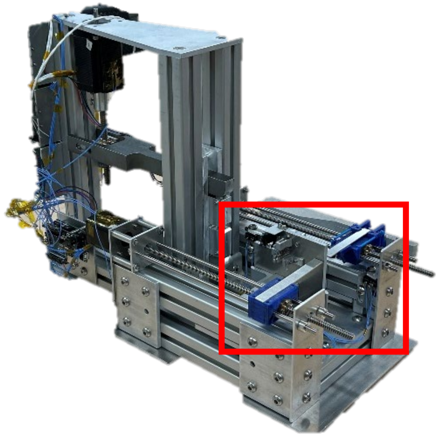


MOCA's alignment mechanism moves the pieces through the Cleaning Mechanism and into the Pressure Mechanism.

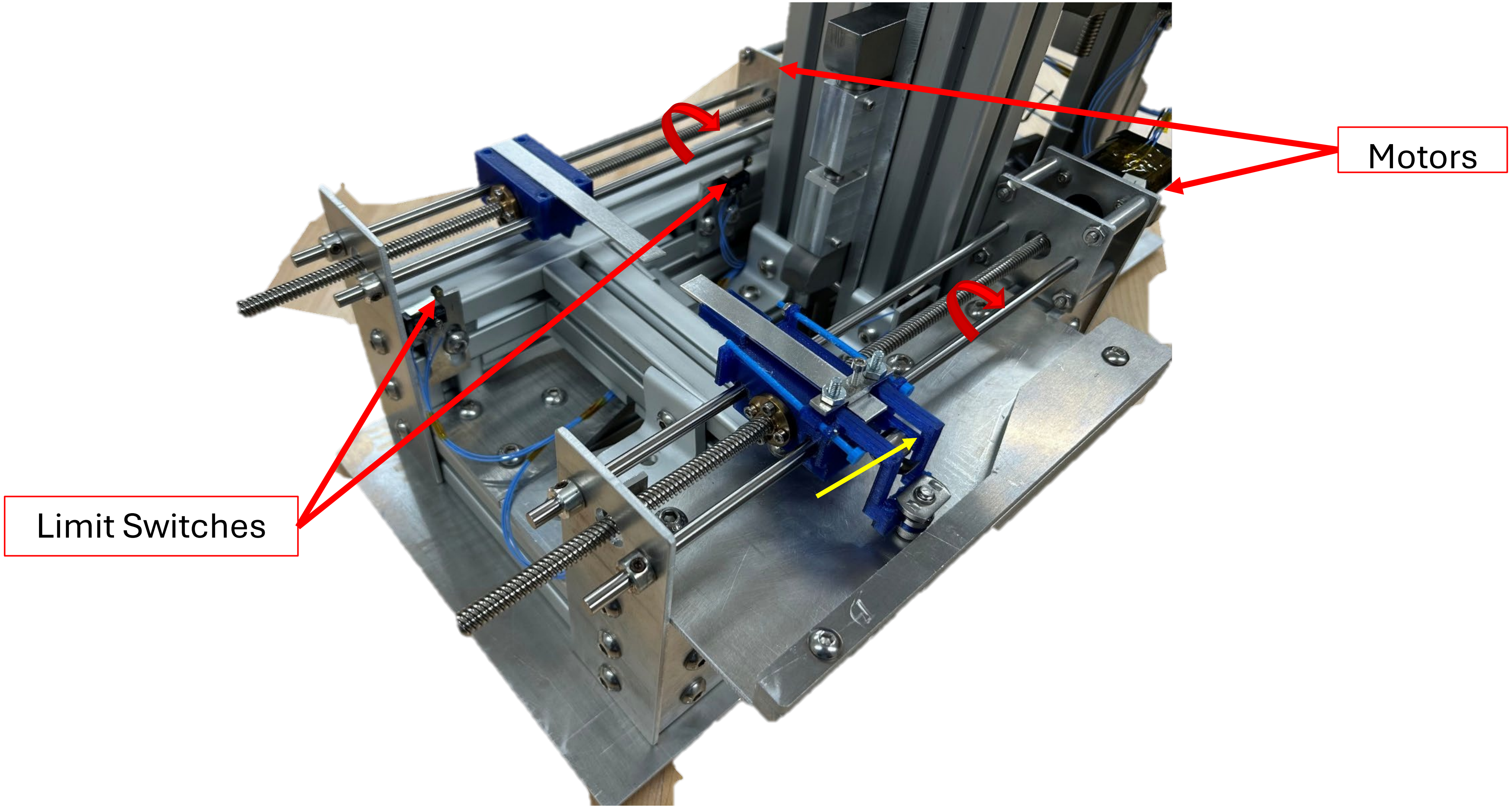


Aluminum members are inserted and maneuvered through the Cleaning Mechanism.

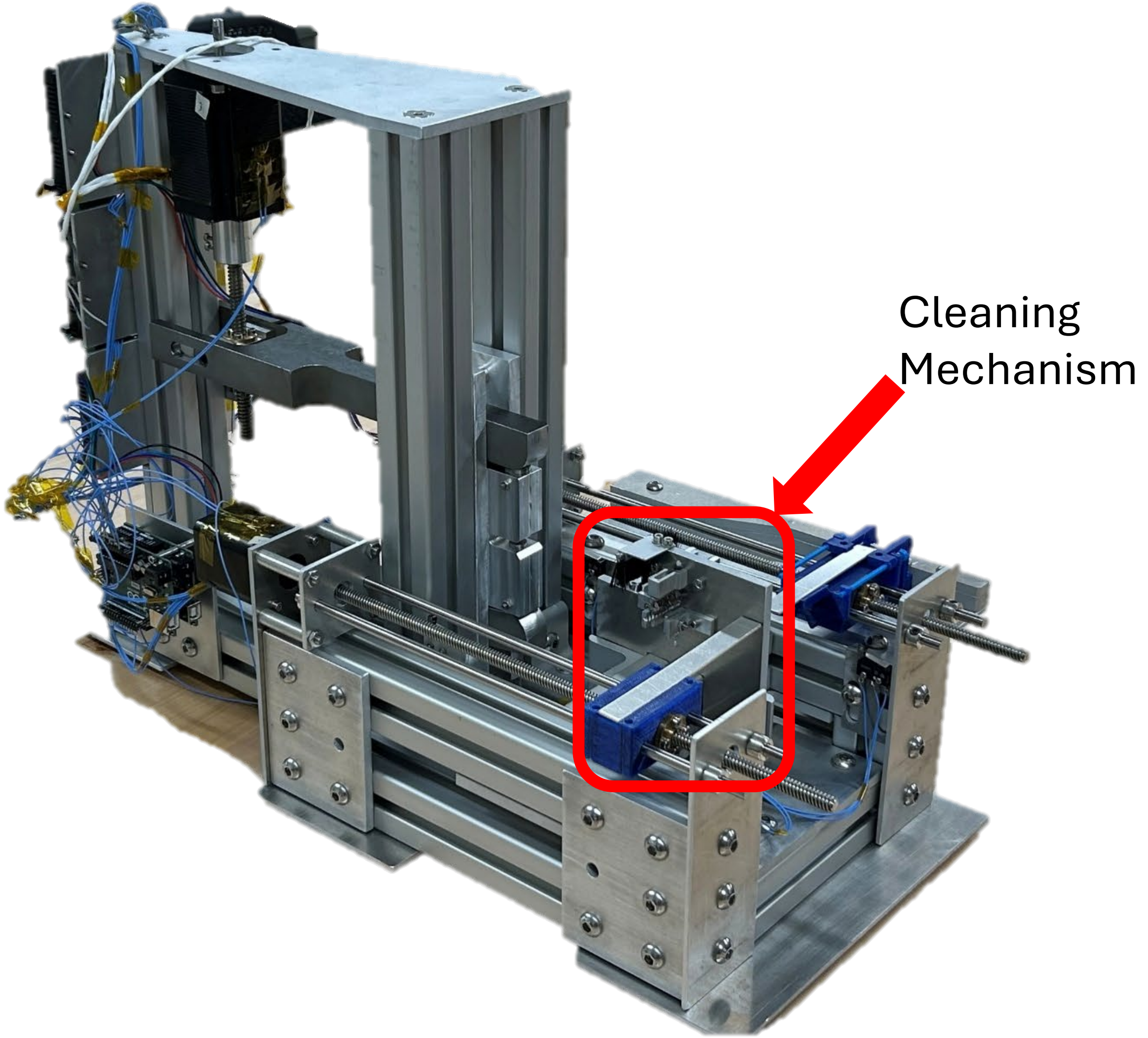




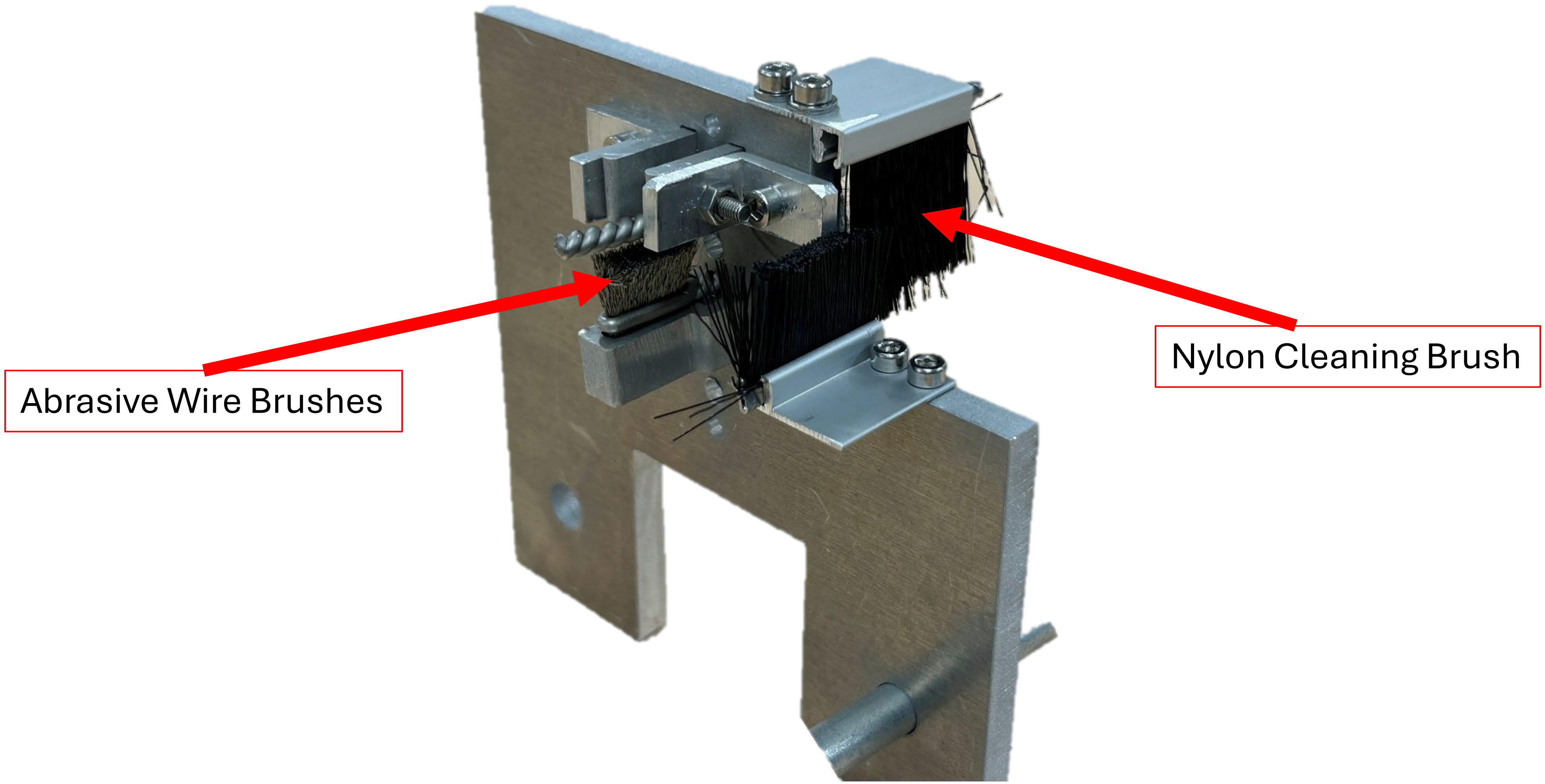
The Alignment Mechanism maneuvers the aluminum members into the Pressure Mechanism.



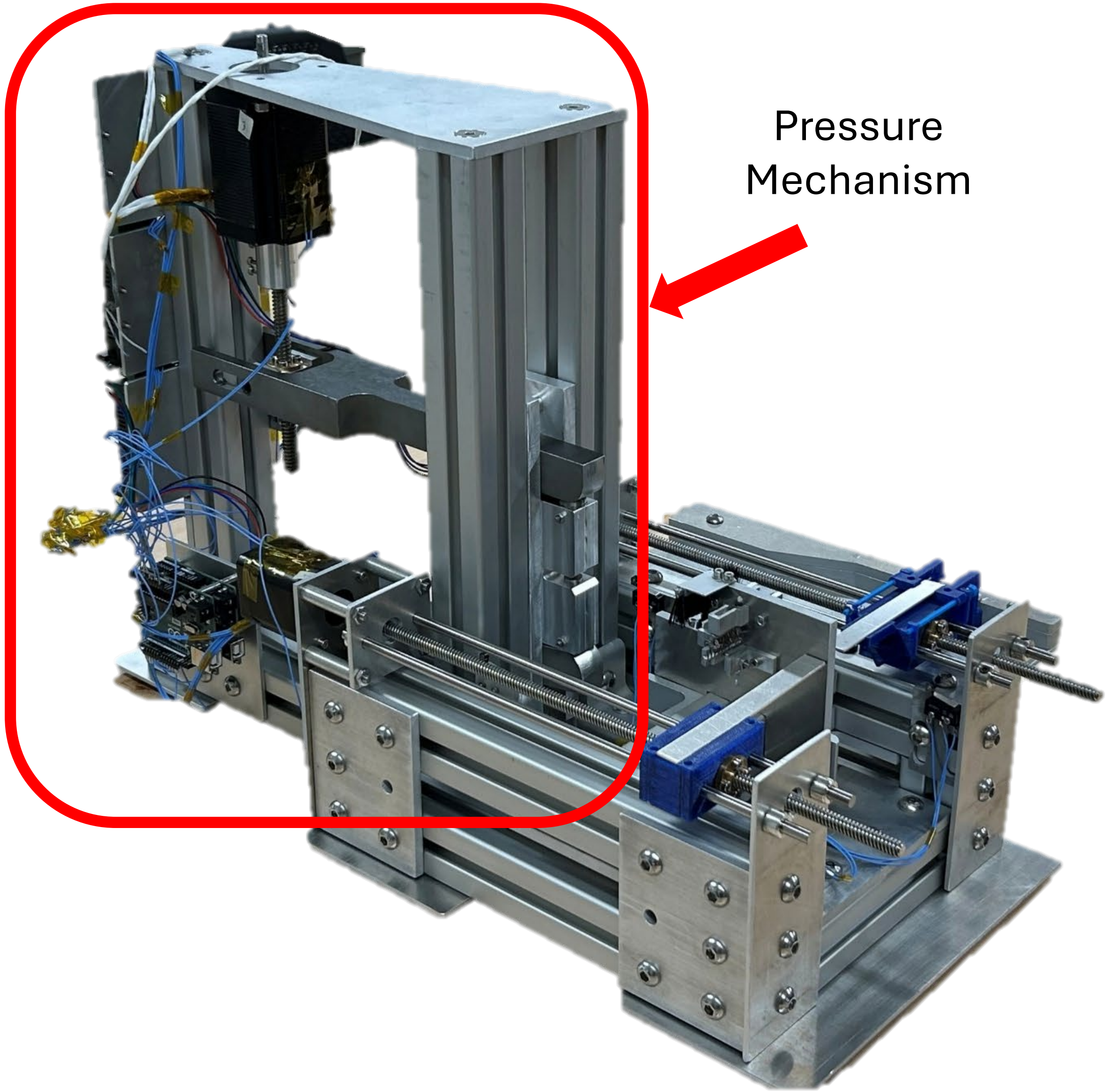
MOCA's Cleaning Mechanism removes the oxide layer and brushes off the contaminants.



The Cleaning Mechanism has the required abrasiveness needed to scrap the oxide layer off.

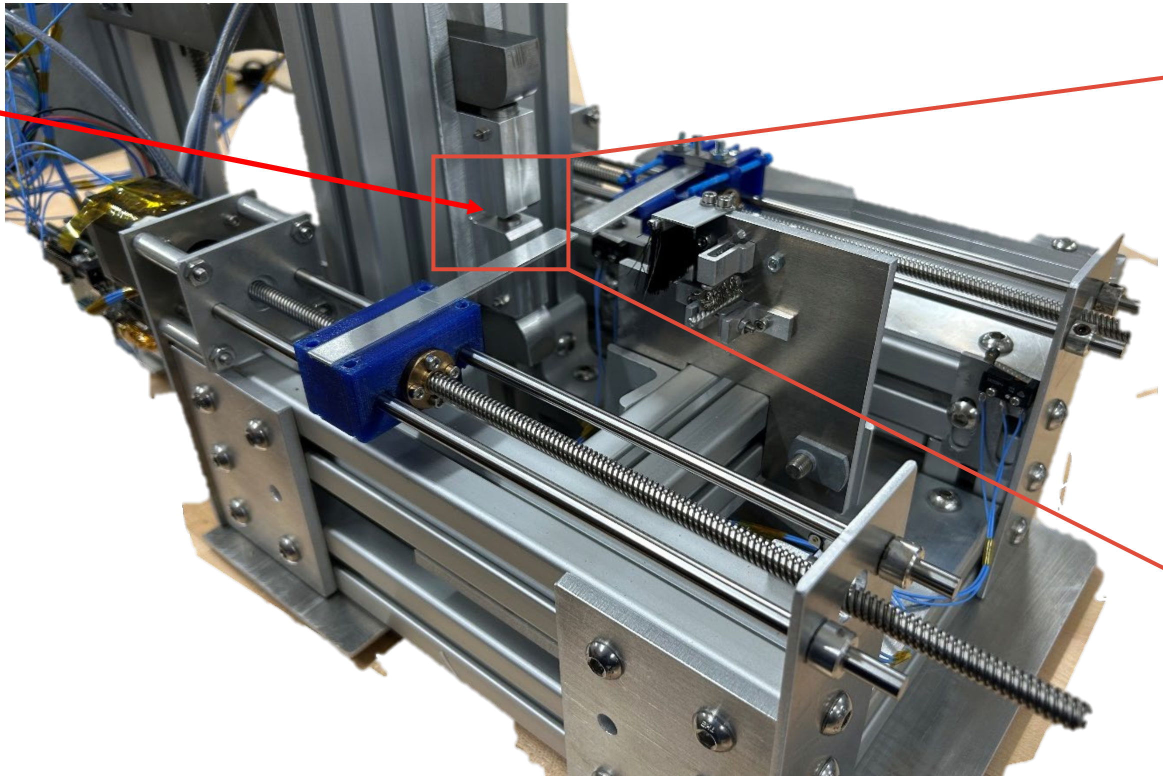


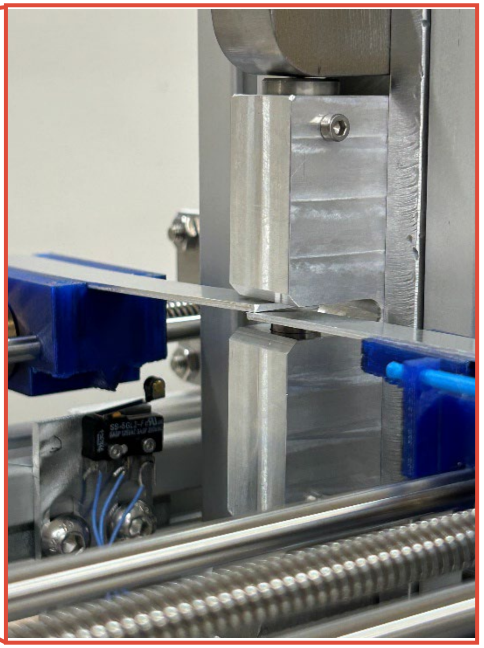
MOCA's Pressure Mechanism applies pressure to the members.

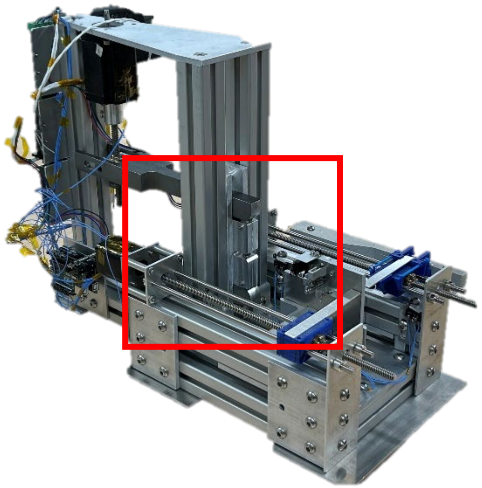


The Pressure Mechanism is a clamp that applies pressure to a very small point.

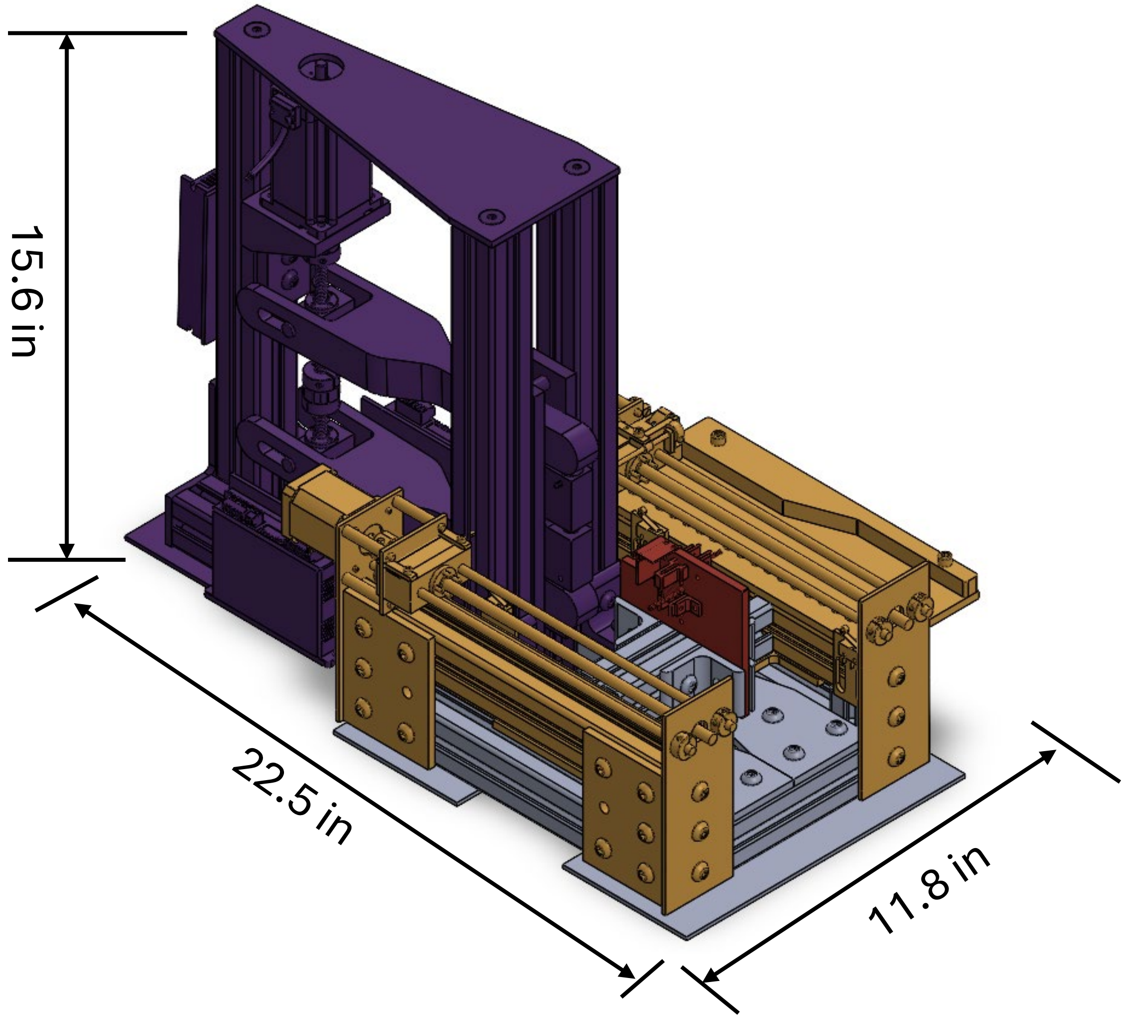
Apply Pressure to Create Weld

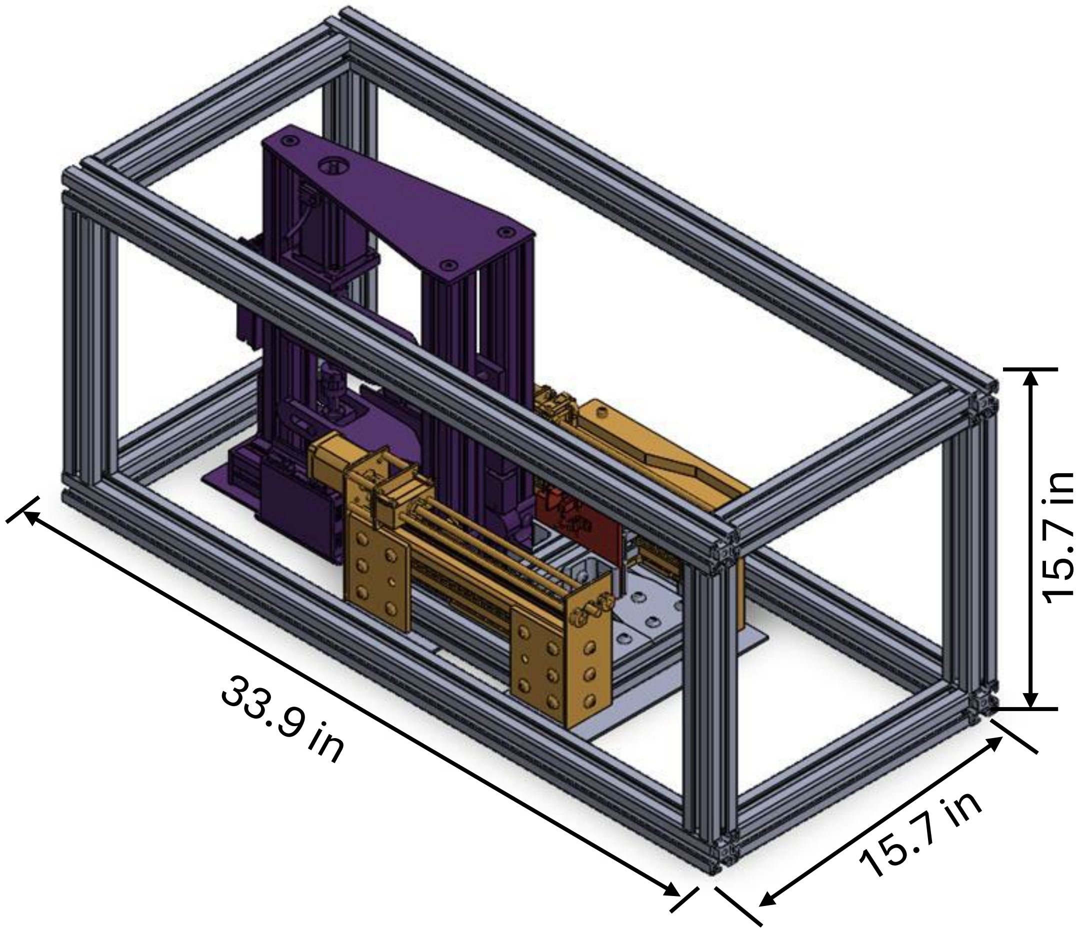




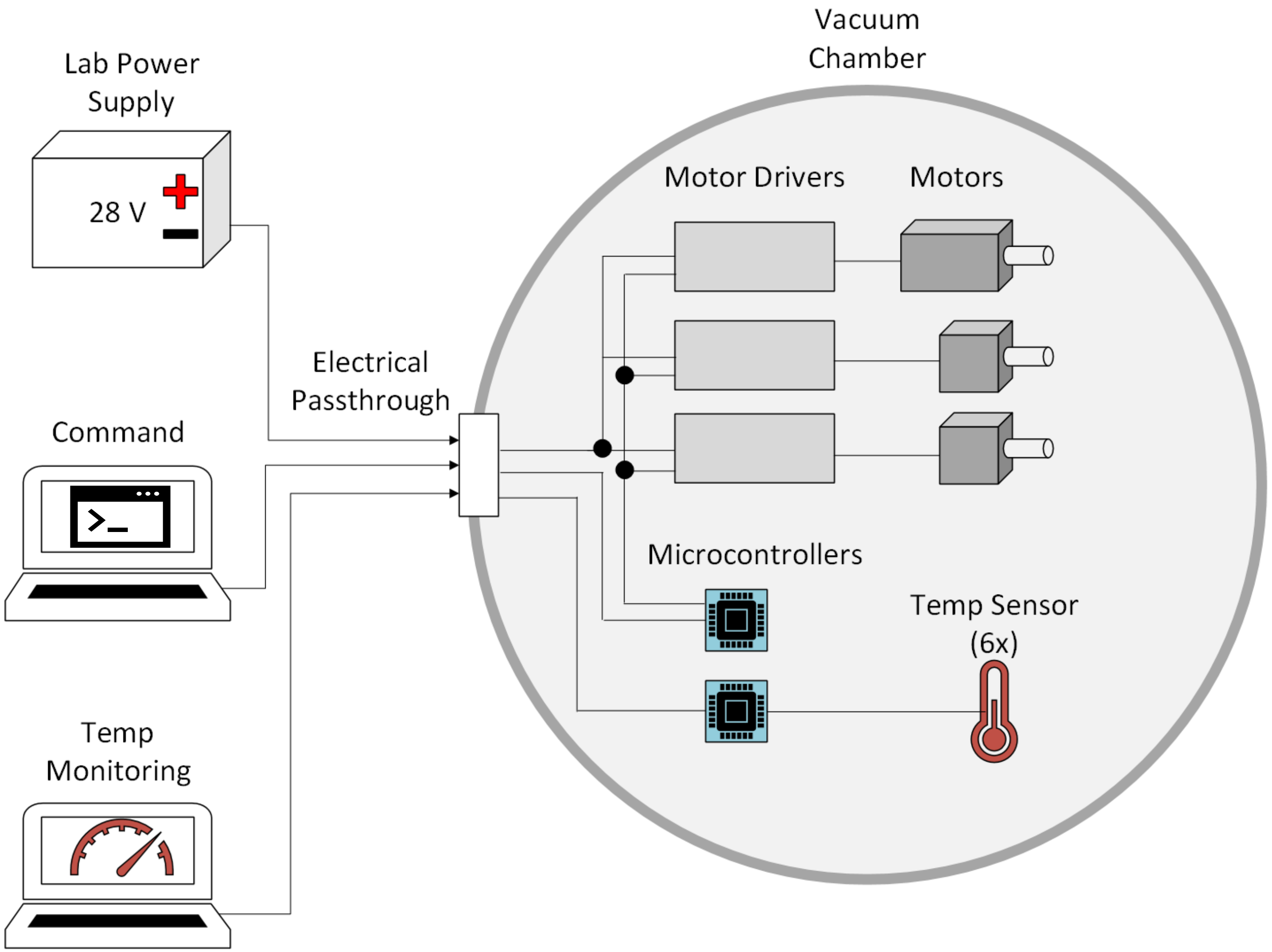


MOCA is designed to fit within the Arkisys's Bosuns Locker, following C3 regulations.



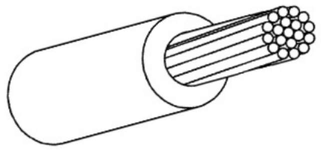


The Electrical Subsystem will require two harnesses.

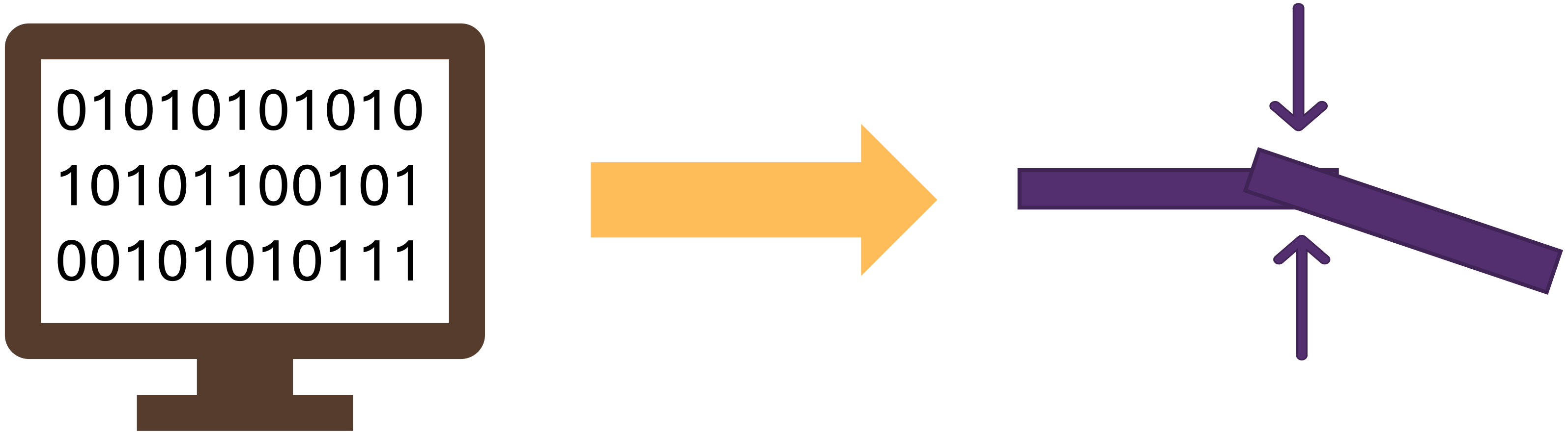


Electrical Passthrough

Vacuum Compatible
Wire

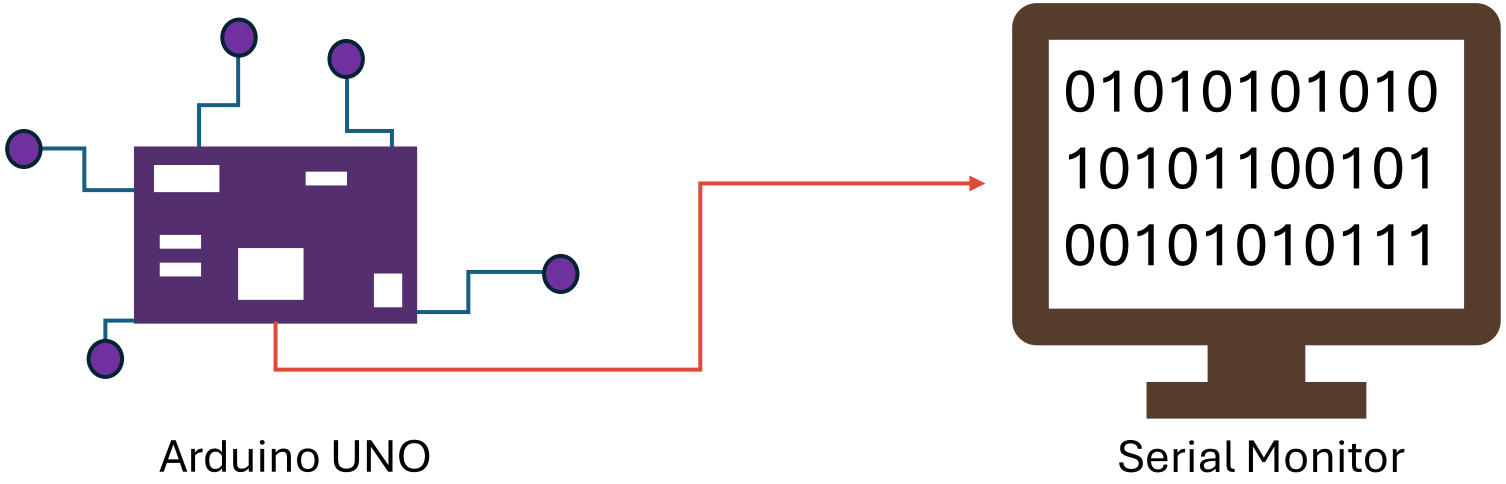


MOCA uses I2C to gather data from the sensors and initiates each step with code written in Arduino IDE.



MOCA code with I2C initiating cold welding process

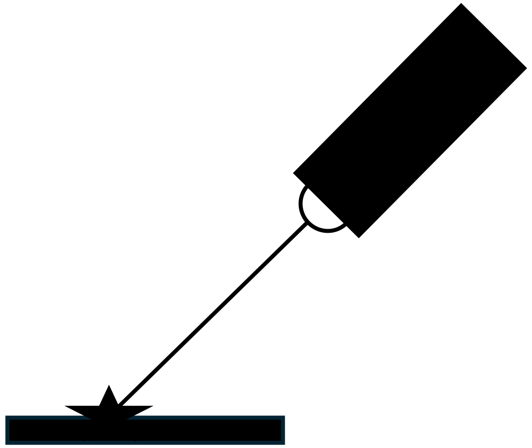
MOCA inputs commands and displays the sensor and status data with the serial monitor.



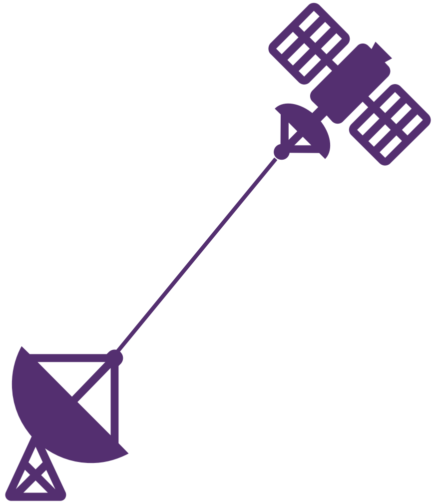
4.1 Innovative Concepts

MOCA explored several innovative ideas.

Cold Welding

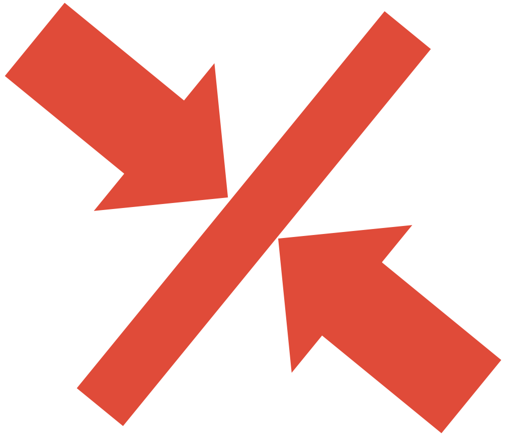


Laser Cleaning

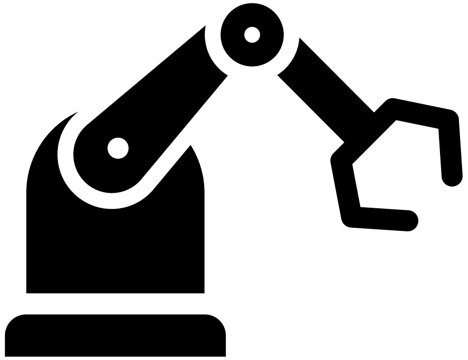


Laser Communication

MOCA requires additional technological development to become a usable product in space.



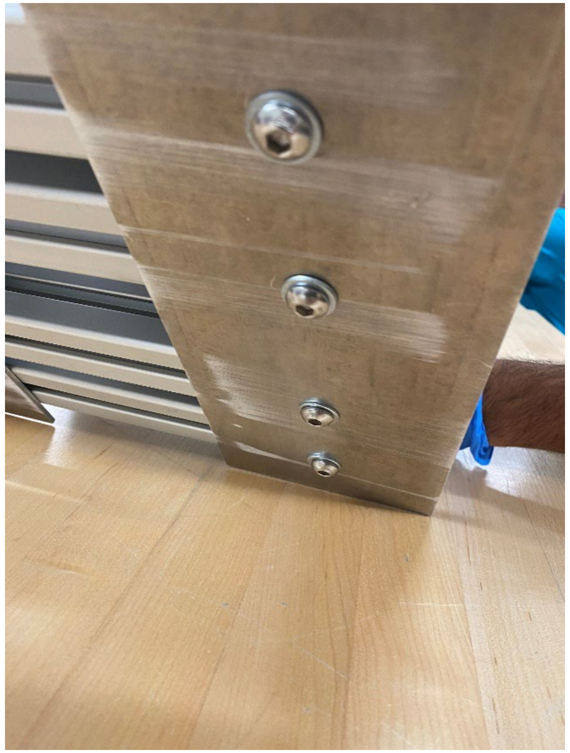
Increased Pressure



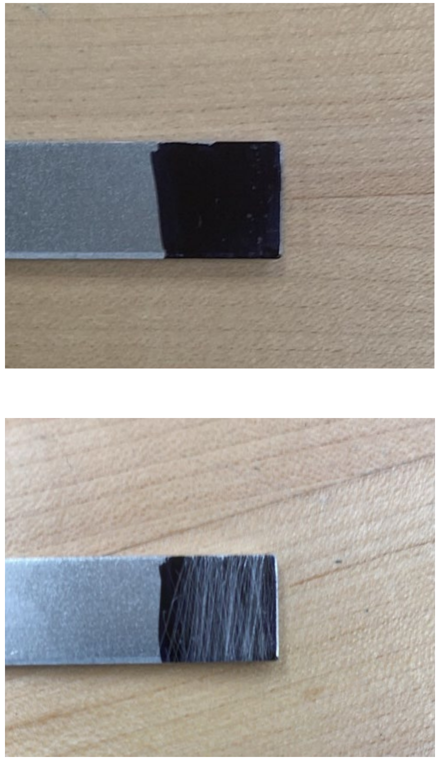
Degrees of Freedom

Particle Confinement

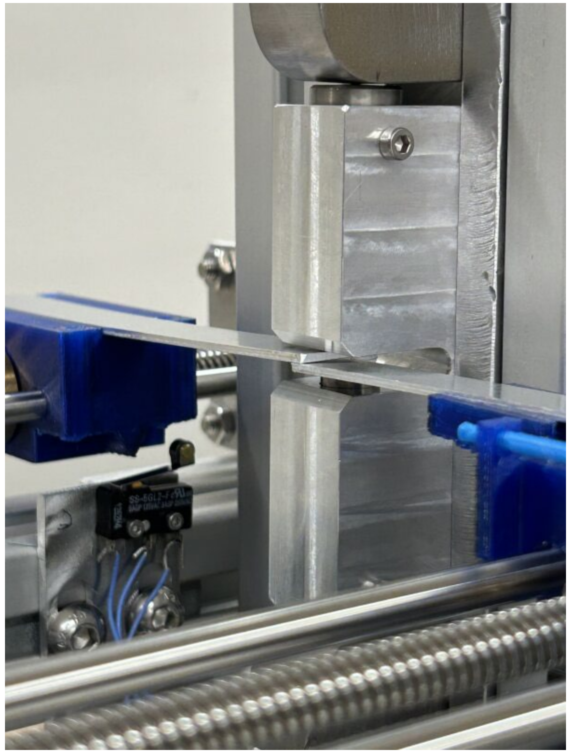
MOCA faced several challenges during development.



Manufacturing



Cleaning Quality



Weld Quality

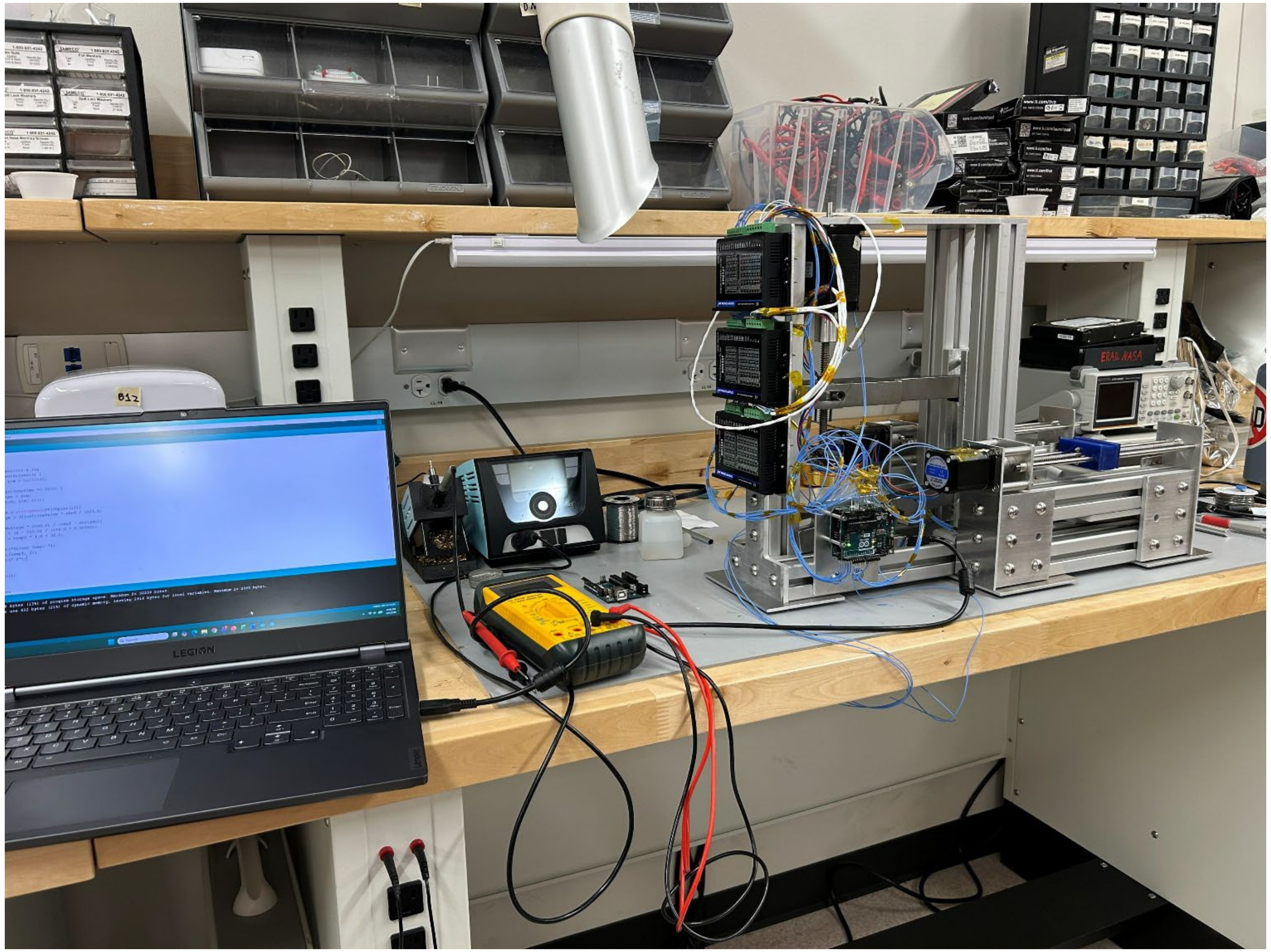
MOCA's Risk Matrix and risks decreased impact after mitigation techniques are implemented.

Consequences

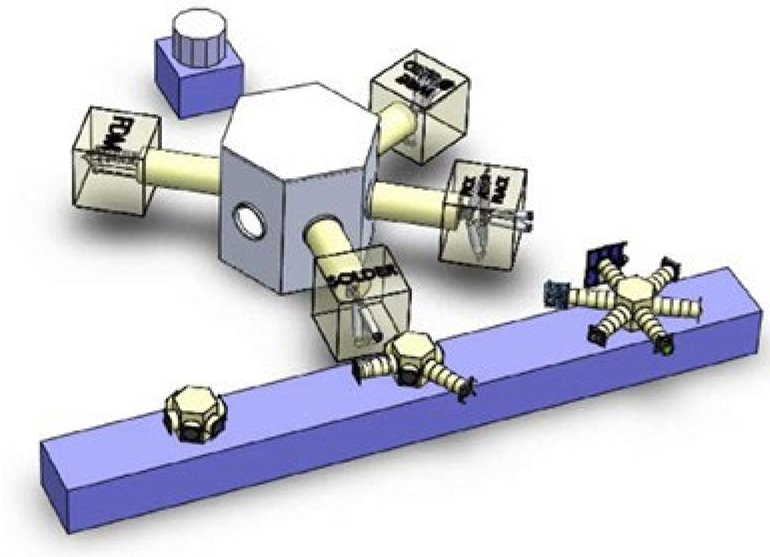
Possibility of Occurance (%)	**Minimal**	**Minor**	**Moderate**	**Significant**	**Severe**
Level 5: 81-100 %					
Level 4: 61-80%				Motor Damage*	Code Error*
Level 3: 41-60%		Carriage Stalling	Motor Skipping Tandem Motor Issues	Unintended Collisons	Misalignment During Assembly*
Level 2: 21-40%			Brush Binding Lead Screw Stripping **Motor Skipping** **Tandem Motor Issues**	Lead Screw Stripping **Motor Damage***	**Misalignment During Assembly***
Level 1: 0-20%		**Code Error*** **Carriage Stalling**	**Brush Binding** **Lead Screw Stripping**	**Unintended Collisons** Lead Screw Stripping	

Legend
Plain Text - Pre-Mitigation
Bold Text -Post Mitigation
* - Critical Risk

MOCA will perform thorough testing of the prototype in preparation for PDR.



Cold welding will support missions such as NASA's Small Satellite Factory.



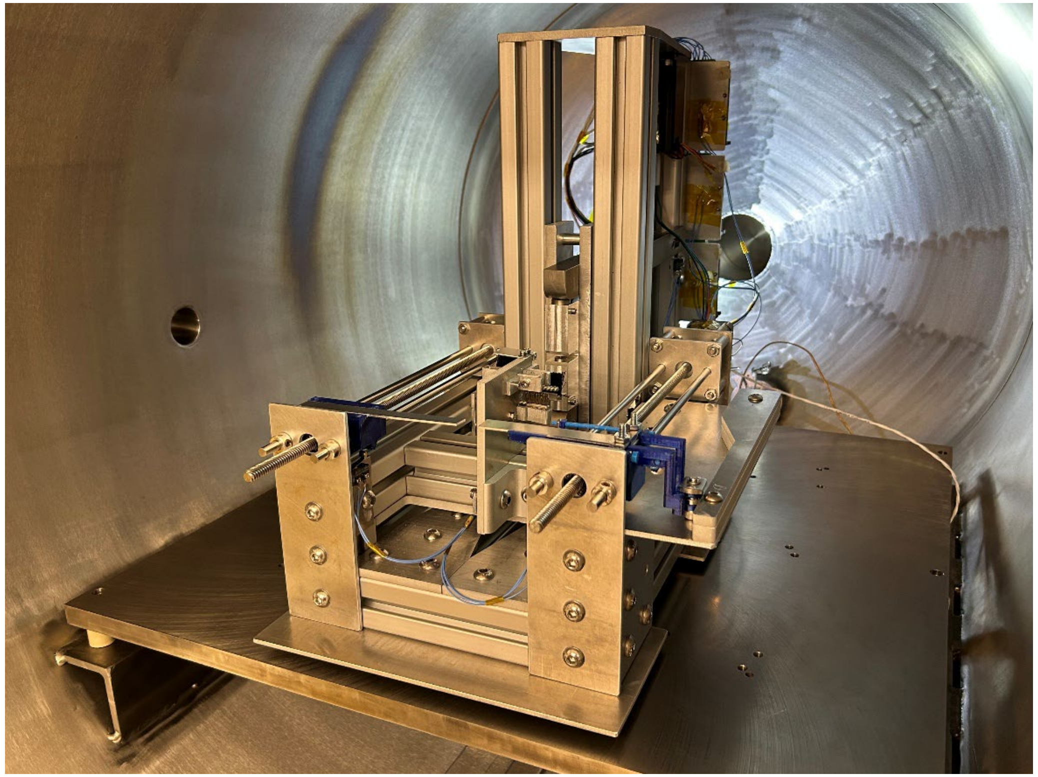
[1]

A paper has been written detailing MOCA's operation, objectives, and requirements.

- 230 word abstract
- 10 pages
- 2 references

- Proposed publish location: AIAA SciTech Fest

MOCA will enable the construction of cold welded truss joints while in orbit.



Questions?

MOCA would like to acknowledge the assistance and advice provided from the following people and groups.

Dr. Kaela Martin

Dr. Dawn Armfield

Ben Grieger

Sara Mitran

Dr. David Lanning

Abigail Storey

Dr. Daniel White

Dr. Ahmed Sulyman

Joseph Chandler

Jared Vanatta

Prescott Steel

References

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Orbit Pic - https://www.skyatnightmagazine.com/space-science/what-is-gravity-facts-about-force

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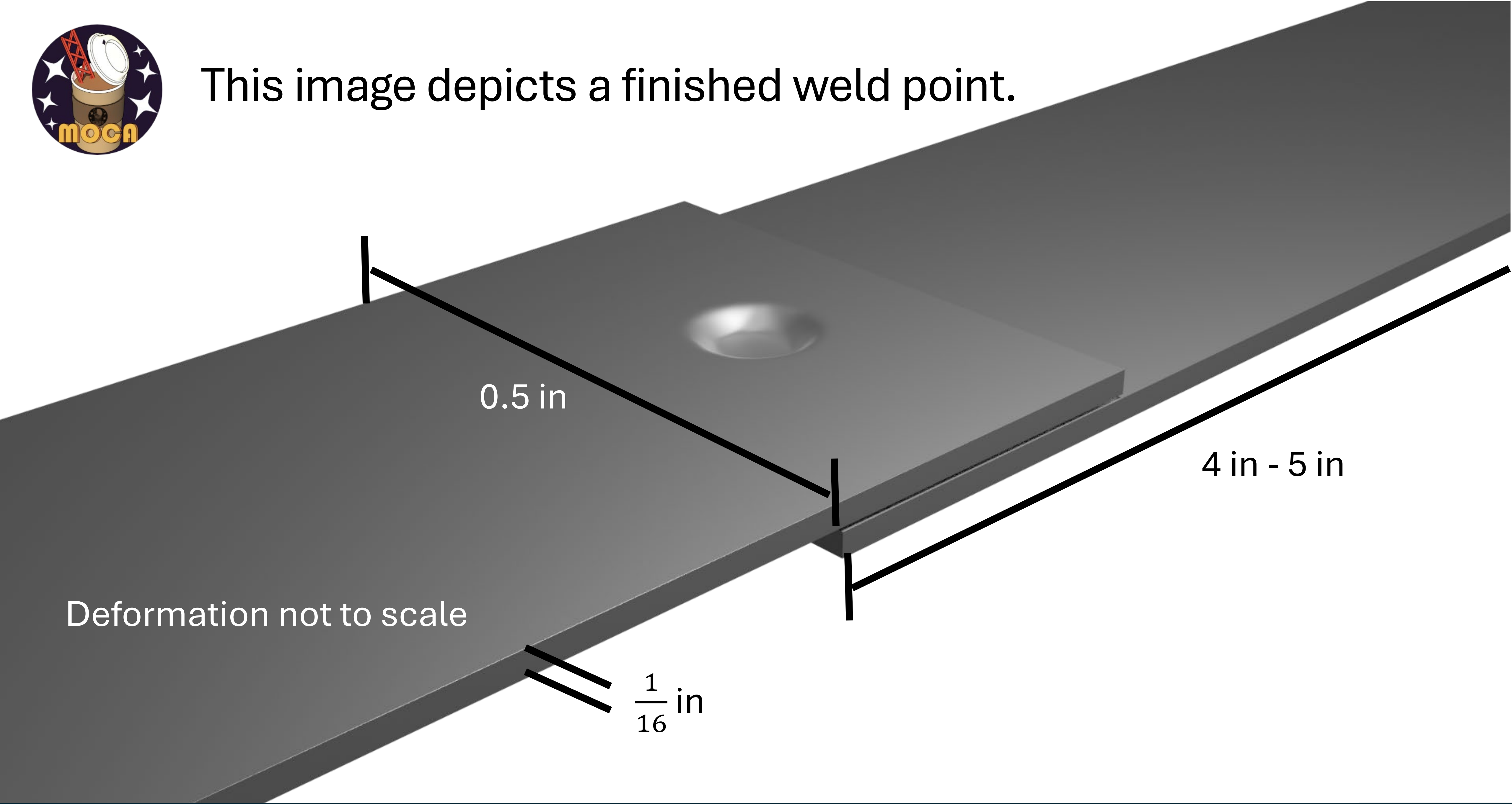
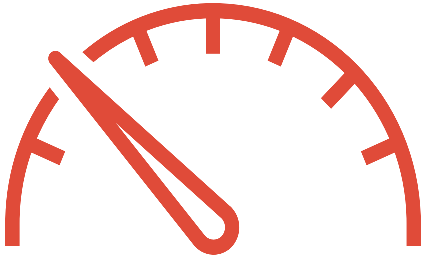
Backup Slides

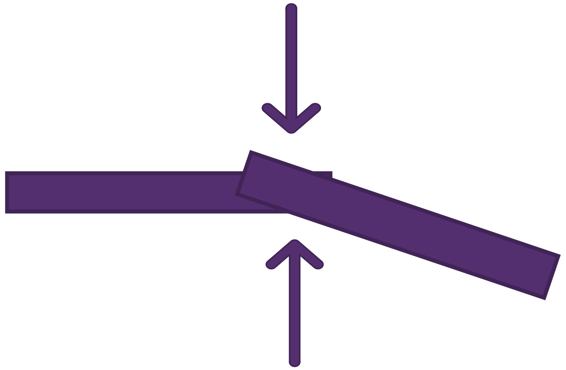
This image depicts a finished weld point.



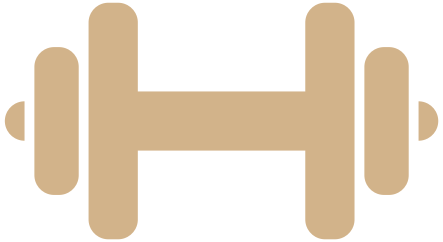
MOCA has three critical system level requirements.



Operating Pressure

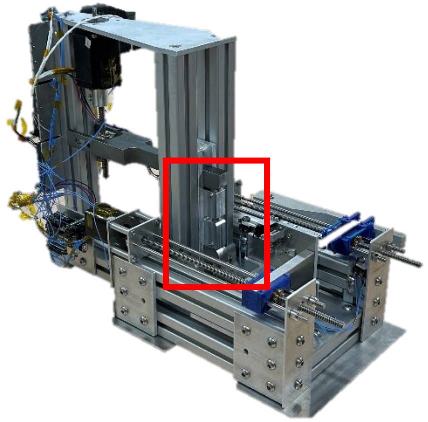


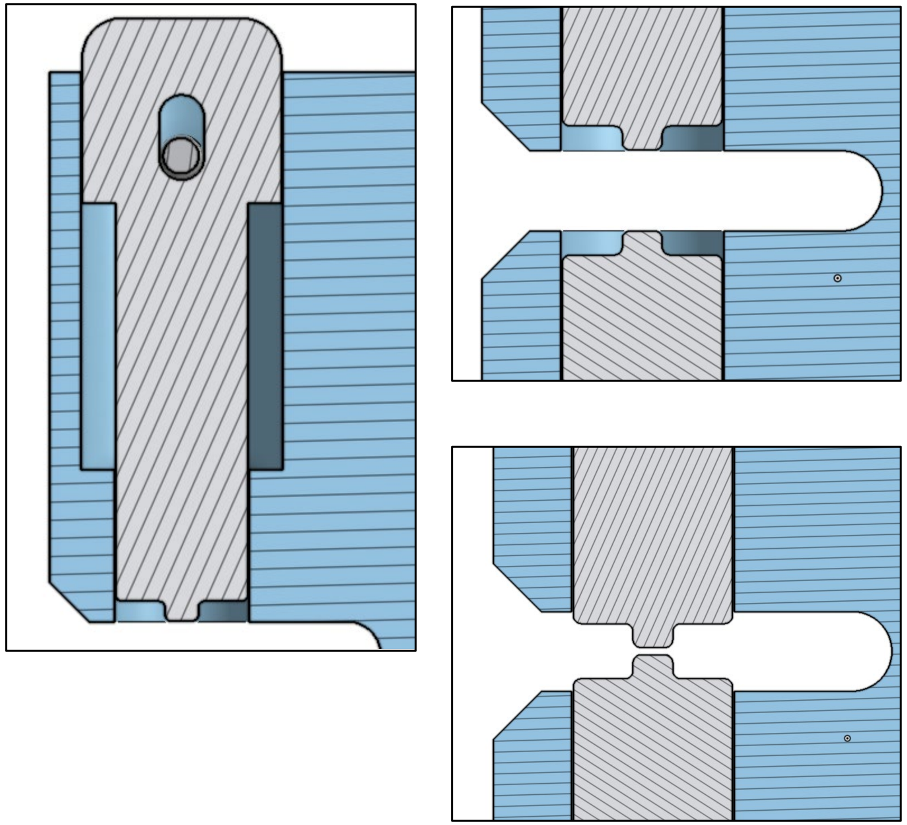
Joint Creation

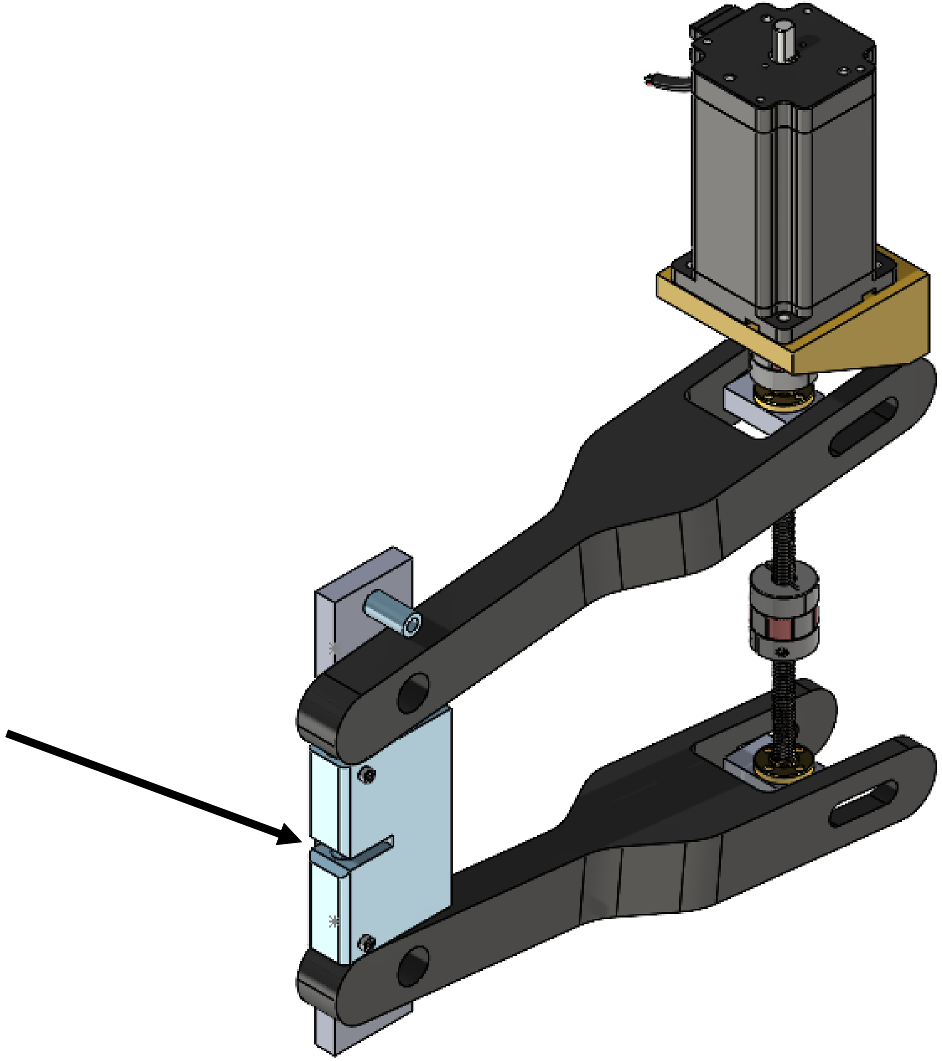


Shear Metric

The Pressure Mechanism is a clamp that applies pressure to a very small point.

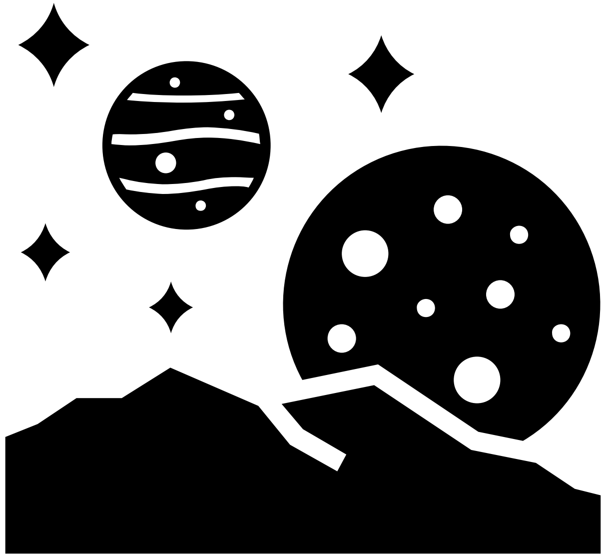


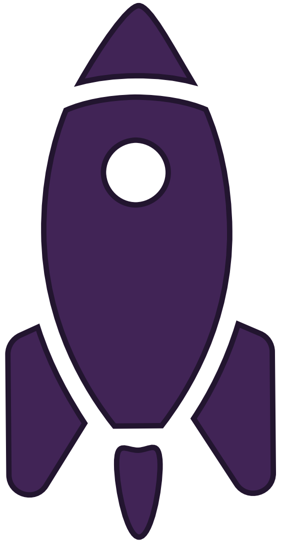


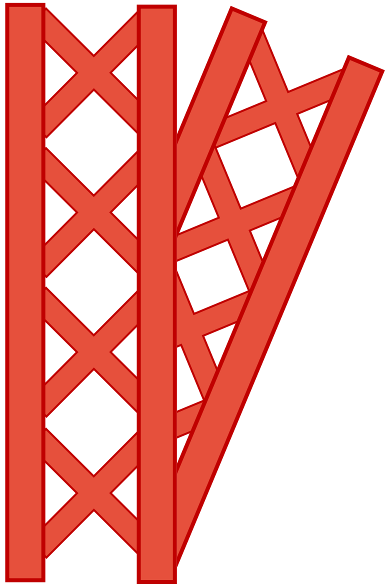


MOCA developed a system to perform the concept of operations.

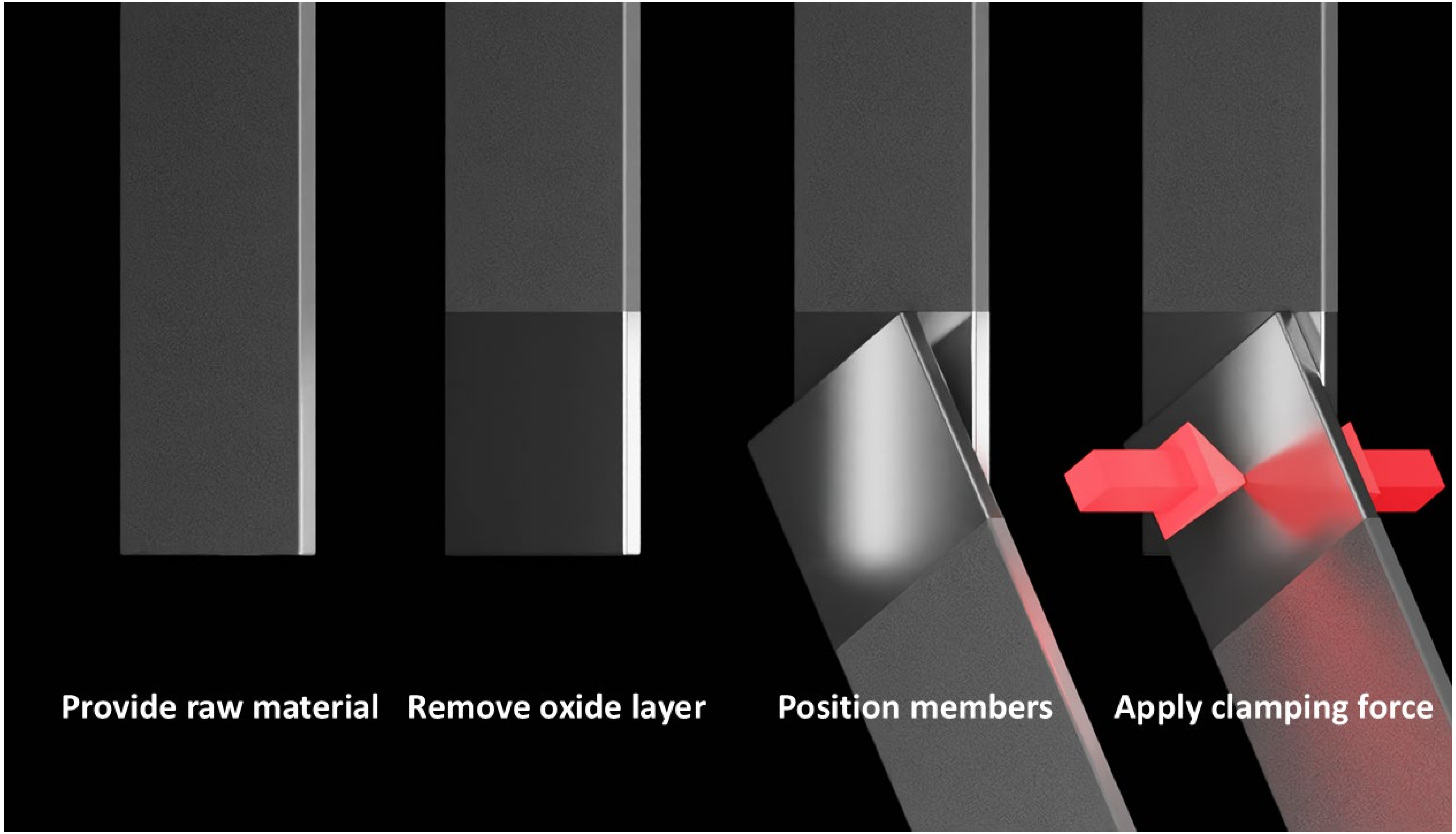
MOCA will support future space exploration by providing major benefits.







MOCA enables truss joints to be cold-welded by removing the oxide layer and applying pressure.



Total mass of MOCA is 365 kg, total power is 252 W, and costs $1,450.

Table 8.6: Subsystem Mass Allocation

Subsystem	**Mass [lbs]**
Mechanical	50
Electrical	5
Total System Mass	**55**
Mass Requirement	882
Leftover Mass	**827**

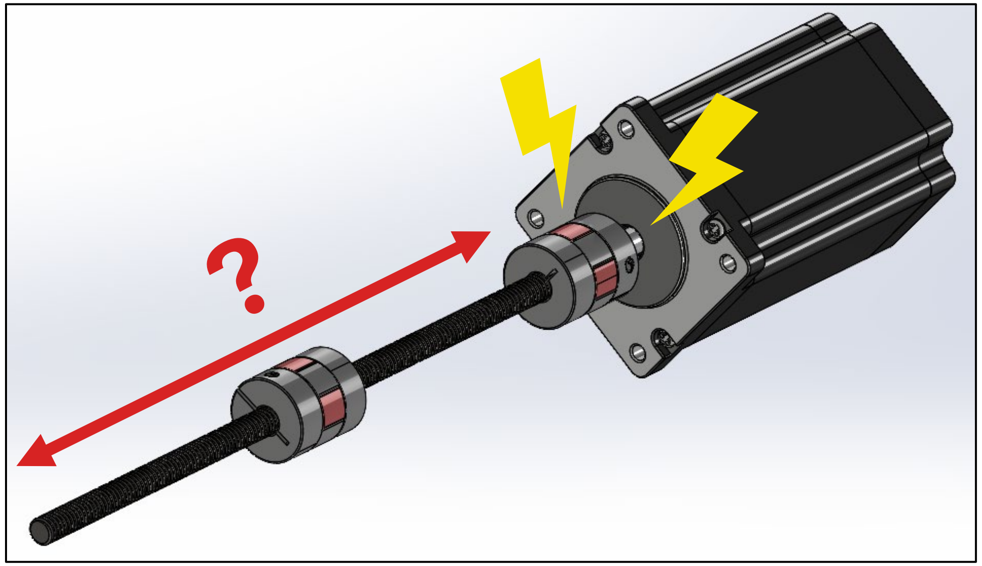
Table 8.7: Subsystem Power Allocation

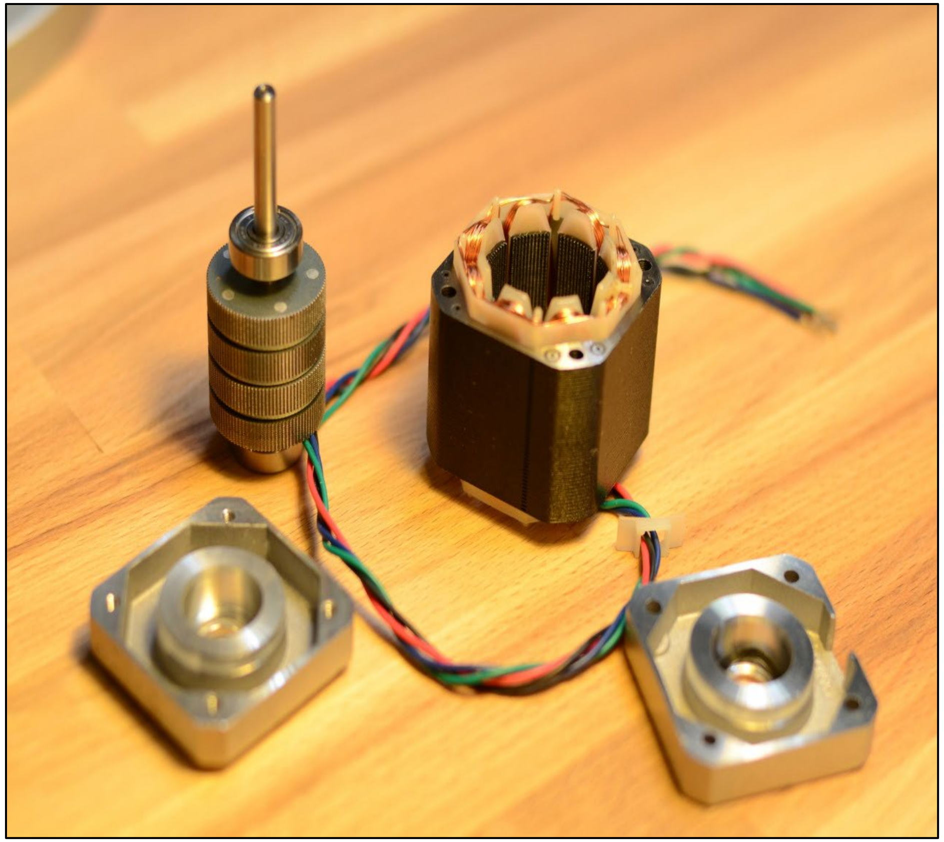
Subsystem	**Power [W]**
Mechanical	-250
Electrical	-20
Total System Power	**570**
Power Requirement	300
Leftover Power	**-270**

Table 8.8: Subsystem Cost Allocation

Subsystem	**Cost [$]**
Mechanical	$700.00
Electrical	$300.00
Management Reserve (20%)	$290.00
Total System Cost	**$1,290.00**
Cost Requirement	$1,450.00
Leftover Cost	**$160.00**

MOCA has operational and manufacturing risks.

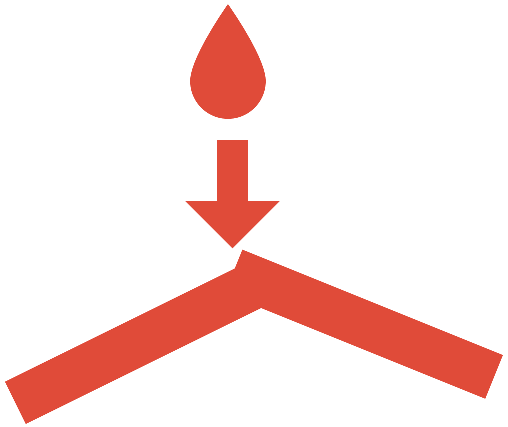




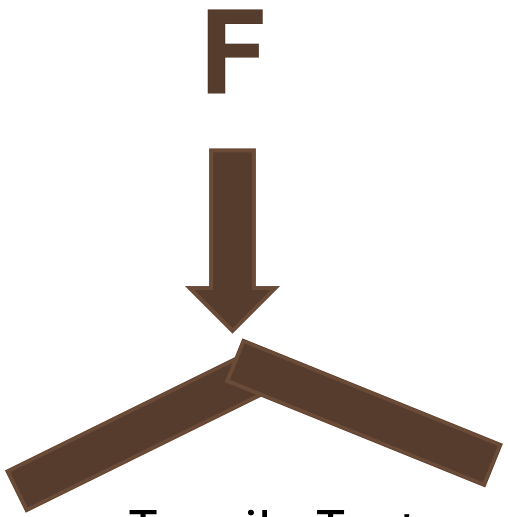
[11]

MOCA's weld quality will be evaluated through Non-Destructive and Destructive test methods.

Inspection

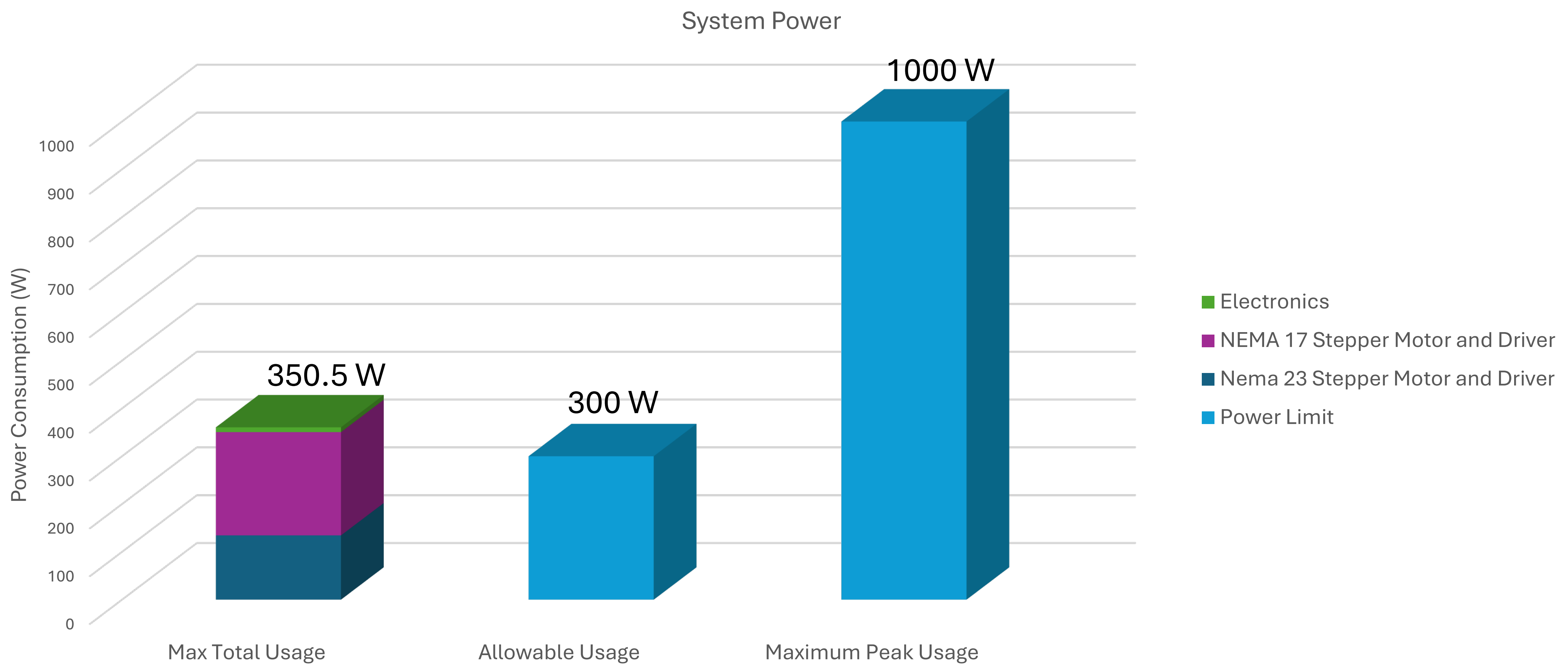


Dye Penetrant



Tensile Test

MOCA analyzed a worst-case power draw with all motors running at stall torque.



Power Sample Calculation

$$P = VI$$

$$P = (24V)(5.6A)$$

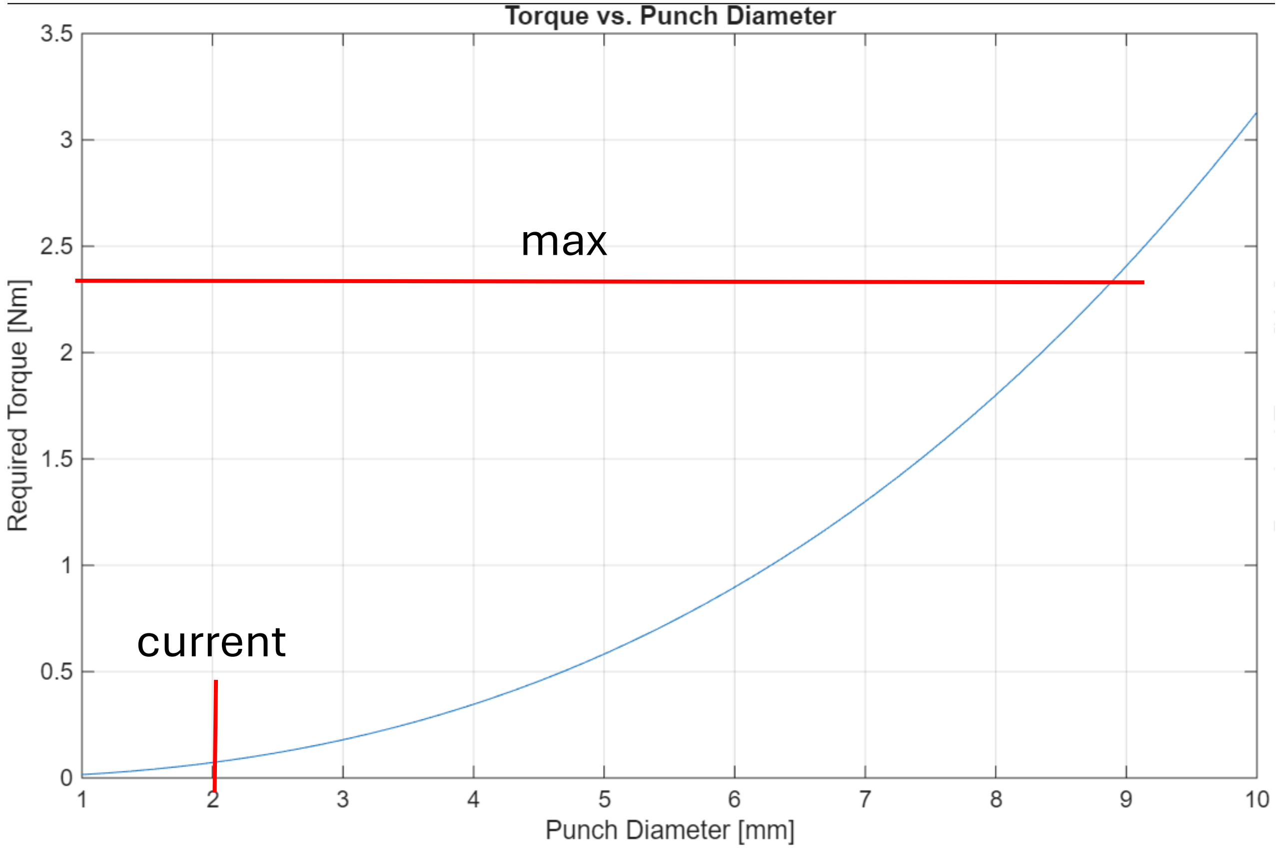
$$P = 134.4W$$

NEMA 23 Input Voltage = 24V

MAX CURRENT DRAW = 5.6A

System Prediction Analysis of Performance - Pressure Mechanism

$$F = \frac{2T}{d_m} \cdot \frac{\pi d_m - \mu L \sec(\alpha)}{L + \pi \mu d_m \sec(\alpha)}$$

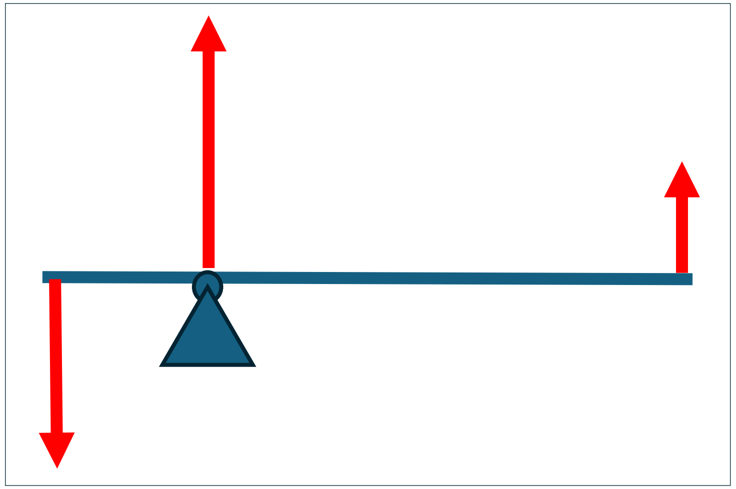


System Prediction Analysis of Performance - Alignment Mechanism

$$F = \frac{2T}{d_m} \cdot \frac{\pi d_m - \mu L \sec(\alpha)}{L + \pi \mu d_m \sec(\alpha)}$$

Torque	0.59	Nm
T8 Lead	0.002	m
T8 Thread Angle	15	
T8 Pitch	0.002	m
T8 OD	0.008	m
Dm	0.007	m
Friction Coefficient	0.15	
Force	674.9213423	N
Carriage Weight	0.06	kg
Normal Force	0.5886	N

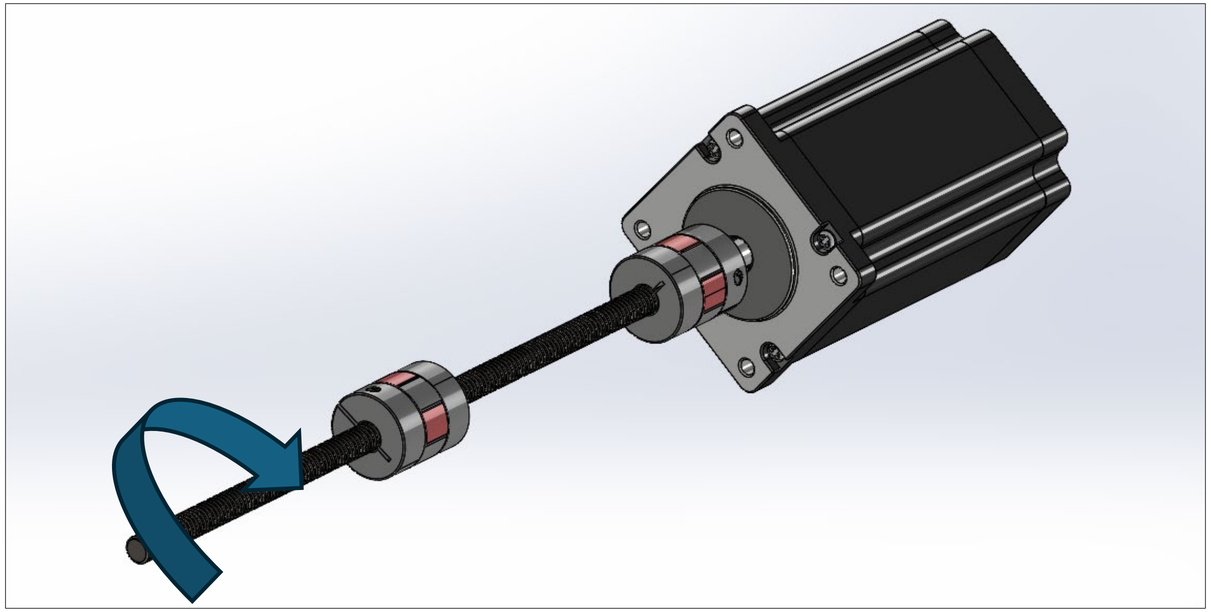
Three analyses were conducted for the pressure subsystem.



Pivot Point Reaction Force

[10]

Leadscrew Nut Thrust Load



Torque Calculation

Pressure Mechanism Analysis Calculations

$P_{cr} = \frac{n^2\pi^2 EI}{4L^2}$ Critical buckling force for two supports (n=1), one pined, one fixed.

Pin yields before buckling, use load allowable.

```
load_all_die = pi*0.001^2 * sigma_all        %N, allowable load on crimp nub
```

```
load_all_die = 3.9270e+05
```

```
P_cr_s = (pi^2*E_s*I)/(4*L_s^2)          %N, pressure crit, buckling pressure
```

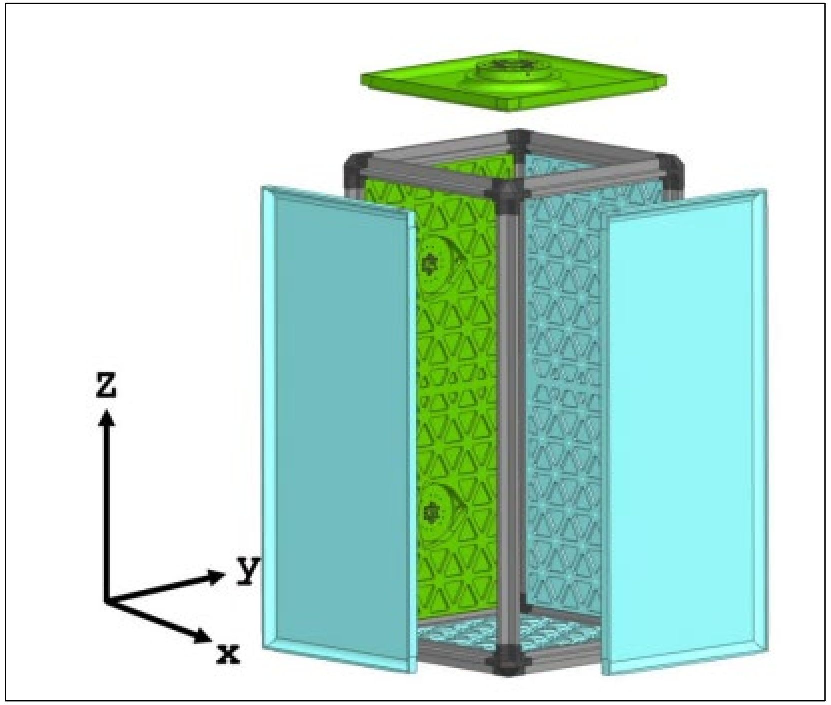
```
P_cr_s = 8.5826e+03
```

```
sigma_ct_s = P_cr_s/(pi*(d/2)^2)         %Pa, stress crit, buckling stress
```

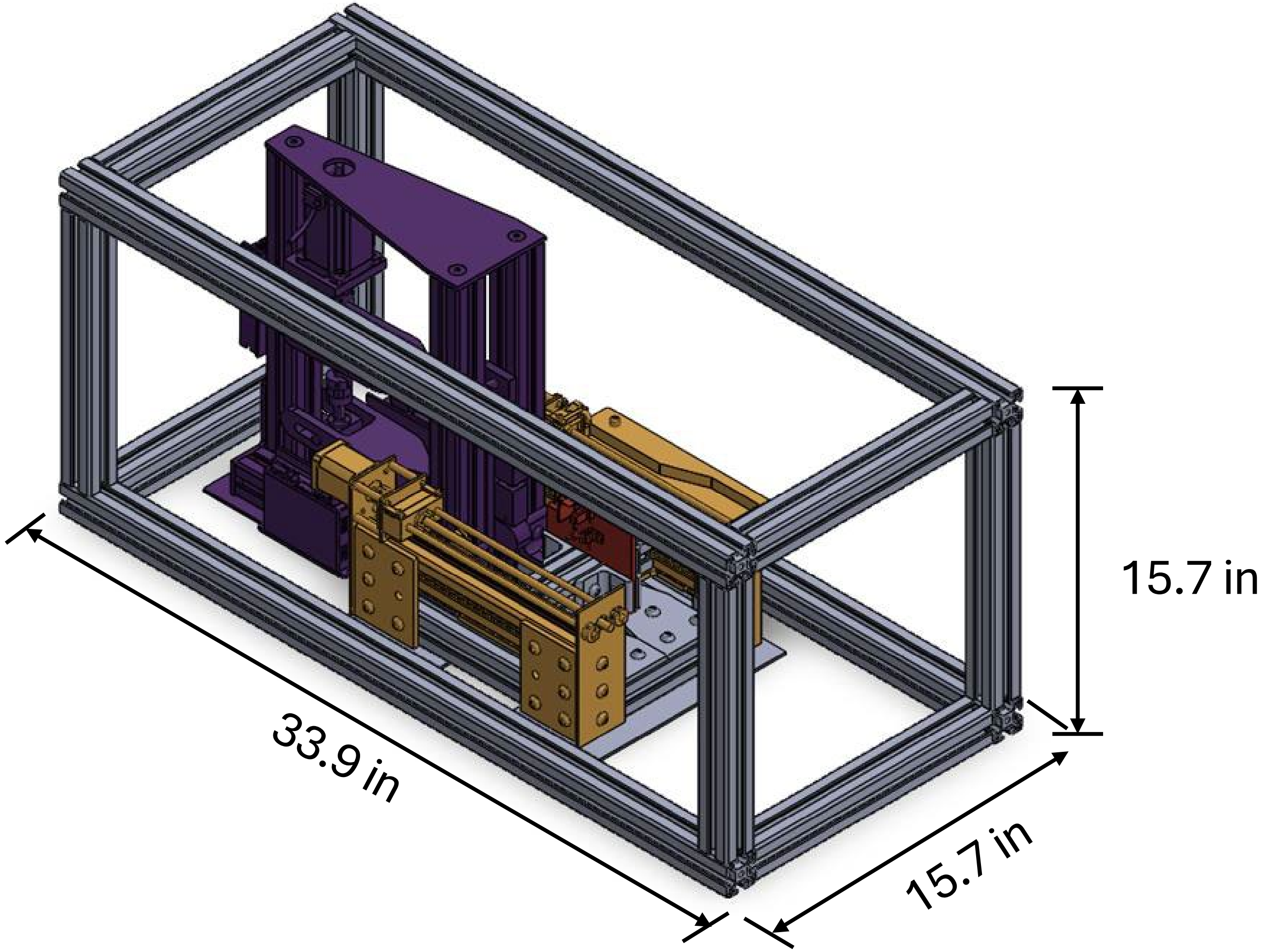
```
sigma_ct_s = 1.0928e+08
```

Leadscrew buckles before yield

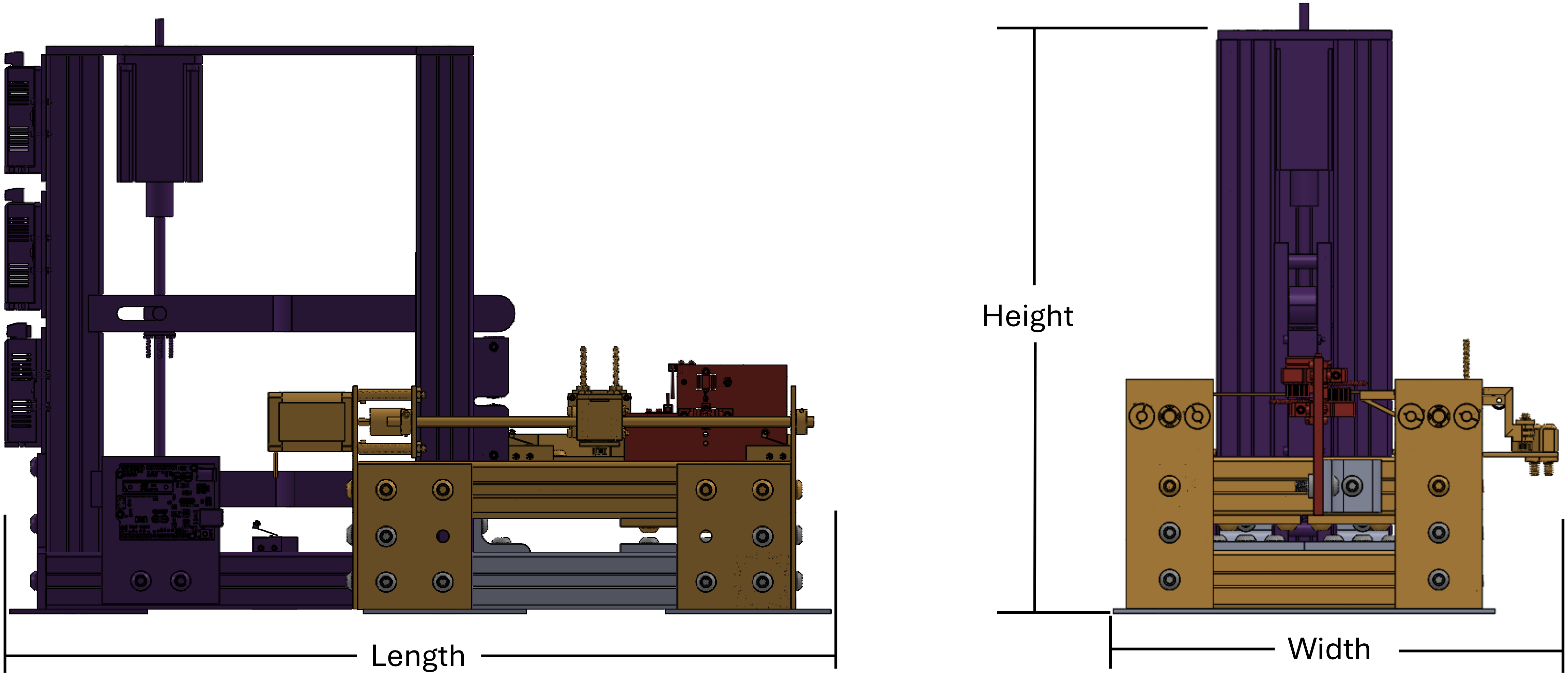
MOCA is designed to fit within the Arkisys's Bosuns Locker, following C3 regulations.



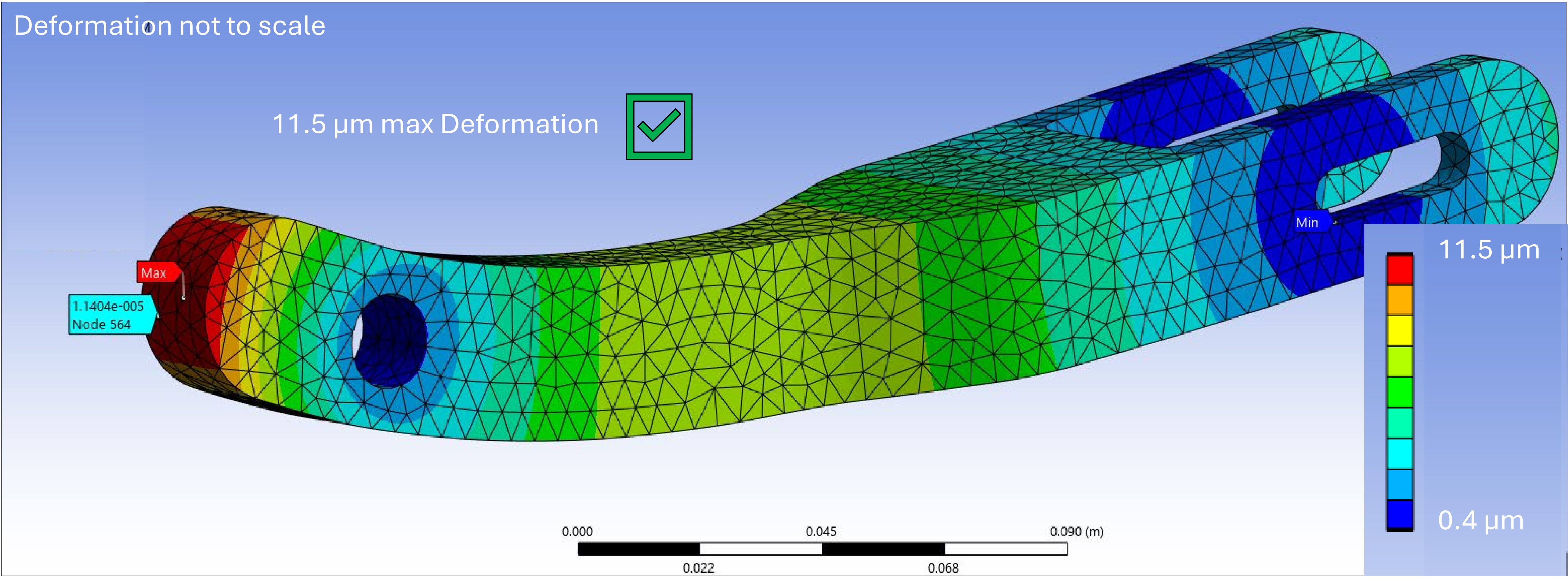
[4]



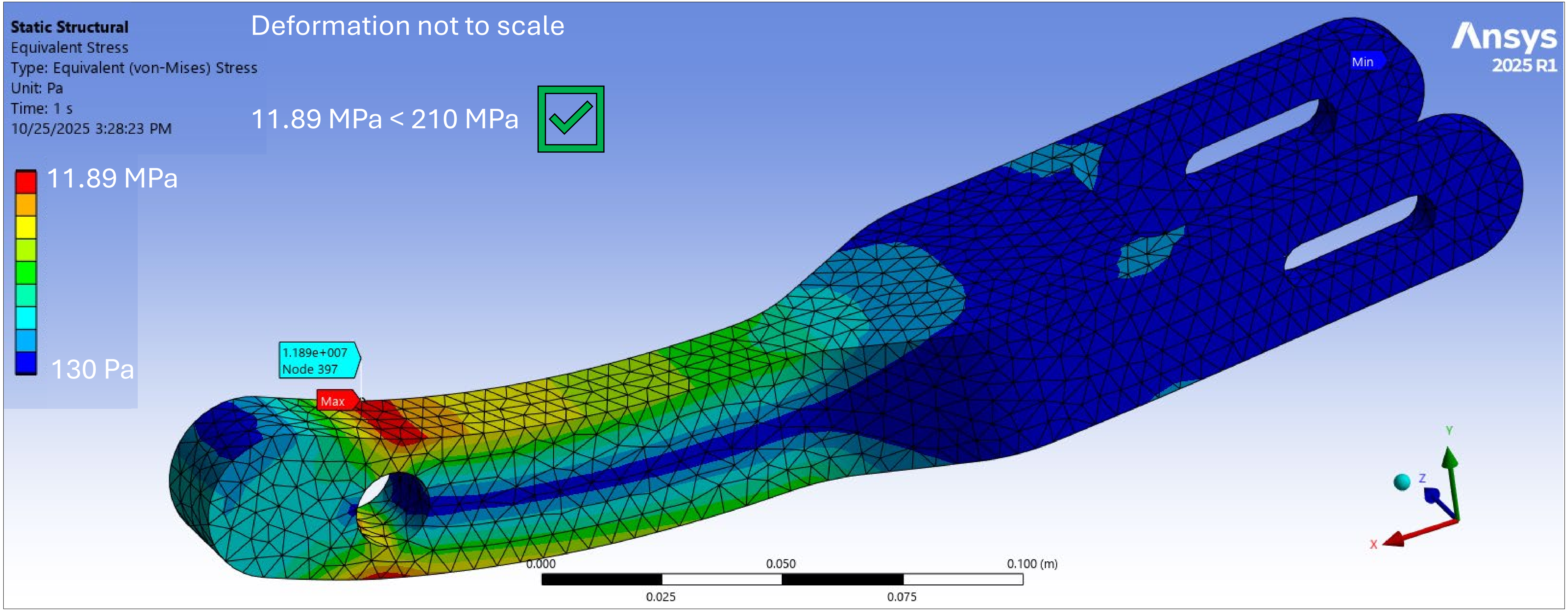
The Mechanical Subsystem provides a compact and lightweight structure.



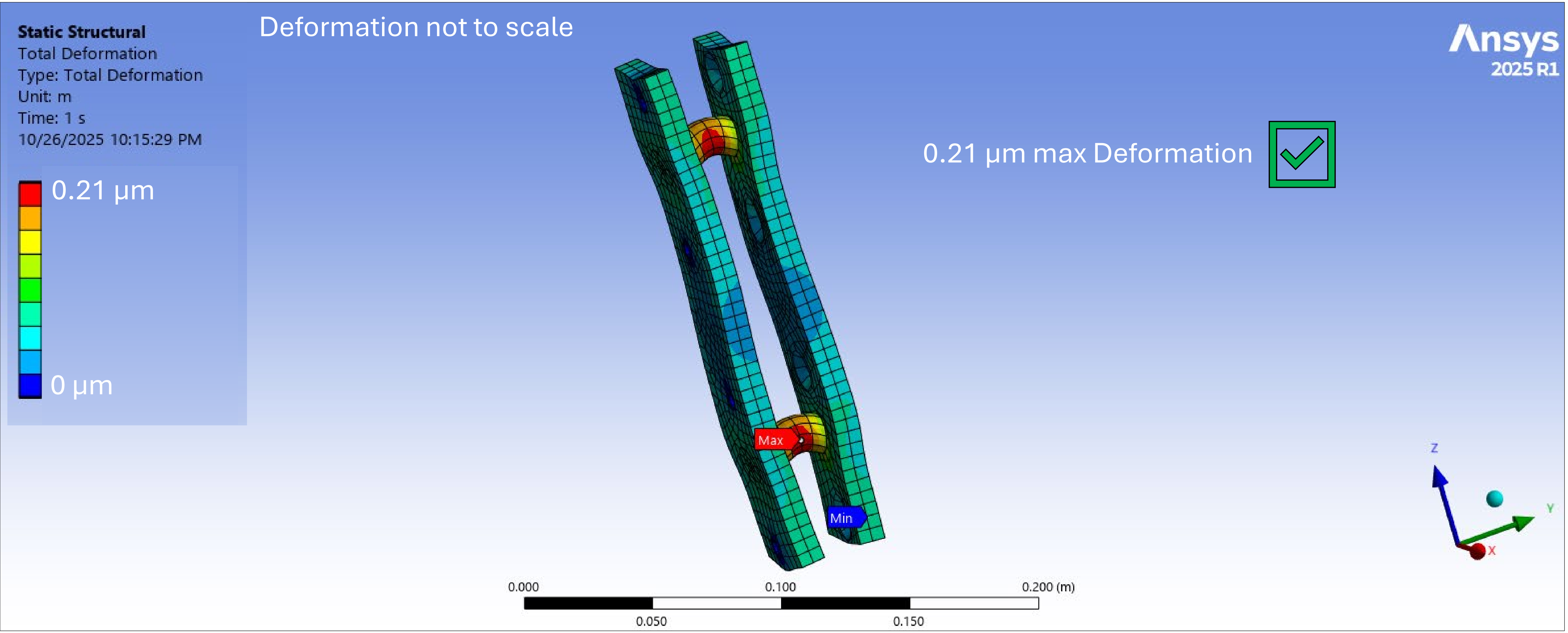
The deformation of the pressure lever was examined and has a very small magnitude.



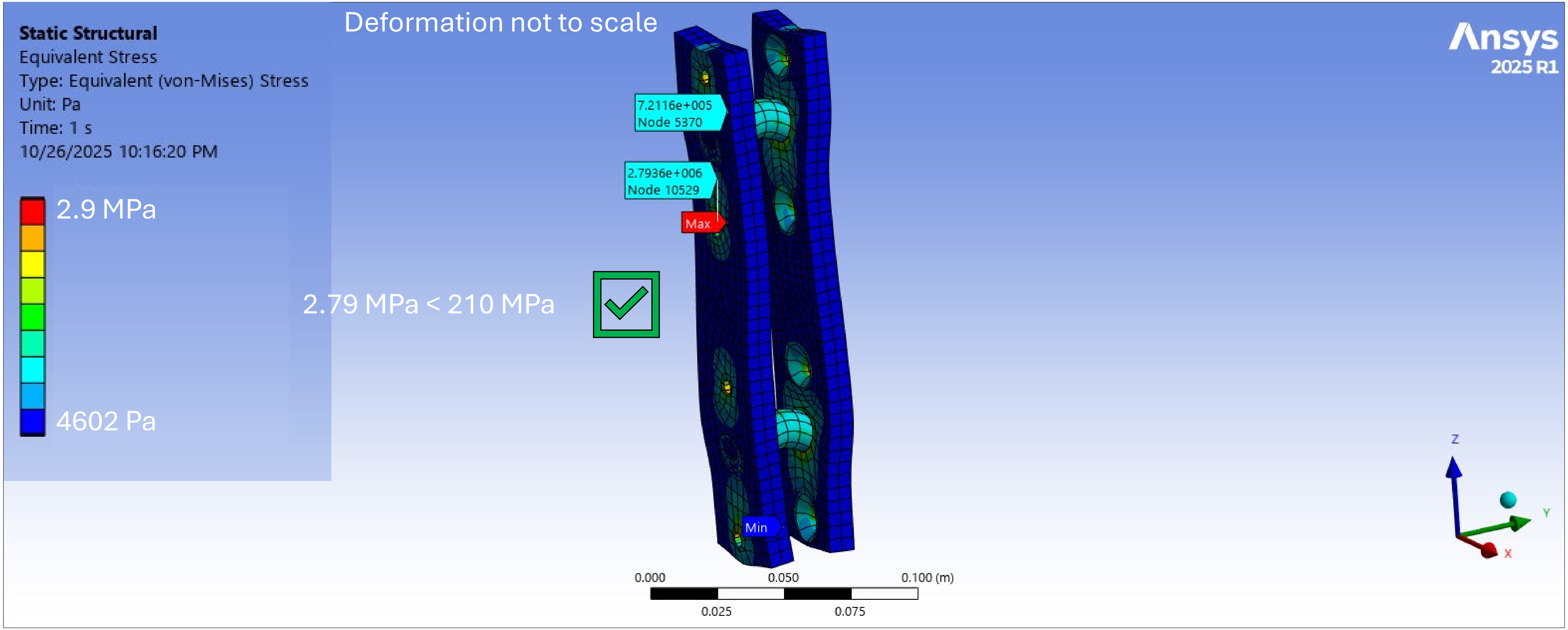
The stress distribution of the pressure lever was examined and determined to not exceed structural limits.



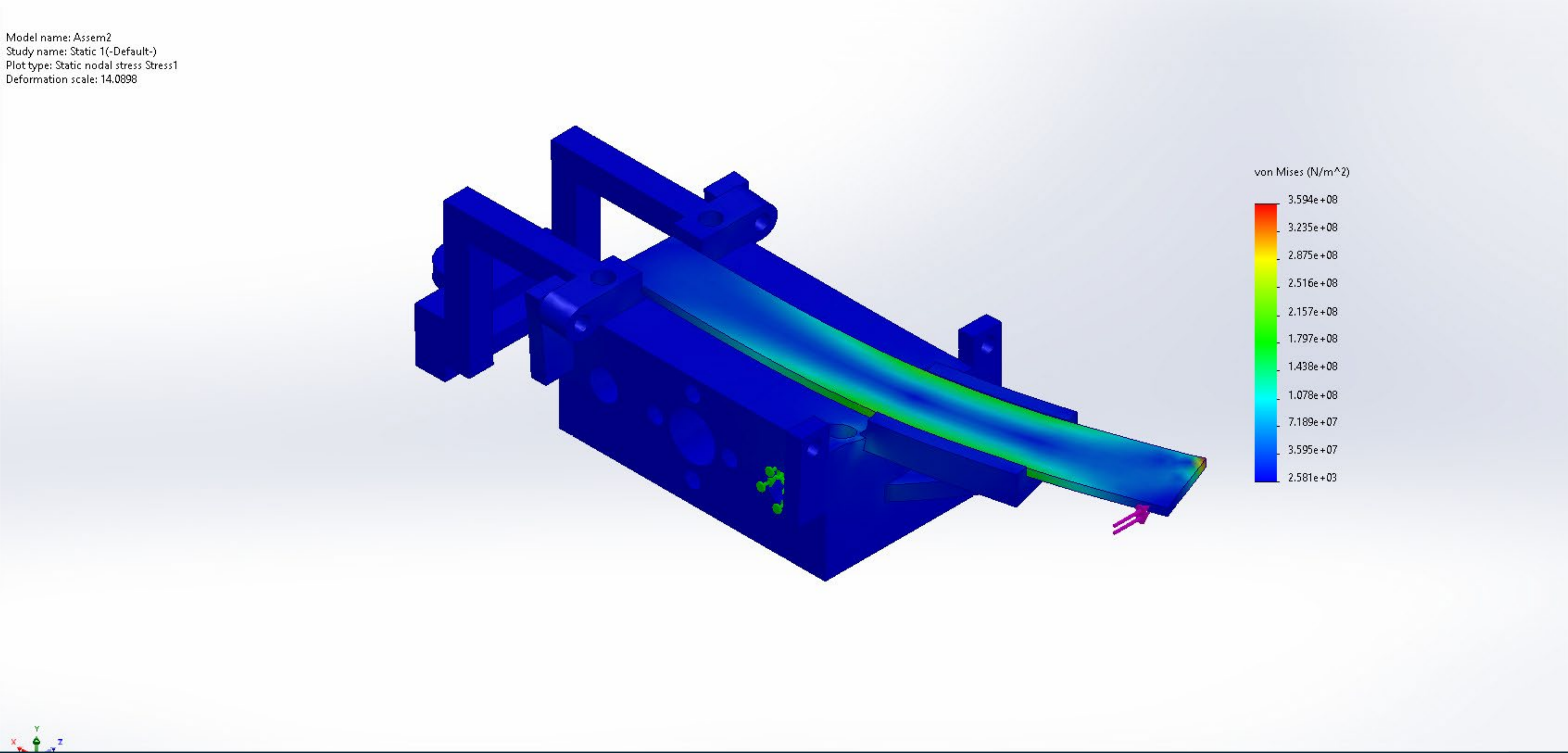
The deformation of the pivot pin and support was examined and determined to be very small (<0.21 micrometers).



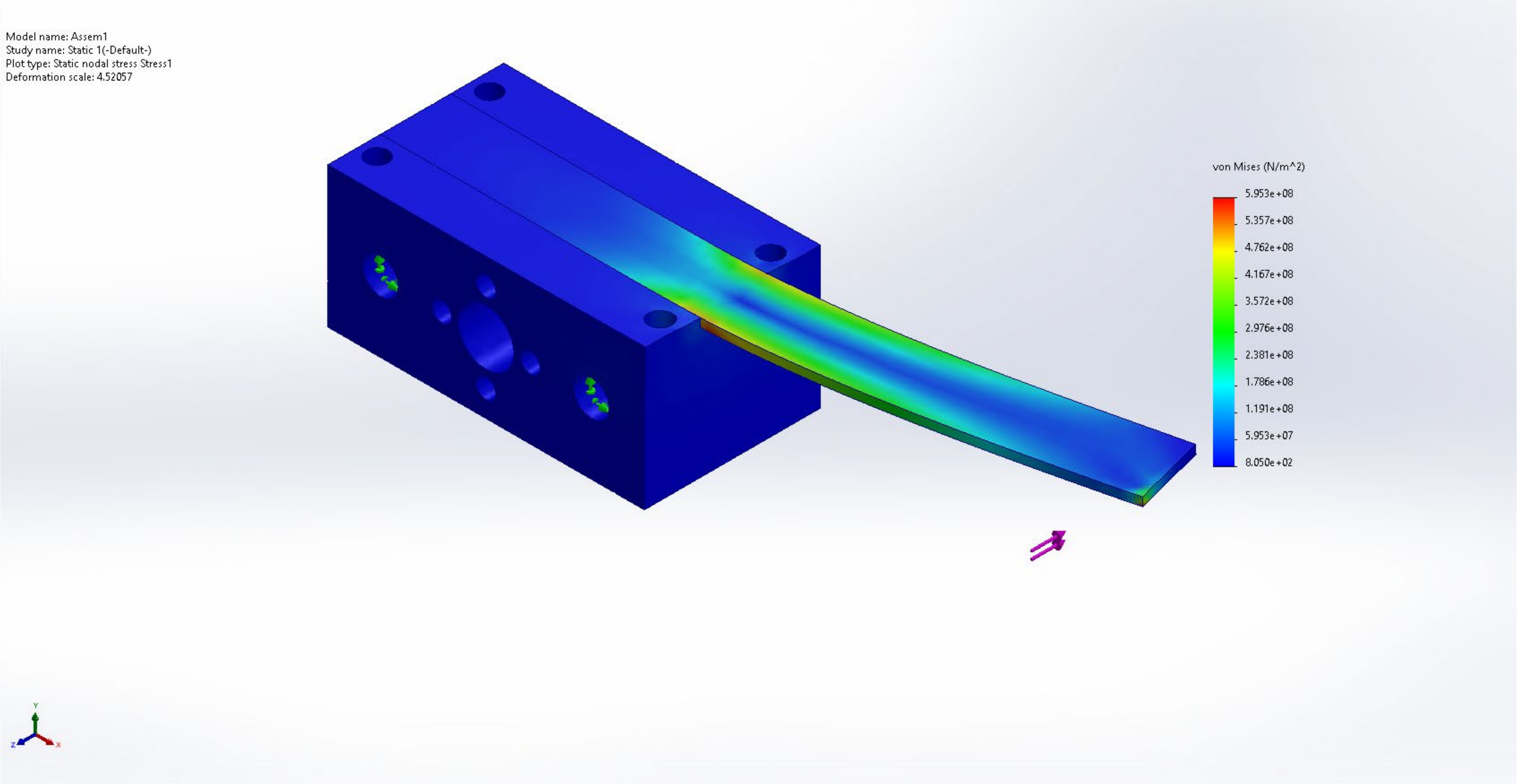
The stress distribution of the pivot pin and support was examined and determined to be within structural limits.



The stress on the carriage was examined and determined to have a FOS of 1.94



The stress on the carriage was examined and determined to have a FOS of 1.97



Weld Pin Shear Stress

$$\tau = \frac{F}{A} = \frac{F}{\pi \cdot r^2} \quad (1)$$

$$\tau_{max} = \text{YieldStrength}_{Al-3003} \cdot \frac{1}{2} \quad (2)$$

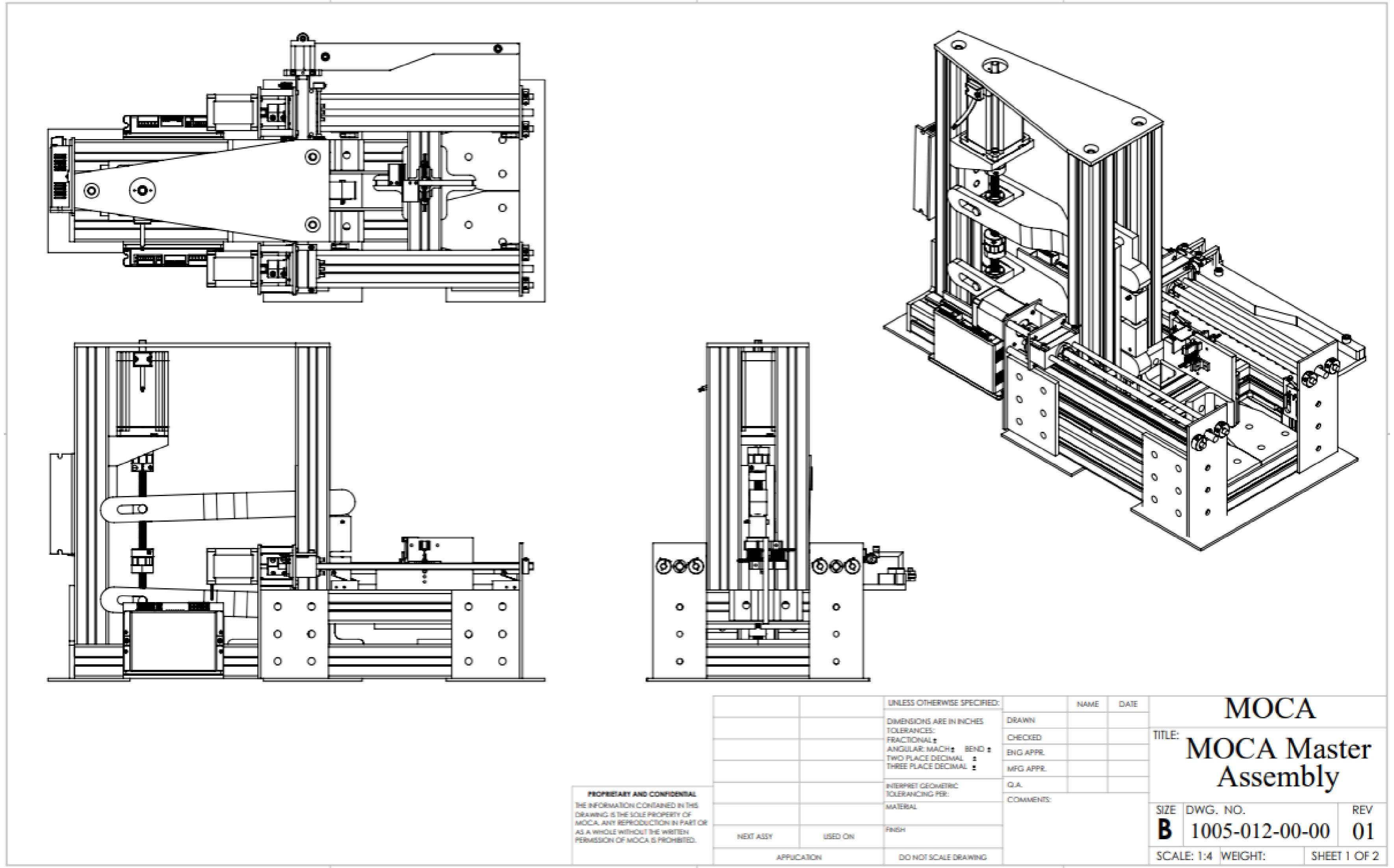
$$\tau_{max} = 97MPa \cdot \frac{1}{2} \quad (3)$$

$$F_{max} = 97MPa \cdot \frac{1}{2} \cdot \pi r^2 \quad (4)$$

$$F_{max} = 97MPa \cdot \frac{1}{2} \cdot \pi \cdot 1mm^2 \quad (5)$$

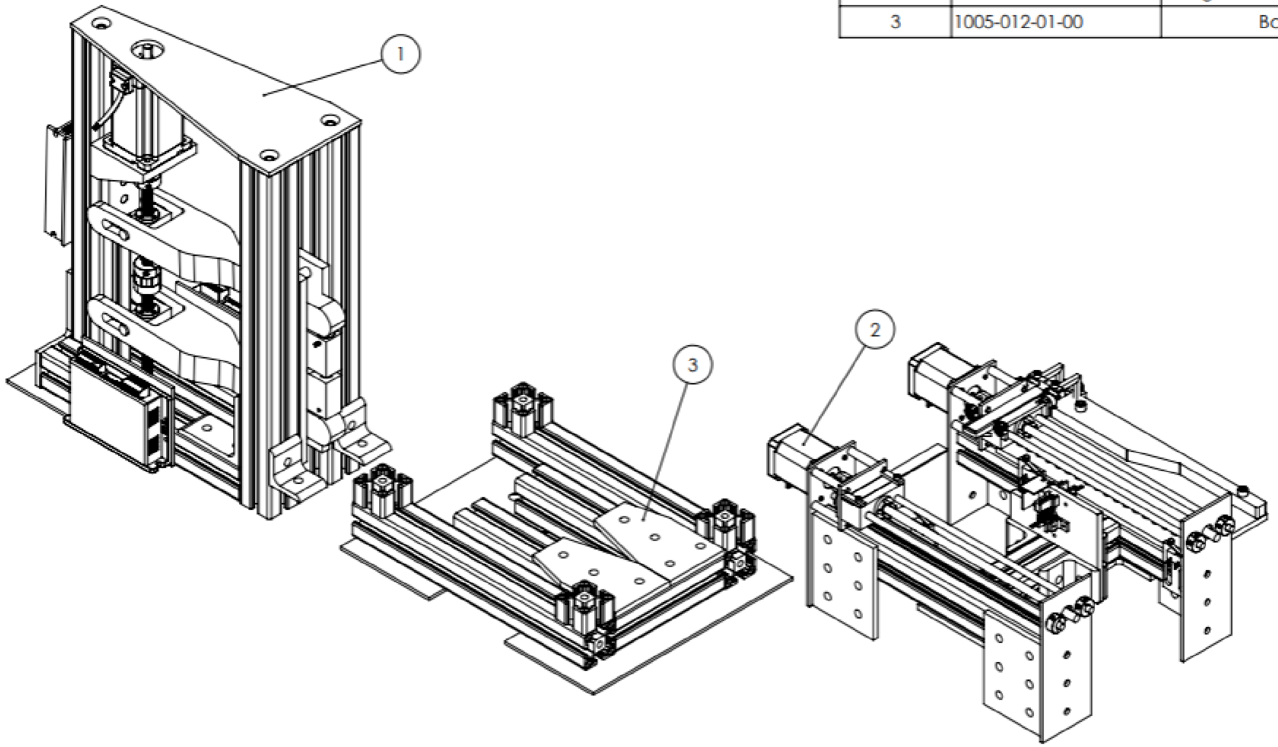
$F_{max} = 152.4N$ per weld point.

MOCA Master Assembly Drawing



MOCA Master Assembly Exploded Drawing

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1005-012-03-00	Pressure Mechanism	1
2	1005-012-04-00	Alignment & Cleaning Assembly	1
3	1005-012-01-00	Base Structure	1



PROPRIETARY AND CONFIDENTIAL
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NEXT ASSY | USED ON
APPLICATION

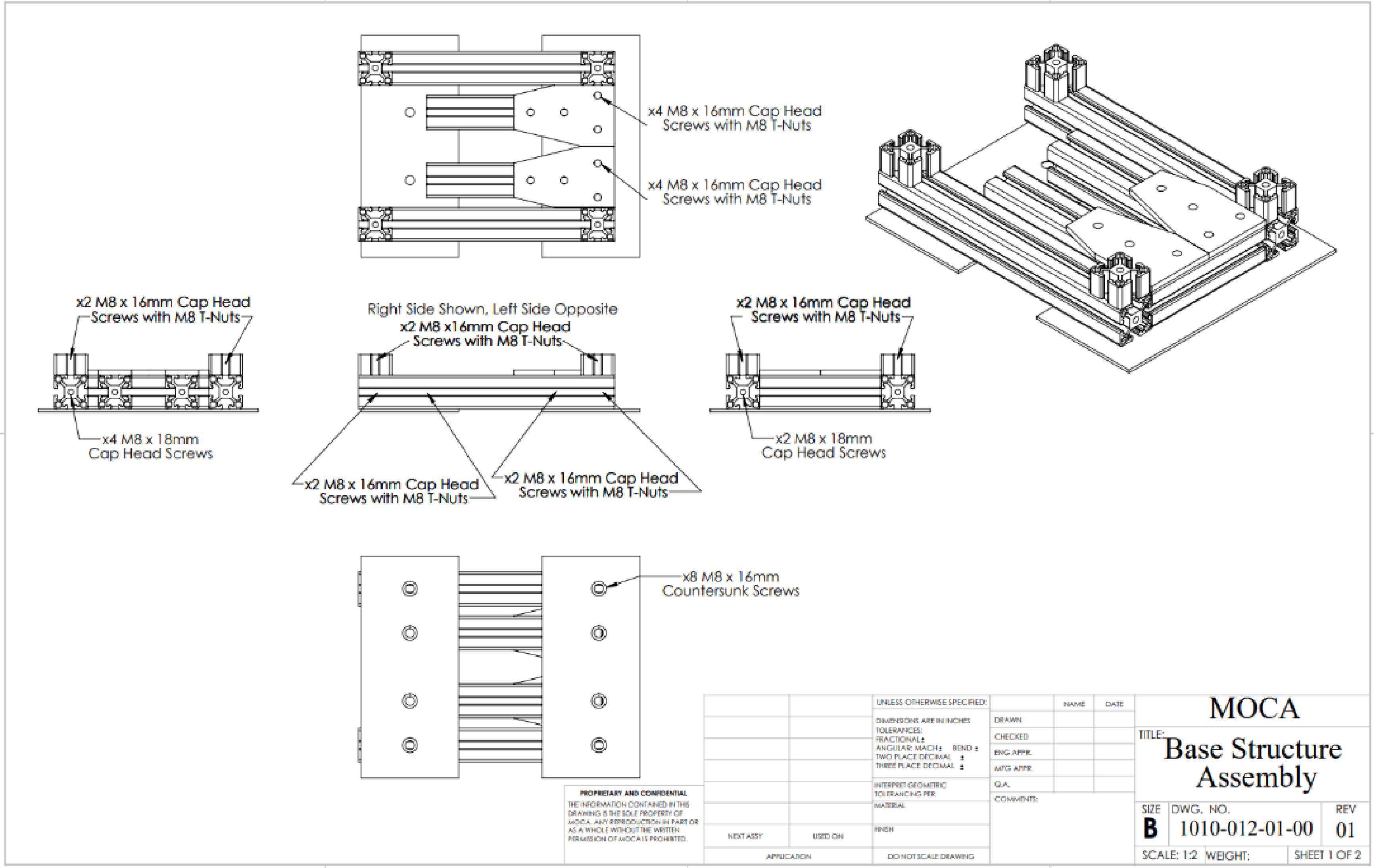
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

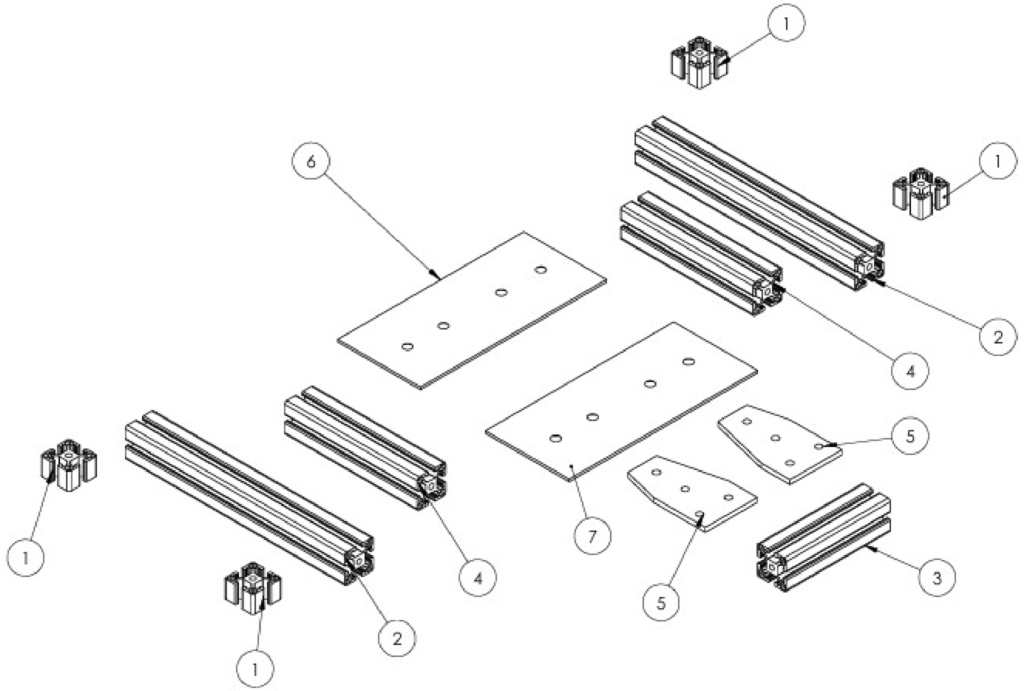
MOCA
TITLE: MOCA Master Assembly
SIZE B | DWG. NO. 1005-012-00-00 | REV 01
SCALE: 1:4 | WEIGHT: | SHEET 2 OF 2

Base Structure Assembly Drawing



Base Structure Assembly Exploded Drawing

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	2100-012-02-00	0.95in Extrusion	4
2	2100-012-03-00	12in Extrusion	2
3	2100-012-04-00	5.68in Extrusion	1
4	2100-012-05-00	7.23in Extrusion	2
5	2100-012-01-00	Trapezoid Plate	2
6	2100-012-06-00	Middle Base Plate	1
7	2100-012-07-00	Large End Base Plate	1
8	2732-012-02-00	M8 x 14mm T-slot General	8
9	2732-012-03-00	M8 x 14mm T-slot Countersunk	8



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NEXT ASSY | USED ON | APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	CK	1/29/2026
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

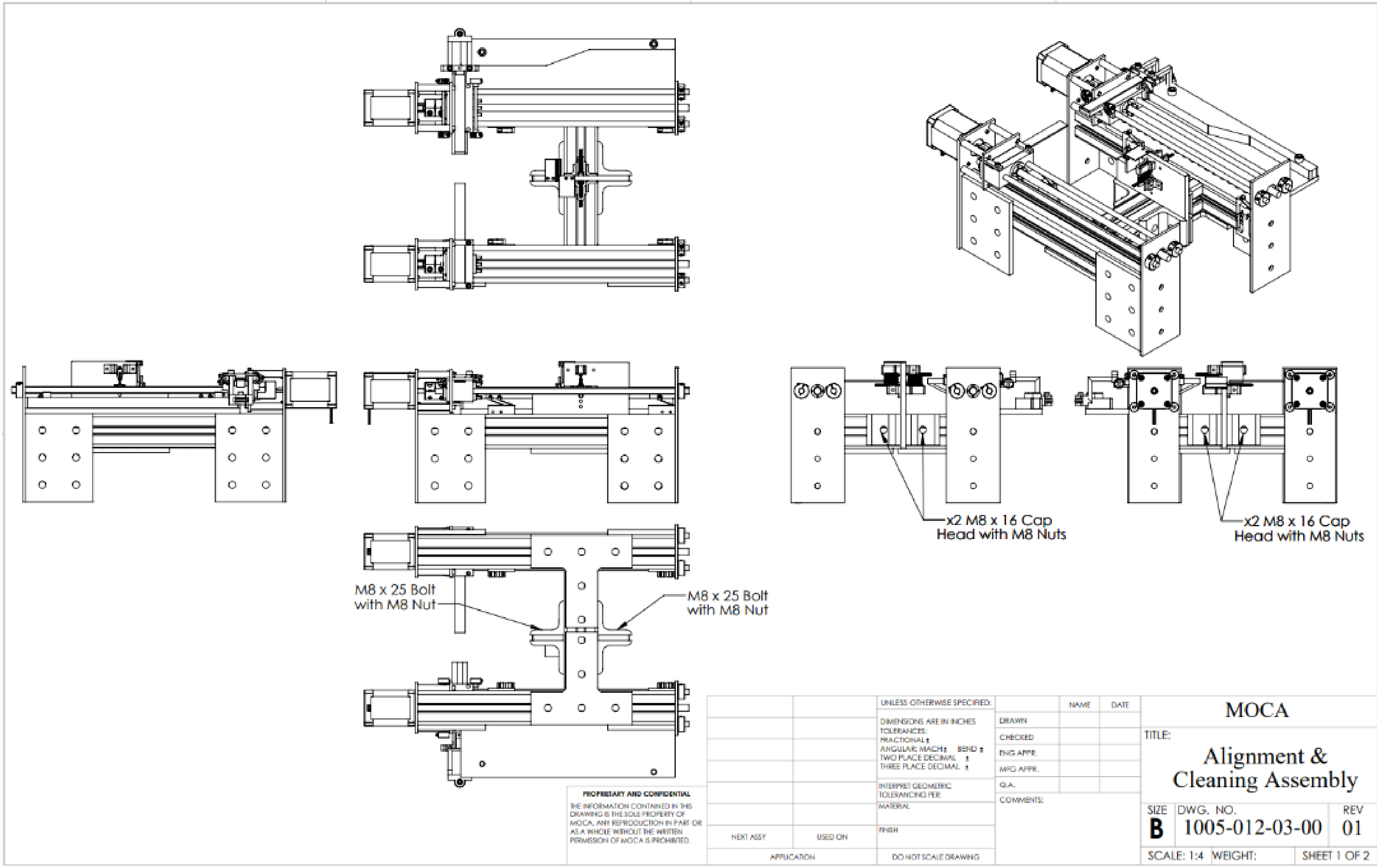
MOCA

TITLE: Base Structure Assembly- Exploded

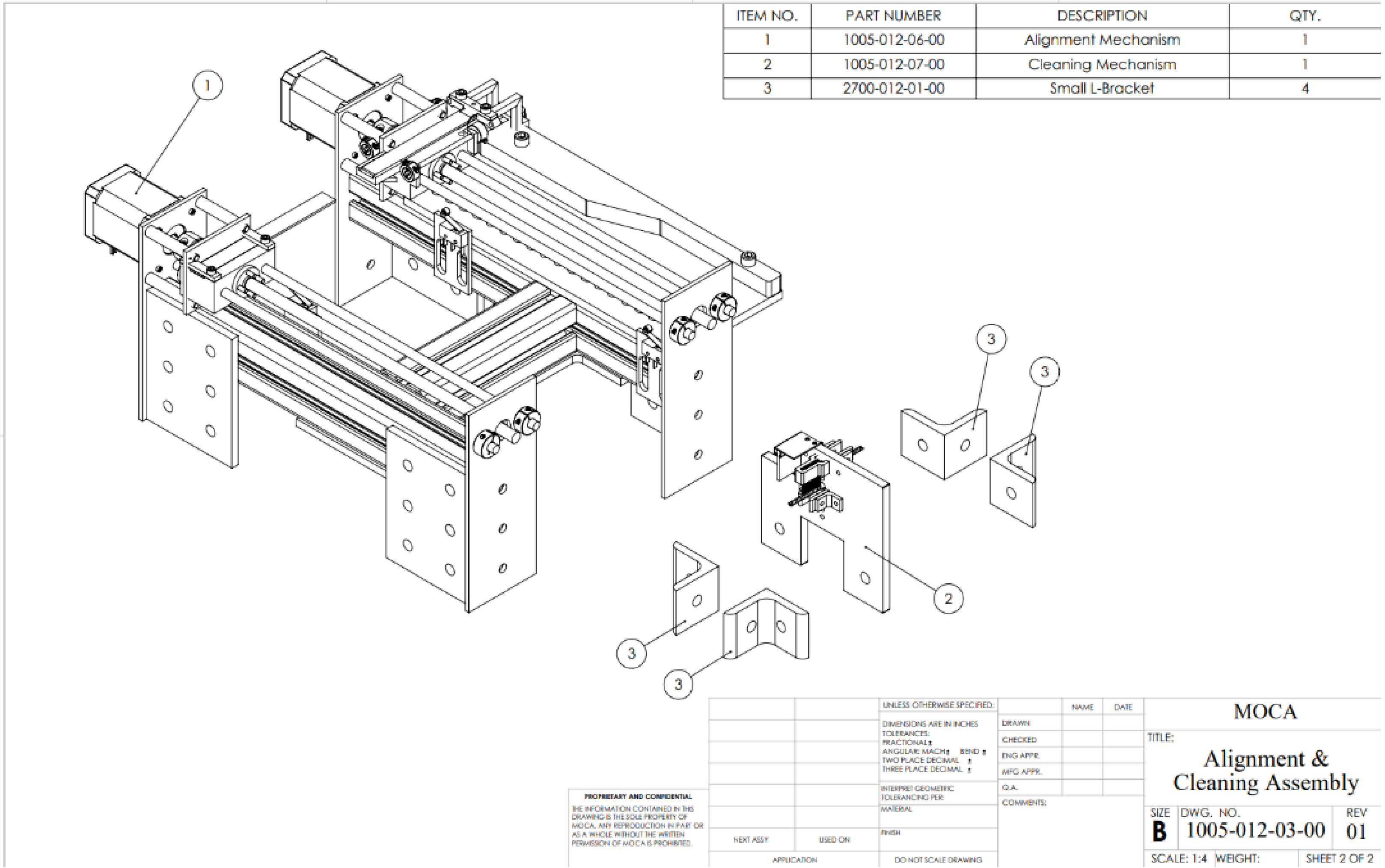
SIZE B | DWG. NO. 1010-012-01-01 | REV 0

SCALE: 1:4 | WEIGHT: | SHEET 2 OF 2

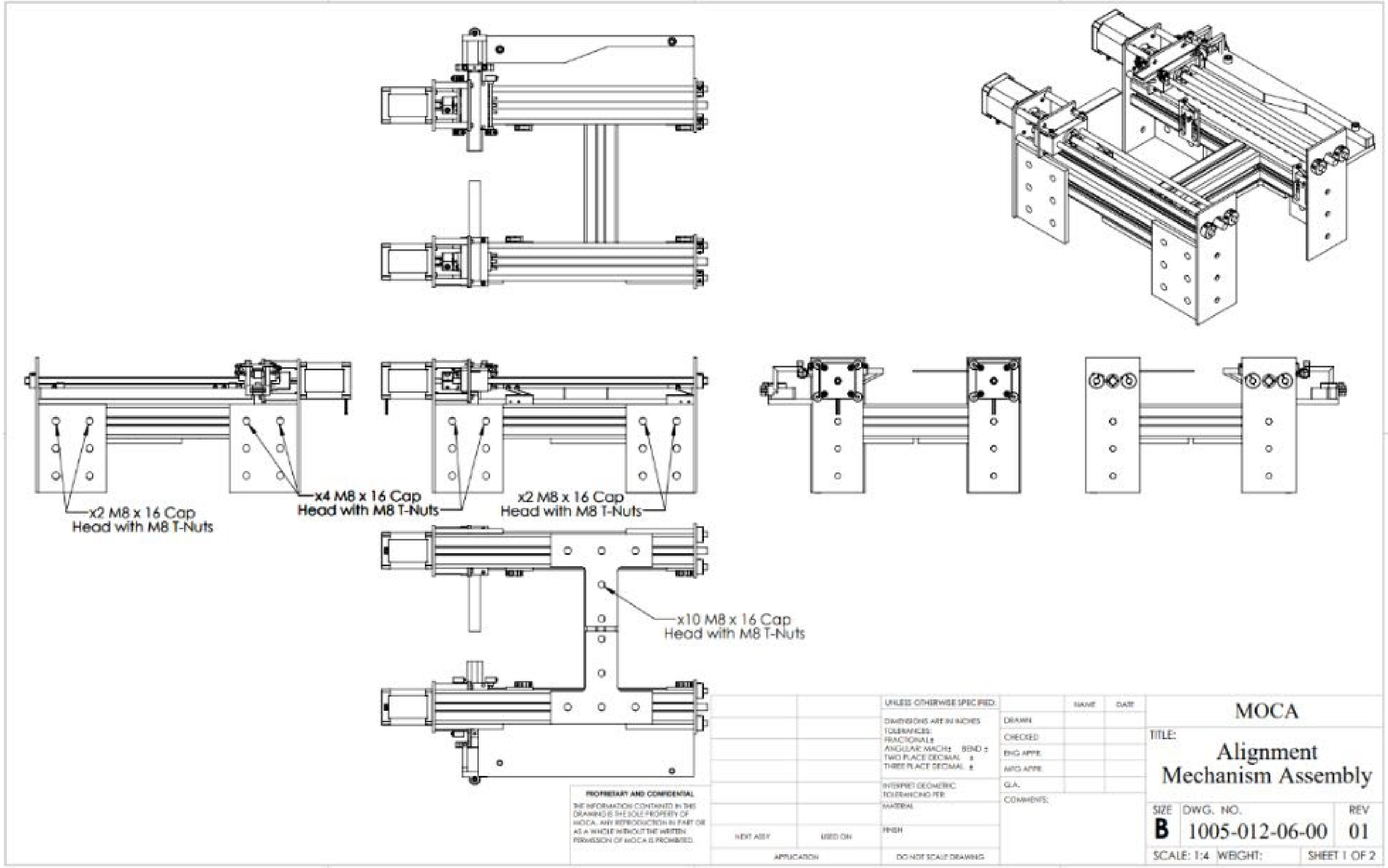
Cleaning & Alignment Assembly Drawing



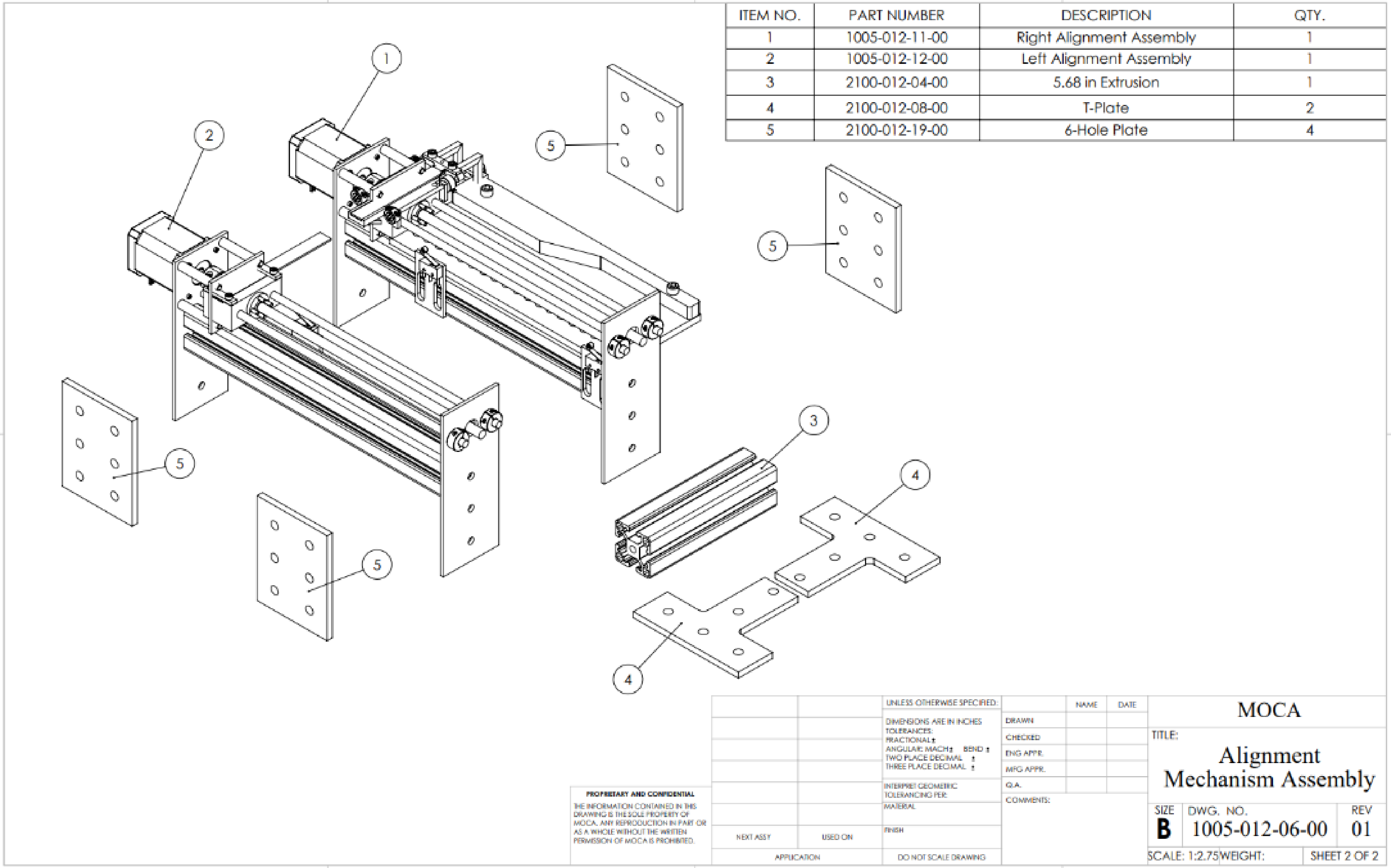
Cleaning & Alignment Assembly Exploded Drawing



Full Alignment Assembly Drawing

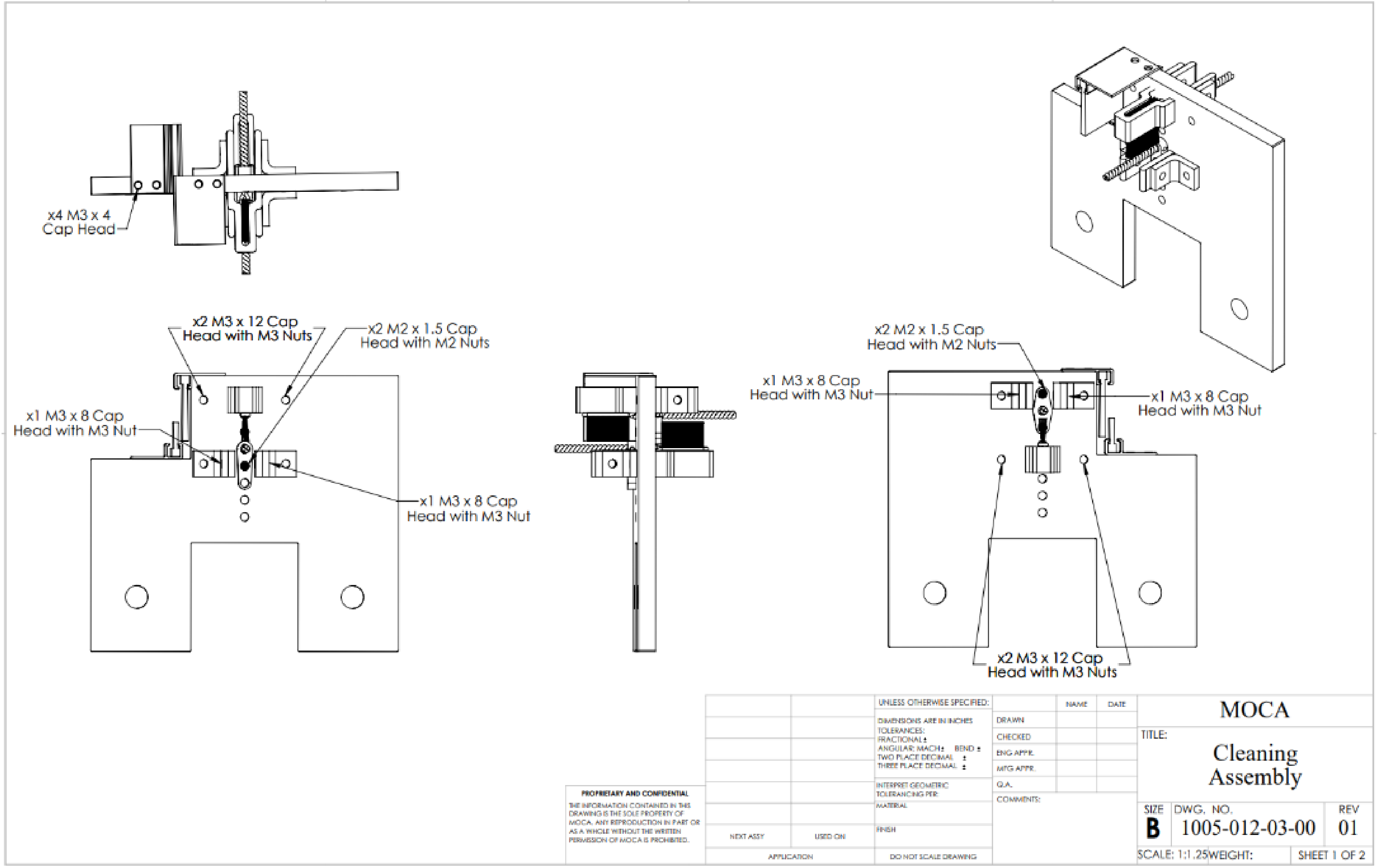


Full Alignment Assembly Exploded Drawing



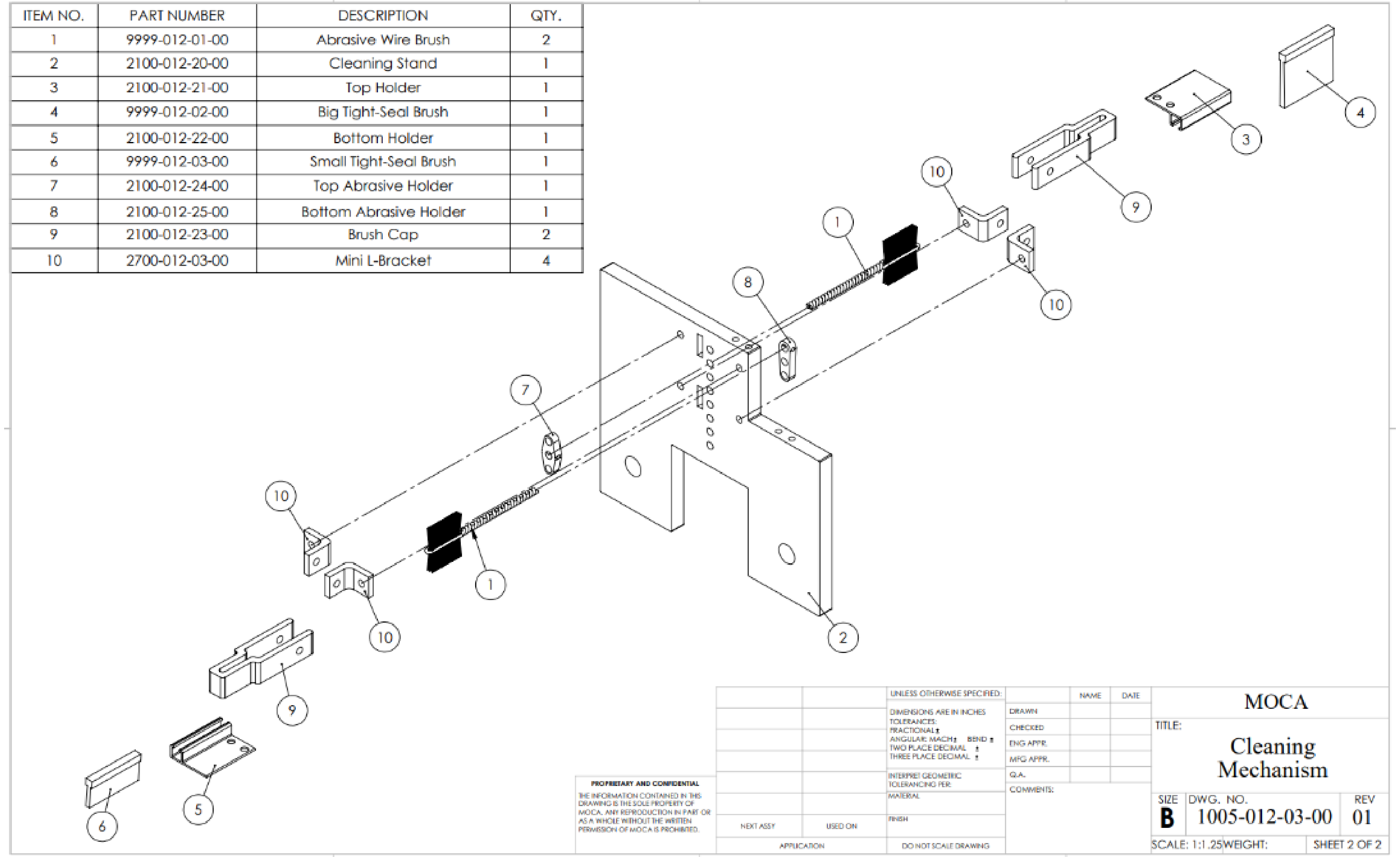
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1005-012-11-00	Right Alignment Assembly	1
2	1005-012-12-00	Left Alignment Assembly	1
3	2100-012-04-00	5.68 in Extrusion	1
4	2100-012-08-00	T-Plate	2
5	2100-012-19-00	6-Hole Plate	4

Cleaning Mechanism Assembly Drawing

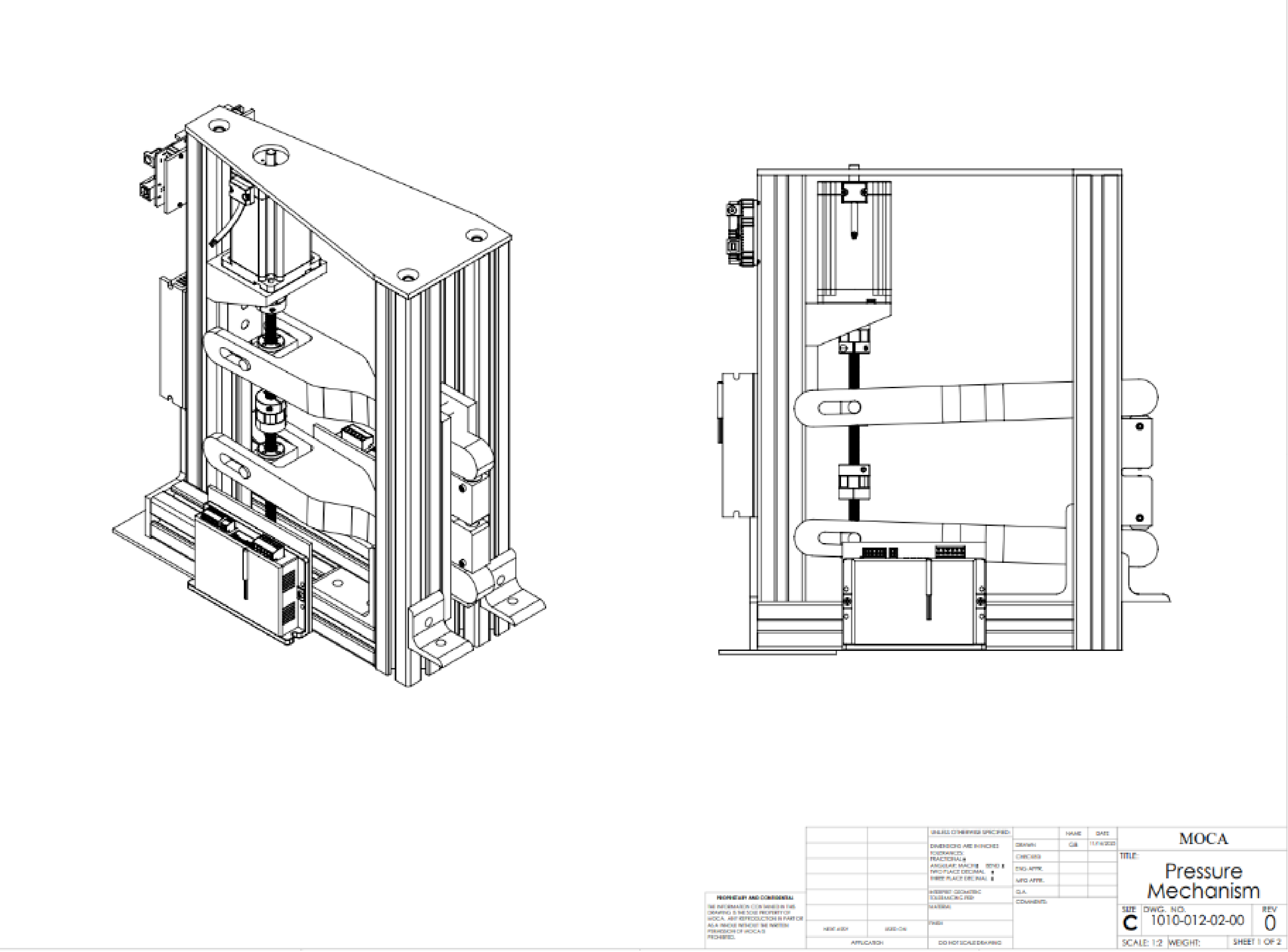


Cleaning Mechanism Assembly Exploded Drawing

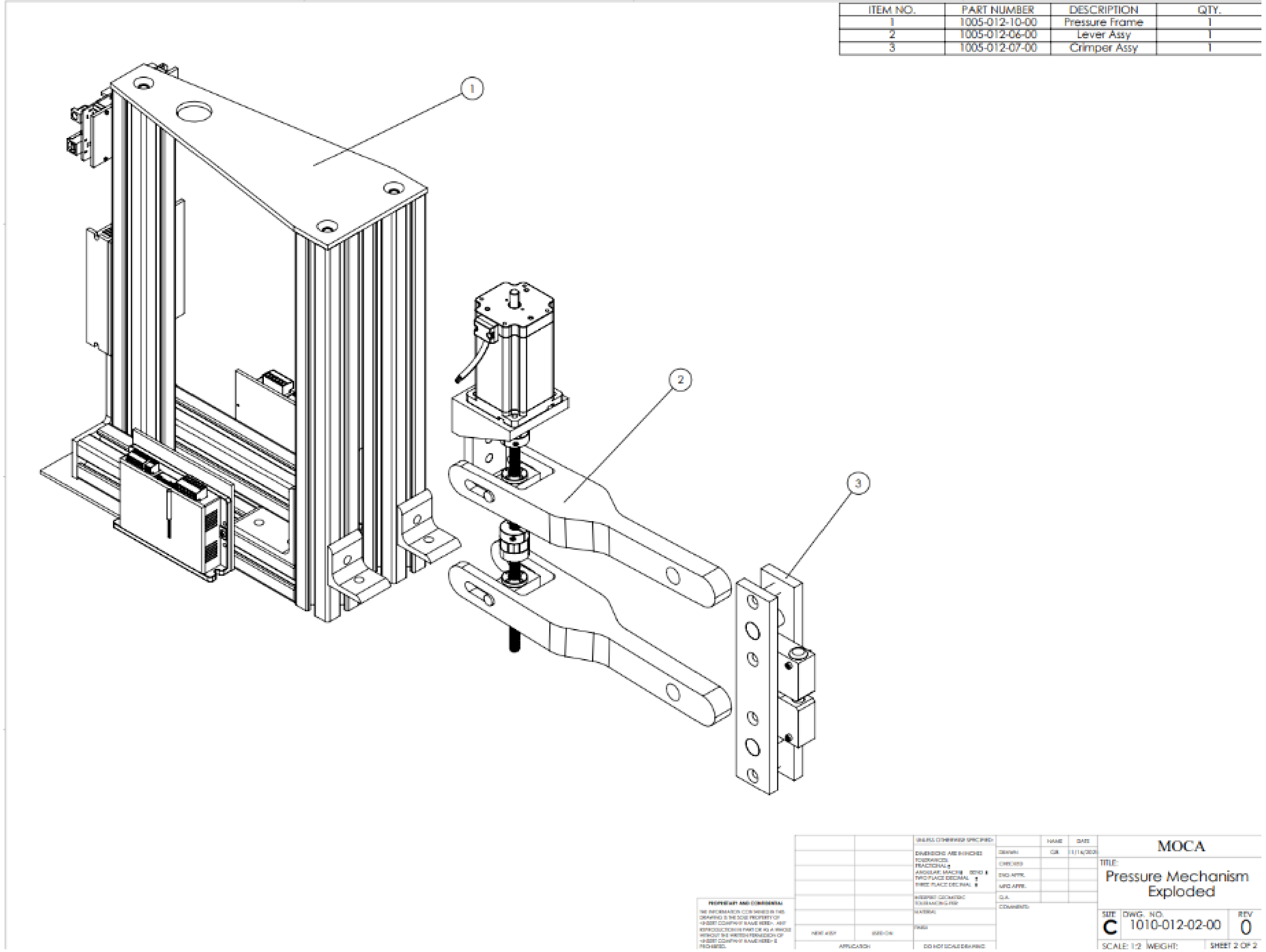
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	9999-012-01-00	Abrasive Wire Brush	2
2	2100-012-20-00	Cleaning Stand	1
3	2100-012-21-00	Top Holder	1
4	9999-012-02-00	Big Tight-Seal Brush	1
5	2100-012-22-00	Bottom Holder	1
6	9999-012-03-00	Small Tight-Seal Brush	1
7	2100-012-24-00	Top Abrasive Holder	1
8	2100-012-25-00	Bottom Abrasive Holder	1
9	2100-012-23-00	Brush Cap	2
10	2700-012-03-00	Mini L-Bracket	4



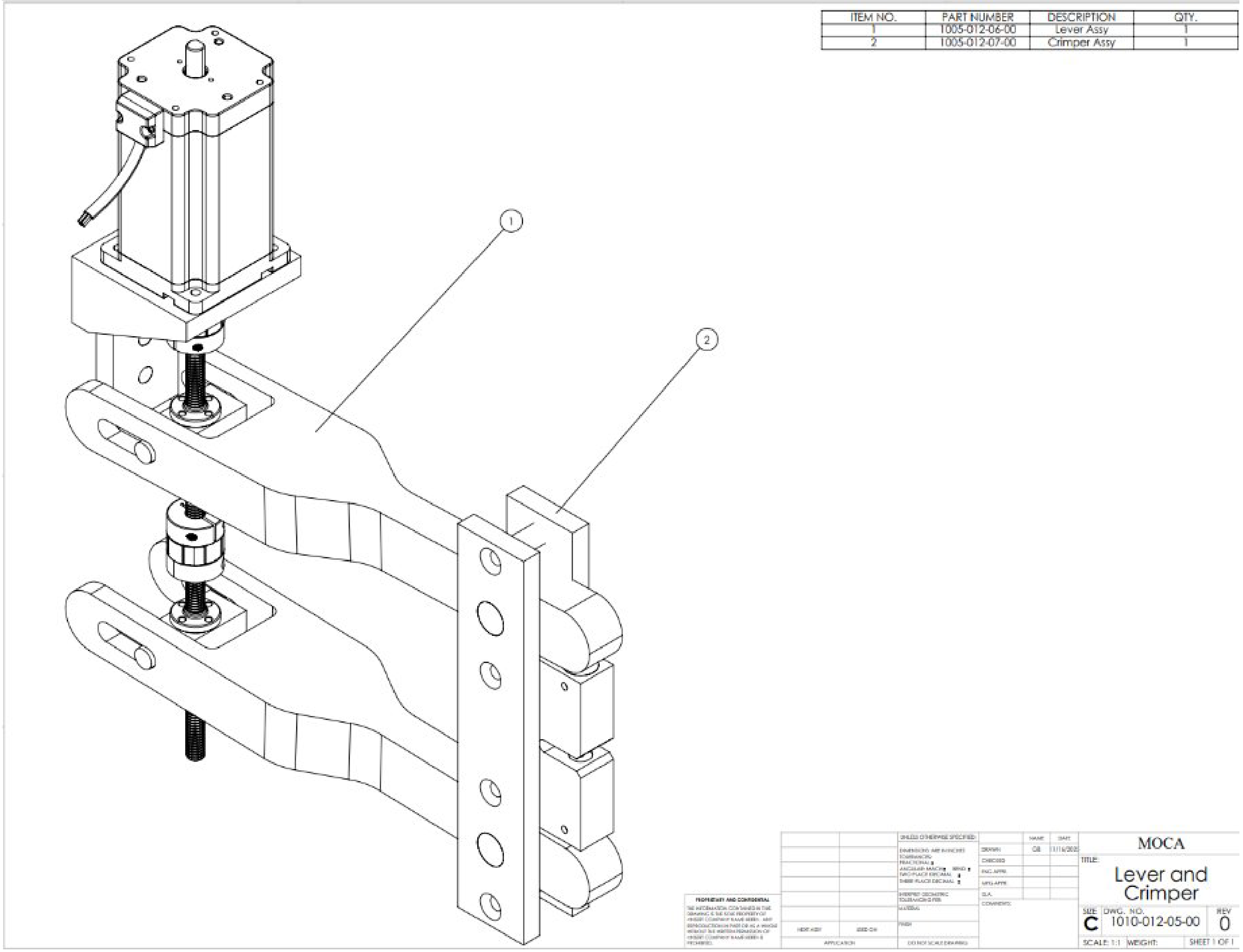
Pressure Mechanism Assembly Drawing



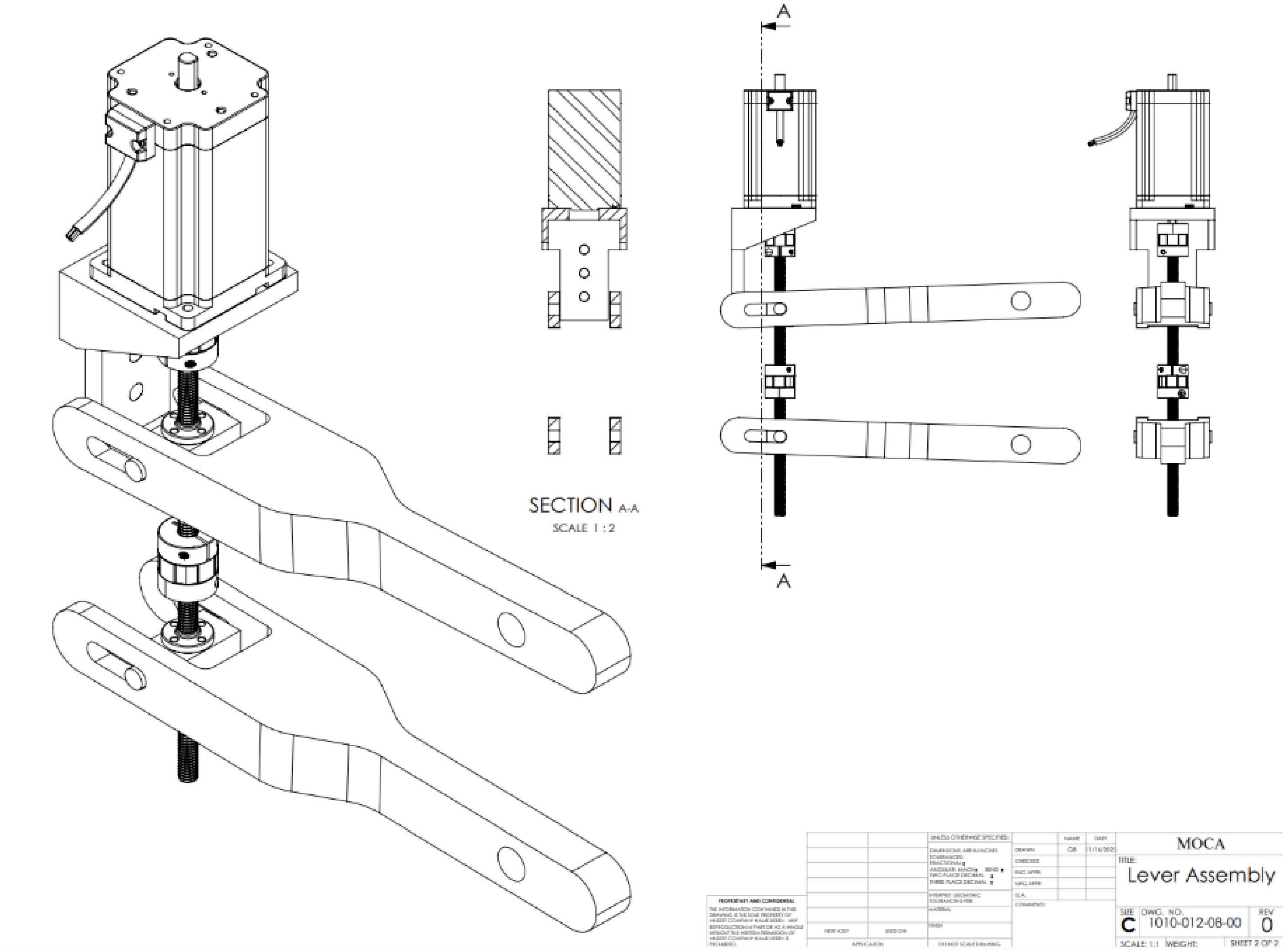
Pressure Mechanism Assembly Exploded Drawing



Lever & Crimper Assembly Drawing

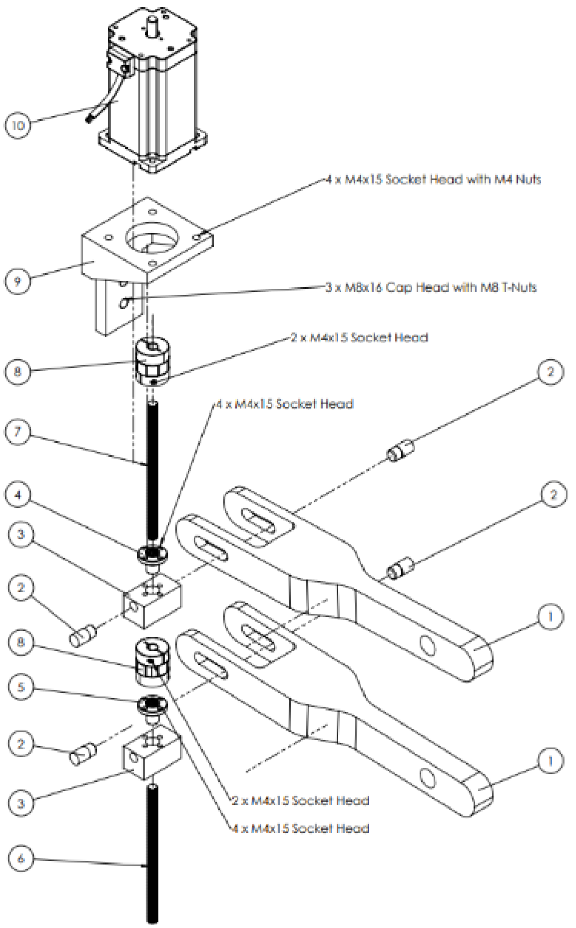


Lever Assembly Drawing



Lever Assembly Exploded Drawing

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	2164-012-01-00	Lever	2
2	2164-012-02-00	Lever Pin	4
3	2100-012-15-00	Nut Mount	2
4	2108-012-02-00	RH T8 Nut	1
5	2108-012-01-00	LH T8 Nut	1
6	2164-012-04-00	LH T8 Lead Screw	1
7	2164-012-03-00	RH T8 Lead Screw	1
8	2743-012-01-00	8mm-8mm Coupler	2
9	2764-012-01-00	Motor Holder	1
10	1925-012-01-00	NEMA 23 Motor	1



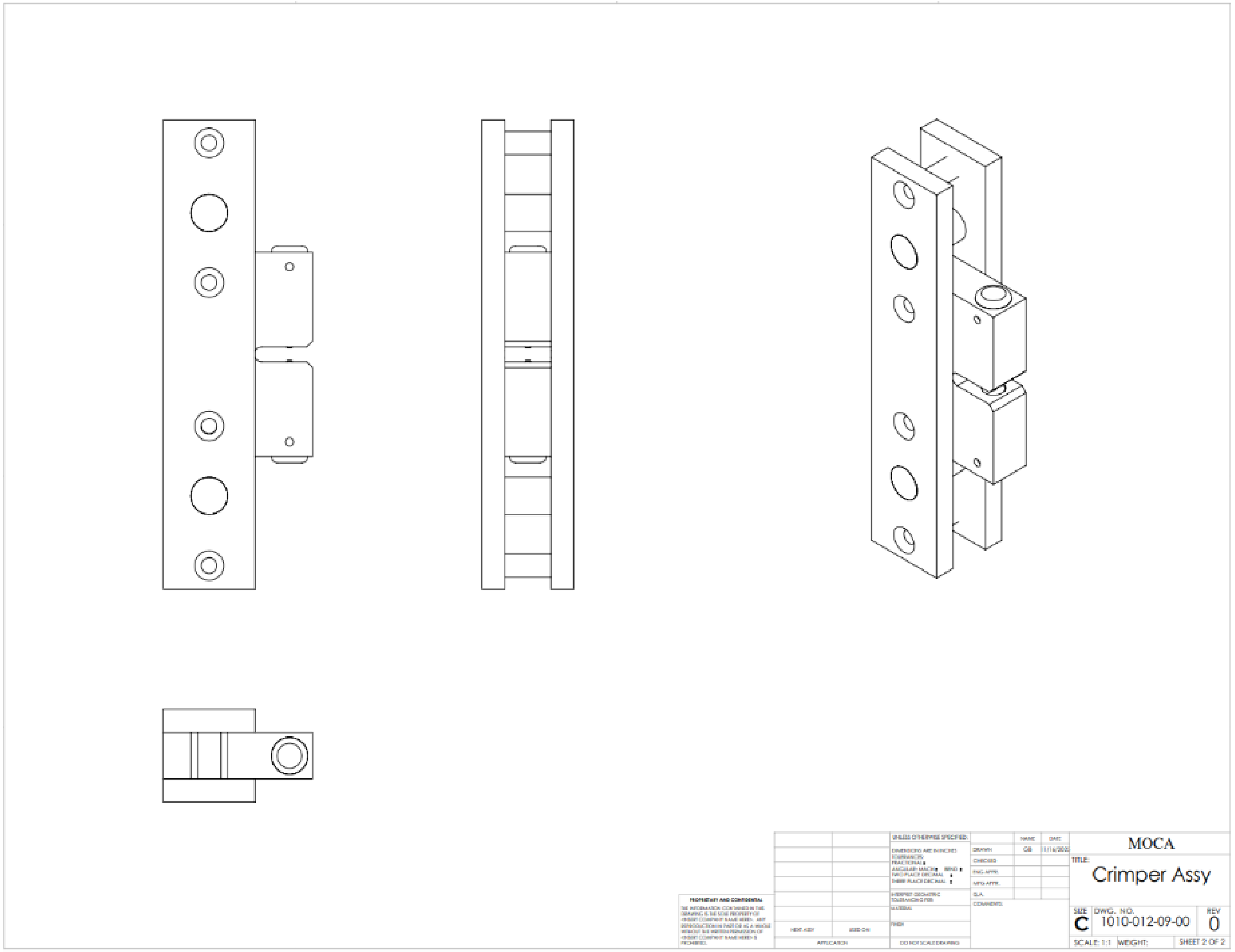
MOCA

TITLE: Lever Assembly Exploded

SIZE C | DWG. NO. 1010-012-08-00 | REV 0

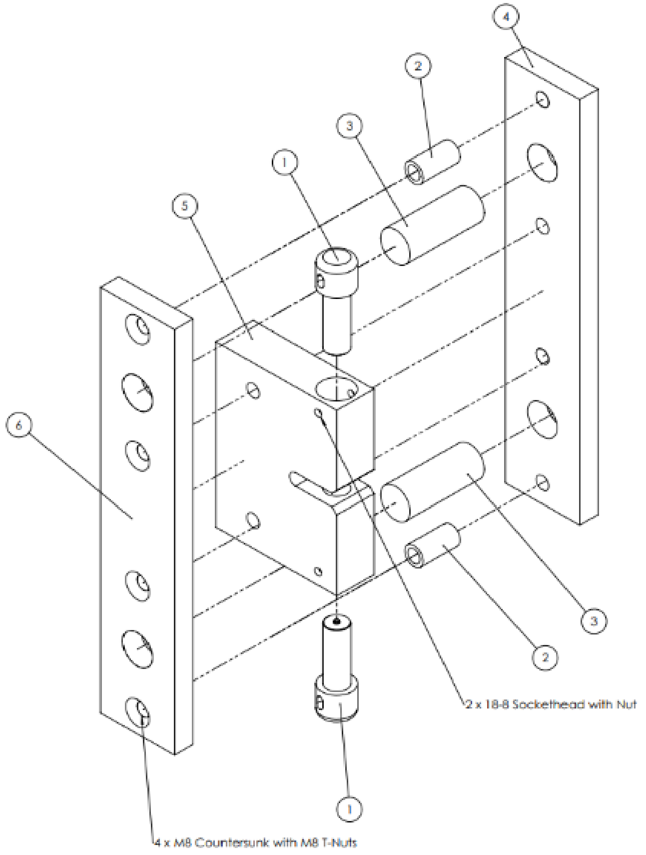
SCALE: 1:2 | WEIGHT: | SHEET 1 OF 2

Crimper Assembly Drawing



Crimper Assembly Exploded Drawing

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	2156-012-01-00	Crimp Pin	2
2	2772-012-01-00	Pivot Plate Spacer	2
3	2164-012-05-00	Forward Lever Pins	2
4	2100-012-18-00	Pivot Plate	1
5	2100-012-16-00	Crimper Frame	1
6	2100-012-17-00	Pivot Plate Countersunk	1



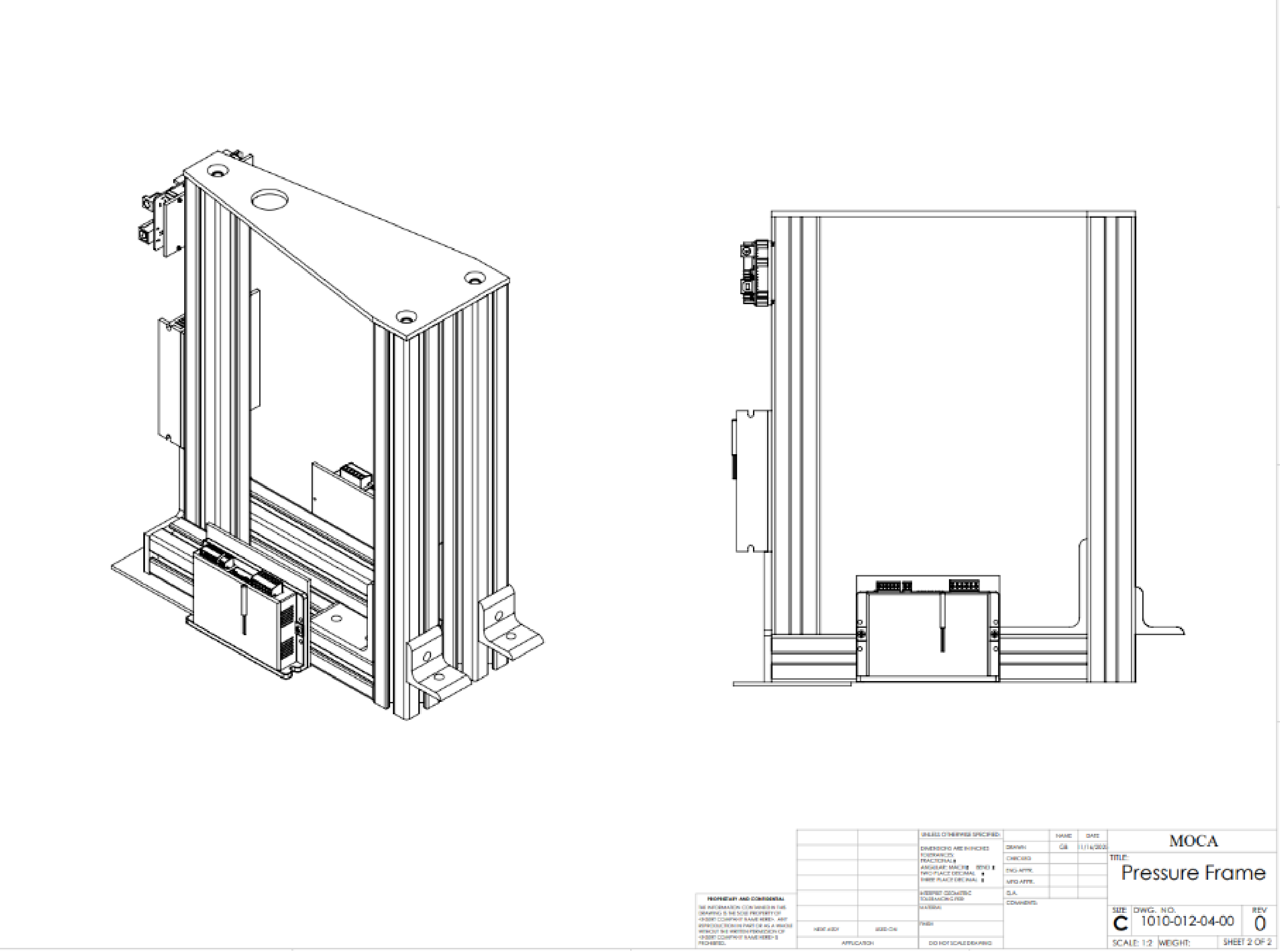
MOCA

TITLE: Crimper Assembly Exploded

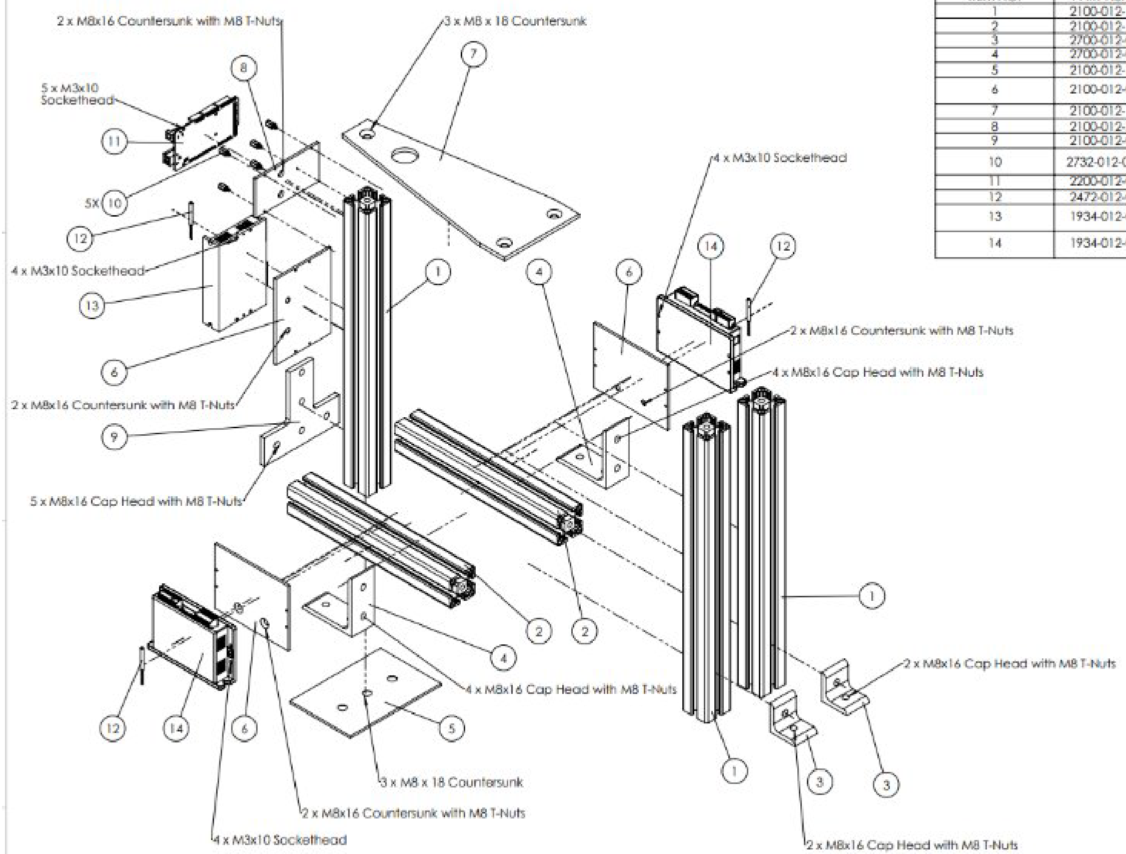
SIZE C DWG. NO. 1010-012-09-00 REV 0

SCALE: 1:1 WEIGHT: SHEET 1 OF 2

Pressure Frame Assembly Drawing



Pressure Frame Assembly Exploded Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	2100-012-13-00	15.36 in Extrusion	3
2	2100-012-14-00	10.25 in Extrusion	2
3	2700-012-01-00	Small L-Bracket	2
4	2700-012-02-00	Large L-Bracket	2
5	2100-012-11-00	Small Base Plate	1
6	2100-012-09-00	Stepper Driver Mount	3
7	2100-012-12-00	Top Plate	1
8	2100-012-33-00	Arduino Mount	1
9	2100-012-08-00	T-Plate	1
10	2732-012-026-00	Hex Male-Female Standoff	5
11	2200-012-01-00	Arduino Mega	1
12	2472-012-01-00	PT100 Sensor	3
13	1934-012-02-00	DM556T Stepper Driver	1
14	1934-012-01-00	DM542T Stepper Driver	2

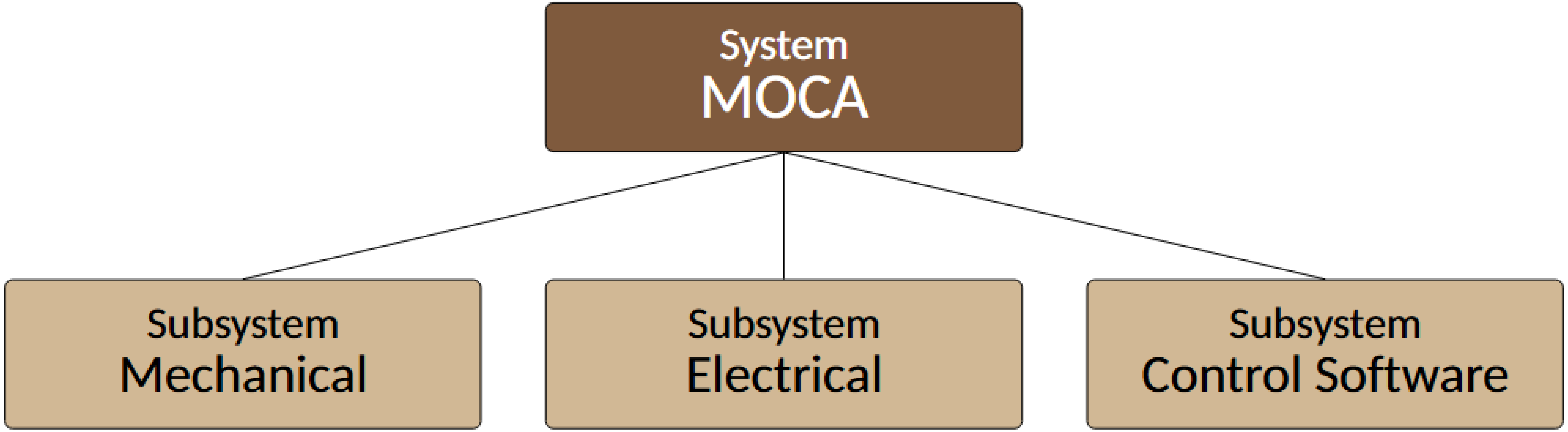
MOCA

TITLE: Pressure Frame Exploded

SIZE C DWG. NO. 1010-012-04-00 REV 0

SCALE: 1:2 WEIGHT: SHEET 1 OF 2

MOCA created three subsystem teams to address building the full system in one semester.



Pressure Mechanism Trade Study – Electromechanical Screw and Spring were selected.

Pressure Mechanism												
Criteria	Mass Limit		Sustained Power		Clamping Force		Complexity		Ability to operate in vaccuum			
Mechanism	Justification	Score	Justification	Score	Justification	Score	Justification	Score	Justification	Score	Total Score	Sensitivity Score
Pneumatic Piston	likely pump/compressor involved- unnecessarily heavy	1	likely continously very high for pump/compressor losses	1	compressibility of gas may reduce force	3	multiple parts that dont directly contribute to force application	2	Seals and pressurized fluid involved - not suited for vacuum	1	1.6	2.1
Hydraulic Piston	likely pump/compressor involved- unnecessarily heavy	1	likely continously very high for pump/compressor losses	1	very high forces possible	5	multiple parts that dont directly contribute to force application	1	Seals and pressurized fluid involved - not suited for vacuum	1	1.8	3
Electromechanical Ramp	Ramps would be solid pieces- heavy	2	same Motor - Power selectable and dependent on RPM	3	lower force possible without high currents because of motor stall	4	lubrication/roller system between ramps may be quite complex	3	No pressurized/outside pressure dependent components involved	5	3.5	3.5
Electromechanical Screw	lighter than ramps	3	same Motor - Power selectable and dependent on RPM	3	lower force possible without high currents because of motor stall	4	few parts, no novel interfaces	4	No pressurized/outside pressure dependent components involved	5	3.8	3.8
Electromechanical Spring	spring can remain light while soring more energy	4	same Motor - Power selectable and dependent on RPM	3	lower force possible without high currents because of motor stall	4	few parts, no novel interfaces, but spring is addtional complication	3	No pressurized/outside pressure dependent components involved	5	3.7	3.9
Electromechanical Cam	very few components involved	4	liekly higher Torque needed	2	backdriving more prominent	3	very simple, just cam-follower system	5	No pressurized/outside pressure dependent components involved	5	3.6	3.5

Cleaning Mechanism Trade Study – Scraping was selected.

Cleaning Mechanism										
Criteria	Complexity		Cleanliness		Cost of Main Component		Heritage			
Mechanism	40%	Score	30%	Score	20%	Score	10%	Score	Total Score	Sensitivity Score
Pizeo - Electric	Low	5	Fairly Well	4	$500	1	High	5	3.9	3.6
Belt Sander	Low	5	Fairly Well	4	$99.95	4	None	2	4.2	3.9
Chemical Cleaning	Very High	1	Very Well	4	$61.85	4	Slightly	2	2.6	3.1
Scraping	Moderate	3	Fairly Well	3	$14.96	5	Not in Space	2	3.3	3.35
Stretching	High	2	Moderate	3	>$100	3	None	1	2.4	2.5
Peening	High	2	Fairly Well	4	>$ 250	2	Not in Space	2	2.6	2.8
Laser Cleaning	High	1	Very Well	5	$30,000	1	Not in Space	2	2.3	2.75
Plasma Cleaning	High	2	Fairly Well	4	$6,000	1	Not in Space	2	2.4	2.55

Alignment Mechanism Trade Study – Linear Rail was selected.

Allignment Mechanism										
Criteria	Complexity		Power		Size		Mass			
Mechanism	30%	Score	20%	Score	30%	Score	10%	Score	Total Score	Sensitivity Score
Robotic Arms	Very High	1	Very High	1	Very Large	2	Very Large	1	1.2	1.35
Hinge Mechanism	Very High	1	Very Low	5	Very Small	5	Very Small	5	3.3	4
Roller Tracks	Very Low	4	Very Low	5	Fairly Small	3	Fairly Small	3	3.4	3.65
Magnetism	Very Low	4	Fairly High	2	Very Small	5	Fairly Small	3	3.4	3.75
Linear Rail	Very Low	5	Low	4	Fairly Small	4	Fairly Small	3	3.8	4.05

Material Trade Study – Aluminum 3003 was selected to cold-weld in space.

Material												
Criteria	**Space applications**		**Hardness**		**Cost 12x12x0.063 in Grainger**		**Formability (ductility)**		**Availability**			
Material	**Commonality**	**Score**	**Brinell Rating**	**Score**		**Score**		**Score**		**Score**	**Total Score**	**Sensitivity Score**
Aluminum 3003	Very common in aerospace	5	40 BHN	5	11.77	5	Cold Workable	5	Delivered weekly by Coast Aluminum	3	**3.1**	**3.4**
Aluminum 6061 T6	Common in aerospace	4	150 BHN	1	10.54	5	Fractures when Cold Working	5	AXFAB stocked	5	2.2	3.4
Aluminum 6061 O	Common in aircraft	3	30 BHN	5	12.95	5	Cold Workable	5	Delivered weekly by Coast Aluminum	3	2.9	3
Aluminum 1100 H14	Common in aircraft	3	32 BHN	5	16.55	4	Soft, Formable	4	Delivered weekly by Coast Aluminum	3	2.8	2.8
Aluminum 5052 H32	Very common in aerospace	5	60 BHN	4	9.43	5	Formable	5	Delivered weekly by Coast Aluminum	3	2.8	3.3
Indium	Uncommon (Common in Electrical Components), Not used strucutrally	2	0.9	1	1000	1	Very soft	1	<1 Month	3	1.2	1.6
304L Stainless	304L used in Starhip tank structure, but not very common	2	<= 201 BHN	1	142.48	1	Excellent Formability	1	<1 Month	3	1.2	1.6
Cast Iron	Not Common	1	226 BHN	1	66.91	2	Hard, Not Formable	2	Within a Week	3	1.2	1.6
Magnesium AZ31b	Common in Aircraft	3	46 BHN	5	212.12	1	Formable at 260°C	1	<1 month*	3	2.5	2.2
Titanium Grade 2	Common in Aerospace	4	70BHN	4	111.3	1	Formable	1	<1 month	3	2.3	2.3

Joint Type Trade Study – Lap Joints were selected.

Joint Type										
Criteria	Extra Processing		Multiple Shapes		Plastic Deformation of Material		Complexity			
Joint Type		Score		Score		Score		Score	Total Score	Sensitivity Score
Butt	yes- extra material from the plastic deformation builds up on the outside of the weld location and must be removed	1	yes, multiple shapes able to be welded together	5	moderate, with material loss to outside of joint untile weld forms	3	lots of manuvering, lots of space	1	2.2	2.6
lap	no, plastic deformation from the weld results in smaller cross section	5	not really, mostly only wire and sheets	1	moderate, moderate material loss in overlap and cleaning	3	moderate movment, may need multiple pressure points	3	3	3

Data Transmission Trade Study – Laptop Transmission of Commands was selected.

Data Transmission												
Criteria	Complexity		Cost		Safety		Commands		Compatability with the Vaccum Chamber			
Solution	No. of Parts	Score	Cost	Score	Safety	Score	Degree of Autonomy	Score	Compatibility	Score	Total Score	Sensitivity Score
Laptop-Transmission of commands to System	Requires few additional parts	5	<20$	5	Low Risk, High Mitigation	5	Semi autonomous	3	Makes full use of vacuum chamber interfaces	5	4.8	4.8
Custom Controller - direct Control of System	Requires some additional parts	3	>= 300$	1	Low Risk, High Mitigation	5	Direct Control	1	Makes full use of vacuum chamber interfaces	5	3.6	3.6
Laptop- Interfacing Controller-Communication with Slave Controller in System	Requires some additional parts	3	>=$20	4	Low Risk, High Mitigation	5	Semi autonomous	3	Makes full use of vacuum chamber interfaces	5	4.1	4.4
Preplanned program, runs fully autonomously	Requires few additional parts	5	<20$	5	High Risk, Low Mitigation	1	Autonomous	5	Makes full use of vacuum chamber interfaces	5	3.8	3.8

Testing Methods Trade Study – Vacuum, Compressive, Visual, Tensile, and Bending Tests were selected.

Testing Methods												
Criteria	Availability		Set-Up Complexity		Load Capability		Destructiveness		Structual Integrity Analysis			
Mechanism	0.15	Score	0.1	Score	0.3	Score	0.5	Score	0.2	Score	Total Score	Sensitivity Score
Bending	On Campus	5	Moderately Simple	4	1000	5	Y	1	Necessary	5	4.15	4.1
Tensile	On Campus	5	Moderately Simple	4	1000	5	Y	1	Necessary	5	4.15	4.1
Visual Inspection	On Campus	5	Moderately Simple	4	DNA	5	N	5	Necessary	5	6.15	4.3
Compressive	On Campus	5	Moderately Simple	4	1000	5	Y	1	Necessary	5	4.15	4.1
X-Ray	Not On Campus	1	Medium Complexity	3	<1000	1	N	5	Not Necessary	1	3.45	1.5
Torsion	Not On Campus	1	Medium Complexity	3	<1000	1	Y	1	Not Necessary	1	1.45	1.3
Vacuum	On Campus	5	Moderately Simple	4	DNA	5	N	5	Necessary	5	6.15	4.3

Weld Quality Trade Study – Inspection was selected.

Weld Quality										
Criteria	Cost		Complexity		Accuracy		Destructiveness			
Mechanism	0.15	Score	0.15	Score	0.4	Score	0.3	Score	Total Score	Sensitivity Score
Macro Etch	On Campus ($0)	5	Simple	5	Highly Accurate	5	Destructive	1	3.8	3.6
Dye Penetrant	125	2	Simple	5	Generally Highly Accurate	4	NDT	5	4.15	4.05
Inspection	On Campus ($0)	5	Simple	5	Accurate	3	NDT	5	4.2	4.6
Nick	On Campus ($0)	5	Moderately Simple	4	Accurate	3	Destructive	5	4.05	4.4
Eddy Current	Need Lab	1	Moderately Complex	2	Generally Highly Accurate	4	NDT	5	3.55	3.2
Magnetic Particle	Need Lab	1	Complex	1	Generally Highly Accurate	4	NDT	5	3.4	3
Radiographic	Need Lab	1	Complex	1	Highly Accurate	5	NDT	1	2.6	1.8

Size and Shape of Members Trade Study – 1/16'' or 1/8'' Thickness was selected.

Shape Size								
Criteria	Complexity		Ease of Welding		Ease of Manipulation			
Mechanism	0.3	Score	0.2	Score	0.3	Score	Total Score	Sensitivity Score
Flat Sheet Rect 1/16" thick	Low Comlexity	4	Very Easy	5	Very Easy	5	4.7	4.65
Flat Sheet Rect 1/8" thick	Very Low Complexity	5	Easy	4	Very Easy	5	4.6	4.8
Wire 1/16" diameter	High Complexity	2	Difficult	2	Medium	3	2.3	2.45
Wire 1/8" diameter	High Complexity	2	Very Difficult	1	Difficult	2	1.6	1.8

Frame Material Trade Study – Aluminum 6061 T6 was selected.

Frame Material															
Criteria	Application in Space		Density		Cost Per Welded Sample		Availability Lead Time		Tesnile Strength, Yield		Thermal Conductivity		Scoring	
Material	5%	Score	10%	Score	40%	Score	30%	Score	15%	Score	15%	Score	Total Score	Sensitivity Score
Aluminum 6061T6	Common in aerospace	4	0.0975 lb/in^3	5	10.54	5	AXFAB Stocked	5	276 MPa	3	276 MPa	3	4.65	4.65
Aluminum 5052	Very common in aerospace	5	0.0968 lb/in^3	5	9.43	5	Delivered weekly by Coast Aluminum	3	193 Mpa	1	193 Mpa	1	3.8	3.6
304 Steel	304L used in Starhip tank structure, but not very common elsewhere	2	0.289 lb/in^3	1	142.48	1	<1 Month	3	215 Mpa	3	215 Mpa	3	1.95	2.15
Titanium	Common in aerospace	4	0.16 lb/in^3	3	111.3	1	<1 month	3	880 Mpa	5	880 Mpa	5	2.55	2.95

Material Handling Actuators Trade Study – NEMA 17 was selected.

Actuators for Material Handling										
	Integration Complexity		Vacuum Compatibility		Cost (including driver)		Availability		Total Score	Sensitivity Results
NEMA 17	Driver	4	paint and grease removal	3	$10-$30	4	Leftovers and in-stock	5	3.7	4.5
Brushless DC	Driver&sensor	3	bearing grease removal	4	$50-$100	2	Leftovers and in-stock	5	3.4	3.8
Brushed DC	Driver&sensor	3	commutator cold weld	1	$10-$30	4	In-stock	4	2.5	3.5
Servo	PWM	2	grease and plastic	2	$10-$30	4	In-stock	4	2.6	3.4

Actuator Interface Trade Study – Screw was chosen.

Actuator Interface						
	Integration Complexity		Vacuum Compatibility		Additional Parts	
Belt	Med	3	Incomp	1	Some	3
Chain	Med	3	Vac	5	Some	3
Screw	Low	5	Vac	5	Few	4
Bevel Gear	High	1	Vac	5	Lots	1

Power Supply Trade Study – Lab Power Supply was selected.

Power Supply								
Criteria	Cost		Voltage Range		Maximum Wattage			
Supply	Price	Score	Range	Score	Power	Score	Total	Sensitivity
Benchtop Power Supply	$223.38	2	1-36V	5	108W	1	2.3	2.6
Current-Limiting AC to Adjustable DC Transformer	$298.74	1	0-36V	5	126W	1	1.9	2.4
Lab Power Supply	On Campus	5	0-30V	5	360W	4	3.5	4.55

Temperature Sensor Trade Study – Pt100 Sensor was selected.

Temperature Sensor								
Criteria	Cost		Accuracy		Temperature Range			
Sensor	Justification	Score	Justification	Score	Justification	Score	Score	Sensitivity Score
Pt100	$12	3	0.5K	5	-50 to 280 C	3	3.6	3.8
Type T Thermocouple	$90	1	1K	3	-70 to 400C	5	2.4	3
Type K Thermocouple	$10	3	2.2K	1	-73 to 482 C	5	2.8	2.8

Microcontroller Trade Study – Raspberry Pi Zero was selected.

Microcontroller										
Criteria	# GPIO pins		RAM		ports		cost			
Microcontroller		score		score		score		score	total score	sensitivity score
Raspbery Pi Zero	40	4	512MB	4	5	3	$10.00	5	4.1	4
Raspberry - Pi 5	40	4	2 ,4, 6, 8GB	5	10	5	$91.00^	1	3.7	3.9
Arduino Nano	14	2	32 KB	1	1	1	$25.70	4	2.1	1.9
Arduino Mega	54	5	256 KB	1	1	1	$49.90	2	3.2	2.4
ESP32	34	3	520 KB	2	0	1	$1.68	5	3	2.7
Commondore C64	9	1	128 MB	3	7	4	$299.99	1	1.7	2.2
Raspberry Pi 4	40	4	1,2,4,8 GB	5	9	5	$96.28*	1	3.7	3.9