DMT Seminar 2020/21

Biomechanical Rehab Device for Long COVID

Group-5C [Actuation Subassembly] :

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Project Overview

- Shoulder exoskeleton to assist patients with Long COVID symptoms

- Subsystems:
    - Actuation
    - Structural
    - Limb Support

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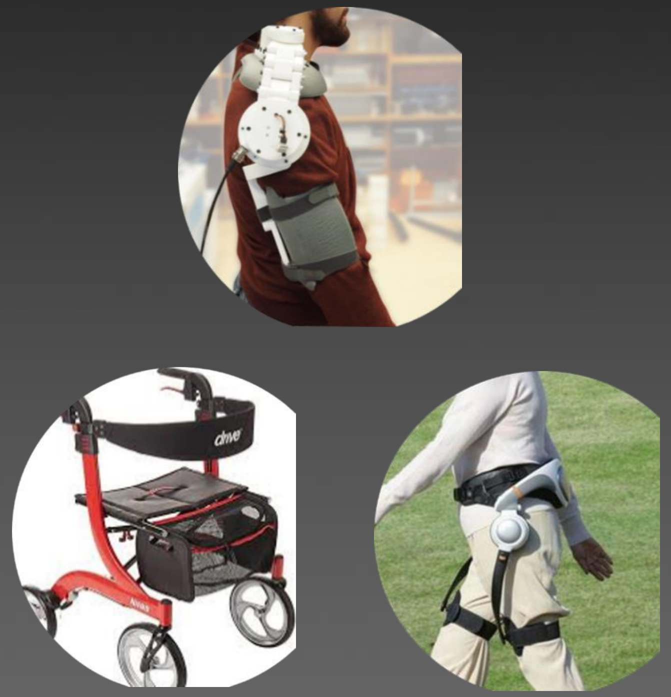
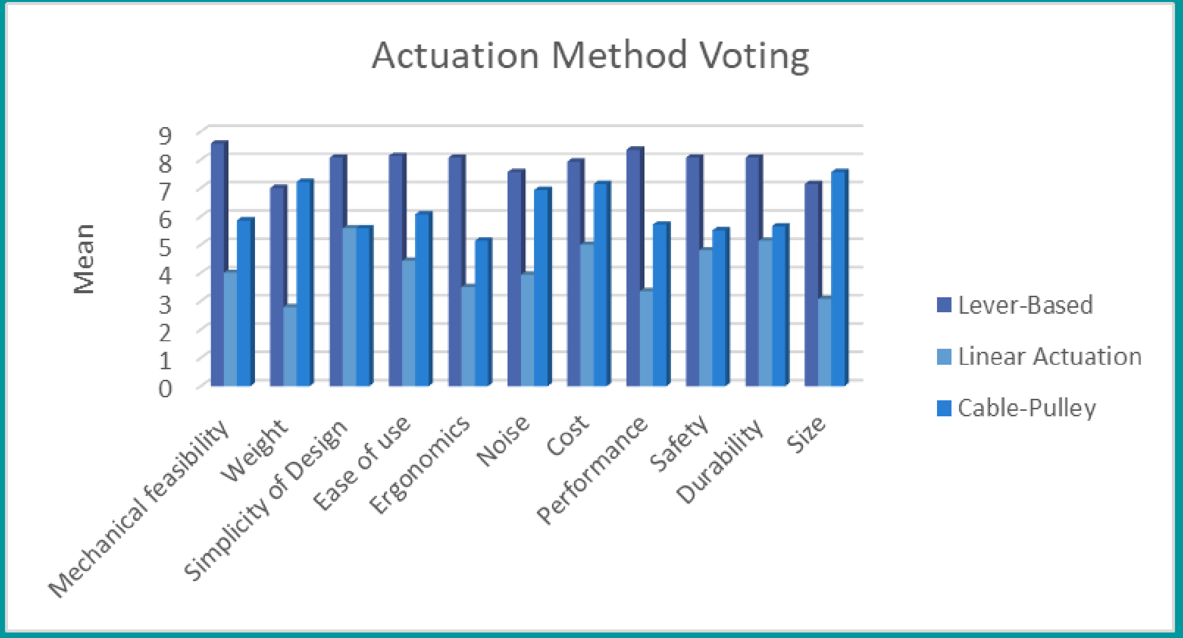
Ideation

1. Rehabilitation device



Assistive or resistive? Body part?

2. Assistive single shoulder exoskeleton.



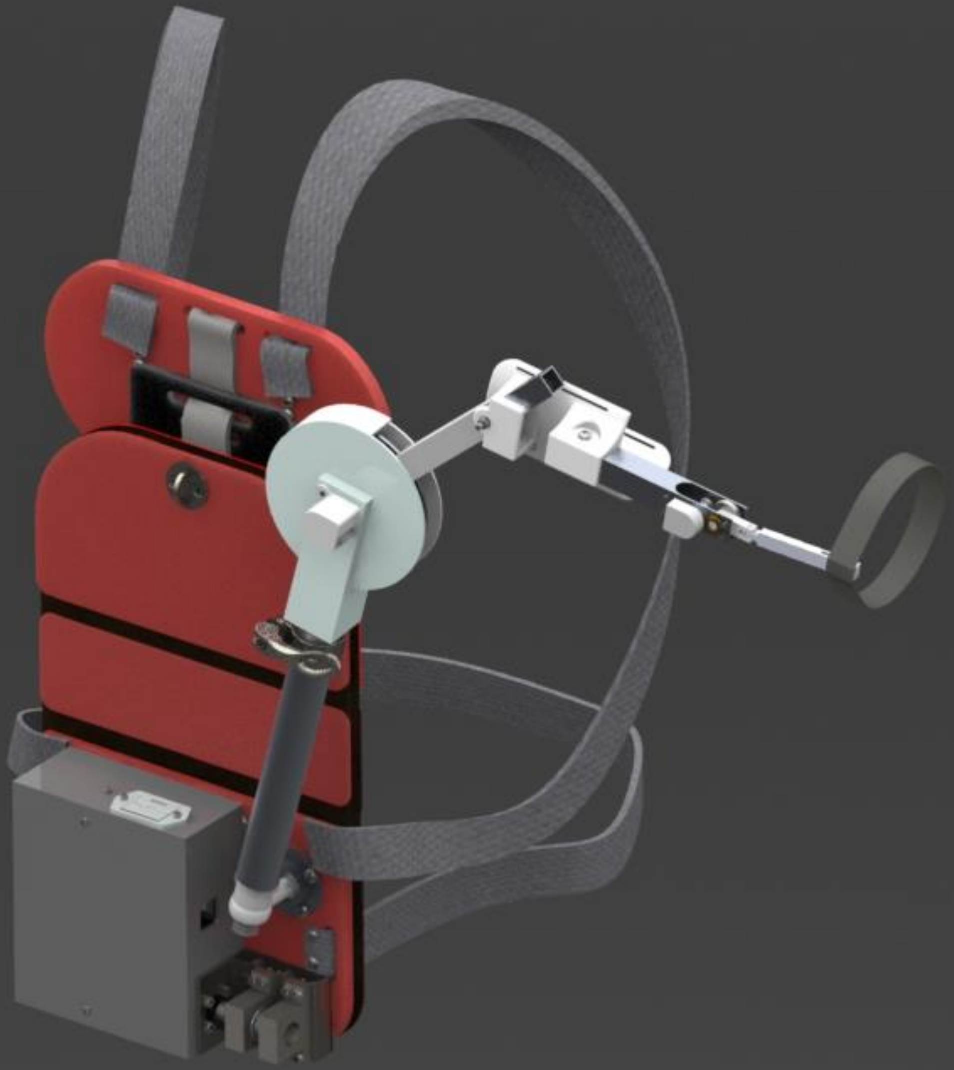
Linear actuators? Cable push? Cable pull?

3. Cable push.

Subassembly split: Structural support 05A, limb support 05B, Actuation 05C

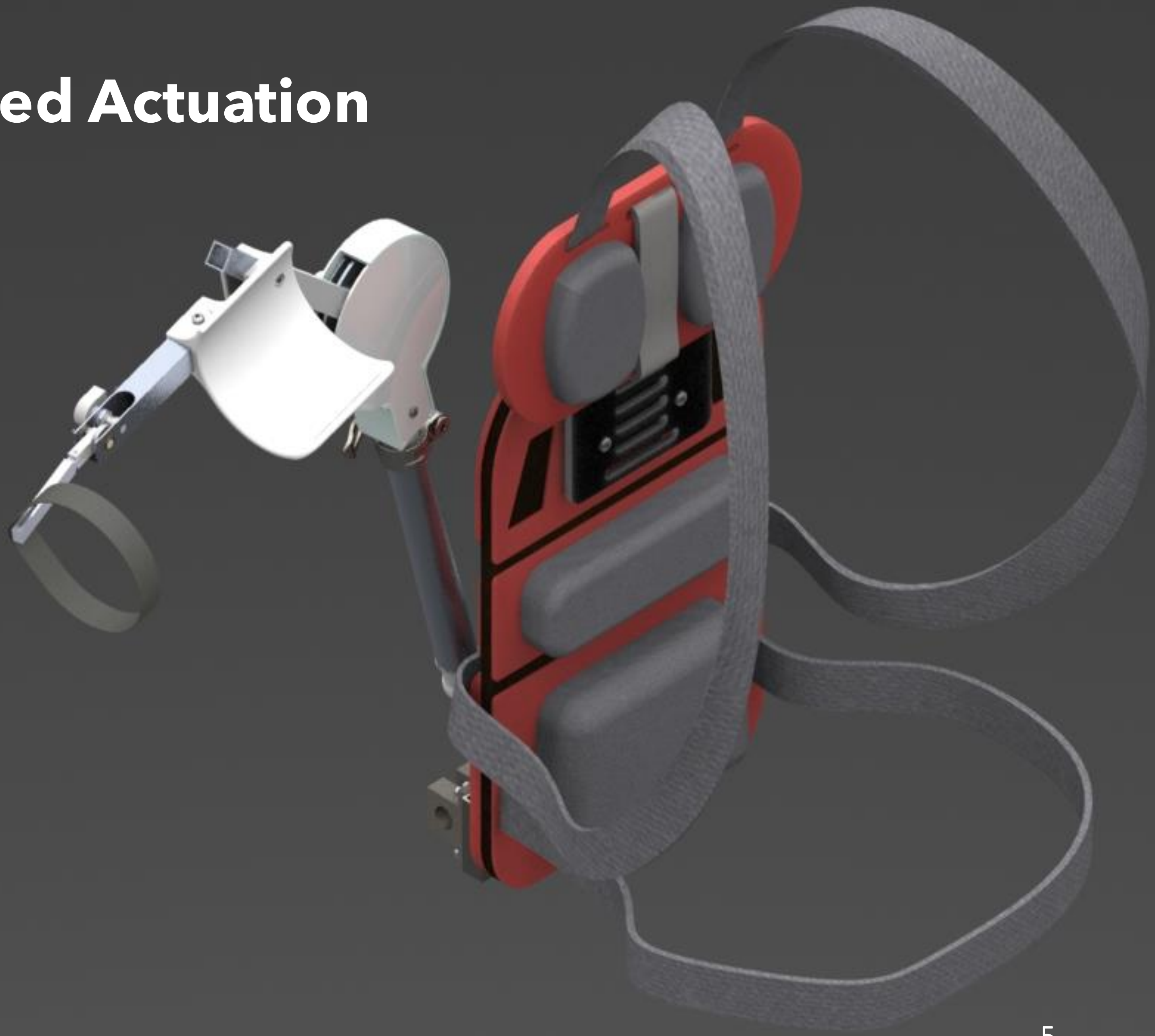
PDS Development

- Gravity compensation of 6 kg arm
- Full arm flexion in 5 s
- Continuous operation 2 hours
- Noise < 50 dB
- Mass < 2.5kg
- Product life > 2 years
- Complies with WEEE



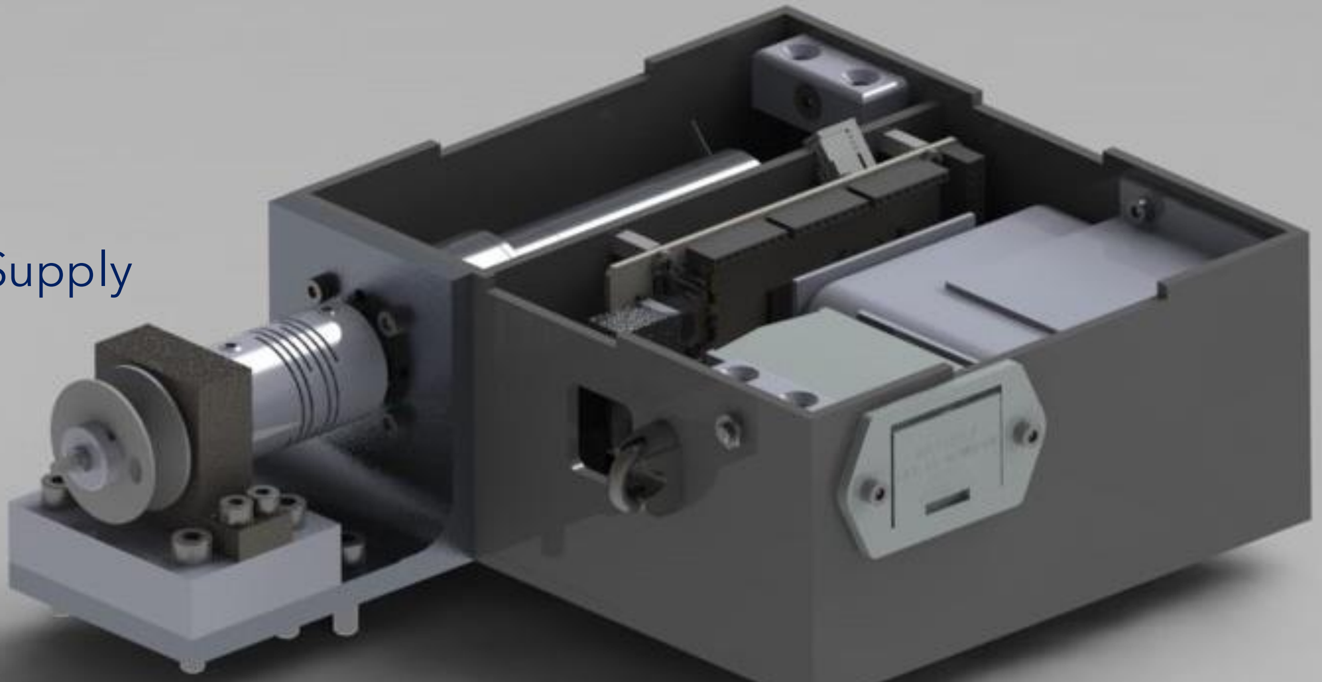
Final Design : Lever Based Actuation

- Pushes on triceps to raise the arm
- Pulley system to rotate shoulder joint
- Position & Force Sensors for user control
- Motor-gearbox actuates spool



Actuation Subassembly

- 12V DC Motor
- 172:1 Gearbox Transmission
- 77Wh Battery Pack & 9V Auxiliary Supply
- Electronics Enclosure
- Drive Shaft-Spool Assembly
- Sensors
- Control System



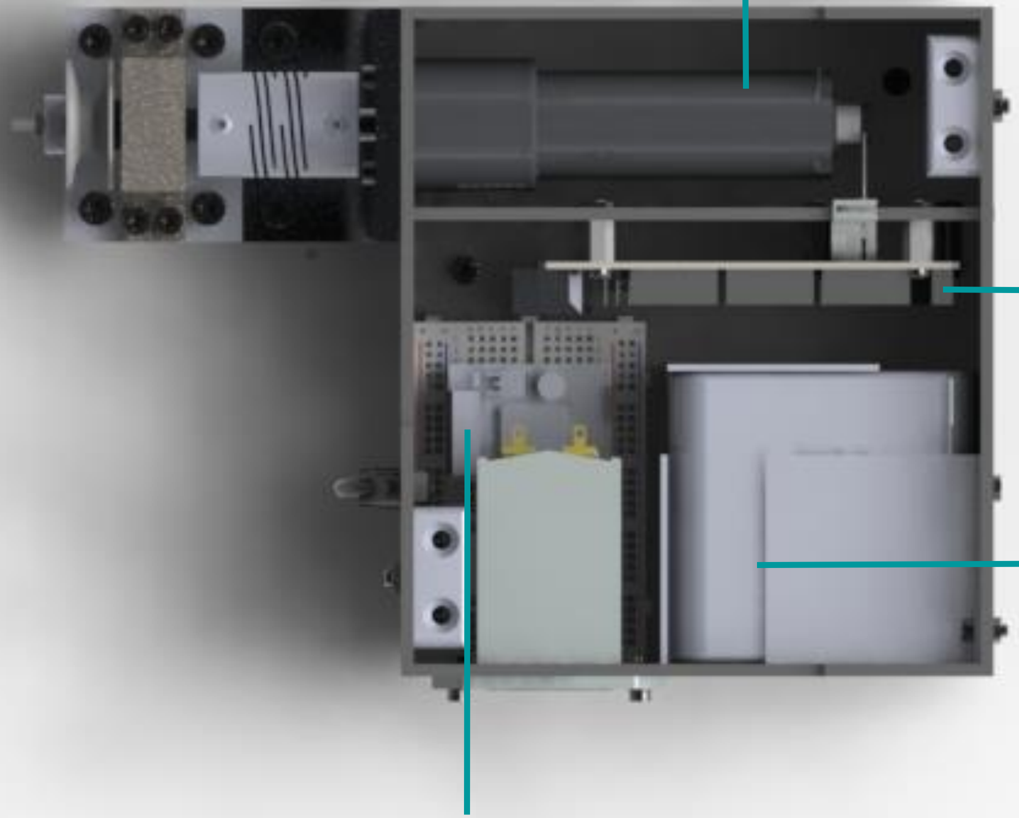
Power Considerations

Required:

- Torque : 49.9 mNm
- Power : 26.5 W

Max Capability:

- Torque : 54.3 mNm
- Power : 40 W



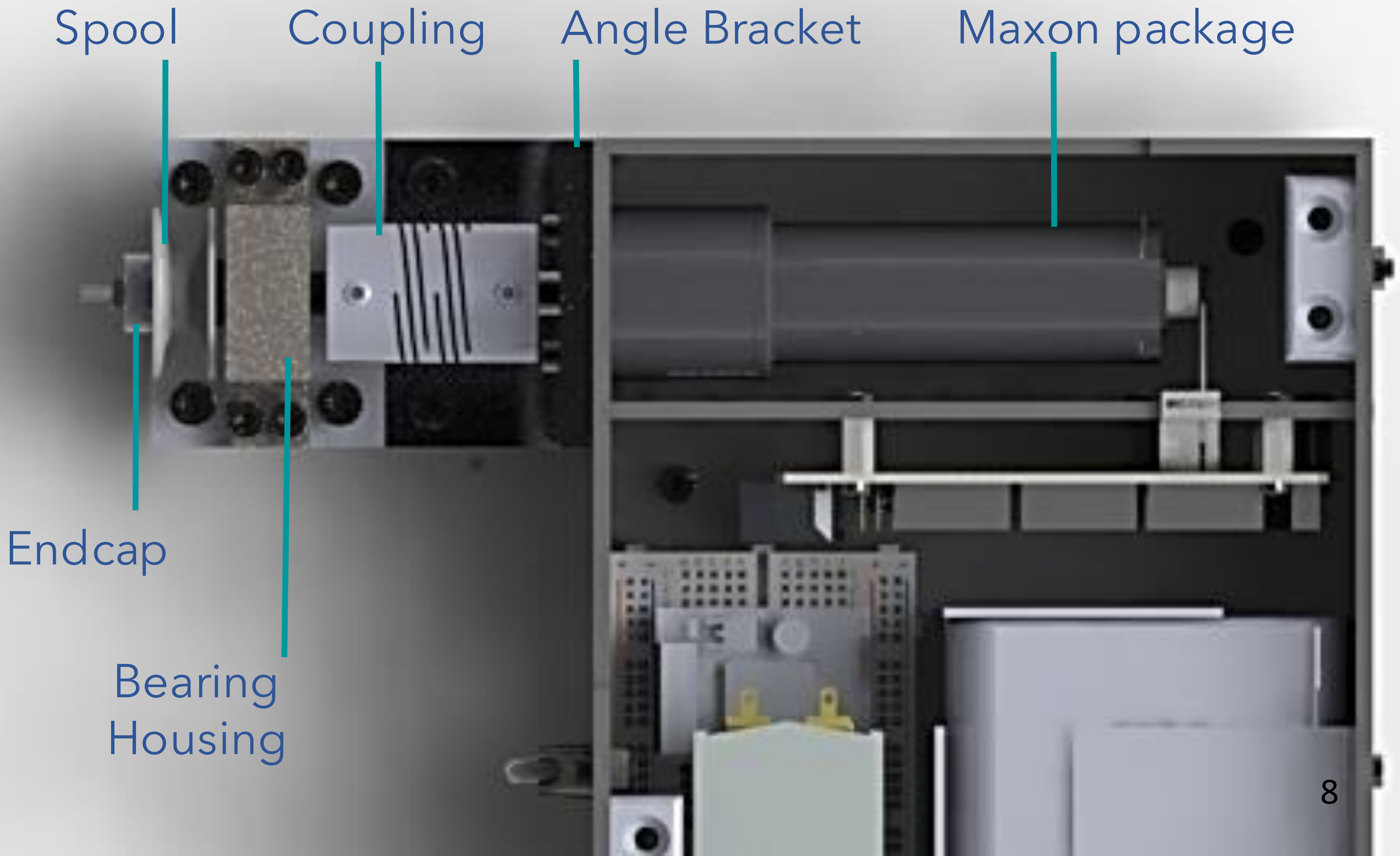
Drivetrain

Cantilevered Spool

Flexible Coupling

Min. Required Gear Ratio : 441

Achieved Gear Ratio : 488



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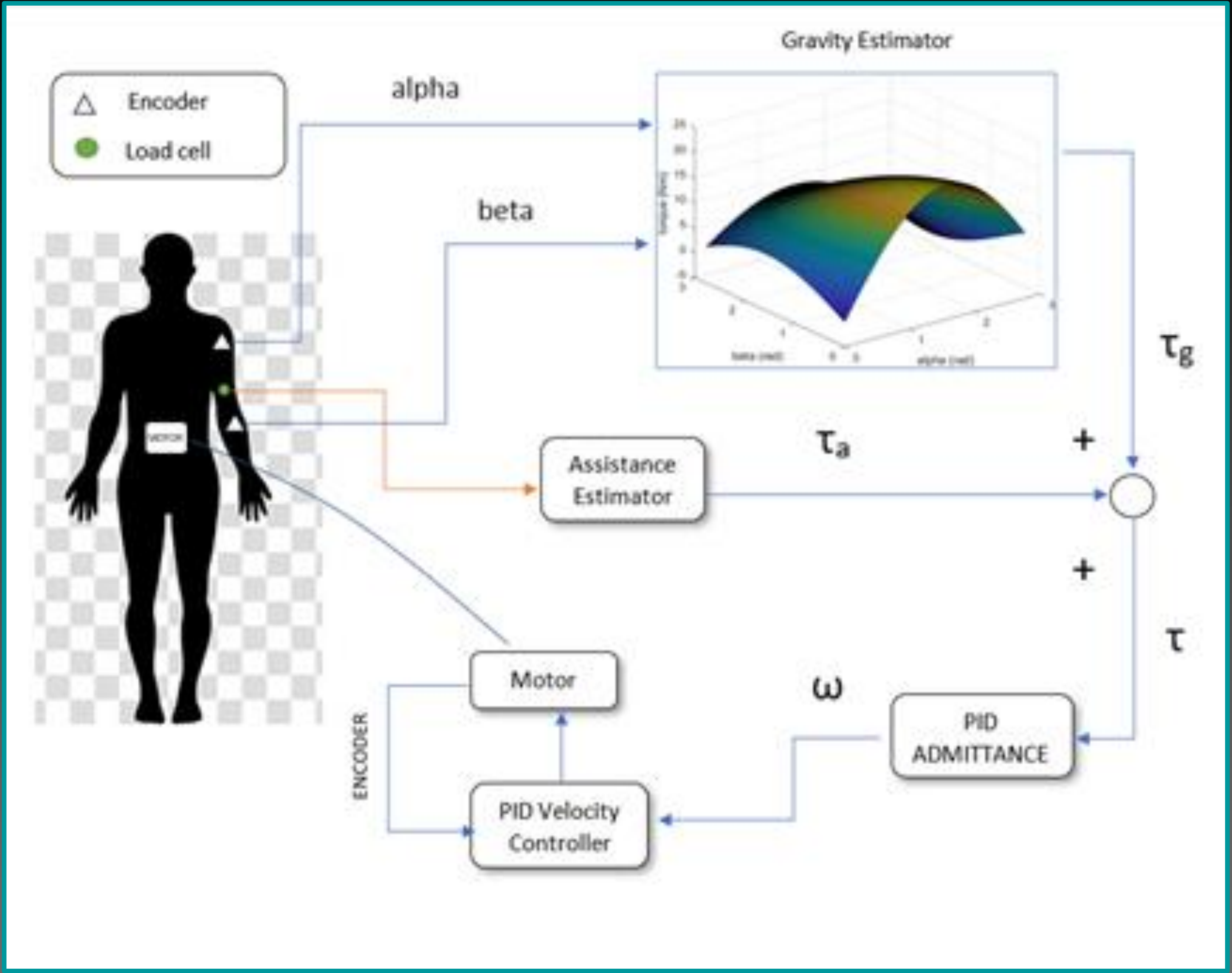
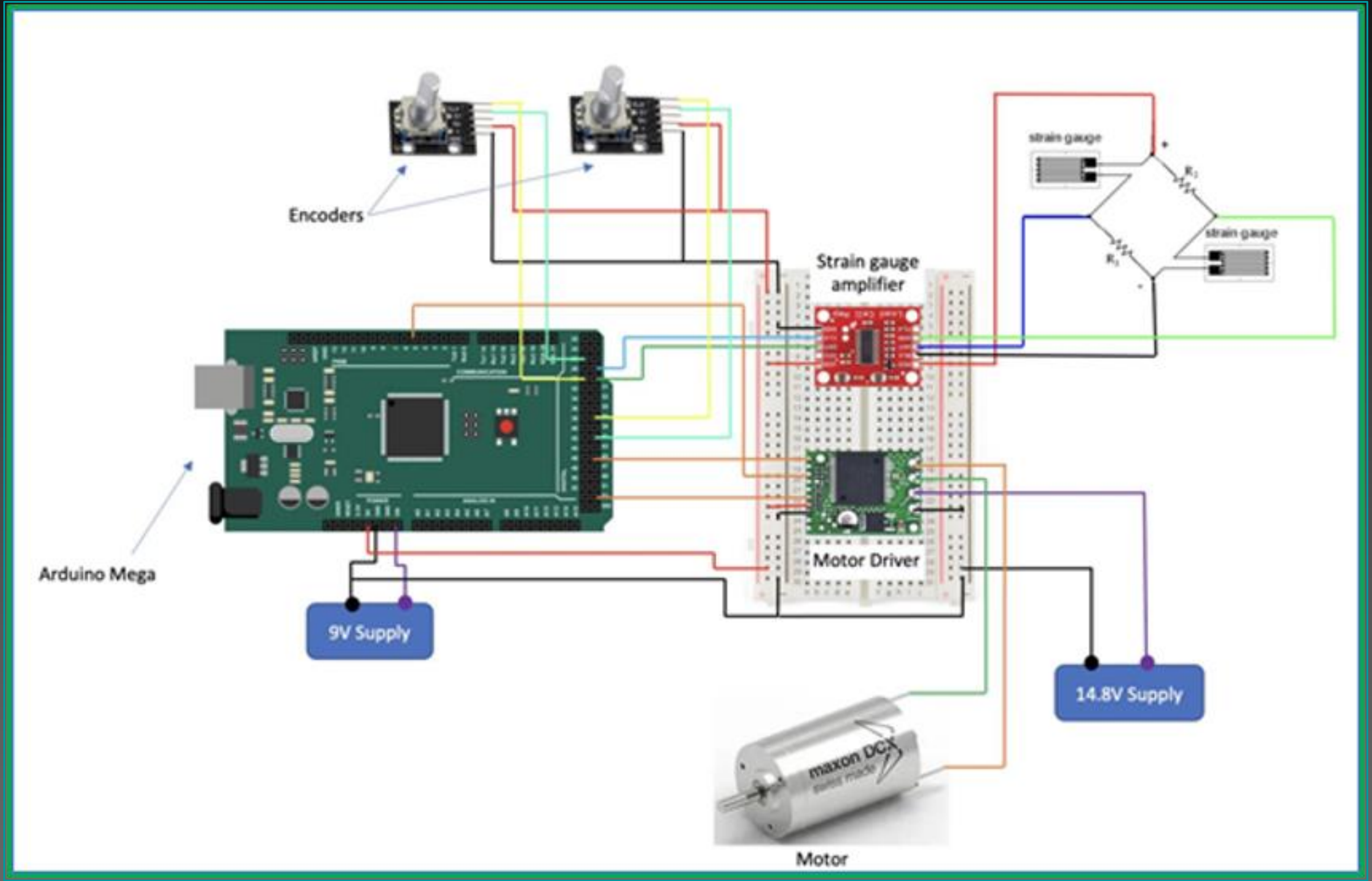
Control System

- Control system adopted from literature
- Gravity Estimator modelled
- Encoders for position sensing
- Strain gauge for force sensing



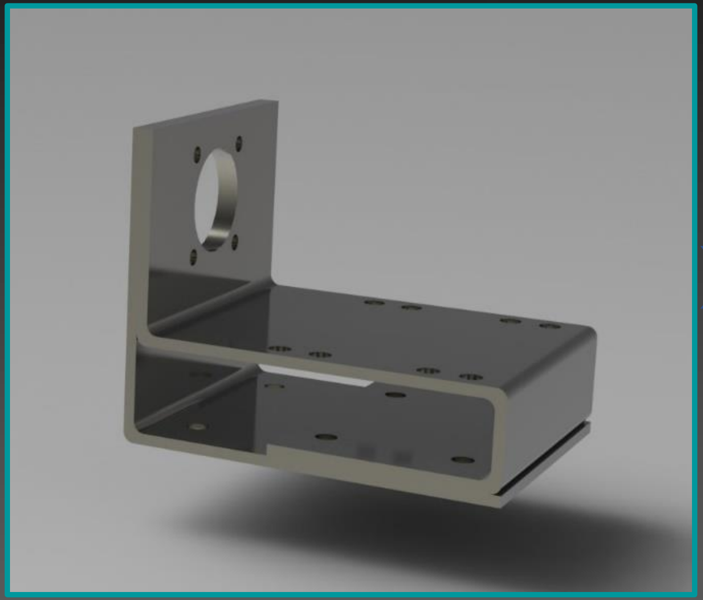
Circuit Diagram

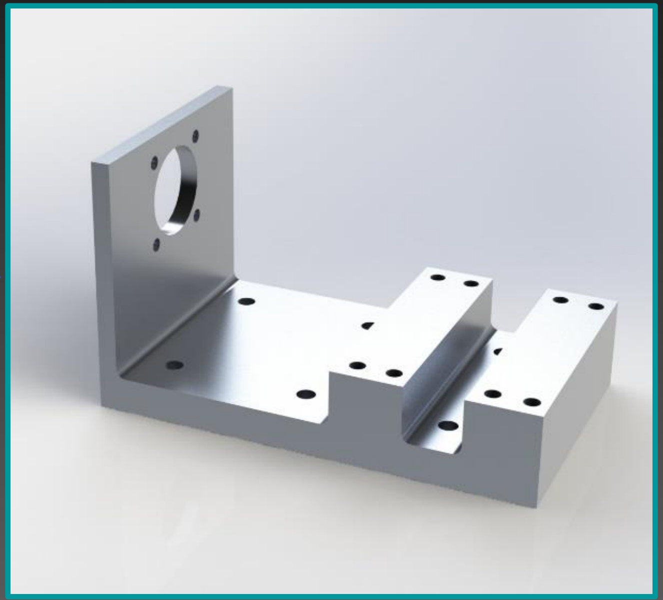
- Arduino Microcontroller
- Two Rotary Encoders
- Two Strain Gauges [Half Bridge Config.]
- 9V Arduino Supply
- Motor Driver

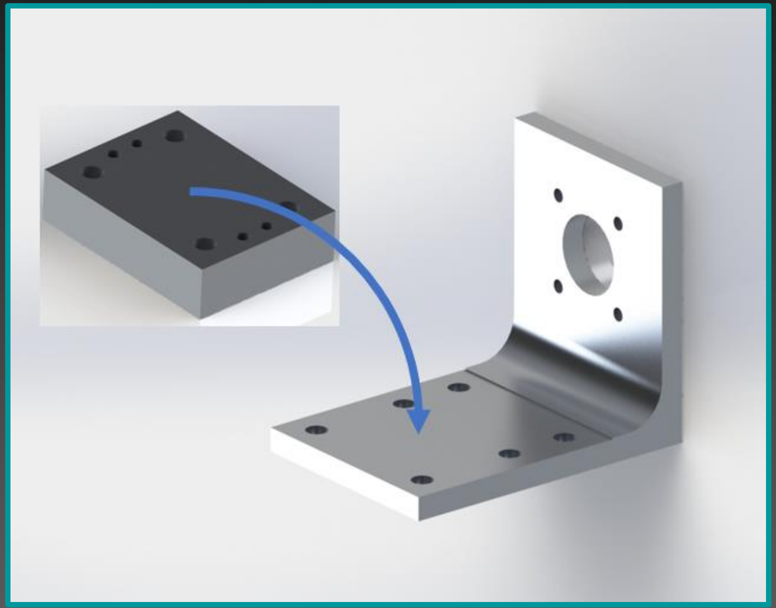


Manufacturing Considerations

[Angle bracket 1st 2nd and 3rd iterations]







1st iteration

Bent Aluminium

2nd iteration

Milled Aluminium Block

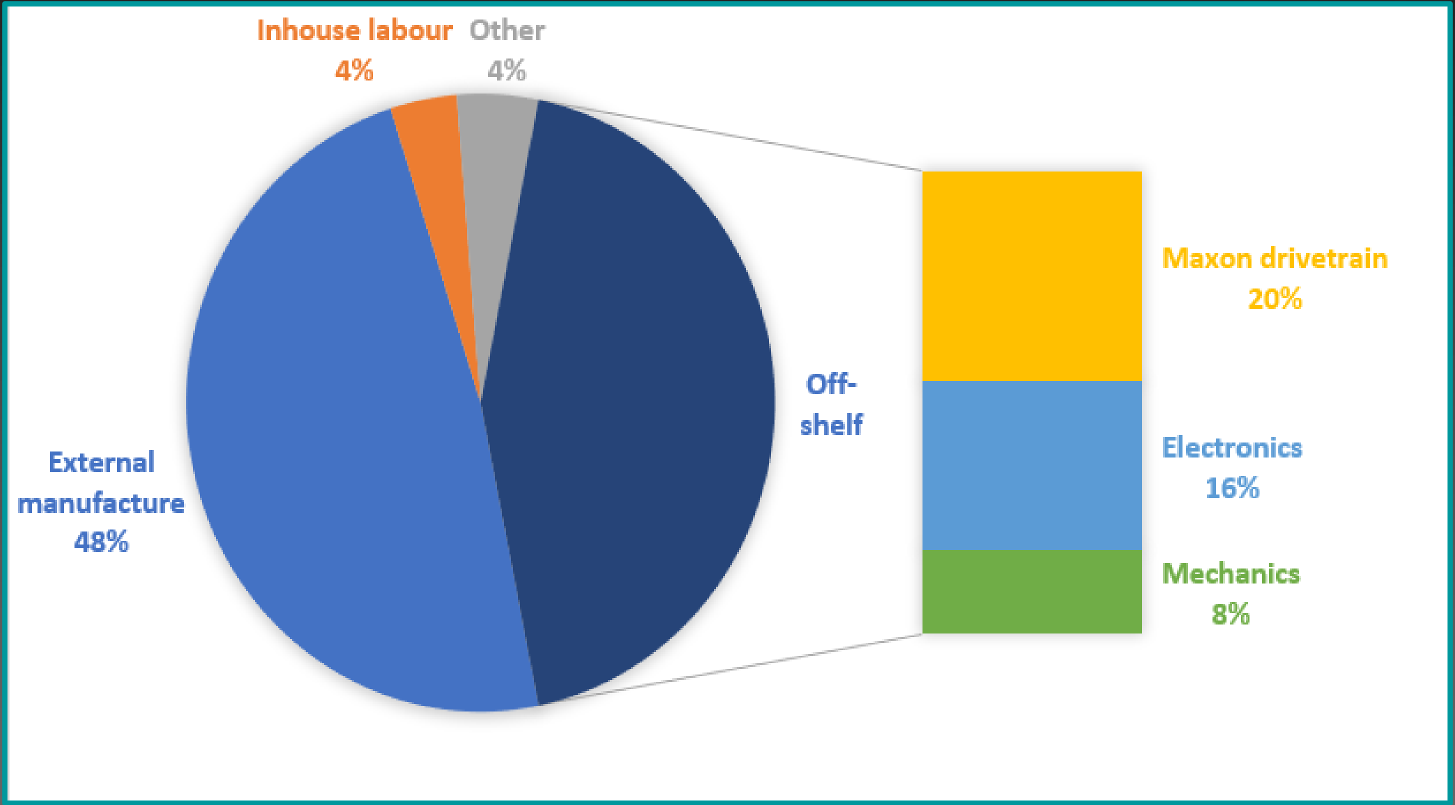
3rd iteration

Milled from L-Shape Aluminium Block

Budgeting

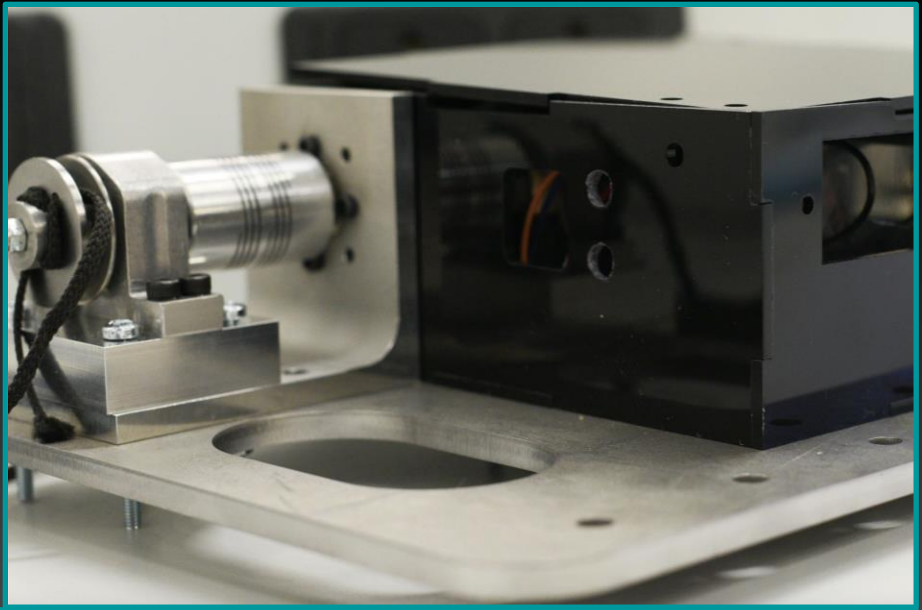
- Maxon drivetrain : highest cost component
- Manufactured parts from workshops
- Bulk Production will be cheaper

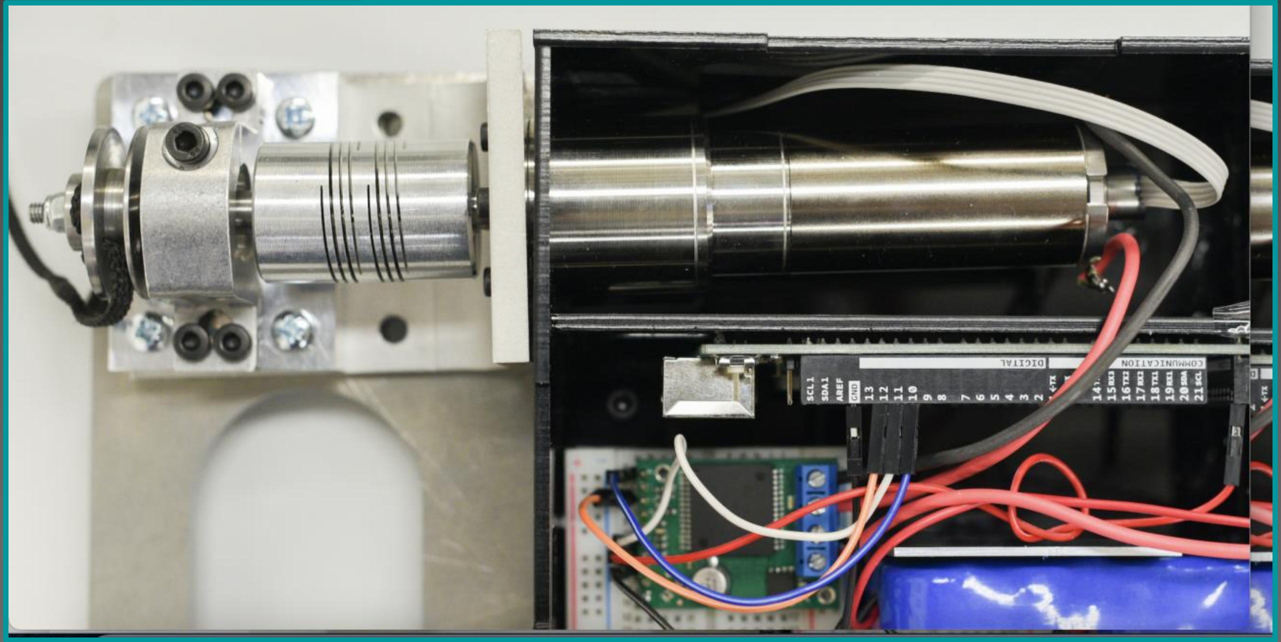
Total Subassembly Iteration #1
Cost: £2243.27 *(incl. Testing)*



Manufacturing Review

- Overall effective assembly
- Tolerances functional
- Shaft had minor lip [removed]
- Spool needed press fit onto shaft





Overview

Major Tests:

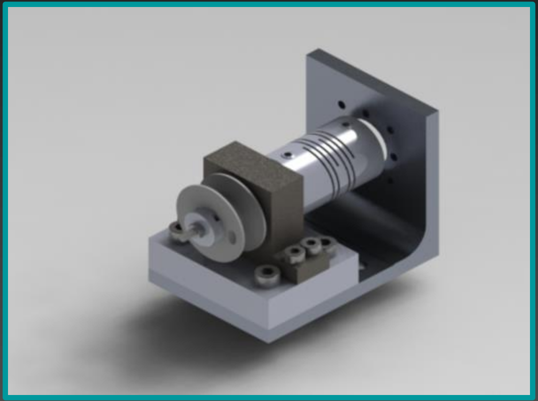
Probable Failure Points
[Critical & Complex]

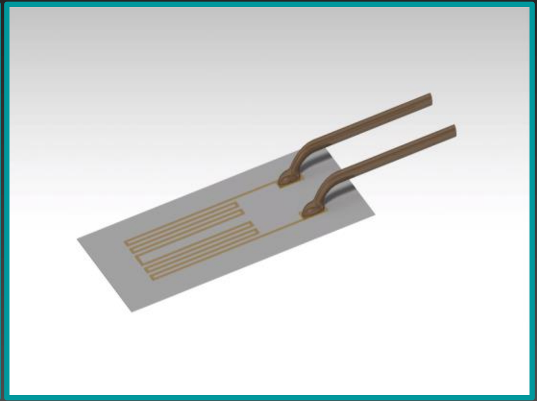
- Shaft-Spool Loading Test
- Strain Gauge Test

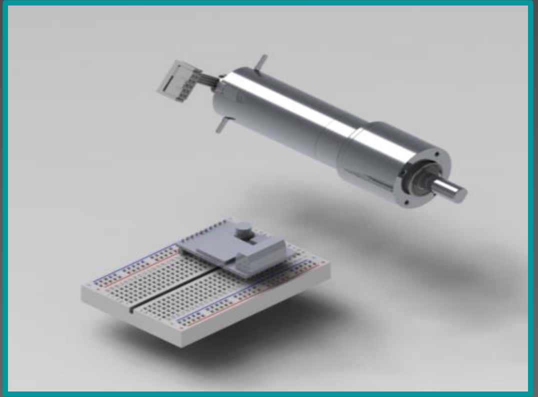
Further Tests:

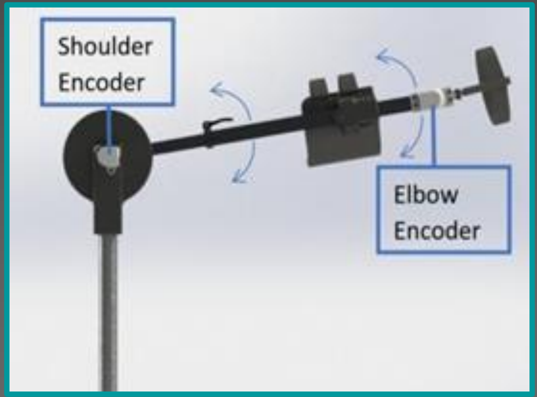
Possible Failure Points
[Separate & Basic]

- Encoder
- Motor Control
- Battery Life









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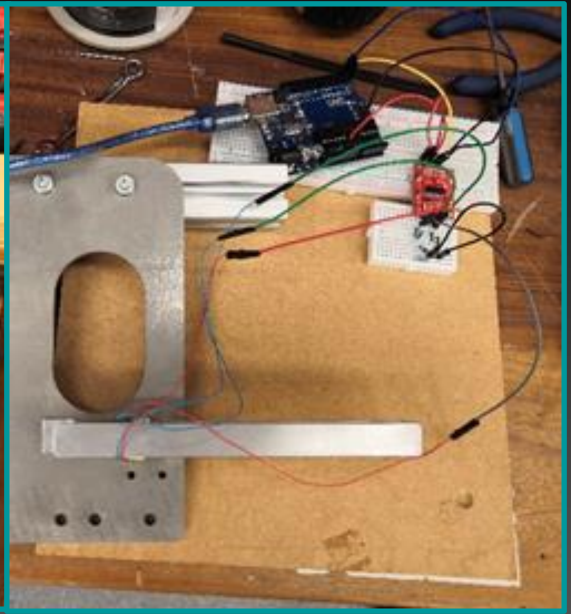
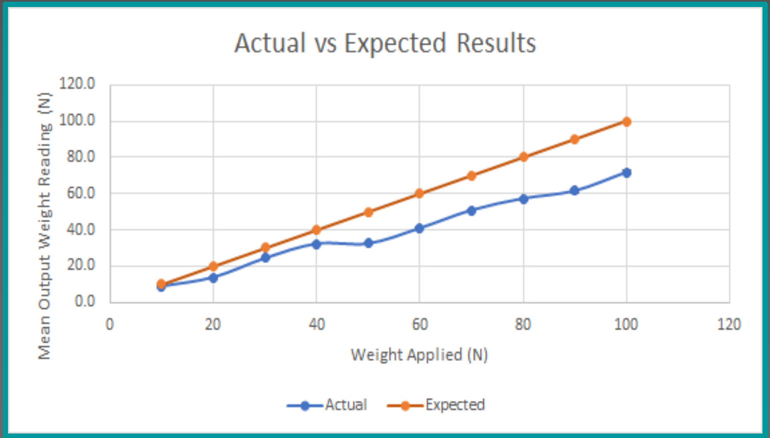
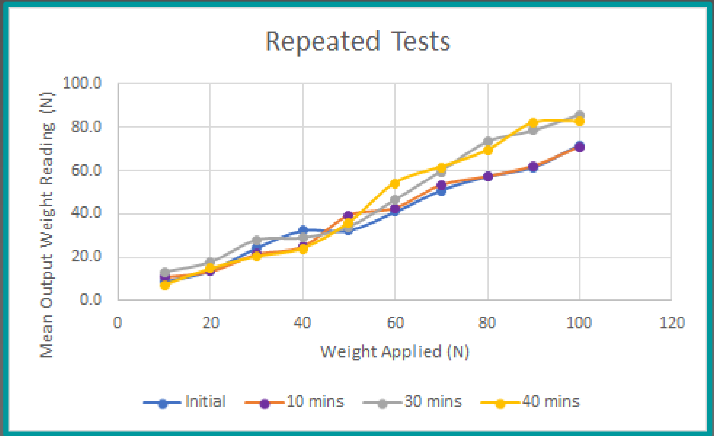
Major Test #1: Strain Gauges

- ☑ Manufactured test plate
- ☑ Attached Strain Gauges to Group 5B Bar
- ☑ Applied Force Readings
  - ☑ Correlative
  - ☑ Low Errors [< 1.5 N]
  - ☒ Moderate Inaccuracies [1 - 30 N]
  - ☑ Minimal drift [tested up to 20 mins]



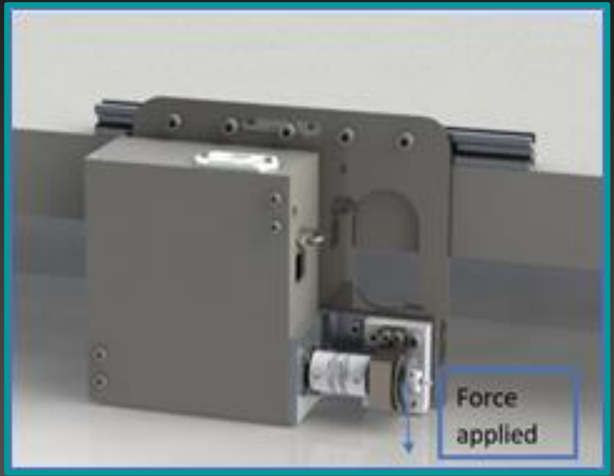


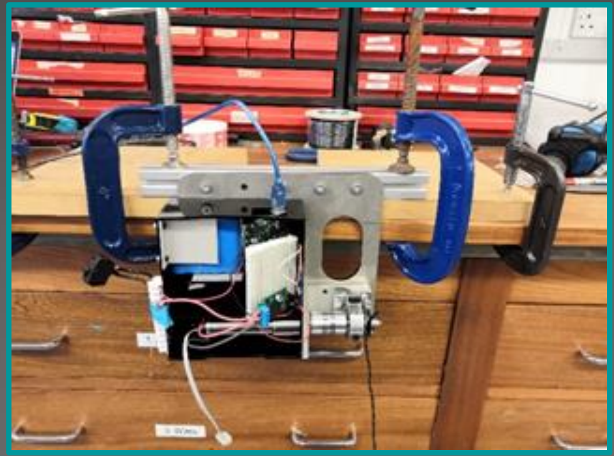


* 440 N = 95th percentile tension estimate of adult arm weight

Major Test #2 : Shaft-Spool Assembly

- ☑ Static Loading up to 450 N *
  - ☑ 5-minute periods
- ☑ Dynamic Loading up to 450 N *
  - ☑ Max Speed = 5 m/s User Actuation
- ☑ Backdrivable
  - ☑ Free User movement
  - ☒ Wear on shaft-spool assembly





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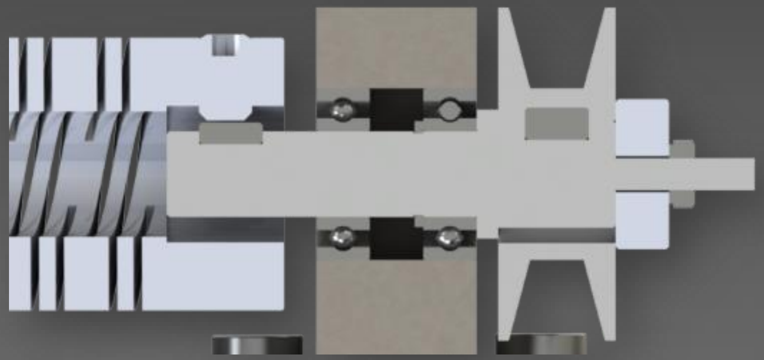
Spool and Shaft

- Spool changed to hourglass shape
- Increased flange thickness
- Cable routing hole now at a 45° angle
- Second keyway added to the shaft



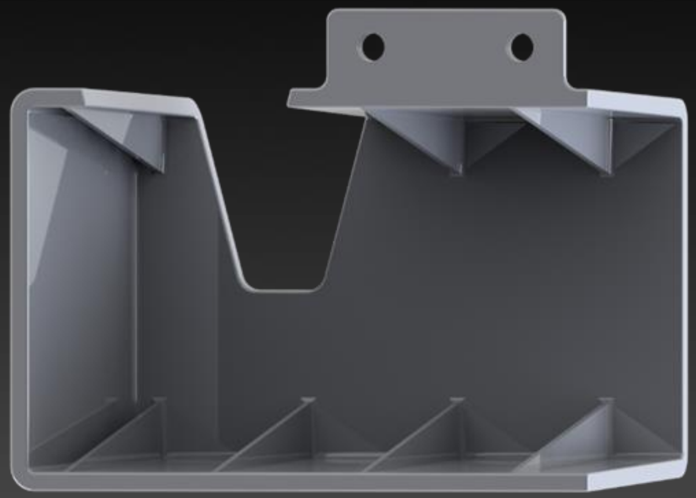
Before

After

Before

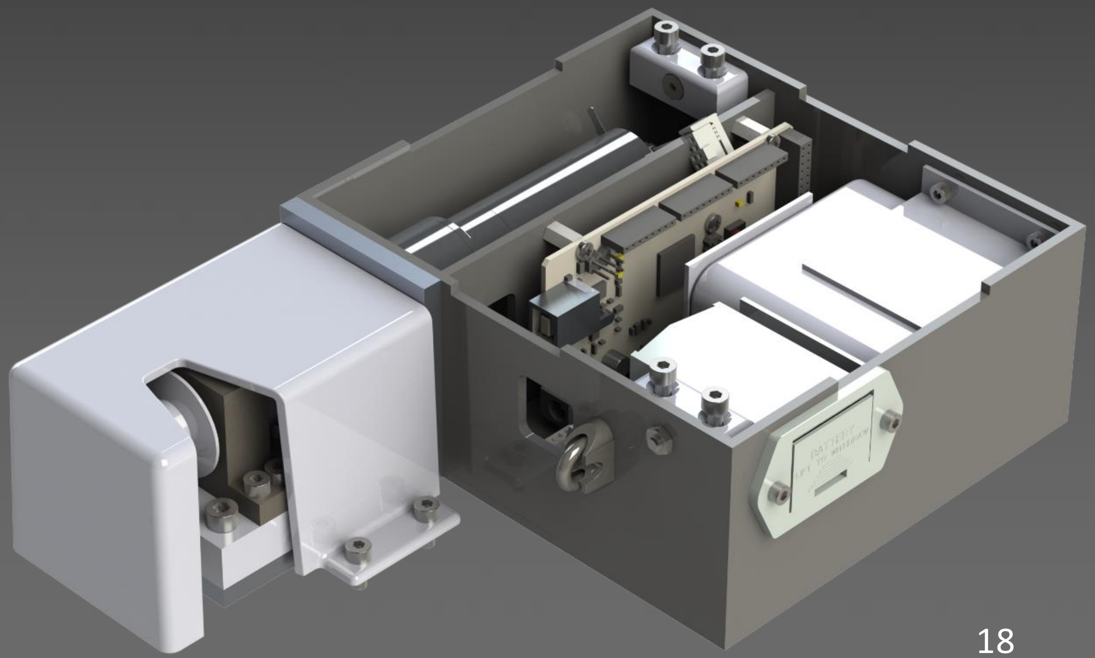
After

Casing



- 3 mm wall thickness
- 2° draft angle
- Acrylic (PMMA)

- Mould Quote: **£ 4812**
- Total cost per unit: **£10.79** for 500 units
- Additive manufacturing Quote : **£66.19**
- At 79 units injection moulding becomes cheaper (**£64.45** per unit)



Evaluation: PDS vs Prototype

		Element	Statement or Criteria	Evaluation
Operation	1	Performance	Actuation system must provide suitable power to enable full arm flexion in minimum time of 5 seconds	Verified output RPM and torque transmitted to lever system in the shaft loading test under maximum expected loading conditions as described in detail in section 9.1.
	2		Range of movement: Assisted Forward Flexion 0° to 160°	Perform a full test of each motion 3 times and measure angles. Check if range of movement is within set boundaries (See Main PDS). Not completed due to limited GTA time.
	3		Actuation provides minimum torque to lift an arm of maximum mass of 6 kg	Verified torque transmitted to lever system in the shaft loading test under maximum expected loading conditions as described in detail in section 9.1.
	4		Battery life: 5 hours	GTA time limitations did not allow for low priority battery life test, but manufacturers specifications ensure 5 hours lifetime.
	5		Battery charging: <6 hours for full charge, <2 hours for 50%	Manufacturer specifications.
	6		User interface, including power switch and fail-safe mechanism.	Part of future progression of the project due to shift of focus from electrical to mechanical aspects.
	7		Design primarily for indoor use	Test the product under minor splash conditions while turned off and check if water is entering electronics
	8		Aim for water resistance. Withstand minor water splashes. IP65-66	Discarded during early design stages. Benefits do not justify the effort, consensus amongst all three subteams to remove criterion from PDS.
	9	Noise	The device must not cause noise that hinders conversation. Aim for max of around 50 dBA	Manufacturer Maxon specifies an operating noise of 44 dBA for the motor and testing confirmed no significant additional frictional noise.
	10	Weight	The entire device should weigh less than 2.5 kg	CAD model evaluation of the Actuation subassembly yielded 1.7kg which exceeds a third of the given limit considerably. Main weight contributions stem from the motor-gearbox assembly (404g), battery pack (365g) and further steel drivetrain components which need to withstand loads of up to 440N.
	11	Ergonomics	Any switches or buttons can be activated without need for excessive force (approx. under 200g)	Standard switch, manufacturer specifications.

Evaluation: PDS vs Prototype

	12	Safety	All machined parts deburred and chamfered. No exposed transmission elements. Safety stop button that brings system to halt (does not just cut power)	Assembling and testing the final product confirmed.
Life	13	Service Life	2 Year total product life Motor: 2 hours daily (1451 Hrs) Sensor and Frame: 4-5 Hours Daily (3652 Hrs)	Bought from established manufacturers, components are rated to last 2 years.
	14		Maintenance matches the service life of 2 years	Bought from established manufacturers, components are rated to last 2 years.
	15	Sustainability	Optimise for use of recyclable materials and reusable elements	Design reviewed.
	16	Maintenance	Minimal maintenance required, e.g., user should not be required to lubricate moving parts themselves. Quick and easy replacement of critical parts if necessary	Design reviewed.
Producer	17	Quantity	Produce 1 prototype with 3 sub-assemblies	N/A
	18	Product Cost	Total £3000 to purchase all the components and external manufacture and external testing cost, £1000 for each sub-assembly	Budgeting, details in "Design Report" [7]. Budget exceeded but sufficiently justified.
	19	Materials Consideration	Materials with high fatigue life. High strength to weight ratio materials. Metallic parts must be corrosion resistant	Used Cambridge Engineering Selector and selected materials that satisfy the relevant performance indices.
	20		Materials in contact with skin must be inert and pliable. Does not cause allergic or dermatological reactions	Material Data Sheet from supplier confirms this.
	21	Manufacturing Constraints	Use standard components where possible	Used suppliers from the Imperial College Information System.
	22		Parts able to be manufactured in local plants (United Kingdom)	Only UK based manufacturers were used. (Maxon is Swiss, but the parts were off-shelf and had an acceptable lead time of 10 days.)
Regulatory	23	End of Life Disposal & Sustainability/ Environmental concerns	Electric and Electronic components must comply with Waste Electrical and Electronic Equipment (WEEE) regulations Use of recyclable plastics Batteries must be adequately disposable	Design reviewed.

Fully met: 78% Missed: 9% (Waterproofness: Discarded)

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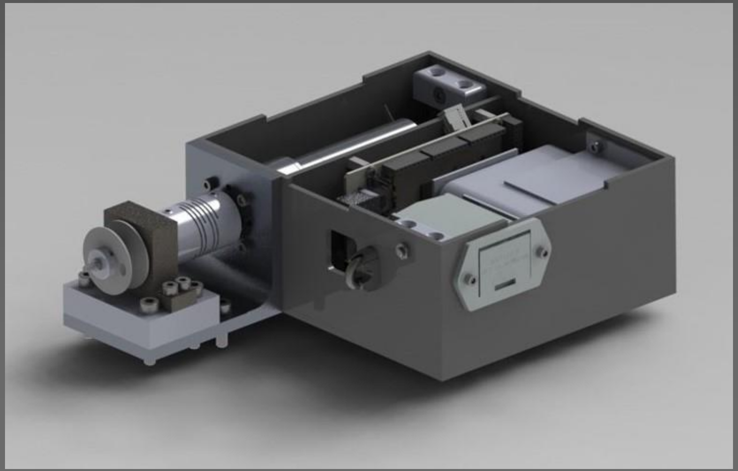
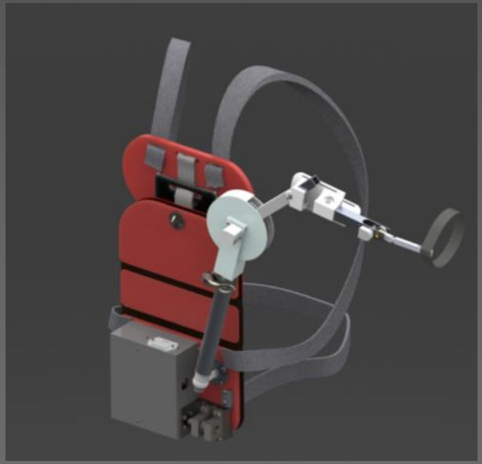
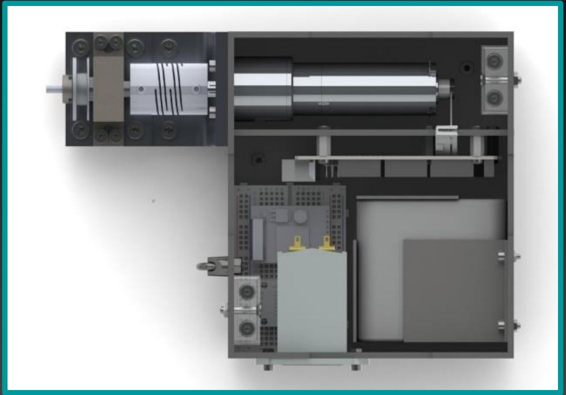
Steps To Market Entry

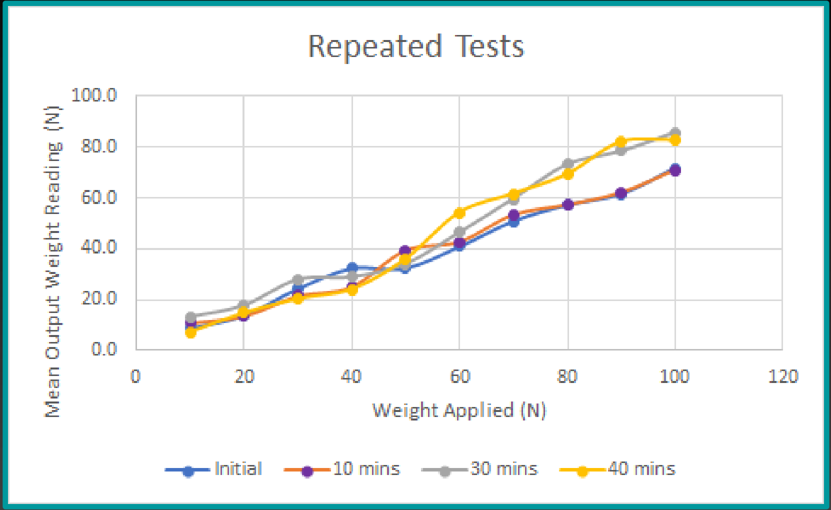
- Super-assembly test and revision
- MHRA compliance
- Rollout to volunteering patients
- Design iteration
- Serial production
- Market entry





Summary

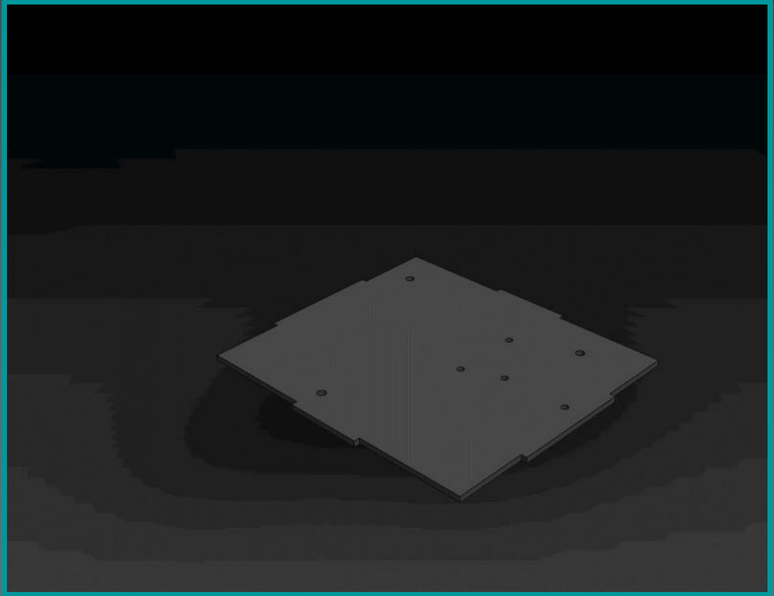




DESIGN → **MAKE** → **TEST** → **REDESIGN**

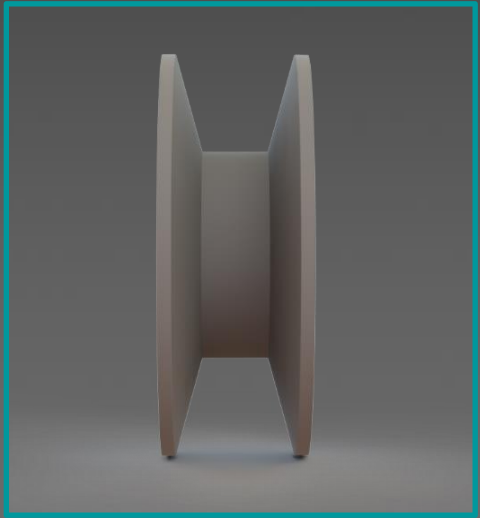
Slides 5-11

Slides 12-13



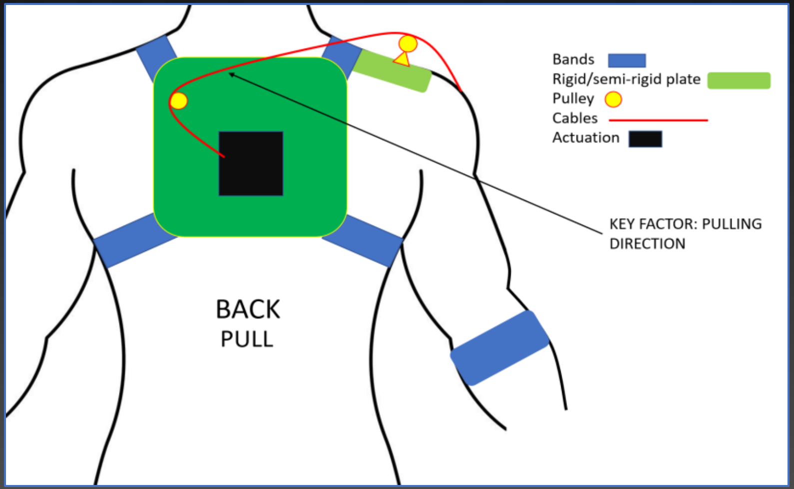
Slides 14-16

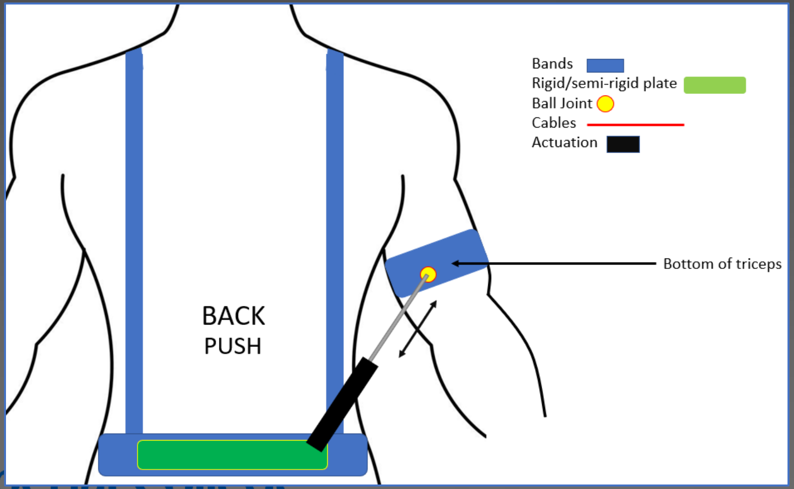
Slides 17-18

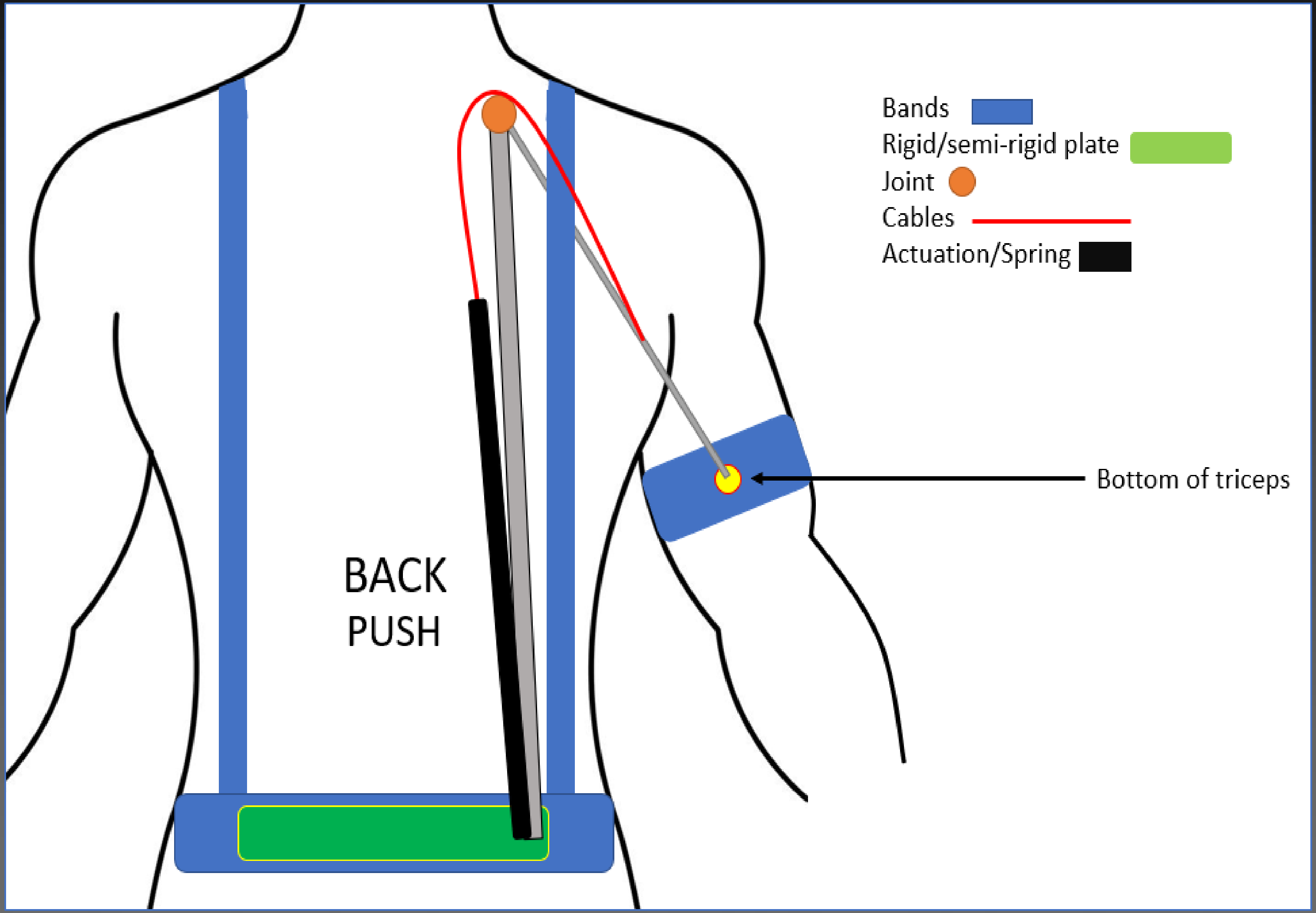


APPENDIX

Shoulder Concepts







Calculations: Gear Ratio

Spool radius   Cable radius

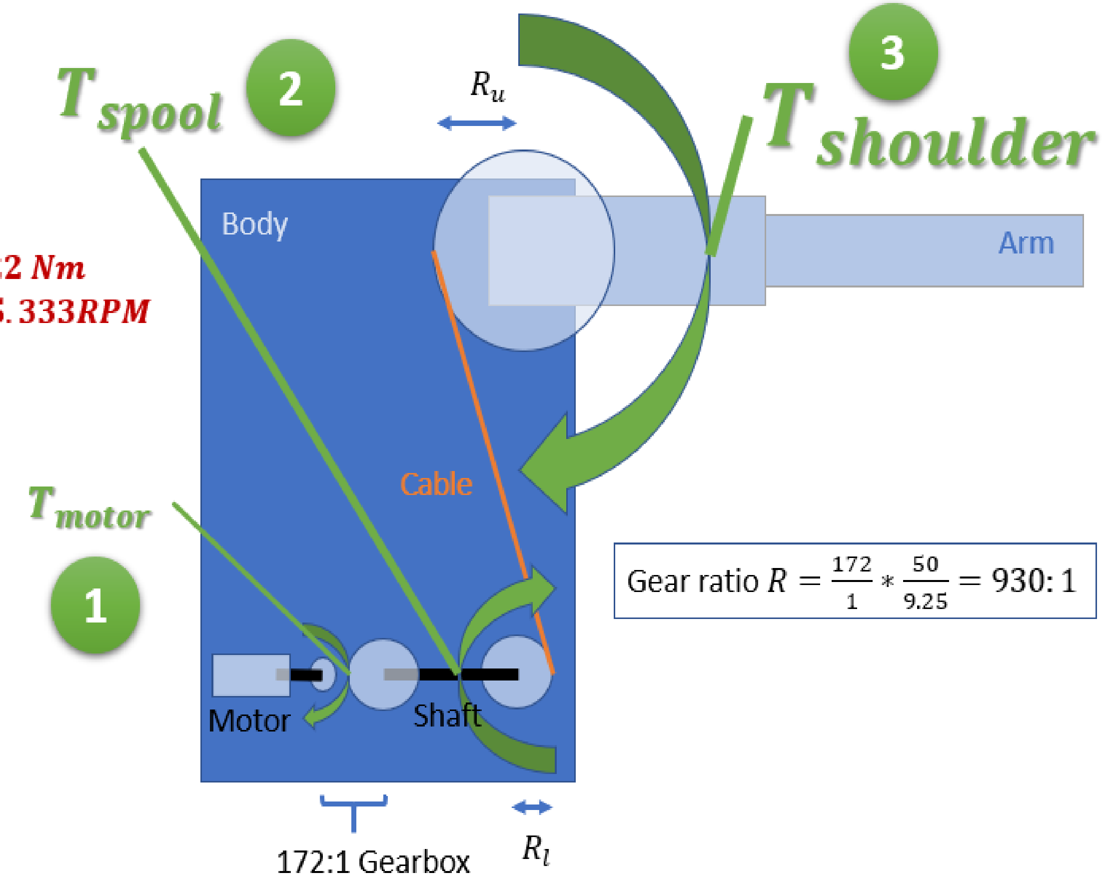
$$R_l = (8 + 2.5/2)\text{mm} = 9.25\text{mm}$$
$$R_u = 50\text{mm}$$

$$T_3 = T_{shoulder,max} = 22\ Nm$$
$$\omega_3 = 160/360 * 60/5\ RPM = 5.333RPM$$

	3	2	1
T (Nm)	22	4	0.023
ω (RPM)	5.333	29	4958

$* 50/9.25$ $*172$

$$T_{motor,nominal} = 0.0469\ \text{Nm}$$
$$\omega_{motor,nominal} = 9460\ \text{RPM}$$



$$\text{Gear ratio } R = \frac{172}{1} * \frac{50}{9.25} = 930:1$$

Calculations: Torque And Max Tension

$$m_{body} = 102kg$$

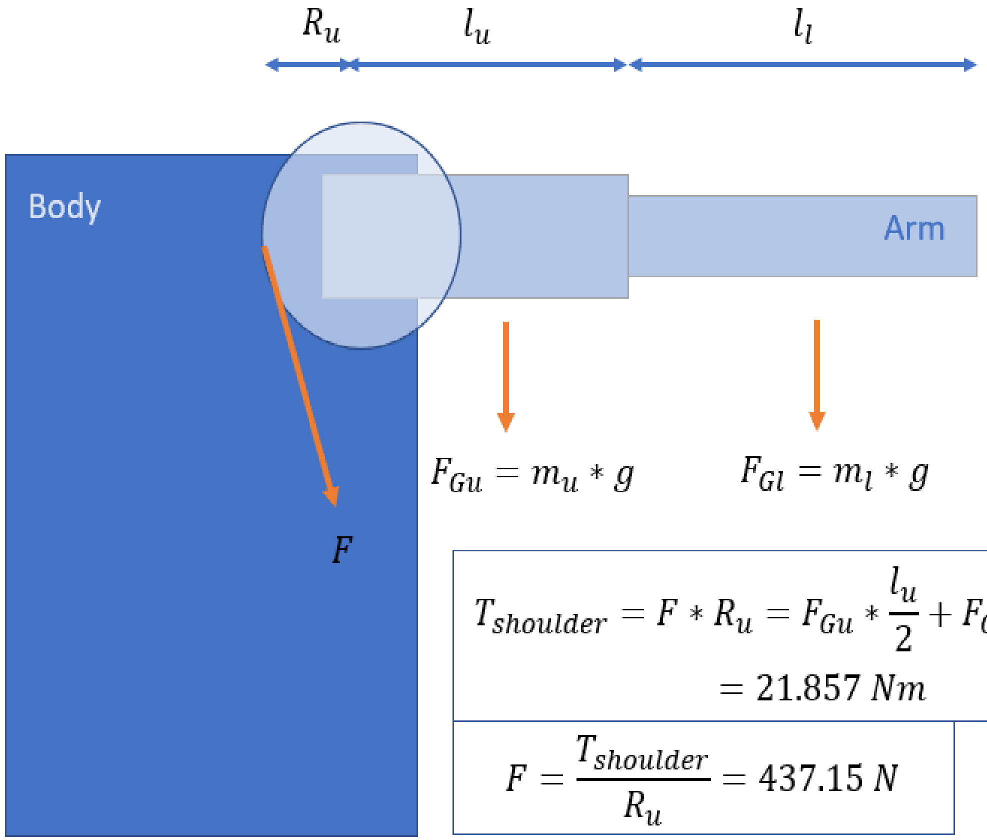
$$m_{upper} = m_u = 0.0325 * m_{body}$$

$$m_{lower} = m_l = 0.0252 * m_{body}$$

$$l_u = 0.375\text{m}$$

$$l_l = 0.5\text{m}$$

$$R_u = 0.05\text{m}$$

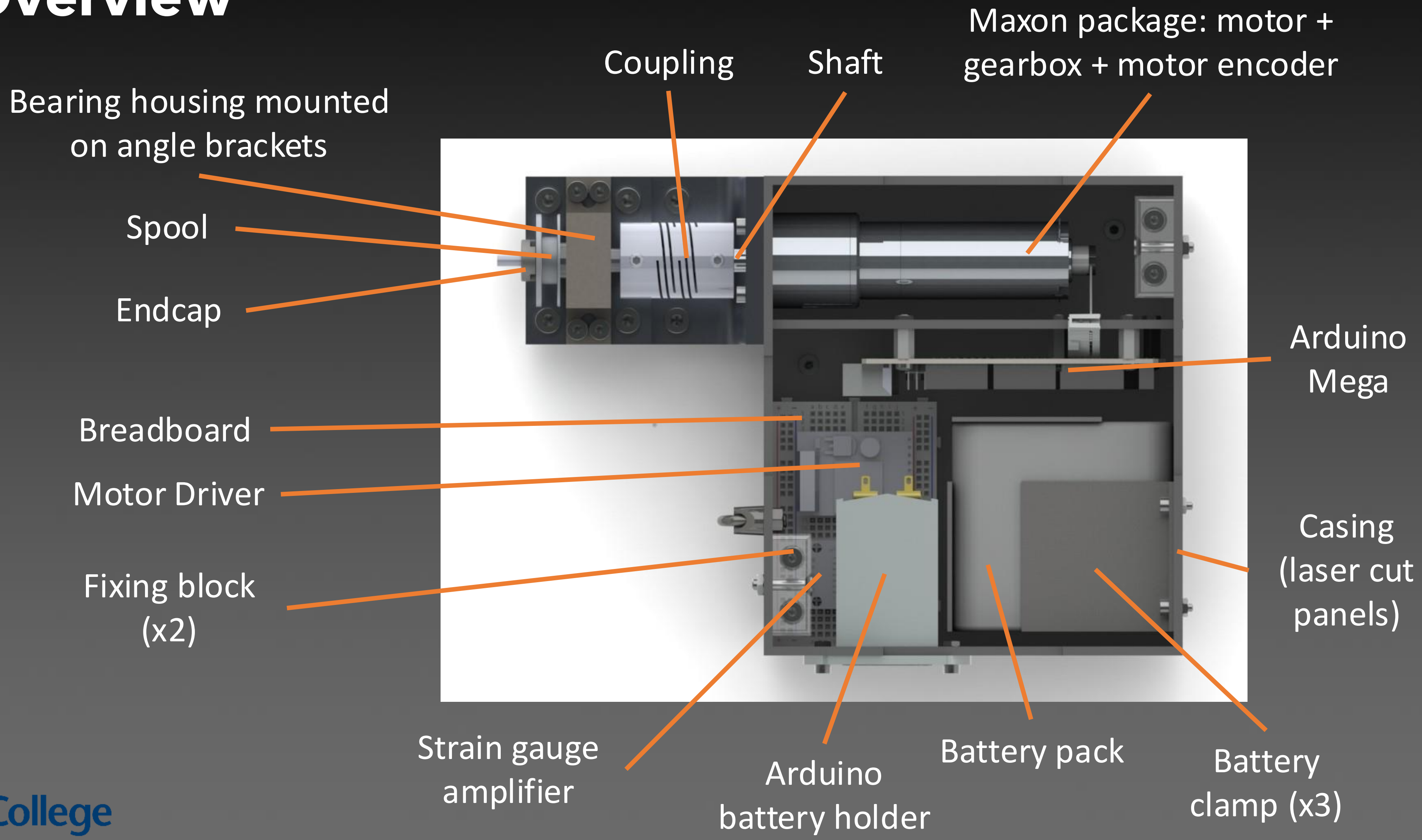


$$T_{shoulder} = F * R_u = F_{Gu} * \frac{l_u}{2} + F_{Gl} * \left(l_u + \frac{l_l}{2}\right) = 21.857\ Nm$$

$$F = \frac{T_{shoulder}}{R_u} = 437.15\ N$$

APPENDIX

Actuation Subassembly – Full Component Overview



Battery Considerations