4B7 Computer Aided Design

Assignment 3 – 6 DOF Desktop robotic arm link optimization

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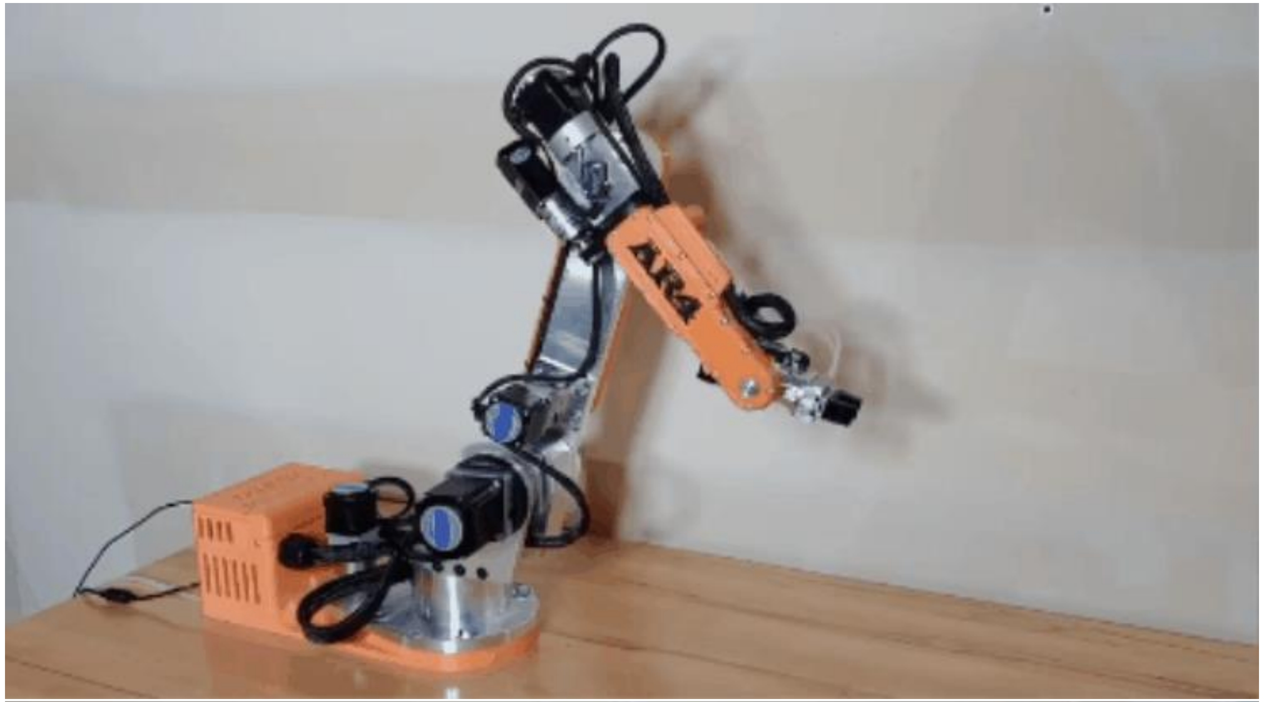
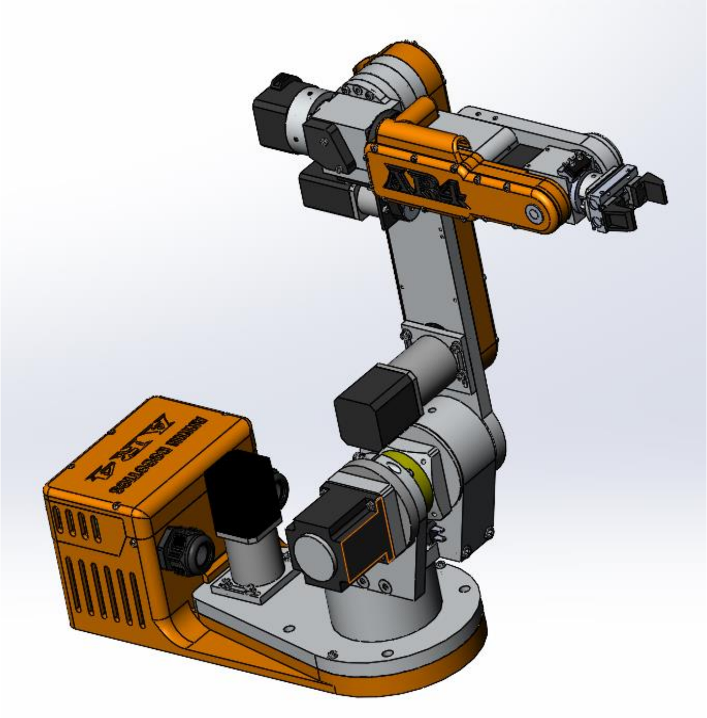
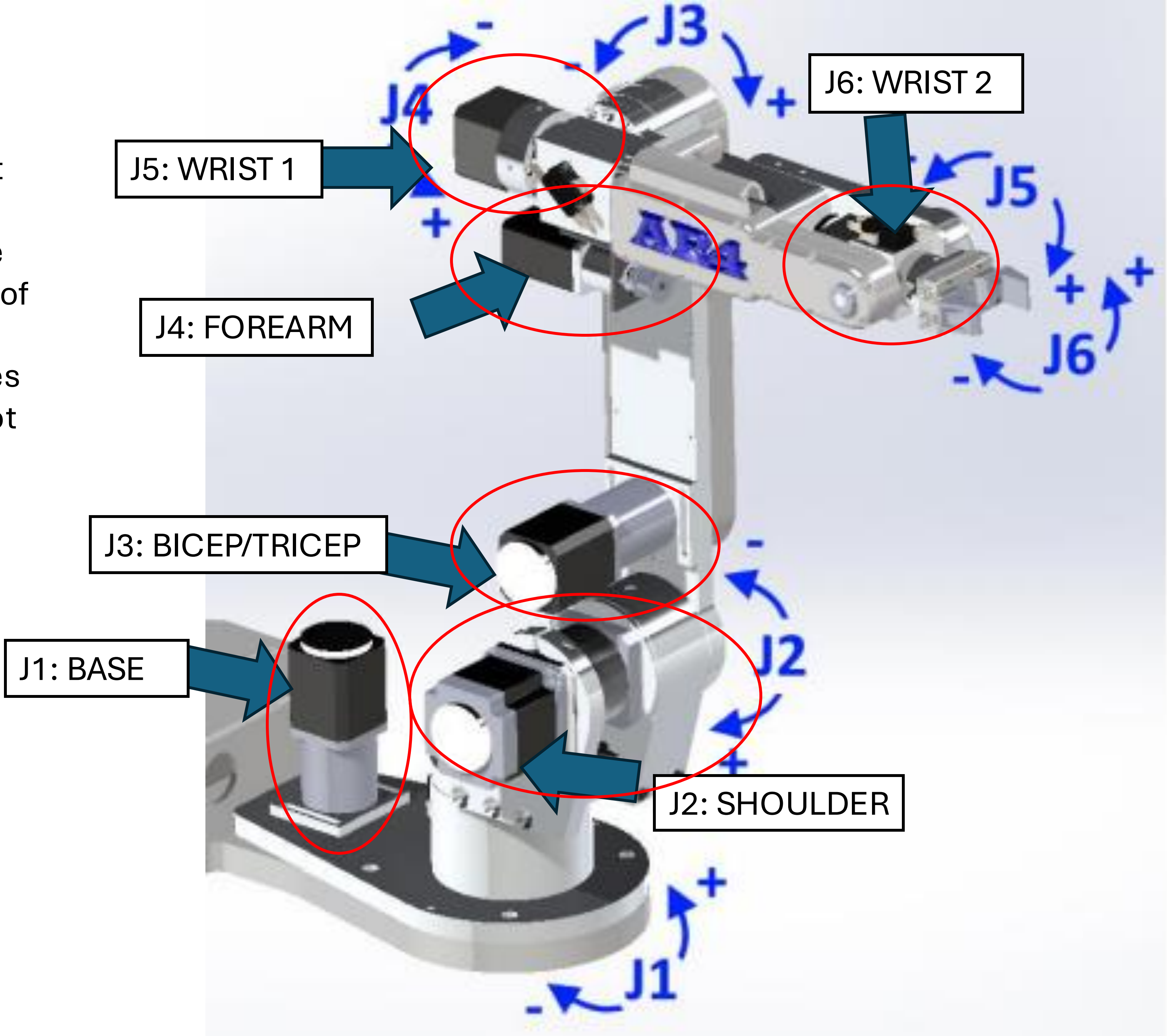

AR4


AR4

Robot layout

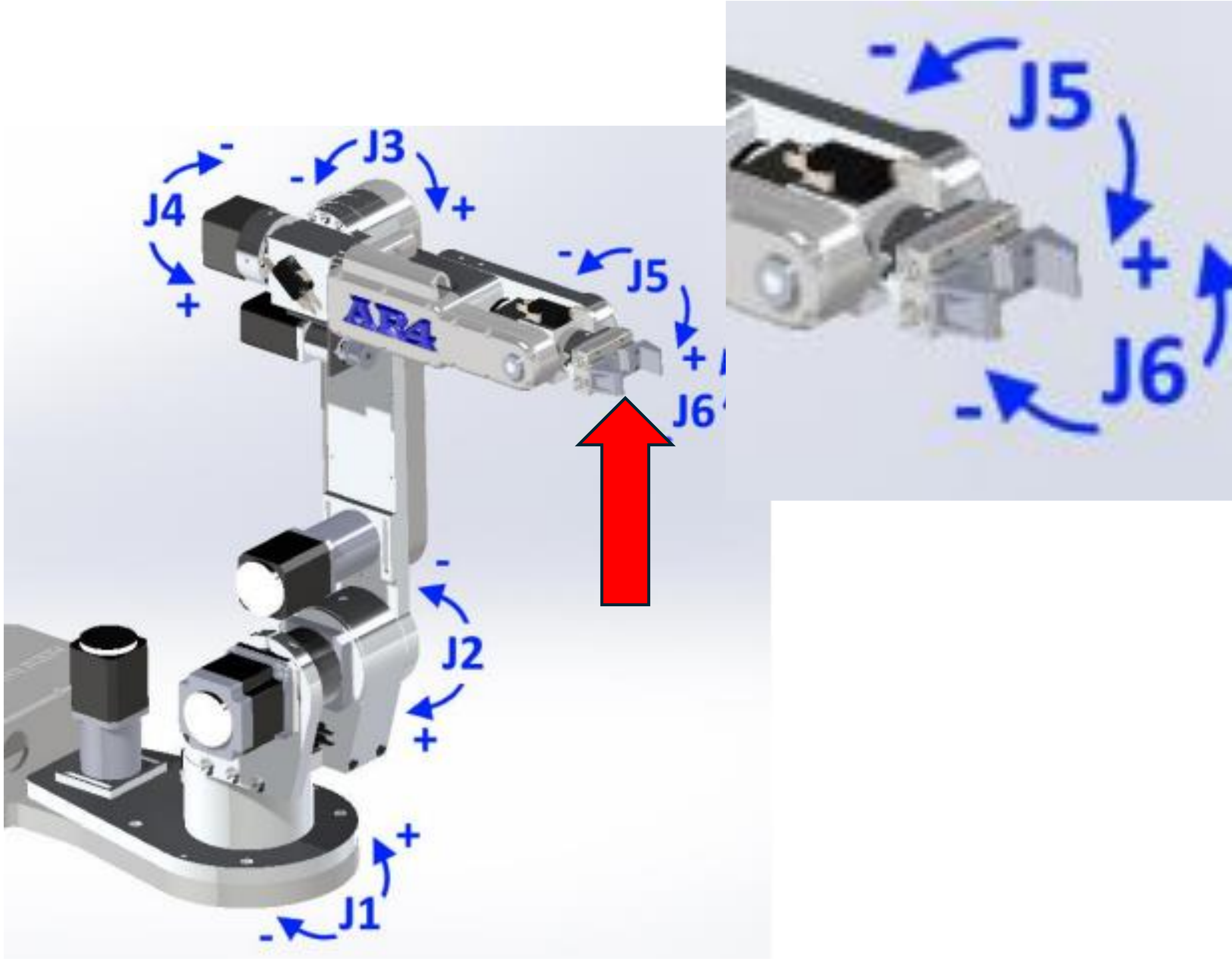
- The AR4 MK3 is a desktop size robot with 6 DOF
- Electric Motors of different sizes are used to actuate each of its degrees of freedom
- Transmission and bearing type varies throughout the structure of the robot





Robot layout

- We are interested in the XYZ coordinates of the robot's end effector and its orientation (see red arrow)
- **Focus: mechanical stiffness of robot's links contribution to displacement of end effector**

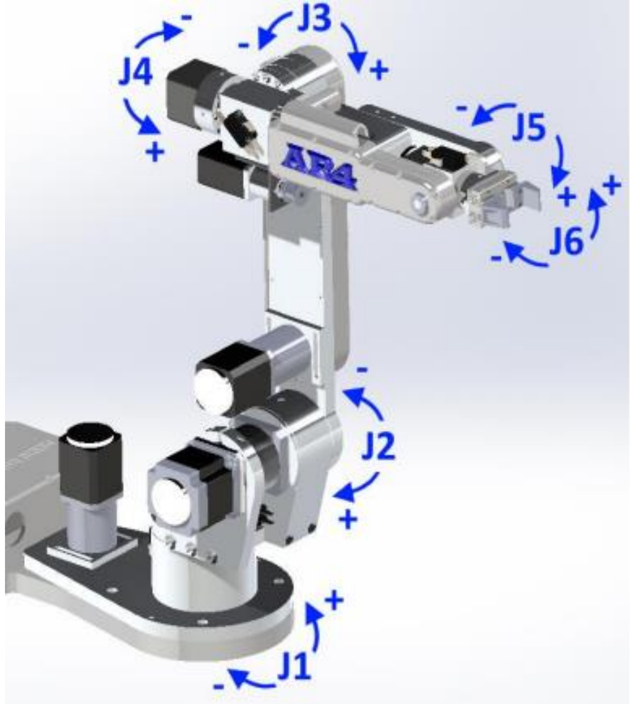


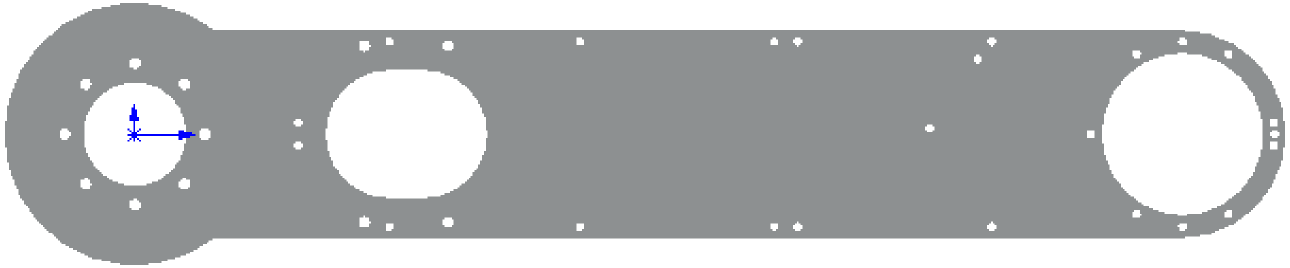
Problem definition

- Optimize the structures of links belonging to 6 DOF desktop robot manipulator so that its structure:
    - Is stiffer
    - Is Lighter
    - Has lower inertia
- While choosing:
    - Suitable material(s)
    - Topology
- Remain cool/deform minimally under both thermal and structural loads
    - Internal loads and moments expected at joints of robot
    - Thermal loads contributed by heat generated by motors

Robot design - Structure

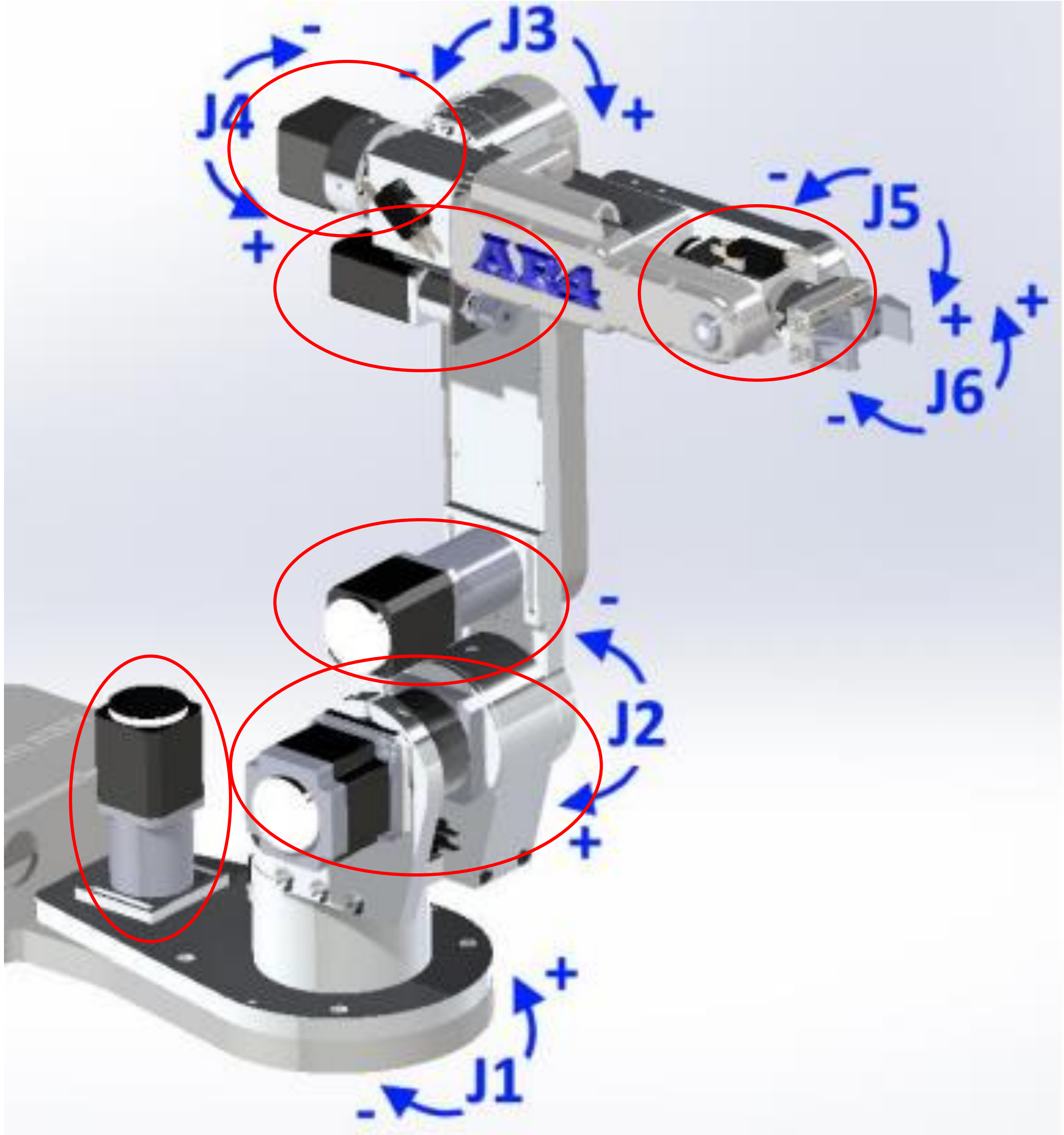
- Structure of robot is made mostly out of aluminum.
- Room for optimization is present in the larger aluminum parts.
- Holes and bores must remain in the same relative locations to fit existing joints on robot.
- **FEA is done on the individual link and not on the full robot at once.**





Robot design - Motor

- Do not change relative locations of motors on the robot
- Consider them only as a source of heat and mass
- Do not change choice or design of motor
- Supports for motor can have its design explored

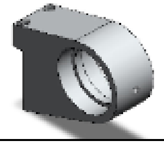
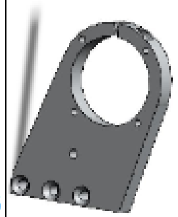
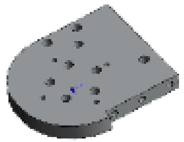
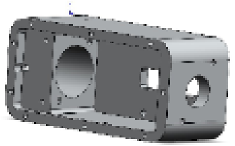
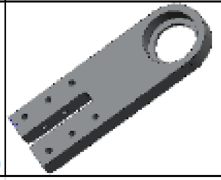


Thermal load

- Assume each motor is a source of heat on the robot
  - 24 Volts
  - See datasheets on each motor to estimate Watts: https://www.omc-stepperonline.com/upgraded-ar4-robot-complete-electric-package-ar4-mk3-stepper-motor-driver-and-power-supply-ar4-mk3
  - Assume P_(loss) = V*I_(rated current)*(inefficiency of motor)
- Room temperature @ 300 Kelvin is the ambient reference
- Check temperature limits of materials used
- Use heat transfer coefficient of h = 40 W/m^2 K   for all exposed faces

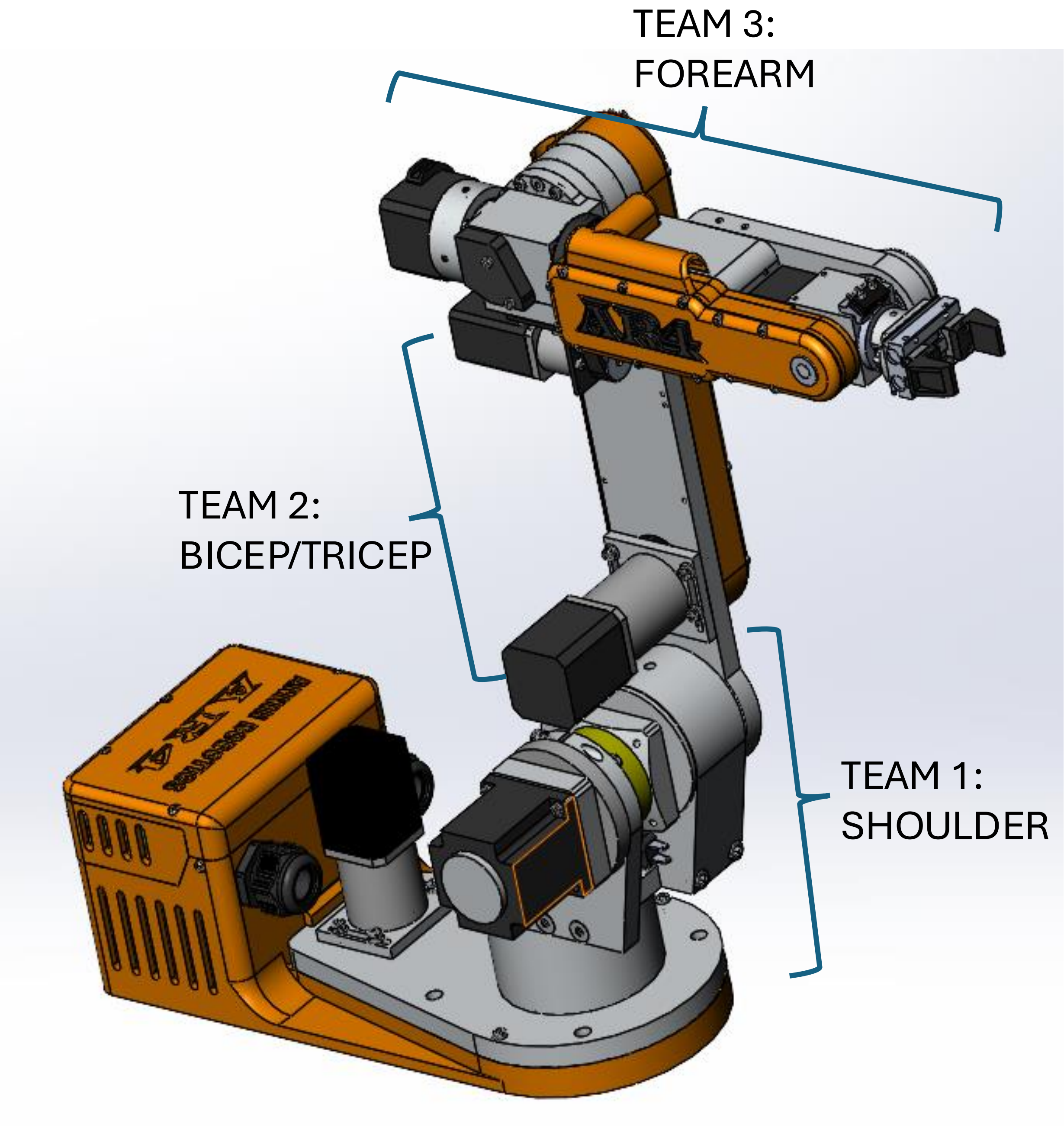
Components to Optimize

- In the assignment, your team should conduct FEA on individual components or significantly reduced assembly files
- Components that make the most sense to optimize are listed on the right ->
- Your team can analyze each part individually given the force conditions or reassemble then conduct FEA studies

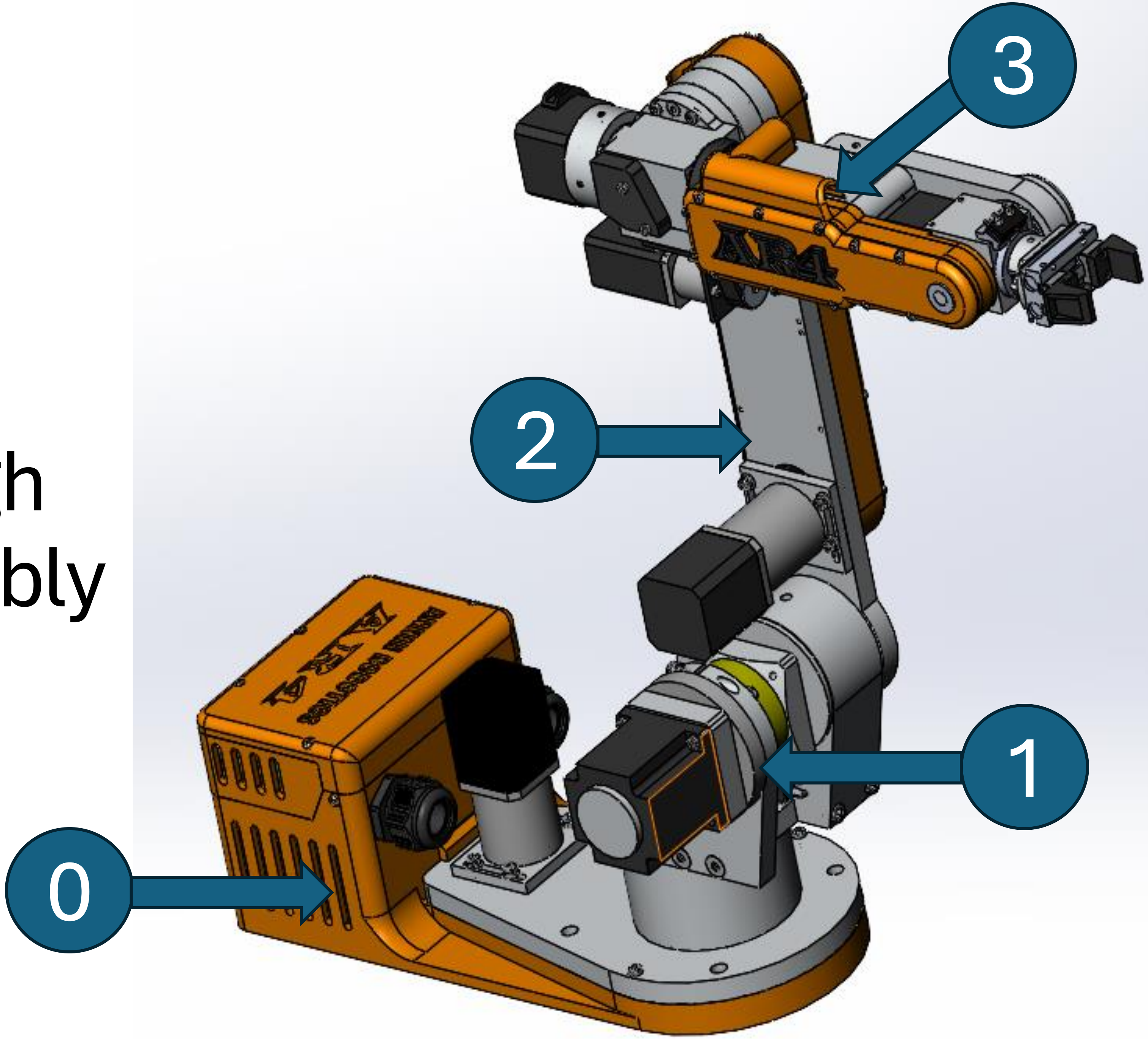
Name of component	Mass (g)	Ixx (g *sq mm)	Iyy (g *sq mm)	Izz (g *sq mm)	Image
J2 Turret housing	554.63	411415	574800.17	836954.3	
J2 Motor Support	207.38	145818.62	187323.78	327529.65	
J1 Turret Platform	262.57	231495.3	175541.4	400094.42	
J2 arm	621.64	6149913.73	227942.55	6361145.43	
J5 housing	228.32	109728.47	313093.13	352231.85	
J6 Main Bearing Arm	202.74	52375.78	296794.03	342465.5	
Total Mass =	2077.28				

Teams

- Each team will focus on different subassembly of robot
- The PDF drawing file for components to optimize each subassembly will be provided to each team
- Important to note that each subassembly of the robot faces different design challenges. Think about the loading and thermal conditions thoroughly!

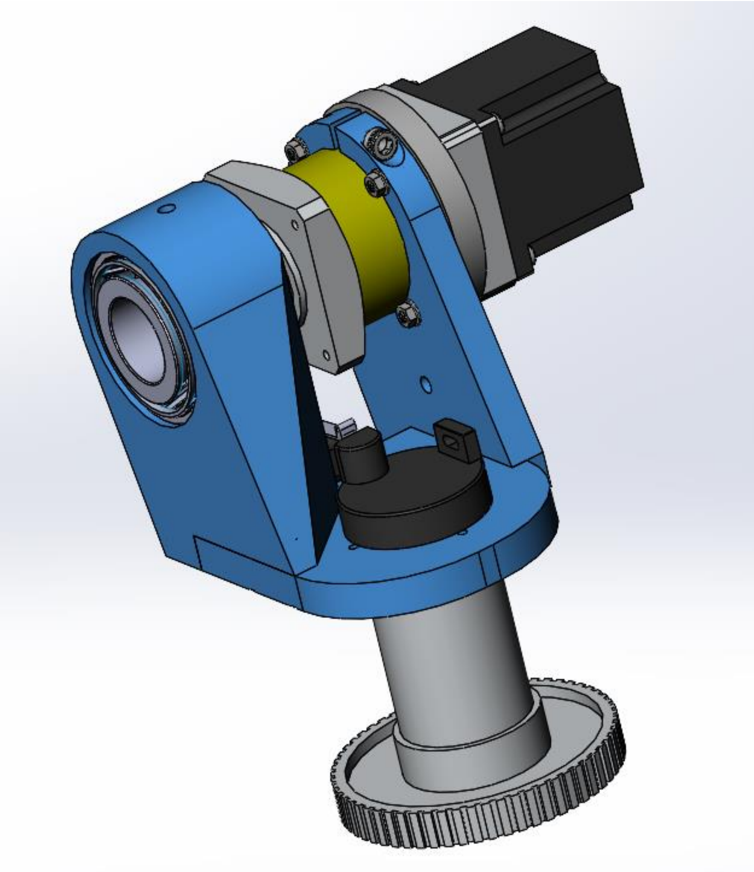


A Quick run through of each subassembly



1

Sample support condition – Link 1



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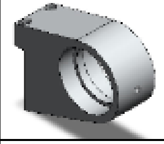
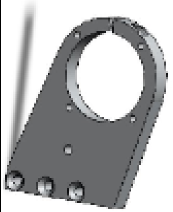
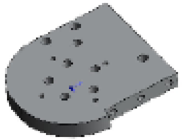
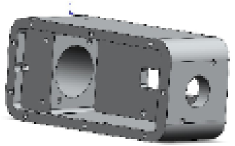
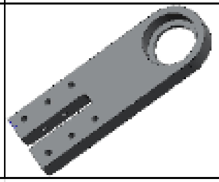
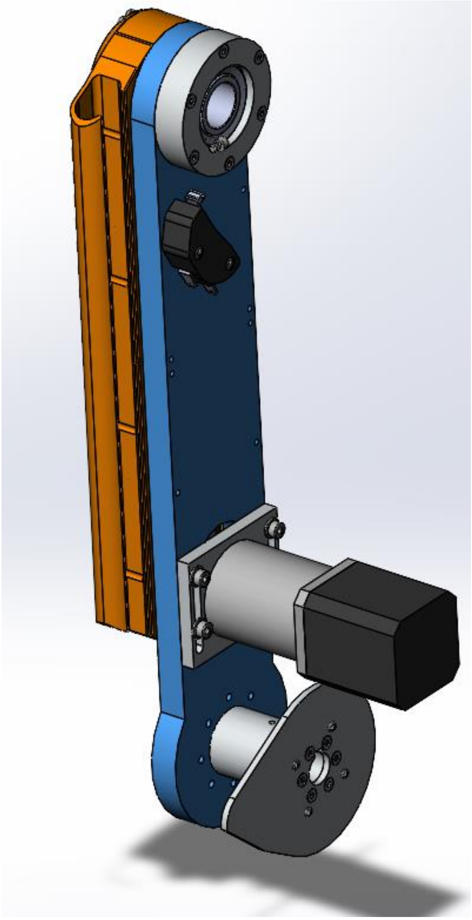
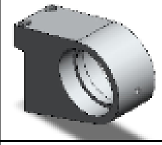
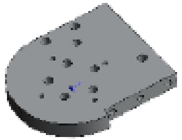
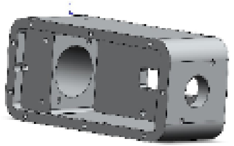
J2 Turret housing	554.63	411415	574800.17	836954.3	
J2 Motor Support	207.38	145818.62	187323.78	327529.65	
J1 Turret Platform	262.57	231495.3	175541.4	400094.42	
J2 arm	621.64	6149913.73	227942.55	6361145.43	
J5 housing	228.32	109728.47	313093.13	352231.85	
J6 Main Bearing Arm	202.74	52375.78	296794.03	342465.5	
Total Mass =	2077.28				

TEAM 1

2

Sample Support Condition – Link 2

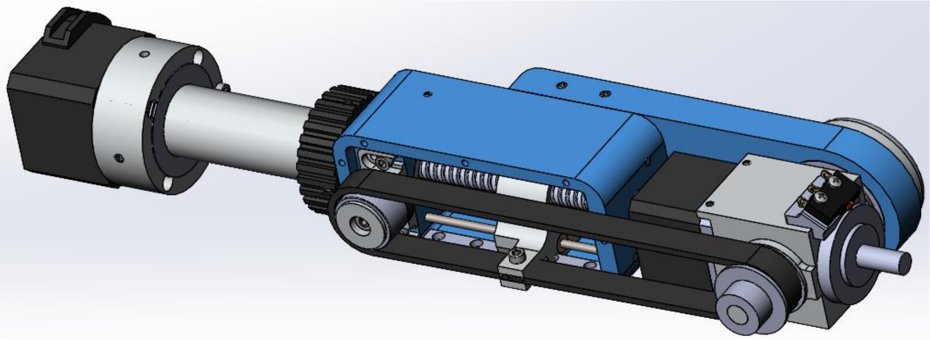


Name of component	Mass (g)	Ixx (g *sq mm)	Iyy (g *sq mm)	Izz (g *sq mm)	Image
J2 Turret housing	554.63	411415	574800.17	836954.3	
J2 Motor Support	207.38	145818.62	187323.78	327529.65	
J1 Turret Platform	262.57	231495.3	175541.4	400094.42	
J2 arm	621.64	6149913.73	227942.55	6361145.43	
J5 housing	228.32	109728.47	313093.13	352231.85	
J6 Main Bearing Arm	202.74	52375.78	296794.03	342465.5	
Total Mass =	2077.28				

TEAM 2

3

Sample Support Condition – Link 4



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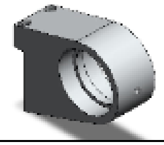
J2 Turret housing	554.63	411415	574800.17	836954.3	
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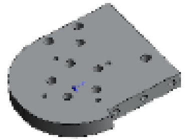
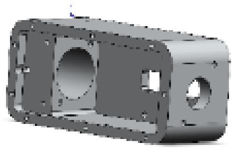
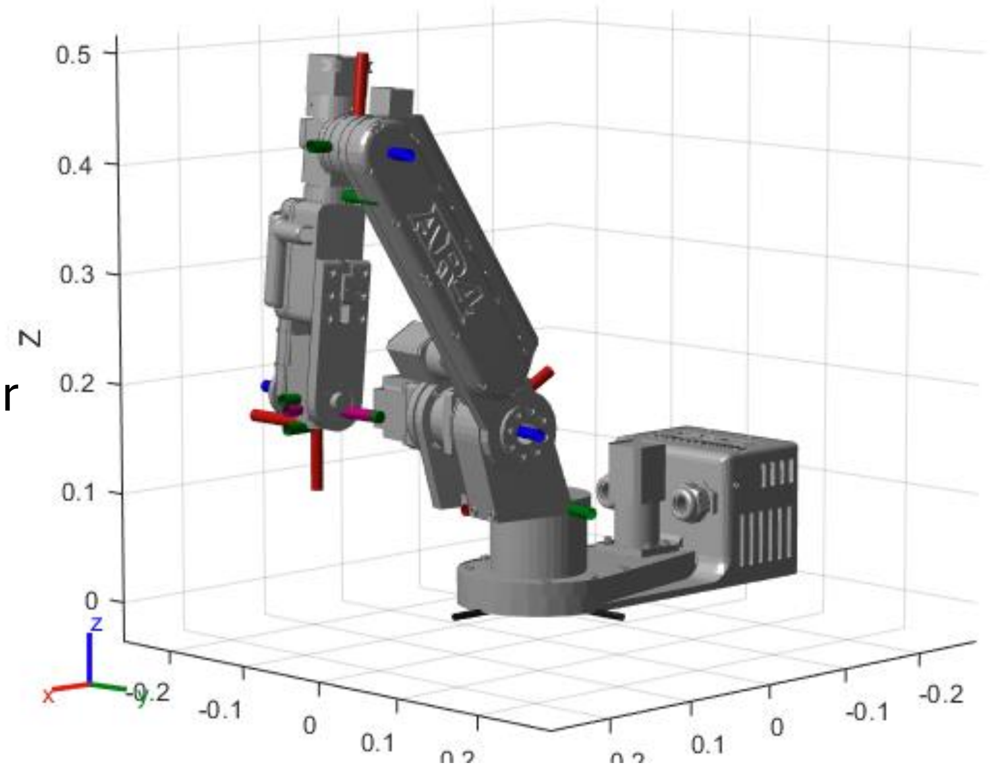
J1 Turret Platform	262.57	231495.3	175541.4	400094.42	
J2 arm	621.64	6149913.73	227942.55	6361145.43	
J5 housing	228.32	109728.47	313093.13	352231.85	
J6 Main Bearing Arm	202.74	52375.78	296794.03	342465.5	
Total Mass =	2077.28				

TEAM
3

Structural load estimation

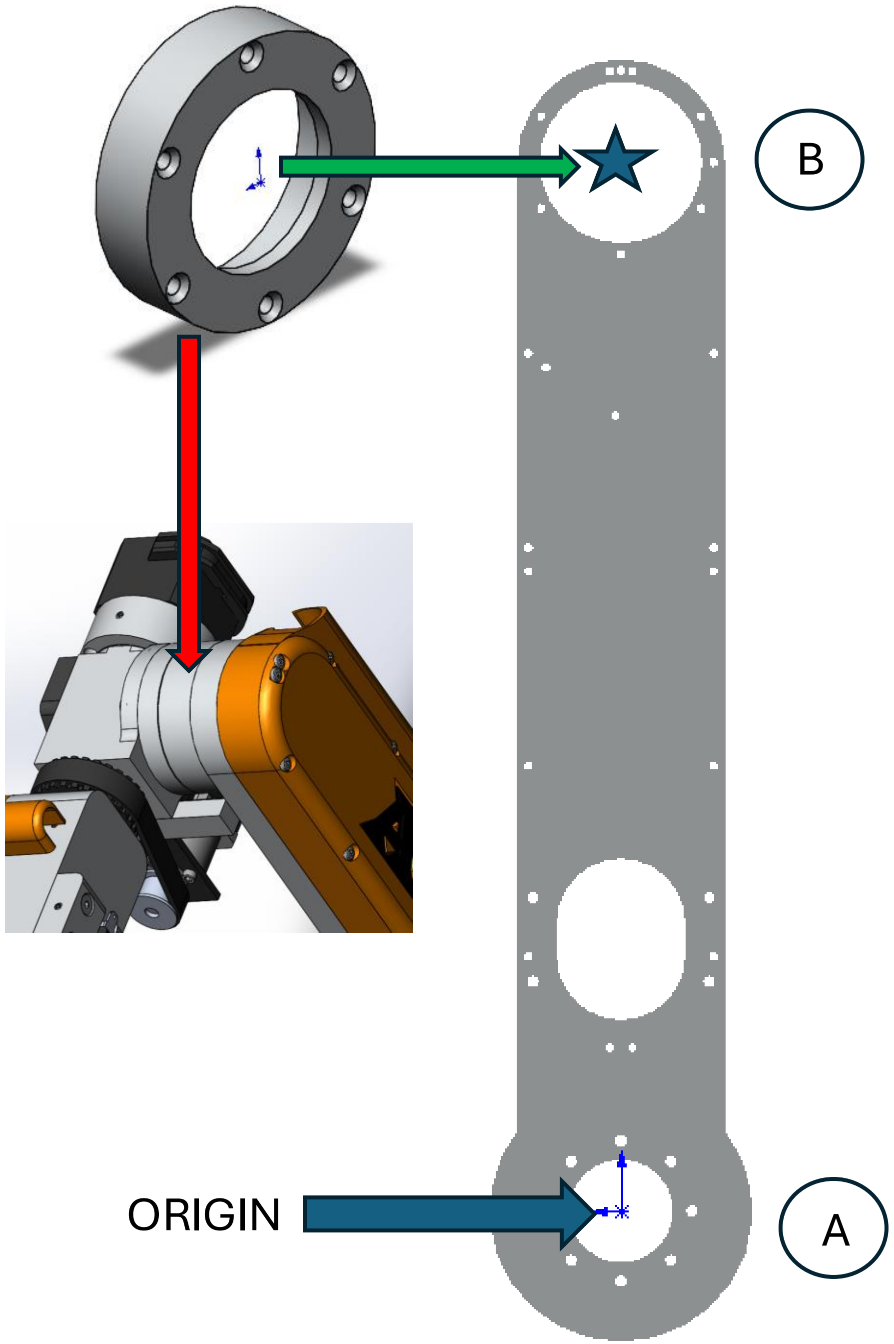
- First, your team should optimize design using unit load testing
- Secondly, you may refine your design based on load/torque estimates (this is to reduce overengineered design concepts)
- Estimating load and torque conditions:
  - A Matlab function is provided for each team to explore loading and torque conditions independently
  - Choose Ideal work region (for example, set waypoints for drawing a cube)
  - Check to see if positions make sense.
  - Payload at end effector (set to up to 2 kg)
- Consider :
  - maximum payload of the robot
  - Torque ratings of each motor
  - Factor of safety
  - Posture of robot



Additional stage: Design refinement

FEA analysis procedure

- Step 0) Determine torque and load @ joint for given posture of robot.
- Step 1) Freeze link at its origin in FEA.
- Step 2) Applied estimated load & Torque at a direction @ origin of succeeding joint/link.
- Step 3) Note deflection in X, Y, Z axes and 3 angular deflections w.r.t each axis and compare to maximum allowed deflection.
- Step 4) Record Factor of Safety achieved.



Optimization

- Shape optimization approach
  - Add/remove material in any locations to increase stiffness, if there is enough room for the components
  - Different materials can be used to optimise stiffness/weight
  - Consider minimizing inertia
  - Optimise the thermal performance of the robot's links
- Use SolidWorks features
  - Consider *Design Insight* and *Topology Optimization* (see SW tutorial)
  - Topology optimization typically leads to complex shapes that are hard to manufacture, unless maybe with additive manufacturing.
    - You may consider complex geometries made with metal AM / FDM methods
    - Analyse component respectively
  - Regard the optimisation as a starting point to redesign/refine the structure rather than an end point

Report

- Report performance metrics of your robot design in table format early in report
- Reduce mass of robot as much as possible while ensuring deflection does not exceed 10 microns with respect to the x, y and z axis
- Be thorough in your analysis
- Important metrics to consider
    - Link mass (g)
    - Link total moment of inertia (kg.m2)
    - Flexural stiffness (N/mm)
    - Torsional stiffness (N/deg)
    - Maximum von Mises stress divided by the material's elastic limit (%)

Report

- Write brief/scientific report
  - Teams of 4 (+/-1) students
    - No solo/duo submissions allowed, no teams with >5 members
    - Briefly explain role of each team member – in case of serious collaboration problems (e.g., someone not responding to calls for input, failing to attend meetings) notify me **before submission**!
    - For each team, submit only 1 PDF via Blackboard
    - Make sure your names and student numbers are on the front page
    - Due Friday of week 12, 6pm