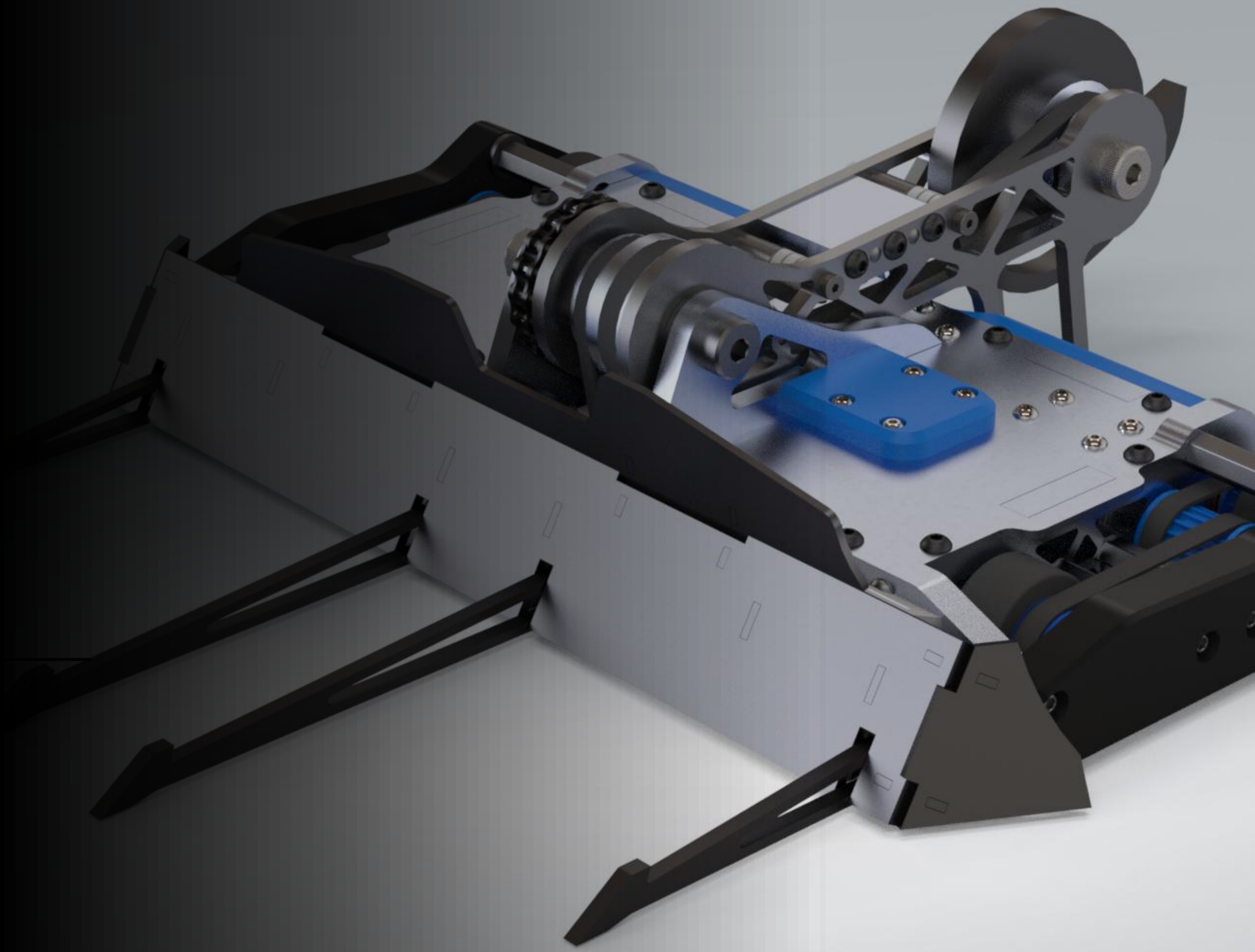
30lb Combat Robot: Colossal Avian

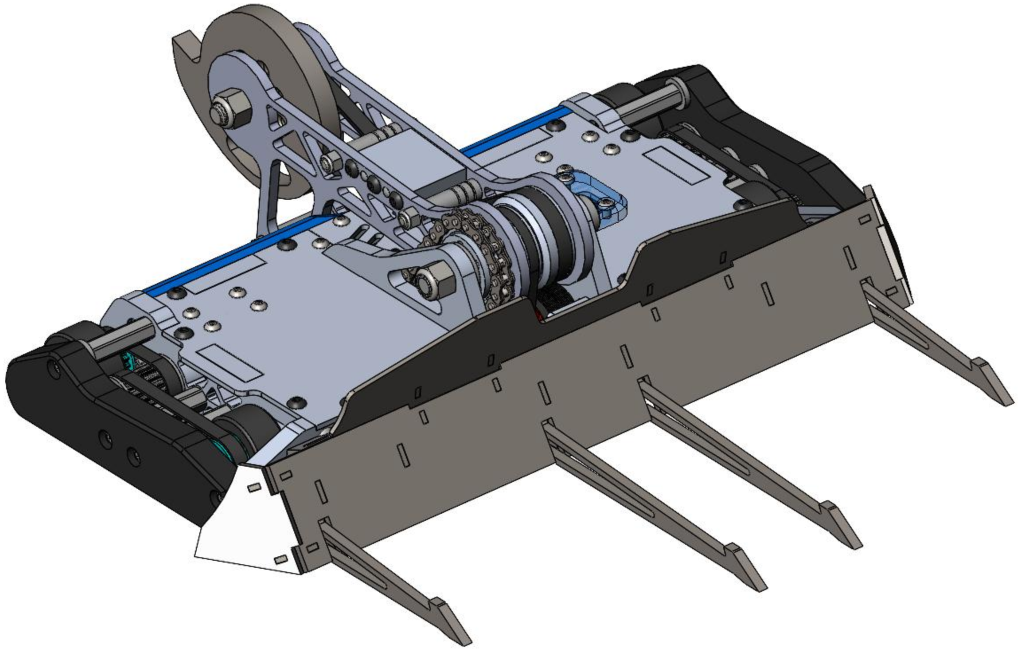


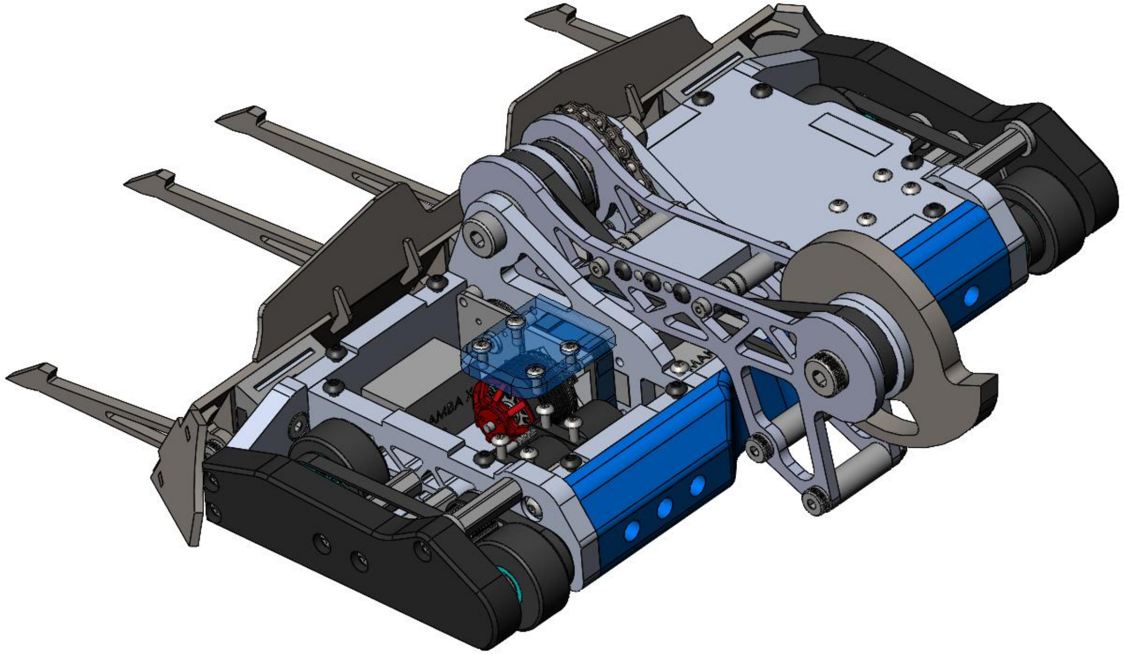
Matthew Zhang

January 3rd 2024

Overview: 30lb BattleBot "Colossal Avian"

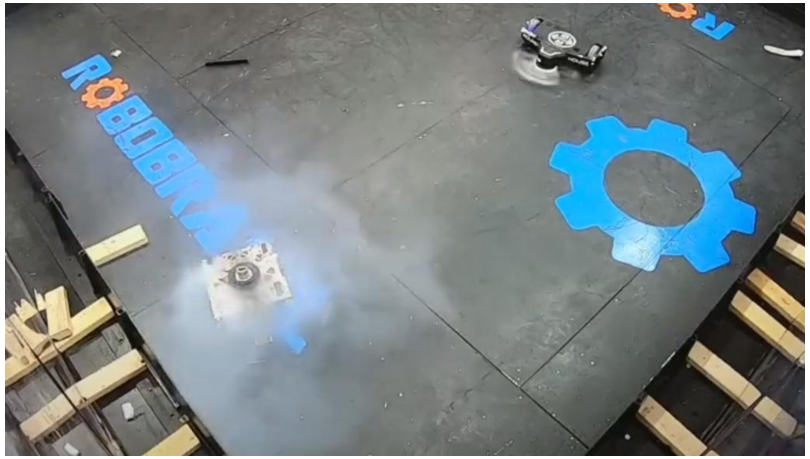
- Swings a high-speed spinning disk mounted to the end of an arm
  - Deals impact damage to opponent top structure
- Personally responsible for structural chassis, drivetrain, and weapon disk/arm powertrain
- Being built for an upcoming competition in late January





Chassis Design Goals

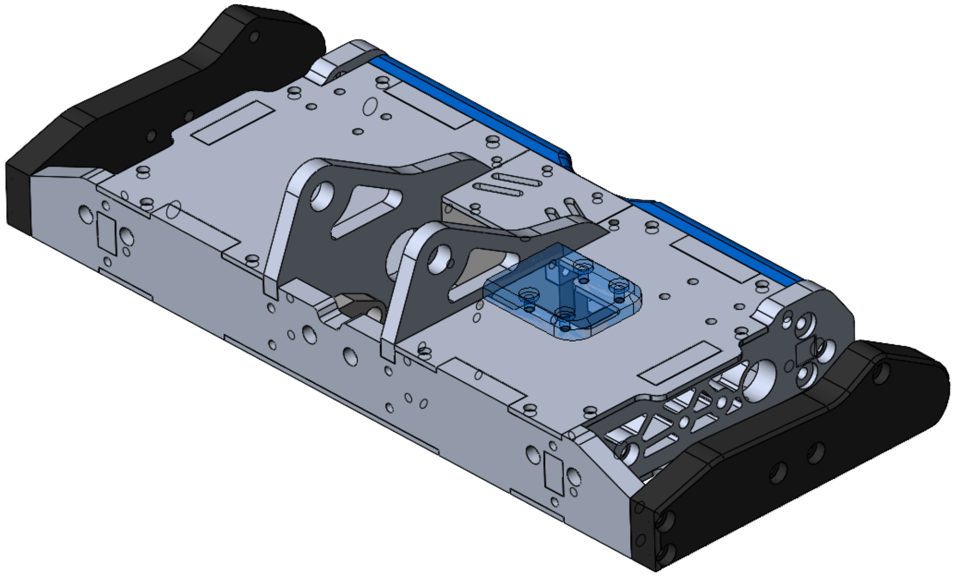
- Protects interior critical components
- Serviceable
- Weight Efficient
- Damage results in non-critical failure modes
- Design for manufacture + cost
  - Limited budget
  - Limited machining capability/skill

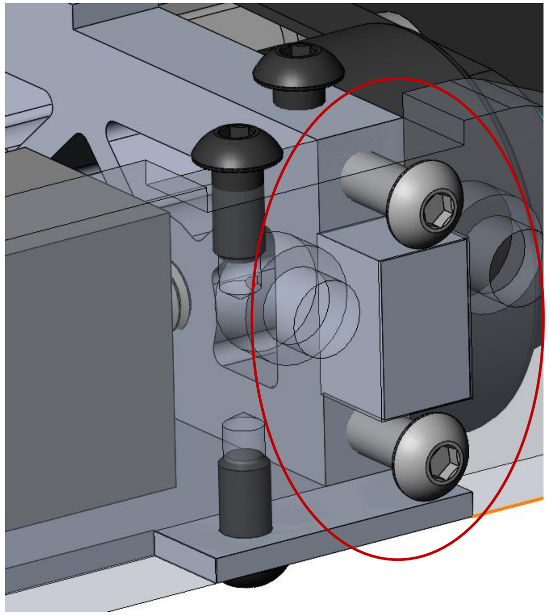


Our previous robot up in smoke, a durable chassis is important!

Chassis Design Summary

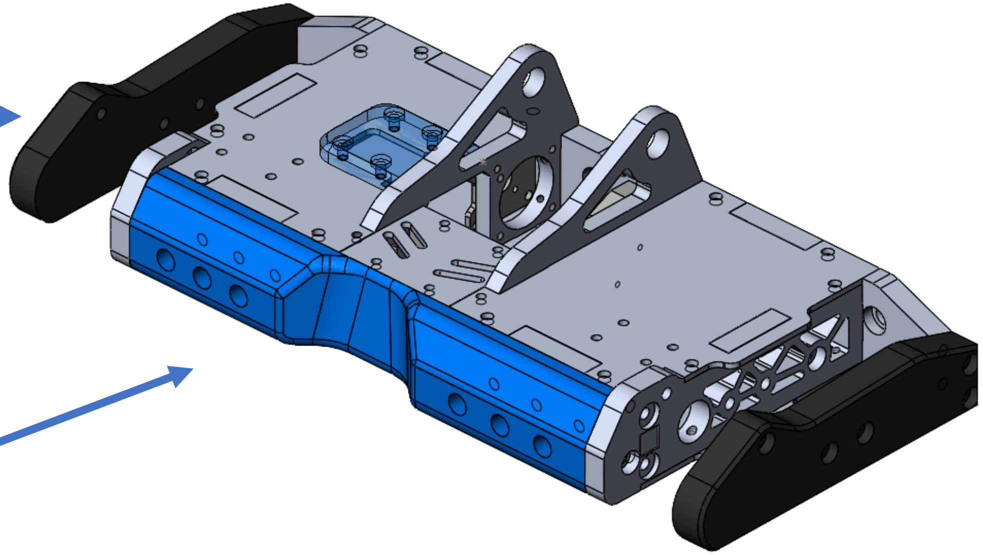
- Aluminum alloy frame (Al 2024-T351)
  - Lightweight and stiff
  - 2024-T351: Relatively high tensile strength and elongation at break
  - Waterjet cut out of aluminum flat stock
  - Joined perpendicularly by drilled and tapped holes
- Tabbed interfaces to prevent loading screws in shear

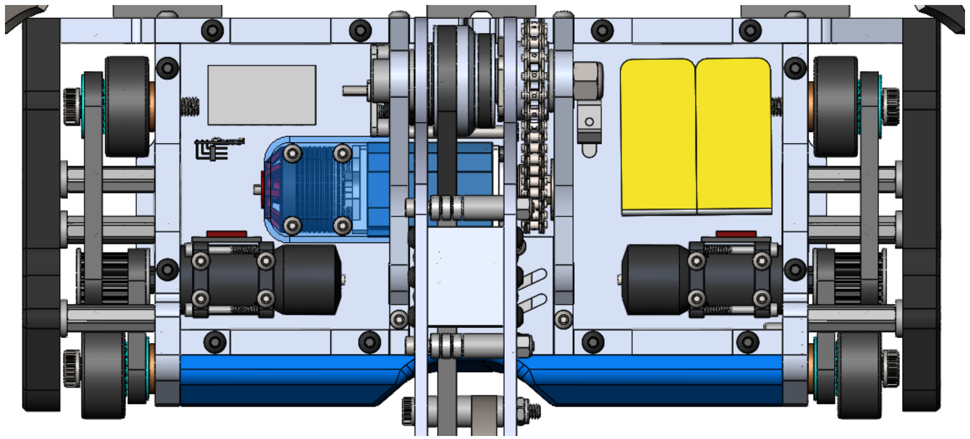




Chassis Design Summary

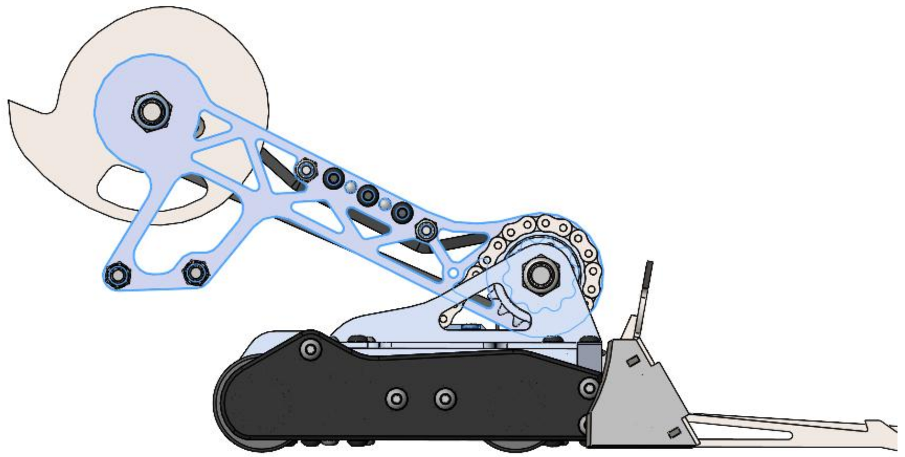
- Sacrificial side armor made of UHMWPE
  - High toughness, gouges on hits rather than cracking
  - Drive functionality not impaired by side armor damage
- Squishy rear armor made of TPU
  - Covers potential rear catchpoints
  - Flexibly material absorbs impact energy
- Top panels easily removable for access to electronics

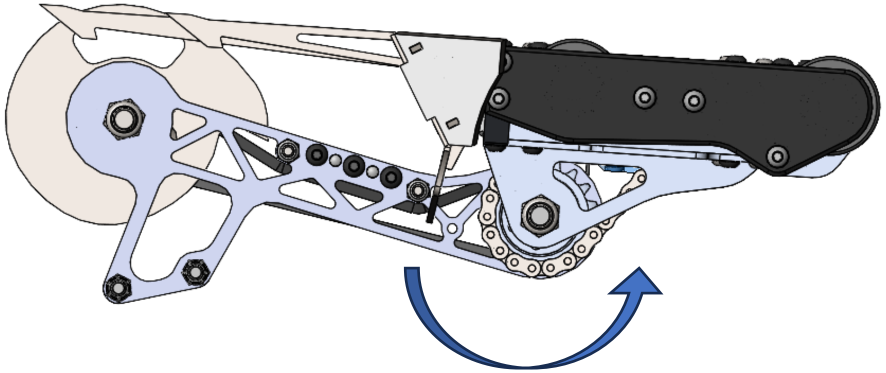




Arm Powertrain: Design Goals

- Swing arm with maximal acceleration and reach a high striking velocity
  - Swing time under 0.25 seconds
- Arm needs to have enough torque to right the robot when upside down
  - Can support 30 lbs at end of arm (r = 220mm)
  - Minimum torque = 29.3 Nm
- Mounting structure and components need to be strong enough to resist high torques induced by swinging the arm





Arm Powertrain: Feasibility Calculations

- Avg angular velocity to swing 180 deg in 0.25s = 12.57 rad/s
- Self-righting torque = 29.3 Nm
- Required power = 29.3 Nm * 12.57 rad/s = 370 Watts
- Candidate motors at target size/weight far exceed required spec

BA3520-970Kv Motor	
Max Continuous Power	2000 W
Max RPM	21k RPM
Weight	224 g

Arm Powertrain: Calculations

1. Determine motor torque from motor constants
2. Select and optimize gear ratio
   - Compute arm acceleration from torque and MOI
   - Excessive reduction: Arm reaches top speed quickly, but final speed is low
   - Insufficient reduction: Arm does not reach top speed before end of swing
   - Adjust gear ratio such that maximum velocity is reached shortly before swing is completed
3. Determine loading on components
   - Chain tensile force determined from maximum torque and sprocket diameter

$$K_t = \frac{K_v}{1352}$$

$$\tau = K_t * I$$

Assumptions:

- Gravity exerts constant torque on arm
- Motor provides constant torque

$$\tau = I\alpha$$

$$\theta = \frac{1}{2}\alpha t^2$$

$$\omega = vt$$

$$\tau = F \; x \; r$$

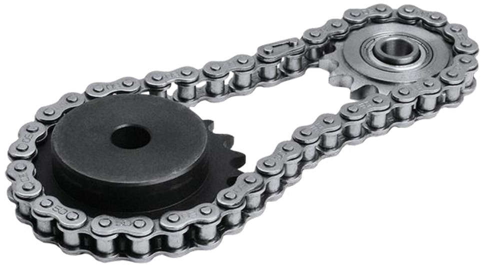
Arm Powertrain: Final Parameters

Known Design Parameters		Calculated Parameters		Target Parameters	
Motor Kv	970	Total Gear Ratio	72:1		
Motor Current	90 A	Arm Max Output Torque	63.85 Nm	Self-righting Torque	29.3 Nm
Arm Length	220 mm	Arm Swing Time	0.10 s	Target Swing Time	0.25 s
Weapon Disk mass	2 lbs	Chain Tension at Max Torque	2100 N		

- Selected gear ratio achieves and exceeds initial design goals
- Knowing the output loads (torque + tension), powertrain components can be selected and sized

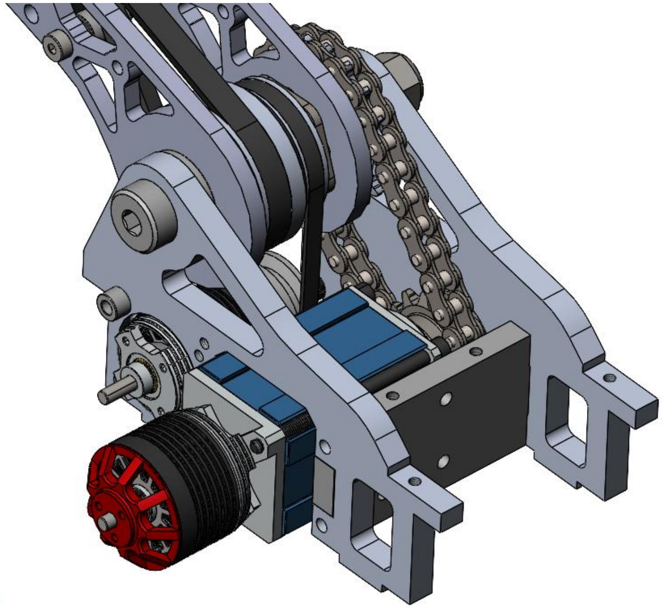
Arm Powertrain: Component Selection

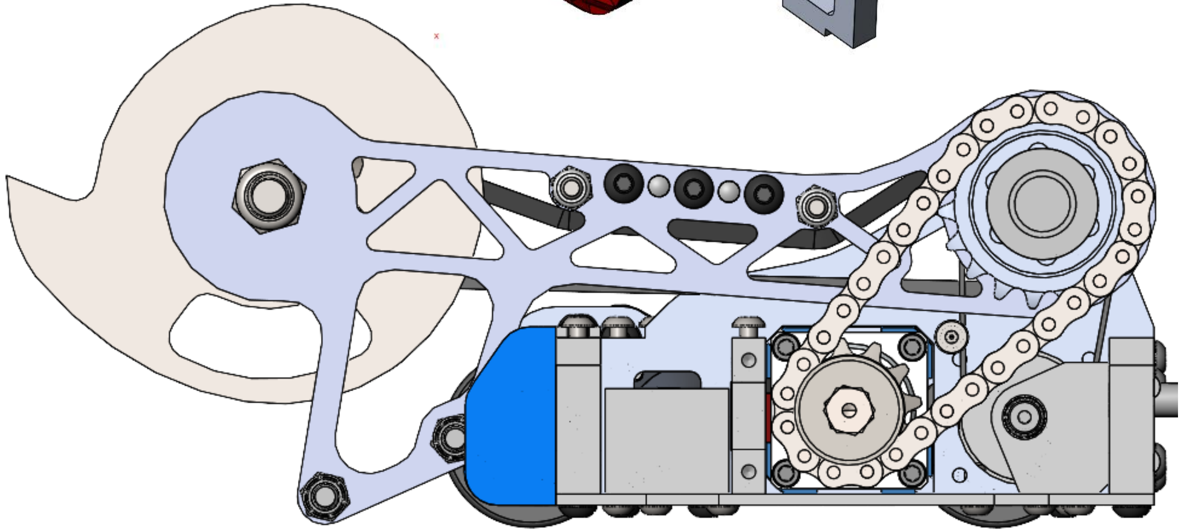
- Gear ❌
  - **Fixed center-center distance**
  - **Hard to package**
- Timing Belt ❌
  - Lightweight, flexible center-center distance
  - **Insufficient load rating**
    - HTD5 Timing Belt Working Tension = 17.8 N/mm width
- Chain ✅
  - #35 Chain working load = 560 lbs = 2500 N
  - **Heavier than belt, but withstands required loads**



Arm Powertrain: Components + Final Design

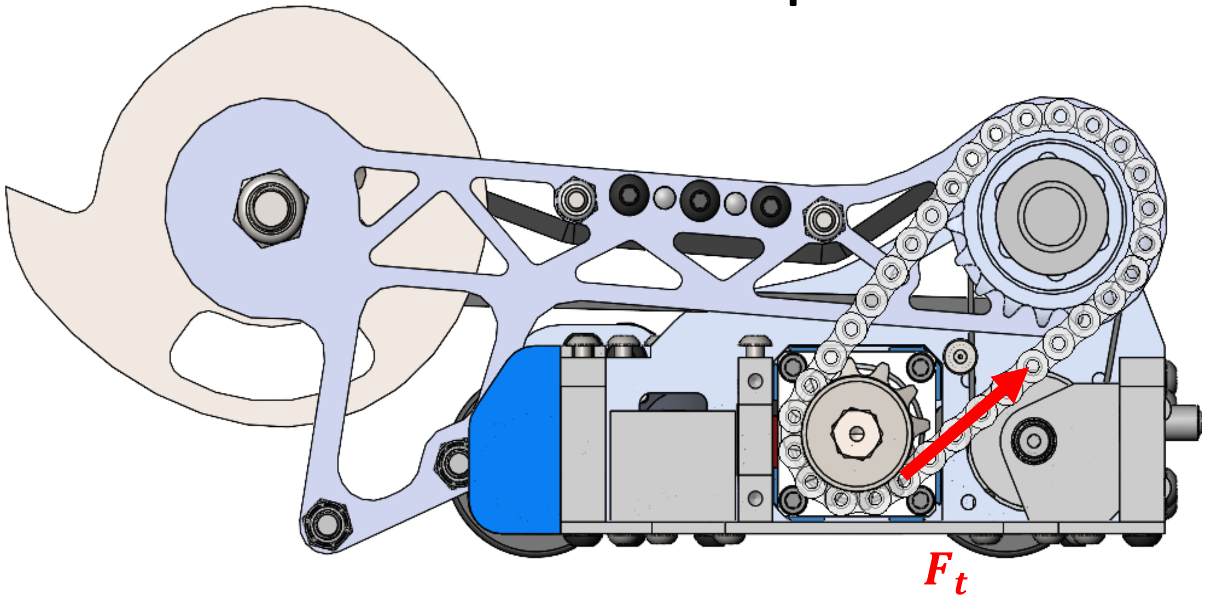
- Aluminum upright panels
  - Aligned parallel to load path to reduce moment loads
  - Keying features keep uprights located within frame
- 48:1 Gearbox for compact reduction, with final 3:2 #35 chain reduction
- Gearbox body is encapsulated in upright panel, providing extra support

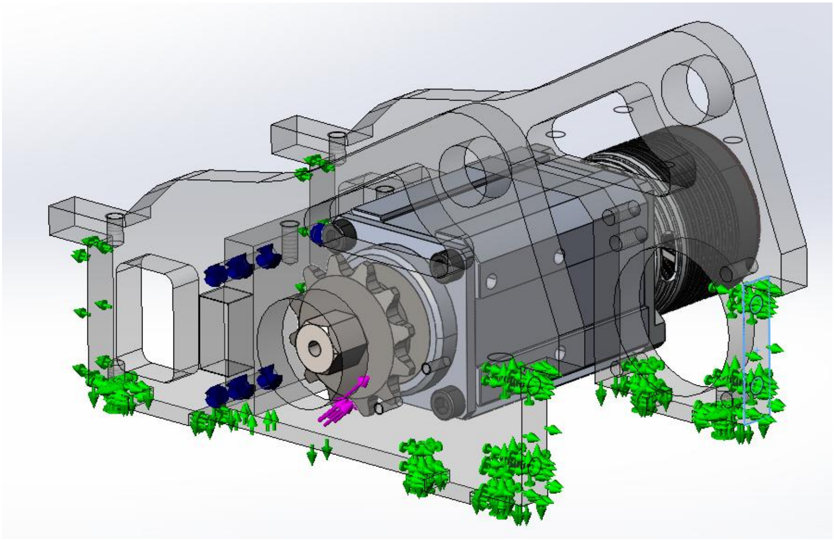




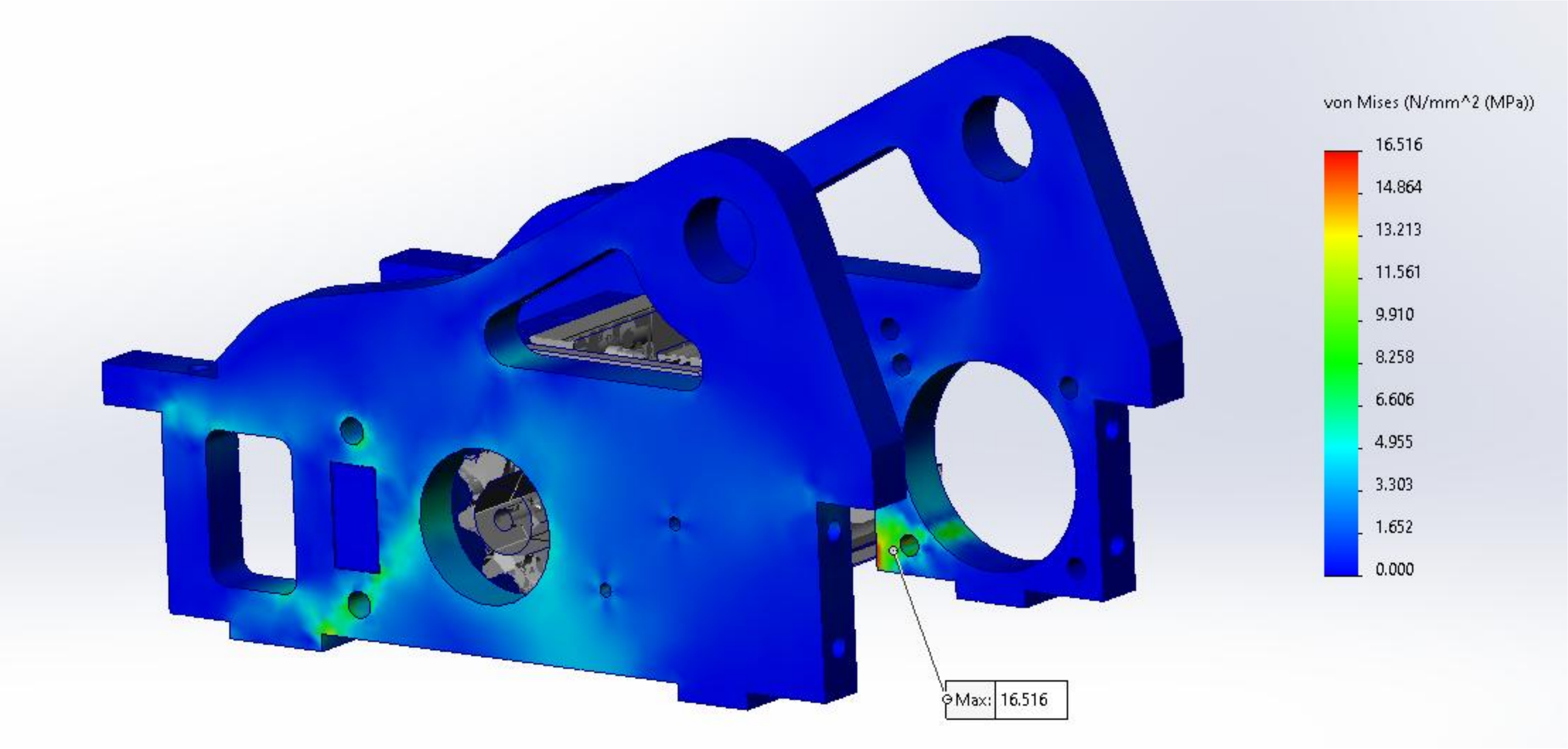
Arm Powertrain: Design Validation Setup

- F_t = 2100 N
- Defined frictionless supports where upright panels interface with the rest of the chassis to simulate contact
- Fixed supports at screw points
- Assume gearbox assembly is a rigid body
- Utilized static structural finite element simulation





Arm Powertrain: Design Validation Results



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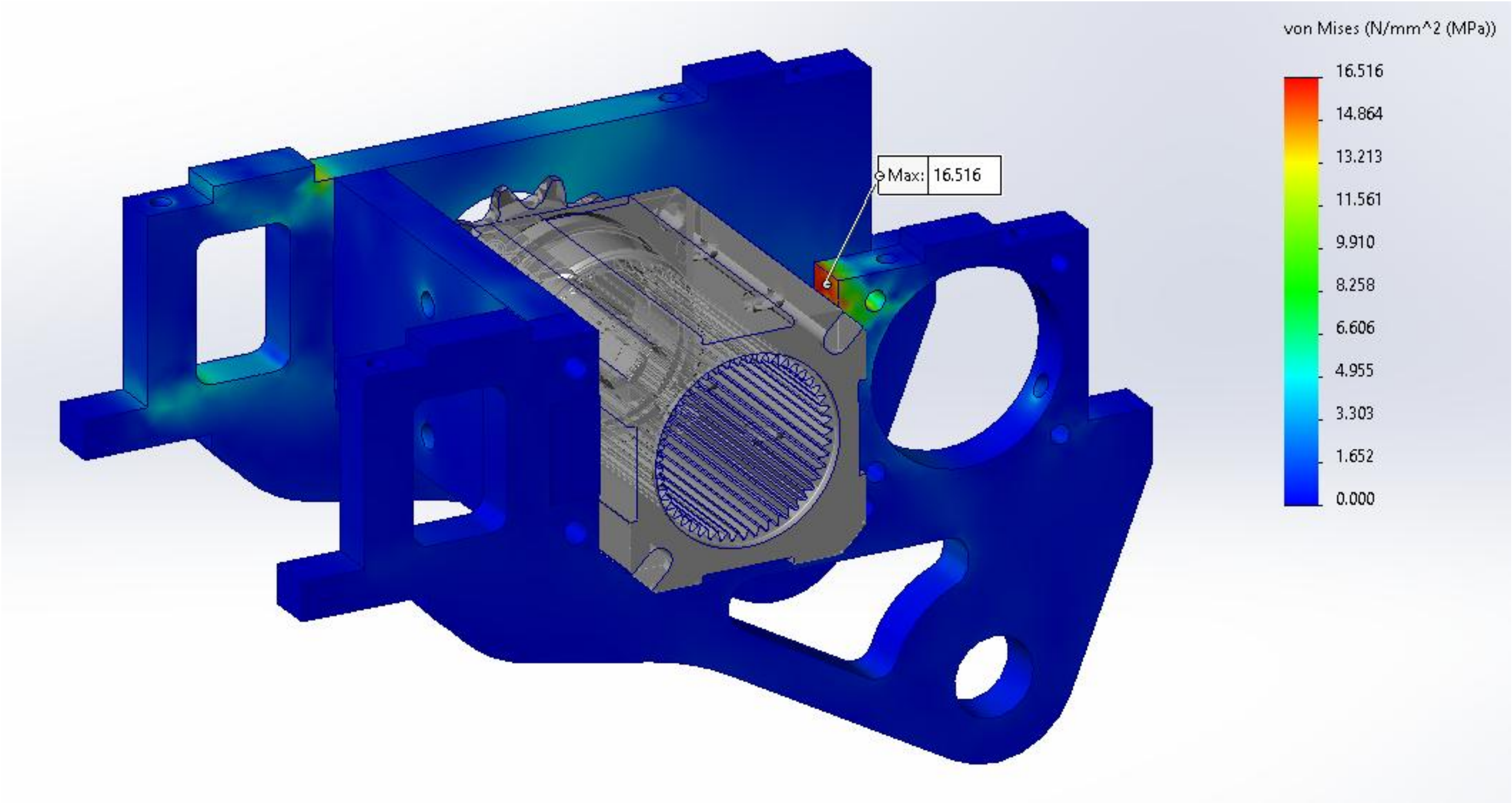

Given yield strength of 2024 Al is 280 MPa, part is unlikely to fail

Arm Powertrain: Conclusion

- Started from initial design goals, verified feasibility
- Optimized high-level design parameters to achieve best performance (minimize swing time)
- Selected power transmission and gearbox according to determined loads and system requirements
- Designed solution based on selected components
- Verified that the assembly is robust and withstands generated forces

Manufacturing in progress…