NAU SAE TOOLBOX

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Engineering 224

Project Description

Department of Mechanical Engineering

- NAU Baja SAE Capstone
- NAU Formula SAE Capstone
- Professor David Willy

Why?

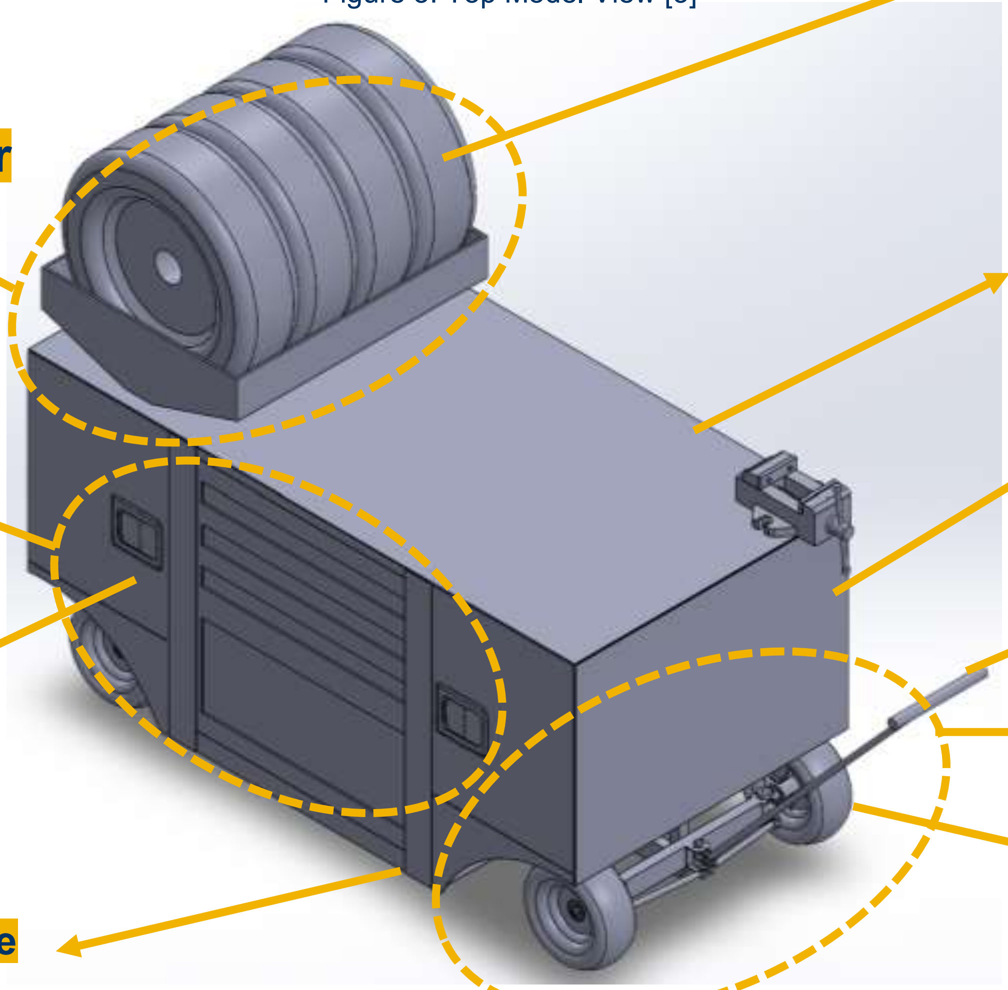
- Yearly SAE collegiate competitions
- Ongoing need for mobile tools and equipment at competition
- Incremental increase from current wagon storage

Figure 1: 2025 Baja SAE Pit Setup

Figure 2: Benchmark/Projected End Goal

Design Description

Figure 3: Top Model View [3]



Frame Sub-Assembly

- 1”x2” Steel base tubing

^ This portion was sponsored

- 1”x1” Steel upwards tubing
- 0.125” (1/8”) Thick
- 60” L x 30” W x 29” H
- Braces where needed
- Reinforced steering mount
- Mig welded

Figure 4: Frame Model View

Steering Sub-Assembly

- 8” eye-to-eye tie-rods
- 35” Long steel tube handle
- Brake lever attached to 10” wide handle
- Separate hubs with axle stub
- ID Bearings in the wheels
- ¾” Through hardware

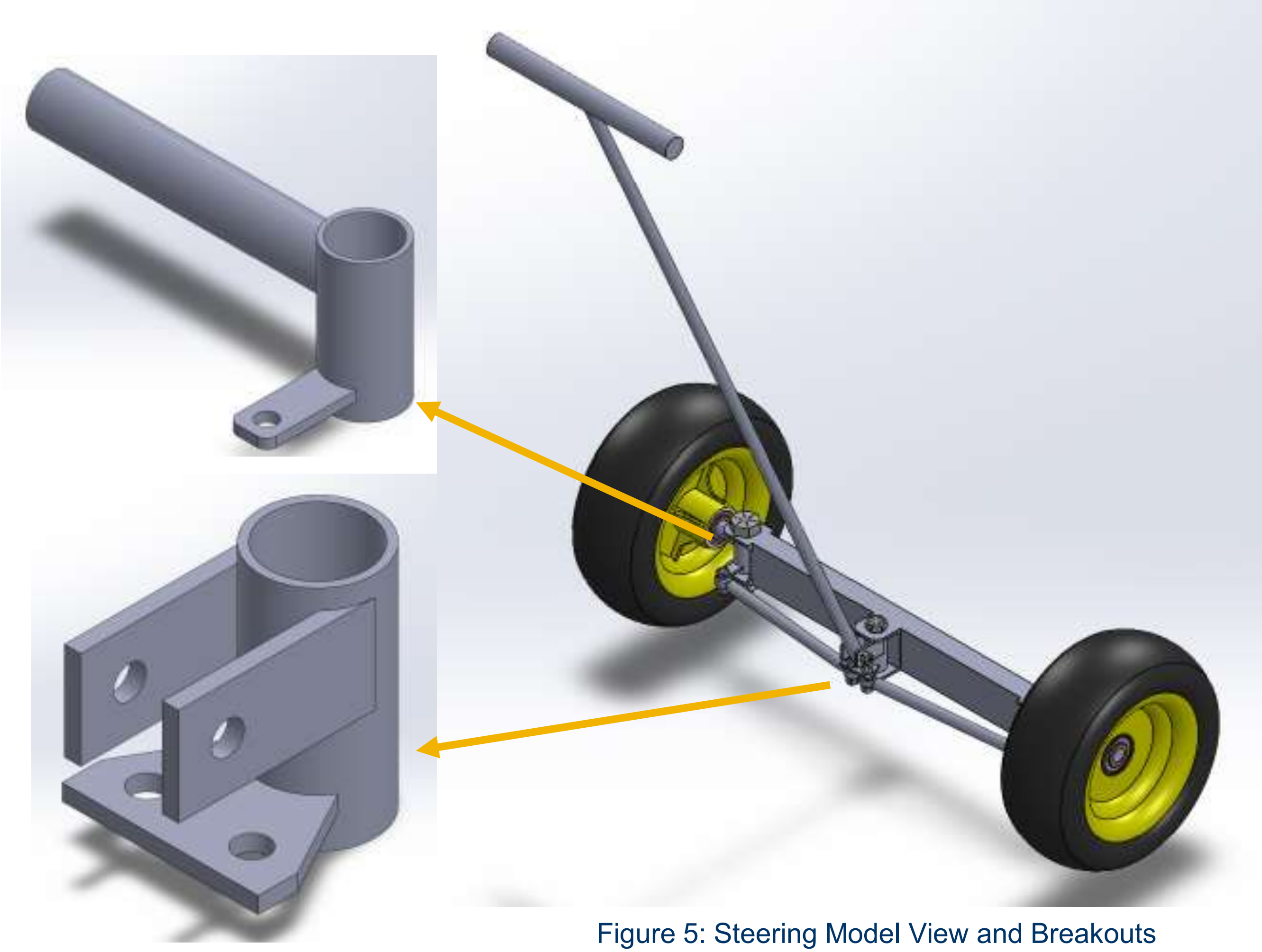


Figure 5: Steering Model View and Breakouts

Tire Carrier Sub-Assembly

- 6061-T6 1/4” Thick aluminum
- 27” long, 21.5” wide
- Holds 4 full size tires (Max 21”)
- Opportunity for center bungee strap
- Easy access loading/unloading
- Lightweight minimalized design

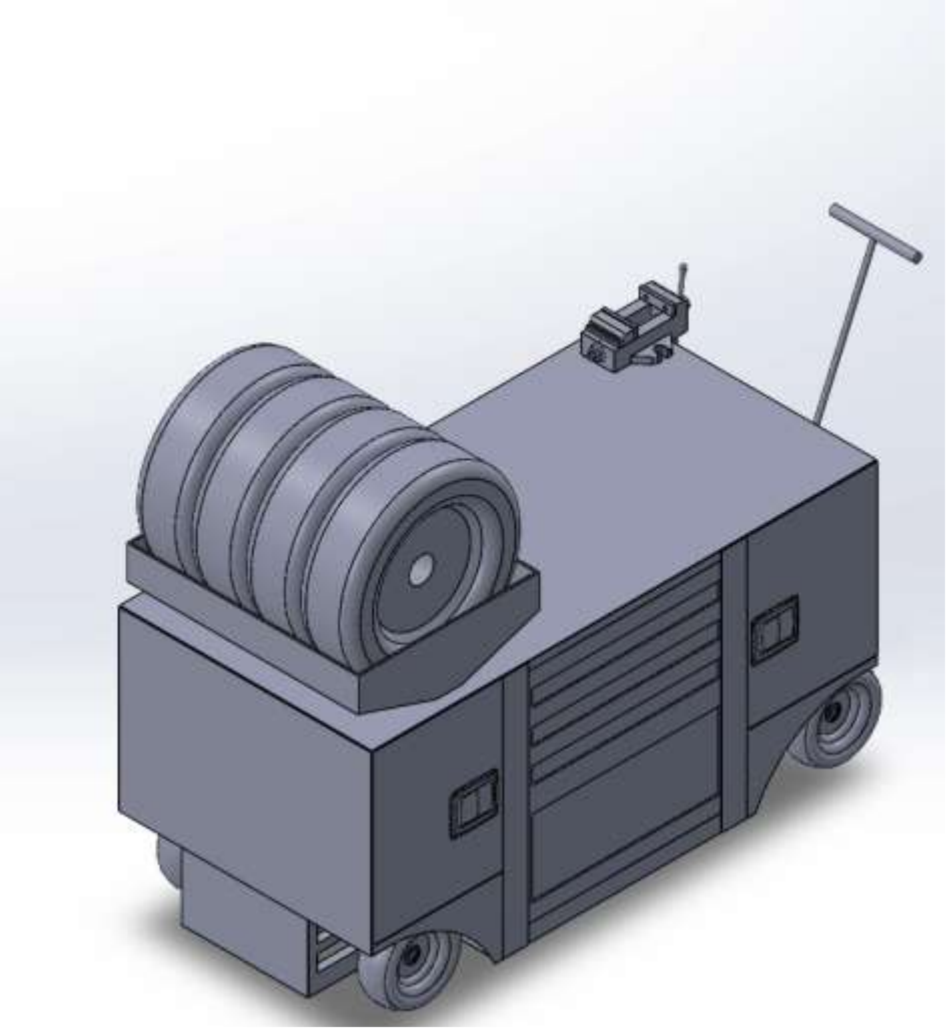


Figure 6: Tire Carrier Model View [10]

Storage Sub-Assembly

- 2 Cabinets left/right of toolbox
- 1 large double door cabinet behind toolbox
- Shelves halfway of 2
- Toolbox drawer storage with foam inserts
- Flush locking door handles
- Hinged aluminum doors

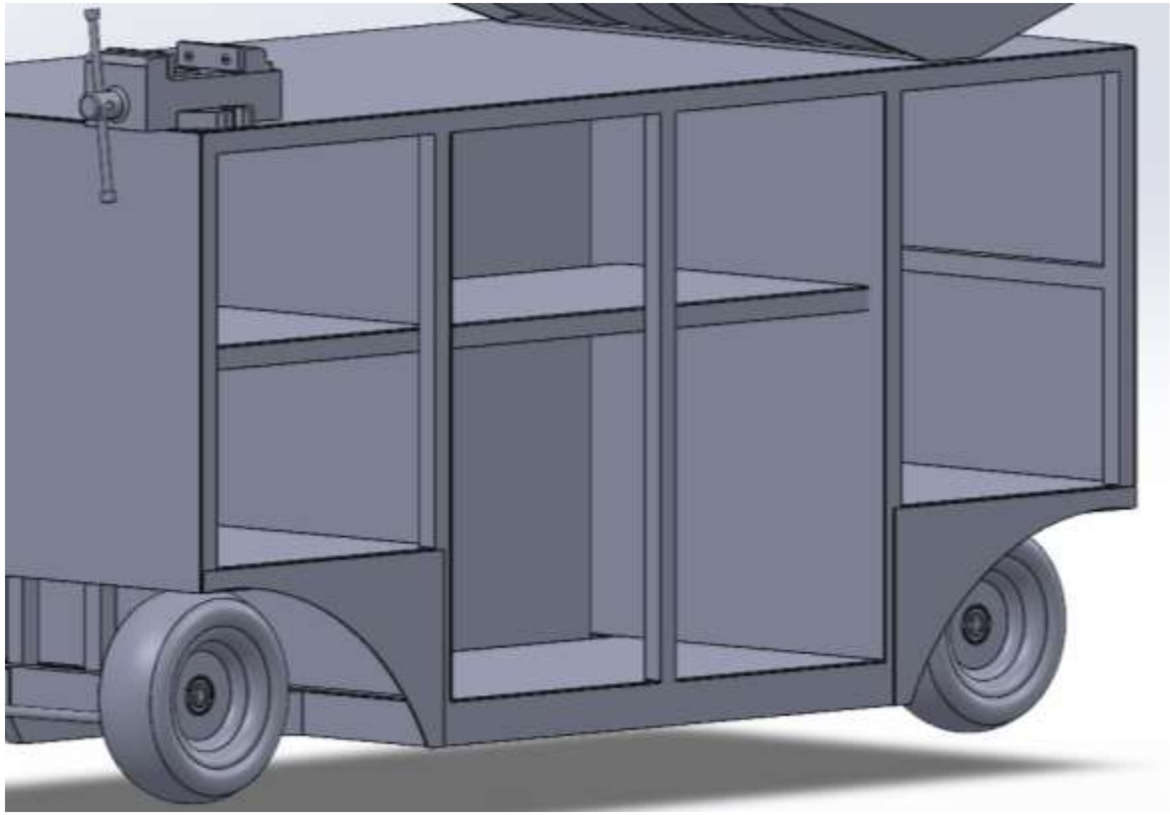


Figure 7: Cabinet Model View

QFD

Figure 8: SAE Toolbox Design Requirements

	Rubber Casters 6" to 10"	Integrated manual steering	Hand Braking/ Locking Wheels	Acceptable Volumetric Footprint in Trailer	Locking Drawers	3'x2'x1' Volume for Driver bag	Fire Extinguisher Mount	Integrated Power System for Tools	Charging Capability	Powered Tools Storage	Sound System (optional)	Mounting locations for vice, arbor press, etc	Shade	Welded Aluminum frame with bolted accessories
Rubber Casters 6" to 10"														
Integrated manual steering	9													
Hand Braking/ Locking Wheels	9	9												
Acceptable Volumetric Footprint in Trailer														
Locking Drawers				6										
3'x2'x1' Volume for Driver bag				6										
Fire Extinguisher Mount														
Integrated Power System for Tools														
Charging Capability								9						
Powered Tools Storage				6	3			9						
Sound System (optional)														
Mounting locations for vice, arbor press, etc				6										
Shade				6										
Welded Aluminum frame with bolted accessories				3	3					3				
Storage for saftey equipment, brake bleed kit, saftey wire puller.				6	9									

Legend	
A	Redline 75" Pit Cart
B	Winter Pit Products
C	DK Hardware

Customer Needs	Customer Weights	Rubber Casters 6" to 10"	Integrated manual steering	Hand Braking/ Locking Wheels	Acceptable Volumetric Footprint in Trailer	Locking Drawers	3'x2'x1' Volume for Driver bag	Fire Extinguisher Mount	Integrated Power System for Tools	Charging Capability	Powered Tools Storage	Sound System (optional)	Mounting locations for vice, arbor press, etc	Shade	Welded Aluminum frame with bolted accessories	Storage for saftey equipment, brake bleed kit, saftey wire puller.	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		Technical Requirements															**Customer Opinion Survey**				
Large Toolbox	4	6	3	6	9	9					6		3		6	3			B		AC
Hold all of driver equipment/ spare wheels + rims	4	6			9		9												AC		B
Mounted items (arbor press, vice, grinding wheel,etc)	4	3			9				3	6	9		9					AC	B		
Price	5	3	3							3		6		6		3	ABC				
Brakes/ steering/ 6-10 inch casters	4	9	9	9															B		AC
Technical Requirement Units		inch	N/A	lbf/ N	ft^3	N/A	ft^3	N/A	Watts	Watts	ft^3	N/A	N/A	ft^3	ft^3	ft^3					
Technical Requirement Targets		10 in	Y	2+	72 ft^3	Y	6 ft^3	Y			2ft^3	Y	3 locations	72 ft^3	Y	2 ft^3					
Absolute Technical Importance		50	50	50	50	30	50	50	30	30	50	10	50	30	50	30	Total Score				
Relative Technical Importance		8%	8%	8%	8%	5%	8%	8%	5%	5%	8%	2%	8%	5%	8%	5%	610				

Added Brake Calculation

Braking Force from Kinetic Energy: [18]

$$F_b = \frac{1}{2}\frac{(227)(2)^2}{3} = 151.33\text{ N} \approx 34\text{ lbf} \qquad (1)$$

Force Balance:

$$F_{b1} * r_1 = F_{b2} * r_2 \Rightarrow F_b \approx 43\text{ lbf} \qquad (2)$$

Spring Rate:

$$k = \frac{d^4 G}{8D^3 N} = \frac{\left(\frac{1}{8}\text{in}\right)^4 (11.5*10^6\text{ psi})}{8\left(\frac{7}{8}\text{in}\right)^3 (13)} = 40.3\text{ lb/in} \qquad (3)$$

Brake Fluid Pressure:

$$P = \frac{F}{A} = \frac{6(30.225\text{ lbf})}{\frac{\pi}{4}(0.4\text{ in})^2} = 1443.14\text{ psi} \qquad (4)$$

Final Breaking Force:

$$F_b = 1443.14(1)^2(.2384) = 344.1\text{ lbf}$$

Figure 9: Miller Custom Fab Cart Brakes [11]

Inverter Calculation

Figure 10: Power Smart Inverter Generator [8]

Power Supply Selection

1. 2500 W Inverter Generator
2. 120 V Power Strip
3. 25 ft Extension Cord

Usage Assumptions

1. Power tool battery chargers
2. Phone chargers
3. Other small electronics (lights, radios)

Inverter Calculation

Usage Duration:
Baja race operation time: 4 hours

Total Energy Consumption:

$$E = P*t = 250W \times 4h = 1000Wh \quad (5)$$

Generator Capacity Check:

- Inverter generator rated output: 2500W
- Actual system load: 250W
- Load Ratio = $\frac{250W}{2500W}$=10%

Table 1: Summarized Power Calculations

Device	Power (W)	Qty	Total Power (W)
Power tool chargers	90W	2	180W
Phone chargers	10W	2	20W
Auxiliary lightings/tools	50W	1	50W
Total Load			250W

Power Calculation Comparison

Previous Calculations:

- Meeting a 4-hour charge supply would require a 12V 185.4Ah battery
- This battery is not readily available in practice.
- We would need to connect 2 - 12V 100Ah batteries in parallel, significantly increasing our cost.

We chose to use a 2500W inverter generator. This decision reduces our overall cost and provides sufficient and reliable power for our needs.

Storage Volume Calculation

Required Parts for Storage

- **Gear bag:**

  3'x2'x1'=10,368 in^3

- **At least 2 helmets:**

  (10"x10"x12")*2 = 2400 in^3

Required Storage Volume: (6)

= 12,768 in^3= 7.4 ft^3

Upper Cabinets: (7)

(19.9"x16"x29")*2= 18,467 in^3

Rear Cabinet:

26.9"x27.8"x17"= 12,713 in^3

Toolbox:

26"x24.4"x13"= 8,247 in^3

Rough Total Storage Volume: (8)

39,427 in^3= 23 ft^3

Calculation Summary

Table 2: Summarized Calculations to Date

Subsystem	Initial Values	Intermediate Values	Values to Date	Improvement?	Customer Need Met
Brakes	3200 *lbf*	34 *lbf*	*344.1 lbf*	Yes	Safety and Achievability
Frame	Critical tipping angle: 27.35°	Critical tipping angle: 43.15°	7500 in/lbf bending moment	Yes	Stability
Casters	9 *N*	2.0232 *lbf*	-	No	Different Terrain
Steering	-	2.46 *lbf*	31.3” Radius	Yes	Maneuverability
Power Supply	-	46.4 *Ah*	2500 W	Yes	Power supply
Storage Volume	-	-	$23\ \mathrm{ft}^3$	N/A	Storing required equipment

Design Validations

Table 3: SAE Toolbox FMEA Analysis [7]

Failure Mode	Cause / Effect	Mitigation Strategy
Steering System Failure	Tie rod bending, fastener loosening, handle deformation → Loss of control	SolidWorks motion study validated geometry; reinforced mounts; rod-end bearings tested
Tire Mount/Carrier Failure	Bolt shear or fatigue cracking in aluminum → Tire loss	FEA simulates ~40 lb load w/ vibration; steel or gusseted aluminum considered
Frame Cracking/Weld Failure	Dynamic loads over rough terrain → Structural collapse	Welded steel tubing with cross-bracing under heavy load zones
Drawer Latch Failure	Latches open during motion → Tool ejection, shifting load	Locking latches designed for vibration, similar to Redline unit
Brake System Fatigue	Spring or lever failure → Inability to hold on slopes	Bike brake-style locking lever w/ fatigue-tested springs and cables

Risk Trade-Off Analysis

Strength vs. Weight:

•Steel for structural areas (frame, supports) ensures durability

•Aluminum for non-structural elements (side panels, tire mount) reduces weight

Cost vs. Reliability:

•COTS (Commercial off the Shelf) components used wherever possible to reduce fabrication time and cost

•All design decisions aimed to stay within $2000 budget without compromising function

Testing Procedures

Table 4: ME 486C Tentative Testing

Testing Procedure	Engineering Requirement Met	Equipment Needed	Testing location
Brake application	Safety, fast brake response	Completed cart	Inclined parking lot outside of 98C
Power Supply	Tool charging, supplied power	Inverter generator, gas	NAU Machine shop 98C
Turning Radius	Able to maneuver swiftly/easily	Completed cart, SAE enclosed trailer	NAU Machine shop 98C
Weight capacity	Able to withstand loads	Various heavy objects	NAU Machine shop 98C
Equipment fitment	Able to store tools, tires, driver suits/helmets	Completed cart, driver equipment, tools, tires	NAU Machine shop 98C
Correct tools	SAE teams can go through tech with the provided tools	Tools and toolbox	NAU Machine shop 98C

Schedule

Gantt Chart SAE Toolbox

7/17 - 12/11/2025 Schedule

Owner	ACTIVITY	PLAN START	PLAN DURATION	DUE DATE	ACTUAL DURATION	PERCENT COMPLETE
All	Peer Eval 2	17-Jul	1	16-Jul	1	100%
Derek	Brake System Prototype	17-Jul	7	24-Jul	5	100%
Hailey	VR CAD Prototype	17-Jun	7	24-Jul	8	100%
Yanbo	Website Check #1	8-Jul	2	24-Jul	3	90%
All	Peer Eval 3	19-Jun	1	24-Jul	1	100%
Haoran	2nd Prototype	18-Jul	10	30-Jul	7	25%
All	Presentation 3	18-Jul	20	31-Jul	8	25%
All	Final BOM	24-Jun	15	1-Aug	12	75%
Yanbo	Website Check #2	8-Jul	1	1-Aug	1	50%
All	Report #2	18-Jul	20	1-Aug	12	50%
All	Peer Eval 4	25-Jul	1	1-Aug	1	0%
Hailey	Final CAD	17-Jul	20	5-Aug	15	40%
All	486C Kickoff	25-Aug	2	25-Aug		0%
All	Individual Analysis'	28-Aug	4	1-Sep		0%
Hailey	Eng Model Summary	1-Sep	8	8-Sep		0%
Yanbo	Website Check #1	1-Sep	1	8-Sep		0%
Derek	Testing Plan Start	10-Sep	3	22-Sep		0%
Haoran	UGRADS Registration	20-Sep	1	22-Sep		0%
All	UGRADS Poster Draft	1-Oct	12	13-Oct		0%
Derek	Finalized Testing Plan	15-Oct	12	20-Oct		0%
All	Final Powerpoint	1-Nov	8	11-Nov		0%
Haoran	Initial Testing Results	8-Nov	6	18-Nov		0%
Hailey	Product Demo	15-Nov	2	24-Nov		0%
Derel	Final Testing Results	20-Nov	6	5-Dec		0%
All	Final Report	21-Nov	8	5-Dec		0%
Hailey	Final CAD Packet	26-Nov	10	5-Dec		0%
Yanbo	Final Website Check	1-Dec	2	7-Dec		0%
All	Client Handoff	5-Dec	8	8-Dec		0%

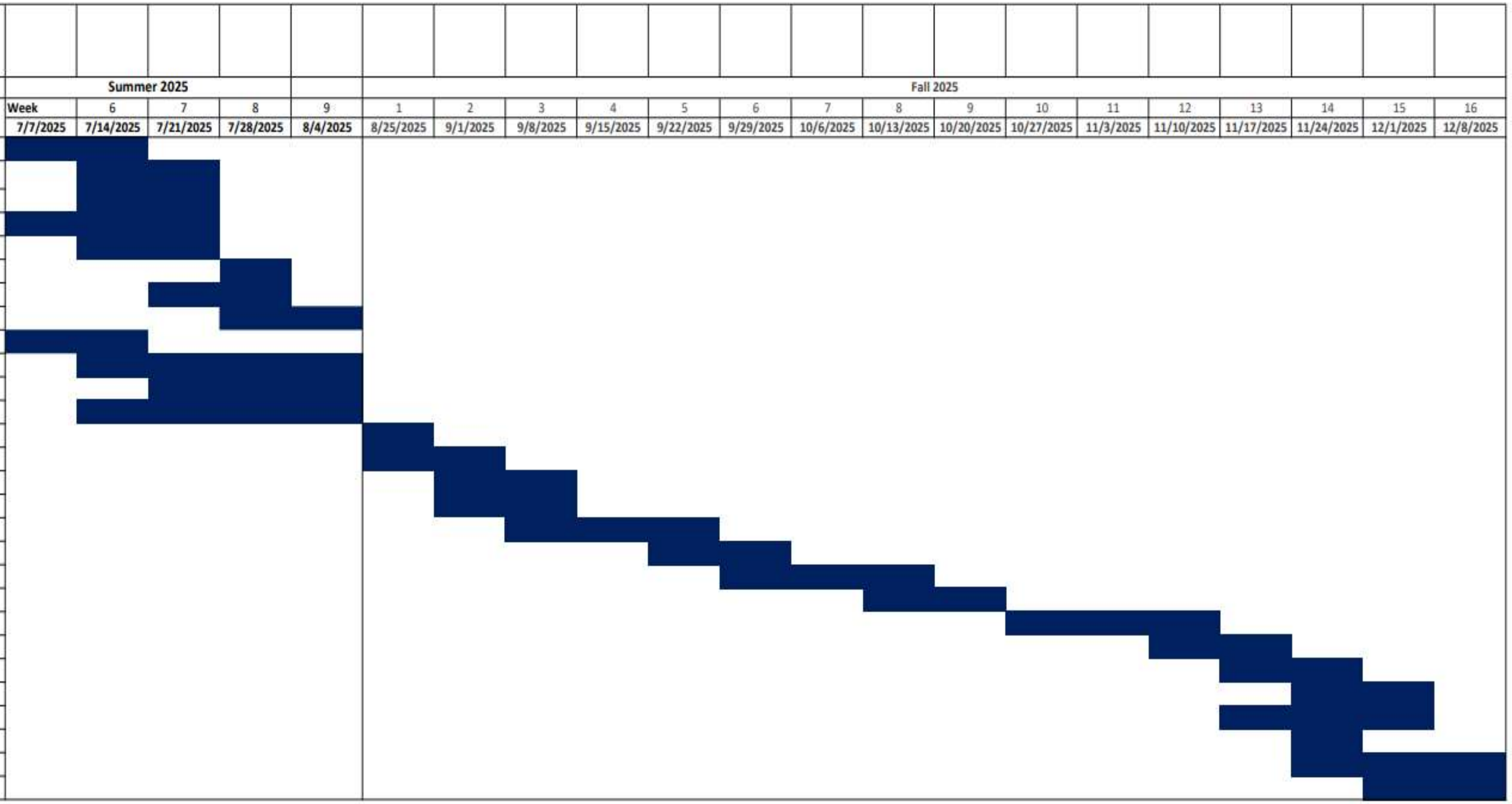


Figure 11: ME 486C Tentative Schedule

Fundraising

- Proposals sent to 67 total companies
- Tier system for logo size/placement
- In-kind parts sponsorships
- Monetary sponsorships
- **$1,651/1000** Raised

Figure 12: SAE Toolbox Sponsorship Tier

Budget

Anticipated Expense Ranges:

- Toolbox ($125-350)
- Tools ($130-250)
- Casters ($50-200/4)
- Brakes ($60-150)
- Power Supply ($320-500)
- Frame Steel ($50/6ft)
- Shade ($120-250)
- Aluminum Panels ($15/12x24in)

Actual expenses:

- Toolbox + Tools ($250)
- Vice + Extinguisher ($54)
- Casters + Frame + Steering ($0)
- Inverter Power Supply ($320)
- Pull out shade ($90)
- Aluminum panels ($120)
- Steel square tubing ($200)
- Brakes ($100)

Resulting Balance:

$ = $1,387

Thank You

Questions?

Prototype 2

Subsystem Checklist

Table 1: Modeling Check and Requirements

Subsystem	Physical	Virtual	Client/ER Requirement
Brakes	-		Needs to brake quickly and safely
Steering		-	Needs to be able to be driven by one person
Toolbox/Cabinets	-	-	Needs to store required tools/equipment/extras
Casters		-	Needs to have a minimum of 8” casters for terrain
Power System		-	Needs to power battery chargers/phones/extras
Base Frame		-	Needs to be durable and as small as possible for trailer storage
Tire Storage	-	-	Needs to carry both Baja and Formula sized tires

Physical Prototype

Scaled (1:6.5) Tool cart outer shell and cabinets

Model Size: L=9.23”, W=4.62”, H=4.92”

Final Design: L=60”, W=30”, H=32”

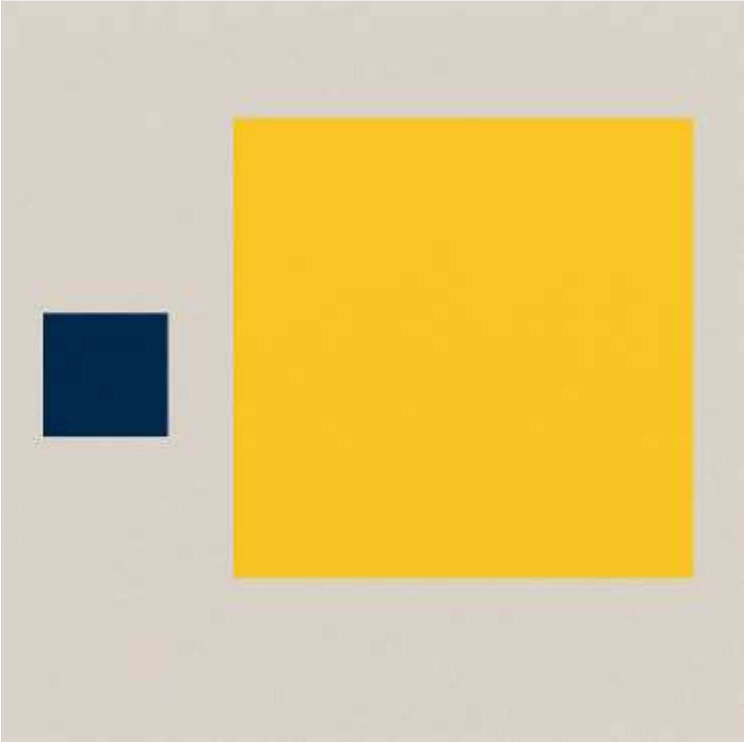


Figure 1: 1:6.5 Model Representation

Question

1. What is the volume of the cabinets
2. Where can we put things on the outside for the best function

   (fire extinguisher, vice, shade, tires)

Prototype Images

Figures 2 & 3: Views of prototype

Prototype Volume Calculations

Prototype Measurements:

- Length = 9.23 *in*
- Width = 4.62 *in*
- Height = 4.93 *in*

Full Scale Measurements:

- Length = 60 *in*
- Width = 30 *in*
- Height = 32 *in*

Model Cabinet Volume Calculation: (1)

$$V = (39{,}427\ \mathrm{in}^3 / 6.5) = 6{,}065\ in^3$$

$$= 3.5\ ft^3$$

Full Scale Total Storage Volume:

$$= 39{,}427\ \mathrm{in}^3 = 23\ ft^3$$

Answer

- The calculated volume of the prototype cabinet is 3.5 ft^3
- We will place frequently accessed tools on the outside, such as the fire extinguisher on the rear, the vice on the front left side, and shade/tires on top for easy access and balance.

Informed Design

This design considers space constraints and optimizes component layout for functionality, accessibility, and compactness.

Virtual Prototype

- Model of the spare tire carrier
- Best material for flexing/weight
- Fits both Baja and Formula tires
- Need a modeled baseline before a physical prototype can be constructed for budgeting

Figure 4: CTW Next Gen Tire Cart Benchmark [10]

Questions

What are we trying to answer?

- Should the tire carrier be additional (attached outward) of the tool cart or integrated (removing cabinet)?
- How much cabinetry is lost if integrated?
- Will 6061 Aluminum be a sufficient material to hold the weight of the tires without flexing and cracking?
- Will a steel tubing/plate holder be more reliable for longevity?
- What design idea should we choose overall?

21” = OD, 6.5” = W, 13” = Rim Size

Figure 5: Largest Tire of Baja and Formula

Initial CAD Design Ideas

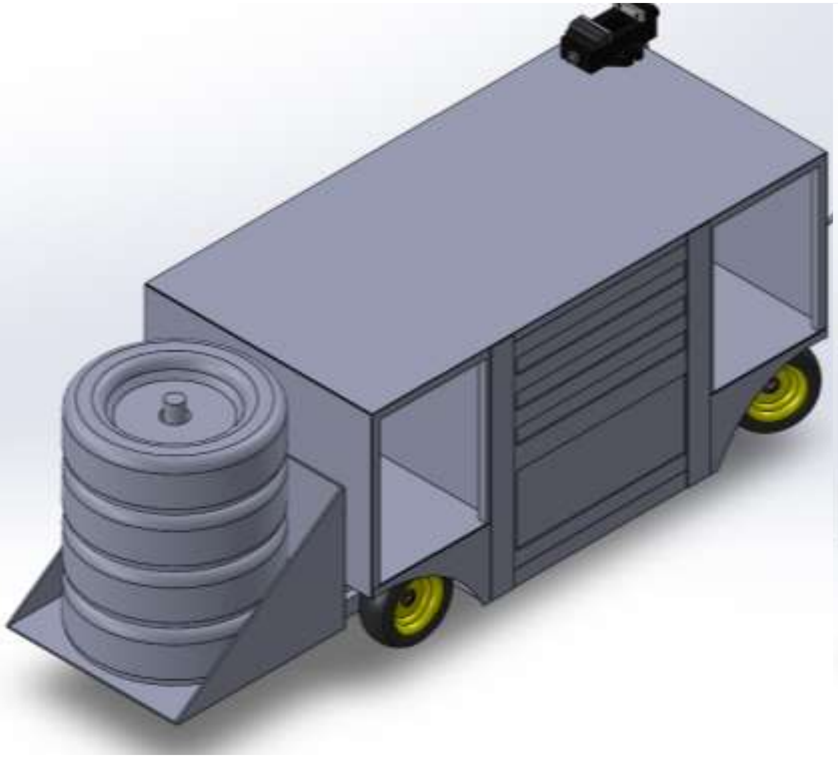


Figure 6: Rear Exterior Mount

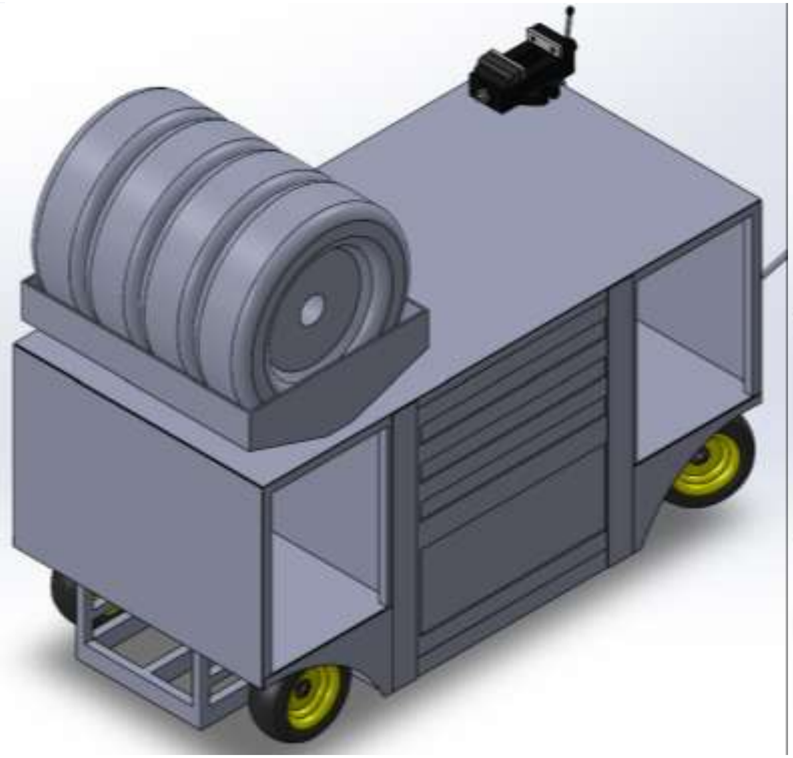


Figure 7: Tabletop Exterior Mount

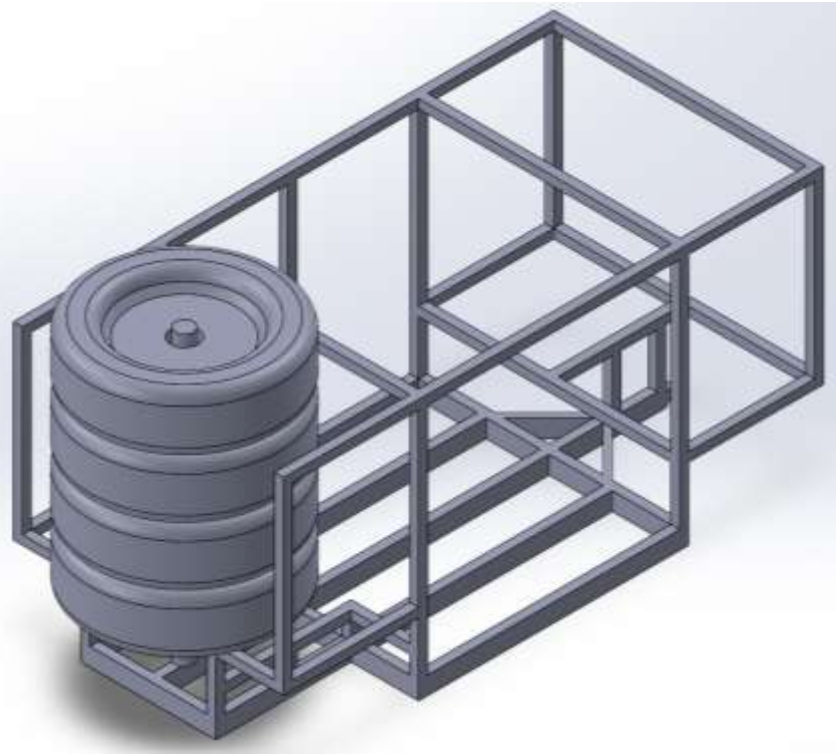


Figure 8: Rear Integrated Mount

Design Option Weighing

Table 2: Three Tire Carrier Comparisons

Option	Pros	Cons
Rear Exterior Mount	• Saves tabletop workspace • Saves cabinet space • Secures tires on center post	• Adds extended length to the overall footprint • Need steel base for strength/bending
Tabletop Exterior Mount	• Saves cabinet space • Doesn’t add overall length • Fits within the width of the cart • Minimal/lightweight material	• Takes away tabletop workspace • Raises center of gravity
Rear Integrated Mount	• Doesn’t add overall length/height • Secures tires on center post • Reduces weight from cutting out tubes	• Takes away cabinet space • Takes away tabletop workspace

FEA Analysis

- 6061-T6 Aluminum “Tub”
- Each tire weighs (high side) 25lbs
- = 444.8 N on all faces they touch
- FEA Force analysis showed 0.0332 in displacement for the whole model

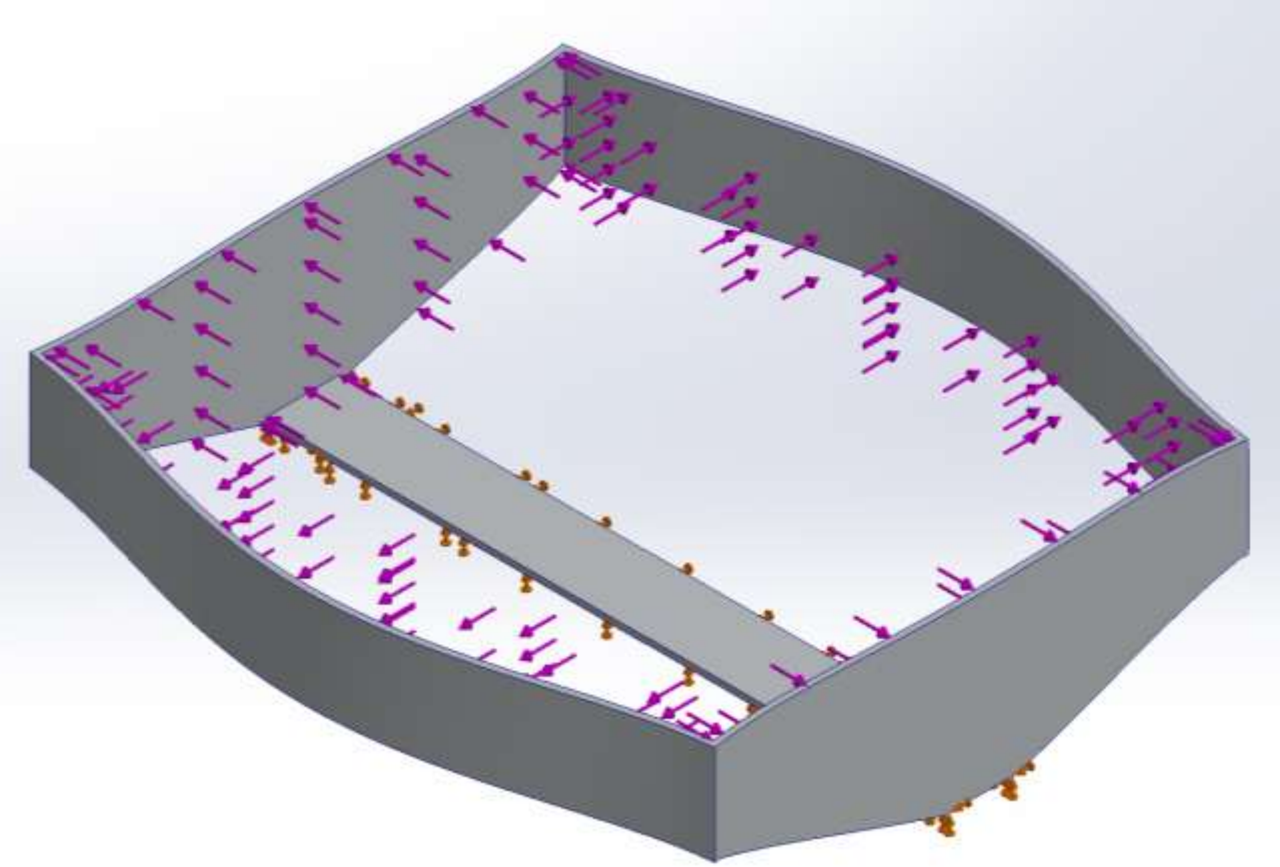


Figure 9: FEA Force Analysis on “Tub” Holder [5]

Answer

The aluminum top mounted tub carrier is sufficient for both Baja and Formula tire sizes and will be strong enough for the application.

Informing the Design

This design allows for easy access, less total cart length and complete range of cabinet storage.

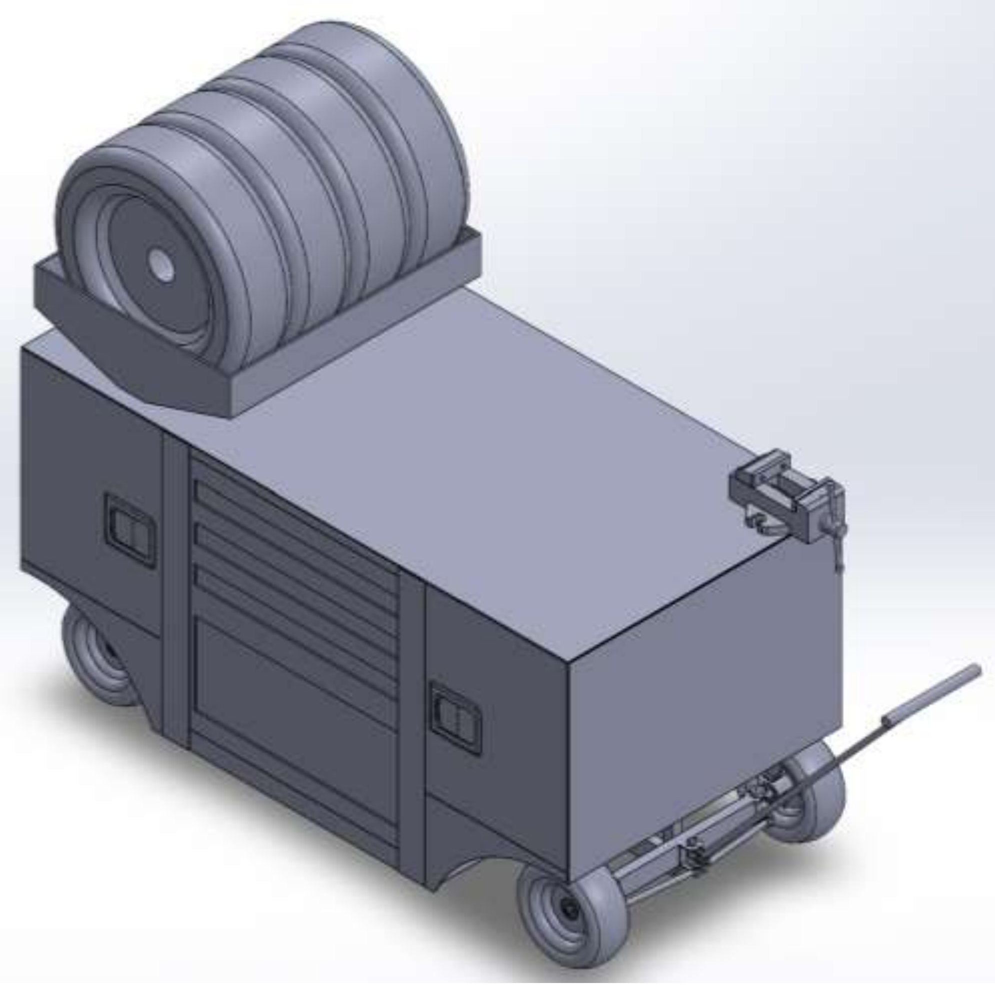


Figure 10: Up-to-Date CAD Assembly

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Thank You

Questions?