Transmission Project CDR

Team 5

“The Wheelers”

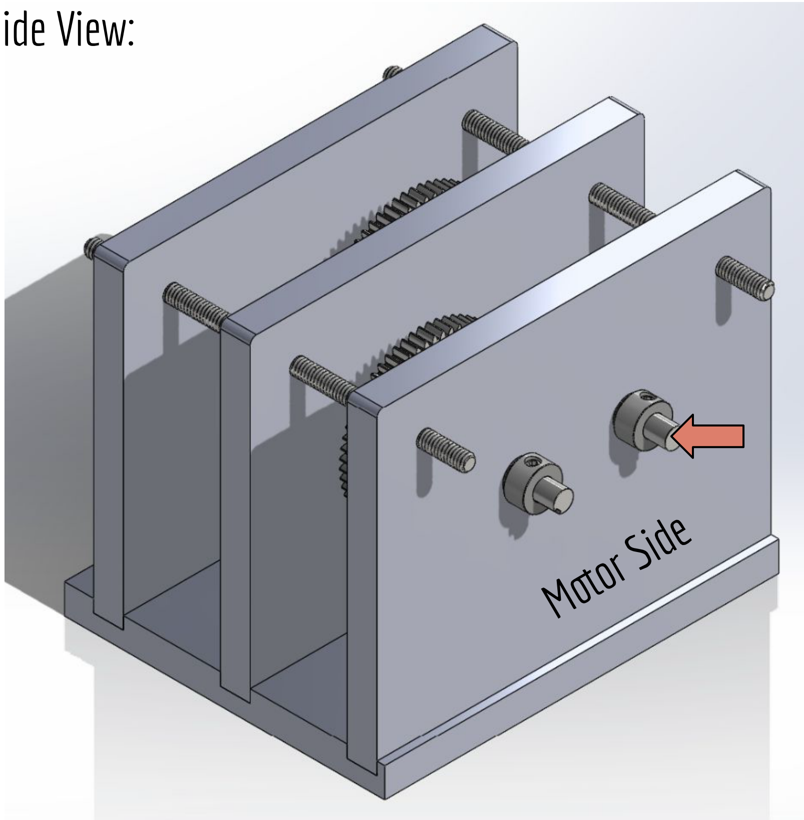
Ana, Anya, Brandon, Hannah, Lily & Miina
5/9/2025

Design Overview

Motor Side

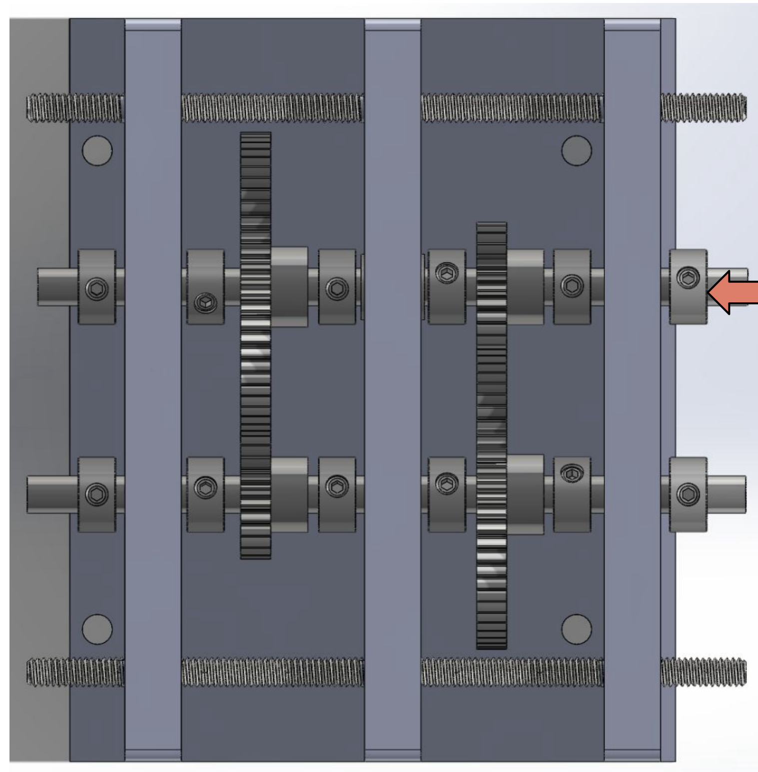
CAD Drawing

Side View:



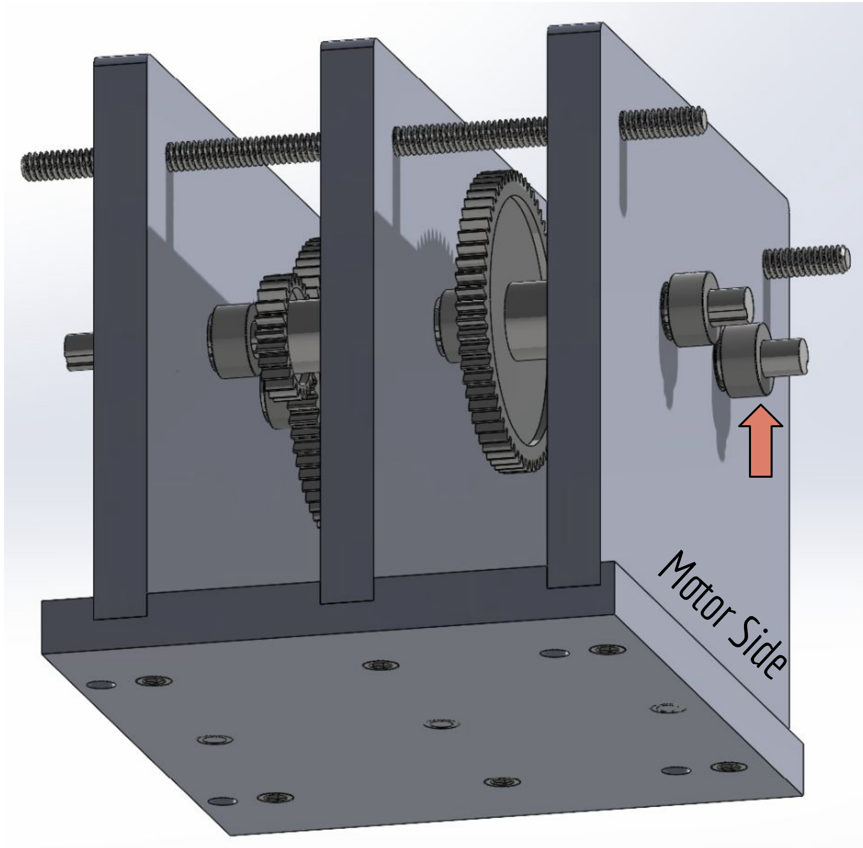
Top View:

Wheel Side

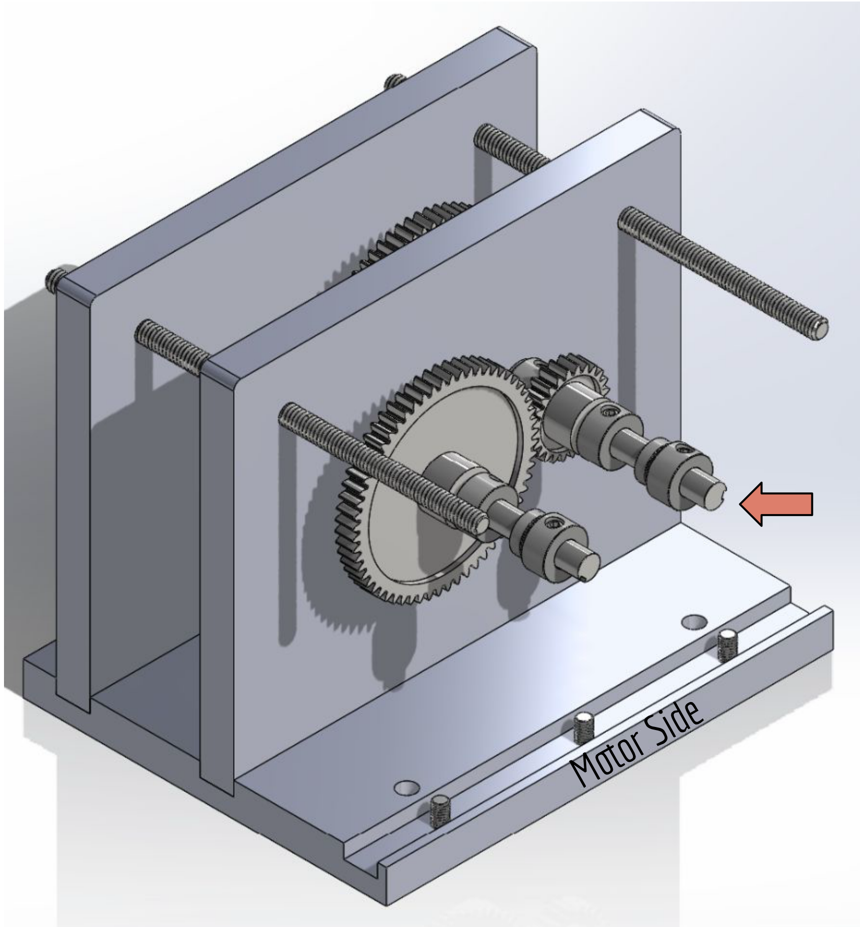


CAD Drawing

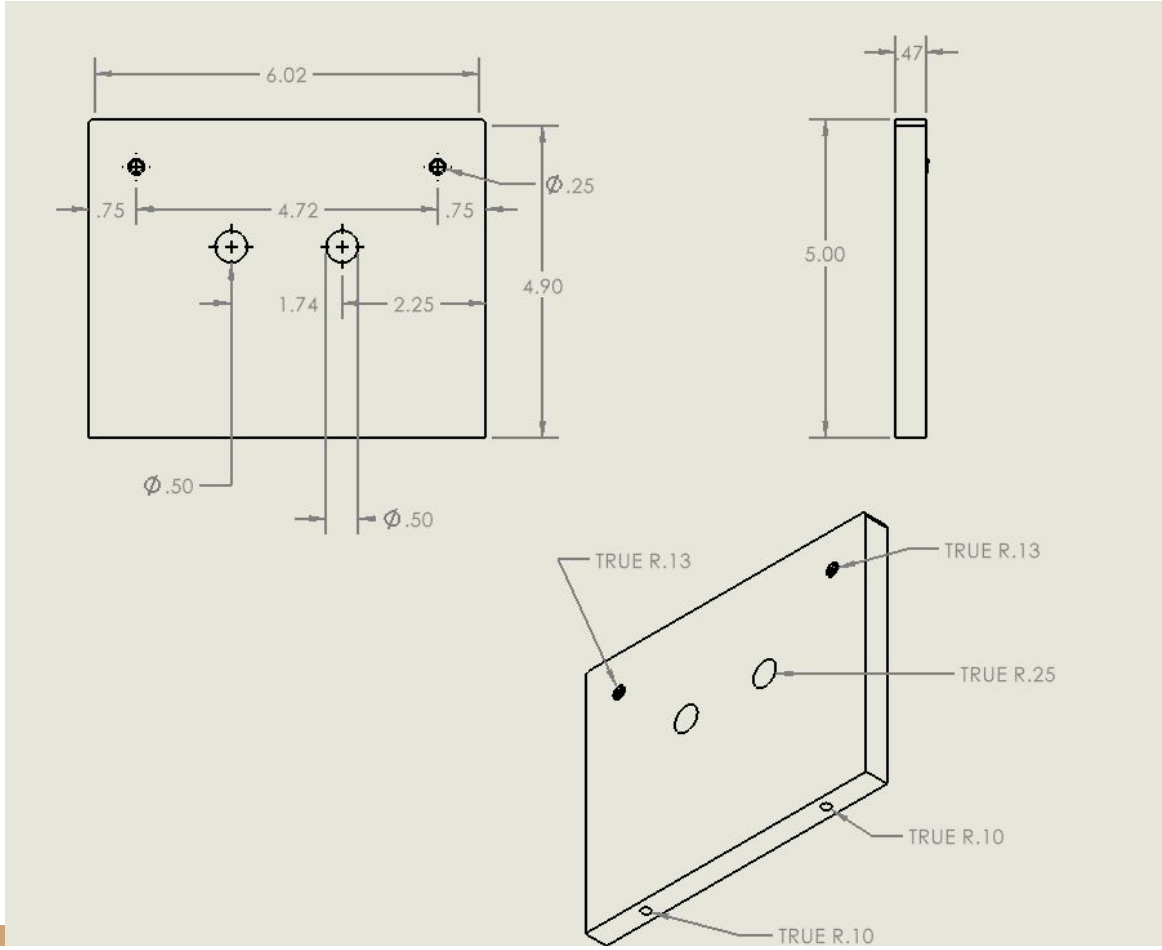
Side View #2:



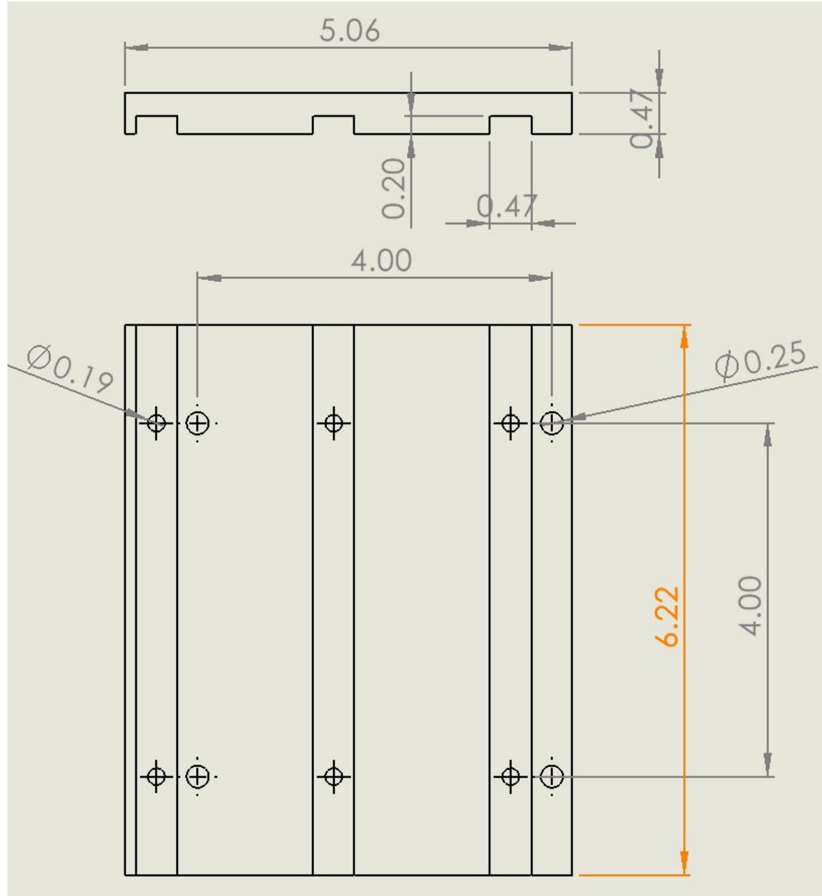
CAD Drawing



Outer Wall Dimensions



Base Plate Dimensions



Major Changes Since PDR

Gears

- 0.25” width
- Fewer teeth

Bearings

- Higher ABEC rating (5 and 7)
- Flanged and extended inner ring for the two in middle wall

Threaded rods

- Reduce vibration in system

Newly selected gears to accommodate shaft

- Have to machine the gears
- Buying extra 24 teeth-gears for machining concerns

Shaft

- 5/16” keyed steel shaft

Calculations

Shaft basis tolerance: Bearings to Wall

Table 1. Description of Preferred Fits

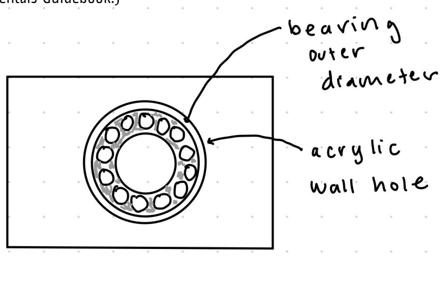
	ISO SYMBOL: Hole Basis	ISO SYMBOL: Shaft Basis	DESCRIPTION	
Clearance Fits	H11/c11	C11/h11	*Loose running* fit for wide commercial tolerances or allowances on external members.	↑ More Clearance
	H9/d9	D9/h9	*Free running* fit not for use where accuracy is essential, but good for large temperature variations, high running speeds, or heavy journal pressures.	
	H8/f7	F8/h7	*Close Running* fit for running on accurate machines and for accurate moderate speeds and journal pressures.	
	H7/g6	G7/h6	*Sliding fit* not intended to run freely, but to move and turn freely and locate accurately.	
	H7/h6	H7/h6	*Locational clearance* fit provides snug fit for locating stationary parts; but can be freely assembled and disassembled.	
Transition Fits	H7/k6	K7/h6	*Locational transition* fit for accurate location, a compromise between clearance and interference.	
	H7/n6	N7/h6	*Locational transition* fit for more accurate location where greater interferance is permissible.	
Interference Fits	H7/p6[a]	P7/h6	*Locational interference* fit for parts requiring rigidity and alignment with prime accuracy of location but without special bore pressure requirements.	More Interference ↓
	H7/s6	S7/h6	*Medium drive* fit for ordinary steel parts or shrink fits on light sections, the tightest fit usable with cast iron.	
	H7/u6	U7/h6	*Force* fit suitable for parts which can be highly stressed or for shrink fits where the heavy pressing forces required are impractical.	

[a]Transition fit for basic sizes in range from 0 through 3 mm.

Table Figure Sources: ME14 and ME13 (Engineering Fundamentals Guidebook:)

Table 5: Assuming 8 mm basic size:

11.979	12.000	−0.010
11.961	11.989	−0.039



All bearings: 0.5" outer diameter, tolerance: -0.0002" to 0"

- **Fit Type:** Interference fit (S7/h6)
- Table indicates:
  - Hole:
    - Max diameter: 11.979 mm = 0.472 in
    - Min diameter: 11.961 mm = 0.4709 in
  - Shaft diameter:
    - Max diameter: 12.00 mm = 0.472 in
    - Min diameter: 11.989 mm = 0.472 in
    - Note: off from actual shaft diameter

Note: table values are approximations

Final tolerances calculated using FS Wizard (per Mr. Stovall's recommendation)

Shaft basis tolerance: Bearings to Wall

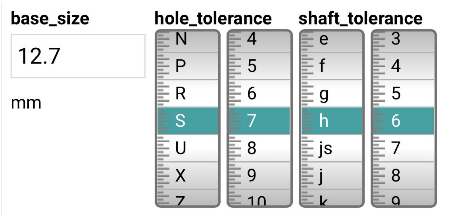
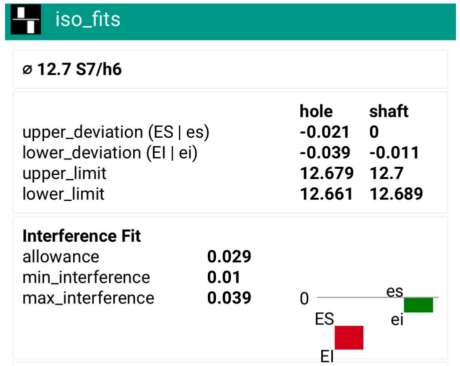


Figure Source: FS Wizard Application



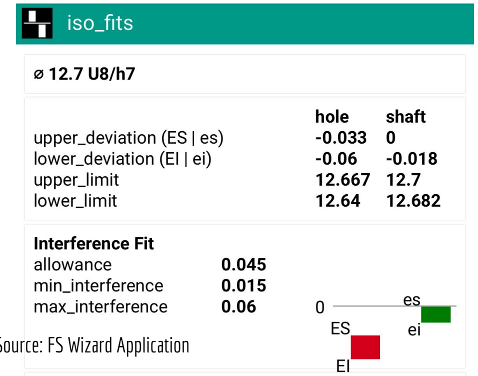


Figure Source: FS Wizard Application

Bearing Press-Fit Tolerances (S7/h6):

- Hole in wall:
  - Max diameter: 0.4992 in
  - Min diameter: 0.4984 in
- Bearing outer diameter:
  - Max diameter: 0.5 in
  - Min diameter: 0.4995 in

Bearing Press-Fit Tolerances (U8/h7):

- Hole in wall:
  - Max diameter: 0.4987 in
  - Min diameter: 0.4976 in
- Bearing outer diameter:
  - Max diameter: 0.5 in
  - Min diameter: 0.4993 in

Shaft basis tolerance: Gears

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	ISO SYMBOL		DESCRIPTION	
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[a]Transition fit for basic sizes in range from 0 through 3 mm.

Table Figure Source: ME14 and ME13 (Engineering Fundamentals Guidebook:)

iso_fits

⌀ 7.9375 S7/h6

	hole	shaft
upper_deviation (ES | es)	-0.017	0
lower_deviation (EI | ei)	-0.032	-0.009
upper_limit	7.9205	7.9375
lower_limit	7.9055	7.9285

Interference Fit

allowance	0.024
min_interference	0.008
max_interference	0.032

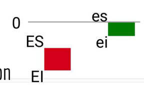


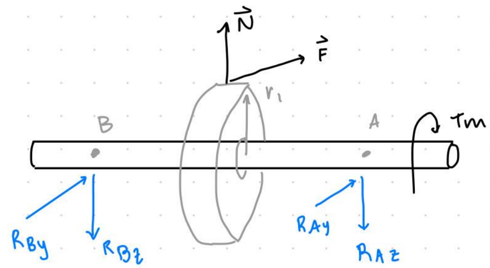
Figure Source: FS Wizard Application

- ***Press Fit:*** 5/16" Shaft to 5/16" Bore Gear
- ***Basic Size***: 0.3125" in (shaft diameter) = 7.9375 mm
- ***Fit Type:*** S7/h6 interference fit
- Gear Hole:
  - Max diameter: 0.3118 in
  - Min diameter: 0.31124 in
- Shaft:
  - Max diameter: 0.3125 in
  - Min diameter: 0.3121 in
- Shaft size is fixed – values used to verify press-fit interference with gear bore

Gears: Forces on Teeth Calculation

Gearbox Analysis:

Shaft #1

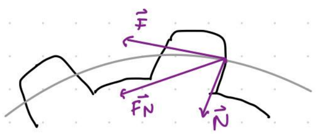


$$\Sigma M_x = Fr_1 - T_i = 0$$

T_i = motor torque = 0.133 N·m

$$F = \frac{T_i}{r_1} = \frac{0.133 \text{ N·m}}{(0.0127 \text{ m})} = 10.472 \text{ N}$$

on the gear teeth:



$$\text{length AB} = \frac{1.53 \text{ in}}{} \Big| \frac{2.54 \text{ cm}}{1 \text{ in}} \cdot \frac{1 \text{ m}}{100 \text{ cm}}$$

$$= 0.038862 \text{ m}$$

diameter of 24 tooth gear w/ 20° pressure angle:

$$\frac{1 \text{ in}}{} \Big| \frac{2.54 \text{ cm}}{1 \text{ in}} \Big| \frac{1 \text{ m}}{100 \text{ cm}} = 0.0254 \text{ m}$$

$$r_1 = 0.0254 \text{ in}/2 = 0.0127 \text{ m}$$

then, $N = F \tan\phi$

$$= (10.472 \text{ N}) \tan(20°)$$

$$N = 3.81165 \text{ N}$$

Forces between the gears - gives an approximation for the expected force acting at the teeth of the small gear

Gears

Background Research - Gears

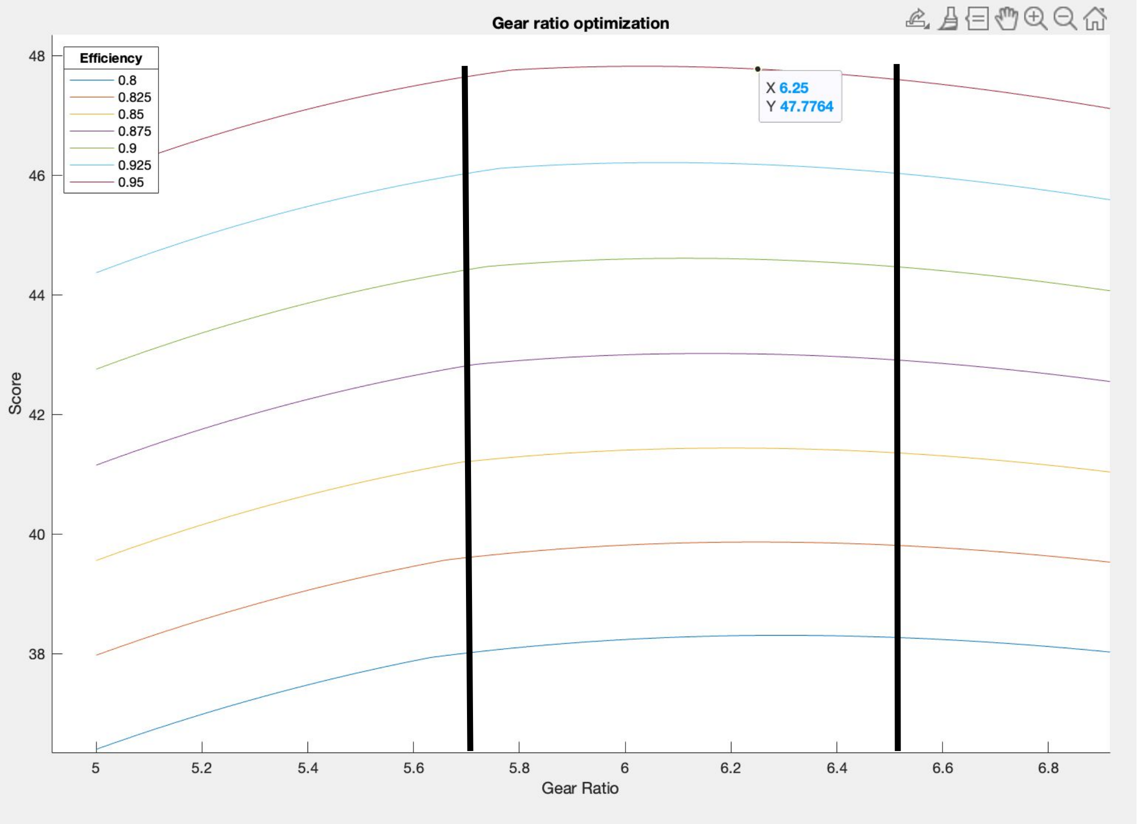


Figure: Simulation results when running Matlab code written by Professor Mello

- **Gear ratio: 6.25**
  - Gear ratio between 5.7 - 6.5 based on simulation
  - G1:G2 = G3:G4 to allow for testing alignment
- Acetal plastic
  - Lower moment of inertia
  - Hubbed with plastic interior
  - Less expensive

Simulations

Gear ratio = 6.25:1, 70% efficiency (assuming 5% loss/bearing)

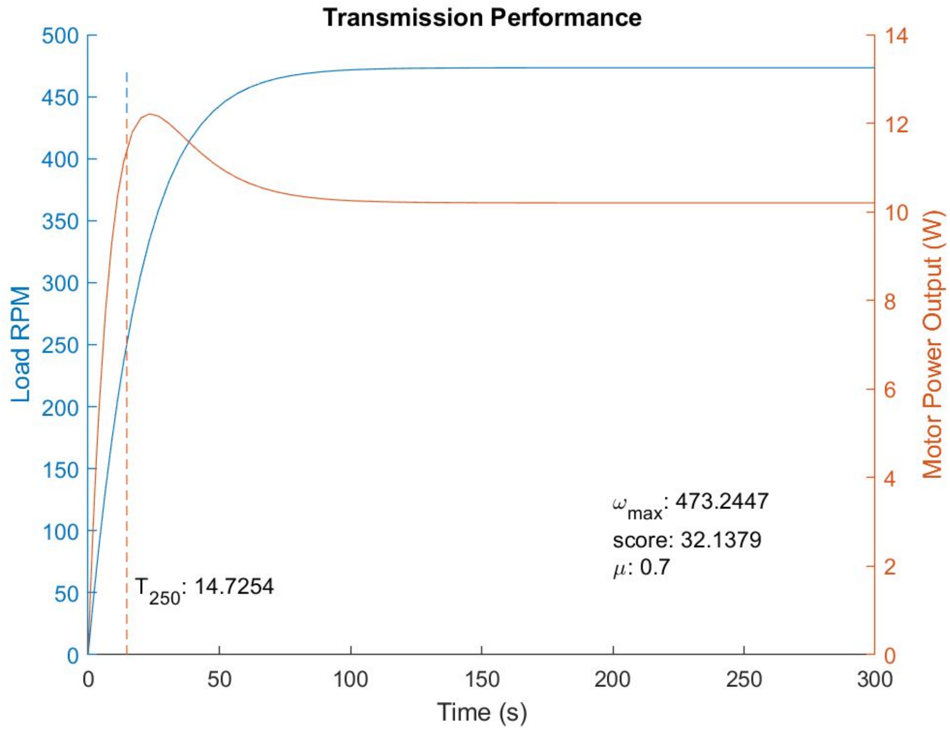


Figure: Simulation results when running Matlab code written by Professor Mello

14.72 s to accelerate to 250 RPM

473.24 rad/s maximum speed ω

Predicted score: 32.14

Gears

$$\textbf{Gear ratio} = \frac{G_1}{G_2} \cdot \frac{G_4}{G_3} = \frac{60}{24} \cdot \frac{60}{24} = 6.25$$

60 teeth
Width: 0.25”
Shaft Dia: 0.3125”

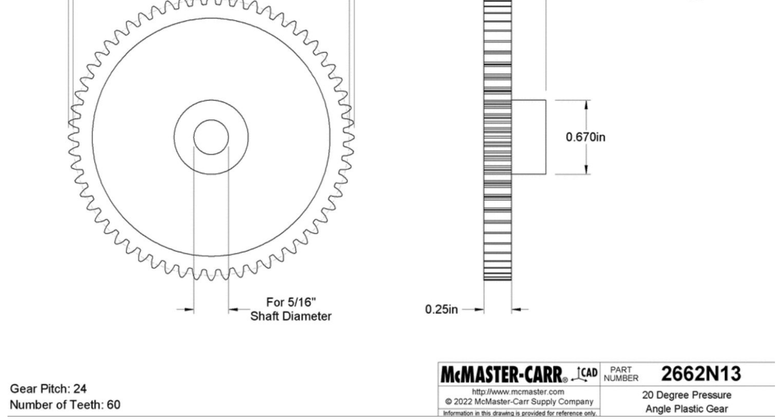


Figure Source: https://www.mcmaster.com/2662N13/

24 teeth
Width: 0.25”
Shaft Dia: 0.25”

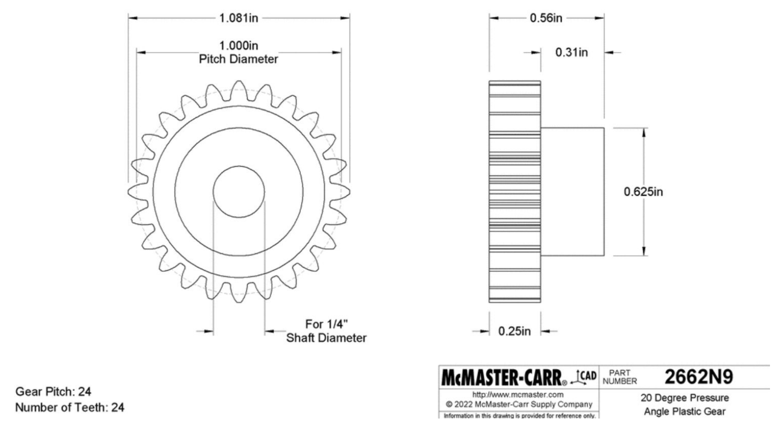


Figure Source: https://www.mcmaster.com/2662N9/

Shaft

Keyd 5/16” Steel Shaft

- 5/16” better than ¼” due to increased moment of inertia reducing stress for the same torque

$$\tau = \frac{Tr}{J} \; where \; J \propto r^4$$

- Machine inner diameter of 24 teeth gear from 0.25” → 0.3125”
- Paul agreed to broach our gears to fit our keys shaft
- Steel shaft from the shop

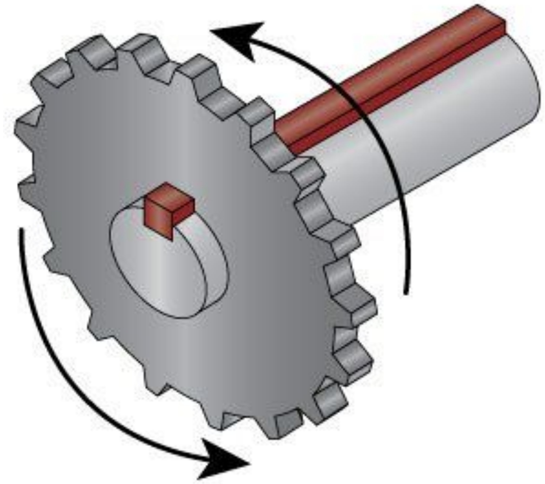


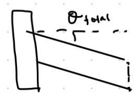
Figure Source: https://www.huyett.com/blog/key-stock-and-machine-keys

Slope Calculation

worst case slopes at endpoints:

• uniform load:

$y = \frac{w}{24EI}(2\ell x^3 - x^4 - x\ell^3) \rightarrow \frac{dy}{dx} = \theta = \frac{w}{24EI}(6\ell x^2 - 4x^3 - \ell^3)$



@ $x=0 \Rightarrow \theta_A = \frac{w}{24EI}(-\ell^3) = -\frac{w\ell^3}{24EI} = -5.775 \times 10^{-9}$

• point load

$y_{AB} = \frac{F}{6EI}(x^3 + 3ax - 3\ell a x) \rightarrow \frac{dy}{dx} = \theta = \frac{F}{6EI}(3x^2 + 3a - 3\ell a)$

@ $x=0 \Rightarrow \theta_A = \frac{F}{6EI}(3a - 3\ell a) = -5.696377 \times 10^{-4}$

$\theta_{A,total} = \theta_A + \theta_A = -5.775 \times 10^{-9} + -5.6 \times 10^{-4} = -5.696 \times 10^{-4}$

maximum slope at bearing: -5.70×10^{-4} rad

- Slope calculations (assuming simple support) show endpoint deflection around 10^{-4} magnitude
- This small deflection poses no concern for system performance
- Avoids issues like irregular movement, accelerated wear, or reduced bearing lifespan
- Minimal impact to bearing motion

Shaft Collars

Set Screw Collars ($\frac{1}{4}$” Black Oxide Steel, x8)

- Secures shaft and gear from axial movement
- Placed right outside the two outer walls and on the side of the gear without hub for extra support.
- In the design to fix all axis of motion
- D-shaft is chosen to accommodate the set screw design

Set Screw Shaft Collars

Keep these shaft collars in place by tightening their set screw into the shaft. The tip of the screw digs in for a secure hold, but will mar the shaft’s surface. For maximum holding power, make sure the set screw material is harder than your shaft material. Use these shaft collars to position and retain power transmission components such as sprockets, pulleys, and bearings. You can also use them to limit the movement of a shaft.

Carbon steel collars are strong and wear resistant. Collars **with a black-oxide finish** have some corrosion resistance, but only in dry environments. Their dark color can be useful for matching other parts in your system.

CAD For technical drawings and 3-D models, click on a part number.

Inch

For Shaft Dia.	OD	Wd.	Set Screw Type	Set Screw No. Included		Each
Black-Oxide 1215 Carbon Steel						
1/4"	1/2"	9/32"	Hex Socket	1	9414T6	$1.85

Figure: Image and specification from (“McMaster-Carr”)
https://www.mcmaster.com/products/shaft-collars/shaft-collars-3~/shaft-diameter~1-4-1/shaft-mount-type~set-screw/

Bearings

Bearing Choice - OUTER WALLS

Bearing Trade Number	For Shaft Dia.	For Housing ID	Wd.	Inner Ring OD	Inner Ring Wd.	Ring Material	Radial Load Cap., lbs. Dynamic	Radial Load Cap., lbs. Static	Max. Speed, rpm	Lubrication	Temp. Range, °F	ABEC Rating		Each
R1810-2Z	5/16"	1/2"	5/32"	0.354"	0.188"	440C Stainless Steel	120	50	48,000	Lubricated	-40° to 240°	ABEC-5	57155K389	$6.78

Figure: Image and specification from ("McMaster-Carr") https://www.mcmaster.com/57155K378/

Advantages:

- **ABEC-5**
- **8.7× safety factor** (48,000 / 5,500 rpm) for motor speed
- **Extended inner ring** avoids need for washers
- **Shielded** to protect against debris

Disadvantages:

- Small width for our wall of 0.47"

Bearing Choice - MIDDLE WALL

Bearings for the middle wall to prevent axial movement of shafts 1&3

Bearing Trade Number	For Shaft Dia.	For Housing ID	Wd.	Flange OD	Flange Thick.	Ring Material	Radial Load Cap., lbs. Dynamic	Radial Load Cap., lbs. Static	Max. Speed, rpm	Lubrication	Temp. Range, °F	ABEC Rating		Each
Shielded														
R1810-2Z	5/16"	1/2"	5/32"	0.547"	0.03"	440C Stainless Steel	90	40	10,000	Lubricated	-60° to 250°	ABEC-7	4262T38	$17.36

Figure: Image and specification from (“McMaster-Carr”) https://www.mcmaster.com/57155K325/

Advantages:

- **ABEC-7**
- **Precision design** for high accuracy and rigidity.
- **Shielded**

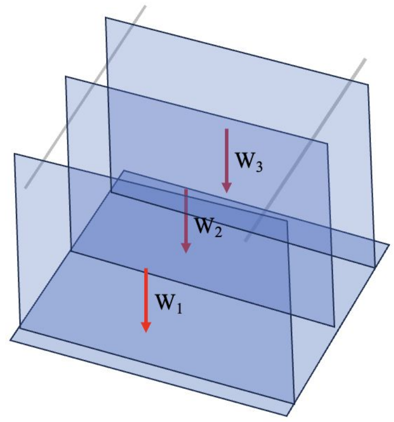
Disadvantages:

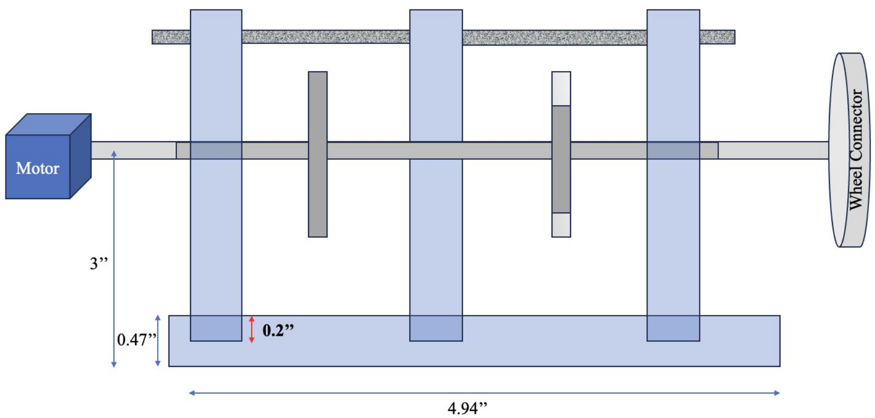
- Small width for our wall of 0.47”
- Cost

Enclosure

Enclosure Design

- Base secured with 0.2” deep slots and 10-32 screws
- Low axial loading ⟶ no top plate required
- 2 threaded rods
  - Benefits: additional constraint from axial vibrations
  - Trade-offs: increase manufacturing time and complicates assembly





Schedule and Milestones

Schedule and Milestones

5/12	5/13	5/14	5/15	5/16	5/17	5/18
Vertical Band Saw Rough cuts of acrylic **Mill** Level acrylic Create slots Machine bores for bearings	**Drill Press & Tap** Drill and tap bore holes for side of walls and base plate **Drill Press** Machine holes in gears with a soft jaw vice **Milestone:** Acrylic Completed	**Horizontal Band Saw** Rough cut of shafts **Lathe** Cut shafts to precise length **Key Gears with Paul** Test gears fit with shaft **Milestone:** All Parts Machined	**Press Fitting Tool** Press fit bearings to acrylic walls **Final Assembly** **Milestone:** Final Assembly	**Testing**		
5/19	**5/20**	**5/21**				
Testing	**Testing**	**Final Competition**				

Strength and Weaknesses

Strengths

Efficient

- Only two gear pairs

Good Gear Ratio

- Compound gear train

Choice of plastic gears allows more expensive bearings

- Bearings crucial part of transmission design

Light-weight

- Plastic gears
- Compact design

Weaknesses

Durability

- Plastic gears wear down over time

Keyway in gear missing

- Must machine keyway ourselves

Precise machining required

- Relatively thin gear width
- Must machine larger hole for small gears

Budget

Budget Proposal

Part #	Description	QTY	Cost
57155K389	Unflanged Bearings	5	$33.90
4262T38	Flanged Bearings	3	$52.08
91177A140	Threaded Rod	2	$9.18
2662N9	24 tooth gear	5	$27.00
2662N13	60 teeth gear	3	$21.00
9414T7	Black-Oxide 1215 Carbon Steel Collar	15	$28.50
90490A029	Hex Nuts (Pack of 100)	1	$4.70

Total: $176.36

Questions?

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