Team 7: Specialized Material Handling Dolly

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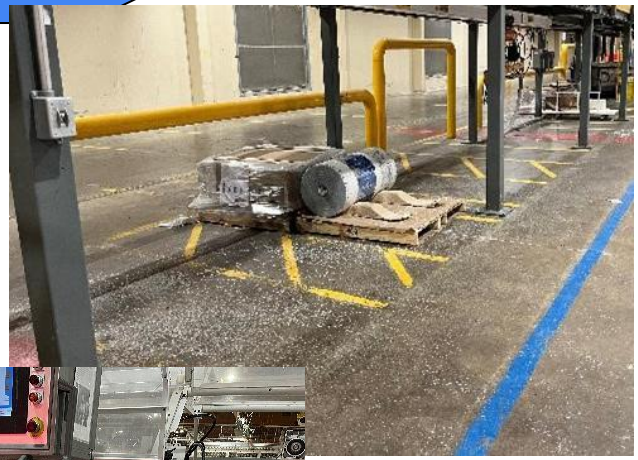
Problem Statement and Background

- Georgia Pacific manufactures paper products
- 200 lb plastic wrap rolls arrive on a tall pallet



Our Task: Scaled prototype

- Lift a 35 pound cylinder and move it
- Maneuver the cylinder through tight corridors without damaging it
- Place the cylinder into wrapping machine

Critical Specifications and Stakeholders

Critical Specifications

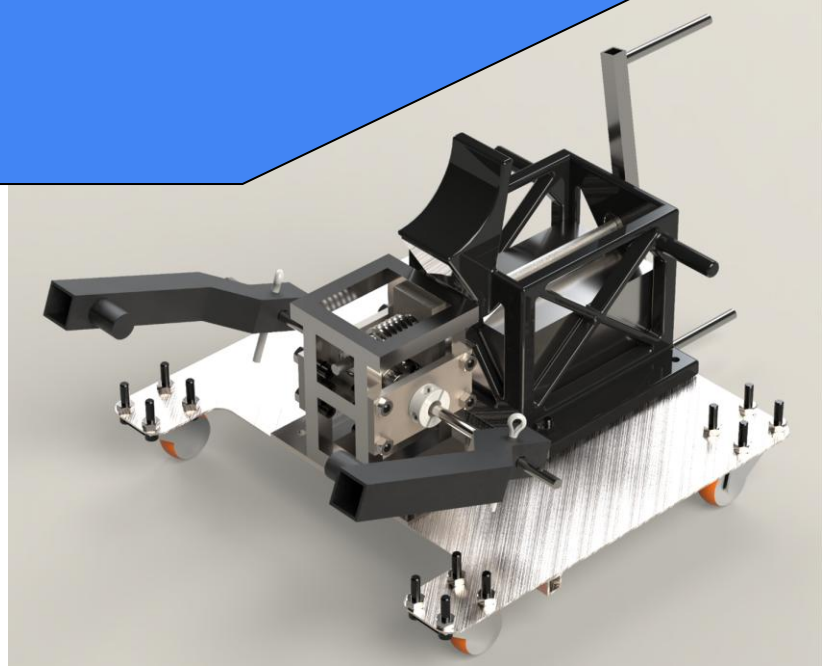
- Must fit within a 14" x 14" x 14" storage container
- No more than 15 lbs of force is required to operate it
- Minimum Factor of Safety of 1.5
- Causes zero injuries
- Navigate the 16-inch-wide factory corridor without "collision"
- Must complete transfer within four minutes

Major Stakeholders

- Operator
- Maintenance Technicians
- Managers
- Georgia Pacific / EIS

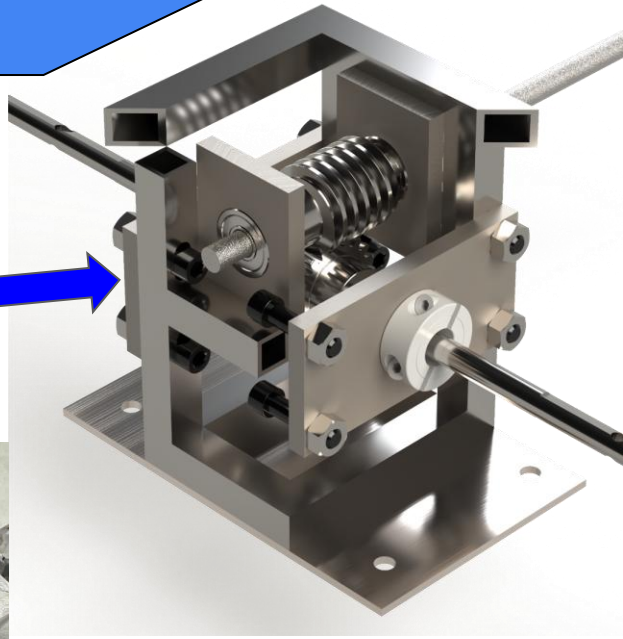
Design Form-30000 ft overview

- Mechanical advantage achieved via worm gears
- Sliding Arms quickly acquire cylinder
- Casters allow for quick maneuverability
- Double sided handle for ease of operation



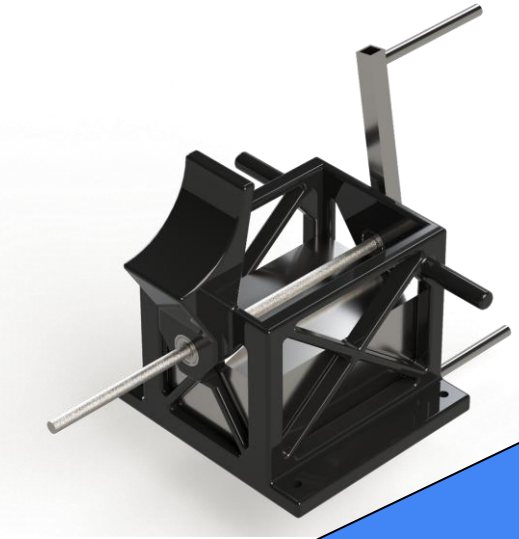
Design Form-Gearbox

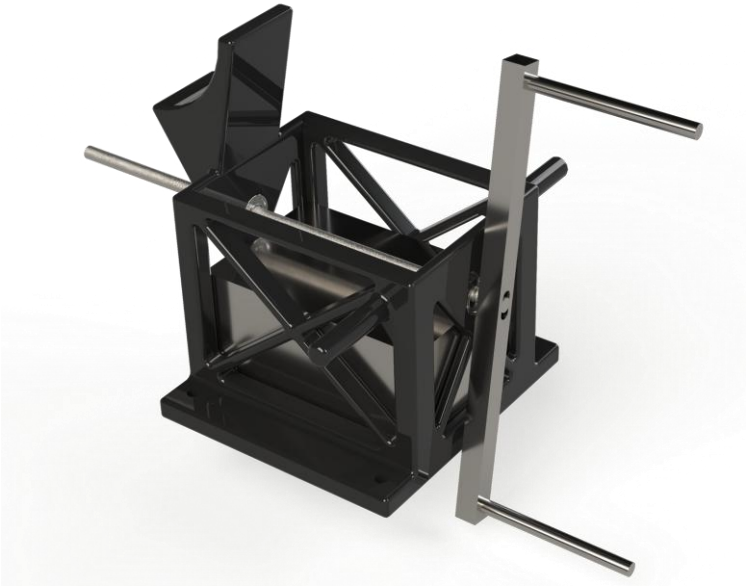
- Utilizes 20:1 Gear reduction
- Welded frame; machined bearing plates optimize gear alignment
- Slotted supports allow for gear mesh adjustment
- Notched shafts prevent gear slippage
- HDPE bushing supports axial load on worm gear



Design Form-Rear Support

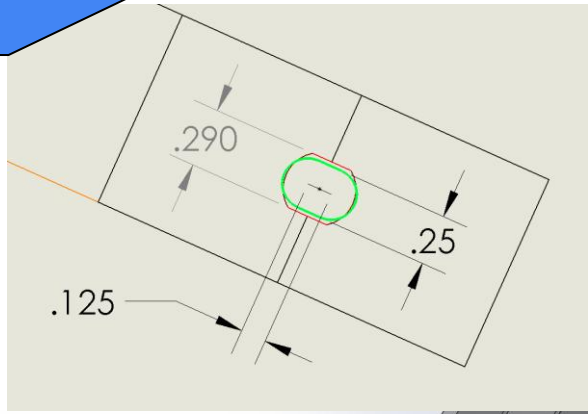
- 3D Printed PLA
- Supports handle shaft
- Cradles cylinder in raised position
- Holds counterweights

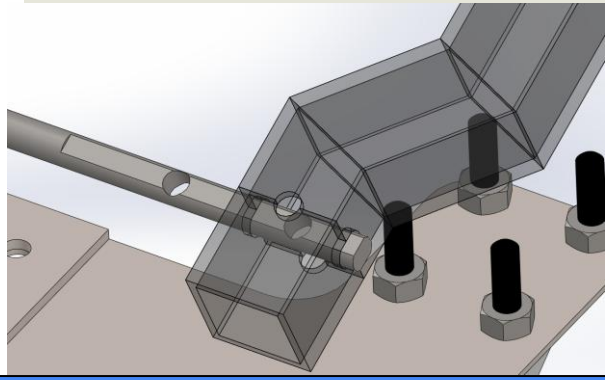




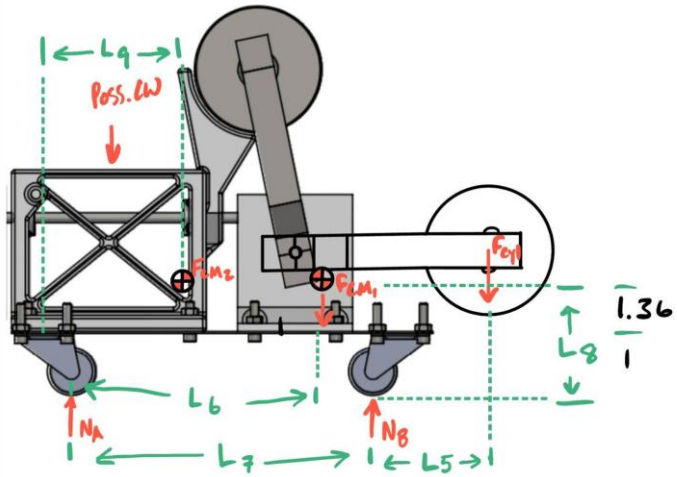
Design Form-Slot attachments

- Standardized method of connecting things to shafts
- Uses .25″ milled slot
- Allows for
  - High torque transfer
  - Adjustability





Design Analysis & Testing- Tipping Moment Analysis



Important note: The center of mass shifts when counterweights are added so we couldn't use the same equation twice

Moment about point a:

$$\sum M_a = -F_{Cm1}(L_6) + N_b(L_7) - F_{Cyl}(L_7 + L_5)$$

Moment about point a with cw:

$$\sum M_a = -F_{Cm2}(L_9) + N_b(L_7) - F_{Cyl}(L_7 + L_5)$$

Sum of forces in the y to find tip:

$$\sum F_y = -F_{Cm1} + N_b + N_a - F_{Cyl}$$

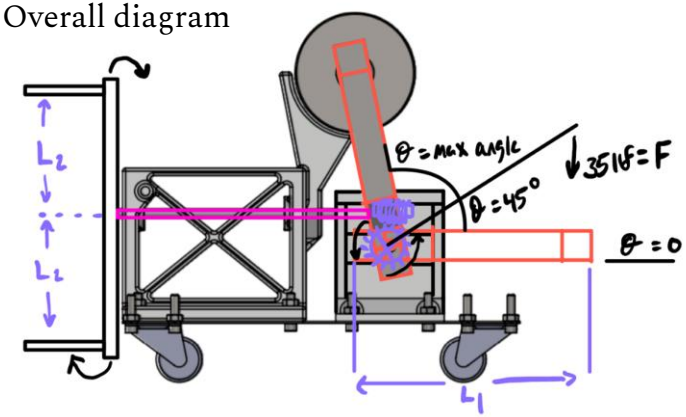
Sum of forces in the y to find tip:

$$\sum F_y = -F_{Cm2} + N_b + N_a - F_{Cyl}$$

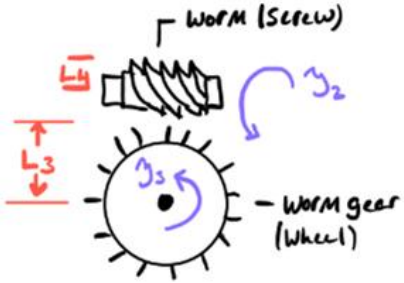
Counterweight	Reaction force at rear wheel (lbf)	Result
No counterweight	-3.46	Tips
15lbs	3.499	Does not tip

Design Analysis & Testing- Handle Moment Analysis

Overall diagram



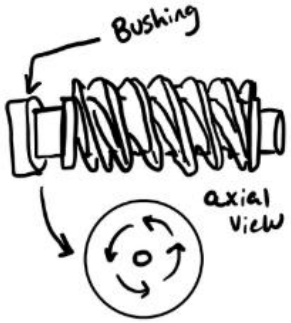
Friction between gears



$$N = \frac{\tau_1}{L_3} \Rightarrow F_{fr} = F\mu cos(\theta)\frac{L_1}{L_3}$$

$$\tau_{fr} = F_{fr}L_4$$

Friction with bushing



$$\tau_{fr} = \int_{r1}^{r2} F_{fr} r)dr = [\mu N \frac{r^2}{2}]_{r1}^{r2}$$

Friction Coefficients

Steel on steel (dry)	μ=0.42
Steel on steel (greased)	μ=0.09
HDPE on steel	μ=0.08

Torque at spur gear: $\tau_1 = Fcos(\theta) \bullet L_1$

Torque at handle: $\tau_2 = \frac{1}{n}\tau_1$

Applied force: $F_{app} = \frac{\tau_2}{L_2}$

Friction is: $F_{fr} \equiv \mu N$

Final force equation: $F_{app} = \frac{\tau_2}{L_2} = Fcos(\theta)\frac{L_1}{L_2}\left(\frac{1}{n} + \frac{\mu_{st-st}L_4 + \mu_{HDPE-st}\left(\frac{r_2^2}{2} - \frac{r_1^2}{2}\right)}{L_3}\right)$

Design Analysis & Testing
Handle Moment Analysis Results

	Considering Friction Between Bearing and Bushing	Considering Friction Between Gears
Lubricated	F = 5.191 lbf	F = 5.07 lbf
Not Lubricated	F = 15.78 lbf	F = 15.67 lbf

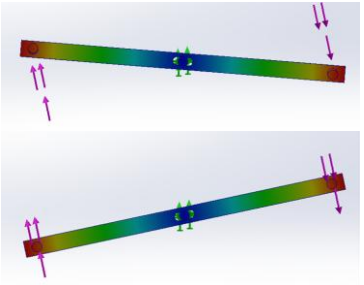
Not Considering Friction: F = 2.19 lbf

Final moment factor of safety: FOS = 15/5.191= 2.9

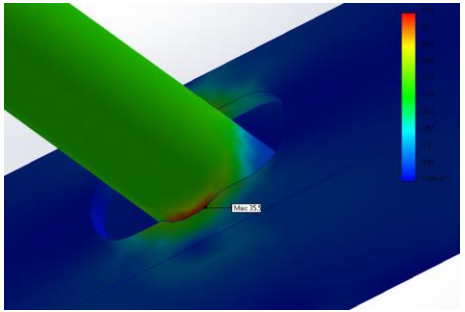
Run Completed in 2 minutes 20 seconds without collisions or injuries

Design Analysis & Testing - Handle Shaft Torsion

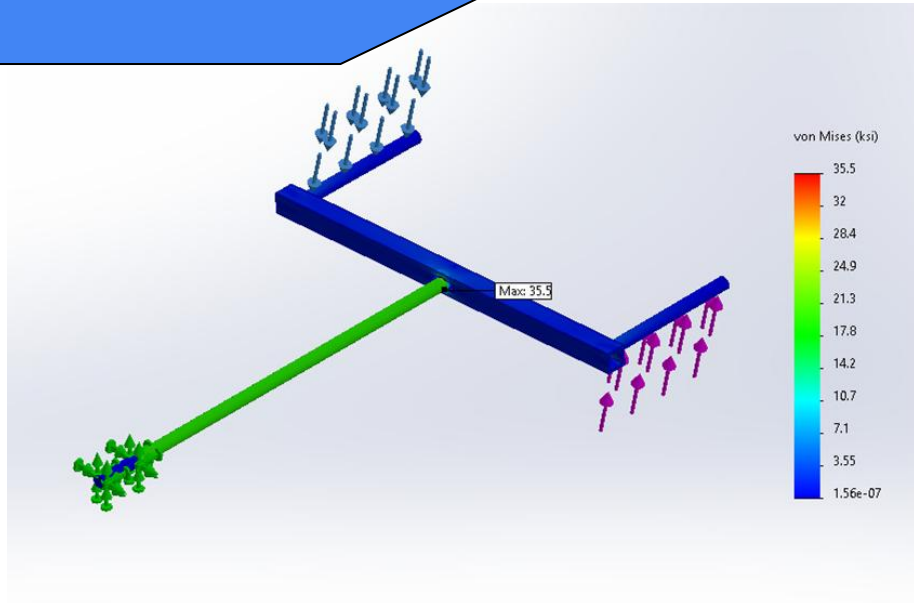
- Hand calcs yielded 11ksi in shaft while FEA says 19.6.
- Discrepancy attributed to the indirect nature of moment application and complexity of shaft-handle connection
- Min FOS is out of spec, see changes slide.



Deformation before and after:
Max: .312 in



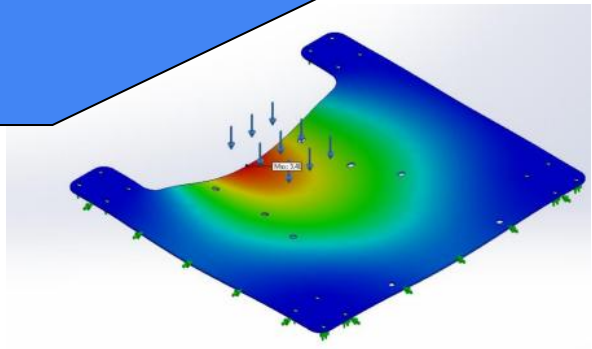
Max Stress: 35.5 ksi



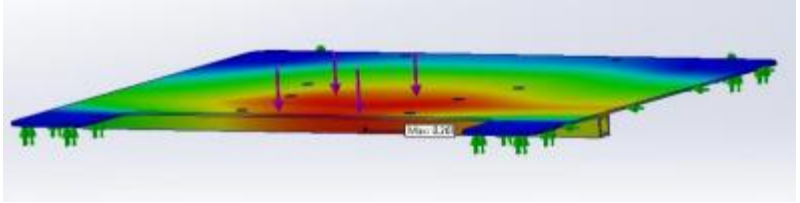
Handle stress: 19.6 ksi. Min FOS: 1.44

Design Analysis & Testing

Plate Deflection	No Support	With Support
Analytical (Hand Calc)	10.13mm	0.251mm
FEA (SolidWorks)	3.48mm	0.261mm



Combined area moment of inertia to account for plate and support, used an effective width for plate area moment of inertia



$$I_t = \frac{b^4 - b_{in}^4}{12} \qquad \bar{y} = \frac{A_t y_t + A_p y_p}{A_t + A_p} \qquad y_{max} = \frac{-F\ell}{48EI}$$

$$I_p = \frac{b_p t_p^3}{12}$$

Final Assessment-Proposed changes

- Slot attachments exhibited stripping issues
  - Solution: Force distribution block in middle of arms
  - Reinforce or weld handle
- High friction between gears
  - Solution: Use 40T gears to halve normal force
- Add pillow bearings to improve main shaft longevity

Final Assessment-Recommendation

Why should the design be selected for full scale prototyping and production?

- The design is scalable
- Easy to use
- Transports payload quickly
- Worm gear provides significant torque multiplication

Questions?

Cad Link