Scissor Jack Analysis

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Design Objective

Objective: Design a lightweight, cost-effective scissor jack capable of lifting a 2,000 lb vehicle load while strictly adhering to safety and geometric constraints.

Optimization Goal: Minimize material weight and cost without compromising structural integrity or user safety.

Design Requirements

Functional Requirements:

- **Peak Load:** Sustain 2,000 lbs (tension) throughout operation.
- **Safety:** Critical failure modes (tearout/shear) require higher safety margins than yielding modes.

Geometric Constraints:

- **Stowed Dimensions:** Must fit within a 40"x10"x10" envelope.
- **Stock Materials:** Designs must utilize standard available stock sizes.

Modeling Assumptions:

  - The lead screw is modeled as an equivalent smooth bar loaded in tension.
  - Fatigue analysis is excluded from this scope.

Safety Factors

Failure Mode	n	Rationale
Pin Tearout (Diagonal)	**4.0**	**Critical:** Sudden, catastrophic failure with no warning.
Pin Shear	**3.0**	**Critical:** Sudden failure mechanism.
Axial Stress (Diagonal)	**3.0**	Standard structural variance.
Buckling (Crossbar)	**2.0**	**Yielding:** Visible deformation occurs prior to failure.
Bearing Stress	**2.0**	**Yielding:** Localized deformation; non-catastrophic.

Table 1. Table showing safety factors set for varying failure modes and perspective rationales.

Computational Design Model

We developed a Python model to iterate through the design space, filter out all non-viable combinations, and optimize viable combinations for weight reduction.

Input Parameters (Variables):

- **Geometry:** Cross section dimensions for pin, crossbar, and diagonal members; lengths; geometry cutouts
- **Materials:** Steel (AISI 1018) and Aluminum (6061-T6); material properties used were yield strength, modulus of elasticity, and density

Model Logic:

- Iterate through a range of sizes for each dimension
- Calculate internal forces (Method of Sections)
- Compute stresses for all failure modes (Axial, Buckling, Shear, Bearing) and calculate safety factor
- Filter designs that don't meet geometry constraints and are below the set minimum safety factor
- Optimize passing options to find the lowest weight jack

Outputs:

- Total weight of the assembly
- Dimensions of each member of the assembly

Design Space Exploration

Optimization Methodology

To identify the global optimum, we performed a comprehensive grid search of the design space.

- **Constraint Filtering:** Our algorithm immediately discarded physically impossible geometries (e.g., designs exceeding the 40" storage box or holes larger than member width) or those failing to meet required safety factors.
- **Material Trade-offs:** We analyzed cross-sections in both Steel and Aluminum. While Aluminum offers greater weight savings, the geometric volume required to prevent buckling often negated the density advantage compared to high-strength steel. Our optimization allowed us to select different materials for different assembly members.
- **Vectorized Analysis:** Evaluating thousands of permutations allowed us to visualize the boundary of the most efficient possible designs.

Model Validations through Hand Calculations

Test Point	Component Parameters	Critical Failure Mode evaluated	Model Result (Safety Factor)	Hand Calc Result (Safety Factor)	% Error
1	Diag: Steel (0.75x0.75x8) Bar: Alum (d = 0.5)	Crossbar Buckling	*2.3*	*2.3*	< *1%*
2	Diag: Steel (1.0x1.0x 8.0) Bar: Steel (d=0.75)	Axial Diagonal	*5.4*	*5.4*	< *1%*
3	Diag: Alum (0.5x0.5x8.0) Bar: Alum (d = 0.375)	Pin Tearout	*1*	*1*	< *1%*
4	Diag: Steel (0.5 x1.0 x 8.0) Bar: Steel (d = 0.625)	Pin Shear	*4*	*4*	< *1%*

Table 2: Table showing validation of the python program by comparing results to hand calculations done separately for the same geometries

Optimized Model Verification

Component	Failure Mode	Calculated Value	Limit / Strength	Safety Factor (n)	Validation
Diagonal (Steel)	**Axial Stress**	10,151 psi	32,000 psi (S_{yd})	**3.15**	PASS
	Tearout (von Mises)	7,692 psi	32,000 psi (S_{yd})	**4.16**	PASS
	Bearing Stress	8,882 psi	32,000 psi (S_{yd})	**3.60**	PASS
Crossbar (Aluminum)	**Axial Stress**	5,882 psi	16,000 psi (S_{ycb})	**2.72**	PASS
	Buckling Stress	5,882 psi	13,445 psi (P_{cr})	**2.29**	PASS
	Bearing Stress	2,887 psi	16,000 psi (S_{ycb})	**5.54**	PASS
Pin (Steel)	**Shear (von Mises)**	7,958 psi	32,000 psi (S_{yp})	**4.02**	PASS

Note: The limiting factor is Crossbar Buckling (n=2.29), which is safely above the requirement of n=2.0.

Table 3. Table Showing safety factors of members for optimized geometry compared to needed value

Exploration: Design Choices

Material & Geometry Selection

- **Material Selection:** We selected Steel for the diagonal arms due to high stress concentrations at the pin connections (tearout risk). Aluminum was selected for the crossbar to reduce mass where buckling was the primary constraint rather than bearing strength.
- **Stock Sizing:** Dimensions were restricted to standard bar stock to ensure manufacturability and low cost. We avoided custom machining requirements.
- **Geometry:** We chose to limit the scope of our geometry exploration to the most common scissor jack design. The lengths were optimized to maximize mechanical advantage while fitting strictly within the storage container.

All Feasible Options

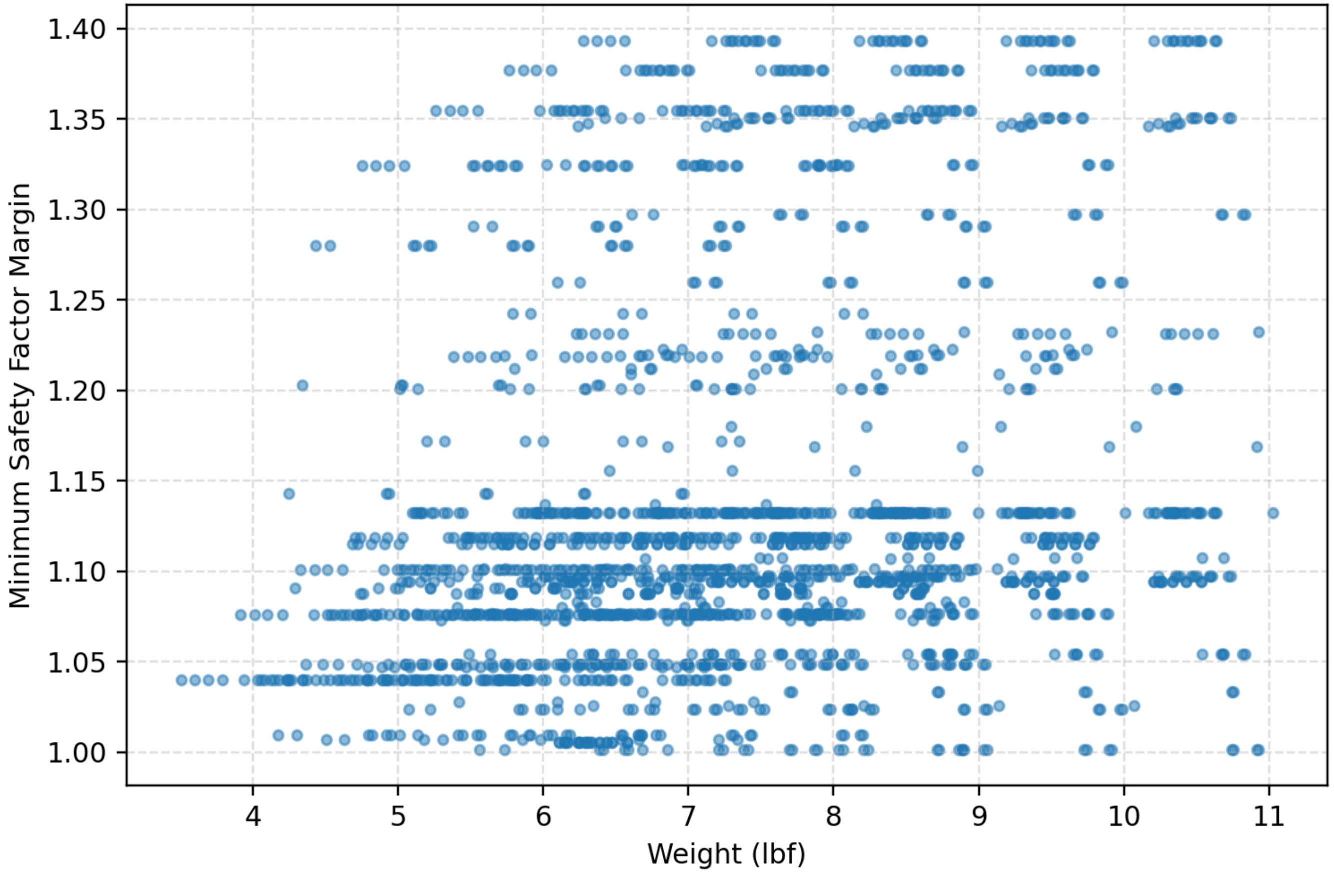

Figure 1. All feasible scissor jack designs that meet the given constraints. Safety factor margin is calculated by dividing the actual safety factor of the design by the minimum required for the design.

Analysis: Promising Options

As expected, reductions in component dimensions lead to lower overall weight while also reducing stress capacity.

Designs with higher safety factors generally weigh more.

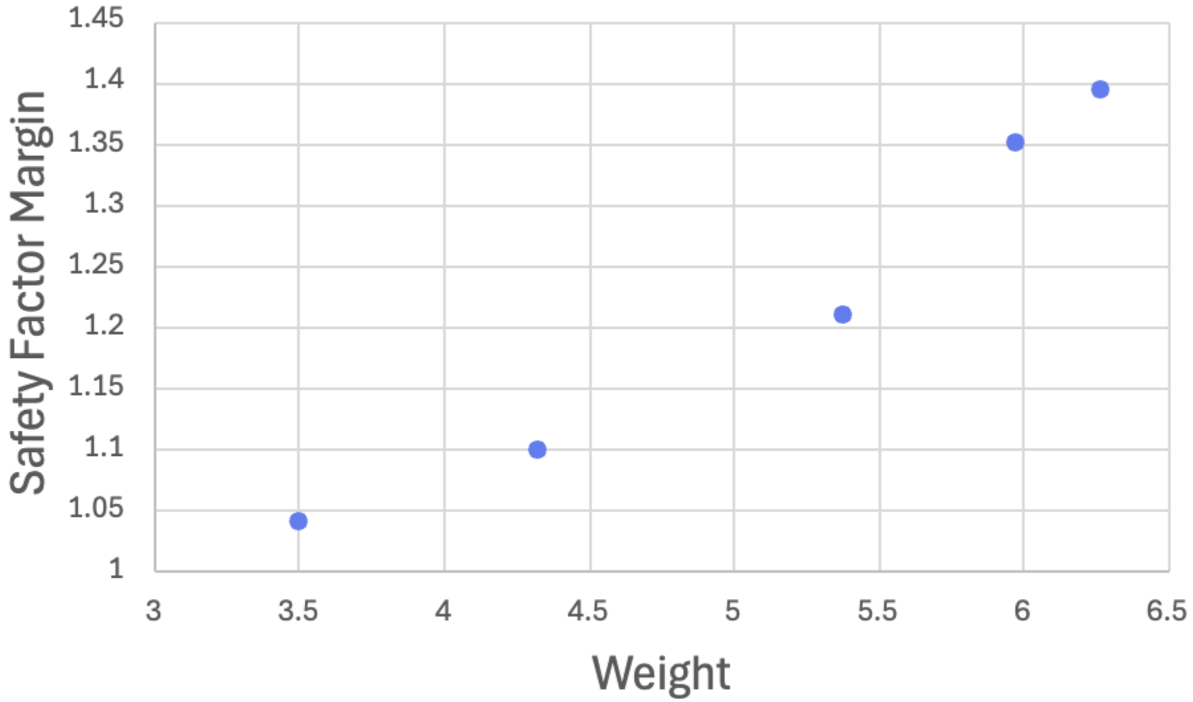

Figure 2. Several promising options for scissor jack design drawn from the results of Figure 1.

Analysis

- Relationships appears between crossbar diameter, pin diameter, and the resulting minimum margin.
    - Larger crossbar diameters increase buckling resistance, which raises the minimum margin, but also adds weight.
    - Decreasing pin diameter lowers shear and bearing strength in both the diagonal and the crossbar, tightening the feasibility window. This shows a clear tradeoff: you can lighten the system, but you must simultaneously protect the margin by letting another variable increase to compensate.

- The best-performing designs came when variables were balanced: thin enough to reduce weight, but paired with sufficient hole edge distance, pin size, and other dimensions to preserve the minimum safety margin above 1.0.

Success Measures

Table 4 – Design requirement fulfillment

Design Requirements	Model Specs
Minumum 2,000 lbs load	2,000 lbs was used as a constant in all of our calculations.
Safety factors are all met	See slide seven.
Must fit within a 40"x10"x10" envelope.	The widest part of the jack is the pin at 2". The longest part of the jack is the crossbar at 8". The height of it is calculated using geometry to be 11.3". Since we are minimizing weight, we are well within the size constraint.
Designs must utilize standard available stock sizes.	Diagonal bar thickness is adjusted to standard sheet metal thickness (gauge 8) and the pin diameter is adjusted to standard size (7/16). All other dimensions were already standardized.

Cost, Manufacturing, and Usability

- As weight is directly proportional to cost, by minimizing the weight of our design we have also minimized the cost.
- To avoid adding excess manufacturing costs, we have ensured all our parts and holes are standard sizes.
- The light and compact but strong design we have opted for will make maneuvering and storing the jack much easier for the user
    - It is possible, however, that some users may inherently mistrust the reliability of the jack due to how lightweight it is

Final Design

Diagonal bar:
- Width = 0.75 in
- Height = 0.75 in
- Length = 8 in
- Thickness = 0.1644 (0.1625)in
- Hole to end = 0.4 in
- Material = Steel 1020 CD

Crossbar:
- Diameter = 0.5 in
- Length = 8 in
- Material = Aluminum 6063 T6

Pin:
- Diameter = 0.4375 or 7/16ths (0.4) in
- Length = 2 in
- Material = Steel 1020 CD

Figure 3: CAD Model of Final Design