SMDC 23

STAGE MACHINE DESIGN COMPETITION

2023 Guess Who?

Indiana University

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INTRODUCTION

You and your team have been hired to design a machine for an upcoming museum event centered around family game night. Your specific challenge: for an installation based on the game Guess Who, children will have to be able to flip panels that are approximately 3' wide by 5' long. The event designers have created the actual flipping panels and the structures they are housed in; **your task is to design a drive train that would allow a child to flip these panels by hand, at a distance from the axis of rotation**.

1. PROJECT REQUIREMENTS

1.1. Physical Requirements

- The operating height of the handle must be 21" from the floor
- The pivoting panel must stay in an up/down position without any additional force applied at end of travel
- The pivoting panel will be constructed using 3/4" plywood; for the given size (3′x5′), it will weigh approximately 28 lb.

1.2. Mechanical Requirements

- Transfer a maximum applied force of 22 N (5 lb) at the handle/lever to the shaft of the provided pivoting panel with sufficient torque to pivot the panel.
- Transfer the motion of the handle to the shaft of the provided pivoting panel such that a push on the handle will cause the panel to pivot up and a pull will cause the panel to pivot back down.
- The interface point to the pivoting panel will comprise a 1" diameter keyed shaft; you will need to ensure that your mechanism can be securely fastened to the shaft for operation.

1.3. Movement Requirements

- horizontal translation of the handle/lever cannot exceed 8"
    - Note: the handle level does not need to travel only in a straight line—it can rotate around some axis a la a crank of some kind; however, the maximum horizontal translation must be no more than 8"
- 28# Panel must rotate the required 100° (*See Appendix 1*)

1.4. Provided at Competition

- ¾" Ply 3'x5' panel, weighing 28#
- Rotating base w/ 1" Diameter keyed shaft (*See Appendix 2*)
- Up to 15A 110-120VAC power per participating team will be available for testing and competition
- 100 PSI air pressure available by 1/4" tube or quick-connect by request. Requests for air supply must be made prior to May 1 by emailing the competition hosts.

1.5. Competition Requirements

- A written proposal with corresponding paperwork

    - Design specification documents (detailing the requirements of the machine, as best as the team understands them, etc.).
    - Concept designs (sketches, drawings, low-fidelity prototypes exploring multiple design solutions to the challenge, and a justification for why the team chose to follow through on a specific concept).
- A working prototype to be tested on-site and at the competition event
    - The prototype itself
    - Any tools required to assemble and operate the prototype
    - Any additional equipment beyond the scope provided in the event venue, within the parameters detailed in the challenge
- Design documentation
    - The proposal
    - Detail design materials (estimates, parts lists, technical drawings, appropriate mathematical/engineering analyses, etc.).
    - As-built drawings.
    - Documentation of actual costs.
    - Any relevant safety and/or operation manuals.
    - Assessment of successes/failures of the design.
    - Assessment of successes/failures of the team.
- Teams will be provided with time prior to testing to calibrate and tune their devices.
- No pyrotechnics

2. DESIGN CONCEPTS

The team broke down this challenge into three separate parts. How the machine will connect to the shaft, what type of mechanism will be used to create the movement, and what the handle/lever itself could be. *Fig 1 & Fig 2* show rough sketches of various concepts.

2.1. Connection to shaft

2.1.1. Lever Arm

The Concept:

A lever arm attached to the keyed shaft that can be pulled/pushed the appropriate amount for the needed 100° of travel.

Pros:

- Simple
- Larger arm helps with torque needed to lift the 28lb board

Cons:

- Don’t think it will work without an actuator driven design
- The element that attaches to the arm would require rotation to account for the rotation of the arm

2.1.2 V-Belt

The Concept:

A sheave attached to the keyed shaft driven by a v-belt

Pros:

- Torque needed to rotate board easily achieved via the mechanical advantage of a smaller input sheave driving a bigger output sheave (the sheave attached to the keyed shaft)

Cons:

- Minimum ⅛ HP motor needed
- Needs a power source
- V-belt needs to be tensioned
- With continued usage and testing original v-belt could stretch out and need re-tensioning/replacement
- Even with tension, the v-belt could slip

HMI (Human Machine Interface) lever arm could be used

2.1.3 Chain and Sprockets

The Concept:

A sprocket is attached to the keyed shaft and driven by chain

Pros:

- Torque needed to rotate the board easily achieved using gear ratios
- Could be moved by hand or motor

Cons:

- Force needed to raise the board might be too much to be achieved by hand
- Bevel Gear needed to change the axis of rotation
- Needs to be tensioned (chain must have a certain amount of links before being tensioned)
- Minimum ⅛ HP motor needed

2.2. Movement Mechanism

2.2.1. Ratcheting Hand Crank

The Concept:

A ratcheting hand crank that will allow the panel to be moved by hand, without an additional motor necessary

Pros:

- Simple
- The ratcheting crank might keep the board at the needed up and down position

Cons:

- The extra tension on the ratcheting crank, might cause the locking mechanism to slip
- Very high mechanical advantage needed
- All around not good plan

2.2.2. Actuator

The Concept:

An Electric or Pneumatic Actuator (used with the arm connection at the keyed shaft) that would push/pull the arm rotating the board 100°

Pros:

- Electric/Air: one power source, readily available
- Doesn't need limit switches

Cons:

- Electric/Air: Needs power
- Translating from linear to rotational motion may be difficult to calculate accurately
  - Addition design needed to properly choose clevis mount
- Likely complicated and costly

2.2.3. Motor

The Concept:

Motor with sufficient torque that will rotate the panel via a sprocket or sheave

Pros:

- Simple
- Motor we might be in stock
- Slight mechanical advantage
- Pushbutton or joystick
- Uses readily available 110 AC power
- Motor brake would automatically keep the panel at a 100° position

Cons:

- Limit Switch needed
- Sizing correct motor
- Tension on chain
- Wiring
- 3 phase AC power not available
- Would need to manipulate the speed of the motor

2.3. Interactive Handle

2.3.1. Crank

The Concept:

The most interactive with the senses, the motion and noise of a ratcheting crank could be fun and aesthetically pleasing for people who interact with the machine.

2.3.2. Button

The Concept:

While a button would be less interactive, there would be no need for force to be acting upon a handle for the mechanical designs.

2.3.3. Joystick

The Concept:

More interactive than the button, less interactive than the crank, the joystick would be great for a design that is motorized or pneumatic.

2.4. Housing Kiosk

- Steel structure to keep the distance between handle and panel accurate
- Operating height of handle 21" from floor

2.5. Contingencies

The contingencies are the problems/solutions that we may face regardless of the concept chosen

- Maintaining tension between sprockets/sheaves
  - Keep a consistent distance between the motor and the panel
    - Add a spacer (steel, wood, etc.)
    - Add additional weight at the source
- Distance to power source
  - Bring extension cords
    - Appropriately sized for length of travel
- Repairs at competition
  - After deciding on a concept, putting together a repair kit containing everything necessary to repair the machine if needed

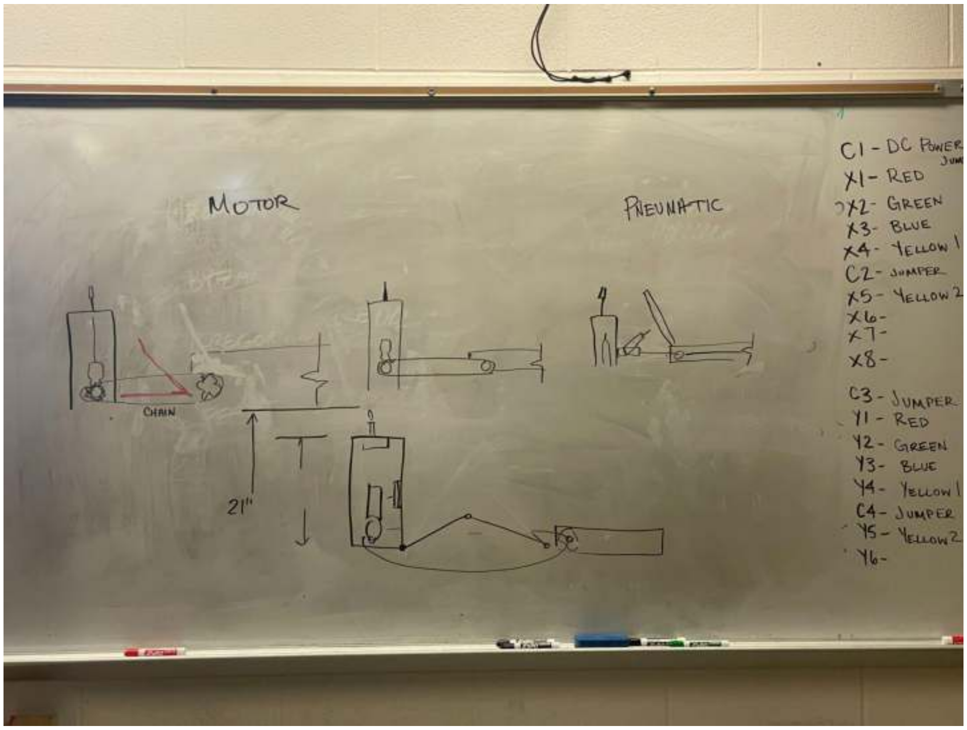


Fig 1
Early design concepts & potential tension solutions

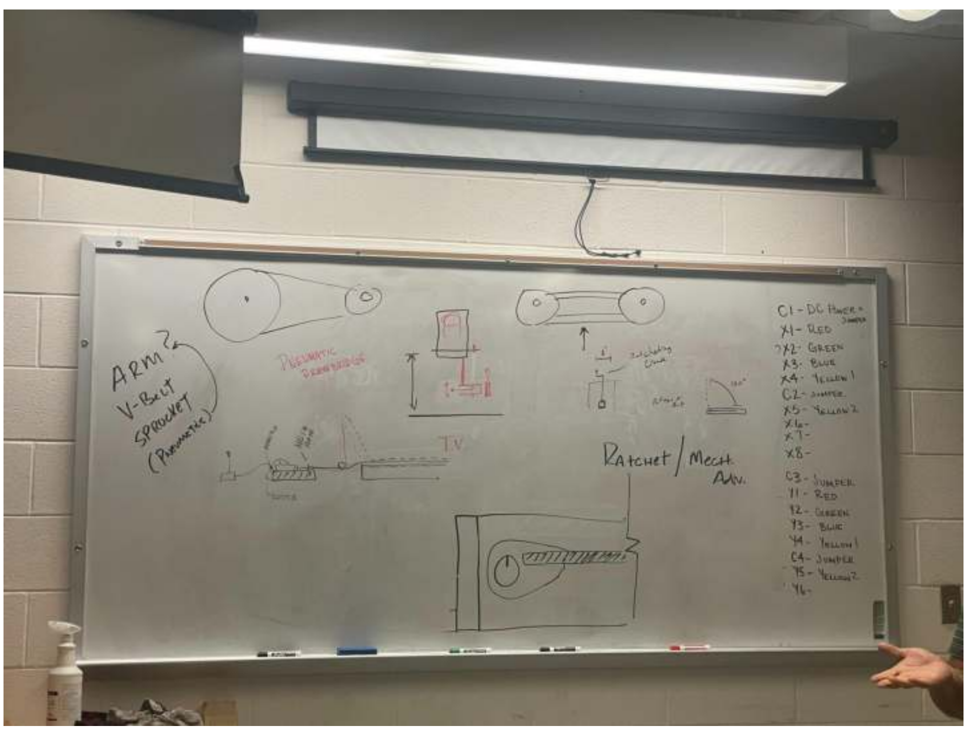


Fig. 2
Early concepts of connection to keyed shaft

3. FINAL DESIGN

After taking all of our design concepts into consideration, we decided to move forward with a motor-driven sprocket and chain design.

3.1. How it works

Participants will manipulate the motor via a HMI on top of the housing kiosk. This in turn will make the motor drive a small sprocket connected to a larger sprocket on the keyed shaft. The motor, with sufficient torque, should rotate the panel the needed 100° both up and down. The load/motor brake will keep the panel locked in place at both ends of its rotation. See Fig. 3

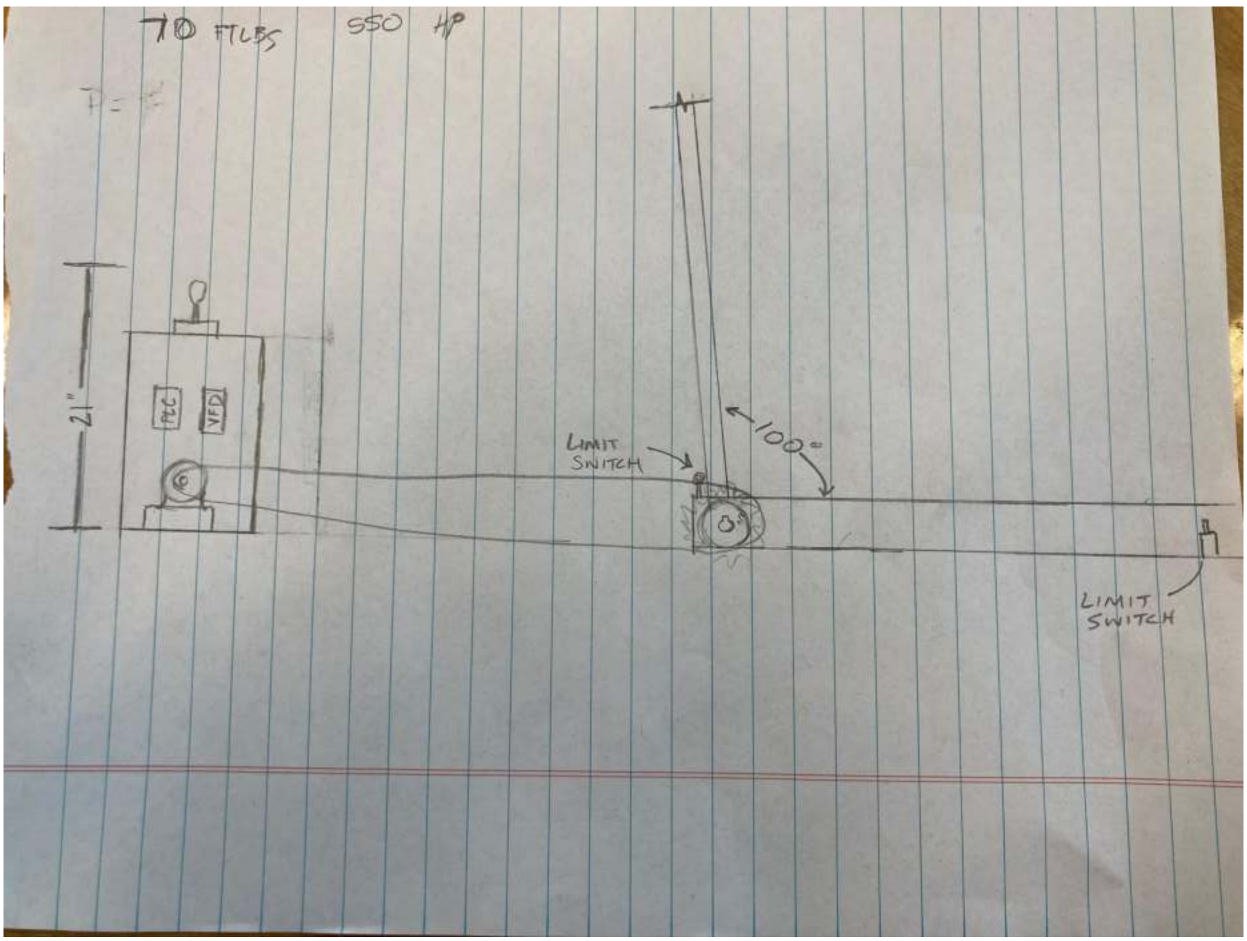


Fig. 3

3.2. Pros

- Uses 110 AC Power (available at competition)
- Load/motor brake acts as a lock, keeping the panel in place at end of rotation
- Might have a motor in stock
- Mechanical Advantage
- Minimal force and movement needed on HMI to rotate the panel

3.3. Possible Challenges and Solutions

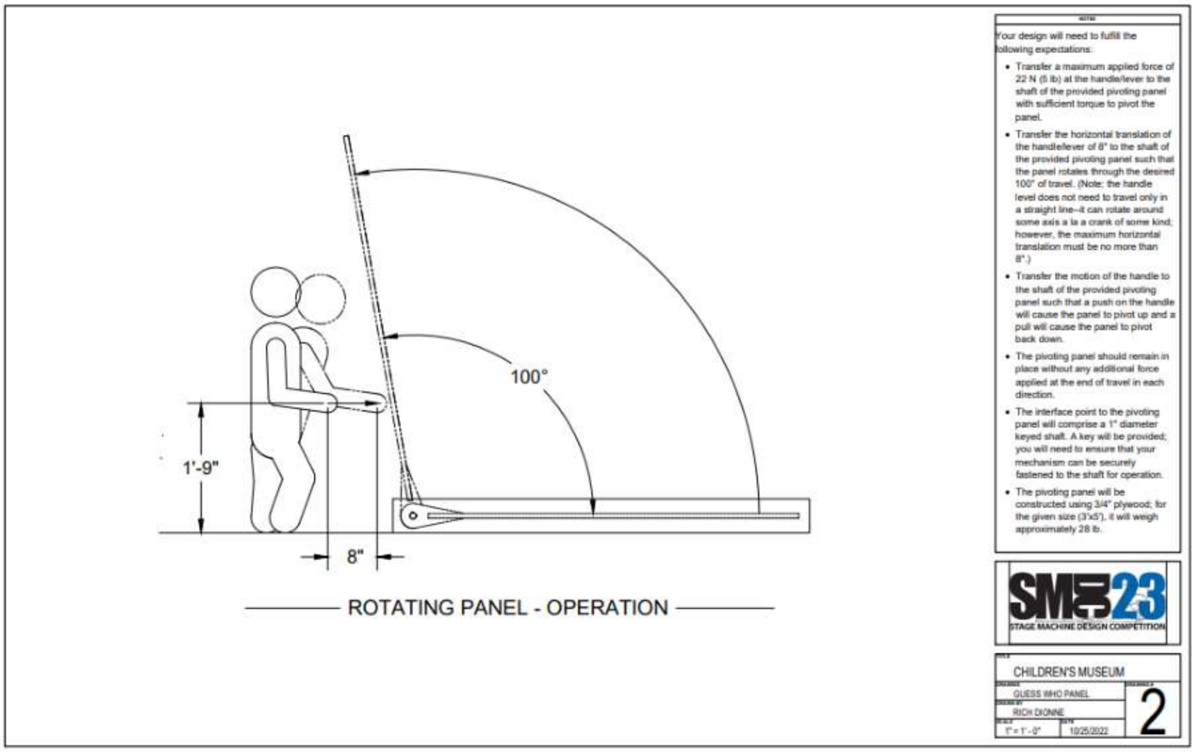
- Limit switch needed (connection to panel mechanism might be complicated)
  - Rotary limit switch could be mounted elsewhere, and provide more control over rotation travel
- Sizing correct motor (if stock motor does not work)
  - See Appendix 3
- Tensioning sprocket and chain
  - A folding (for aesthetic and practical purposes) tensioner which keeps the housing the required distance from the panel flipping mechanism in order to keep the sprockets and chain tensioned. Will make load-in efficient.
- Wiring
  - With a limit switch, an additional electrical component (relay switch, PLC, etc.) is needed
- Load in
  - Fine-tuning the rotary limit and ensuring the tensioner works correctly.

3.4. Next Step

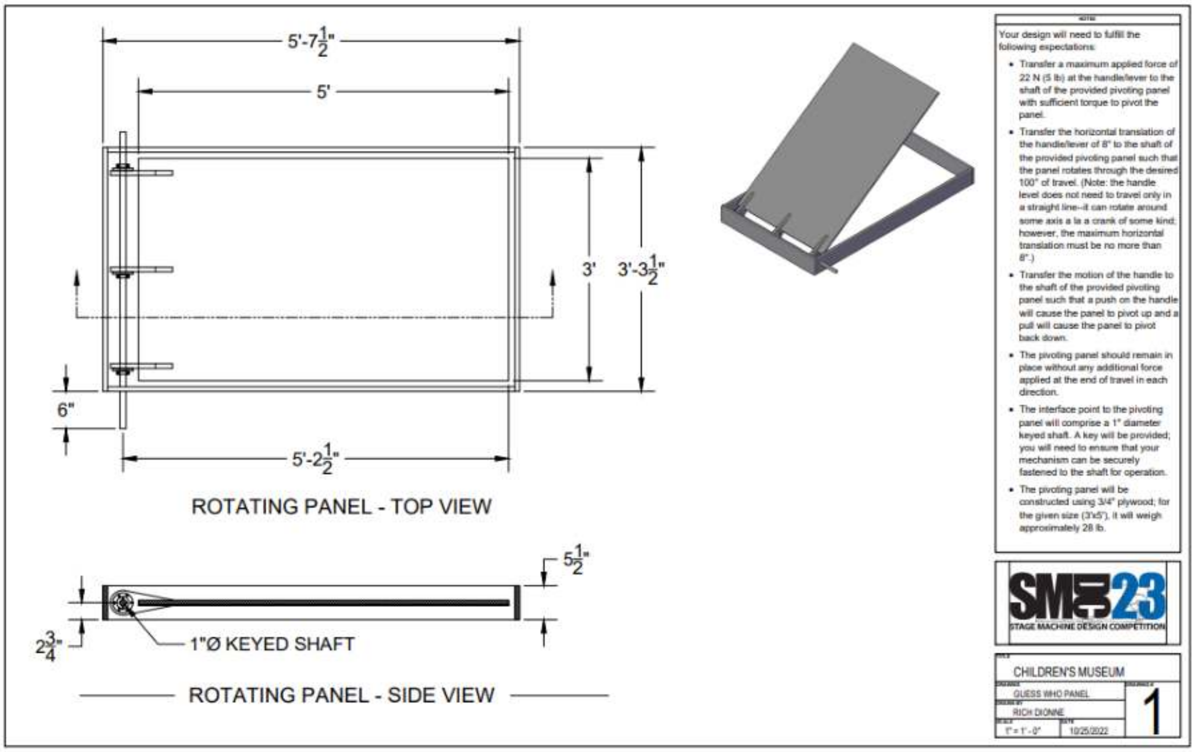
- Creating a replica of the panel flipping mechanism
- Acquiring a correctly sized motor
- Creating a prototype of our mechanism to ensure the reliability of the design
- Fine-tuning folding tensioner

APPENDICES

Appendix 1



Appendix 2


5'-7 1/2"
5'
3'
3'-3 1/2"
6"
5'-2 1/2"
ROTATING PANEL - TOP VIEW
5 1/2"
2 3/4"
1"Ø KEYED SHAFT
ROTATING PANEL - SIDE VIEW
Your design will need to fulfill the following expectations:
• Transfer a maximum applied force of 22 N (5 lb) at the handle/lever to the shaft of the provided pivoting panel with sufficient torque to pivot the panel.
• Transfer the horizontal translation of the handle/lever of 8" to the shaft of the provided pivoting panel such that the panel rotates through the desired 100° of travel. (Note: the handle level does not need to travel only in a straight line--it can rotate around some axis a la a crank of some kind; however, the maximum horizontal translation must be no more than 8".)
• Transfer the motion of the handle to the shaft of the provided pivoting panel such that a push on the handle will cause the panel to pivot up and a pull will cause the panel to pivot back down.
• The pivoting panel should remain in place without any additional force applied at the end of travel in each direction.
• The interface point to the pivoting panel will comprise a 1" diameter keyed shaft. A key will be provided; you will need to ensure that your mechanism can be securely fastened to the shaft for operation.
• The pivoting panel will be constructed using 3/4" plywood; for the given size (3'x5'), it will weigh approximately 28 lb.
STAGE MACHINE DESIGN COMPETITION
CHILDREN'S MUSEUM
GUESS WHO PANEL
RICH DIONNE
1" = 1'-0"
10/25/2022
1

Appendix 3

Max amount of torque required & amount of torque required to overcome gravity to hold in place
Using the power formula to figure out what size motor is needed.

Assume Max Acceleration is 10 degrees/sec^2 = .174 rad/sec^2

Assume Max Speed is 30 degrees/sec = .524 rad/sec

Assume Friction is Negligible

$$P_{max} = (T_{accel} + T_{lift})\omega_{max}$$

Where

P_{max}	Maximum Power Needed (ftlbs/sec)
T_{accel}	Torque from Acceleration (ftlbs)
T_{lift}	Torque from Lifting (ftlbs)
ω_{max}	Maximum Speed (rad/sec^2)

Solving for Torque from Acceleration

$$T_{accel} = I\alpha$$

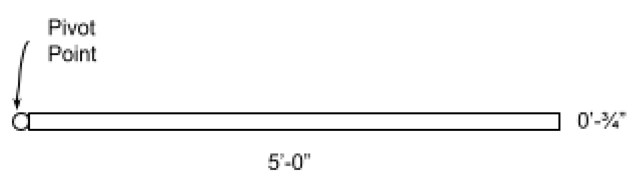
$$I = \frac{m}{12}(a^2 + b^2) + mr_{tr}^2$$

Where

I	Moment of Inertia (slugft)
α	Maximum Acceleration (rad/sec^2)
m	Mass (slugs)
r_{tr}	Transfer distance (ft)

$$I = \frac{28/32.2}{12}(5^2 + \frac{.75}{12}^2) + \frac{28}{32.2}2.5^2$$

$I = 1.812 + 5.435 = 7.248$ slug-ft^2



$$T_{accel} = 7.248(.174) = 1.26\ ftlbs$$

Solving for Torque from Lifting

$$T_{lifting} = r_{c\,of\,m}F_w$$

Where

$r_{c\,of\,m}$	Radius from the center of mass (ft)
F_w	Force weight (lbs)

$T_{lifting} = 2.5(28) = 70\ ftlbs$

Calculating Power

$P_{max} = (1.26 + 70)(.524) = 37.34\ ftlbs/sec$

$37.34 /550 = .067\ hp\ motor$

BIBLIOGRAPHY

Conner, Gareth. *Scenic Automation Handbook*. Routledge, 2018.

Hendrickson, Alan. *Mechanical Design for the Stage*. 1st ed., Focal, 2015.