Airplane Wheelchair Entry

Chair Force One
December 2nd, 2025

Stanford | Mechanical Engineering
Senior Capstone Program

Project Members:

Vicky Haley Brad Rodolfo

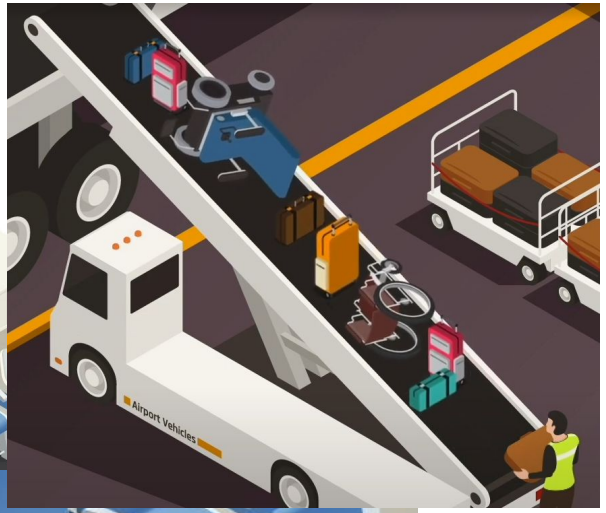
Team Advisors & Support

Coach:
Bill

CA:
Tori

Liaison:
Sean Auer

Project Motivation:



70% of wheelchair users said they forgo air travel due to accessibility concerns.

Project Objective:

Design a **cabin layout specific** solution that allows **manual wheelchairs** users to **independently board and exit an aircraft**, move through its aisle, and secure themselves on **standard aircraft seat.**

Who are our users?

Primary user:

- A traveling manual wheelchair user
- Has upper body functionality
- Weight under 300 lbs

Secondary users:

- Airline and airport staff
- Primary user’s travel companions

High Priority Requirements

UR-1-1	Essential actions can be completed by primary user	ER-1-1	Actions require no more than 12 lbf/hand
UR-1-2	Narrow enough to fit in B737 aisle	ER-1-2	**In the aisle,** wheelchair width < 18 inches
UR-1-5	Solution must be stowable in the aircraft cabin	ER-1-5	Must fit into a space that is 54 x 22 x 14 inches
UR-3-1	Wheelchair withstands static loading conditions	ER-3-1a	300 lb weight at seat without yielding/fracture
		ER-3-1b	Backrest withstands 105 lbf at top point
		ER-3-1c	Solution must not tip with a max of 15 degrees tilt in all directions
UR-4-1	Power system must conform to FAA standards	ER-4-1	Energy capacity ≤ 300 Wh for Li-Ion Battery

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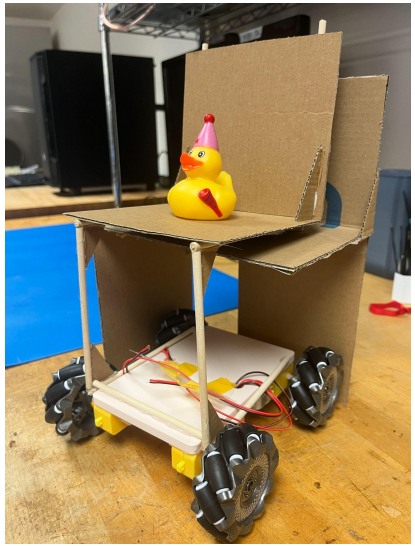
The Foldable, Dual Mode Wheelchair

An adaptation to a COTS foldable manual wheelchair

Overview of 3 Concepts from DR7

Problem: How to get a wheelchair user from the jet bridge to their aircraft seat, and back.

1



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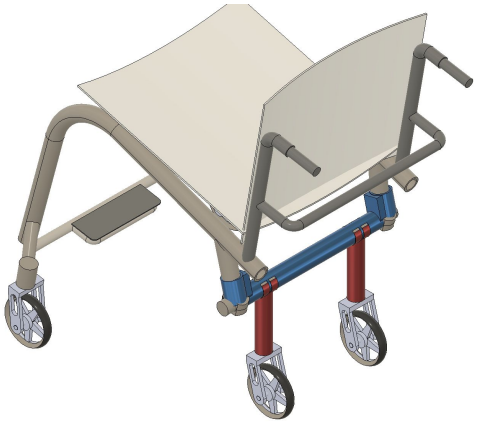

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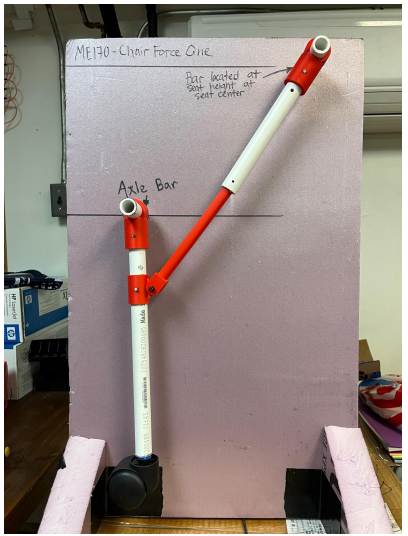
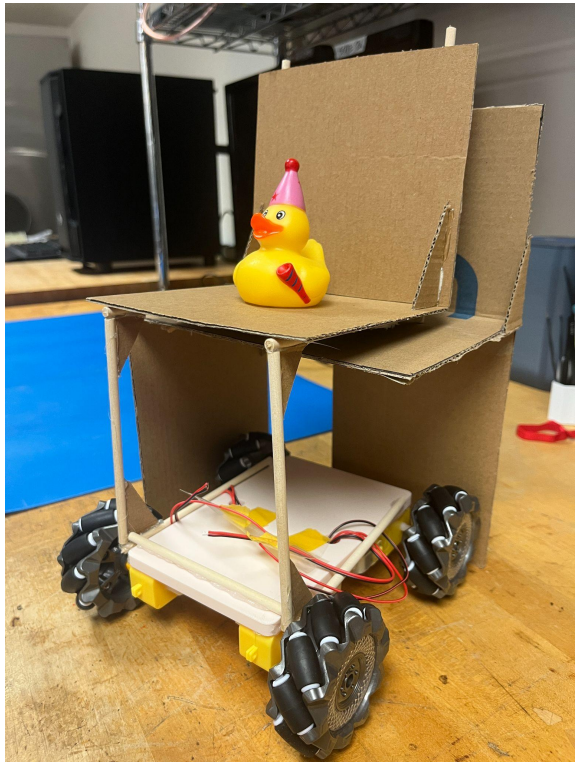
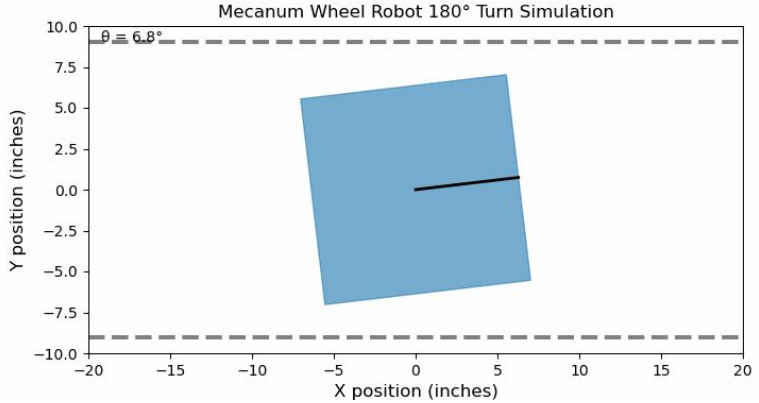
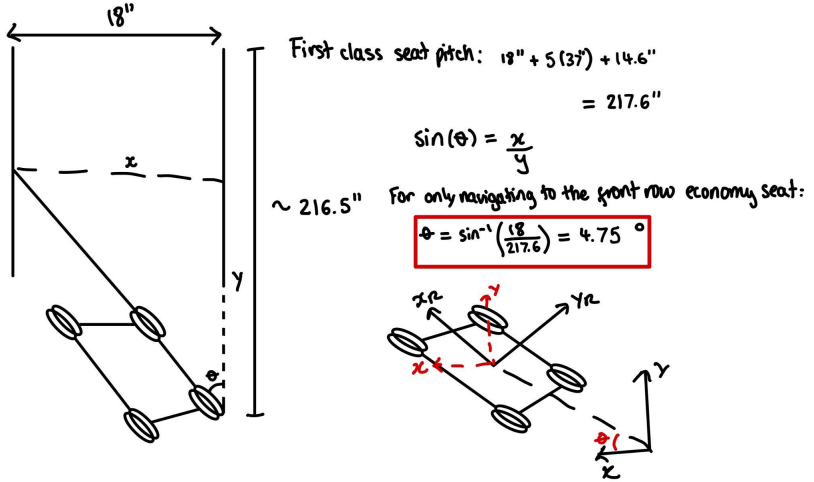


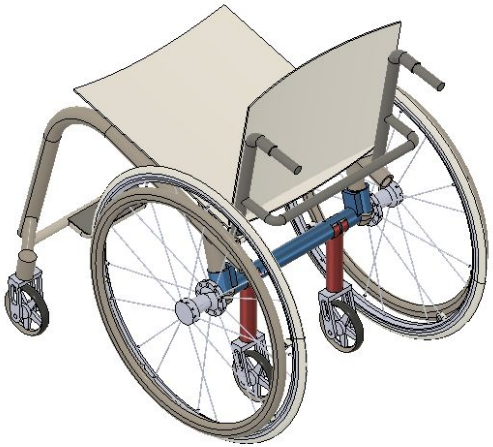
Concept 1: The Electric Air Chair

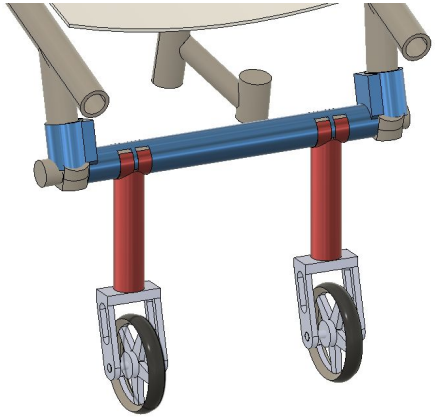




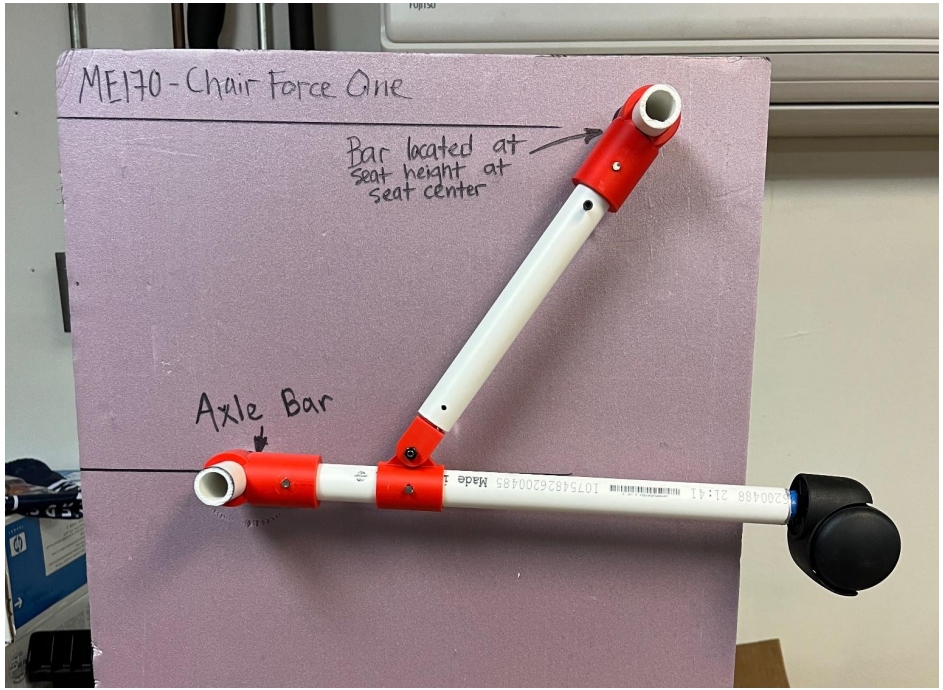


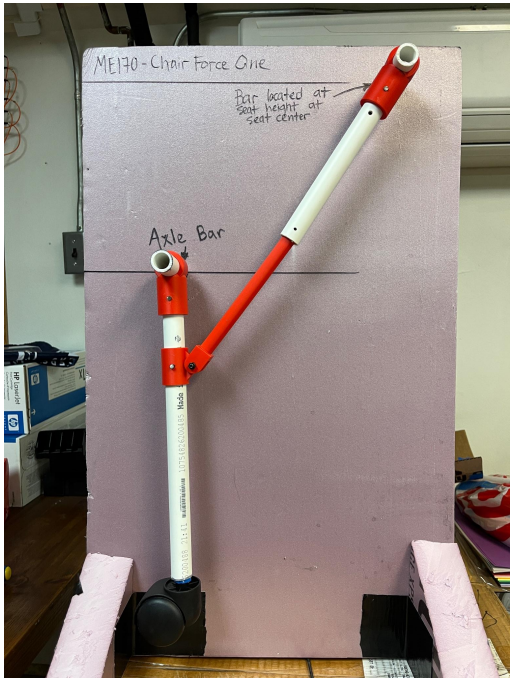
Concept 2: Manual Wheelchair with Solo Struts



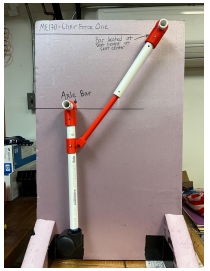


Concept 3: Manual Wheelchair with Telescoping Struts



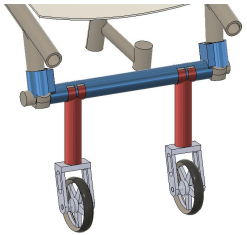


DR7 Concepts



DR7 Concepts				
Applicable ERs	**Weight**	**Electric AirChair**	**Manual WC w/ Solo Struts**	**Manual WC w/ Telescoping Strut**
ER-1-1a: Propeling takes no more than 12 lbf per hand	3	3	2	2
ER-1-2: Wheelchair width in aisle < 18 inches	3	3	3	3
ER-1-5: Wheelchair in stowed configuration fits in 54 x 22 x 14 inch volume	3	1	3	2
ER-1-6: All actuations take < 15 seconds to deploy	1	3	2	2
ER-3-1a: Wheelchair must support 300 lb weight limit without yield/failure	3	1	2	3
ER-3-1c: Tilt 15 degrees without tip-over with 170 lb weight in seat	3	2	3	3
ER-4-1d: Wheelchair weighs < 50 lbs	2	3	2	1
ER-4-2a: Battery must be < 300 Wh capacity	3	1	3	3
	Total	42	54	52

Solo Struts

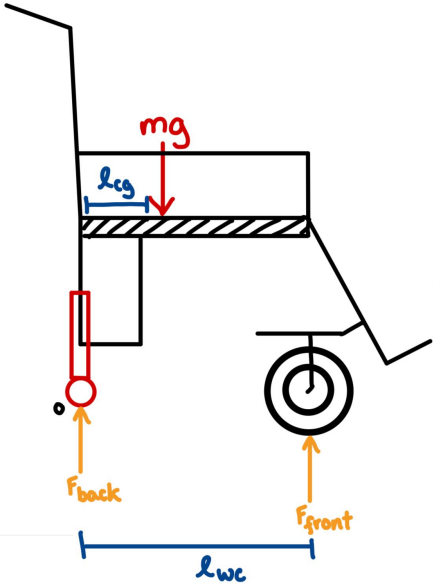


DR7 Feedback

A Foldable, Dual Mode Wheelchair

The Linear Actuators

- **Relevant ERs**
  - ER-3-1a: Integrated components cannot yield with 300lbs
  - ER-3-1c: <15 degree tilt on wheelchair at all times
  - ER-4-2a: Lithium ion batteries < 300Wh
- **Main Risks:**
  - ***Risk of tipping (loss of synchronization)***



$\Sigma F_y = 0$

$F_{back} + F_{front} - mg = 0$

$F_{back} = mg - F_{front}$

$F_{back} = mg\left(1 - \frac{l_{cg}}{l_{wc}}\right)$

$F_{back} \approx 200\,lbs$

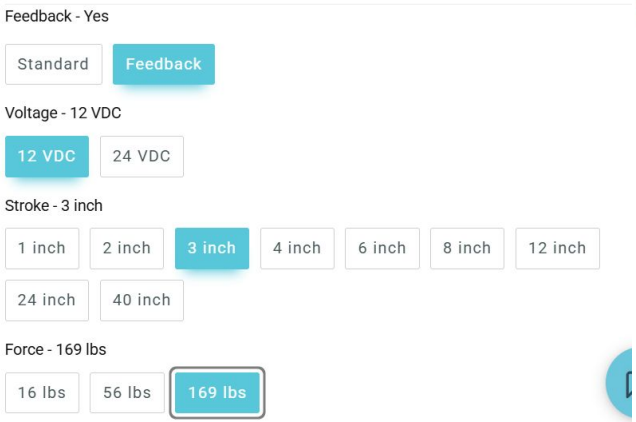
$F_{back}/2 = F_{actuator}$

$F_{act} \approx 100\,lbs$

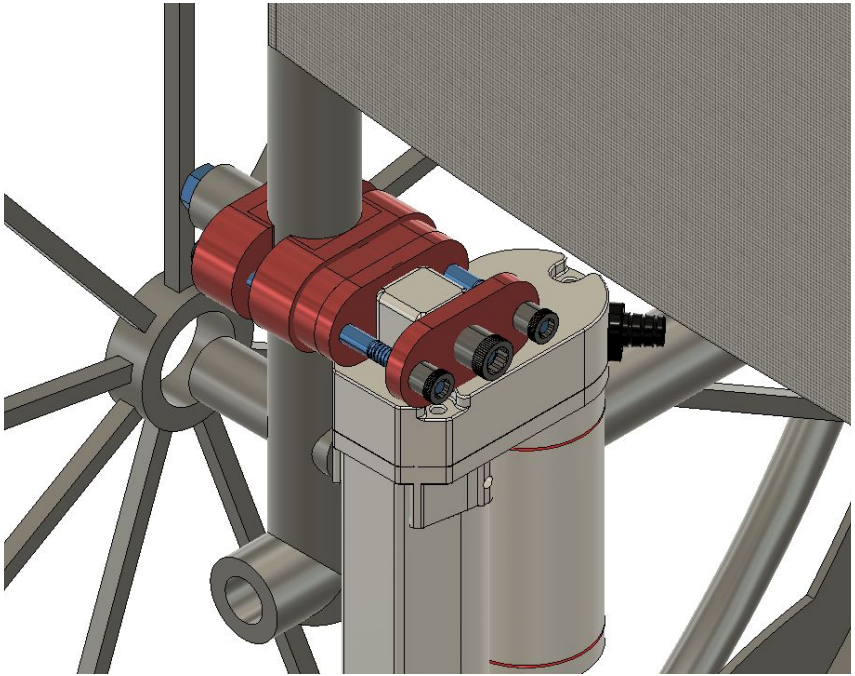
$\Sigma M_O = 0$

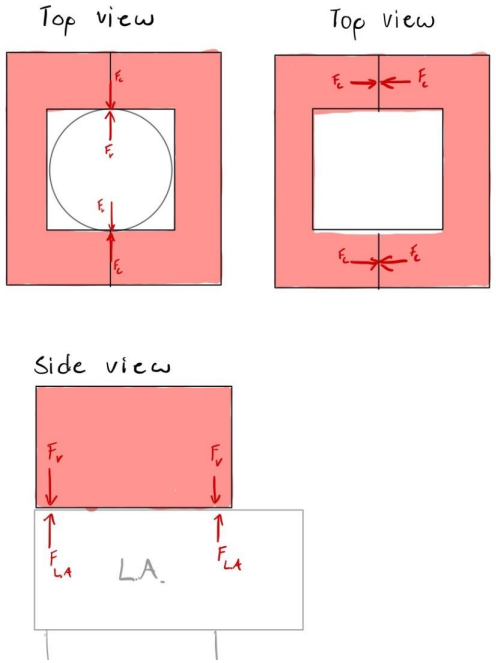
$-mg\,l_{cg} + F_{front}\,l_{wc} = 0$

$F_{front} = \frac{l_{cg}}{l_{wc}} mg$



Attachment of Linear Actuator to Wheelchair

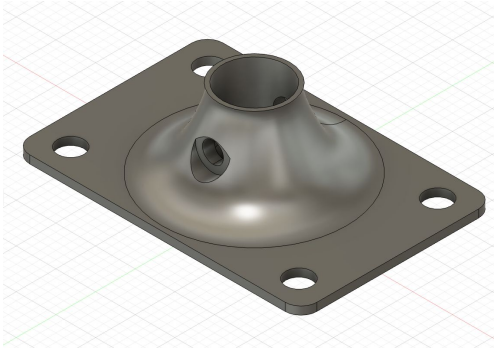




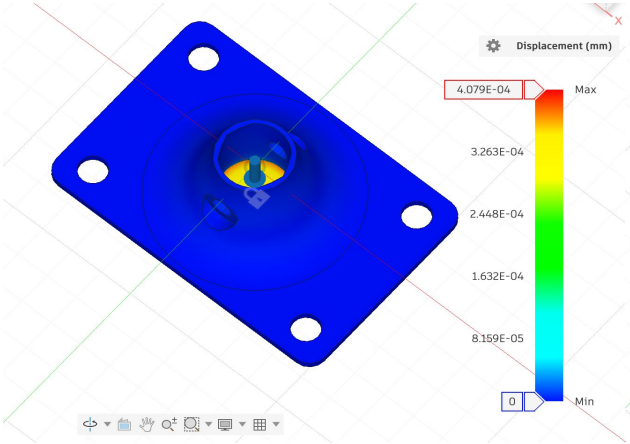
- **Relevant ERs:** ER 3-1a & 3-1c
- **Main Risk:** ***Twisting about connection point***

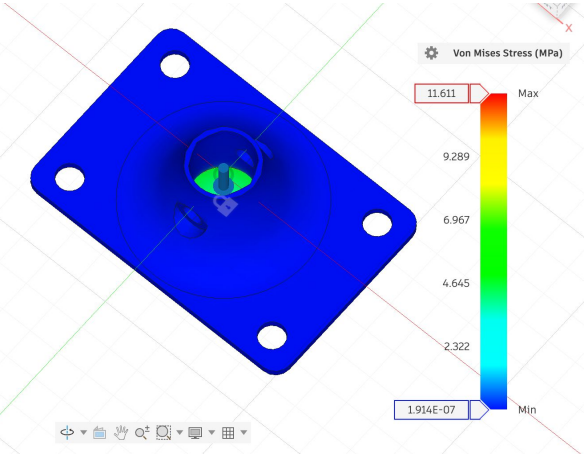
How are we going to attach the actuator to the wheel?

- Attachment with a pin hole



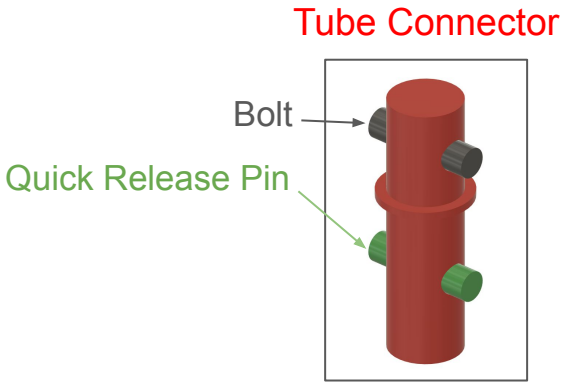
- ER 3-1a: 300 lb weight





Fitting Wheelchair in the Overhead Space

- **High Priority ERs**
  - ER-1-5: Stowed wheelchair fits in 54 x 22 x 14 inch volume
  - ER-3-1b: Backrest withstands 105 lbf of horizontal aft forces
- Original wheelchair, ER-1-5 unsatisfied → split backrest
- **Main Risk:** ***The removable backrest connection***



Stress Analysis + FEA of Backrest

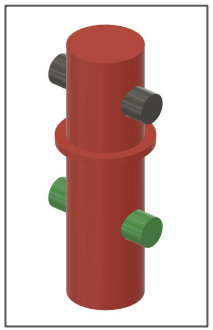
Connector Only

$$M = Fd = (52.5\ lbf)(7\ in) = 367.5\ lb\text{–}in$$

$$I = \frac{\pi}{64} d_O^4 = 0.01655\ in^4$$

$$\sigma_{max} = \frac{Md_o}{2I} \approx 8460\ psi$$

$$\sigma_{yield,\,6061} \approx 40,000\ psi > \sigma_{max}$$

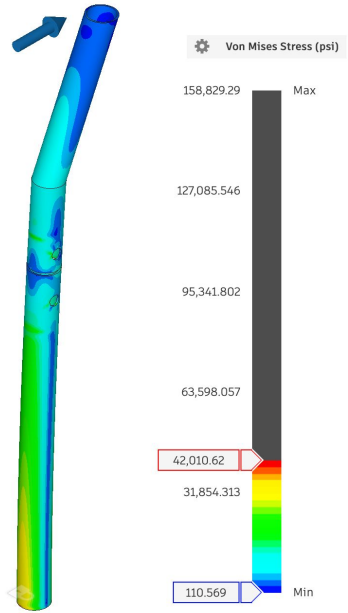


6061 Al → **$FS_{MIN} > 4$**

Backrest Tubes

Upper Tube

Lower Tube



*Unrealistically high stresses at bolt contacts, simulation refinement required

AISI 1060 Steel → **$FS_{MIN} \approx 1.7$**
(bulk tube stress)

Ethics of Our Design

Consideration

Safety for primary and secondary users (ASME Canon 1)

Steps Taken

Sufficient safety factors (Medium ER)

Design across multiple failure modes

Wheelchair max weight = 50 lbs

- Reduce physical strain on secondary users

Ethics of Our Design

Consideration

Balancing client interests of Boeing, airlines, and users (ASME Canon 4)

- Comfort & independence vs. Efficiency (time & cost)

Steps Taken

Linear actuators → increase independence

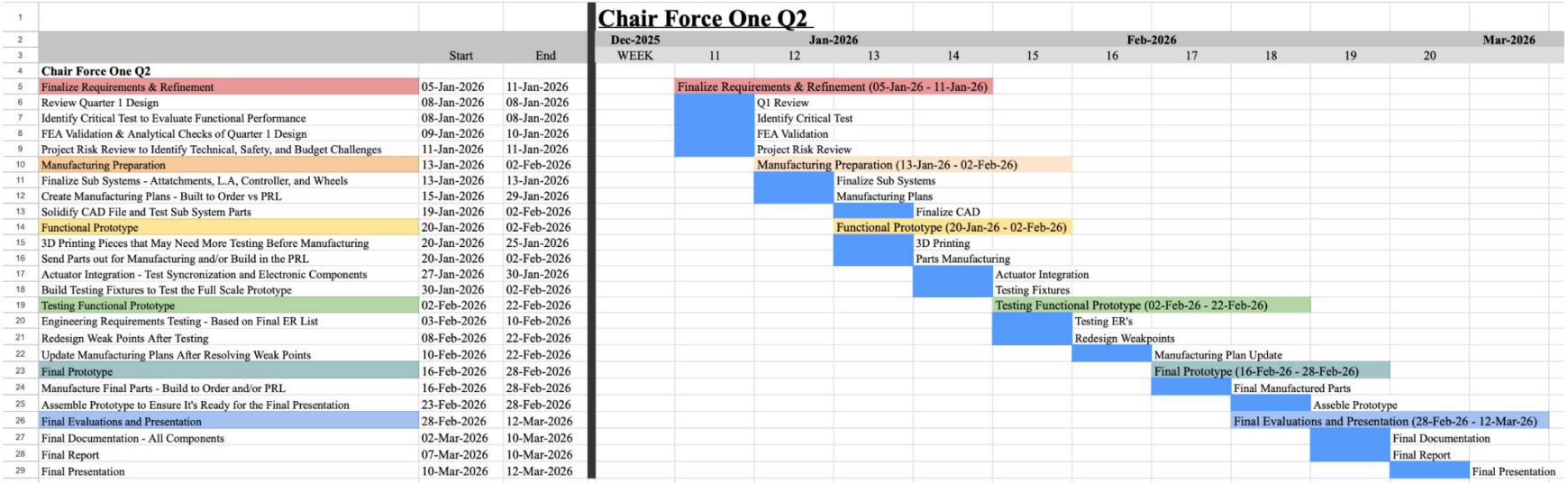
Stowable in an overhead bin

- Reduces boarding/deboarding times

Immediate Next Steps

Subassembly	Action Item
Linear Actuators	● Decide between rechargeable vs. single-use battery ● Purchase hardware: linear actuators, microcontroller, battery
Linear Actuators & WC Frame Attachment	● Redesign to reduce risk of twisting about frame connection point
Linear Actuator & Wheel Attachment	● Finalize material selection (CF vs. PLA)
Removable Backrest	● Refine FEA simulations to improve contacts ● Finalize material selection (PC-CF vs. Al) ● Develop a full backrest testing procedure

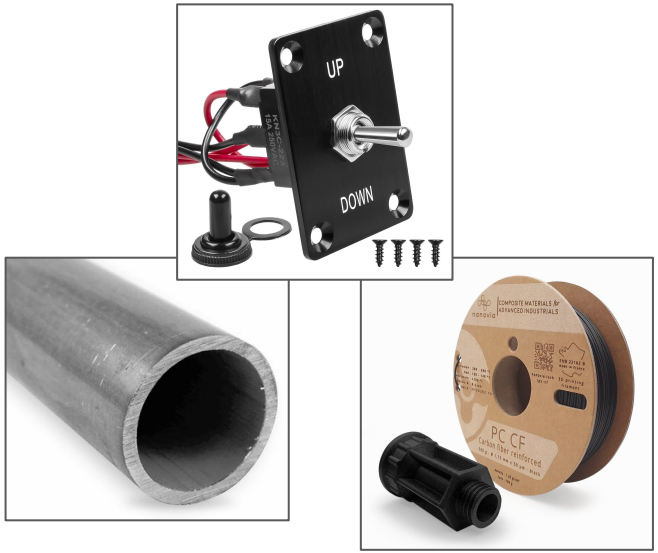
Gantt Chart



	Start	End
Chair Force One Q2		
Finalize Requirements & Refinement	05-Jan-2026	11-Jan-2026
Review Quarter 1 Design	08-Jan-2026	08-Jan-2026
Identify Critical Test to Evaluate Functional Performance	08-Jan-2026	08-Jan-2026
FEA Validation & Analytical Checks of Quarter 1 Design	09-Jan-2026	10-Jan-2026
Project Risk Review to Identify Technical, Safety, and Budget Challenges	11-Jan-2026	11-Jan-2026
Manufacturing Preparation	13-Jan-2026	02-Feb-2026
Finalize Sub Systems - Attatchments, L.A, Controller, and Wheels	13-Jan-2026	13-Jan-2026
Create Manufacturing Plans - Built to Order vs PRL	15-Jan-2026	29-Jan-2026
Solidify CAD File and Test Sub System Parts	19-Jan-2026	02-Feb-2026
Functional Prototype	20-Jan-2026	02-Feb-2026
3D Printing Pieces that May Need More Testing Before Manufacturing	20-Jan-2026	25-Jan-2026
Send Parts out for Manufacturing and/or Build in the PRL	20-Jan-2026	02-Feb-2026
Actuator Integration - Test Syncronization and Electronic Components	27-Jan-2026	30-Jan-2026
Build Testing Fixtures to Test the Full Scale Prototype	30-Jan-2026	02-Feb-2026
Testing Functional Prototype	02-Feb-2026	22-Feb-2026
Engineering Requirements Testing - Based on Final ER List	03-Feb-2026	10-Feb-2026
Redesign Weak Points After Testing	08-Feb-2026	22-Feb-2026
Update Manufacturing Plans After Resolving Weak Points	10-Feb-2026	22-Feb-2026
Final Prototype	16-Feb-2026	28-Feb-2026
Manufacture Final Parts - Build to Order and/or PRL	16-Feb-2026	28-Feb-2026
Assemble Prototype to Ensure It's Ready for the Final Presentation	23-Feb-2026	28-Feb-2026
Final Evaluations and Presentation	28-Feb-2026	12-Mar-2026
Final Documentation - All Components	02-Mar-2026	10-Mar-2026
Final Report	07-Mar-2026	10-Mar-2026
Final Presentation	10-Mar-2026	12-Mar-2026

Q2 Budget Overview

- Spent: $362
- **Anticipated Total Spend: $2240**
- Major Anticipated Expenses
  - Linear actuators: ~$720
  - 2x foldable wheelchair + scissor brakes: ~$500
  - Stock/hardware for parts + test fixtures: ~$515



Conclusion

- **Objective:** Design a wheelchair that allows manual wheelchair users to independently board and exit an aircraft, move through its aisle, and seat themselves on standard aircraft seating.

- **Recommended Solution:** A manual, foldable, dual-mode wheelchair that stows in an overhead bin.

Alfonse the Duck
Fully Approves this Concept

Backup Slides

Selection Rationale

- **Our Users**
  - What’s important to them
- **Engineering Requirements**
  - Feasibility
- **Potential Risks**
  - Stowing
  - Modifications

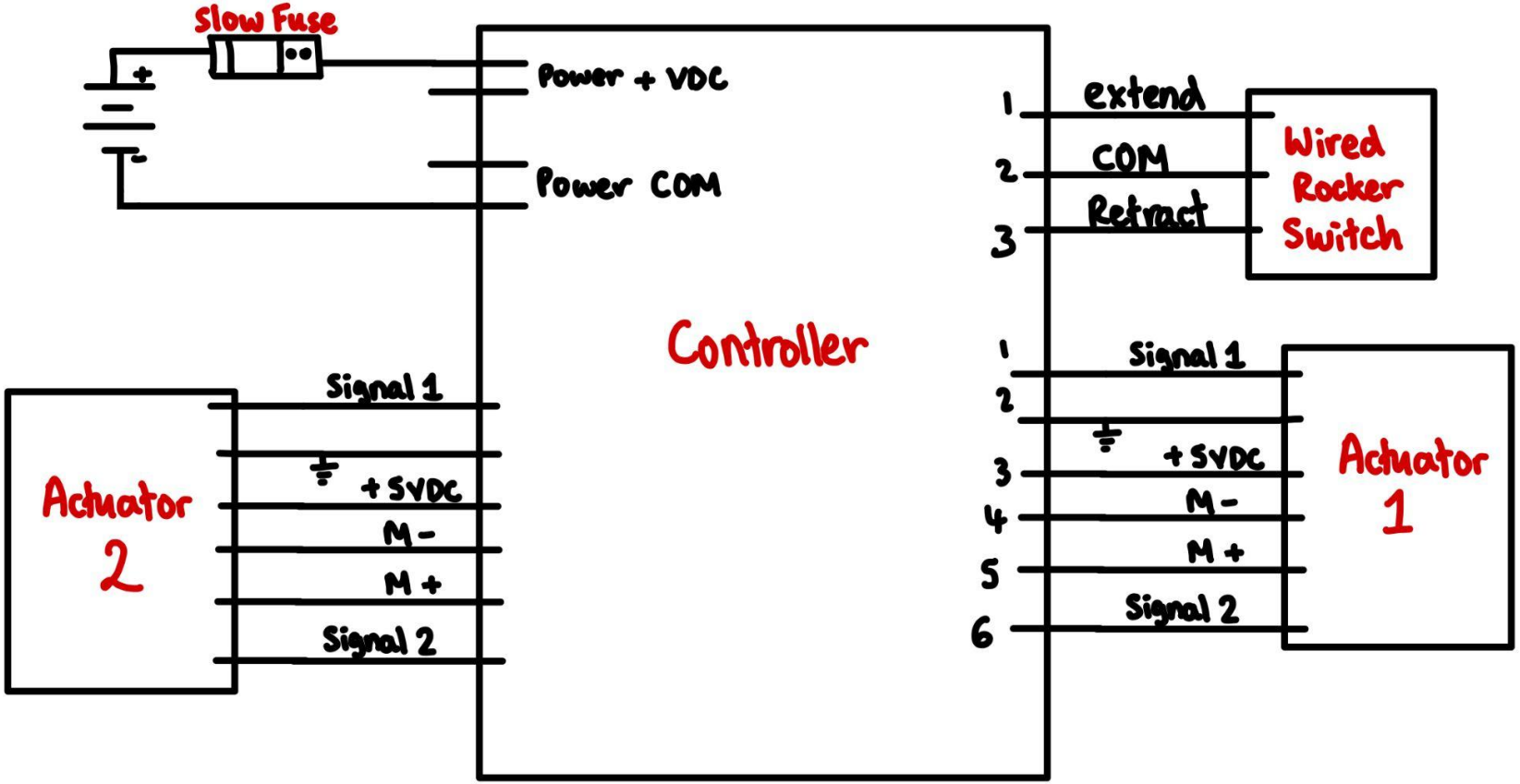
Modular Attachment vs Full Solution

Applicable ERs	Weight	Modular Attachment	Full Solution
ER 1-5: Airplane Stowability	2	1	3
ER 1-1: End-User Independence	3	1	2
ER 3-3a, b: Durability	1	1	3
ER 4-2a, b, c: Safety to End-User	3	2	2
	Total	12	21

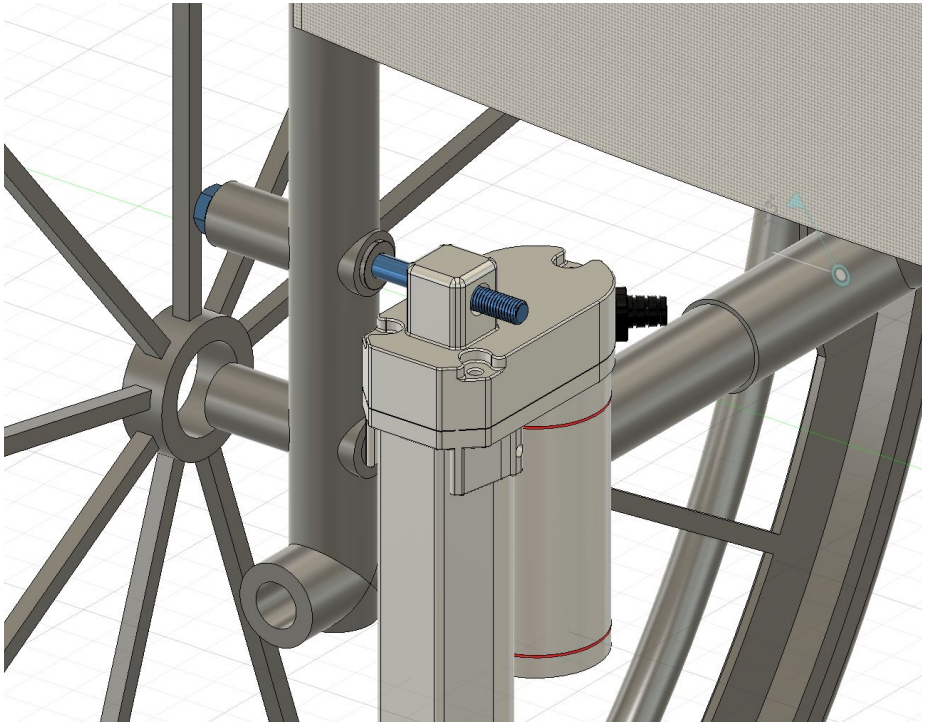
Decision matrices 3 - Rigid vs. Foldable Wheelchair

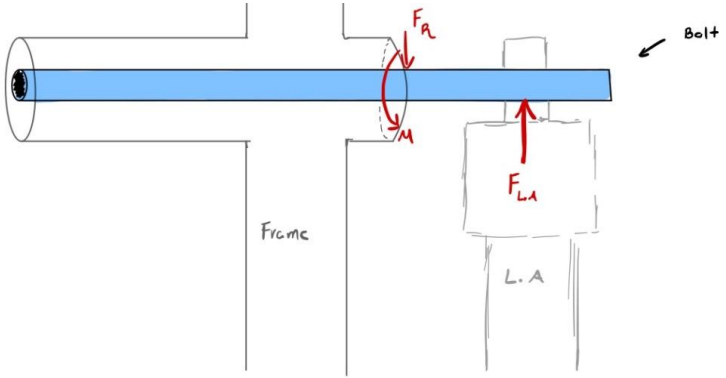
Applicable ERs	Priority (1-3 scale)	Rigid	Foldable
Can be independently operated by the user ER 1-1a	3	3	3
Without our attachment - wheelchair can brake ER 1-1b	1	3	2
Fits through the cabin aisle ER 1-2	3	3	3
Can get over the gap between the plane and jet bridge ER1-3	2	2	2
Can be stowed away ER 1-5	3	1	3
Must support 300 lbs ER 3-1a	3	3	3
Must weight under 50 lbs ER 4-1d	3	3	3
	Total	**46**	**51**

The Linear Actuator Circuit

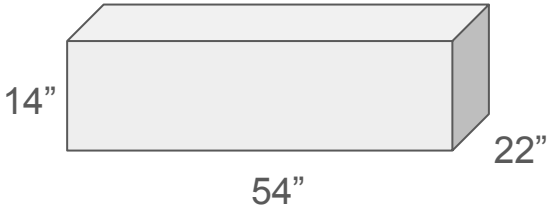


Attachment of Linear Actuator to Wheelchair

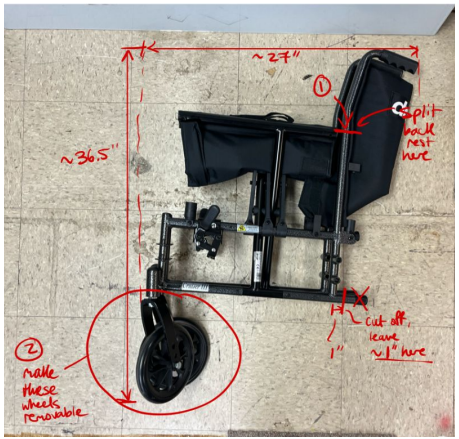


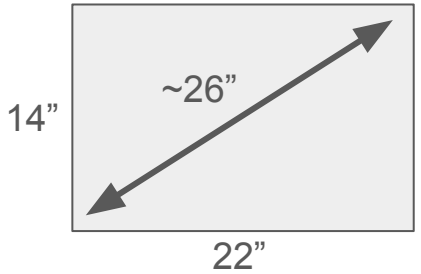


Wheelchair Folded

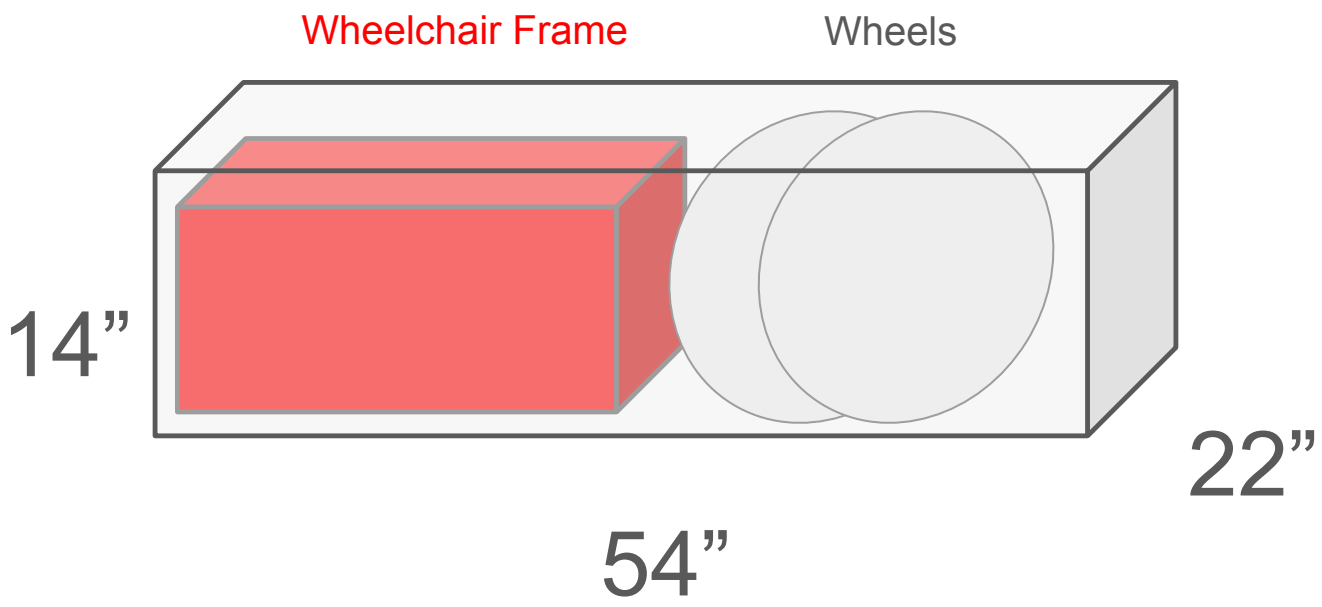


- Required volume to fit in: 54 x 22 x 14 inches
- Wheelchair w/o parts: ~27 x 21 x 12 inches
- Main wheels are 24 inch diameter, can fit along diagonal of volume (~26 inch)
    - Can also reduce diameter using other COTS wheels





Proposed Stowing Configuration



Design/Stress Analysis of Backrest

Main risk: Tube stress concentrations at edges

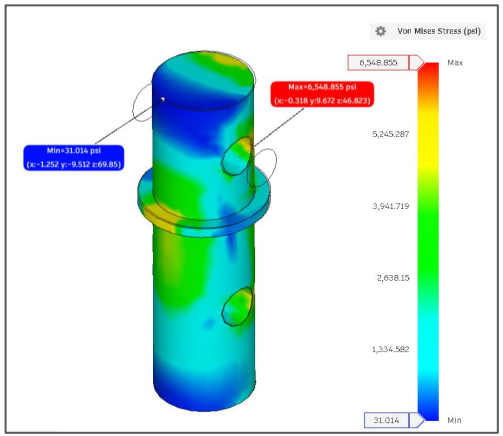
Tube Connector

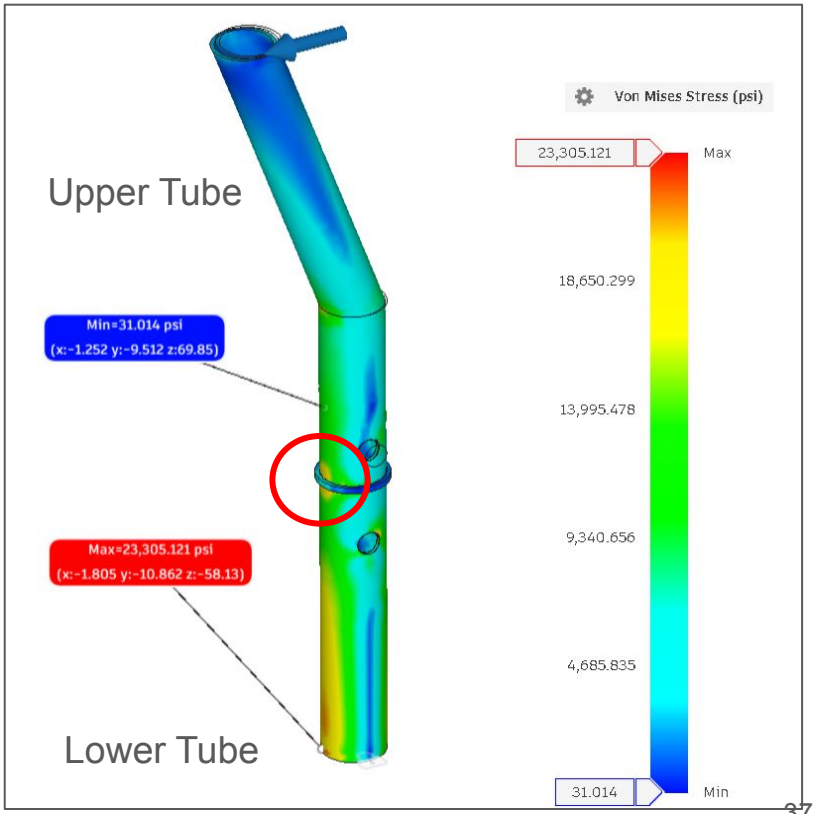
$$M = Fd = (52.5\ lbf)(7\ in) = 367.5\ lb\text{–}in$$

$$I = \frac{\pi}{64} d_o^4 = 0.01655\ in^4$$

$$\sigma_{max} = \frac{Md_o}{2I} \approx 8460\ psi$$

$$\sigma_{yield,\ 6061} \approx 40,000\ psi > \sigma_{max}$$





ASME Canons Incorporated into Design

(1) Engineers shall **hold paramount the safety, health, and welfare of the public** in the performance of their professional duties.

(4) Engineers shall **act in professional matters for each employer or client as faithful agents or trustees** and shall avoid conflicts of interest or the appearance of conflicts of interest.

Ethics of the Design

- **Considerations**
  - **Safety** for primary and secondary users
  - **Balancing interests** of Boeing, airlines, and wheelchair users
    - Comfort & independence
    - Efficiency (time & cost)

- **Steps Taken**
  - **Design to sufficient factor of safeties** and **multiple** failure modes
  - Wheelchair max weight, **50 lbs**
  - Improved independence of end-user
    - Linear actuators
  - **Stowable** in an overhead bin
    - Reduces boarding/deboarding times