Robotic Arm Platform

Team Victory Lap

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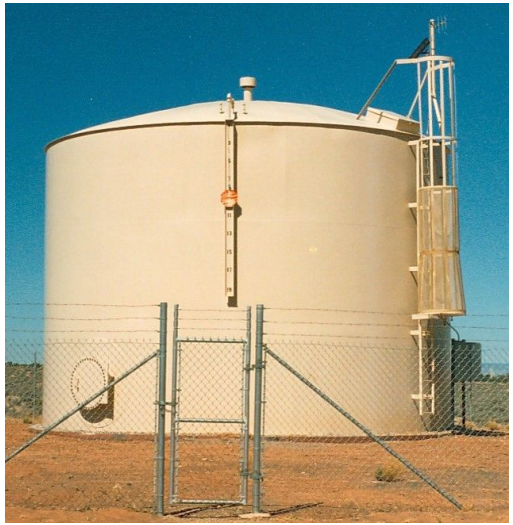
Introduction

- Suez Water Advanced Solutions is a water service provider that focuses on providing clean drinking water and wastewater management across North America
- Provides water services to 7.5 million people
- Maintain over 6,000 water tanks to provide service



suez

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Problem Statement

The current process for sandblasting water tanks requires multiple worker in a hazardous environment. SABRE's autonomous sand blasting arm provides an opportunity to eliminate the presence of workers in the tank during the cleaning process.

Capstone Project: Suez Water Advanced Solutions requires a stable platform to support SABRE's autonomous robot arm while the machine is sandblasting. The platform should be independent from the tank structure and reach all interior surfaces.

Sabre Autonomous Solutions

- Arm and mounting plate: 50 kg
- Operated via operator control panel
  - Operator initializes scan
  - Scans surfaces using infrared laser
  - Determines best motion path
  - Blasting begins.
- Location of arm to be changed between cycles.

Sabre Autonomous Solutions

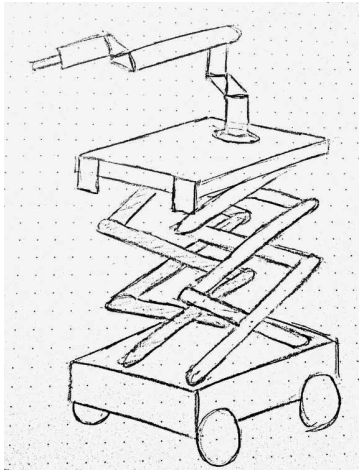
Customer Requirements and Specifications

- Requirements
  - Support 50 kg robotic arm
  - Resist movement and rotation
  - Easily assembled/maneuvered
  - Vertical reach to higher elevation
- Constraints
  - Must fit 24” diameter entry hatch
  - Powered by 120V single phase generator
  - No modifications made to tank

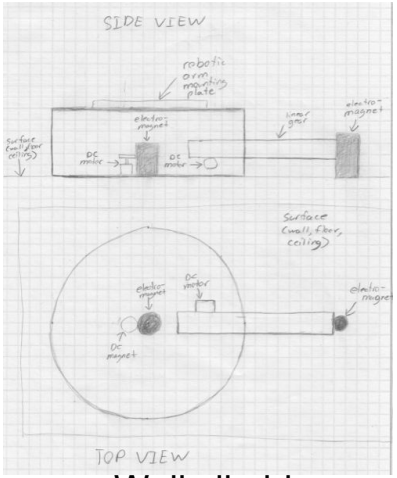
Human Factors

- **Requirements**
  - Parts must fit through a 24” diameter hole
  - Components lifted by 3 man team
- **Material Selection**
  - Lightweight, structural materials - 6061 aluminum
  - Steel used for high load elements
- **Subassemblies**
  - <50 lbs per OSHA recommendation
  - Ergonomic lifting solutions for heavy objects

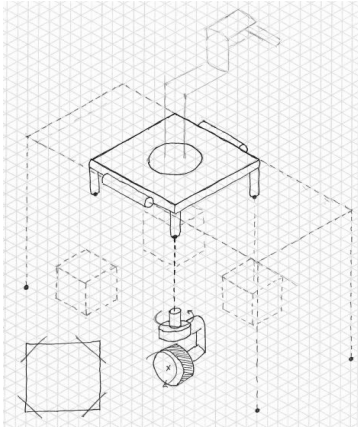
Ideation



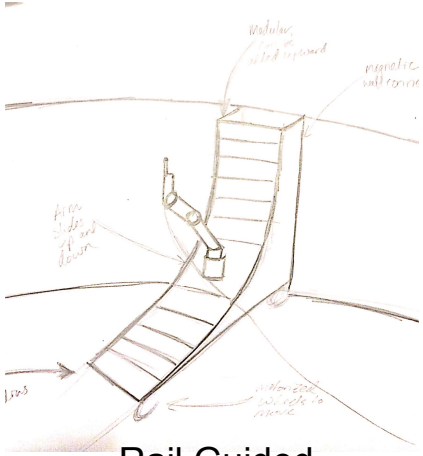
Scissor Lift



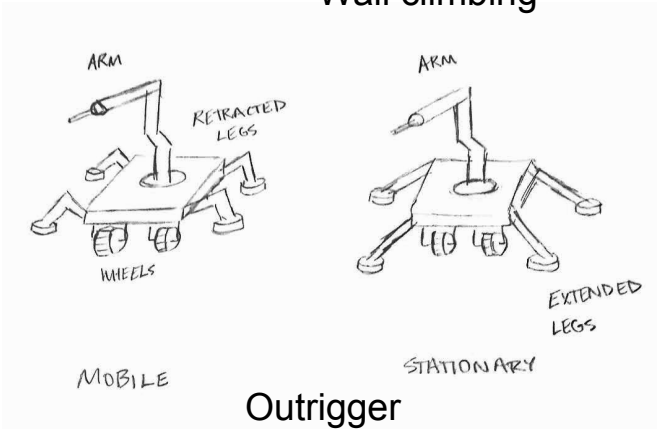
Wall climbing



Modular Scaffold



Rail Guided



Outrigger

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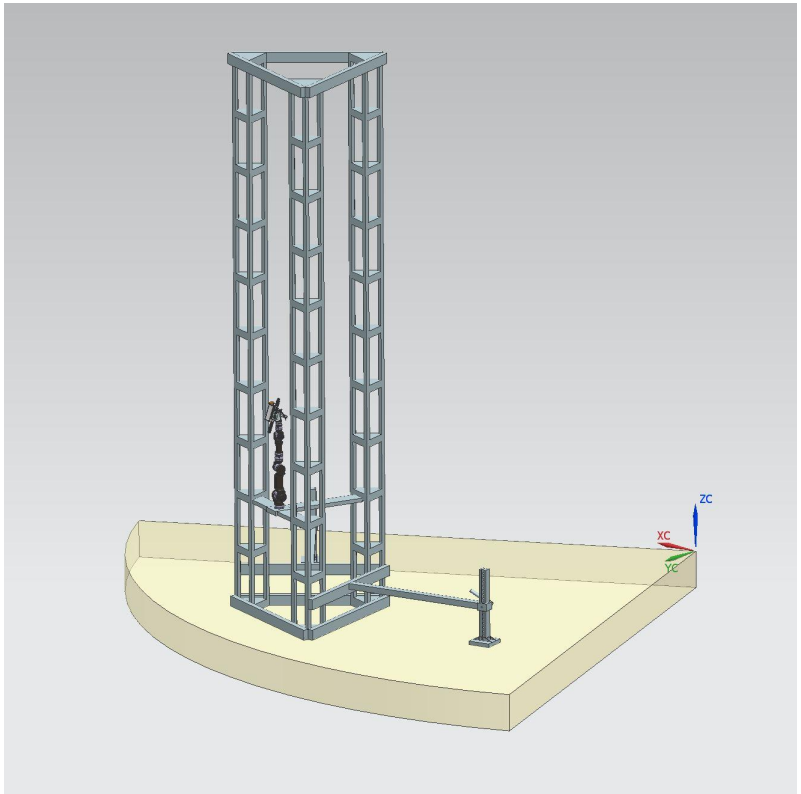
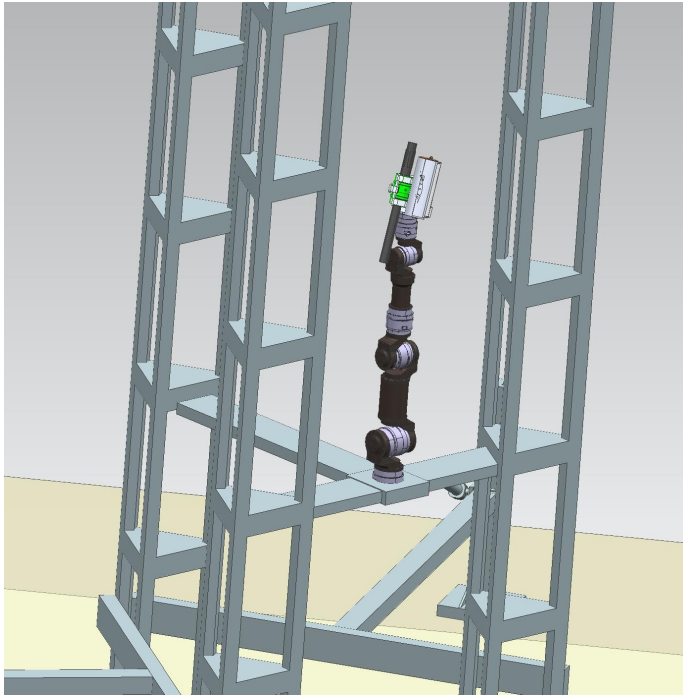
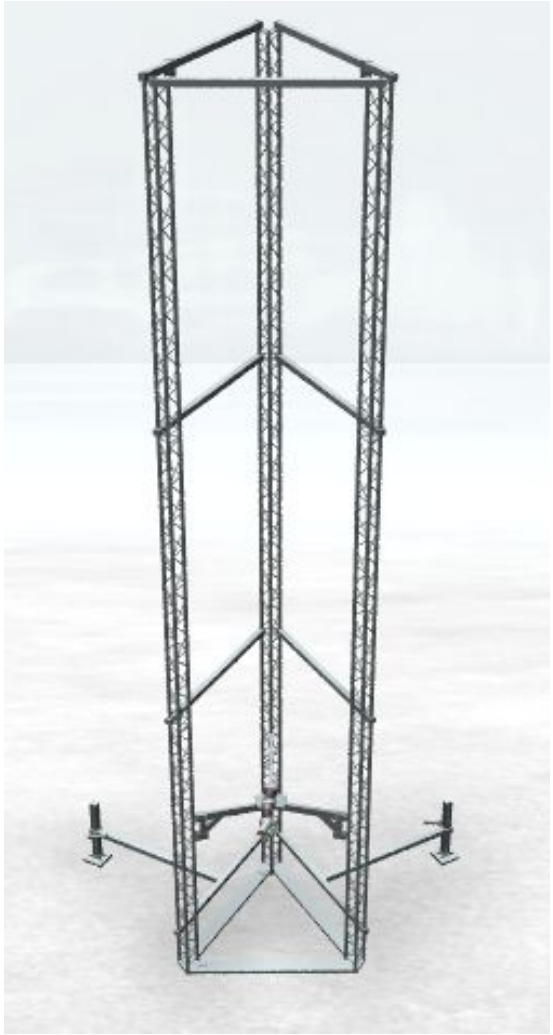
Preliminary Design



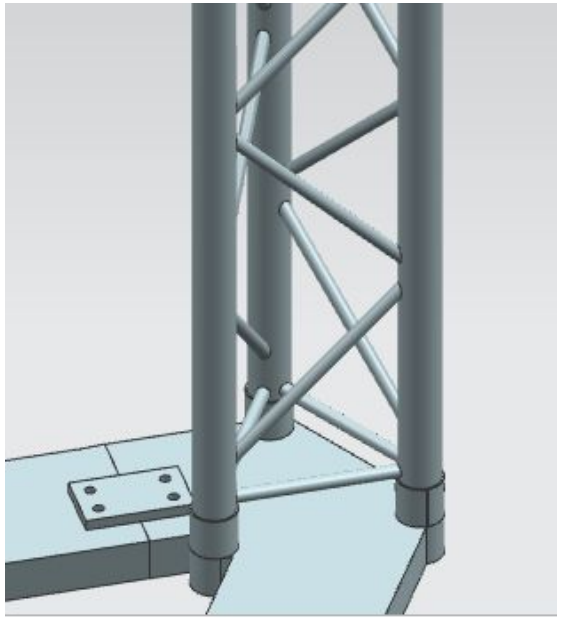


Final Design



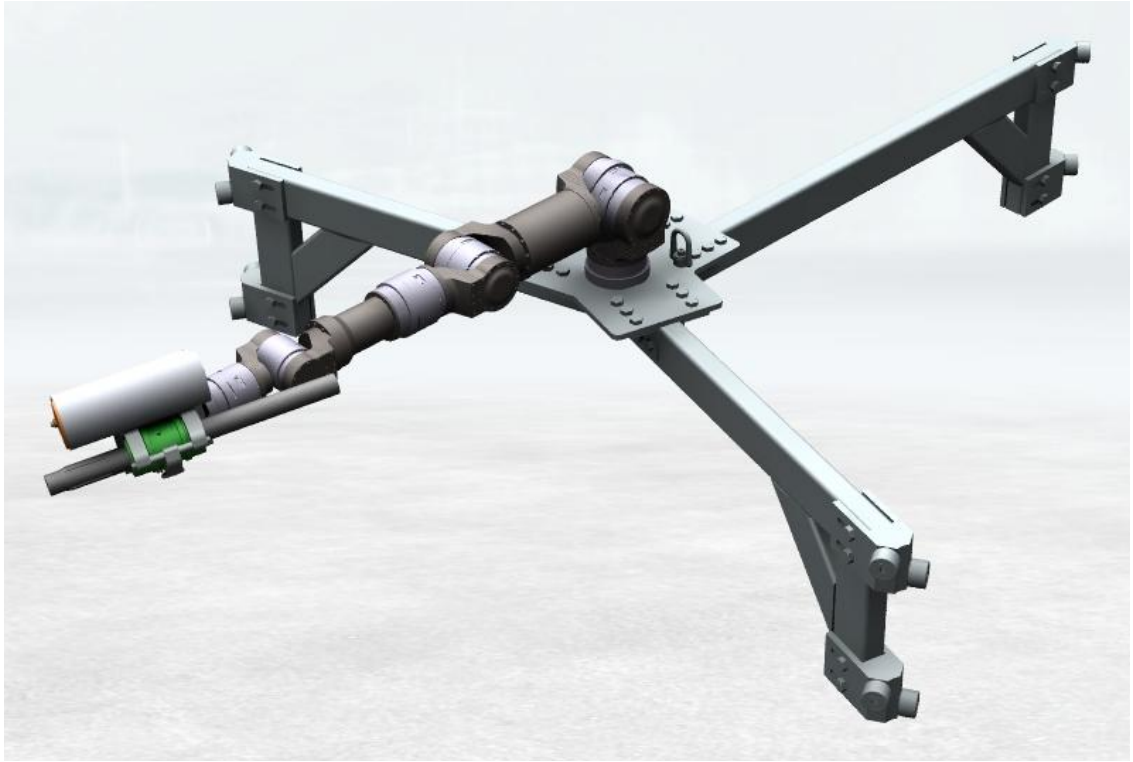
Final Design - Truss Structure

- Aluminum stage and light trusses
- Modular system
  - Trusses available up to 4 m in length
  - 0.5 m increments
- Tank height range: 10 m - 50 m



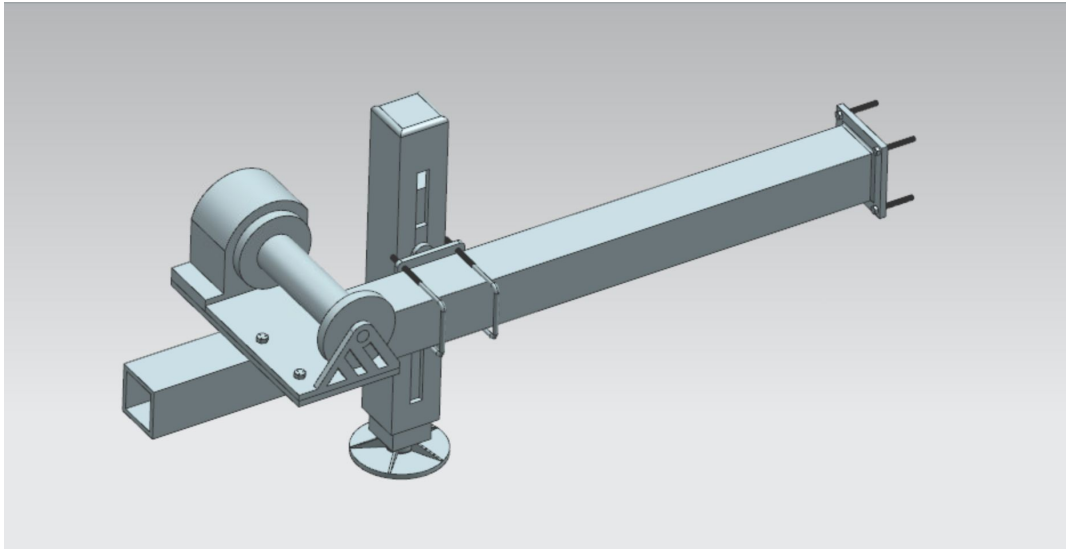
Final Design - Arm Platform

- Arm located off center
- Steel tube construction
- Hoist rings hold weight
- Adjustable roller system
  - 12 points of contact
  - Line contact



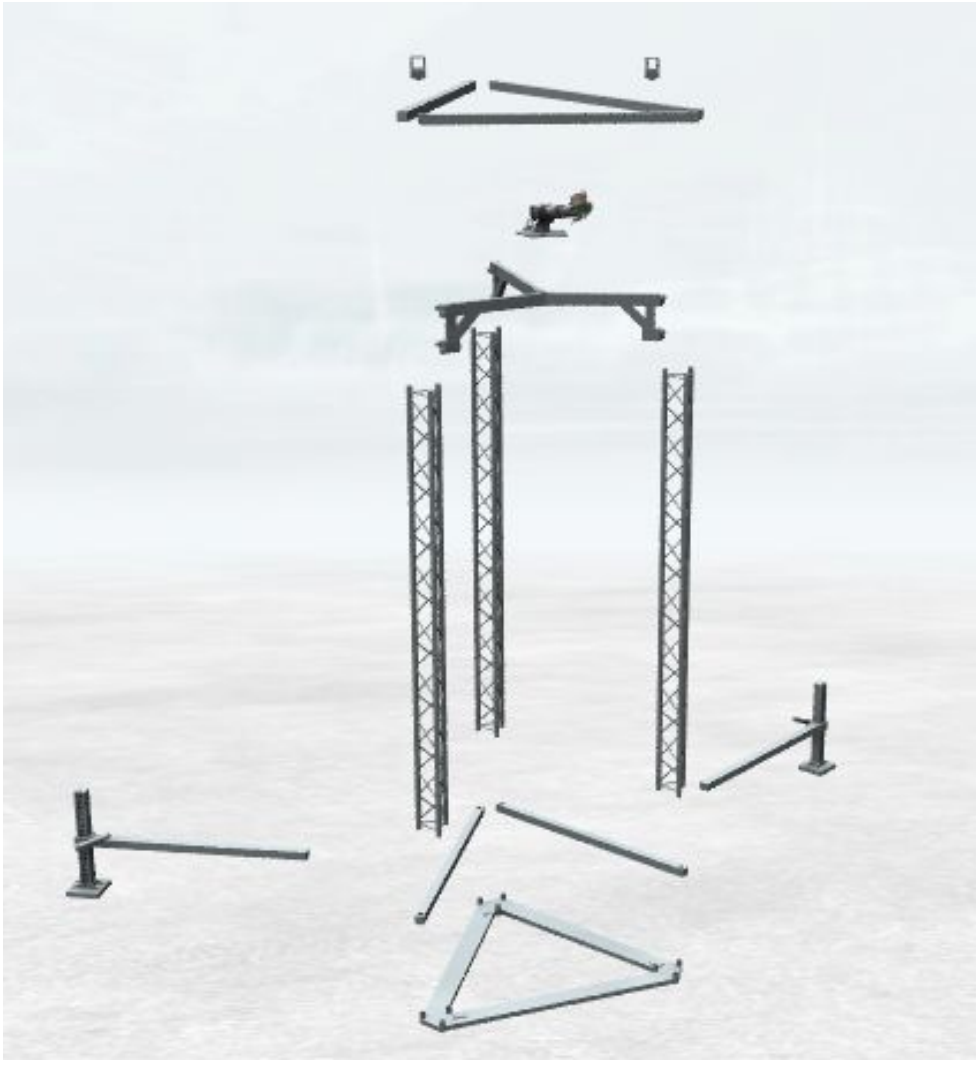
Final Design - Lifting Mechanism

- Cable winch system
- 2 electric winches
  - 120V AC
  - Automatic braking
  - 700 lbs capacity (fully wound)
- Located on outrigger arms



Assembly in Tank

1. Assemble base plate
2. Attach first set of trusses
3. Attach first level truss connectors
4. Attach outriggers to truss connectors
5. Place the two front and back main arms between trusses
6. Attach arm mounting plate to main arms
7. Attach top connectors, with pulleys, to the top of the trusses



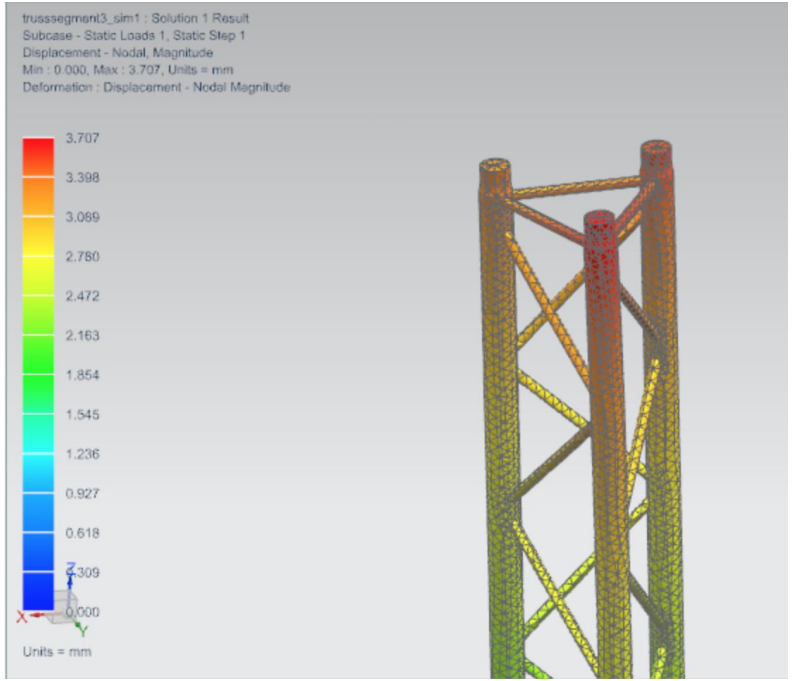
Finite Element Analysis

- Goal: Minimize the movement of arm base
  - Open loop feedback system
- Used supplied truss loading tables to verify model performance
- Assumptions:
  - Arm extended horizontally
  - Results in 500 N side load
  - Single, unsupported truss

Finite Element Analysis

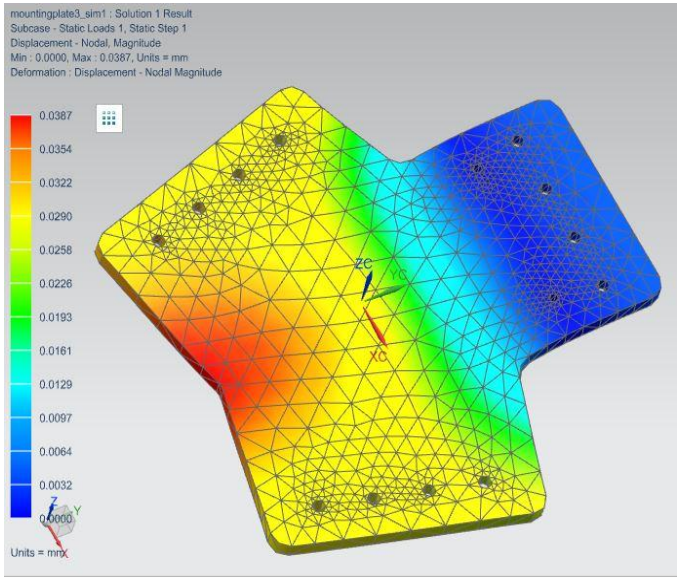
- Max deformation: 3.7 mm
- Max stress: 25 MPa
- Safety factor: 9.5

- Mitigating factors:
  - 3 connected trusses
  - Unidirectional loading
  - Algorithm modifications



Arm Plate FEA

Max Displacement: 0.0387 mm



Max Von Mises: 63 MPa

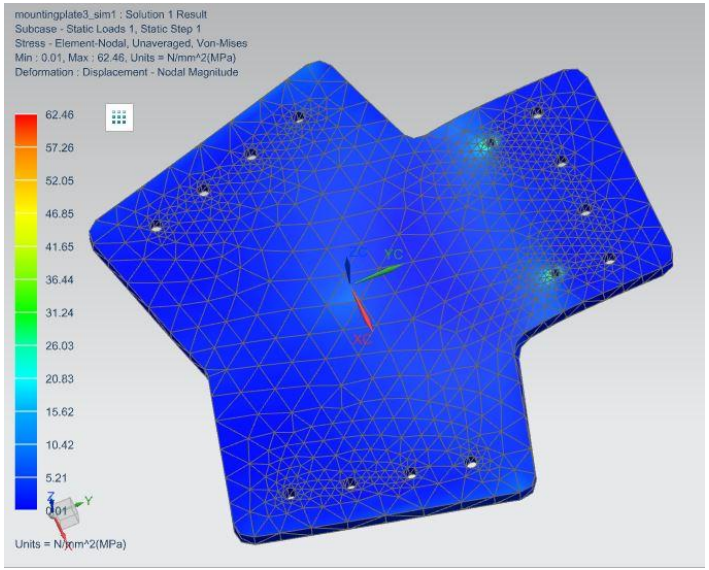


Plate Thickness: ½” (12.7 mm)

Yield strength of steel: 250 MPa

Safety Factor: 3.96

Proof of Concept

Bill of Materials

Qty.	Item	Supplier	Notes
3	Base Plate	Custom Part	For triangular base
3	Base Bolt Plate	Custom Part	For triangular base
12	M12 25 mm Hex Head	McMaster Carr	For bolting base plate
12	XU3D Triangular Truss	Prolyte Stuctures	Quantity will vary by height, 3 base trusses and others attached on top
4	Overall Connector	Custom Part	Quantities will vary based on height
2	Top Connector	Custom Part	For connecting trusses
1	Arm Mounting Plate	Custom Part	For suppoting robot arm
1	A500 Steel Rectangular Tube	MetalsDepot	24 ft. length cut for front, back arms and verticle/angled supports
3	Tensioners	Custom Part	For arm platform, steel plates welded together
12	M16 90mm Hex head	McMaster Carr	For arm platform
9	M16 75mm Hex head	McMaster Carr	For arm platform
18	M16 25mm Hex head	McMaster Carr	For arm platform
39	M16 Flange Nuts	McMaster Carr	For arm platform
12	High Load Track Rollers	McMaster Carr	Connects arm platform to trusses
2	Snatch Pulley	Custom Part	For lifting mechanism
2	Electric Winches (120V AC)	McMaster Carr	For lifting mechanism
2	1/4" Wire Spool	McMaster Carr	Length of spool will vary with height of structure
2	Fulton F2 Jack with Footplate	Fulton	Outrigger
4	304 Stainless Steel Square Tube	MetalsDepot	2-2x2' cuts, 2-2x5' cuts welded together to form L outrigger shape
6	A36 Steel Plate	MetalsDepot	1/2" thick, 6x6" cuts for outrigger
16	Grade 5 Steel Hex Head Screw	McMaster Carr	3/8"-16 thread, 3" long for outrigger

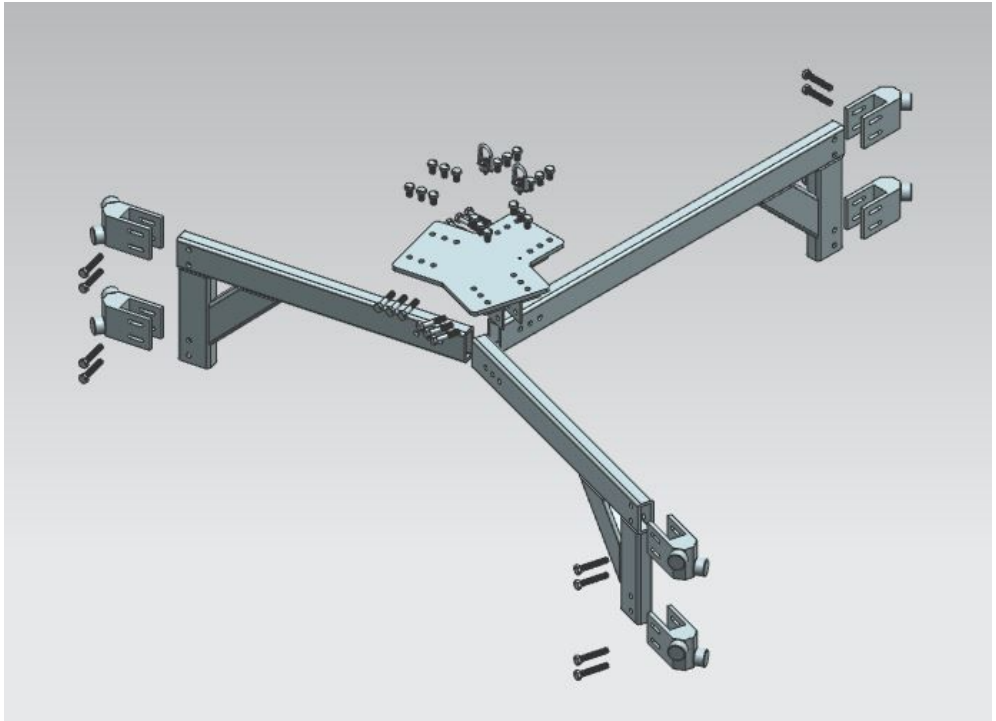
Manufacturing Methods

Small scale production methods

Materials: Steel and Aluminum 6061

Manufacturing constraint: design for assembly and disassembly

Custom pieces required to ensure components would fit through 24” entry hole



Codes and Standards

- OSHA
  - Personal Protective Equipment: Eye, Face, Respiratory, and Hearing protection required
  - Abrasive Blasting: PPE required
  - Fall Protection: Harness required when 6 ft. or higher
  - Scaffolding Requirements
  - Recommended lifting maximum: 50 lbs
- American Water Works Association
  - Manual M42: Coatings, cleaning, inspecting and quality control for steel water tanks

Risk Analysis & Mitigation

No.	Hazard	Frequency	Severity	Mitigation	Risk Level
1	Arm platform fall	Low	High	High load rollers and self-locking wenches	Low
2	Structure tip forward	Low	High	Bolt structure to wall and counterweights	Low
3	Cable snapping	Low	High	Inspect cable before assembly for frays	Low
4	Fall during assembly	Low	High	100% tie-off, full-body harness, double-legged lanyard or cable climb system	Low

Additional Measures: Suez safety training and preventative techniques in place and will continued to be practiced.

Societal, Environmental and Sustainability

- **Societal**
  - Improves the working conditions of Suez employees
- **Environmental**
  - Aluminum 6061 and Steel recyclable
  - Sandblasting in enclosed space, no environmental concerns
- **Sustainability**
  - Product is meant for multiple uses
  - Can use custom pieces for every height

North America's #1 Recycled Material	
Material	**Tons**
Steel	70,790,499
Paper	48,033,079
Aluminum	4,290,333
Glass	2,919,292
Plastic	2,201,127
Estimated Tons Recycled By Material Since January 1, 2016	

Source: Steel Recycling Institute

Patent Claims & Commercialization

- Suez reserves patent rights to the design
- Due to the company's nature and primary goals, they are unlikely to pursue commercialization in the near future

Future Steps

- Suez to create a prototype using the same materials that would be used for a final solution
- Prototype will be 1 truss length high, 4 meters in length
- Test prototype with SABRE's arm
  - Adjust SABRE arm algorithm
  - Slow robot arm to reduce moment
  - Design adjustments as needed
    - Bolt to wall, guidewires, counterweights

Conclusion

Primary goal was to remove workers from strenuous working conditions

Through running worst case scenario analysis, the final solution will provide a stable base for SABRE's autonomous sandblasting robot to function

Algorithm can be adjusted to minimize the effect of displacement

The final solution will allow SABRE's arm to sandblast the interior floor, walls and ceiling without subjecting Suez employees to hazardous conditions.