# Air Entrainment Reduction Final Presentation

**Sponsor: Sargent & Lundy**

Team Members: Garrett Sigrist, Yon Park, Joshua Leicht, Blake Parages, Tyler Klein

FA: Professor Kyle Smith

PM: Fatemeh Pouria

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## Presentation Overview - Joshua

- Problem Statement
- Background Information
- Testing Setup
- Data Collection
- Proposed Solution
- Conclusion

Vortex formation from our experiment

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## Project Overview

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## Problem Statement - Garrett

- Sargent & Lundy – A leading engineering and consulting firm serving the electric power industry
- Often work with water tanks used in power plants
  - Refueling water, condensate, and emergency cooling
- One common issue is air entrainment due to vortex formation within these tanks
  - Leads to decreased pump performance, measurement/control issues, erosion/corrosion, thermal and hydraulic issues
- Desirable to have an effective vortex suppressor inside tank that allows more water drainage and small pressure drop

Sargent & Lundy

https://giw.ksb.com/blog/pump-behaving-badly-it-could-be-air-entrainment
https://www.sargentlundy.com/

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## Project Objectives - Blake

- Design and build an experimental set-up to test vortex suppressor designs
  - A drainable tank able to form vortices while having a long drain time
  - Need to measure amount of entrained air and pressure drop due to suppressor
- Design vortex suppressors
  - Effectively reduce vortex formation such that more water may be drained from the tank without air entrainment
  - Minimize pressure drop across suppressor to prevent straining the pump
  - Determine how changing suppressor traits affect vortex formation
  - Identify geometries and trends affect flow conditions within the tank



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## Project Accomplishments - Tyler

- Constructed experimental set up from scratch
- Collected both quantitative and qualitative data
- Tested 50+ unique vortex suppressor designs
  - Created original designs more successful than industry standard designs
  - Optimized industry standard designs
  - Reduced critical height from 5.625" to 0.625"
  - Measured pressure drop with CFD



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# Background Information

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## Vortex Formation - Yon

**Vortex Formation:**

- Driven by conservation of angular momentum
- Vorticity: $\vec{\omega} = \vec{\nabla} \times \vec{v}$
  - Local spinning motion of fluid
  - Predicts vortex locations
- Air from free surface is drawn into outlet
- Only type 5&6 vortices cause air entrainment
- Still desirable to prevent types 1-4
  - Likely to turn into type 5 or 6
- Vortex formation mainly prevented by adding obstruction to flow field to reduce vertical and rotational motion

| Vortex Type (VT) | | Description |
|---|---|---|
| 1 | | Coherent surface swirl |
| 2 | | Surface dimple (Coherent swirl at surface) |
| 3 | | Coherent swirl throughout water column |
| 4 | | Vortex pulling floating trash, but not air |
| 5 | | Vortex pulling air bubbles to intake |
| 6 | | Full air core to intake |

Haspolat, Determination of Critical Submergence Depth at Horizontal Intakes, 2015



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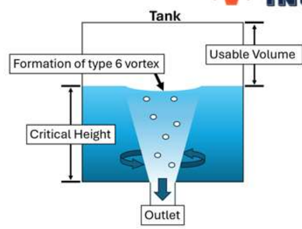
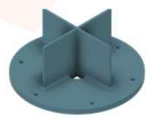
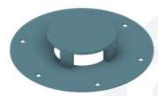
## Background - Joshua

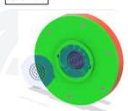
Typical methods to prevent vortices:

- Decreasing flow rate - typically fixed
- High water levels - limits drainable water
  - Higher **critical height** = higher water level
- Outlet obstruction - Typical Industry designs:
  - Disc type
  - Cross type
  - Mesh type





Cross type vortex suppressor


Disc type vortex suppressor


Mesh type suppressor

https://www.chemengonline.com/vortex-breakers-practice/?pagenum=2





## Experimental Setup

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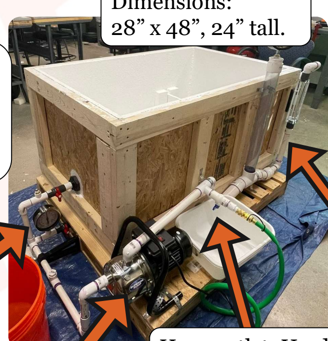
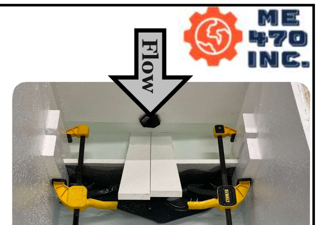
## Tank Setup - Blake

Dimensions:
28" x 48", 24" tall.

Equation below was used to determine tank dimensions

$$h = \left(2 * \left(\frac{V_{out}}{\sqrt{gD}}\right) + .5\right) * D$$






Inlet Design: Recirculates water and limits water velocity with barriers

Flow Meter: Rotameter to measure water flow rate through system

Pressure Gauge: Measures pressure drop induced by vortex suppressors

Pump

Hose outlet: Used to slowly drain the tank



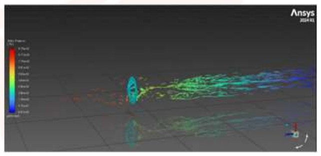


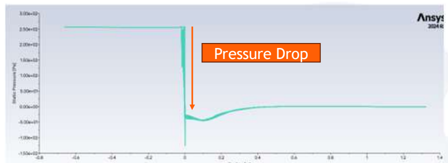
## Experimental Methods - Blake

- Water level starts at almost critical height of tank without any suppressor
  - Recorded starting height and flow rate
- Drained water tank slowly using hose outlet (around 3 GPM)
  - Water level is kept constant if dimples begin to form
- Water level is lowered until a full vortex forms
  - Critical height is recorded
- Other qualitative observations are recorded during the test

## CFD Analysis Setup - Yon

- Computational Fluid Dynamics (CFD) is used to measure pressure ($\Delta P$) drop across the suppressor
  - $\Delta P = \frac{1}{2} \cdot k \cdot \rho v^2 \rightarrow k = \frac{2 \cdot \Delta P}{\rho v^2}$
- Modeling parameters
  - Surface roughness (for vortex suppressor)
  - Velocity-based inlet, pressure-based outlet
  - Turbulent model → k-epsilon realizable model



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## Experimental Results

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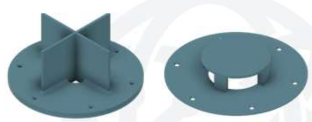
## Design Process - Tyler

- Researched industry standard designs
  - Determined how these affect flow regimes
  - Altered design variables to see affects on suppression
- Ideated changes and new designs based on effective traits
- Design considerations:
  - Preventing vertical flow
  - Obstructing path of vortices
  - Limit pressure drop



Industry Standard Designs



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## Best vs. Worst Design Iteration Results - Yon

BEST: Disc | Cross | Bridged Dome

WORST: Disc | Cross | Bridged Dome

Disc Area ↑ + Disc Height ↓

Divider Count ↑ + Divider Height ↑

Dome Height ↓ + Dome Leg Count ↑

| | Disc | Cross | Bridged Dome | Disc | Cross | Bridged Dome |
|---|---|---|---|---|---|---|
| k [-] | 0.0720 | 0.0600 | 0.0180 | 0.7198 | 0.135 | 0.0135 |
| $h_{cr}$ [in] | 0.875 ± .03 | 0.875 ± .03 | 0.813 ± .03 | 1.263 ± .03 | 5.375 ± .03 | 1.875 ± .03 |



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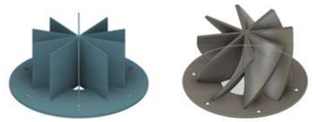
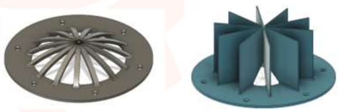
## Successful Design Characteristics - Tyler

Obstruction normal to outlet



Taller and Numerous Vertical Geometries



Unobstructed outlet

Adjustable geometry

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## Poor Performing Characteristics - Garrett

Meshes

Added Geometry to Discs

Propellers

Short Crosses with Few Walls

Small Openings

Tortuosity

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# Proposed Solution

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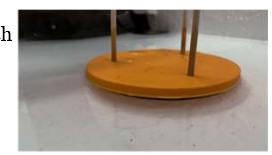
## Best Designs - Garrett

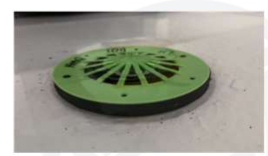
**Floating Disc:** (critical height = 0.625 ± .03 in)

- Works by completely obstructing the free surface such that no vortices may form
- No air entrainment until water drops below the float
- Negligible pressure drop
- Almost no circulation on surface



**Bridged Dome:** (critical height = 0.8215 ± .03 in)

- Obstructs vertical flow and legs break circular motion
- No vortex formation until water is below top of dome
- Negligible pressure drop
- A few dimples throughout draining process



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## Improving Industry Designs - Garrett

**Disc Type:** (critical height = 0.95 ± .03 in)
- Typically, vortices do not form until water drops below disc
- Large area and moderate height works best
- Small openings increase likelihood of vortex formation

**Cross Type:** (critical height = 0.875 ± .03 in)
- Tall and frequent walls decrease vortex formation but cause more pressure drop
- Vortices may form in each section if cross is too short or lacking walls

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## Implementation Considerations - Joshua

| | Manufacturability | Pressure Drop Coefficient | Maintainence Requirements | Critical height Performance |
|---|---|---|---|---|
| **Bridged Dome** | **4** [$1014.22] | **2** [k = 0.2068] | **2** | **2** [0.875" ± .03"] |
| **Cross-type** | **3** [$271.54] | **4** [k = 0.6203] | **3** | **2** [0.875" ± .03"] |
| **Floating Disc** | **2** [$196.98] | **1** [k = 0.0000] | **4** | **1** [0.625" ± .03"] |
| **Flat Disc** | **1** [$163.40] | **1** [k = 0.0000] | **1** | **4** [0.950" ± .03"] |

- All designs contain advantages and tradeoffs
- Manufacturability based on comparison made using Apriori
  - 316 Stainless Steel construction, 50 per year for 5 years
  - Purely for comparison basis due to significant lack of constraints
- Maintenance based on fragility experienced when working with the prototypes

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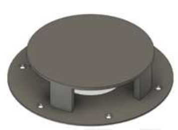
## Conclusion - Joshua

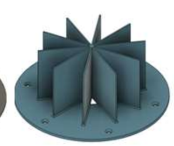
- 4 main designs optimized for different situations
- Beneficial characteristics
  - Obstruction of direct flow
  - Higher frequency baffles
  - Taller interferences
- Harmful characteristics
  - Small openings
  - Significant obstructions
- Total spent $1048.75
- Next steps: Organize and forward data

Floating Plate

Bridged Dome



Flat Disc



Cross Type

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# Questions?

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# Appendix



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## Budget - Tyler

| Category | Cost |
|---|---|
| Tank Construction | $410.58 |
| Pump and Plumbing | $439.13 |
| Sensors | $153.90 |
| Vortex Suppressors | $45.14 |
| Total: | $1048.75 |

- Money Spent: **$1048.75**
- Projected budget: **$1005.52**



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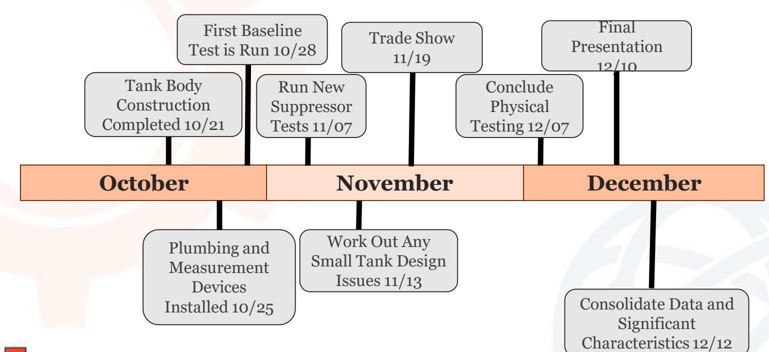
## Schedule- Blake



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