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Sloshing phenomenon in Archimedes screw pumps

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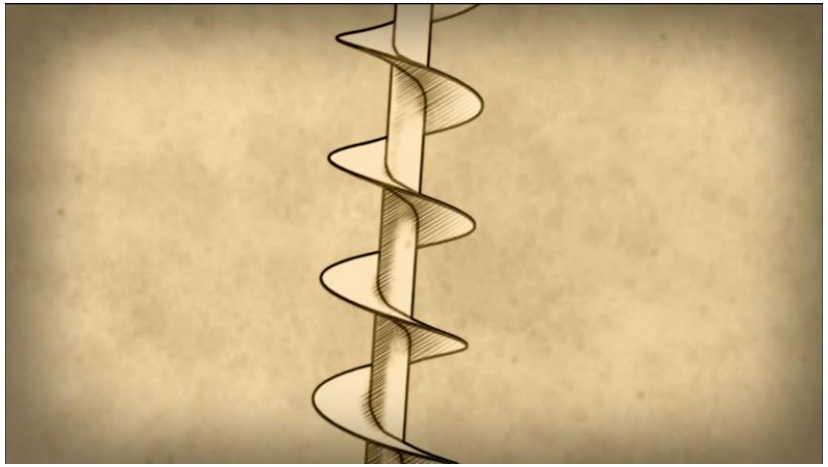
Overview

1. Introduction
2. Historical Context
3. Methods
4. Results
5. Conclusions

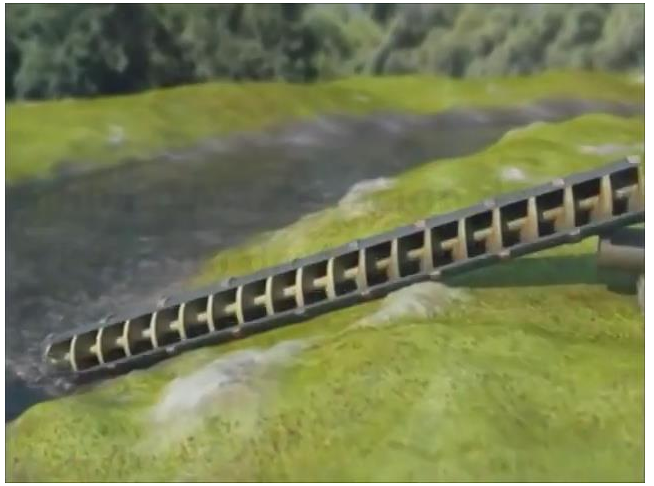
1. Introduction

1. Introduction

- Archimedes screws are an ancient pumping technology
- Named after Archimedes of Syracuse (~287-212 BCE)
- Evidence suggests it was used during reign of King Sennacherib (704-681 BCE) of the Neo-Assyrian Empire
- Trap water between blades as screw rotates due to an applied torque
- Water translates along axis of rotation



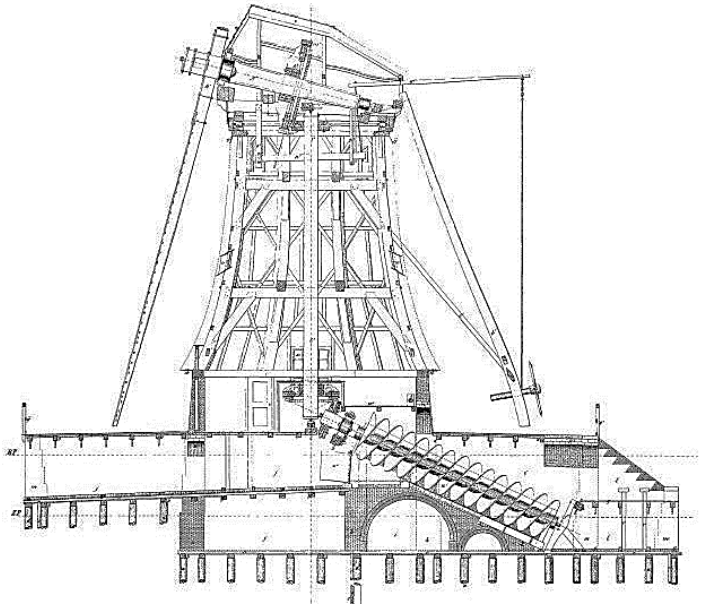
PBS (2014), *Secrets of the dead: Archimedes' screw and the Hanging Gardens of Babylon* [https://www.youtube.com/watch?v=NhNEB_mWvBw&ab_channel=PBS].



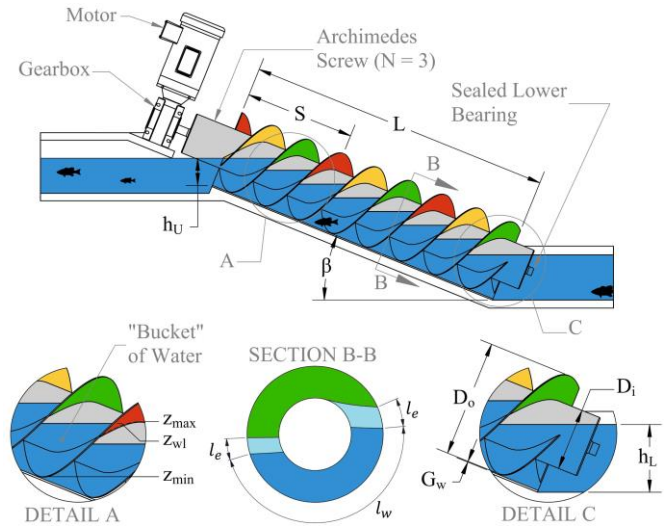
Adriana Tub (2016), *Tornillo de arquimedes* [https://www.youtube.com/watch?v=A_mZ6ekbJtw&ab_channel=AdrianaTub].

1. Introduction

- Archimedes screws have been designed as pumps for millennia
- Design is largely empirical or heuristic
  - State-of-the-art design guidelines were published between 1851 and 1932
- No extensive studies of the effects of scaling design parameters in published literature
- We have performed a comprehensive review of the literature



https://www.notechmagazine.com/2012/10/building-plans-of-dutch-industrial-windmills-1850.html



1. Introduction

- Though they should be consistent, water levels varied along the length of a screw generator

Screw generators work in the opposite flow direction from pumps and as a previous research focus for our group

Highest Here

1. Introduction

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Causes for Varied Levels?

- Gap leakage and an imperfect construction?
- Unexpected overflow properties?
- Dynamic effects?

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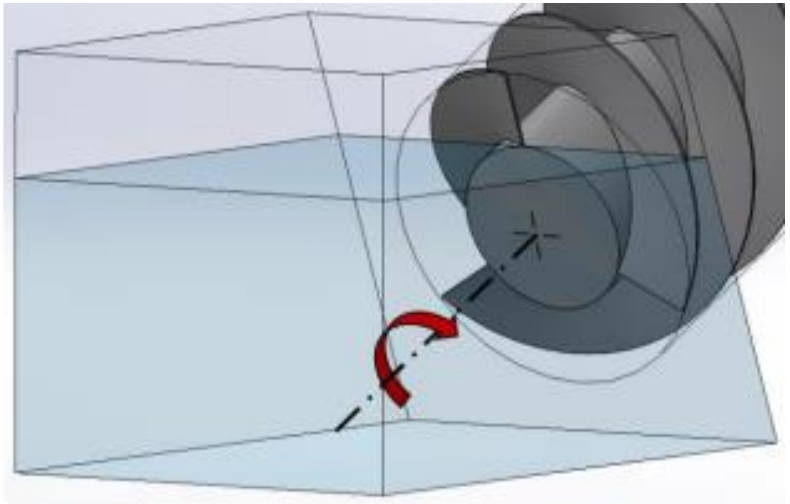
2. Screw Buckets

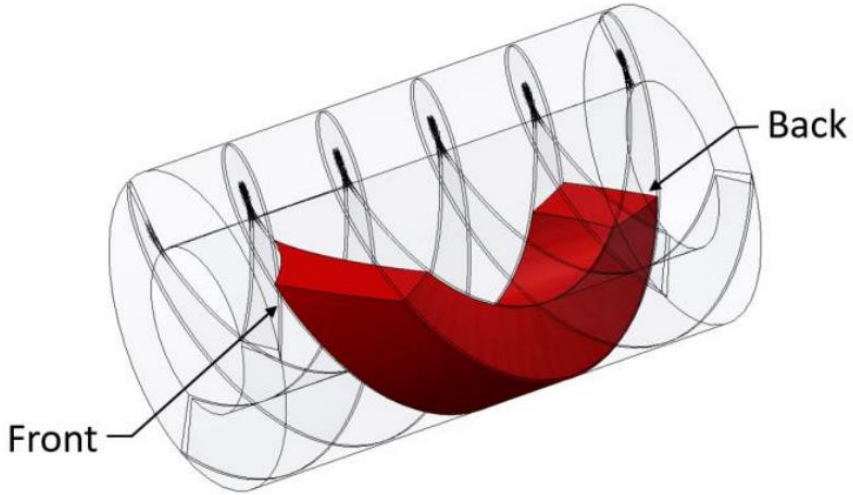
2. Screw Buckets

- Screw rotates to form “buckets” of water
- Blades “chop” through water free surface to fill voids with water volume



2. Screw Buckets

- Bucket “front” closer to inlet (lower end)
- Bucket “back” closer to outlet (upper end)
- Bucket formation causes a surge of water



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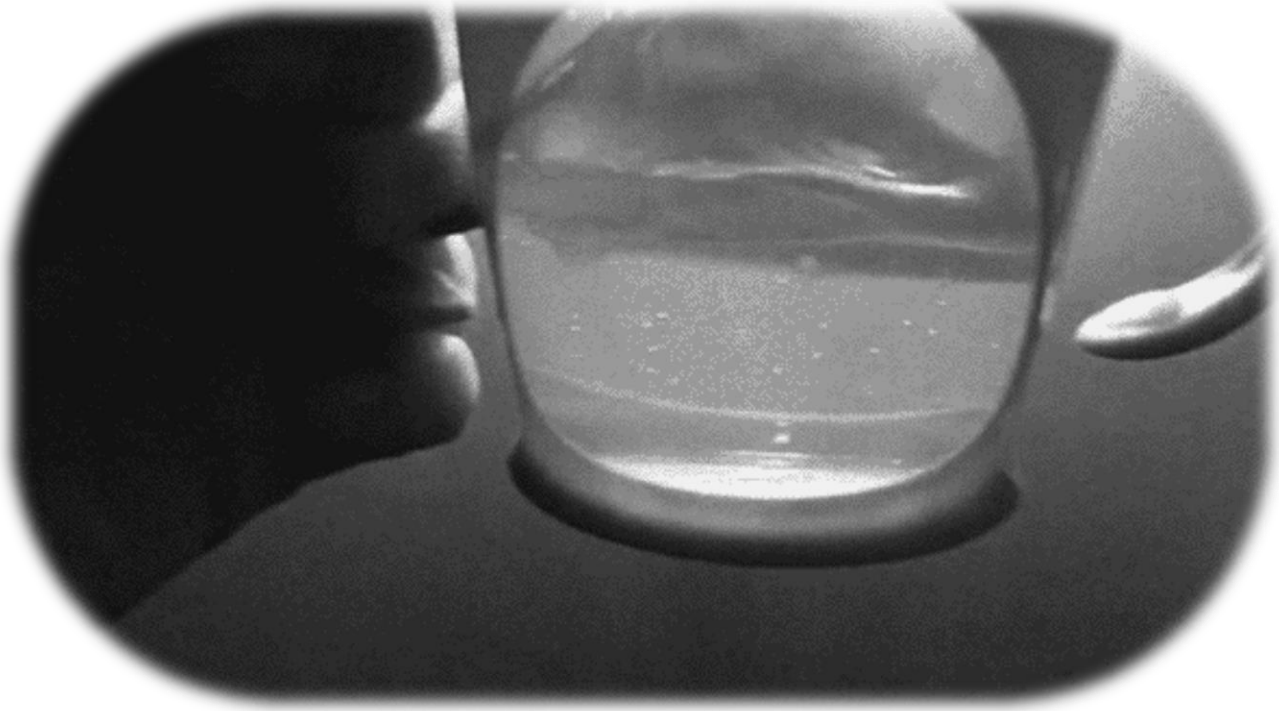

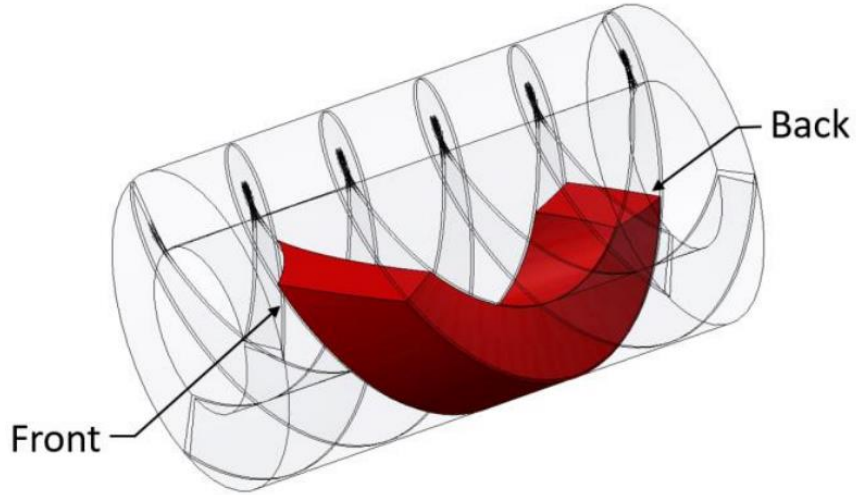

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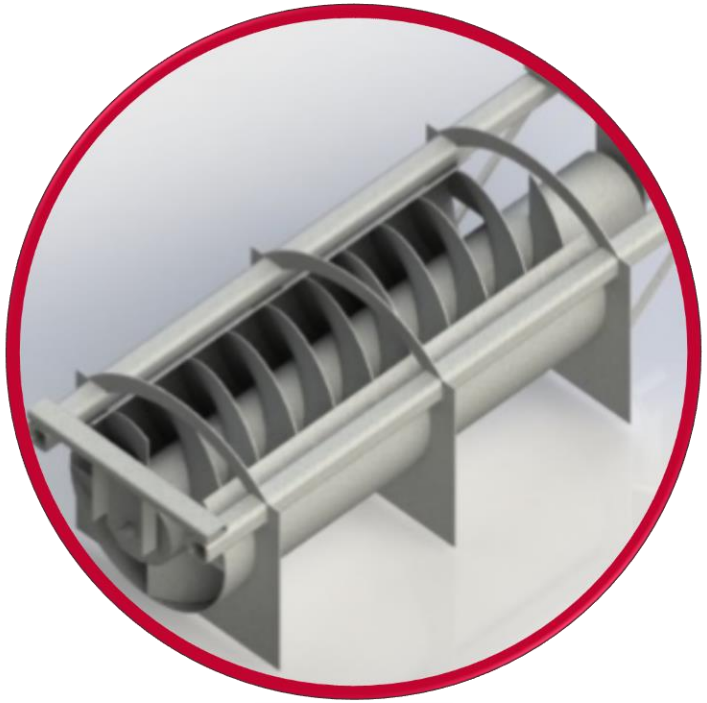
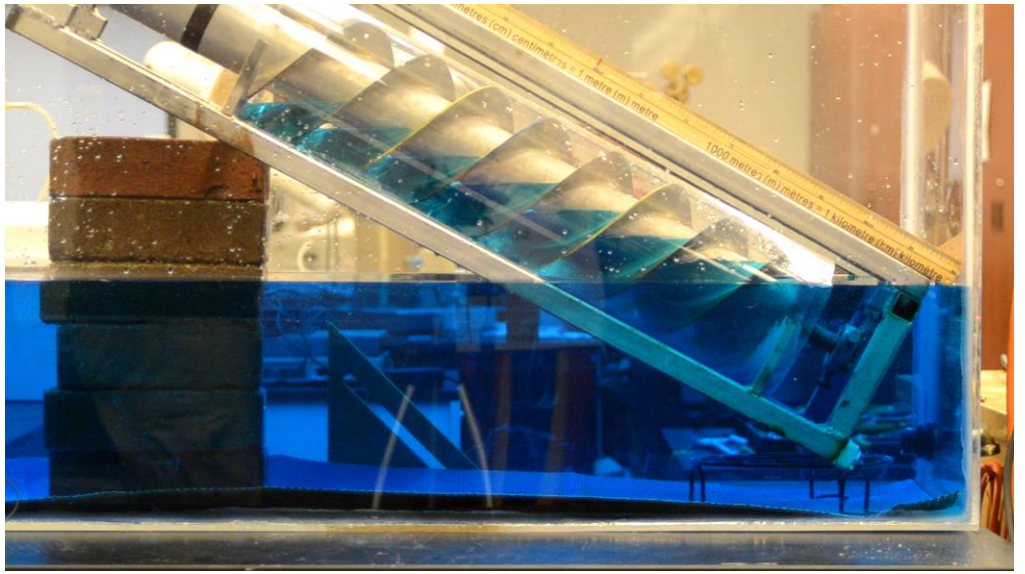
3. Methods

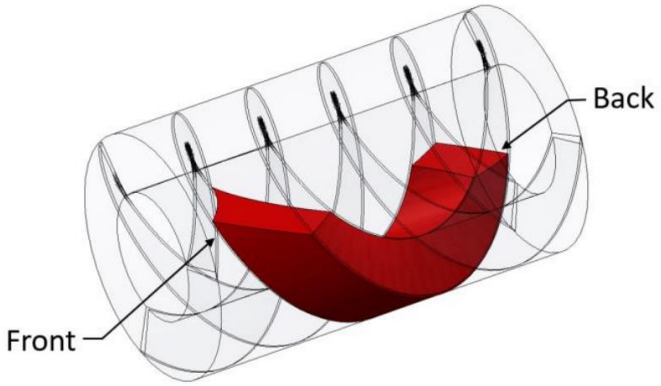


3. Methods

- Used optical measurements in lab to measure water height in buckets during translation
- Used results to evaluate a CFD model
- Measured height of water in CFD simulations

FRONT OF SCREW



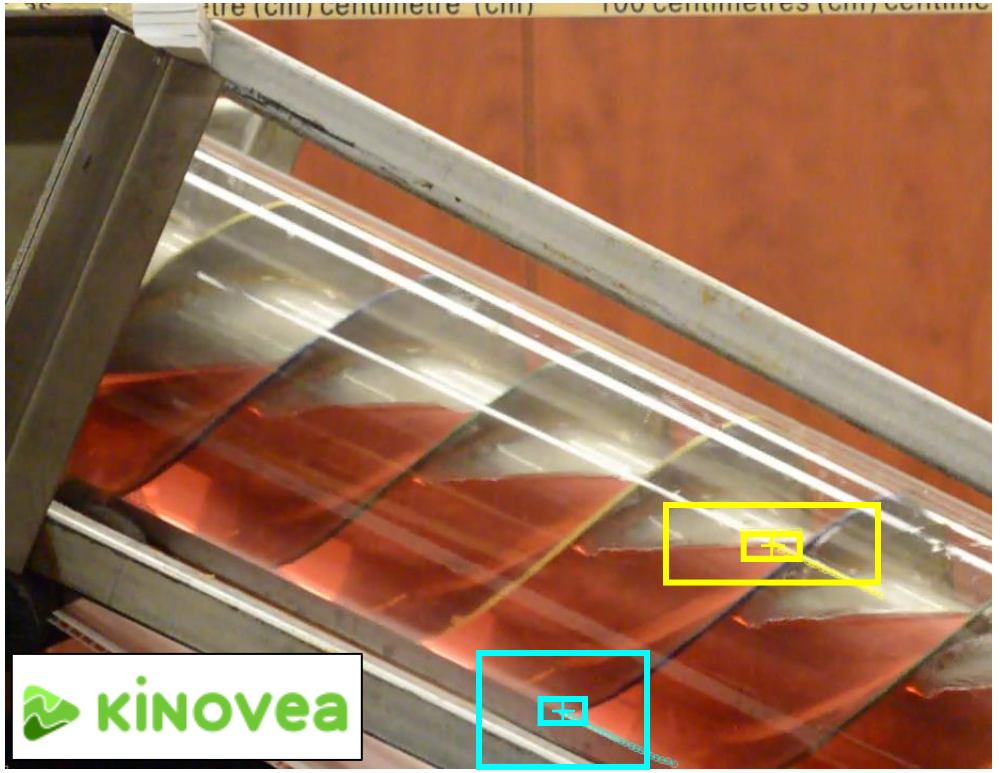


BACK OF SCREW

3. Methods

- Kinovea was used to quantify water levels from video footage
- Kinovea was developed for sports analysis and kinesiology
- It was able to trace water surface (yellow tracer box) and the minimum bucket water level (blue tracer box) of an operating screw

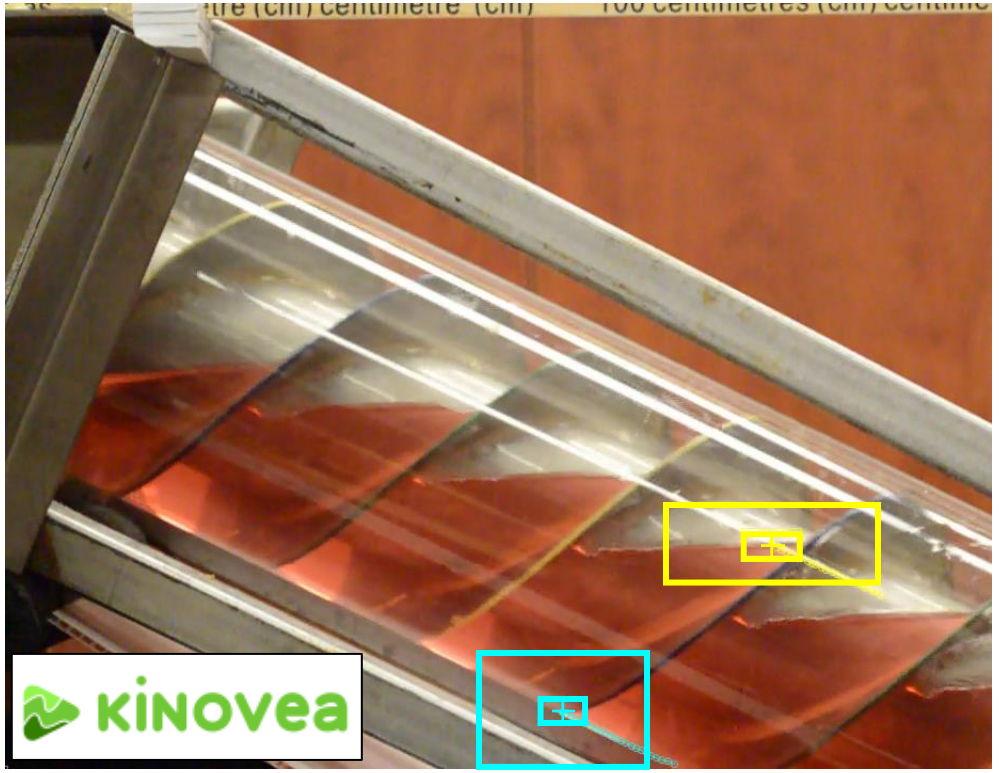
FRONT OF SCREW



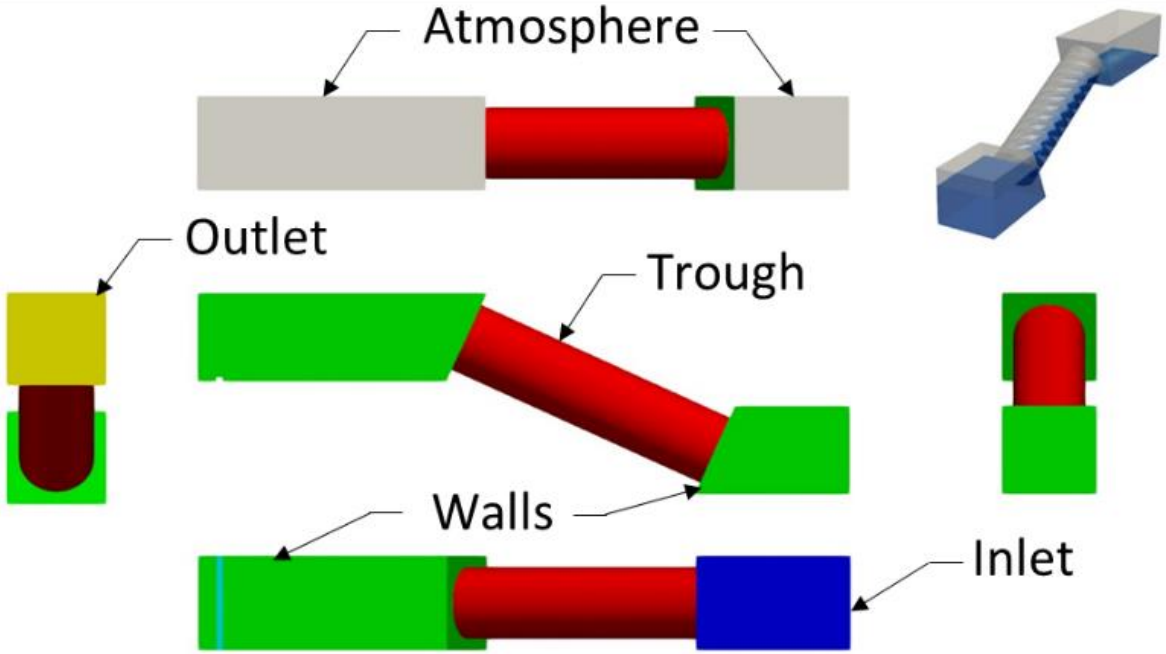
3. Methods

- Water was dyed to increase contrast for video tracing
- Tested screw had three blades – tips were painted Blue, Green, and Yellow
- Measured three consecutive buckets to account for leakages between buckets

FRONT OF SCREW



3. Methods



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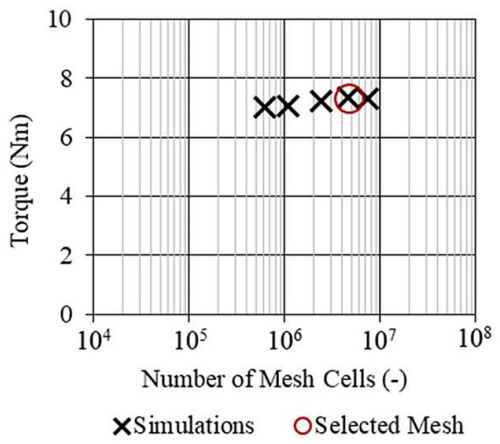
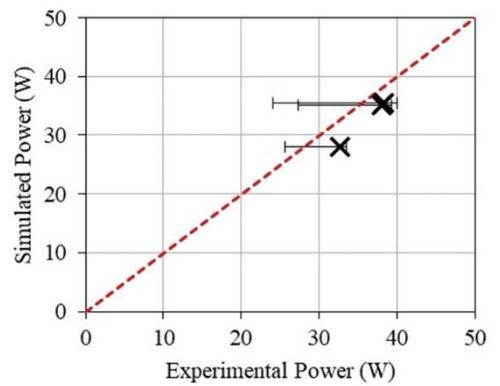
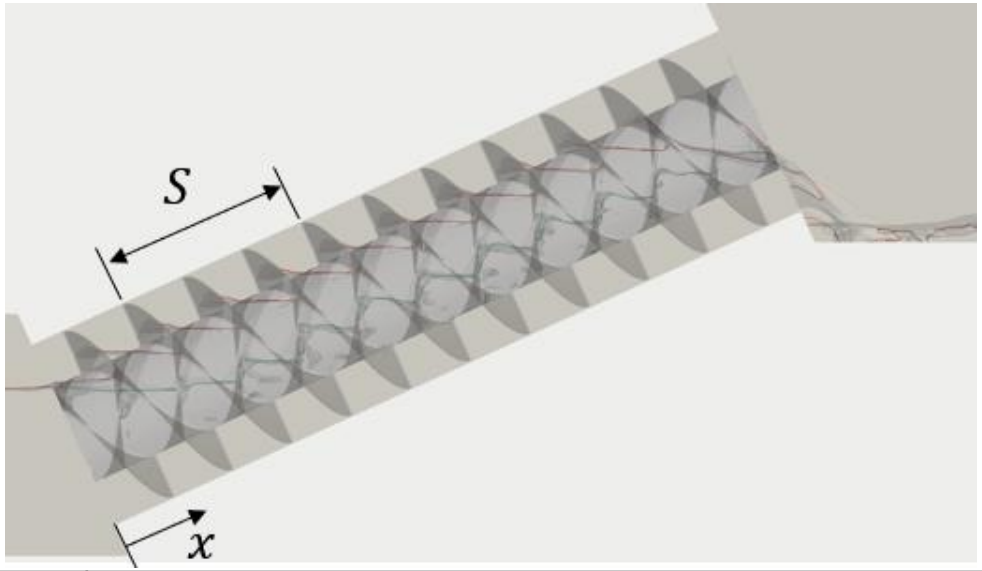
- CFD model (presented last year) was determined to be an accurate approximation of screw pump performance

Mesh Sensitivity	Evaluation ("Validation")
	

3. Methods

- Four simulations were run that varied rotation speed to explore the impacts that speed had on the “sloshing” phenomenon
- Measured front and back bucket water levels



Run	Screw Parameters						
	ω (RPM)	D_o (m)	D_i (m)	S (m)	L (m)	N (-)	β (°)
1	10	0.316	0.168	0.318	1.219	3	24.5
2	20	0.316	0.168	0.318	1.219	3	24.5
3	40	0.316	0.168	0.318	1.219	3	24.5
4	60	0.316	0.168	0.318	1.219	3	24.5

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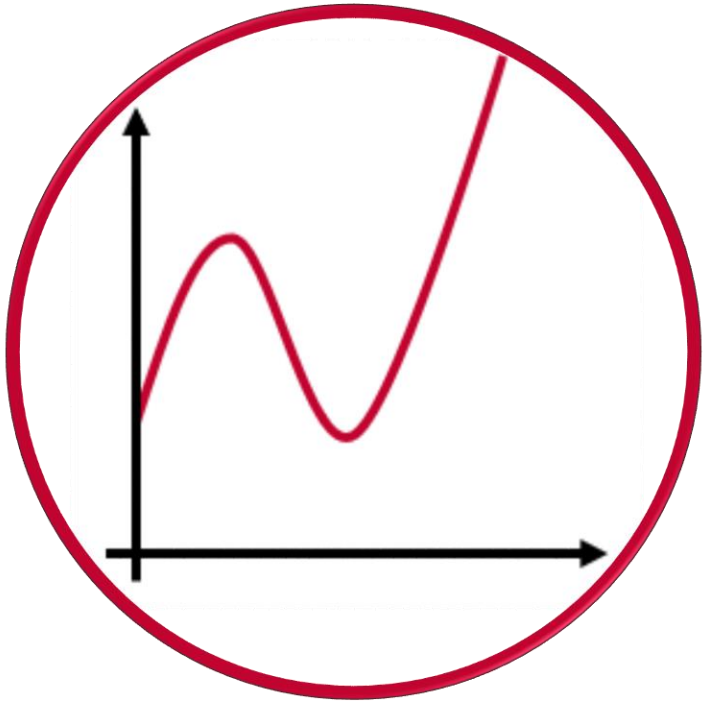
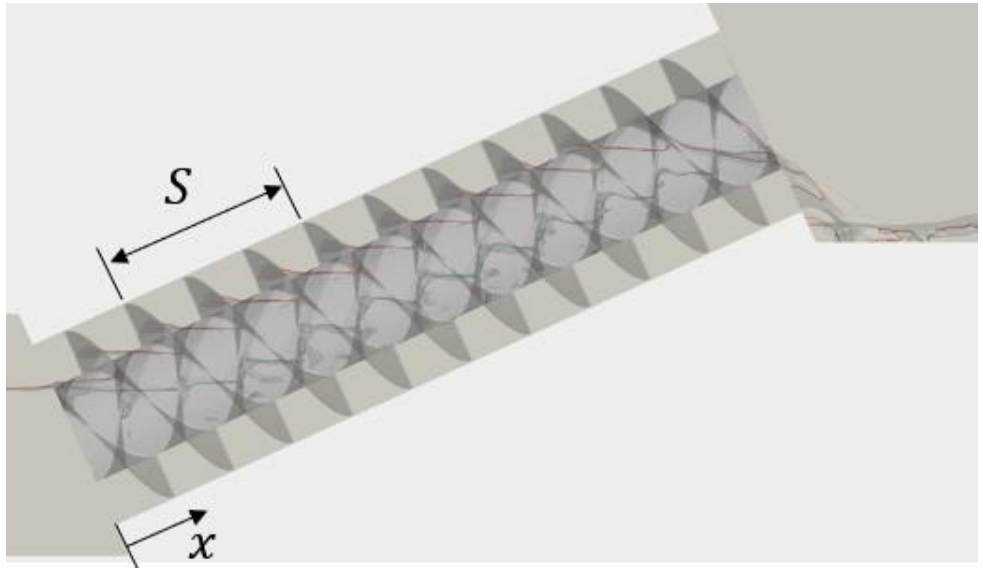
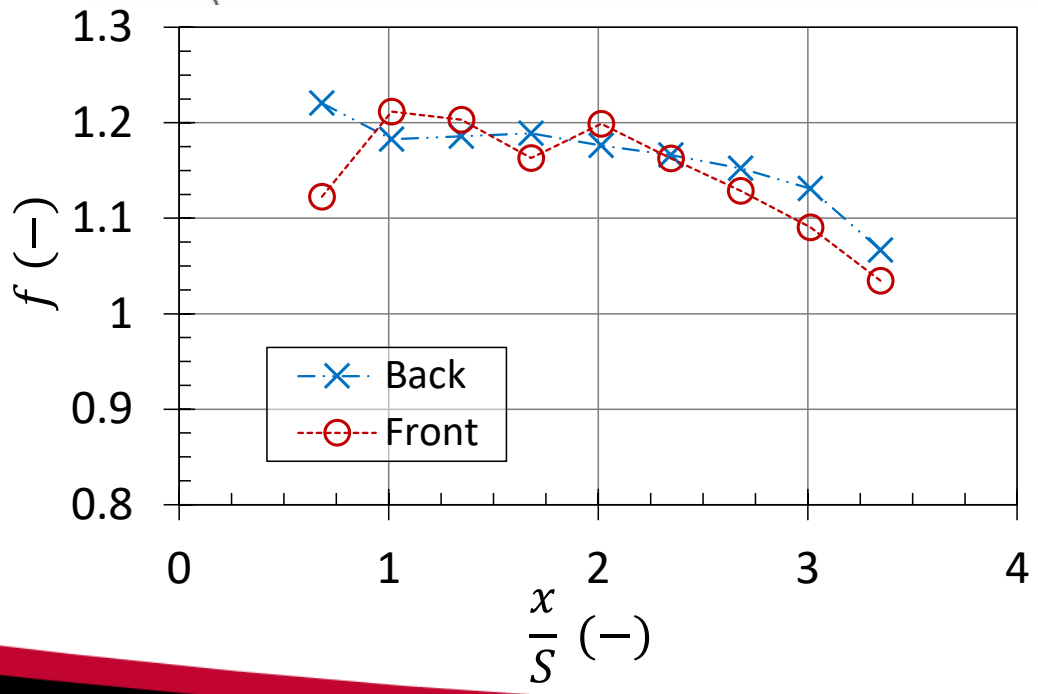
4. Results



4. Results

- Here is an example of the measurements taken from the CFD results
- Due to leakage, screw pumps will decrease in overall fill height throughout operation
- Notice the oscillations in height
  - As the back proportionally decreases, the front proportionally increases





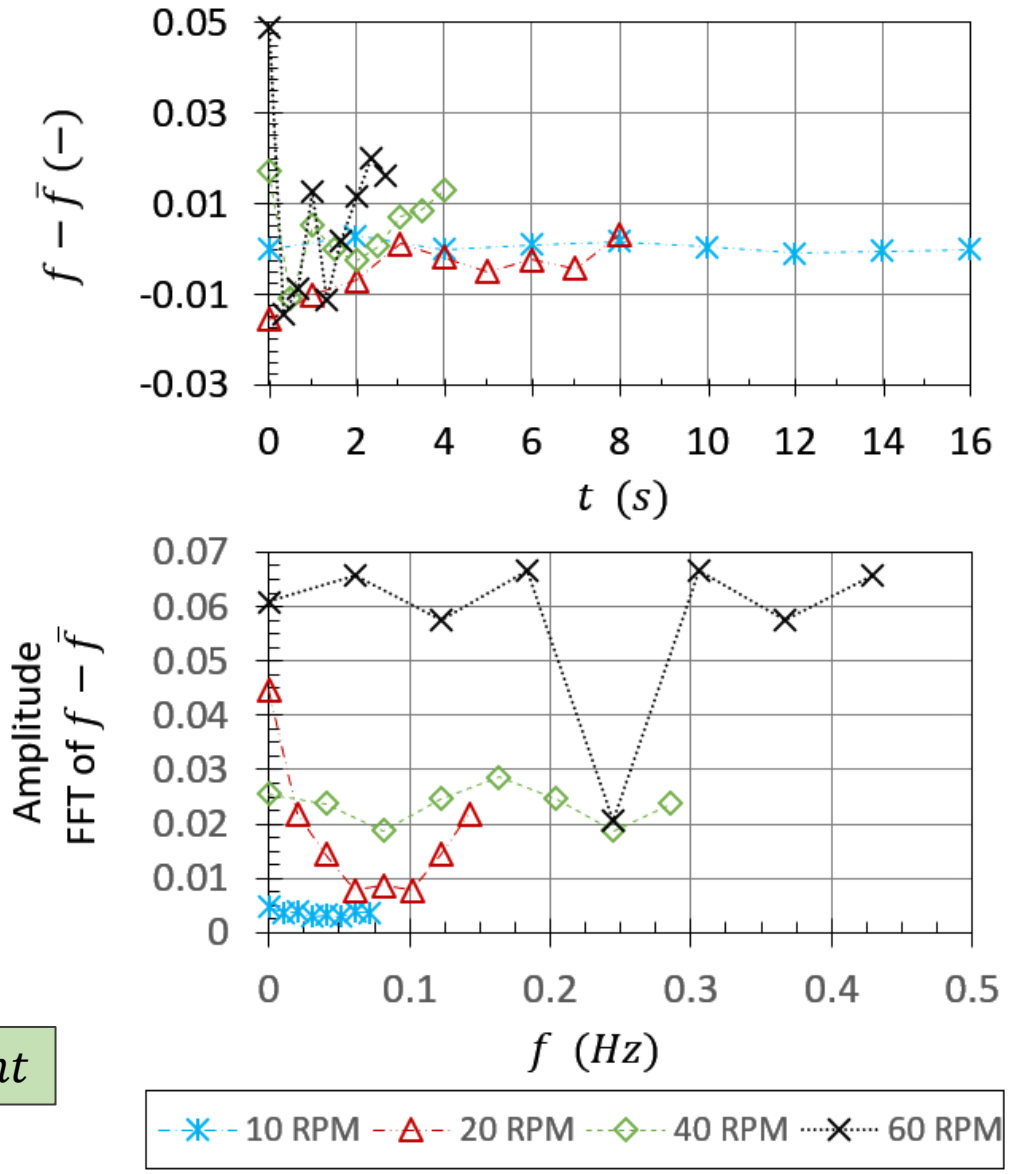
4. Results

- Convert measurements to fill height oscillation amplitude ($f - \bar{f}$) versus time

$$\bar{f} = \frac{f_{front} + f_{back}}{2}$$

- Fast Fourier Transform of that was then plotted to represent waveform frequency

Recall: $f = fill\ height$



5. Conclusions

5. Conclusions

- Statistically significant waveforms exist in operating screw pumps
- Indicating there are dynamic effects in this otherwise largely static-pressure driven system
- Sloshing may impact:
  - Screw performance
  - Gap leakage
  - Fatigue loading
- Future structural analysis will use this data to inform fatigue

Acknowledgements

Thank you all very much for your time.

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