



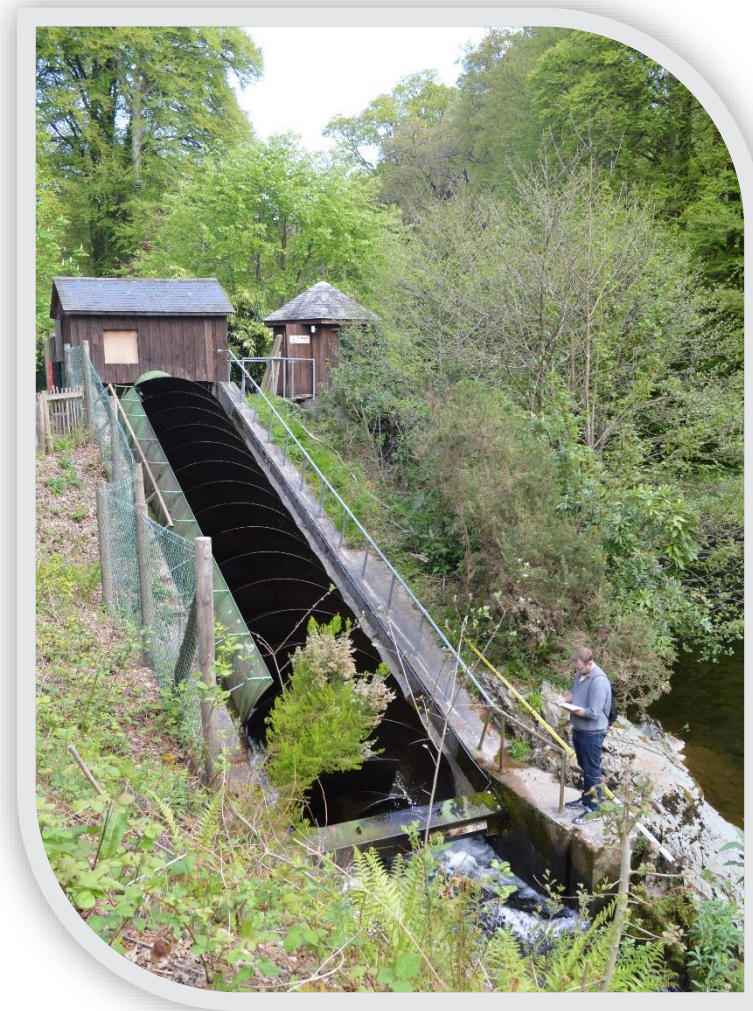
Changing Tides and Ingenuity
Marées changeantes et ingéniosité



Development of a Computational Fluid Dynamics Model for Archimedes Screw Pumps

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Presentation Date: 24 May 2023	Session: Hydrotechnical 1

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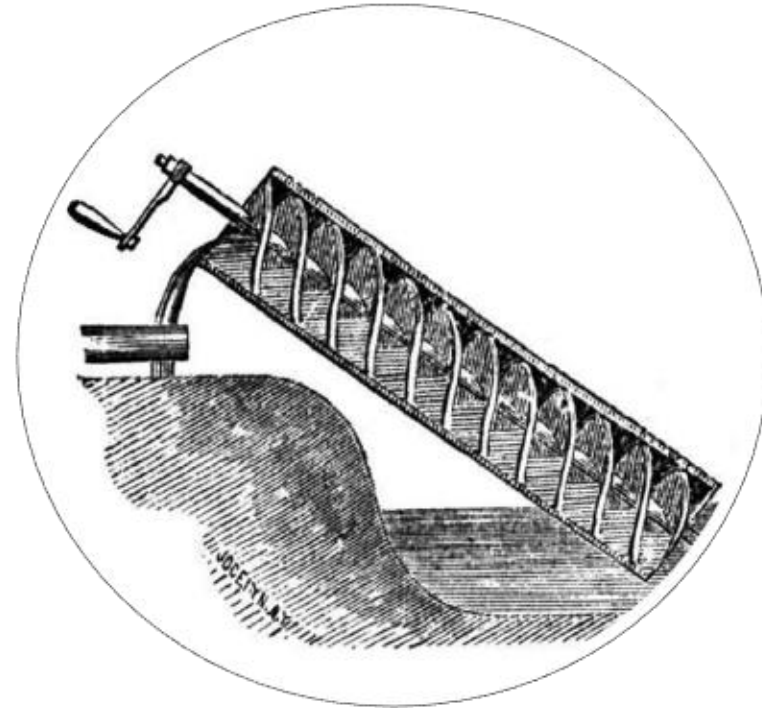




1. Introduction

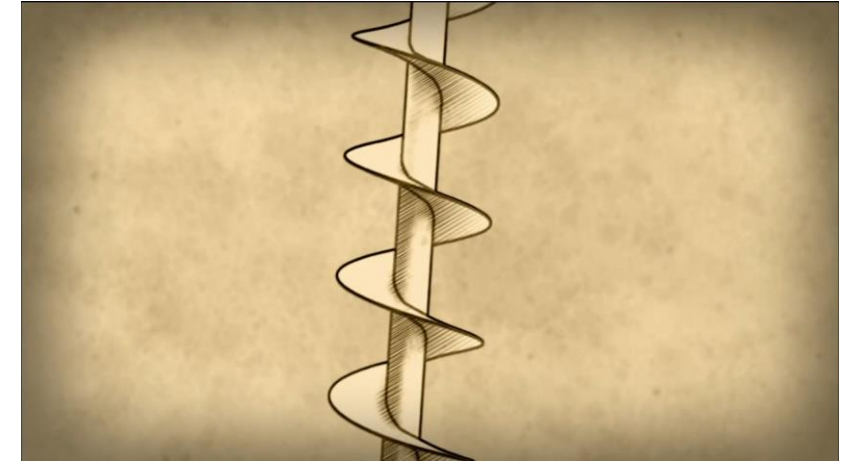


1. Introduction



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



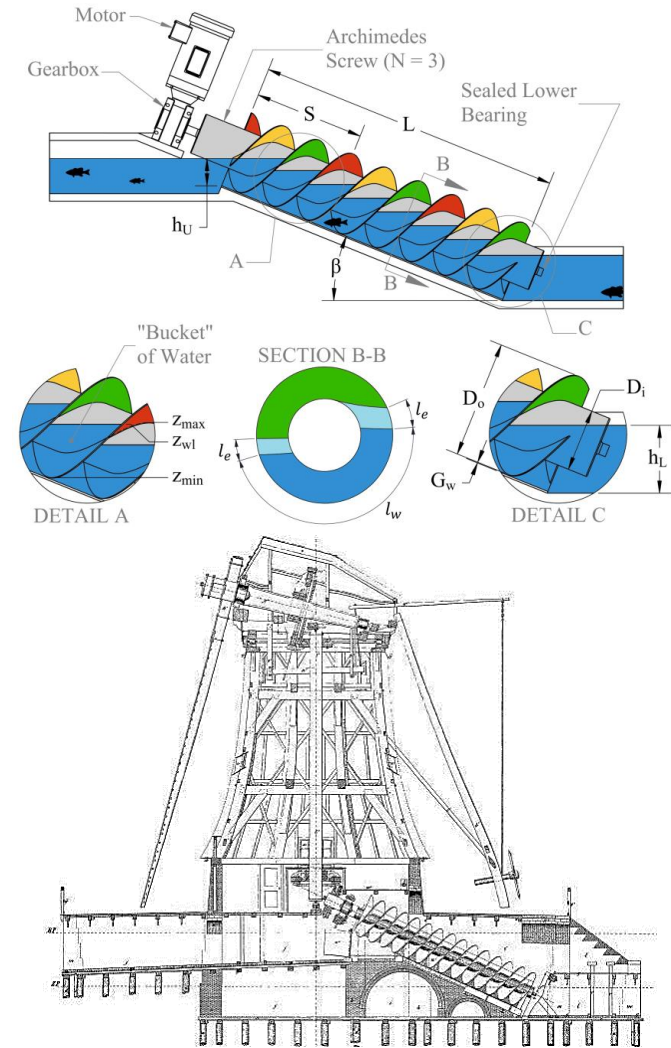
PBS (2014). *Secrets of the dead: Archimedes's crew and the Hanging Gardens of Babylon* [https://www.youtube.com/watch?v=NhNEE_mW6w&ab_channel=PBS]



Adriana Tub (2018). *Tornillo de arquimedes* [https://www.youtube.com/watch?v=A_m26ekbtw&ab_channel=AdrianaTub]

1. Introduction

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



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



2. Historical Context



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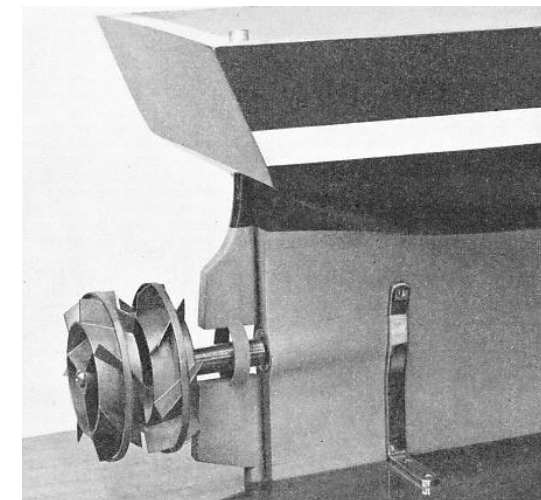
2. Historical Context

- Used for irrigation in:
 - Neo-Assyrian Empire of Sennacherib (c. 704-681 BCE) for irrigation
 - The Nile Delta by Archimedes of Syracuse (c. 287 BCE)
- Used for ship drainage in:
 - Hiero II's Kingdom of Syracuse by Archimedes (c. 280s BCE)
- Used for draining mines in:
 - The Roman Empire (c. 27 BCE to 400s CE)
 - Visigothic Iberia (c. 400s to 711 CE)
 - Al-Andalus Caliphates (711 – 1212 CE)



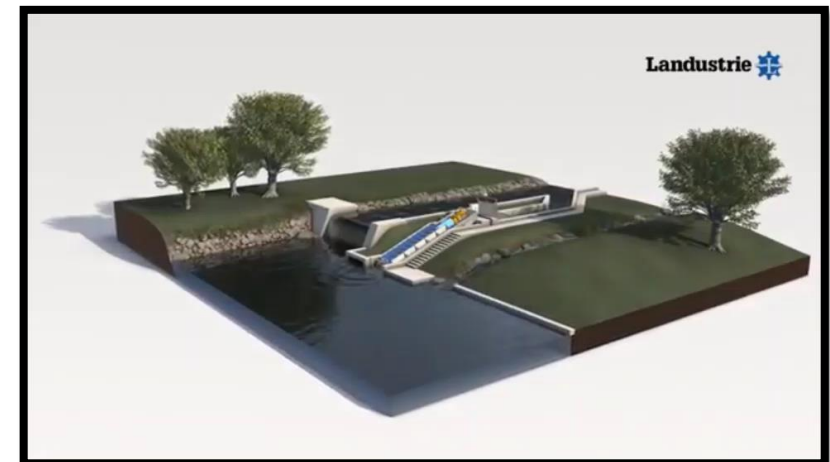
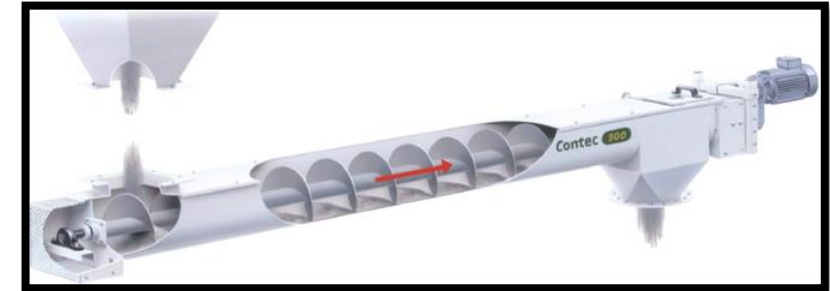
2. Historical Context

- Used for land drainage/reclamation in:
 - Dutch Golden Age (c. 1500s to 1600s CE)
- Used for ship propulsion in:
 - (Possibly) Hiero II's Kingdom of Syracuse by Archimedes (c. 280s BCE)
 - Austria by Josef Ressel (1829 CE)
 - England by Francis Smith (1839 CE)



2. Historical Context

- Modern implementations include:
 - Water and wastewater pump
 - Conveyor for grains
 - Fish ladder
 - Drive mechanism for amphibious vehicles
 - Injector in plastic moulding
 - Heart valve replacements
 - Hydropower generation

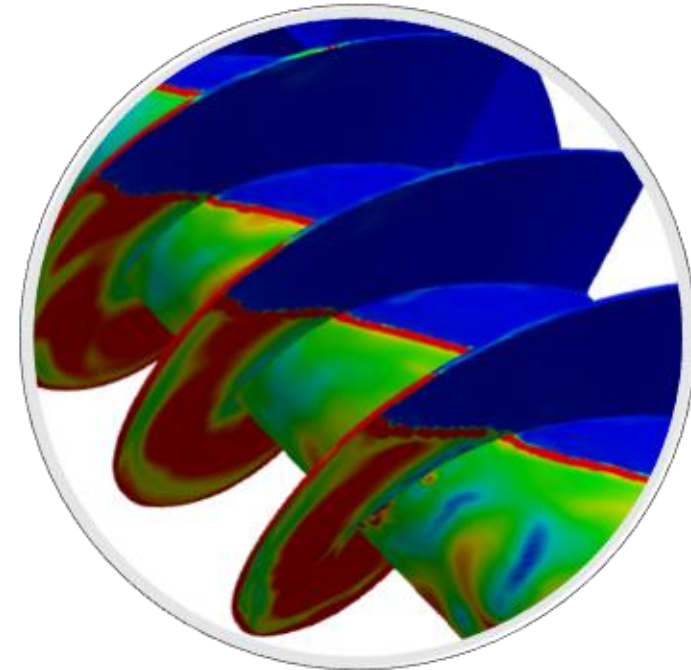




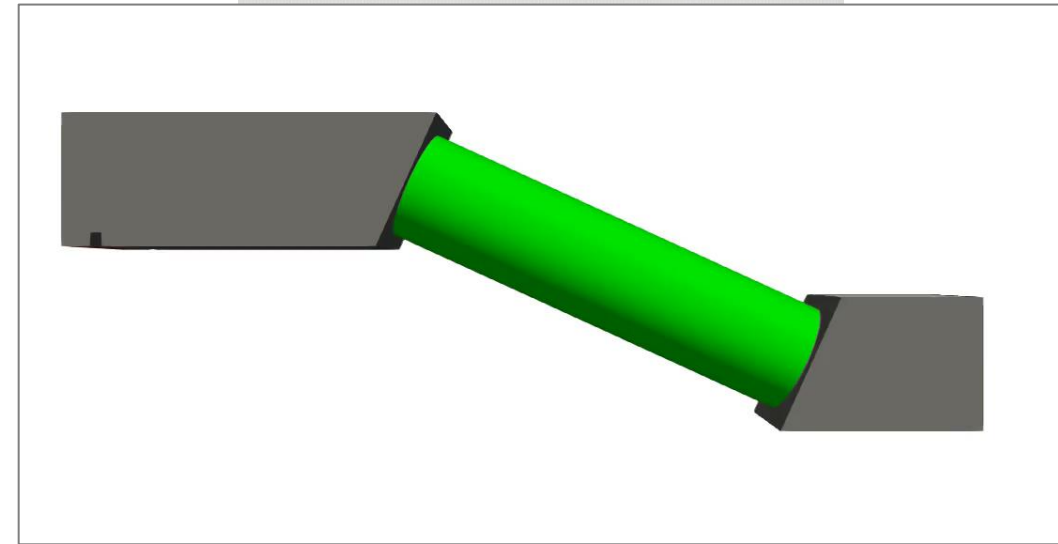
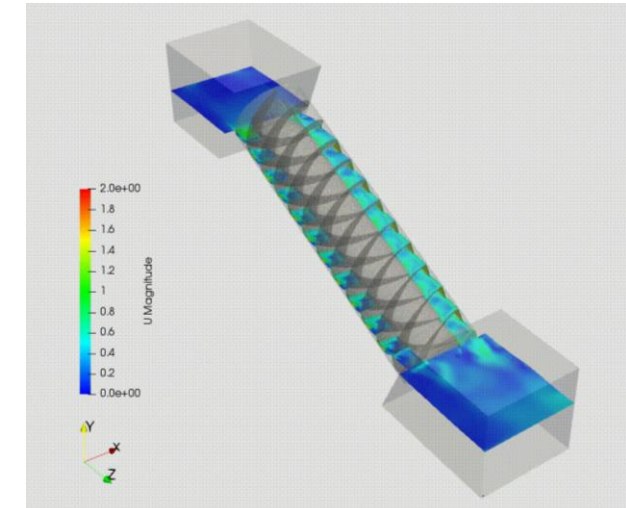
3. Model



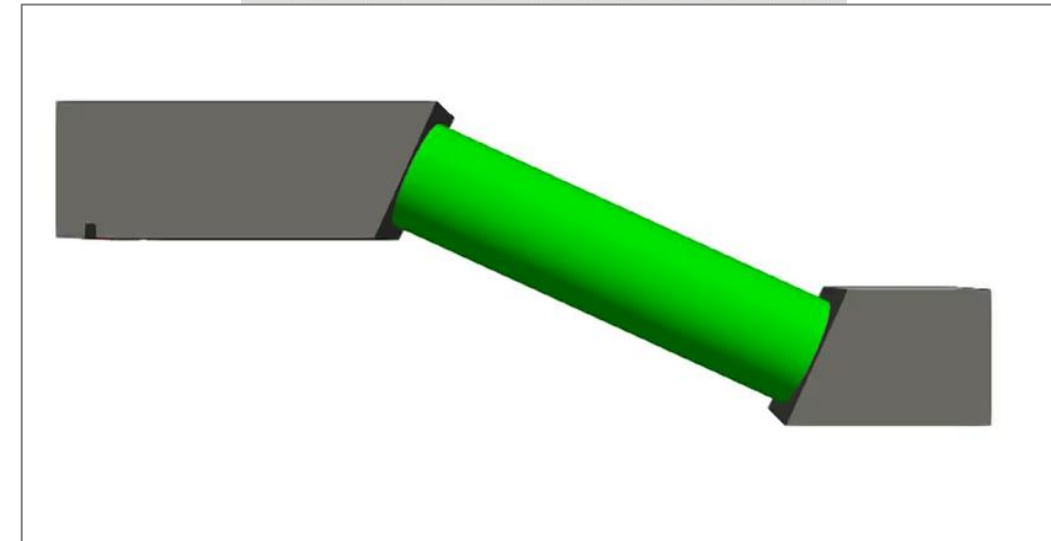
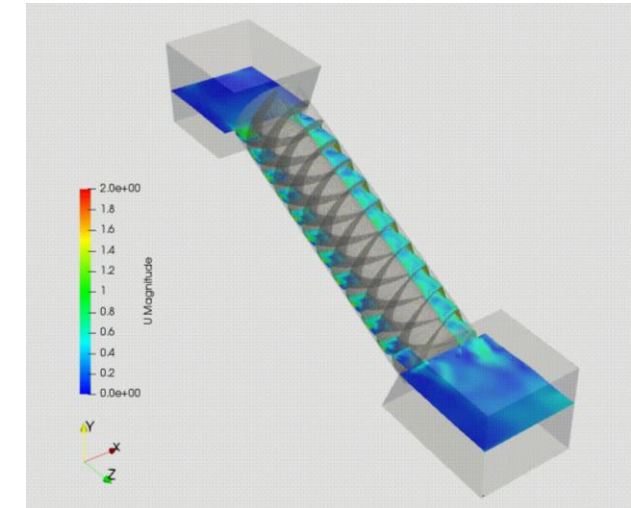
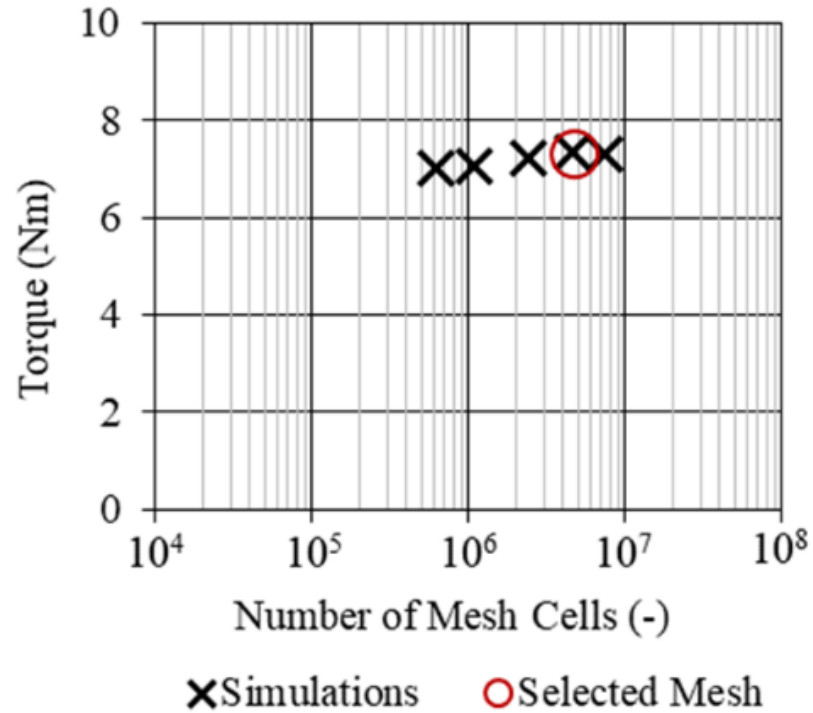
3. Model



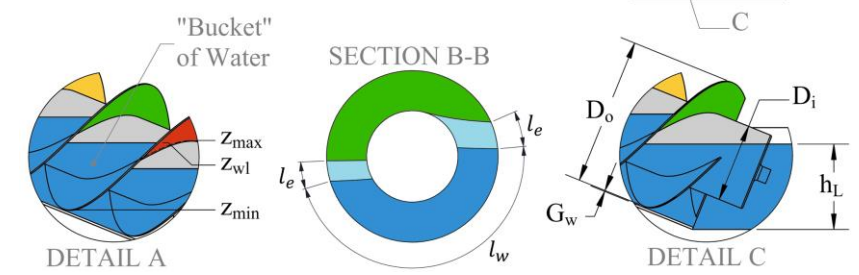
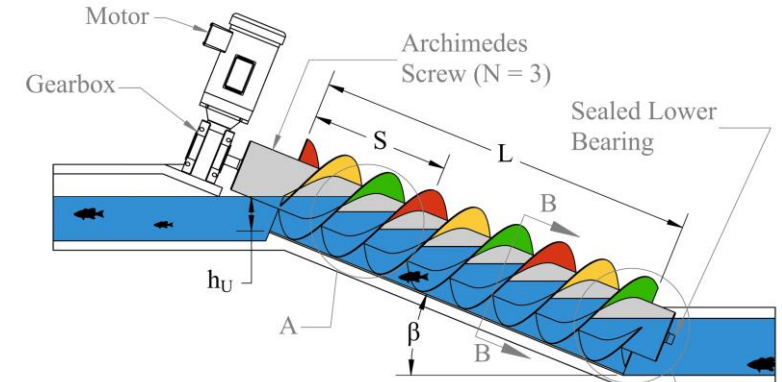
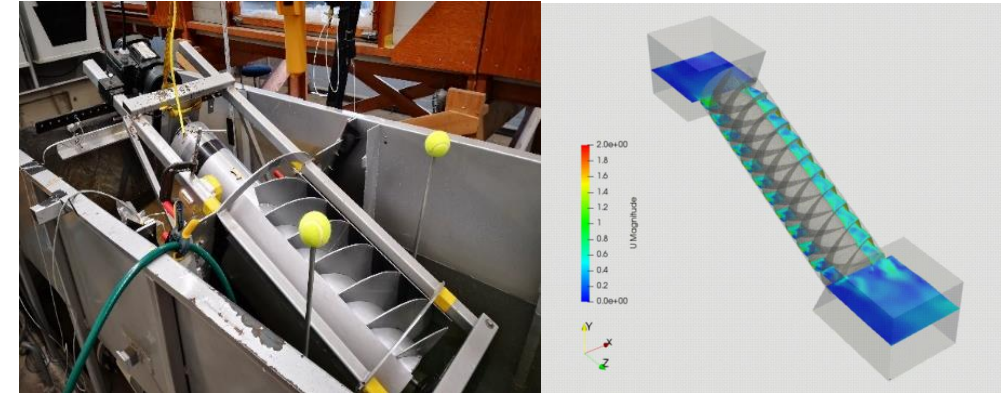
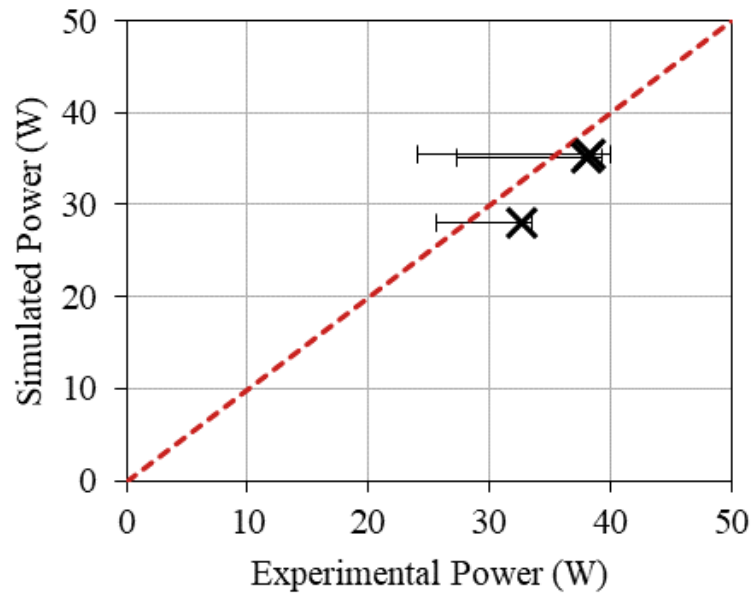
- We use computational fluid dynamics (CFD) to simulate an operating screw and measure performance
 - **Software:** OpenFOAM 8.0, OpenFOAM foundation, 2020
 - **Meshing:** Dynamic mesh to simulate screw rotation
 - **Governing equations:** Reynolds-averaged Navier-Stokes (RANS) equation with the Volume of Fluid (VoF) method to account for two-phase, immiscible flow (water and air)
 - **Turbulence model:** Menter’s Shear Stress Transport (k- ω SST)
- Boundaries:
 - Inlet (**blue**), Walls (**grey**), Outlet (**red**), Trough Wall (**green**), Atmosphere (**light grey**), screw sections (**darker greys**)



- Mesh Sensitivity Study:



- Model Evaluation (or “Validation Study”):



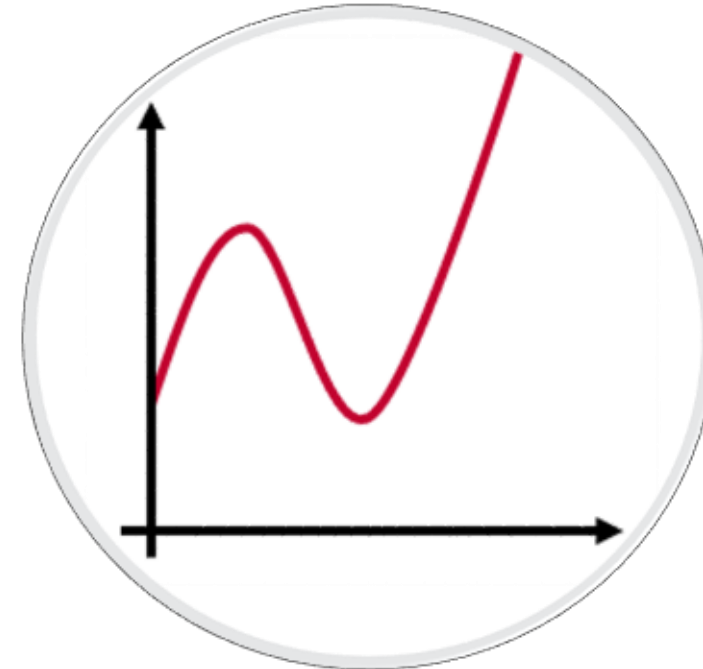
	D_o (m)	D_i (m)	S (m)	L (m)	N (-)	β ($^\circ$)	ω (rev/min)	ψ_U (-)	ψ_L (-)
Run 1	0.316	0.168	0.318	1.219	3	26.4	73.6	0.00	0.39
Run 2	0.316	0.168	0.318	1.219	3	26.3	55.0	0.17	0.59
Run 3	0.316	0.168	0.318	1.219	3	26.3	36.5	0.45	0.78



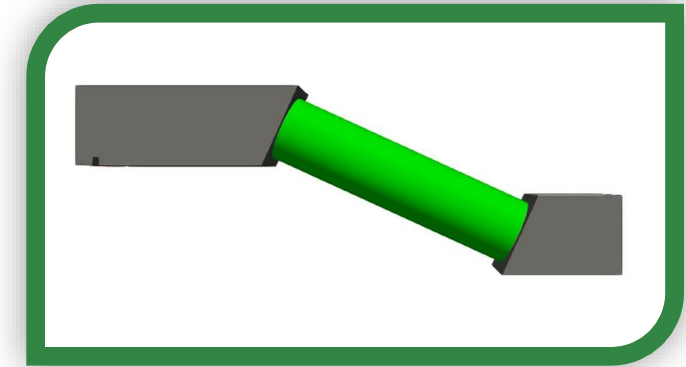
4. Results



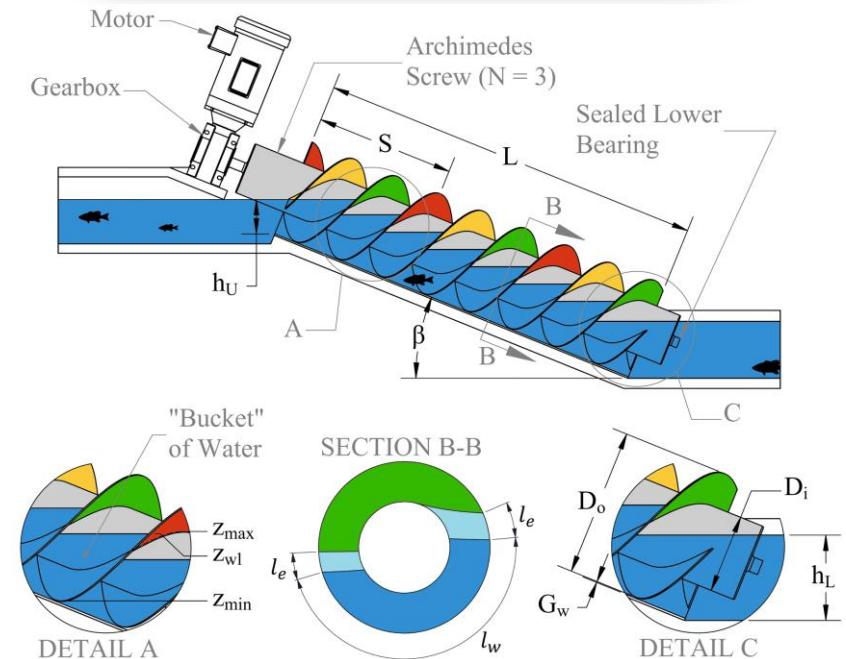
4. Results



- Seven scale-sized screws were modelled
 - Geometrically identical, but varied by scale size
- Screw 2 and Screw 5 were simulated across a range of rotation speeds to determine performance

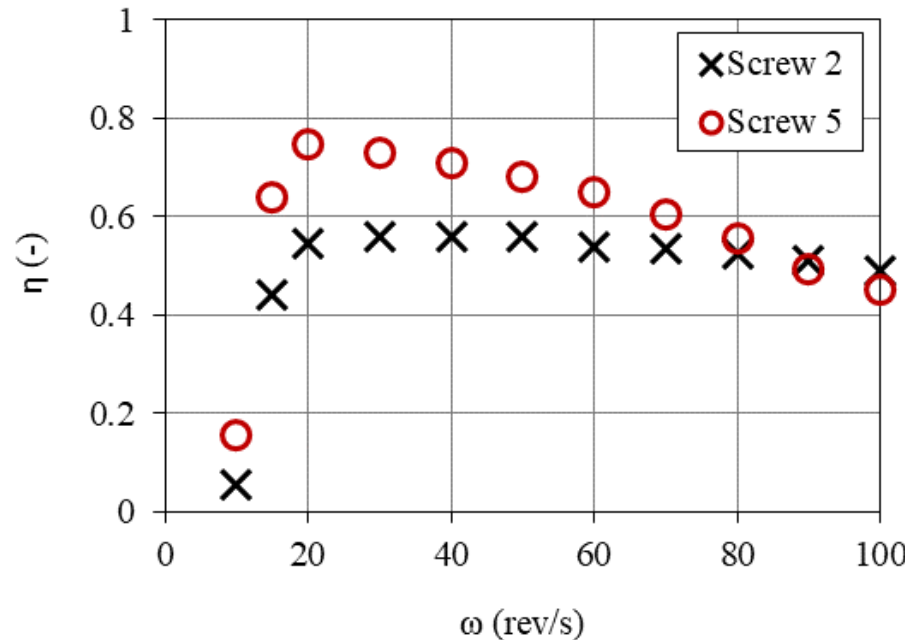
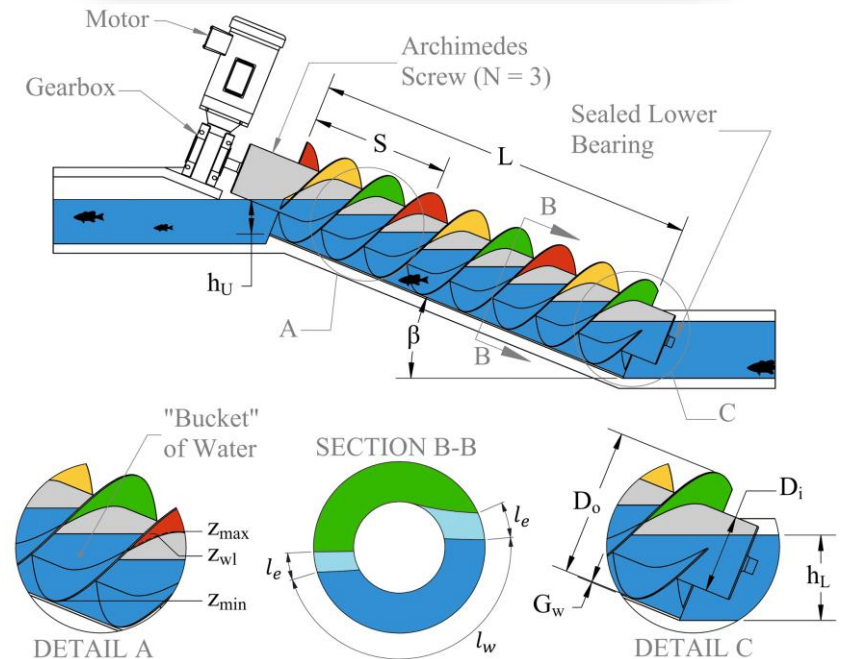
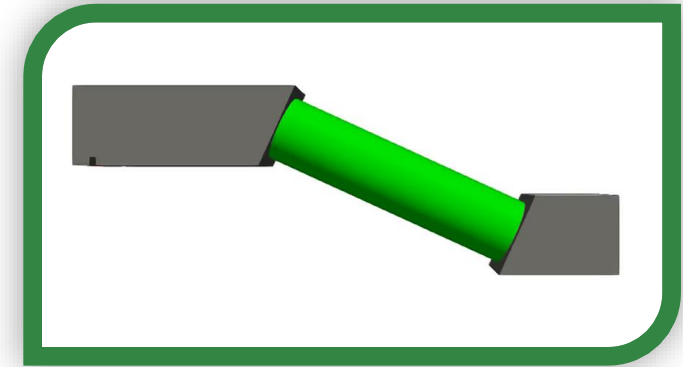


	Scale	D_o (m)	D_i (m)	S (m)	L (m)	N (-)	β ($^\circ$)	G_w (m)
Screw 1	0.47	0.148	0.079	0.148	0.572	3	24.5	0.002
Screw 2	1.00	0.316	0.168	0.318	1.219	3	24.5	0.002
Screw 3	2.13	0.675	0.359	0.678	2.603	3	24.5	0.004
Screw 4	3.16	1.000	0.532	1.004	3.856	3	24.5	0.006
Screw 5	6.33	2.000	1.064	2.008	7.711	3	24.5	0.008
Screw 6	11.07	3.500	1.863	3.514	13.50	3	24.5	0.010
Screw 7	15.81	5.000	2.661	5.020	19.28	3	24.5	0.010



- Screw Pump Performance: Mechanical Efficiency

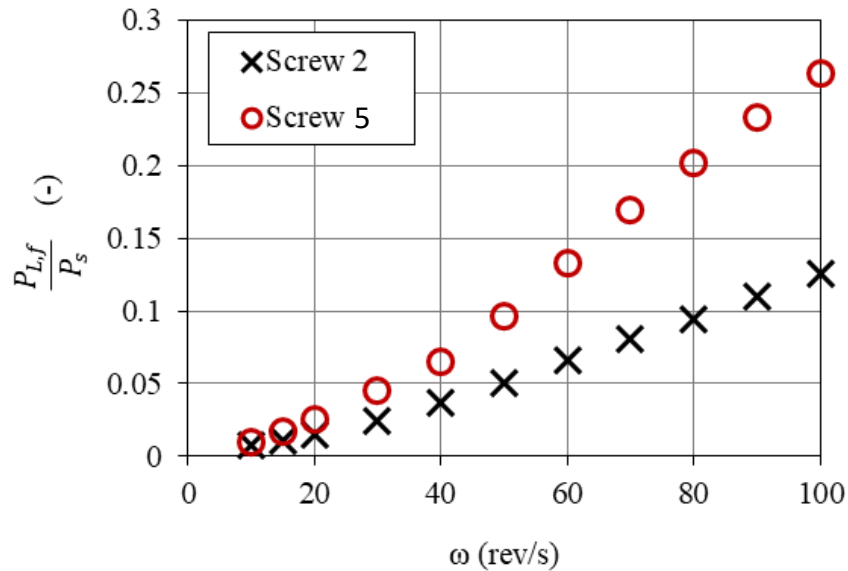
$$\eta = \frac{P_w}{P_s} = \frac{\rho g Q H}{T \omega}$$



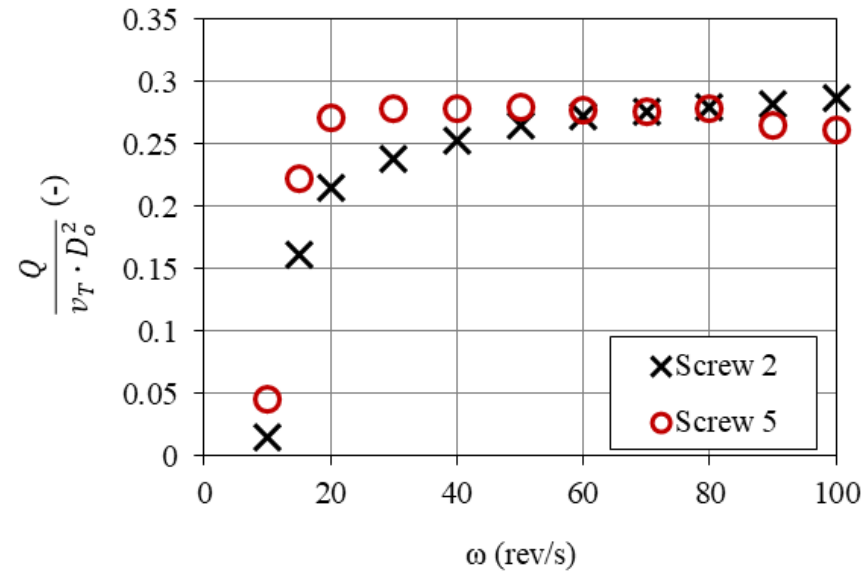
Variable	Definition
η	Mechanical Efficiency (-)
P_w	Hydraulic Power (W)
P_s	Mechanical Power (W)
ρ	Water Density (kg/m ³)
g	Gravitational Acceleration (m/s ²)
Q	Flow Rate (m ³ /s)
H	Head (m)
T	Torque (Nm)
ω	Rotation Speed (rad/s)

- Screw Pump Performance:

- Dimensionless Power Loss Due to Friction

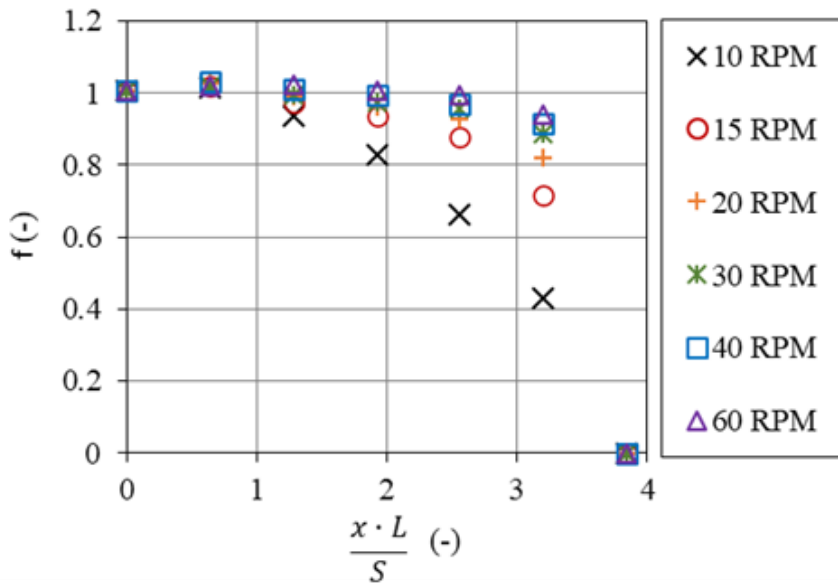


- Dimensionless Flow Rate

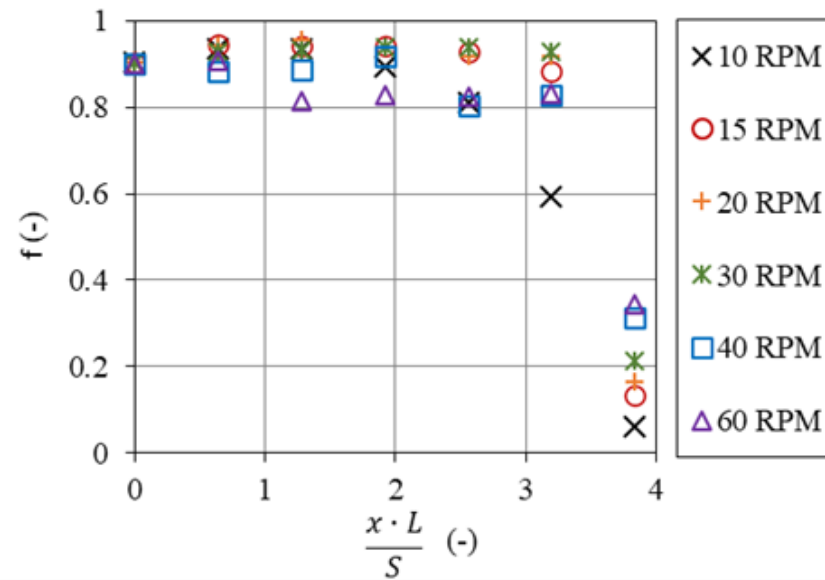


Variable	Definition
$P_{L,f}$	Power Loss due to Friction (W)
P_s	Mechanical Power (W)
Q	Flow Rate (m ³ /s)
v_T	Transport Velocity (m/s)
D_o	Outer Diameter (m)

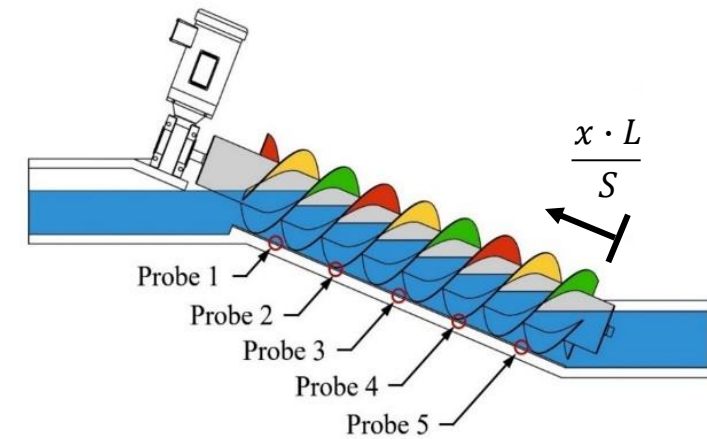
- Screw Pump Performance: Bucket Fill Percentage



Screw 2 ($D_o = 0.316$ m)



Screw 5 ($D_o = 2.000$ m)





5. Conclusions



5. Conclusions



- The “state-of-the-art” is outdated
 - Lacks accuracy, lots of room for improvement
- More data is necessary for development of more accurate models
- There is a lot of room to improve models for flow and leakage rates, hydraulic losses, and geometric optimization





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