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# An updated model for gap leakage in Archimedes screw generators

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1. Background
2. Methods
  - 2.1. Laboratory Experiments
  - 2.2. Field Measurements and Experiments
  - 2.3. Computational Fluid Dynamic Experiments
3. Results and Model Update
  - 3.1. Current Gap Leakage Models
  - 3.2. Gap Leakage Model Update
4. Conclusions



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# 1. Background



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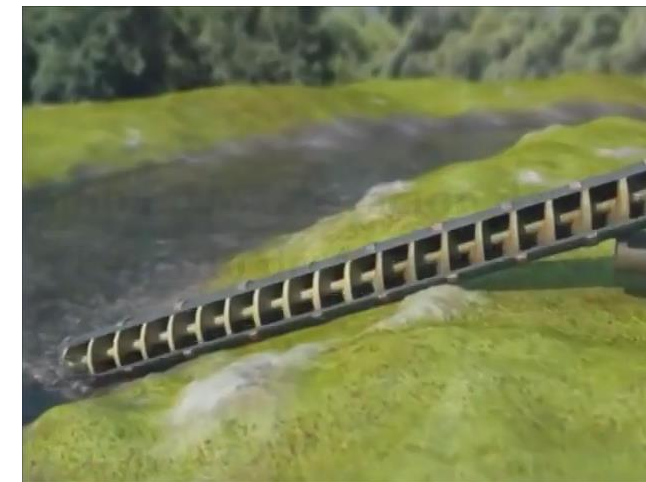
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# 1. Background

- 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\_m2Gekbtw&ab\_channel=AdrianaTub].



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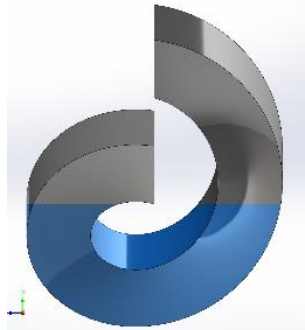
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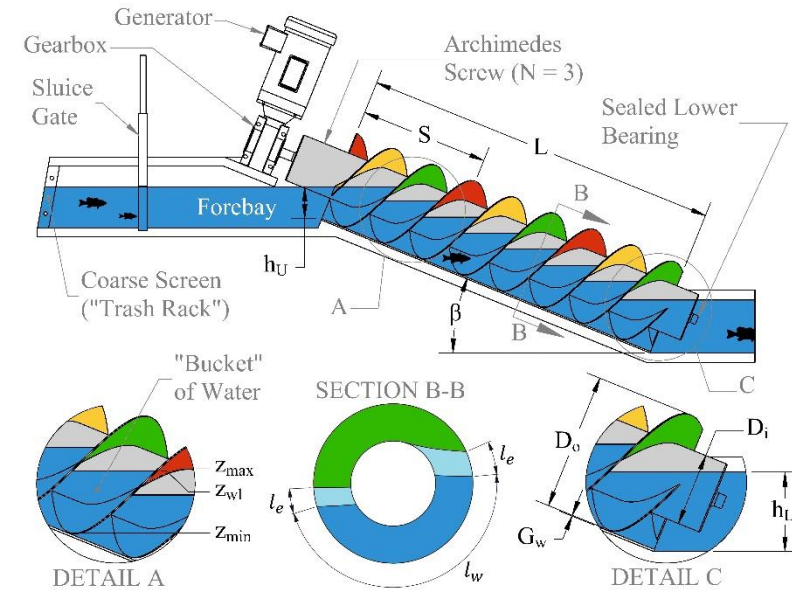
# 1. Background

- Generators operate in reverse to convert mainly hydrostatic pressure into mechanical torque

- Inflow at top fills between blades
  - Termed a "bucket"

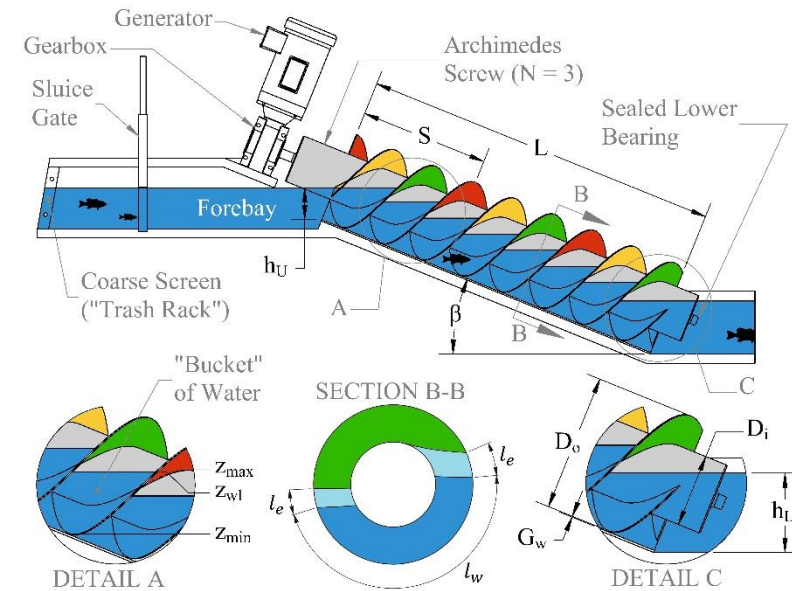


- Water translates down screw and trough and exits into outlet reservoir
- Mechanical torque converted to electrical power by a generator



# 1. Background

- Archimedes screws have been designed as pumps for millennia, similar principles can be used for generators
- No extensive studies of the effects of scaling design parameters in published literature
- We have performed a comprehensive analysis of scale effects on Archimedes screw generators, it includes:
  - Laboratory Experiments
  - Field Measurements and Experiments
  - Computational Fluid Dynamic Simulations

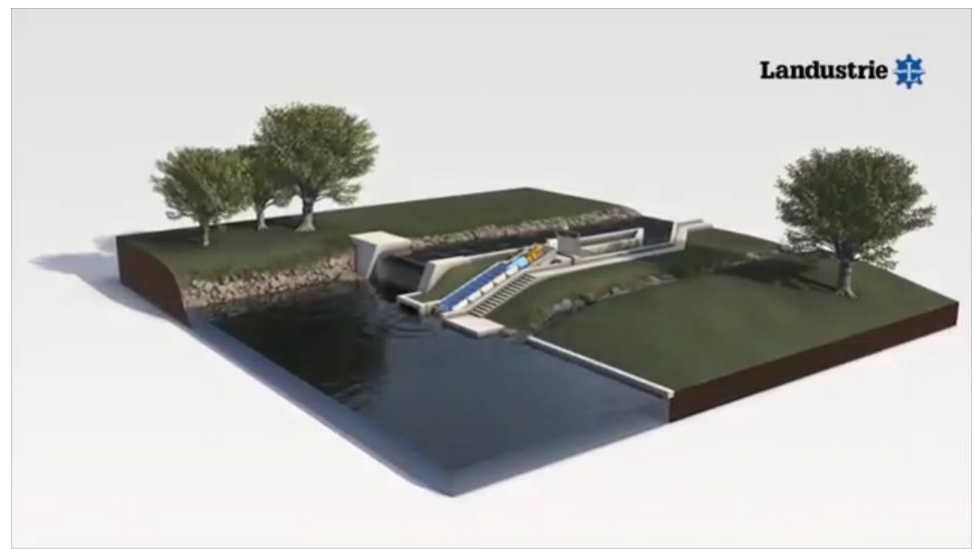
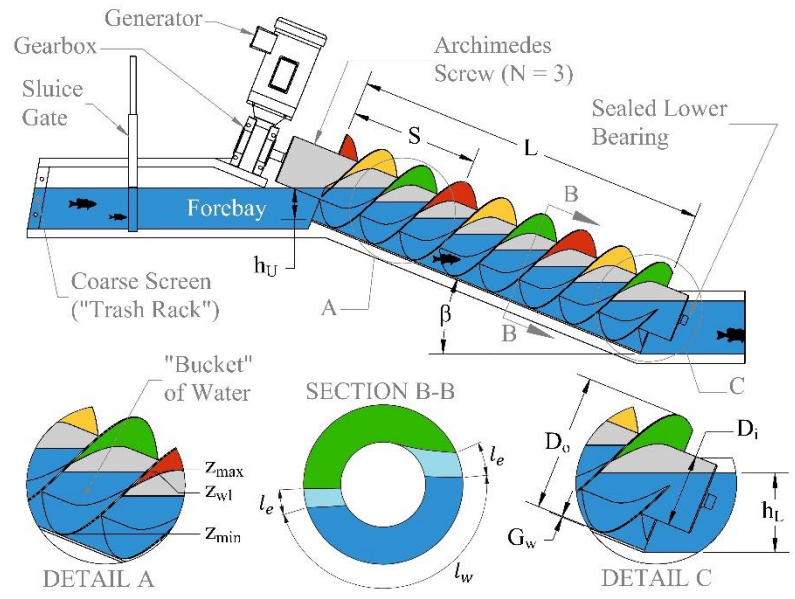


Lubitz, W. D. (2019), Totnes Hydro Powerplant.



# 1. Background

- Archimedes screw generators (ASGs) usually have river-to-wire efficiencies of 75% (or greater in some cases)
- Power production is largely due to hydrostatic pressure in water (head drop)
- Power losses are largely due to both static and dynamic phenomenon
  - Friction loss
    - Hydraulic
    - Mechanical
  - Screw inlet losses
  - Outlet loss
  - Leakage losses
    - **Gap leakage**
    - Overflow leakage

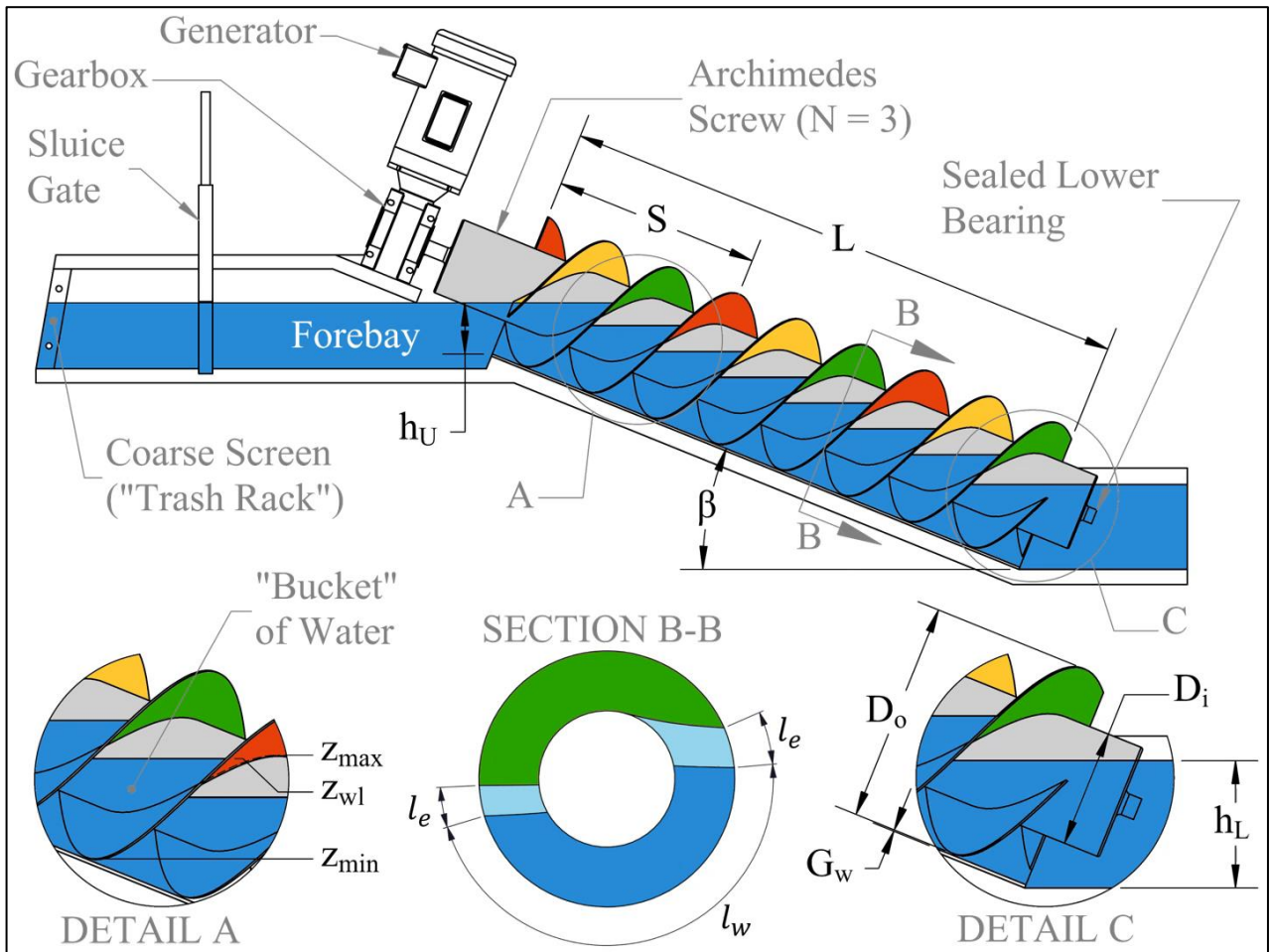


# 1. Background

- What is Gap Leakage?
- Gap Width was suggested by Muysken (1932) and Nagel (1968) to be:

$$G_w = 0.0045 \sqrt{D_o}$$

Screw Plant Name	$D_o$ (mm)	Suggested $G_w$ (mm)	Measured $G_w$ (mm)	Gap Ratio $G_w / D_o$ (-)
Lab Screw A	150	1.74	2	0.0133
Lab Screw 2	316	2.53	2	0.0063
Lab Screw 15	381	2.78	2	0.0052
Waterford, Canada	1390	5.31	6	0.0043
Buckfast, UK	2500	7.12	8	0.0032
Ruswarp, UK	2900	7.66	8	0.0028
Ferrara, Italy	3600	8.54	10	0.0028



2.1. Laboratory Experiments

2.2. Full-scale Experiments

2.3. Computational Fluid Dynamic Experiments



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## 1. Laboratory Experiments



Archimedes Screw Laboratory  
University of Guelph

## 2. Field Measurements



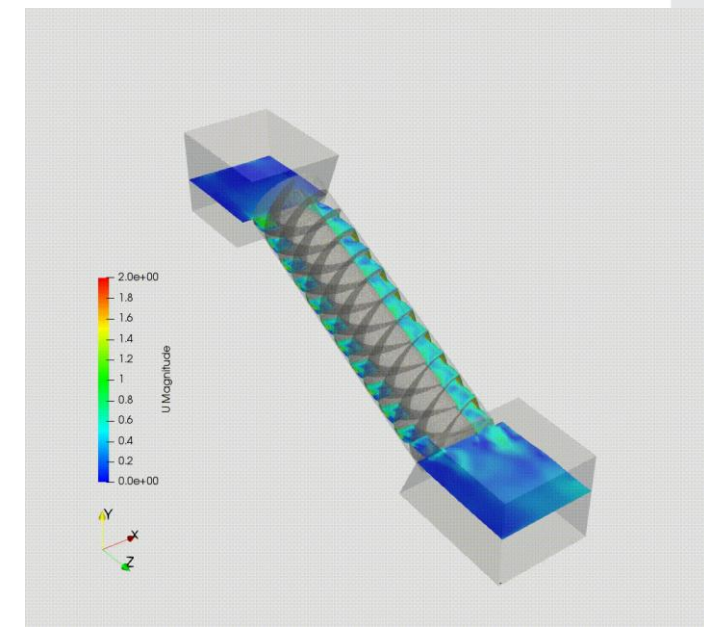
Waterford, Ontario

Buckfastleigh, UK

Ruswarp, UK

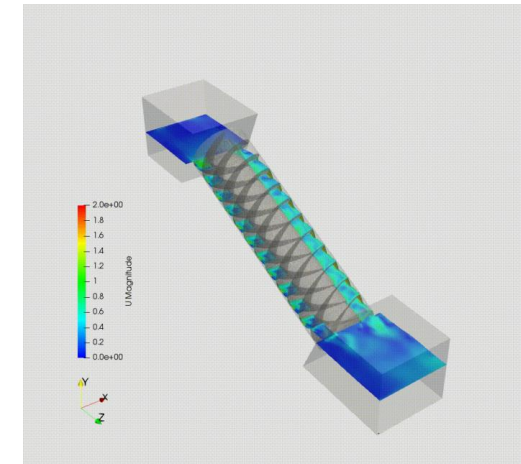
Ferrara, Italy

## 3. CFD Simulations

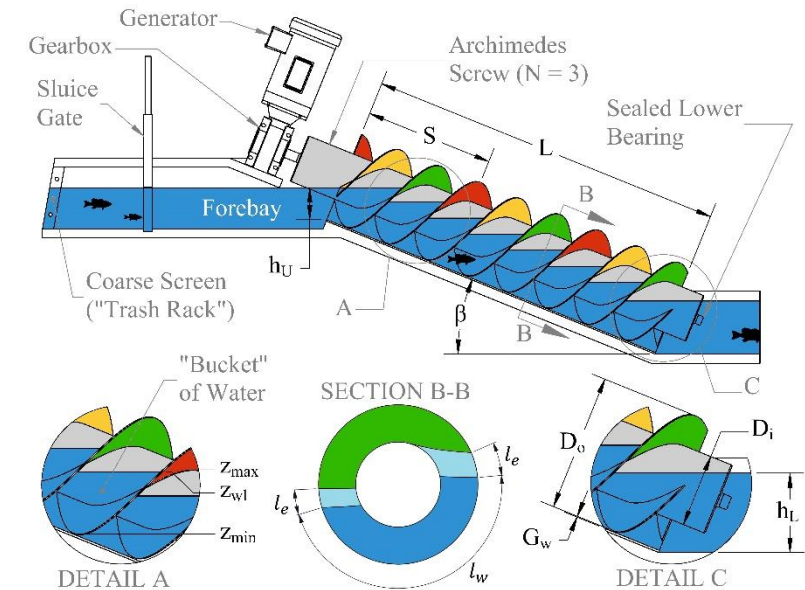


Five simulation sets run that each varied only one parameter, sets include:

1. Rotation Speed
  - $\Omega = 10, 20, 40, 60, 80, 100, 150$  and  $200$  RPM
2. Fill height
  - $f = 0.5$  to  $1.3$  by increments of  $0.1$
3. Inclination angle
  - $\beta = 10$  to  $35$  by increments of  $5$
4. Number of blades
  - $N = 3, 4,$  and  $5$
5. Scale Size (Length-scale)

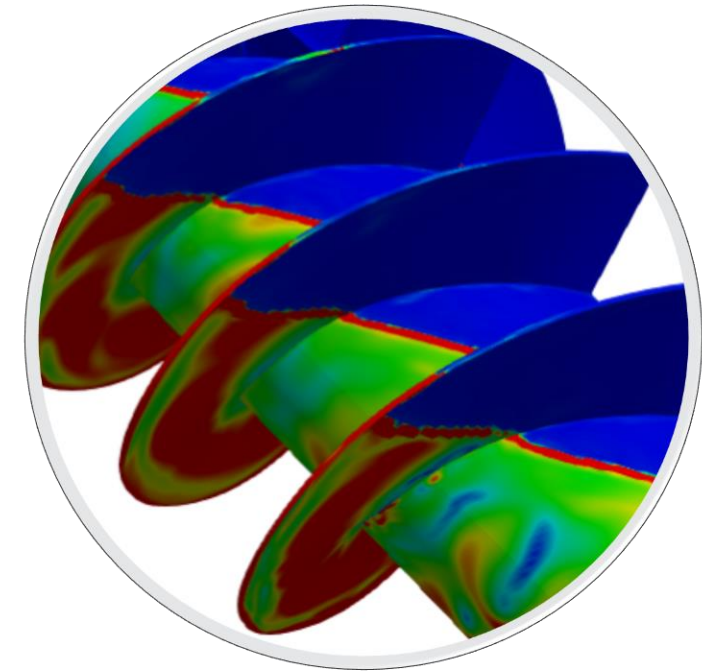


Length-scale (Diameter Scaling)												
Simulation	Scale	$D_o$ (m)	$D_i$ (m)	$D_i / D_o$ (-)	$S$ (m)	$S / D_o$ (m)	$L$ (m)	$S / L$ (m)	$N$ (-)	$\beta$ (°)	$Q$ ( $m^3/s$ )	$f$ (-)
Scale 1	0.47	0.15	0.08	0.53	0.15	1	0.57	0.26	3	24.5	0.001	1
Scale 2	1.0	0.32	0.17	0.53	0.32	1	1.2	0.26	3	24.5	0.008	1
Scale 3	2.1	0.68	0.36	0.53	0.68	1	2.6	0.26	3	24.5	0.070	1
Scale 4	3.2	1.0	0.53	0.53	1.0	1	3.9	0.26	3	24.5	0.202	1
Scale 5	6.3	2.0	1.06	0.53	2.0	1	7.7	0.26	3	24.5	1.23	1
Scale 6	11.1	3.5	1.86	0.53	3.5	1	13.5	0.26	3	24.5	4.51	1
Scale 7	15.8	5.0	2.66	0.53	5.0	1	19.3	0.26	3	24.5	10.26	1



3.1. Current Gap Leakage Models

3.2. Gap Leakage Model Update



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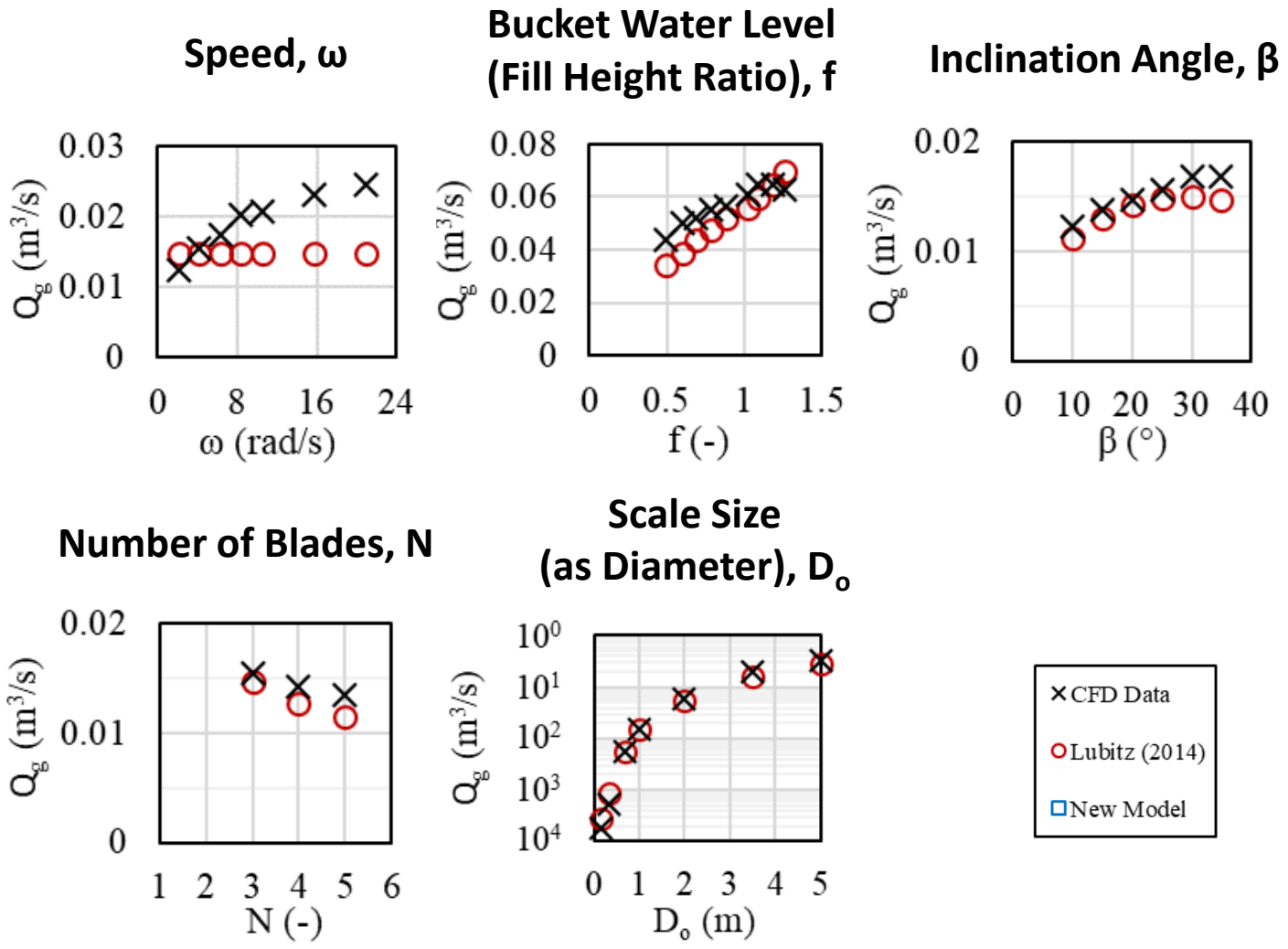
# 3. Results | Current Gap Leakage Models

- The two state-of-the-art gap leakage prediction models are mathematically identical
- Lubitz (2014) model was used:

$$Q_g = C G_w \left( l_w + \frac{L_e}{1.5} \right) \sqrt{2gh_b}$$

- Where,

- $Q_g$  = Gap Leakage Flow Rate (m<sup>3</sup>/s)
- $C$  = Leakage Coefficient (-)
- $G_w$  = Gap Width (m)
- $l_w$  = Wetted Arc Length (m)
- $L_e$  = Extended Wetted Arc Length (m)
- $g$  = Gravitational Acceleration (m/s<sup>2</sup>)
- $h_b$  = Head Drop Between Buckets (m)

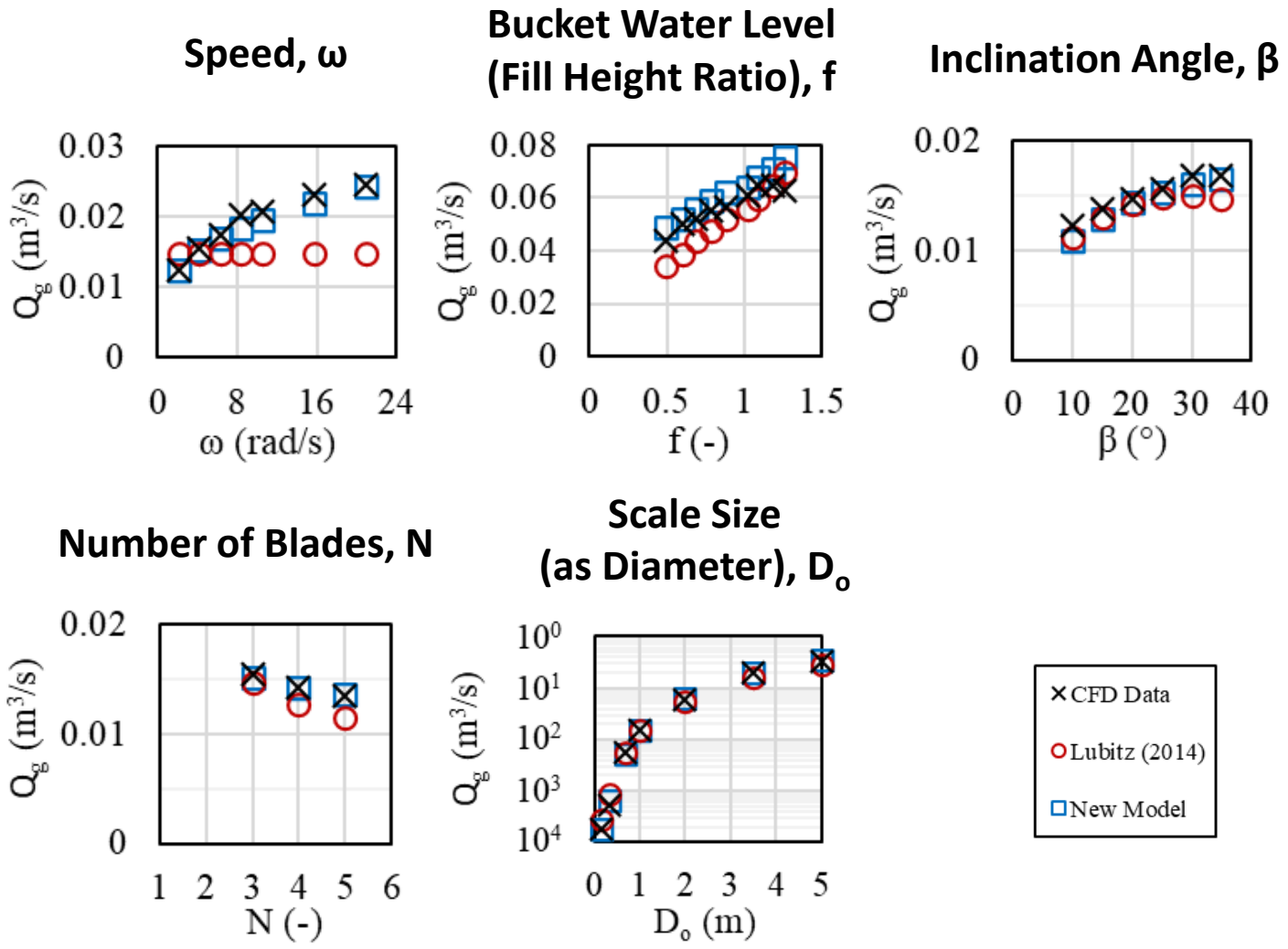


# 3. Results | Gap Leakage Model Update

- The gap leakage model did not account for rotation speed ( $\omega$ ), adding a rotation speed term to the leakage coefficient improved the model drastically
- Terms for fill height ( $f$ ), inclination angle ( $\beta$ ), the number of blades ( $N$ ), and the length-scale ( $D_o$ ) were also added to improve model accuracy
- Regression analysis resulted in the following equation:

$$C = 0.441 \cdot \left( \frac{\omega D_o N}{f} \right)^{0.285}$$

- Average improvement of 10.7%



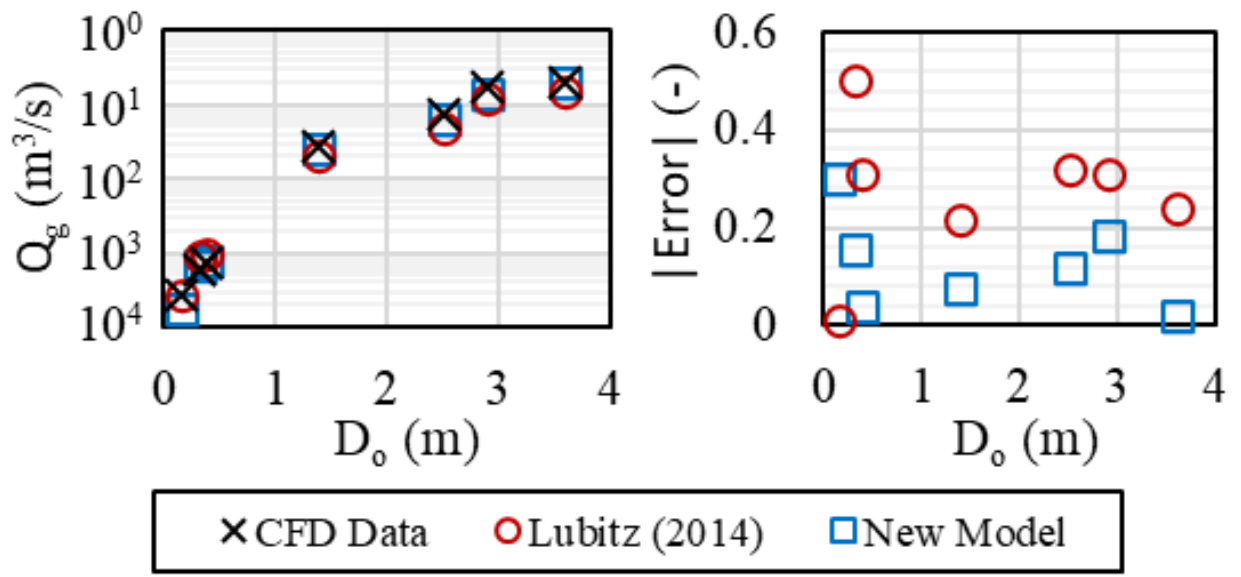
# 3. Results | Gap Leakage Model Update

$$Q_g = C G_w \left( l_w + \frac{L_e}{1.5} \right) \sqrt{2gh_b}$$

$$C = 0.441 \cdot \left( \frac{\omega D_o N}{f} \right)^{0.285}$$

- Average improvement against laboratory and field experiments was 14.3%

Screw Plant Name	D <sub>o</sub> (mm)	Suggested G <sub>w</sub> (mm)	Measured G <sub>w</sub> (mm)	Gap Ratio G <sub>w</sub> / D <sub>o</sub> (-)
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## 4. Conclusions



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# 4. Conclusions

- This study introduced novel, full-scale ASG performance data to the published literature
- CFD simulation seemed to accurately approximate laboratory and real-world screw generator performance, they were used to evaluate model accuracy
- New leakage coefficient relationship improved gap leakage predictions by an average of 10.7% to 14.3%
- Updated model improves overall screw powerplant performance predictions which helps with design optimization



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Thank you all very much for your time.



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