



# Scaling effects on Archimedes screw generators

**Guilhem Dellinger**

Laboratoire ICube

ENGEES

Strasbourg, France

[guilhem.dellinger@engees.unistra.fr](mailto:guilhem.dellinger@engees.unistra.fr)

**Scott Simmons**

School of Engineering

University of Guelph

Guelph, Canada

[ssimmons@uoguelph.ca](mailto:ssimmons@uoguelph.ca)

**William David Lubitz**

School of Engineering

University of Guelph

Guelph, Canada

[wlubitz@uoguelph.ca](mailto:wlubitz@uoguelph.ca)



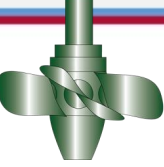
# Overview

1. Background
2. Methods
  - 2.1. Laboratory Experiments
  - 2.2. Field Measurements and Experiments
  - 2.3. Computational Fluid Dynamic Experiments
3. Results
  - 3.1. Length-scale
  - 3.2. Number of Blades
  - 3.3. Bucket Fill Height
  - 3.4. Inclination Angle
  - 3.5. Surface Roughness
4. Conclusions



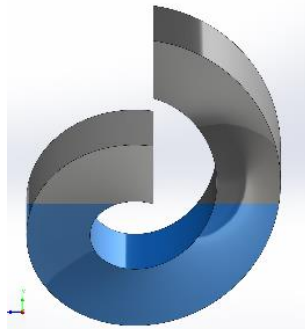
## 1. Background



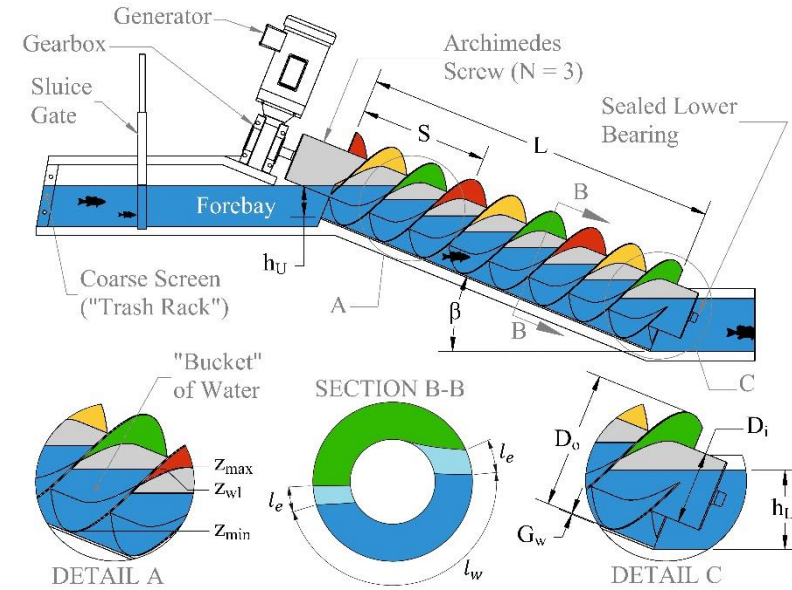


# 1. Background

- Generators operate in reverse to convert mainly hydrostatic pressure into mechanical torque
- Inflow at top fills between blades
  - Termed a “bucket”

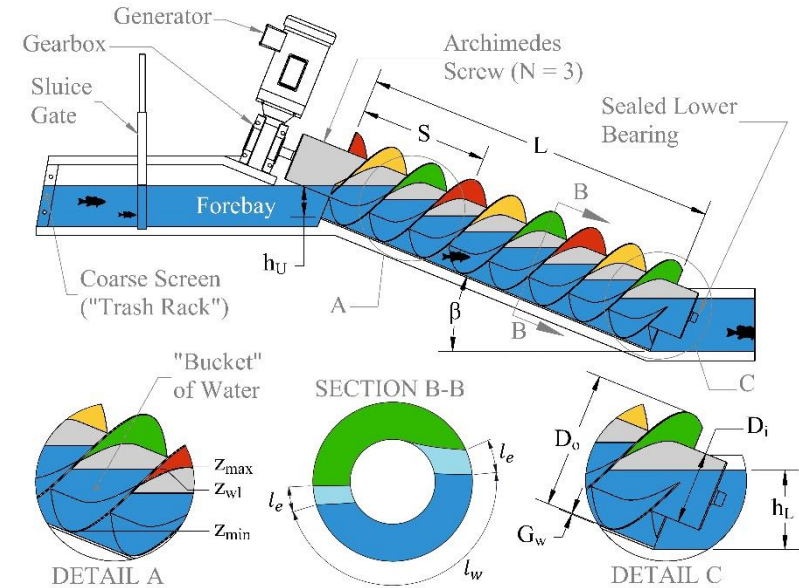


- Water translates down screw and trough and exits into outlet reservoir
- Mechanical torque converted to electrical power by a generator



# 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.

2.1. Laboratory Experiments

2.2. Full-scale Experiments

2.3. Computational Fluid Dynamic Experiments



## 1. Laboratory Experiments



Archimedes Screw Laboratory  
University of Guelph

## 2. Field Measurements



Waterford, Ontario



Buckfastleigh, UK

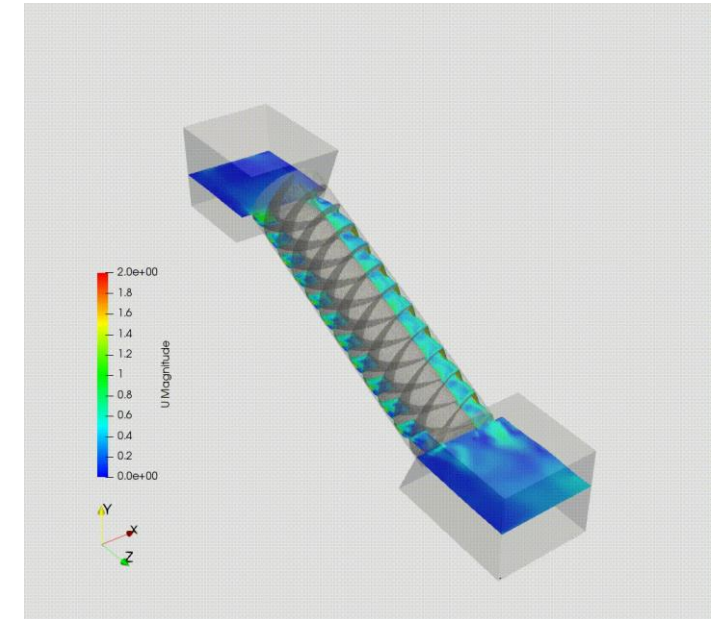


Ruswarp, UK



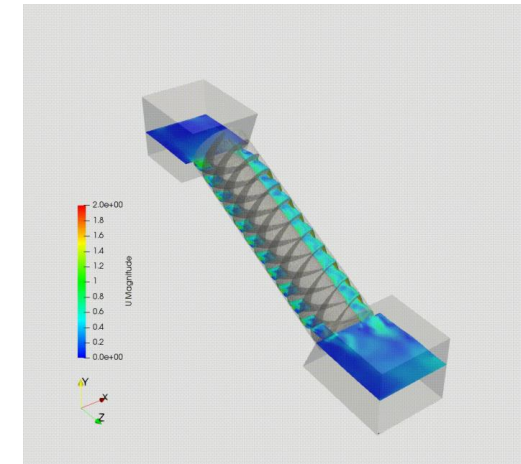
Ferrara, Italy

## 3. CFD Simulations

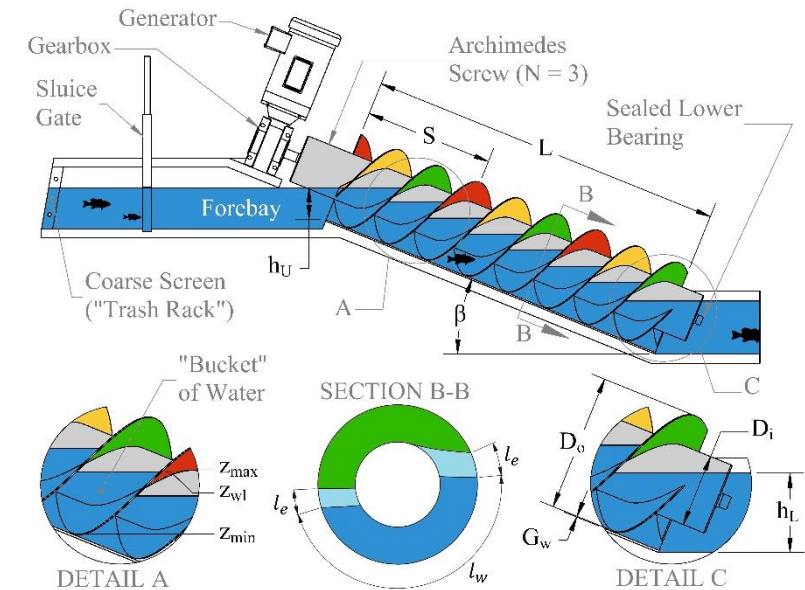


# 2. Methods | CFD Simulations

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 <sup>3</sup> /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

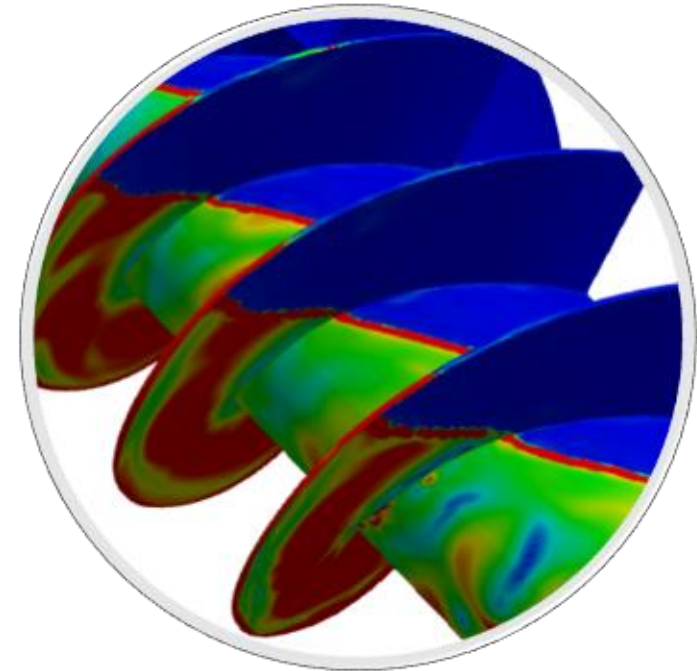


Surface Roughness											
Simulation	$n$ (s/m <sup>1/3</sup> )	$z_0$ (mm)	$D_o$ (m)	$D_i$ (m)	$S$ (m)	$L$ (m)	$N$ (-)	$\beta$ (°)	$Q$ (m <sup>3</sup> /s)	$f$ (-)	
Smooth	0.000	0.0	2.0	1.06	2.0	7.7	3	24.5	1.23	1	
Glass	0.010	0.3	2.0	1.06	2.0	7.7	3	24.5	1.23	1	
Smooth Steel	0.012	1.0	2.0	1.06	2.0	7.7	3	24.5	1.23	1	
Painted Steel	0.014	2.4	2.0	1.06	2.0	7.7	3	24.5	1.23	1	
Algae on Steel	0.018	11.4	2.0	1.06	2.0	7.7	3	24.5	1.23	1	
Corrugated Steel	0.022	37.0	2.0	1.06	2.0	7.7	3	24.5	1.23	1	



3.1. Length-scale

3.2. Surface Roughness



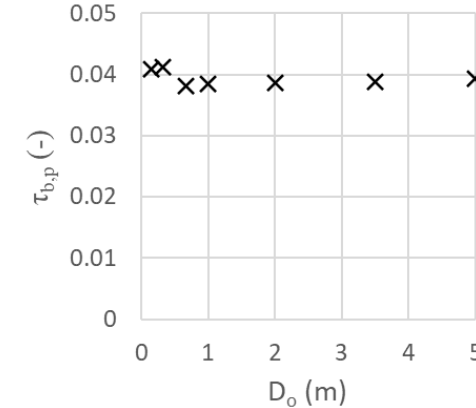
# 3. Results | Length-scale



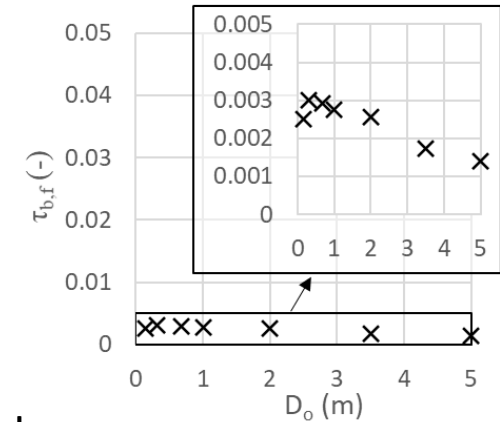
- Dimensionless bucket torque seemed *relatively* consistent across the range of simulations
  - Indicating that screw power production and power losses scale similarly
- Friction loss seems to proportionally decrease as size increases

Length-scale (Diameter Scaling)												
Simulation	Scale	D <sub>o</sub> (m)	D <sub>i</sub> (m)	D <sub>i</sub> / D <sub>o</sub> (-)	S (m)	S / D <sub>o</sub> (m)	L (m)	S / L (m)	N (-)	β (°)	Q (m <sup>3</sup> /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

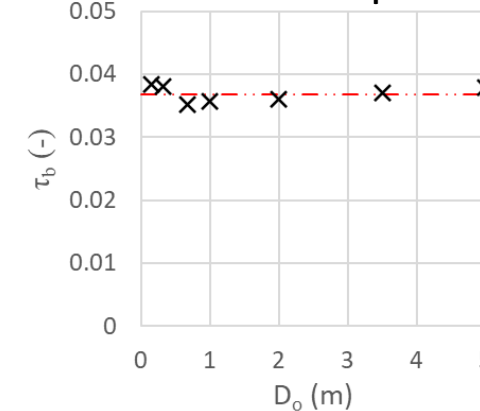
Dimensionless Torque (Pressure Component)



Dimensionless Torque (Friction Loss Component)



Dimensionless Resultant Torque



- Back-of-the-envelope screw torque approximation:

$$\tau_b \approx 0.0369 \quad (6-4a)$$

$$T \approx 0.0369 \cdot \rho g h_b D_o^3 \frac{LN}{S} \quad (6-4c)$$

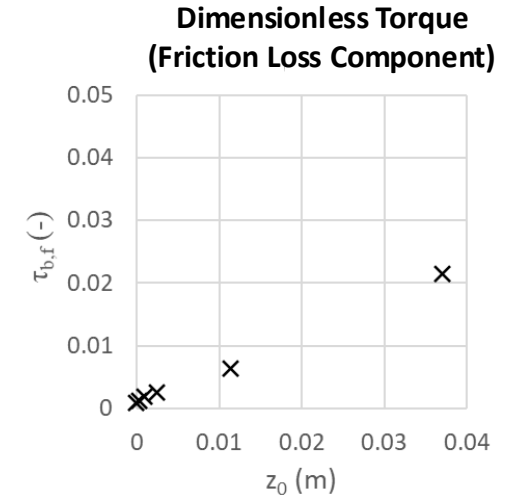
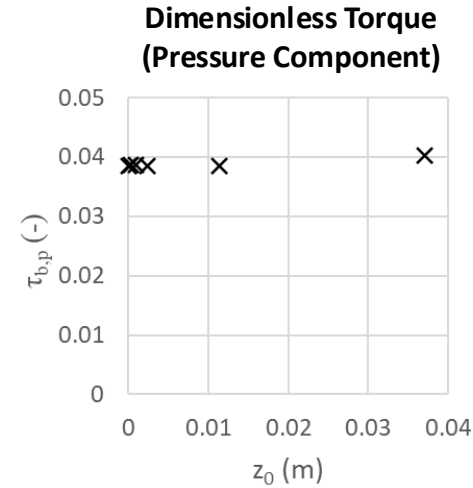
Trend Line Relation

# 3. Results | Surface Roughness



- No significant impact on pressure component
- Can have a substantial impact on resultant mechanical power if roughness values are high

Surface Roughness										
Simulation	n (s/m <sup>1/3</sup> )	z <sub>0</sub> (mm)	D <sub>o</sub> (m)	D <sub>i</sub> (m)	S (m)	L (m)	N (-)	β (°)	Q (m <sup>3</sup> /s)	f (-)
Smooth	0.000	0.0	2.0	1.06	2.0	7.7	3	24.5	1.23	1
Glass	0.010	0.3	2.0	1.06	2.0	7.7	3	24.5	1.23	1
Smooth Steel	0.012	1.0	2.0	1.06	2.0	7.7	3	24.5	1.23	1
Painted Steel	0.014	2.4	2.0	1.06	2.0	7.7	3	24.5	1.23	1
Algae on Steel	0.018	11.4	2.0	1.06	2.0	7.7	3	24.5	1.23	1
Corrugated Steel	0.022	37.0	2.0	1.06	2.0	7.7	3	24.5	1.23	1

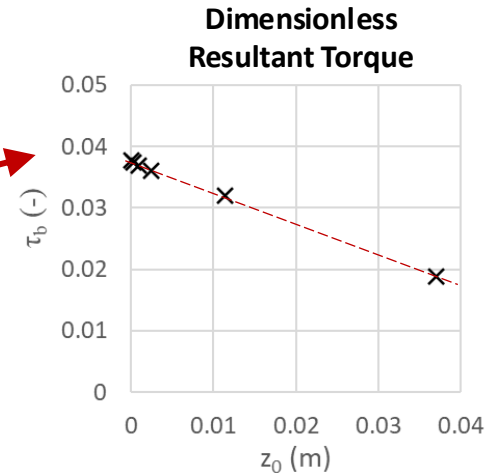


- Overall trend may be approximated using a linear polynomial:

$$\tau_b \approx -0.505 \cdot z_0 + 0.0375 \quad (6-7a)$$

$$T \approx \frac{\rho g h_b D_o^3 L N}{S} (-0.505 \cdot z_0 + 0.0375) \quad (6-6c)$$

Trend Line Relation



## 4. Conclusions and Future Work



# 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
- CFD simulations were then used for further investigation into mechanics of ASG performance
- Data was used to quantify performance parameters, visualize fluid mechanics, and inform model development
- Results suggests that algae growth and other increases in surface roughness can significantly lower screw generator powerplant performance



# Acknowledgements



Thank you all very much for your time.



## Acknowledgements

- Nicola Fergnani..... Hydro Smart Srl. (Italy)
- Adrian Clayton, David Mann, and Stuart Moore..... Mann Power Hydro Ltd. (UK)
- Mike Ford, Colin Mather, Rory Newman, Stephen Larkin, Dave Moore..... Whitby Esk Energy (UK)
- Chris Elliott..... On Stream Energy Ltd. (UK) and Fishtek Consulting Ltd (UK)
- David Dechambeau..... Southeast Power Engineering (UK)