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Mussel-biofouled Mooring Chain Drag in Uniform Currents : Design Standard Comparison

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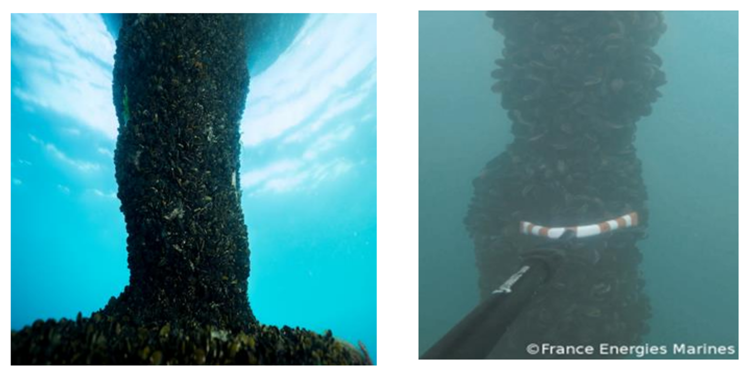
Motivation and research goals

Why is bio-colonization important?

- Increases mooring-line diameter and surface roughness, altering hydrodynamic behavior
- Changes flow regime and increases drag
- Reducing offshore system reliability

Research Goals

- Biofouling characterization
- Drag coefficient evaluation
- Uncertainty quantification
- Biofouling classification and prediction
- Anti-fouling and cleaning strategies



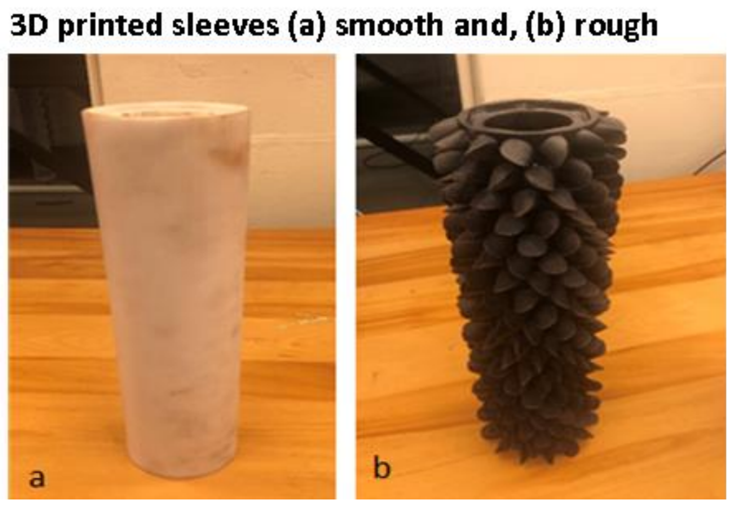
Images captured by *Sea and Littoral Research Institute* (IUML), Université de Nantes, Nantes, France

Methods and data

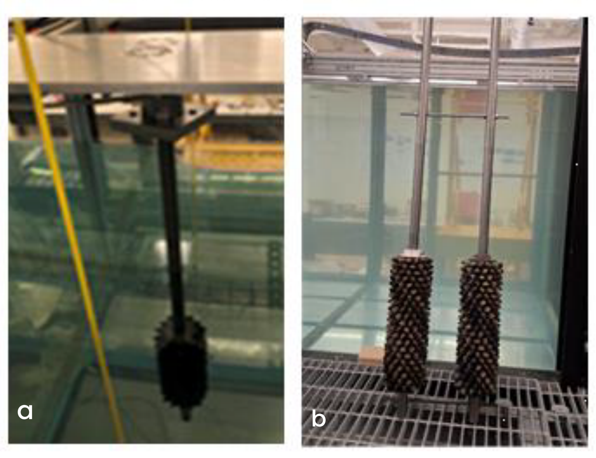
Methods

- Flume tests: 3D-printed mussel sleeves (current–wave conditions)
- Measurements: Velocity and force (time-series)
- Drag analysis: C_d computation using Morison equation

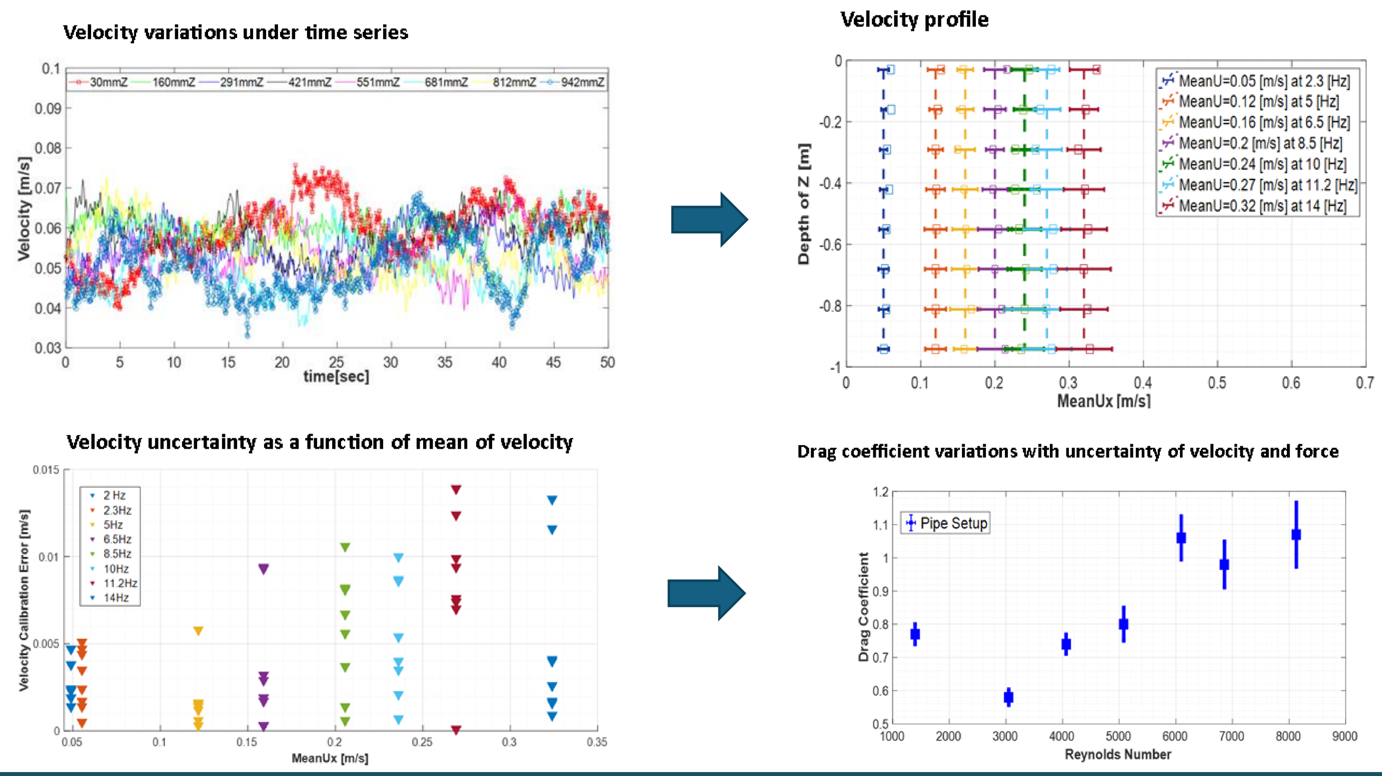
3D printed sleeves (a) smooth and, (b) rough



UMass Flume Setup (a) single and, (b) two sleeves



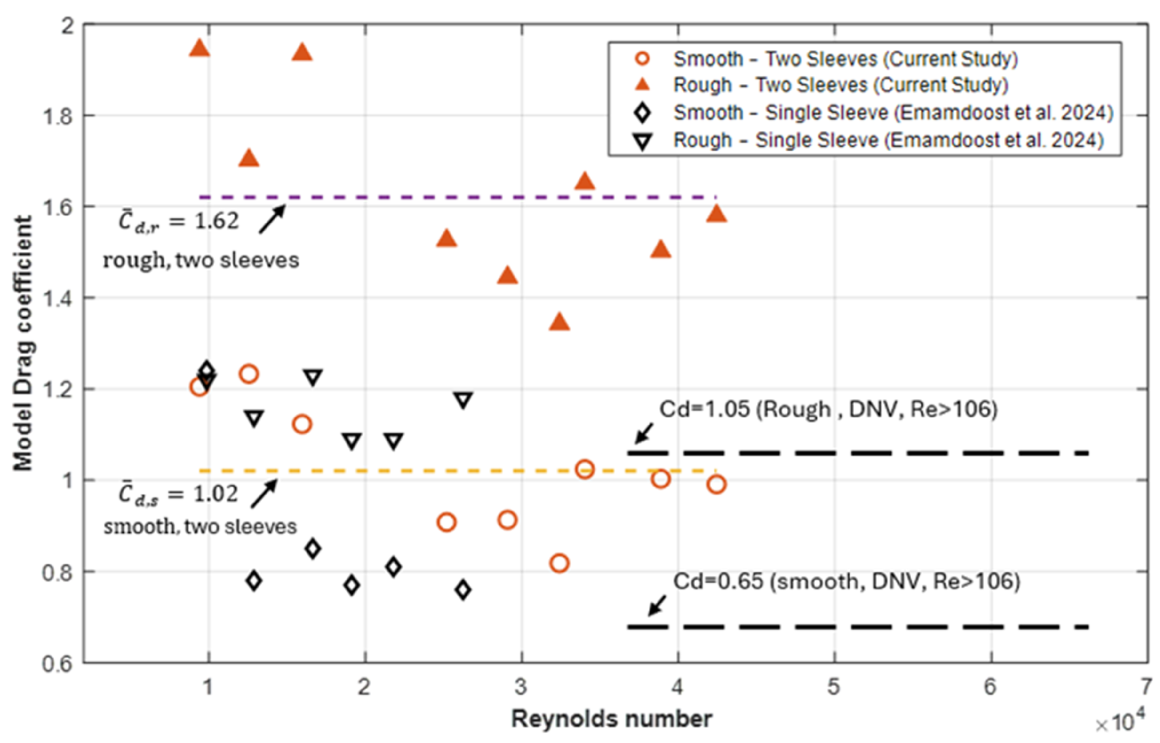
Data processing and uncertainty analysis



Research findings and key takeaways

Recent Works– Uniform Current Conditions

- **Single mussel sleeve:** ~36% drag increase due to biofouling ***(Emamdoost et al., RENEW 2024)***
- **Two-mussel sleeves: Drag coefficients (Cd = 1.34–1.94) exceed design-code predictions *(Emamdoost et al., OTC 2026)***



Source	Surface condition	Relative roughness (ϵ = k/D_e)	Reynolds number range	Recommended / obtained (C_d)
API RP-2A (Sec. 3)	Rough cylinder	Not explicitly specified	Subcritical model-scale regime	1.05 – 1.15
DNVGL-RP-C205 (Sec. 6.7)	Smooth cylinder	$\epsilon < 10^{-4}$	$Re > 10^6$	~0.65
DNVGL-RP-C205 (Sec. 6.7)	Fully rough cylinder	$\epsilon > 10^{-2}$	$Re > 10^6$	~1.05
Single Sleeve (Emamdoost et al., 2024)	Smooth sleeve	≈ 0 (hydraulically smooth)	$4.5 \times 10^3 < Re_m < 2.6 \times 10^4$	0.8 – 2.01
Single Sleeve (Emamdoost et al., 2024)	Rough sleeve	0.25	$4.5 \times 10^3 < Re_m < 2.6 \times 10^4$	1.1 – 2.9
Current study- Two Sleeve	Smooth sleeve	≈ 0 (hydraulically smooth)	$2.3 \times 10^3 < Re_m < 4.2 \times 10^4$	0.54 – 1.23
Current study- Two Sleeve	Rough sleeve	0.25	$2.3 \times 10^3 < Re_m < 4.2 \times 10^4$	1.34 –1.94

Future work on Mussel

Repeat flume tests for mussel-fouled sleeves under combined wave–current conditions with varied mussel arrangements.

Soft fouling and Deep Learning applications

- **Characterize soft biofouling (Laminaria)** and develop **3D-printed models** for hydrodynamic evaluation at Umass Flume
- **Image-based deep learning** for marine biofouling classification and prediction using Nantes University data (Funded by MassCEC, USA)