An assessment of skin-friction drag over a recently cleaned ship hull under steady cruising via in-situ laser based measurement

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1. The University of Melbourne
2. The University of Southampton
3. Institut Teknologi Sepuluh Nopember
4. Universitas Jember
5. PT Biro Klasifikasi Indonesia
6. PT Dharma Lautan Utama

ICMCF, 24-29 June 2018, Melbourne, Florida, United States

Outline

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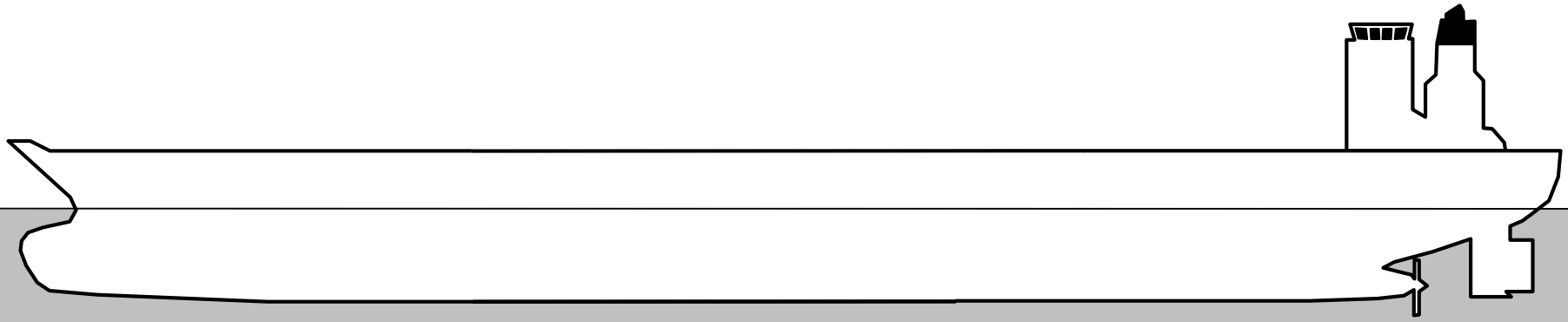

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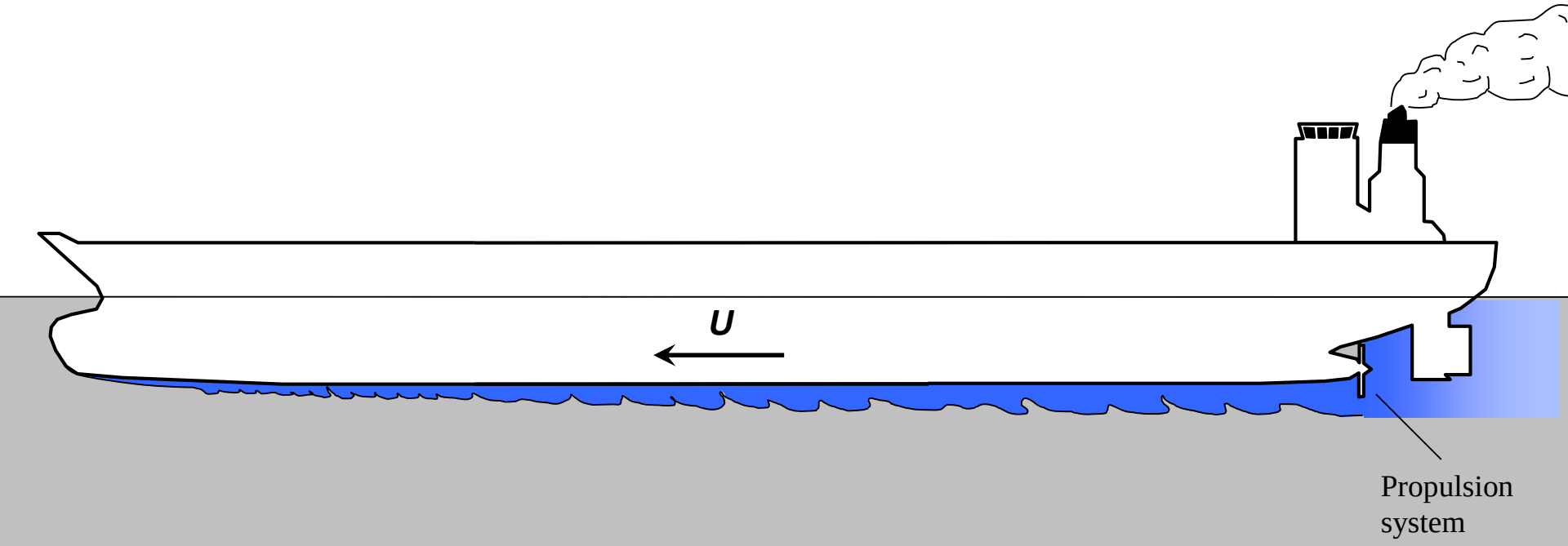

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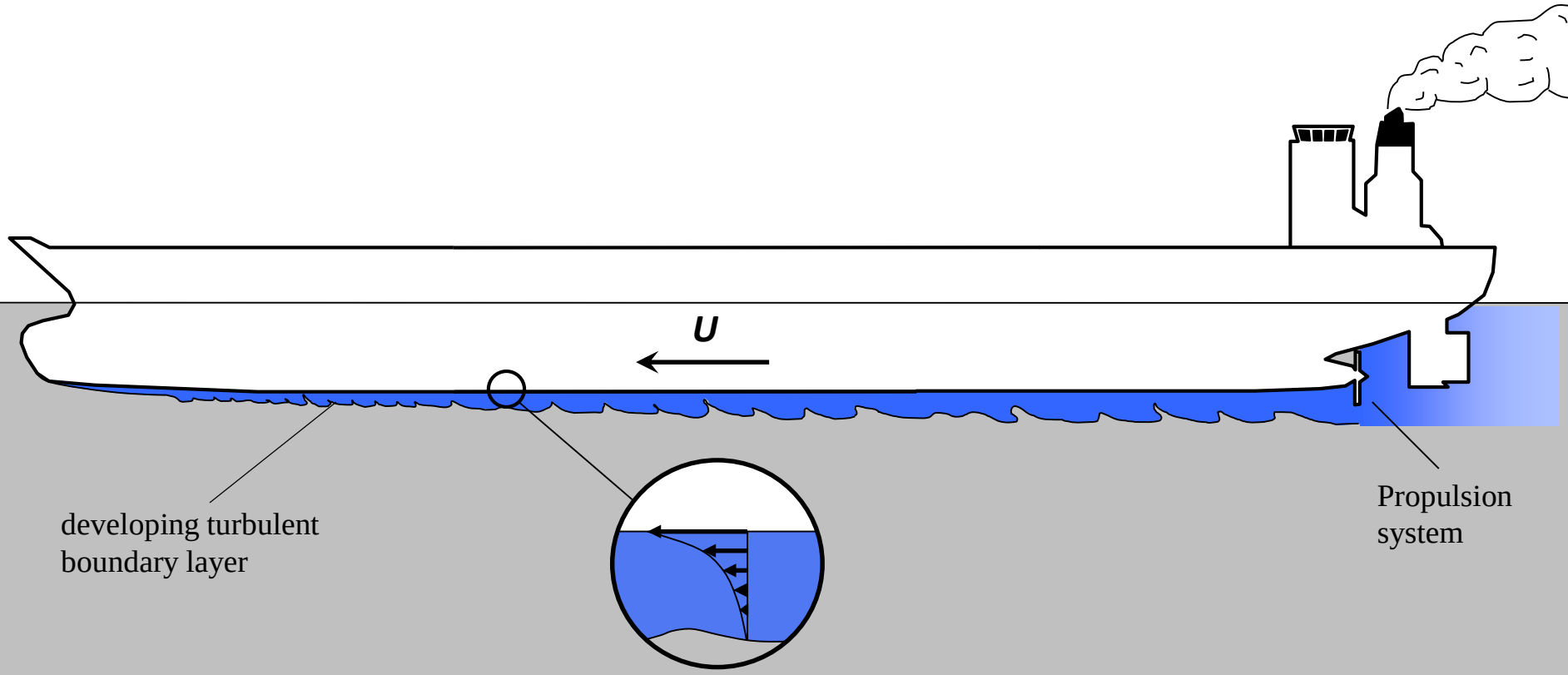

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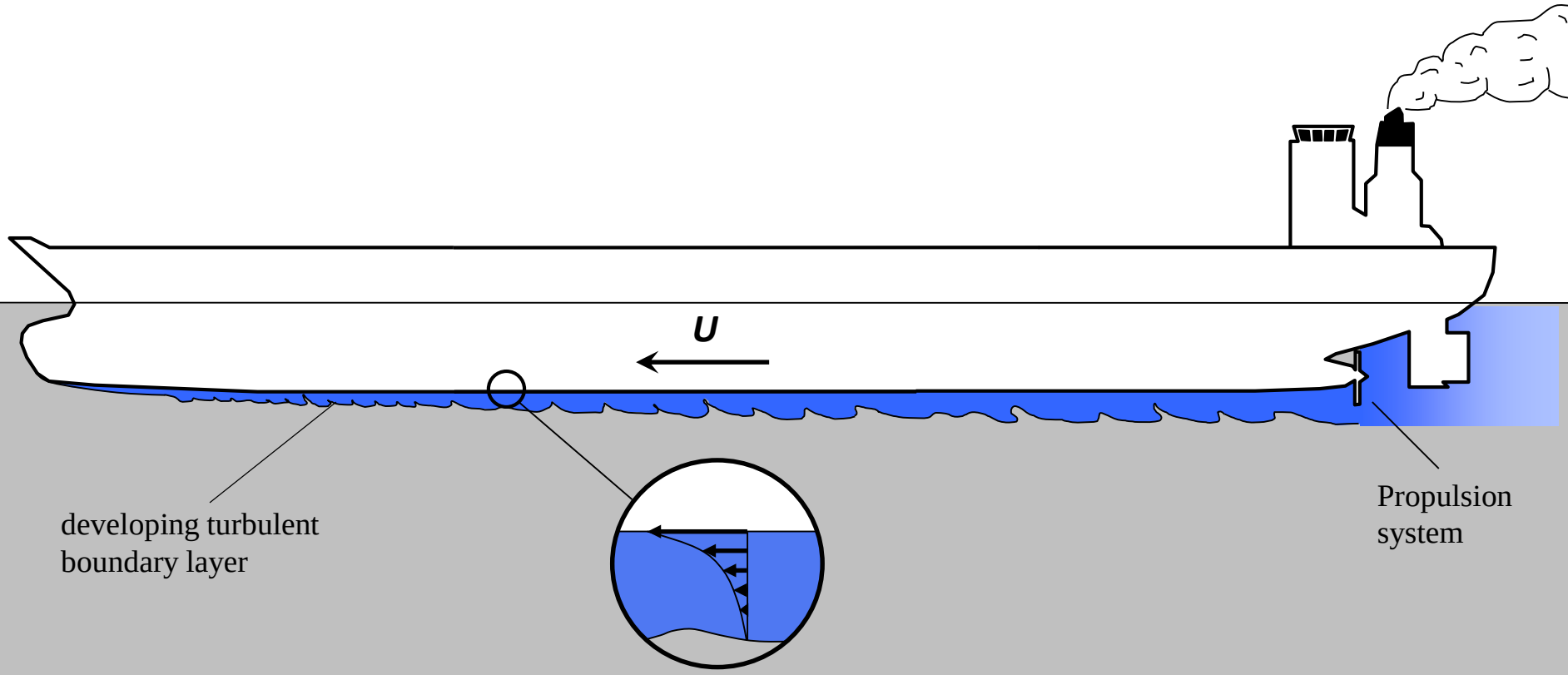
- Up to 80%–90% of the total drag experienced by a large bulk carrier could be due to turbulent skin-friction drag.



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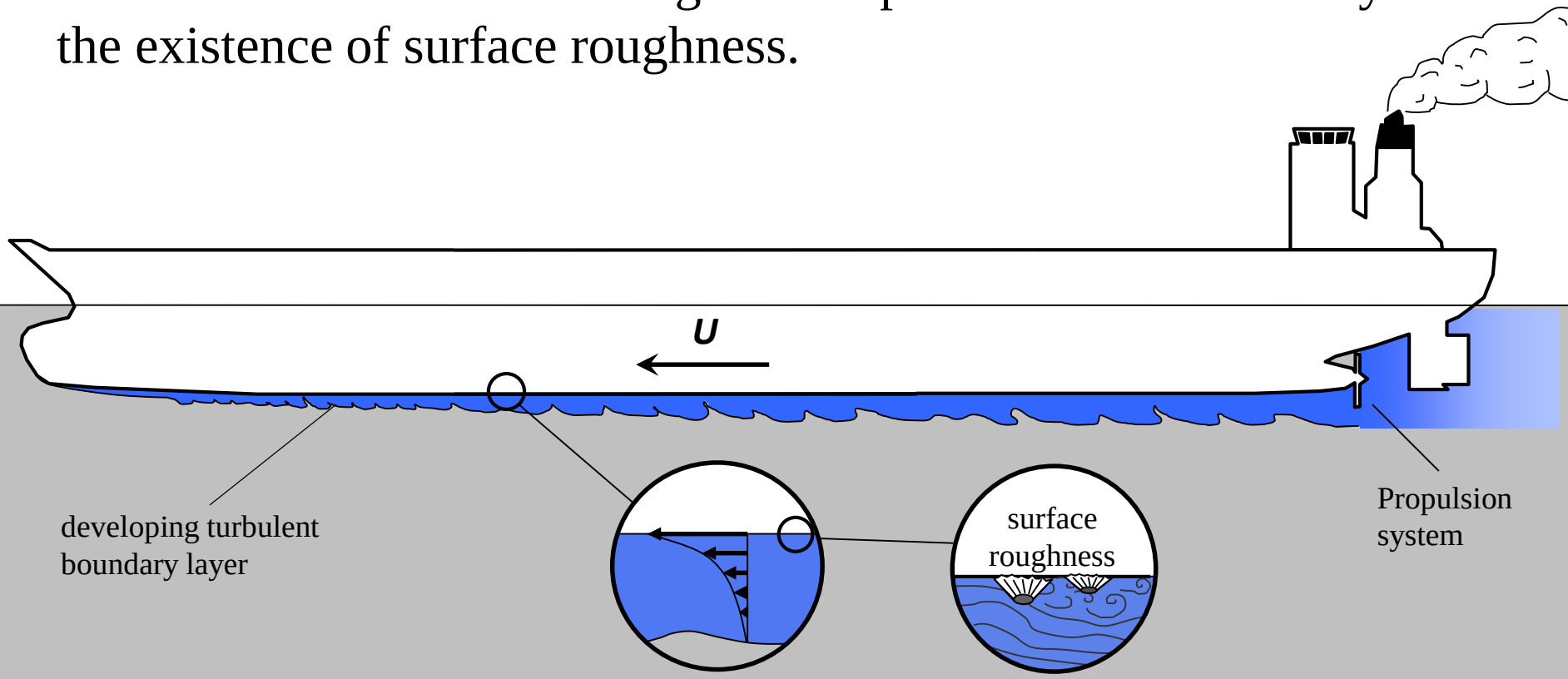
Background

- Up to 80%–90% of the total drag experienced by a large bulk carrier could be due to turbulent skin-friction drag.
- The issue of skin-friction drag on a ship hull is exacerbated by the existence of surface roughness.



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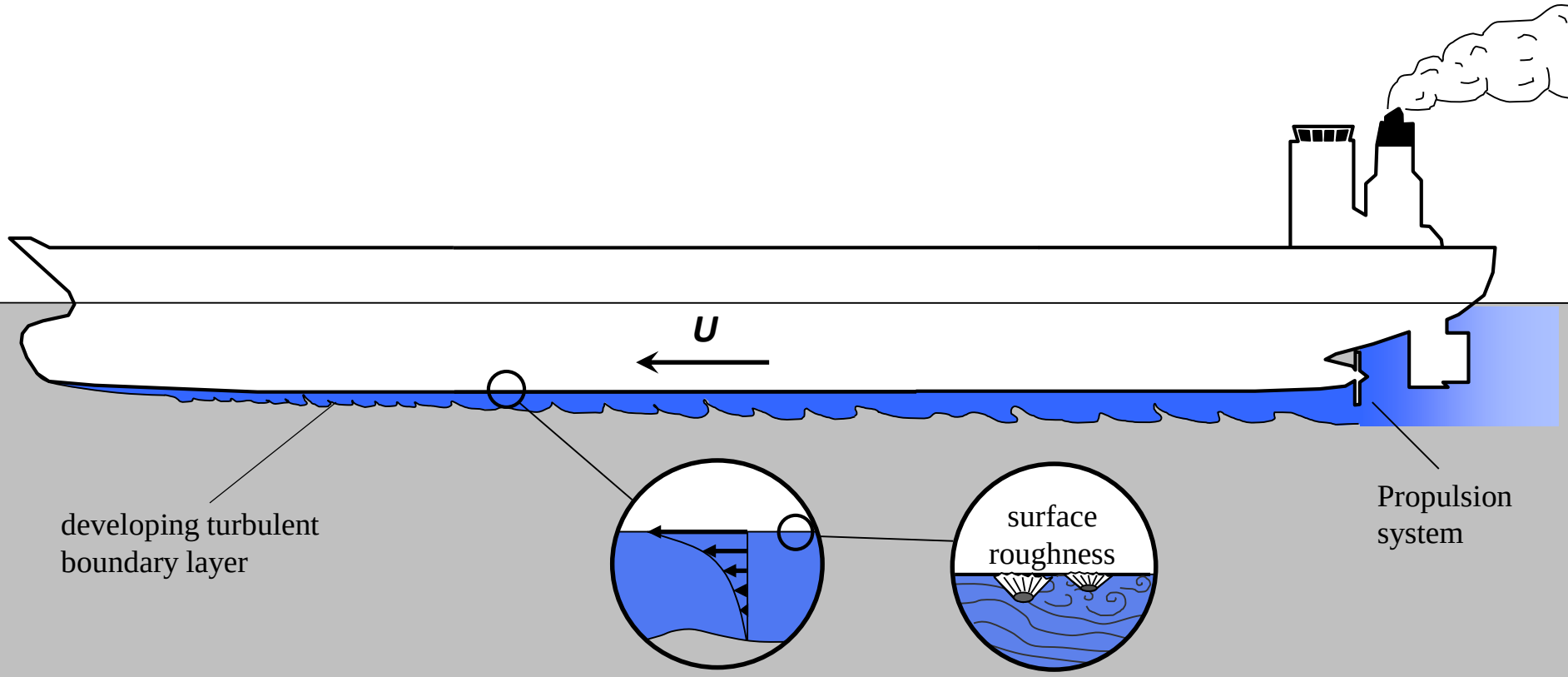
- Surface roughness on a ship hull is generally associated with biofouling or hull imperfections.



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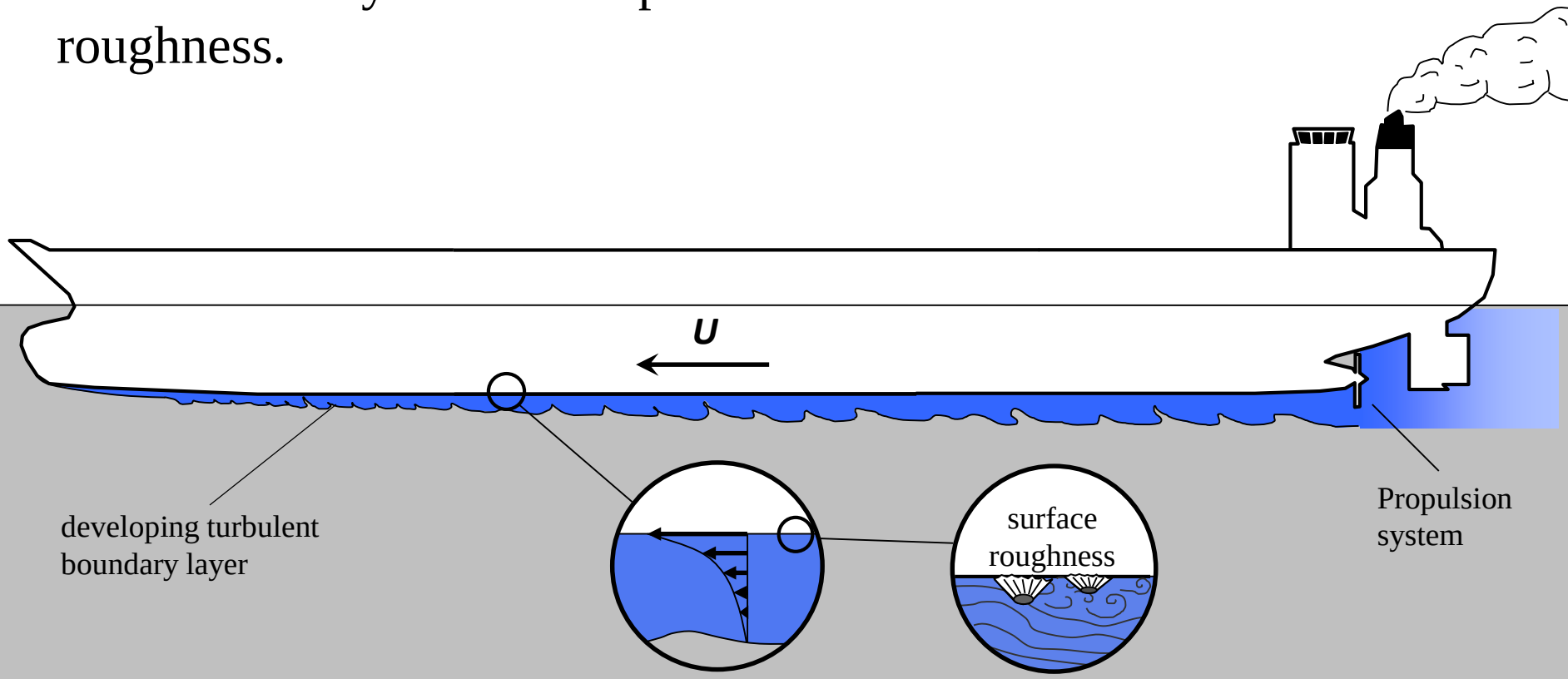
- Surface roughness on a ship hull is generally associated with biofouling or hull imperfections.
- Even a recently cleaned ship hull can still exhibit surface roughness.



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Determining drag penalty via lab experiment

Determining drag penalty via lab experiment

It is a well established method that involves wind or water tunnel/channel.

- Prandtl & Schlichting (1955) Tech. Rep. Navy, 258
- Granville (1958) Tech. Rep. Navy, 1024
- Grigson (1992) J. Ship. Res., 36:2
- ITTC (2008)
- Flack & Schultz (2010). J. Fluids, Eng., 132(041203).
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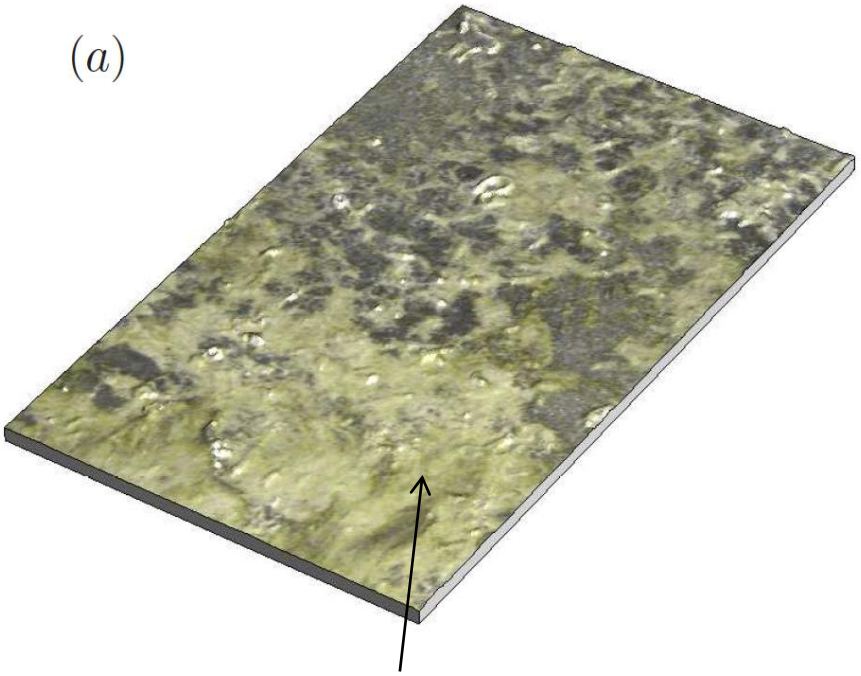
Determining drag penalty via lab experiment

Photograph

(a)

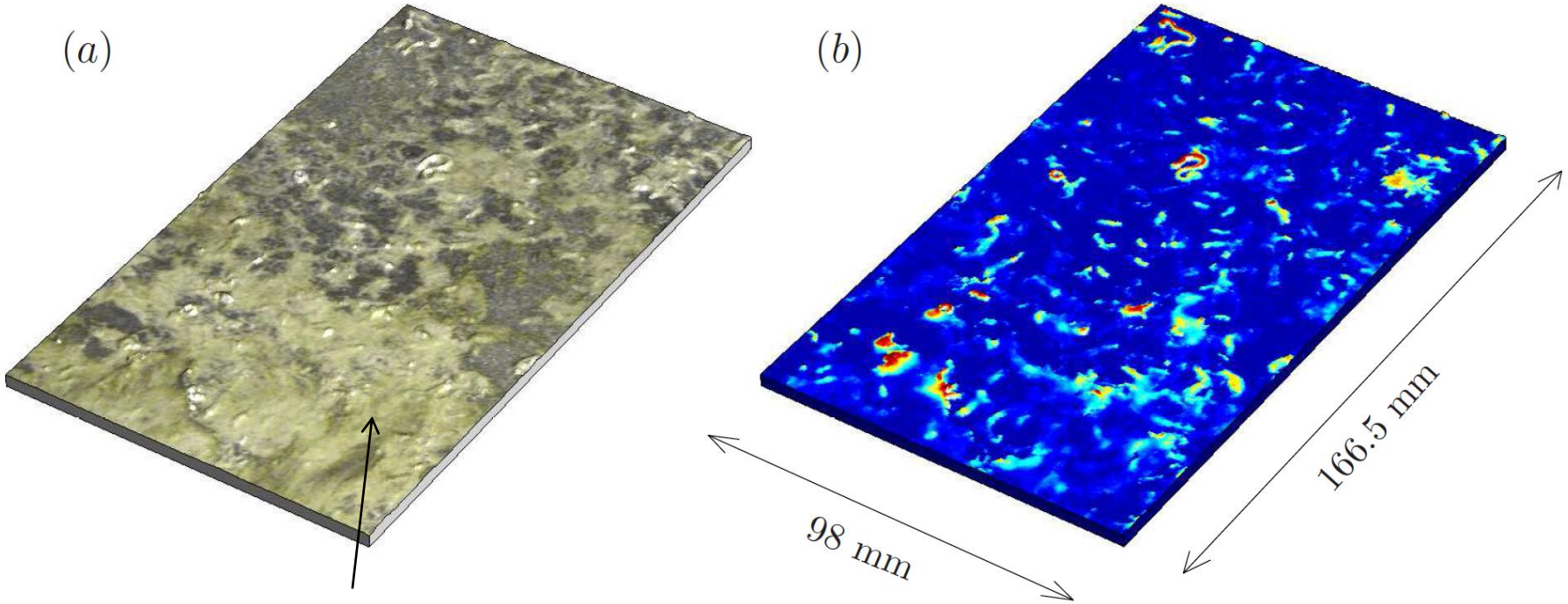


Biofouling on a steel coupon.

Determining drag penalty via lab experiment

Photograph

Laser scan



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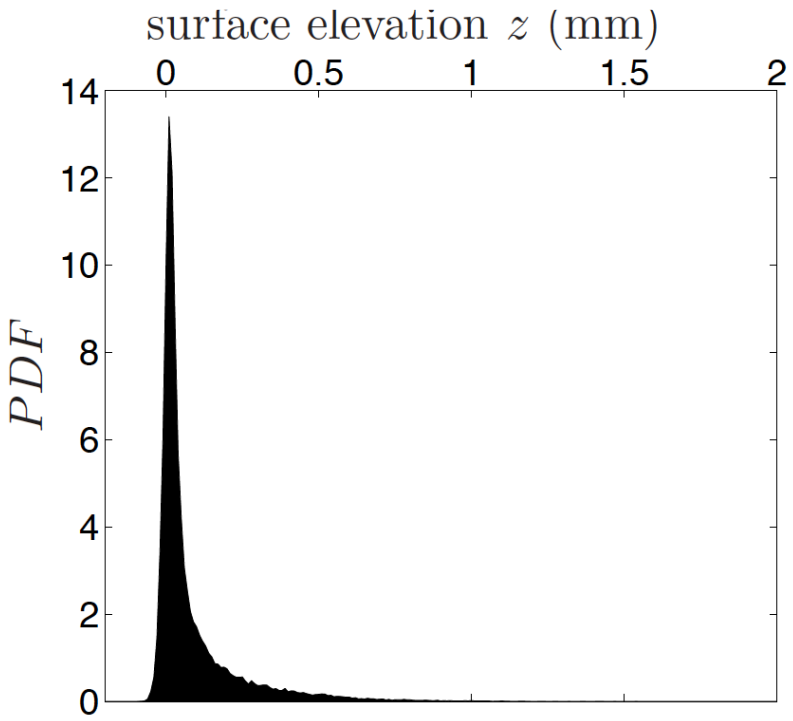
Roughness parameter	value	units	Formula
			—
k_a	0.094	mm	$\overline{\lvert z' \rvert}$
k_{rms}	0.144	mm	$\sqrt{\overline{z'^2}}$
k_p	1.630	mm	$\max z' - \min z'$
k_{sk}	2.963	–	$\overline{z'^3}/k_{rms}^3$
k_{ku}	14.180	–	$\overline{z'^4}/k_{rms}^4$
ES_x	0.134^a	–	$\overline{\left\lvert \frac{dz'}{dx} \right\rvert}$



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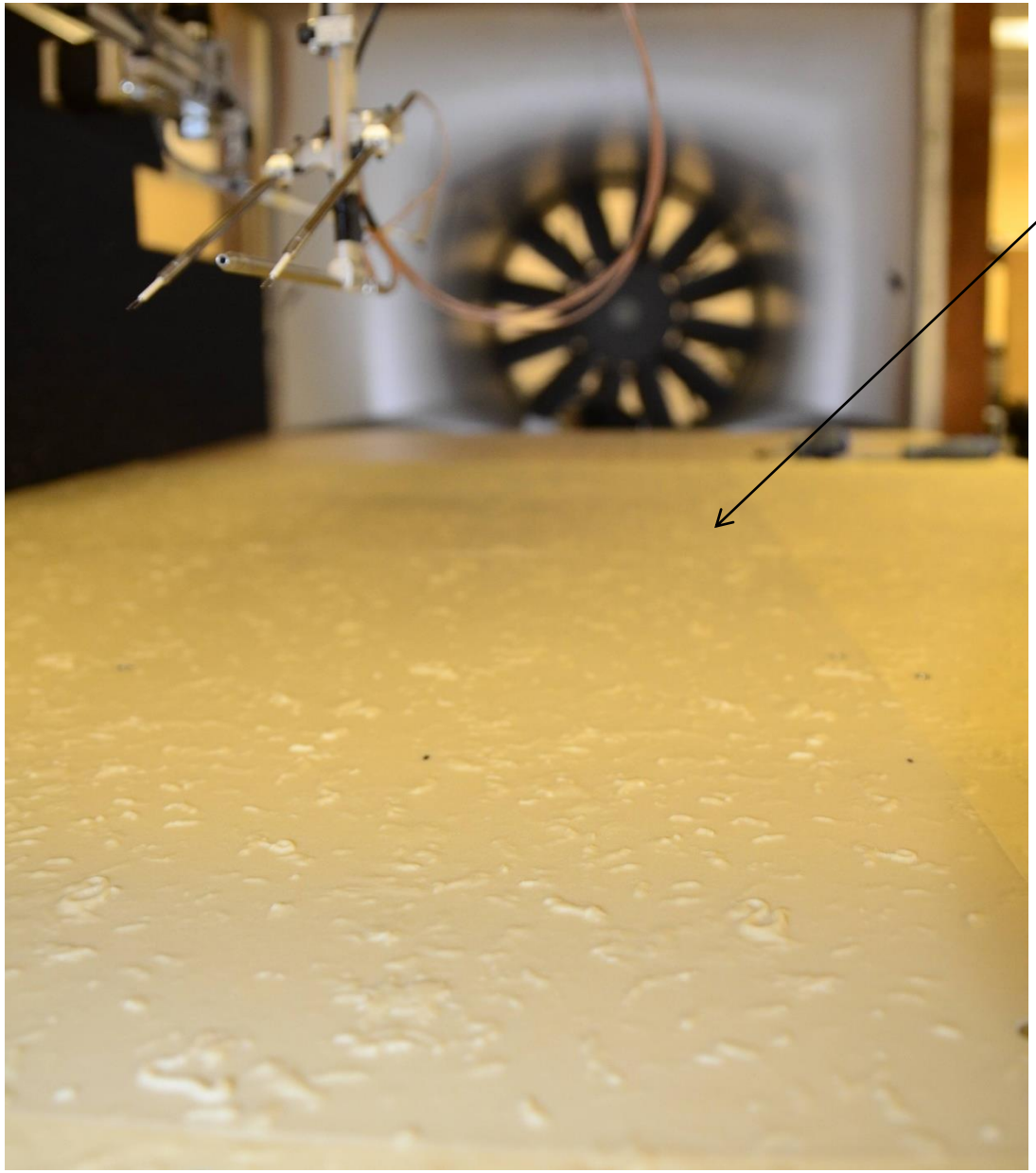
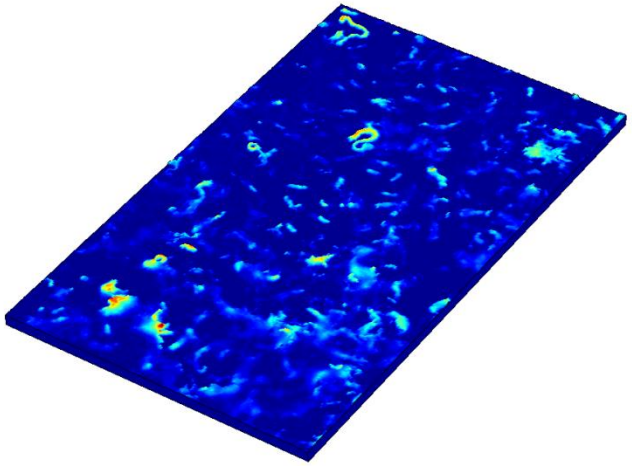


Replicated surface via CNC cutting and Moulding-Casting.



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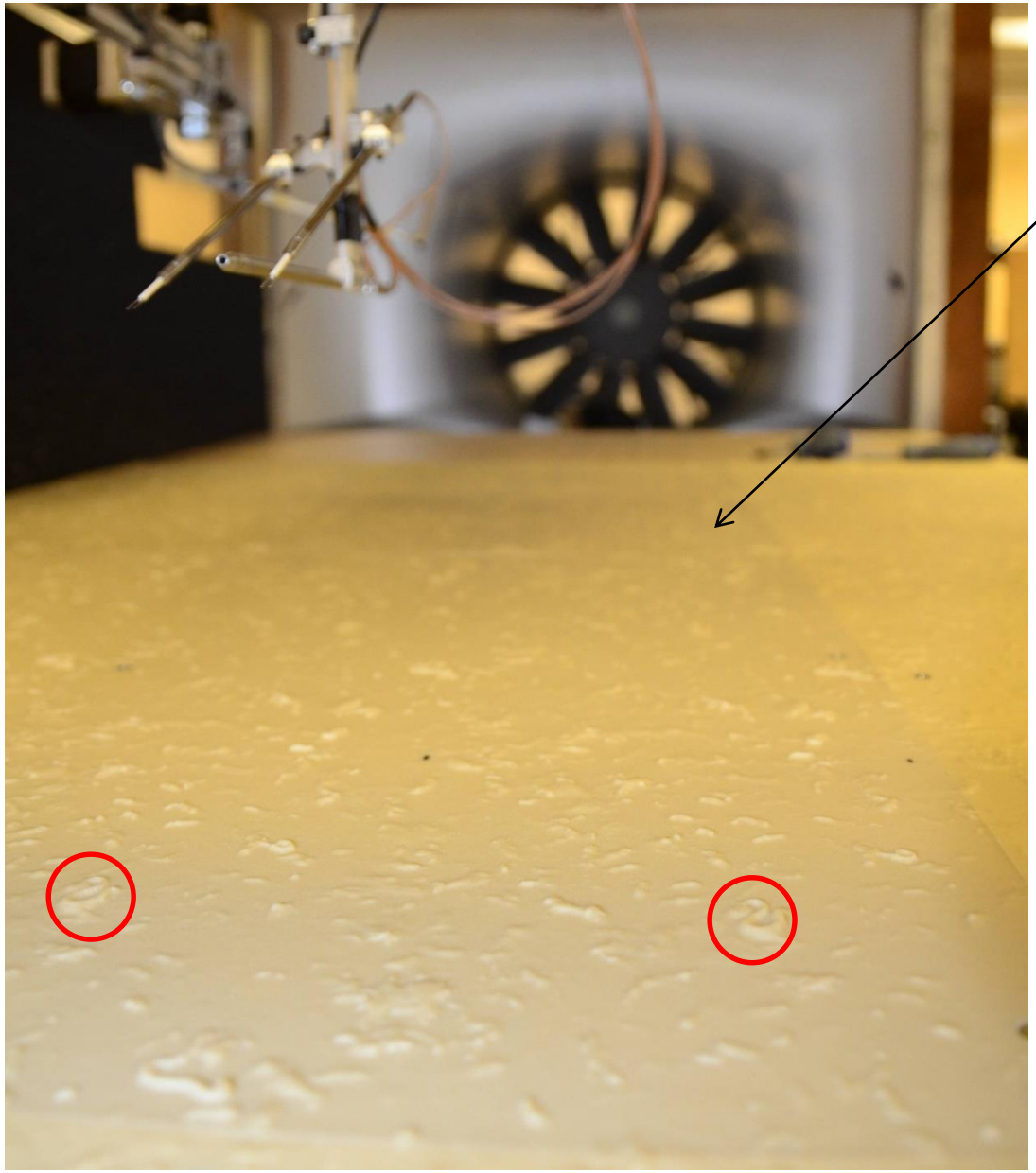

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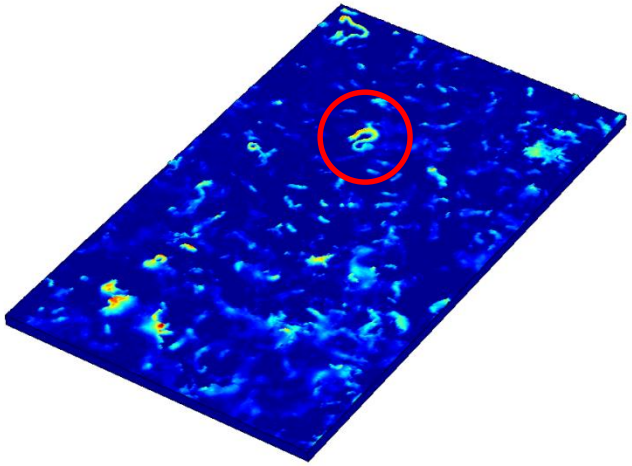

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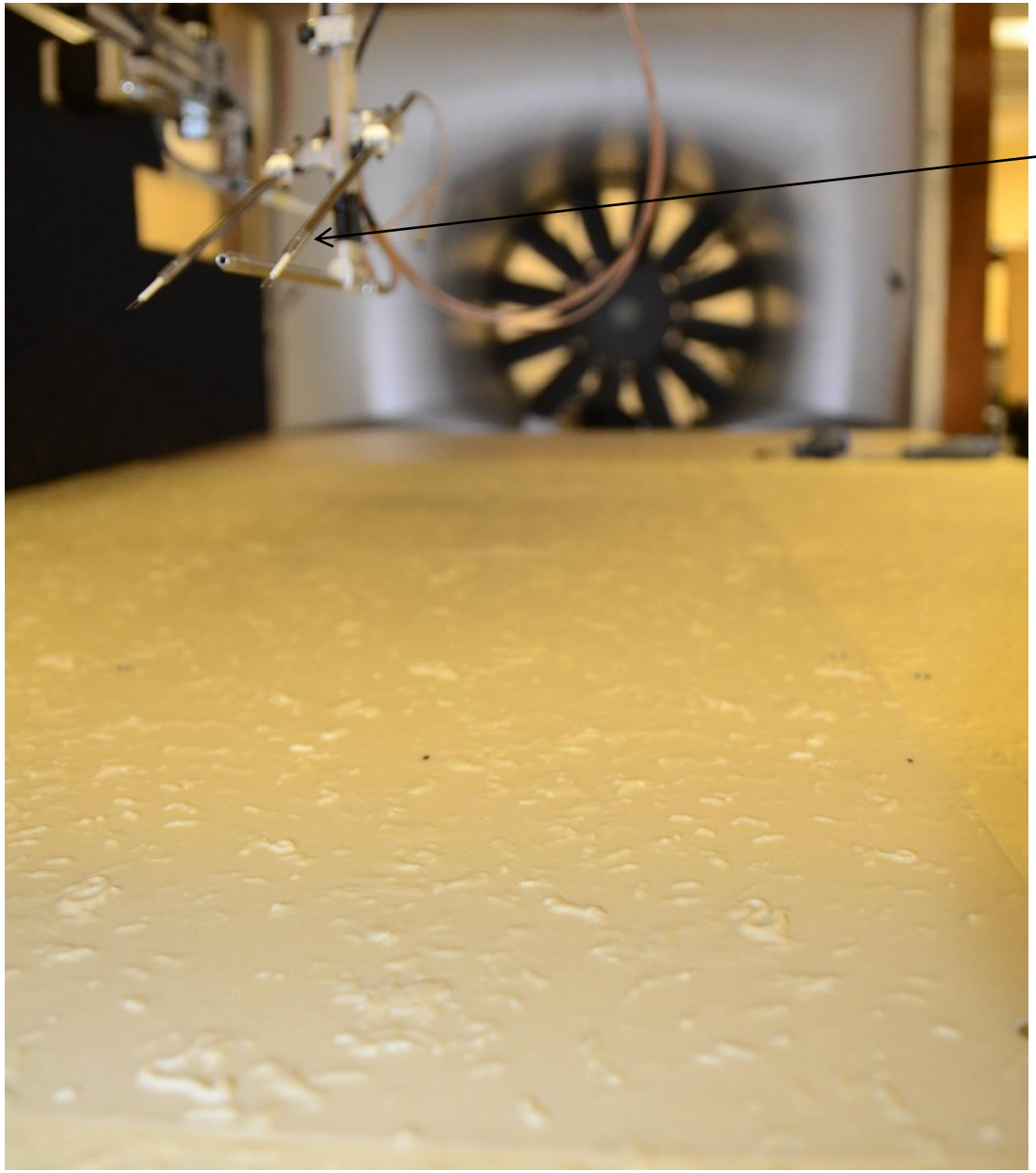
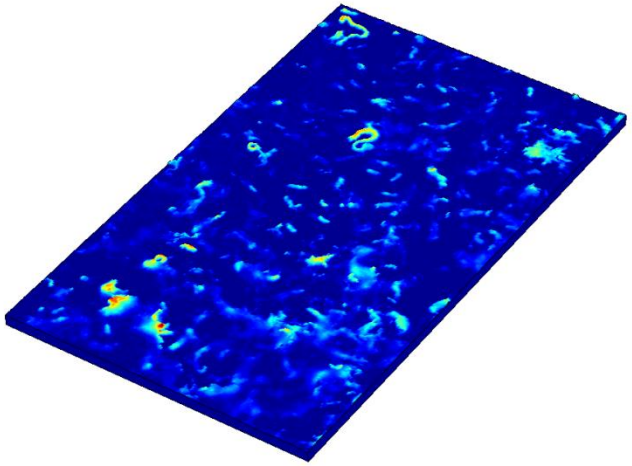


Mean velocity profile measurement via hot-wire Anemometer.



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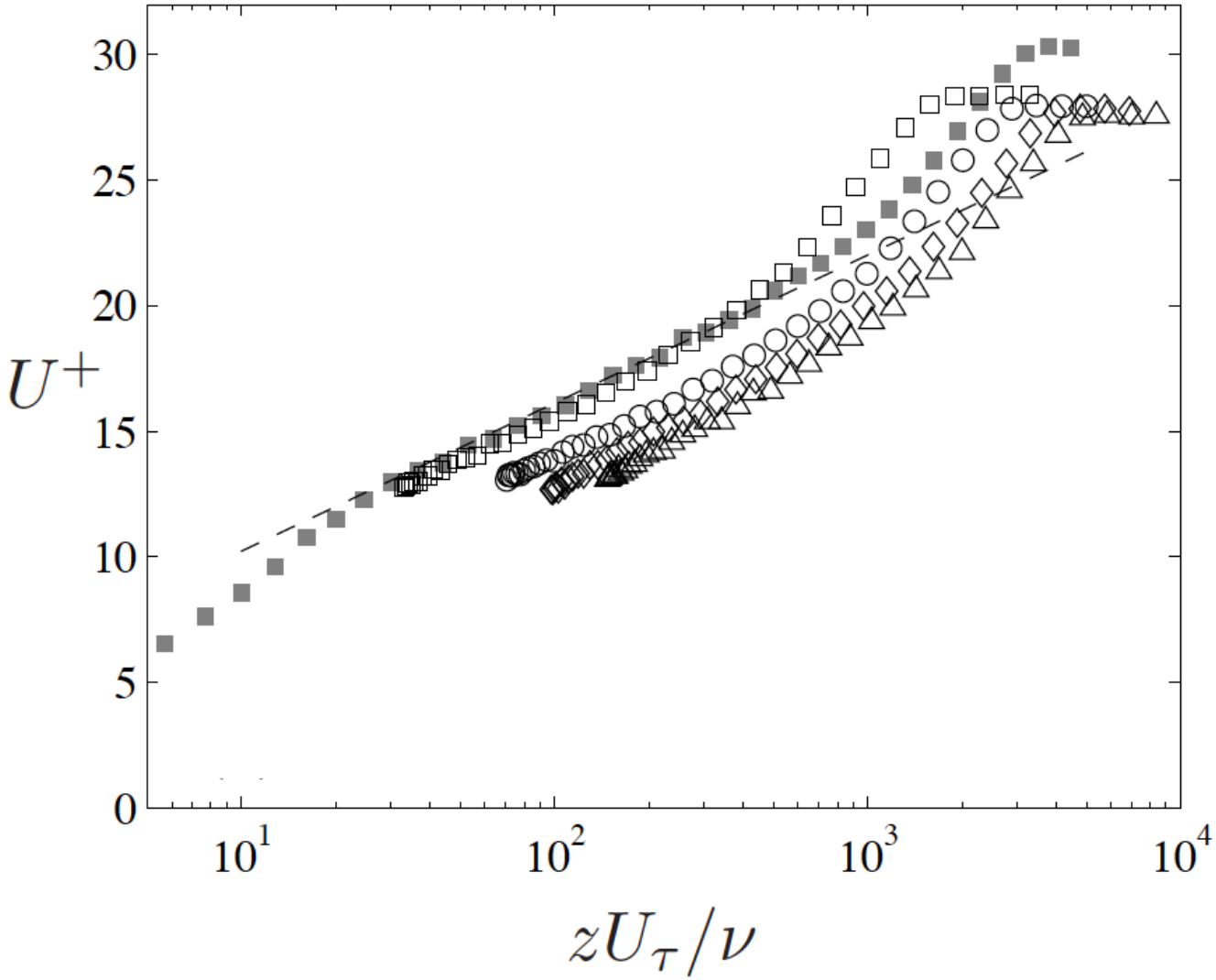
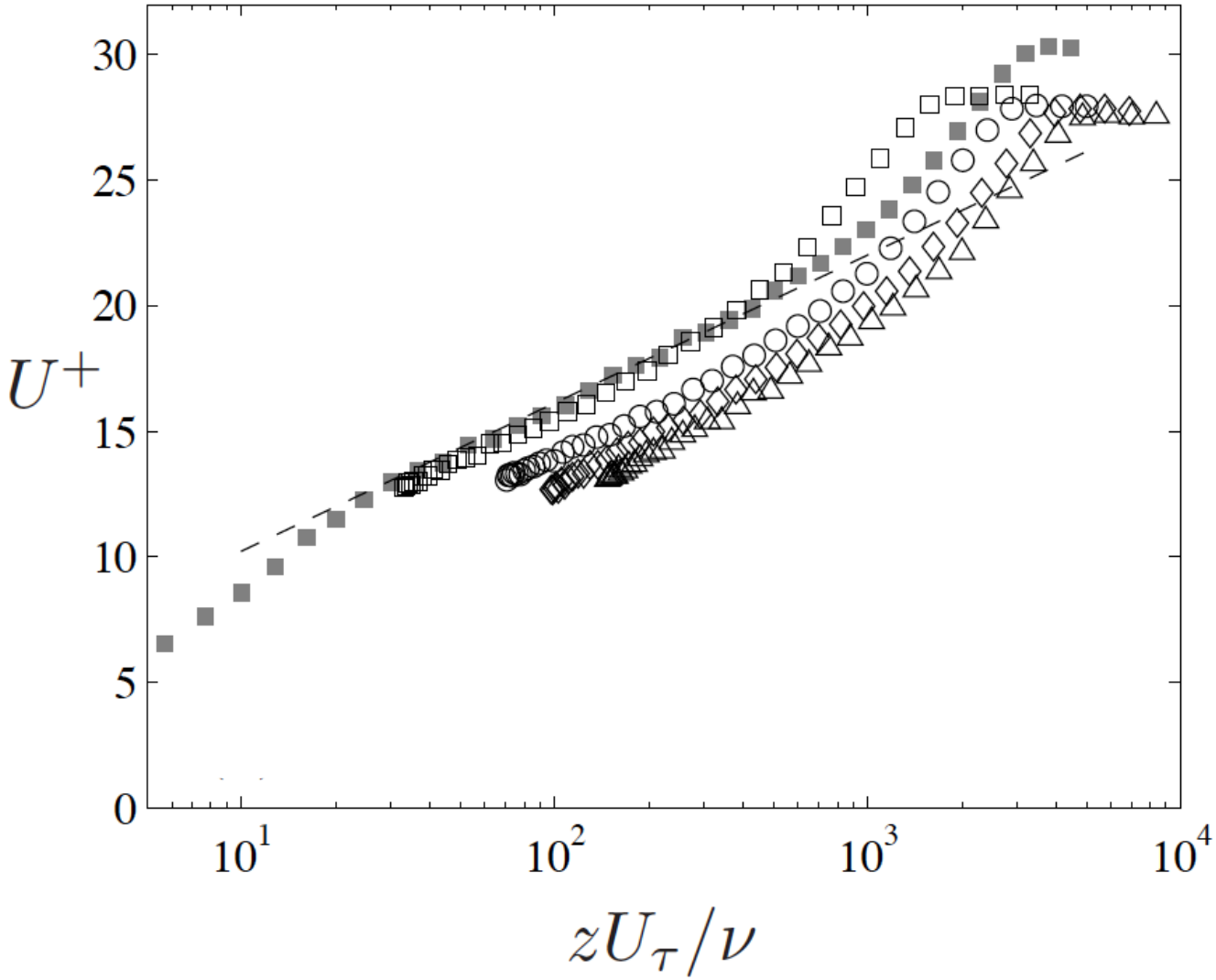


Determining drag penalty via lab experiment

Mean Velocity profile to obtain skin friction velocity and Hama roughness function



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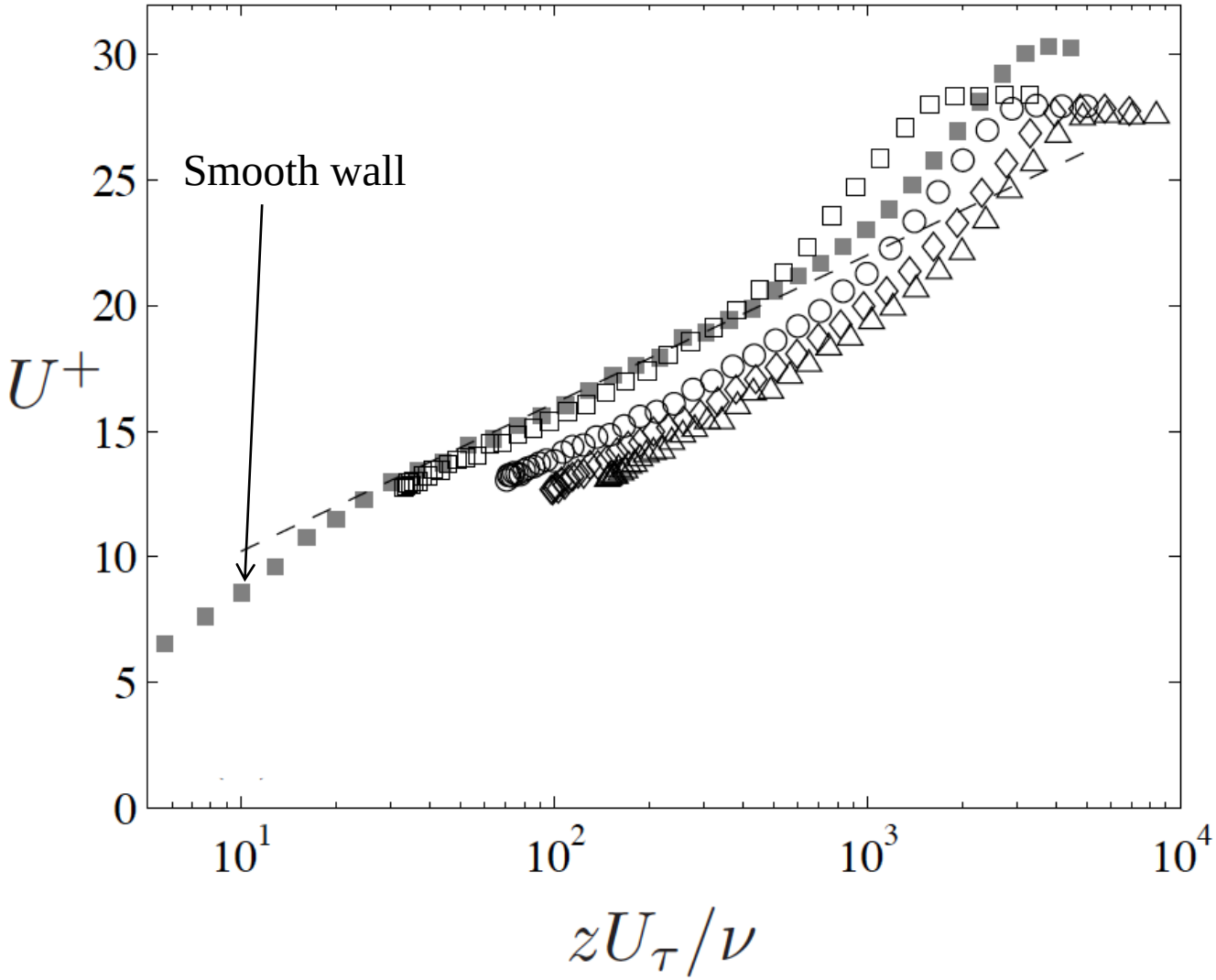

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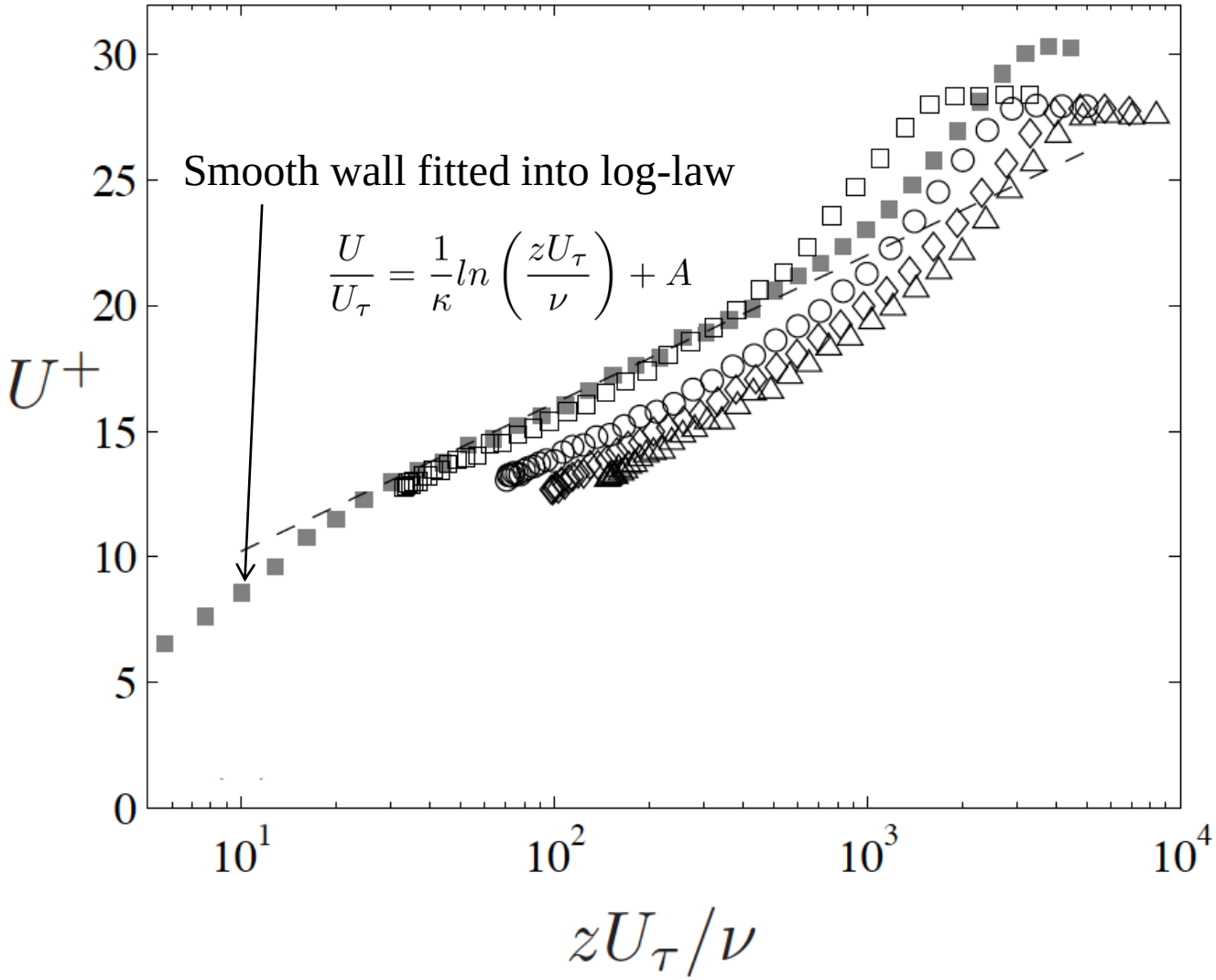

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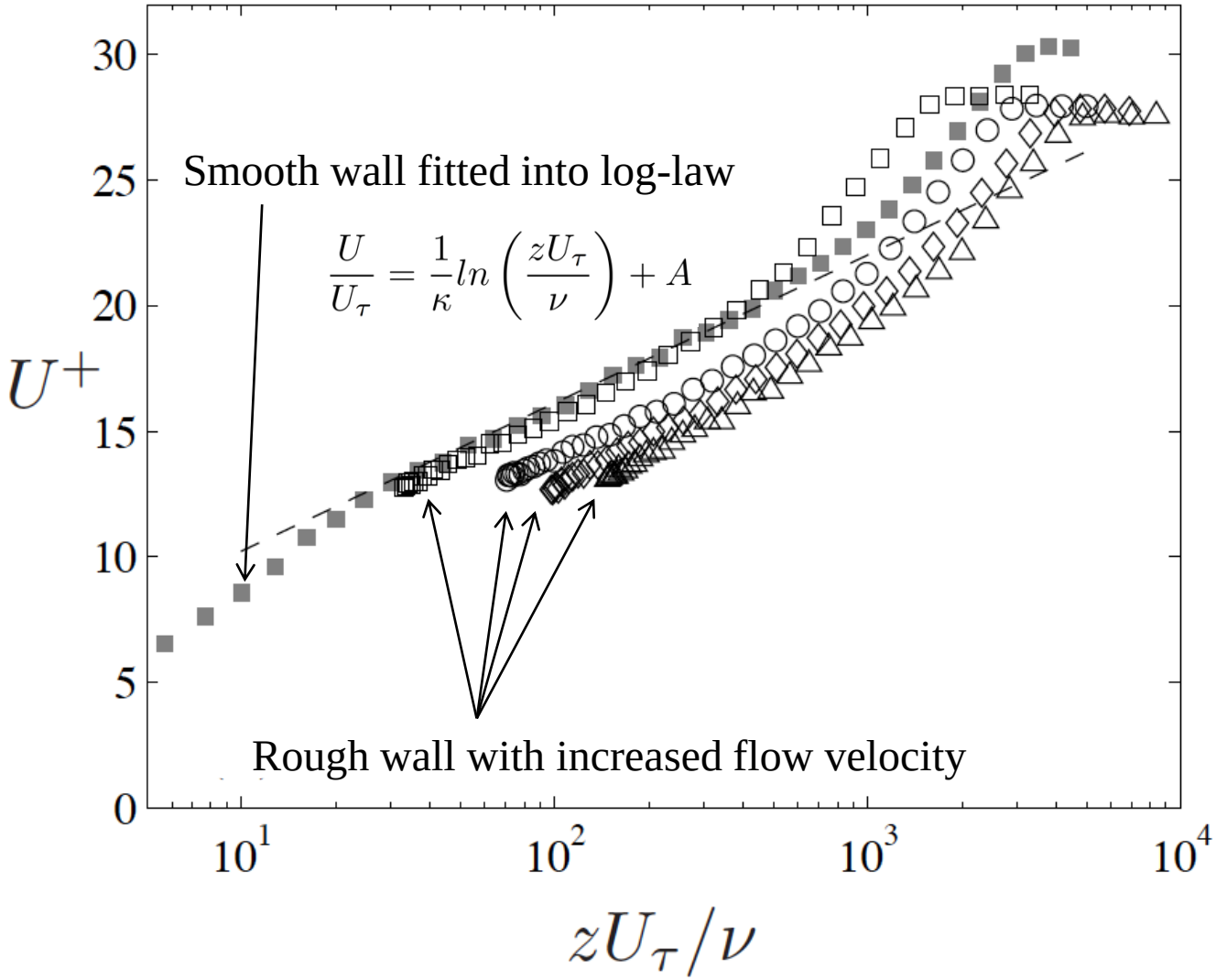

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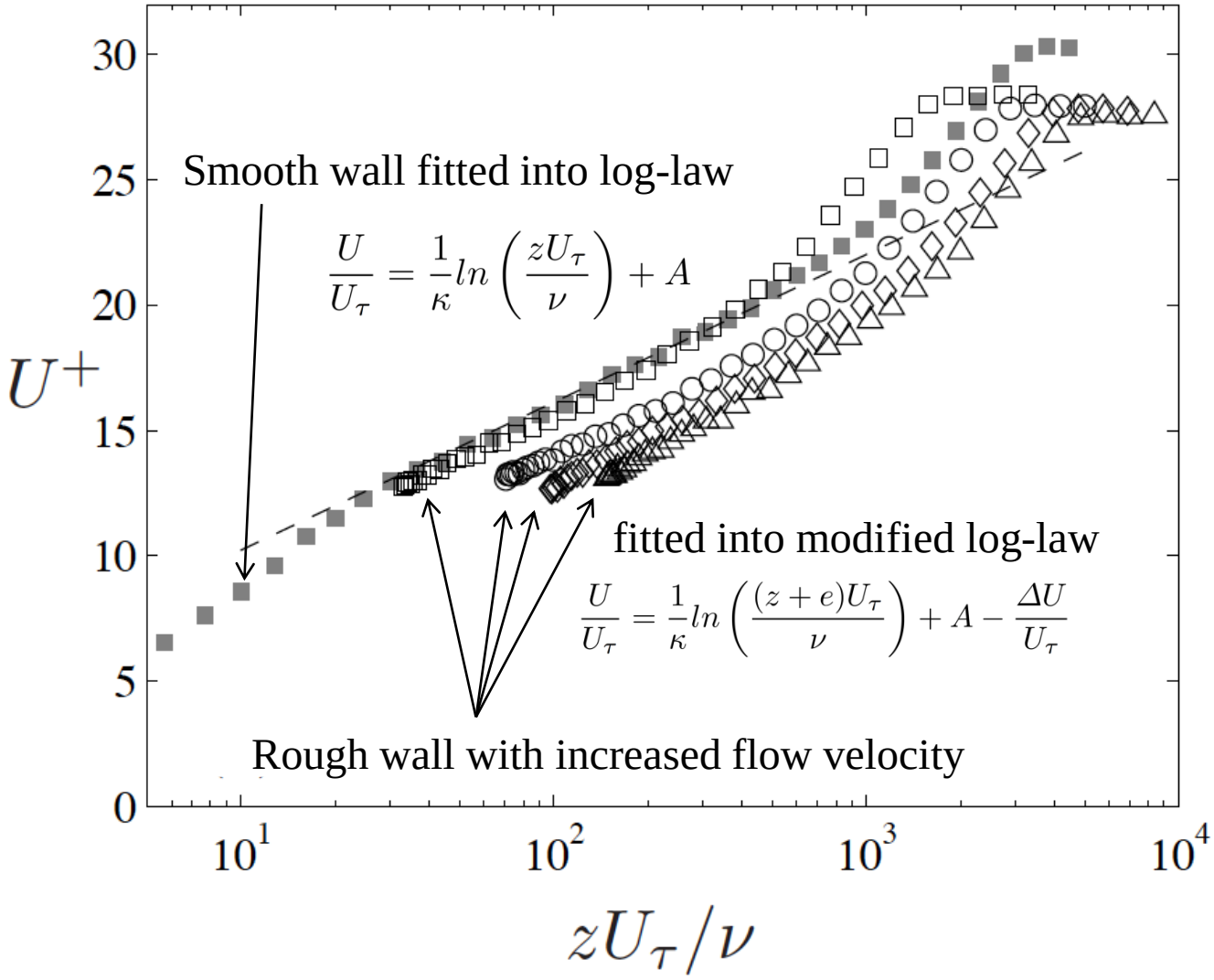

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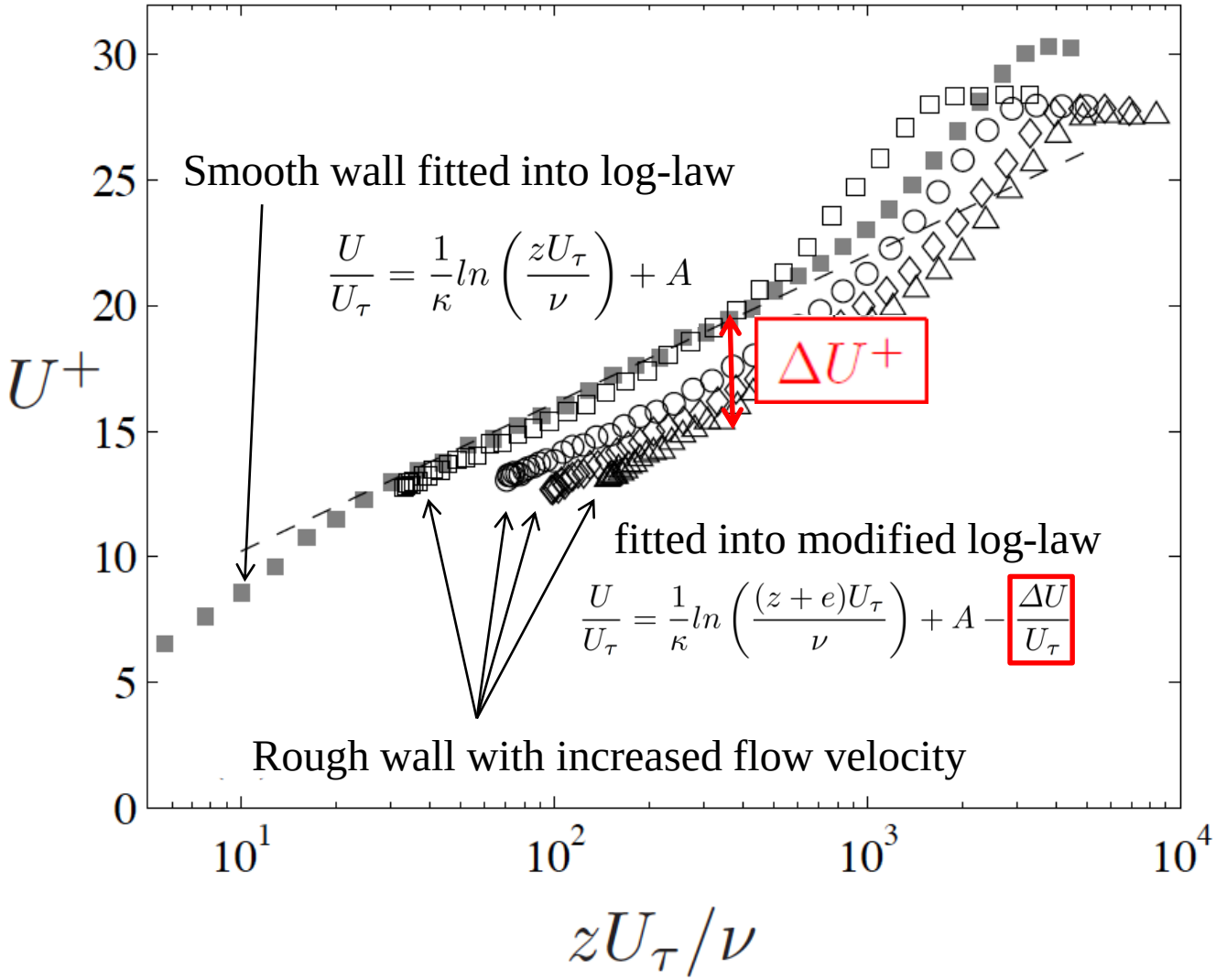

Determining drag penalty via lab experiment

Next step is to obtain sand-grain equivalent roughness height k_s

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k_s is a measure of the rough surface effect on turbulent boundary layer.

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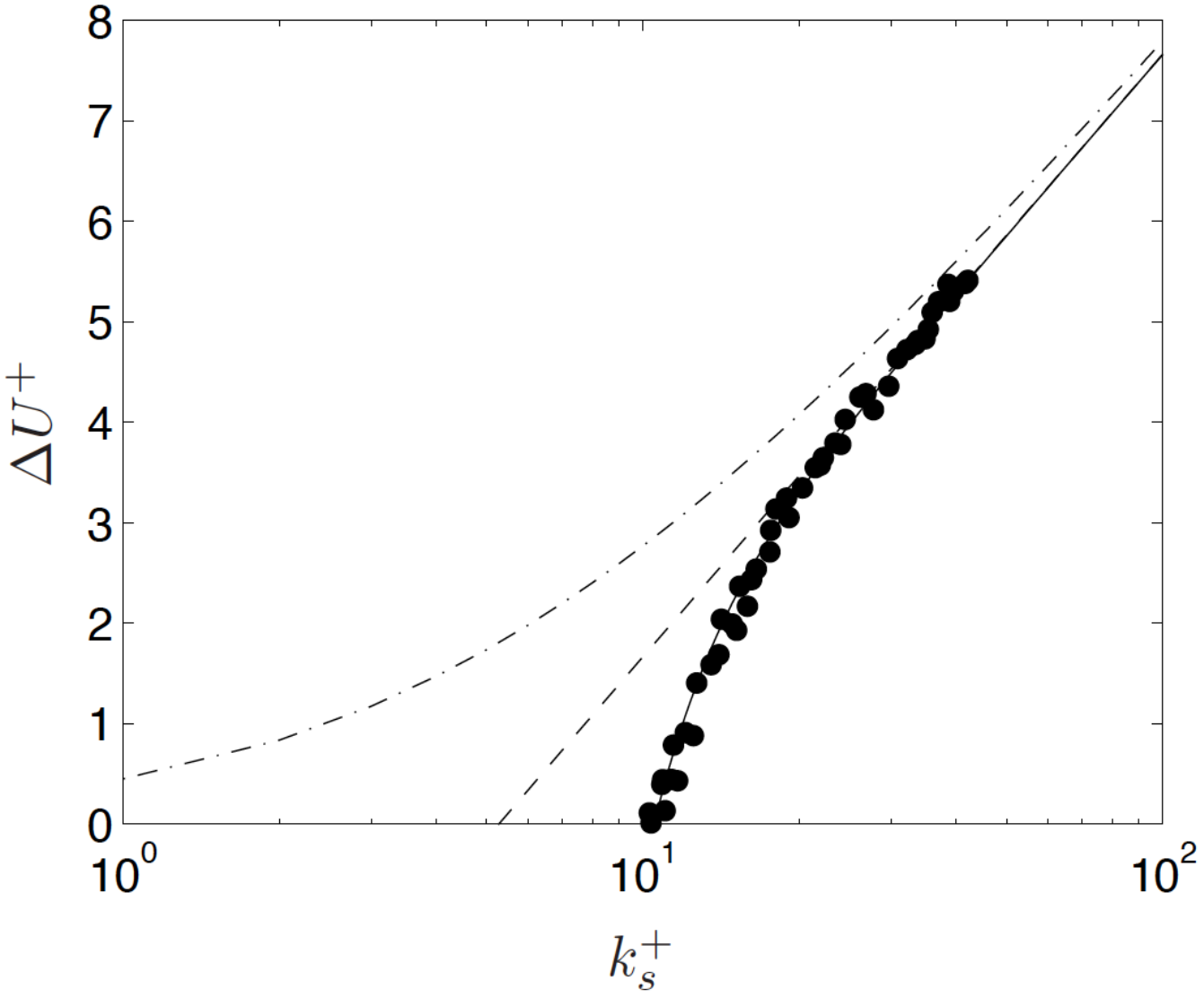
k_s is a measure of the rough surface effect on turbulent boundary layer.

k_s unit is in meter and cannot be measured directly, such as using profilometer.

Determining drag penalty via lab experiment

Profile to obtain sand-grain equivalent roughness height



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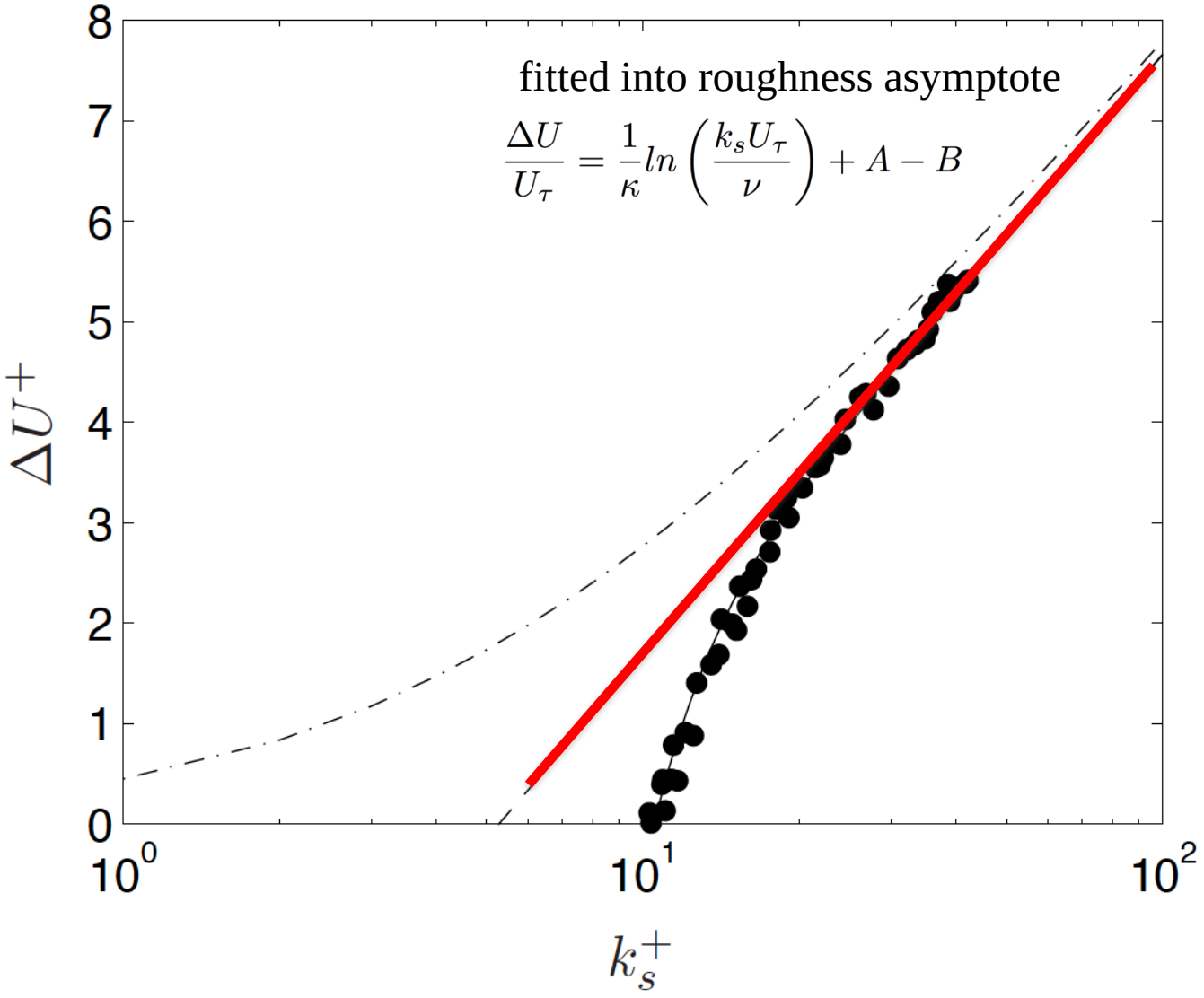

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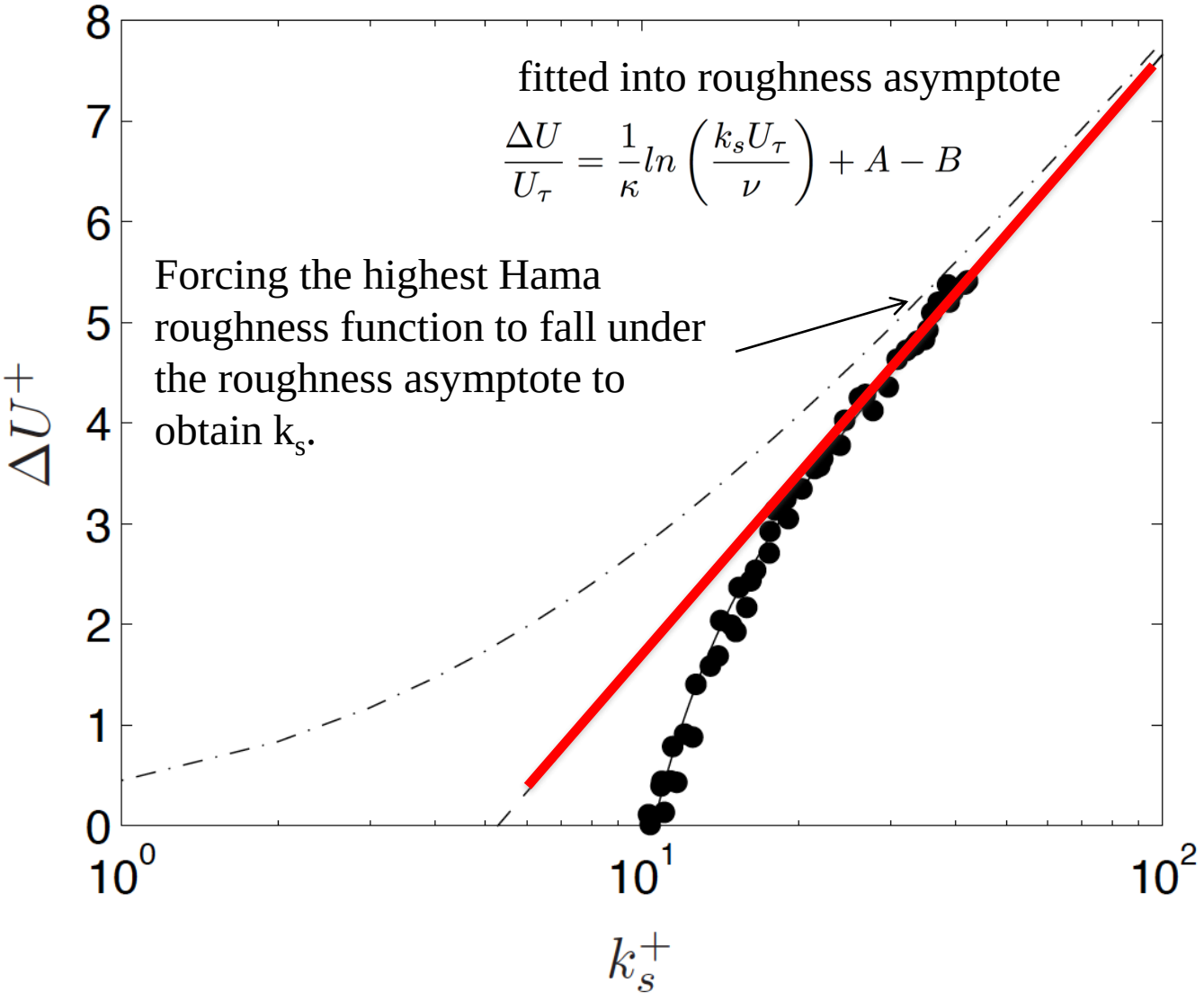

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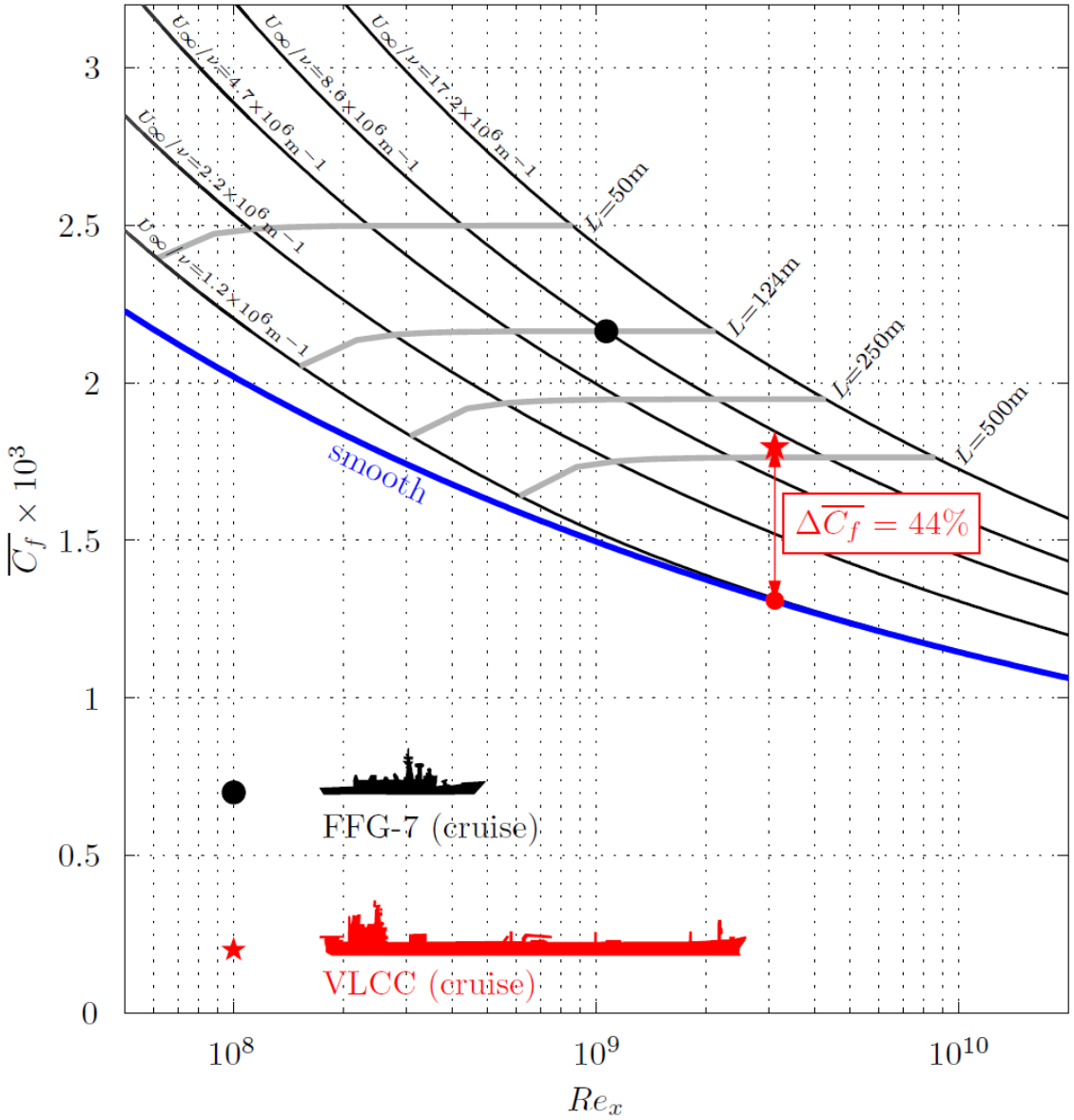
Estimating full-scale ship drag via mean momentum integral



Determining drag penalty via lab experiment

Issue with lab experiment:

1. Very expensive in term of facility and time.

2. Difficult to obtain sand grain equivalent roughness.

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1. Bypass the costly laboratory experiment.

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2. Measure the drag penalty directly.

Direct ship board experiment

Previous works:

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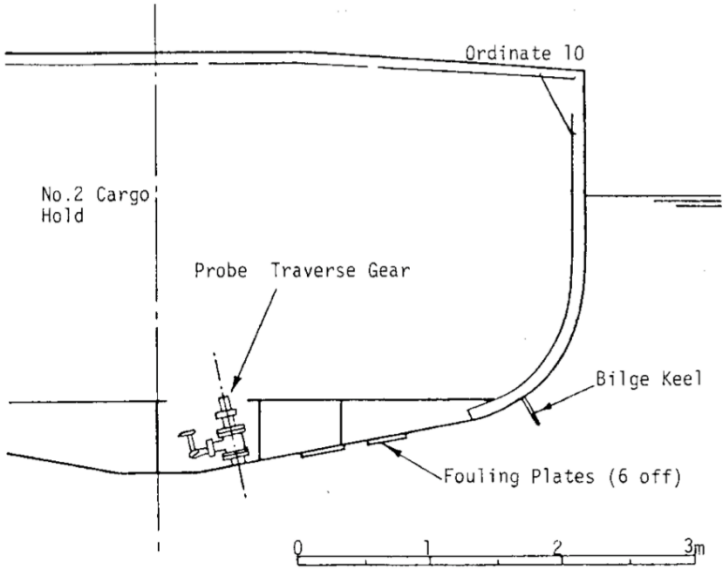
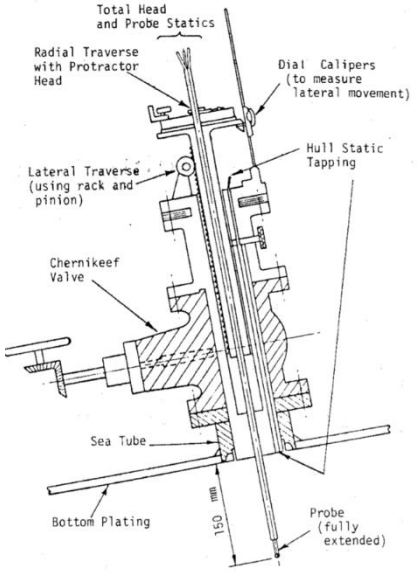
Generally it involves pitot tube that goes through ship hull.





Denny, M.E., 1951. BSRA resistance experiments on the 'Lucy aAhton' : Part 1. Full scale measurements. *R. Inst. Naval. Architects. Trans. 93, 40–57.*

Smith, S.L., 1955. BSRA resistance experiments on the 'Lucy Ashton' : Part 4. Miscellaneous investigations and general appraisal. *R. Inst. Naval. Architects. Trans. 97, 525–548.*

Lewthwaite, J.C., Molland, A.F., Thomas, K.W., 1984. An investigation into the variation of ship skin frictional resistance with fouling. *R. Inst. Naval. Architects. Trans. 127, 269–284*

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Issues with pitot tube measurement:

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Issues with pitot tube measurement:

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3. Prone to blocking from marine objects.
4. Requires full hull penetration.

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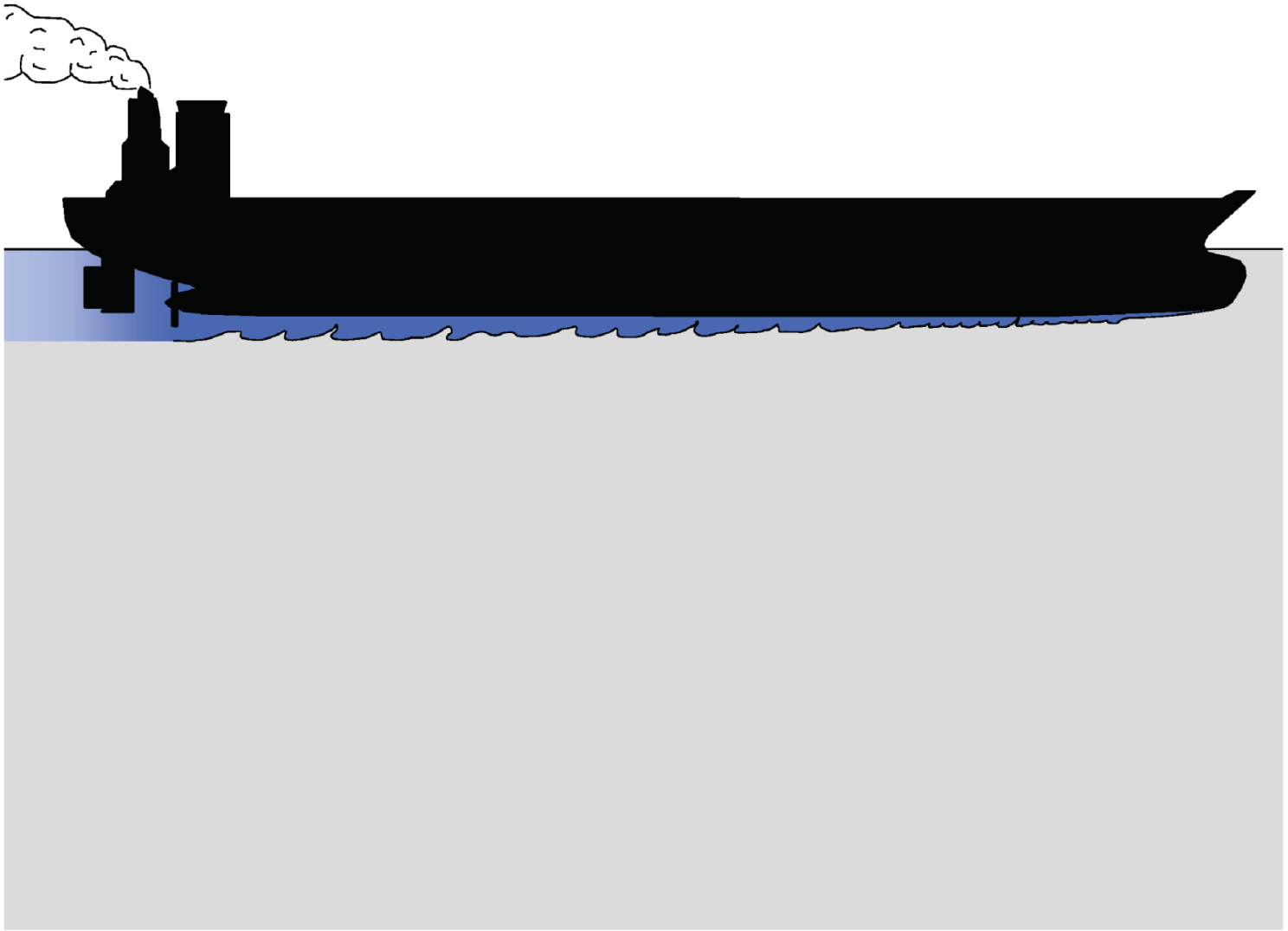

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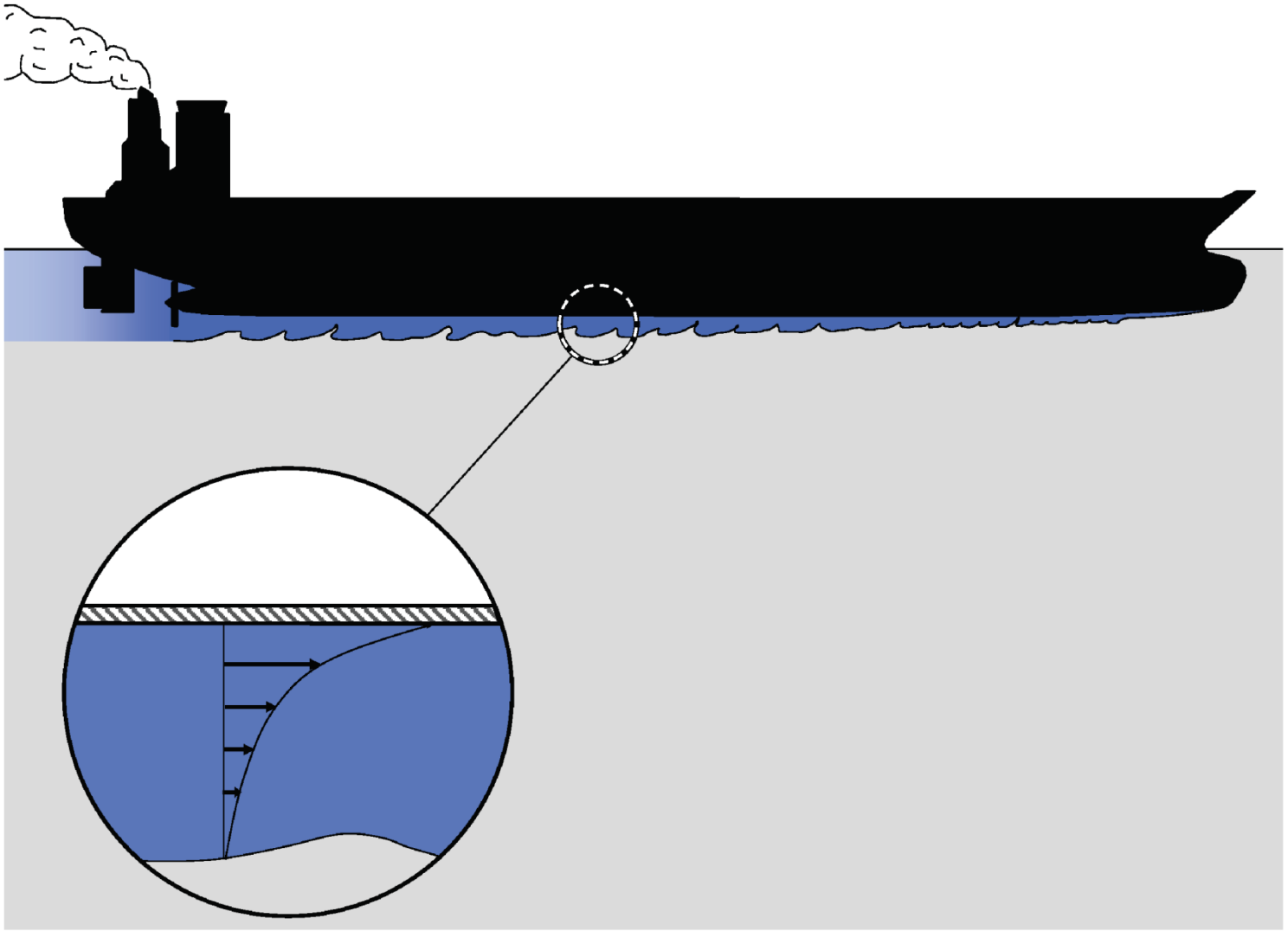

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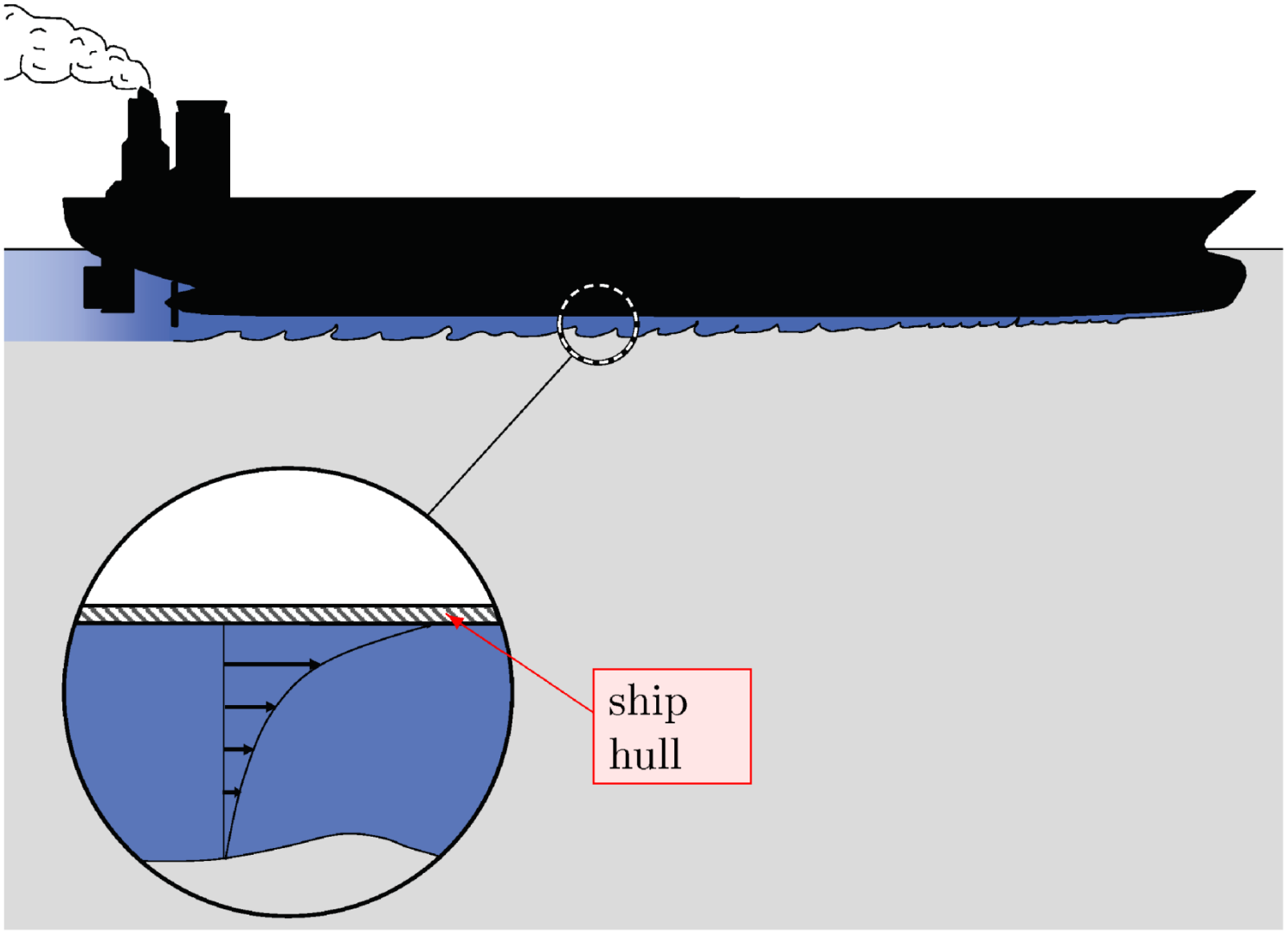

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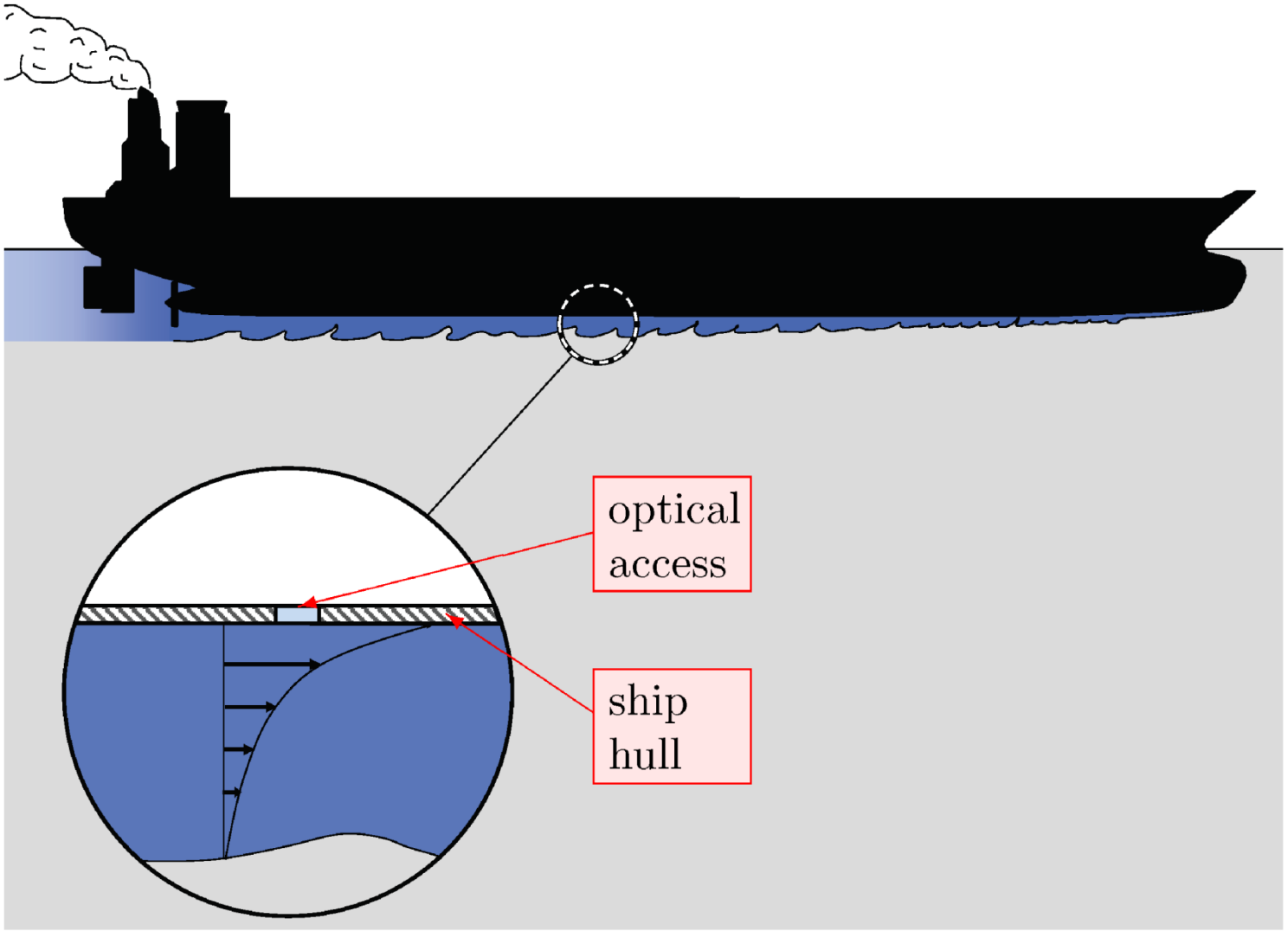

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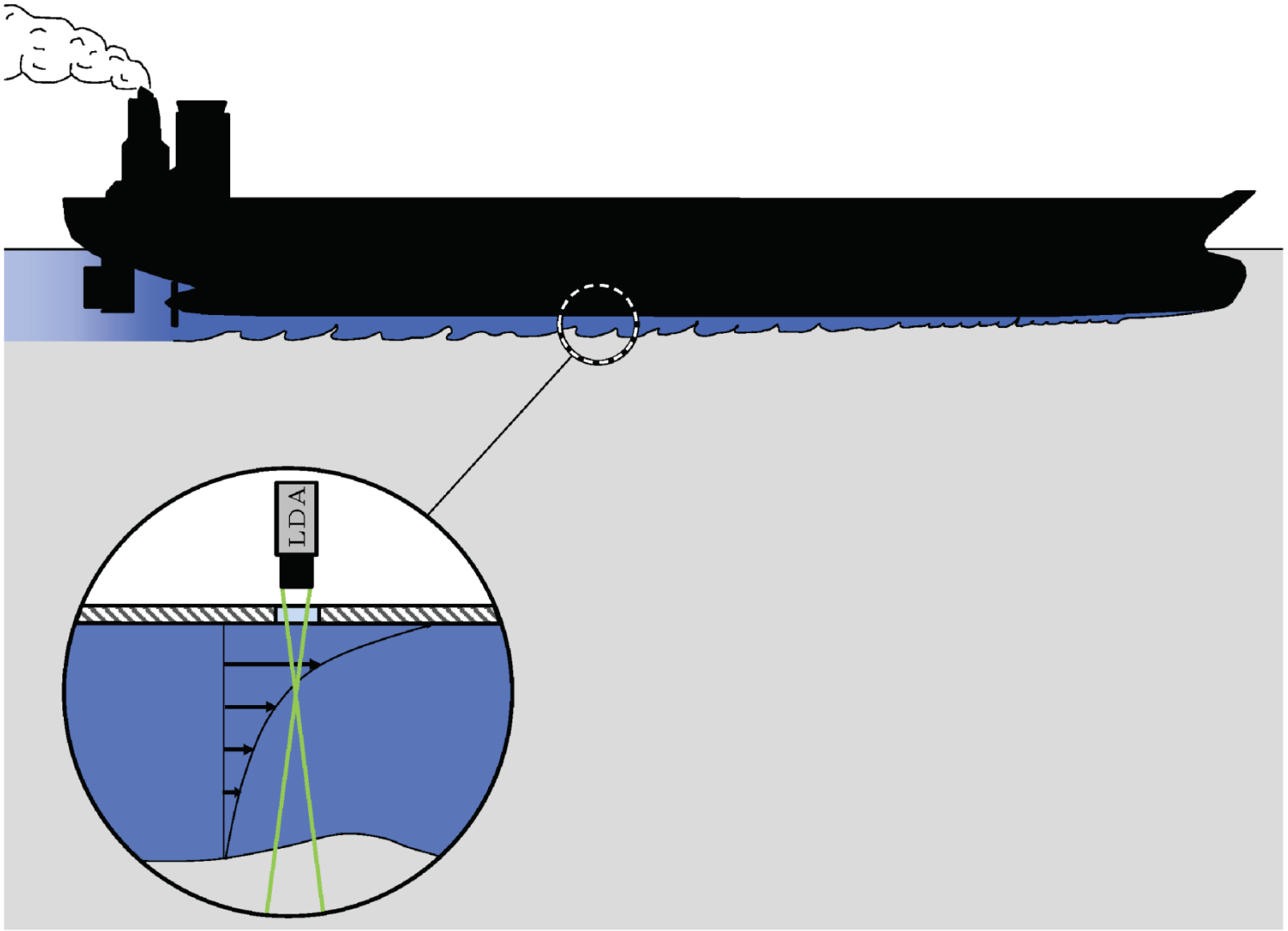

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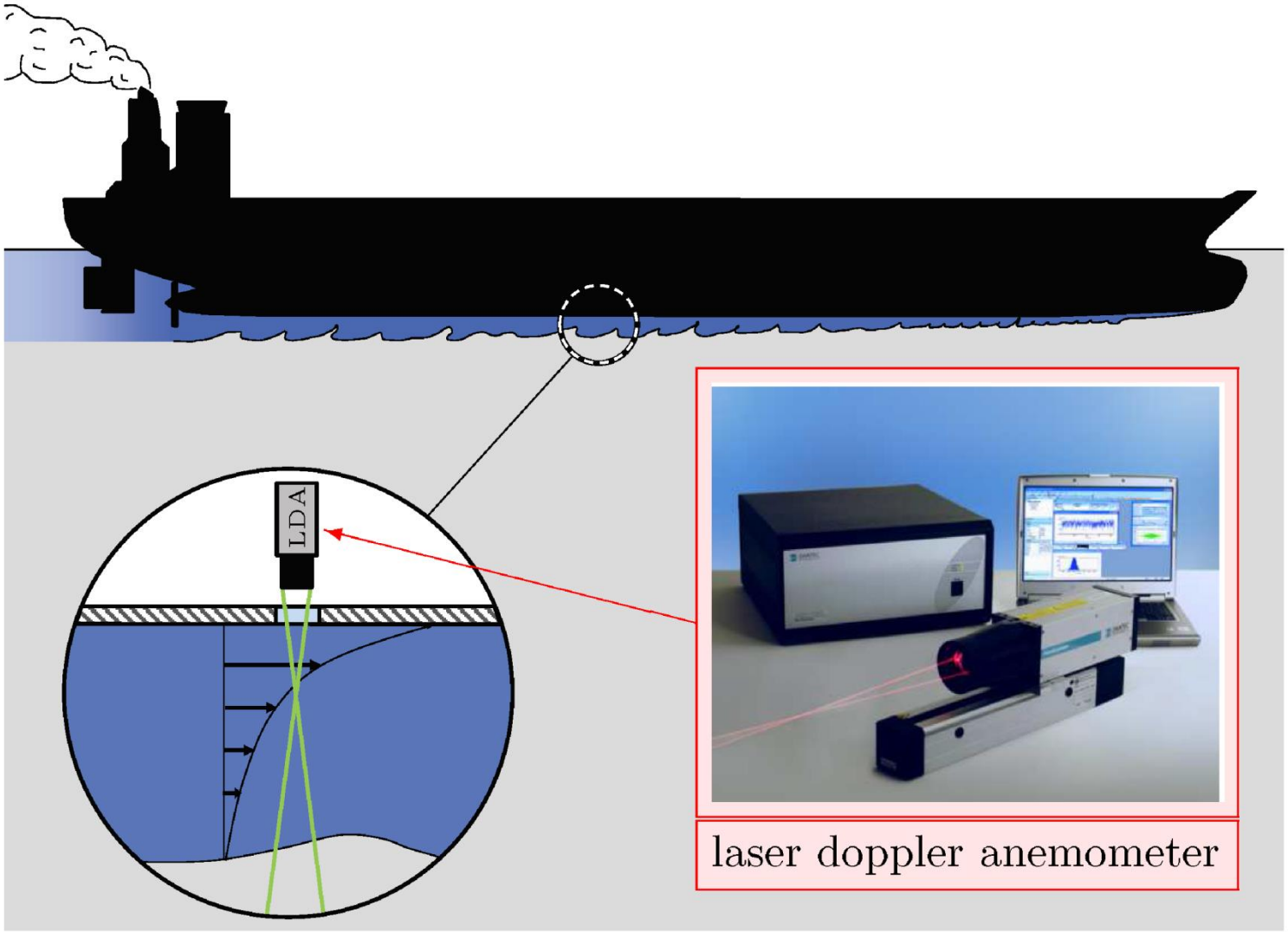

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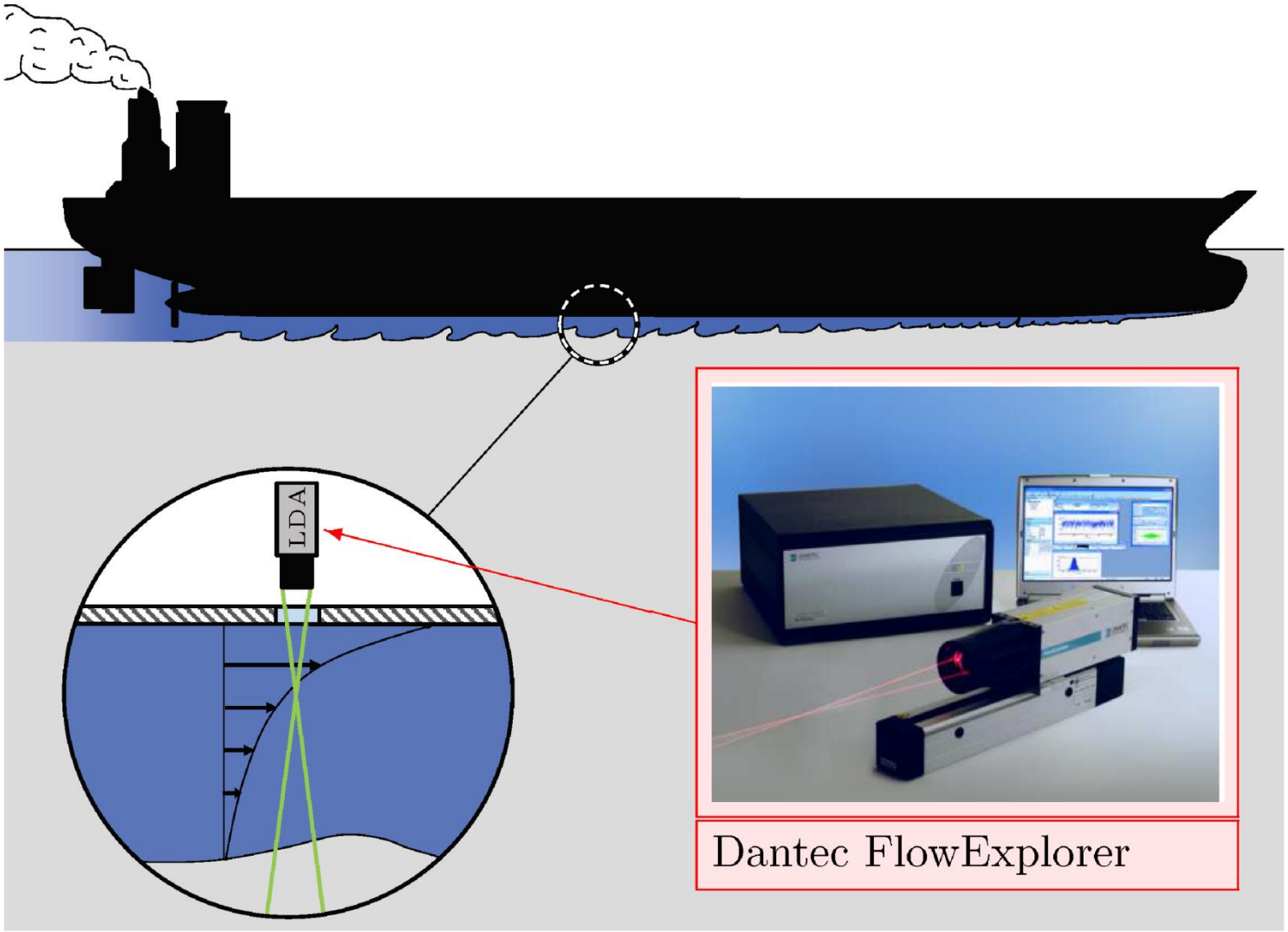

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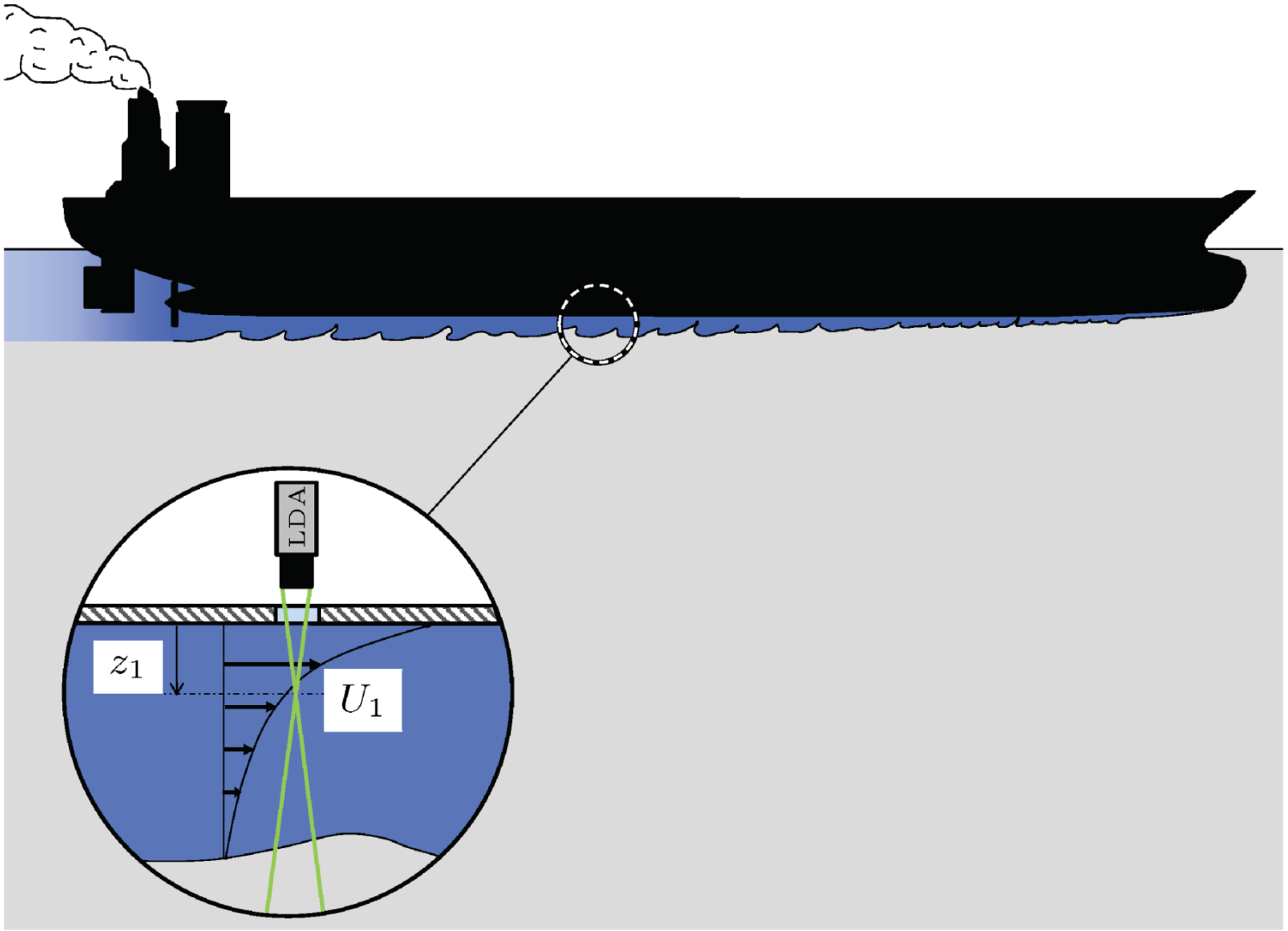

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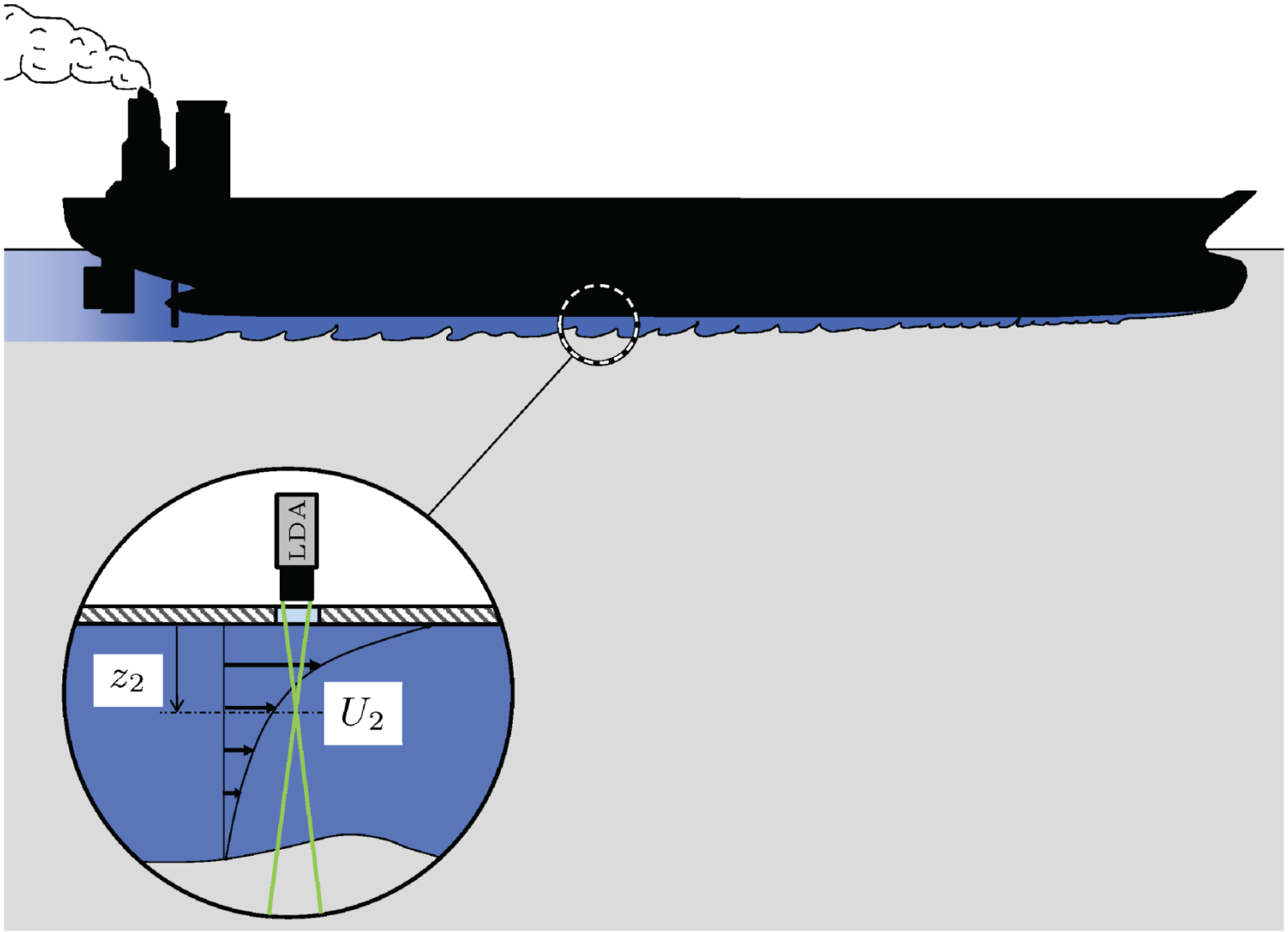

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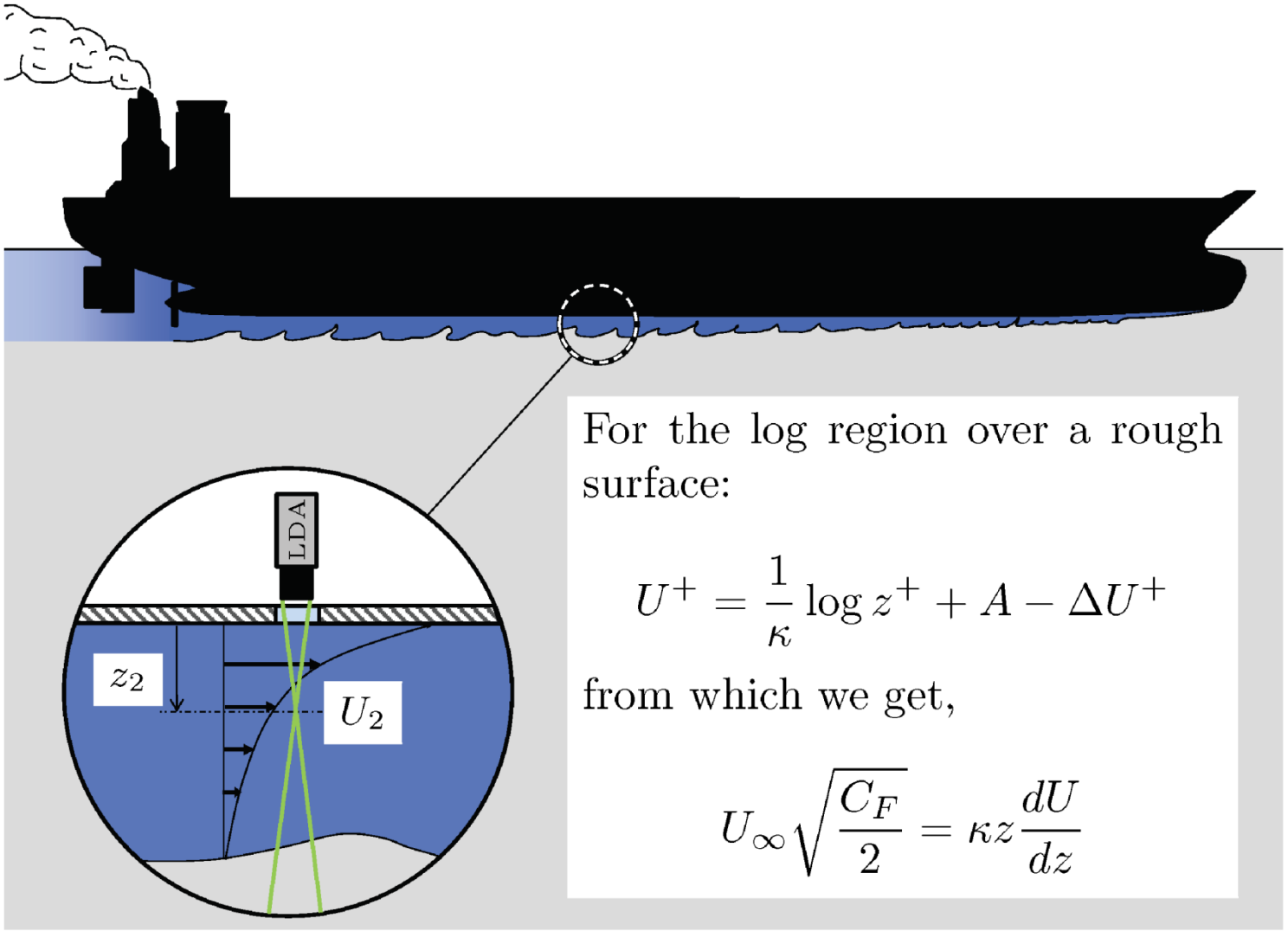

For the log region over a rough surface:

$$U^+ = \frac{1}{\kappa} \log z^+ + A - \Delta U^+$$

from which we get,

$$U_\infty \sqrt{\frac{C_F}{2}} = \kappa z \frac{dU}{dz}$$

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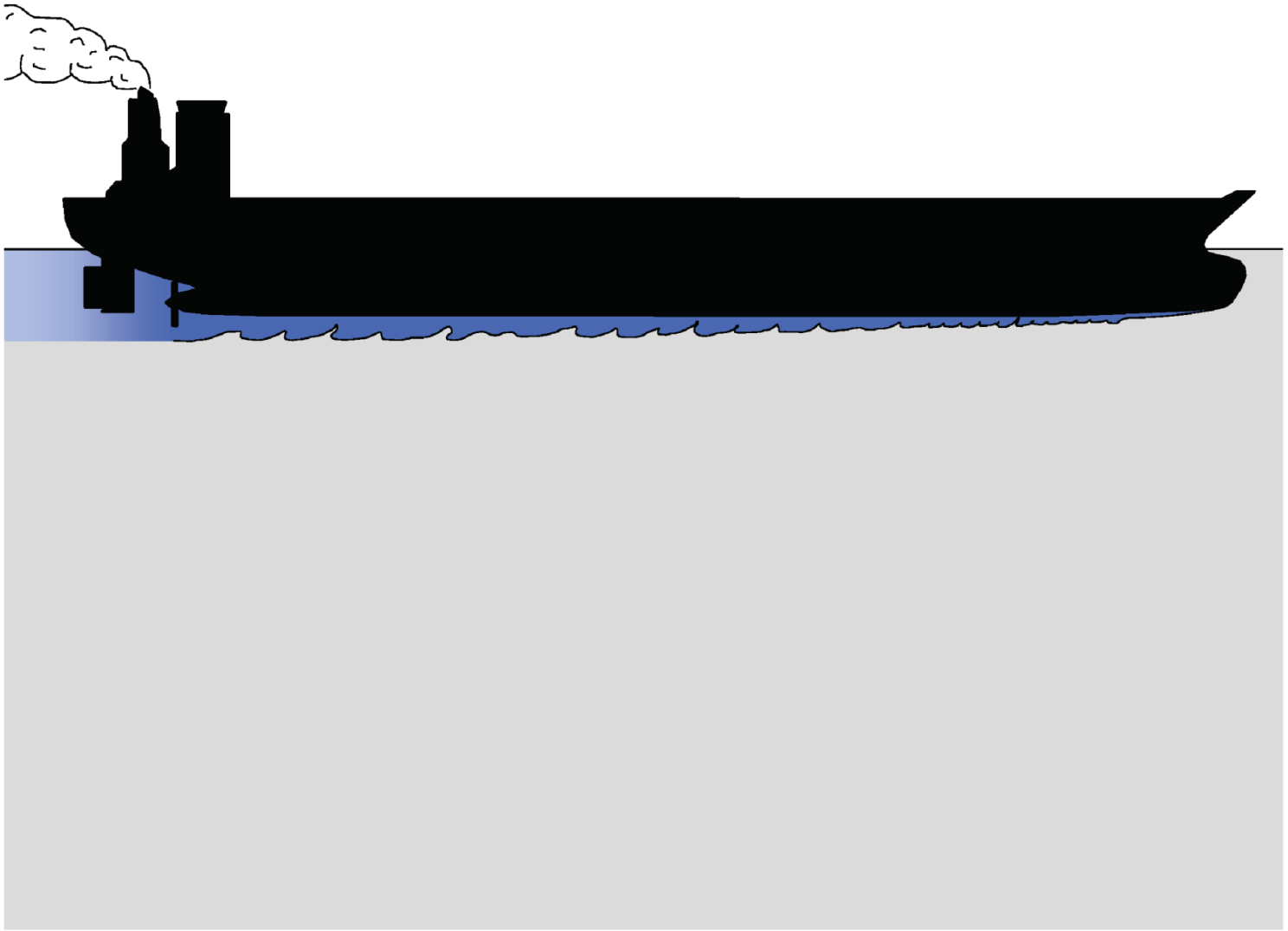

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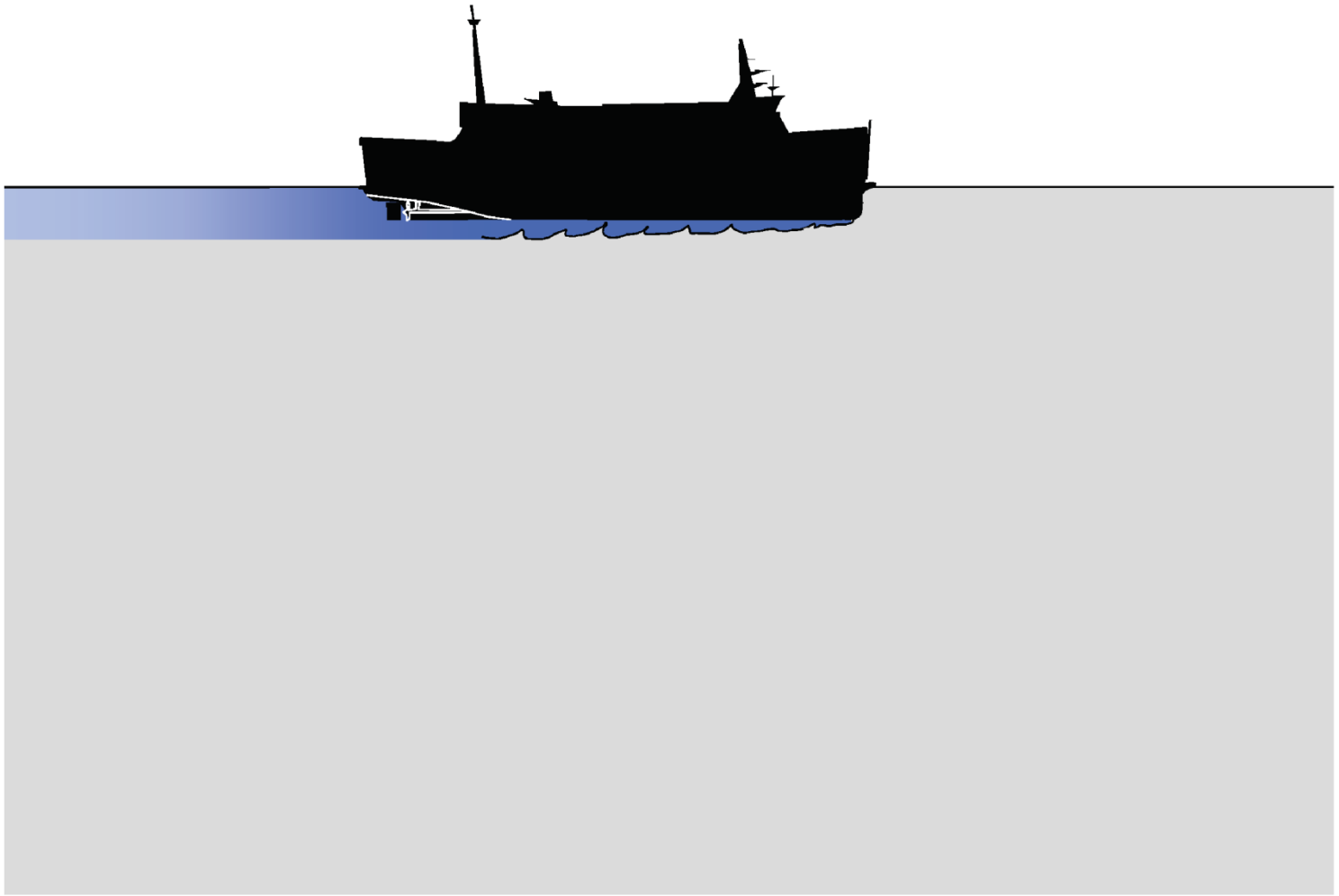

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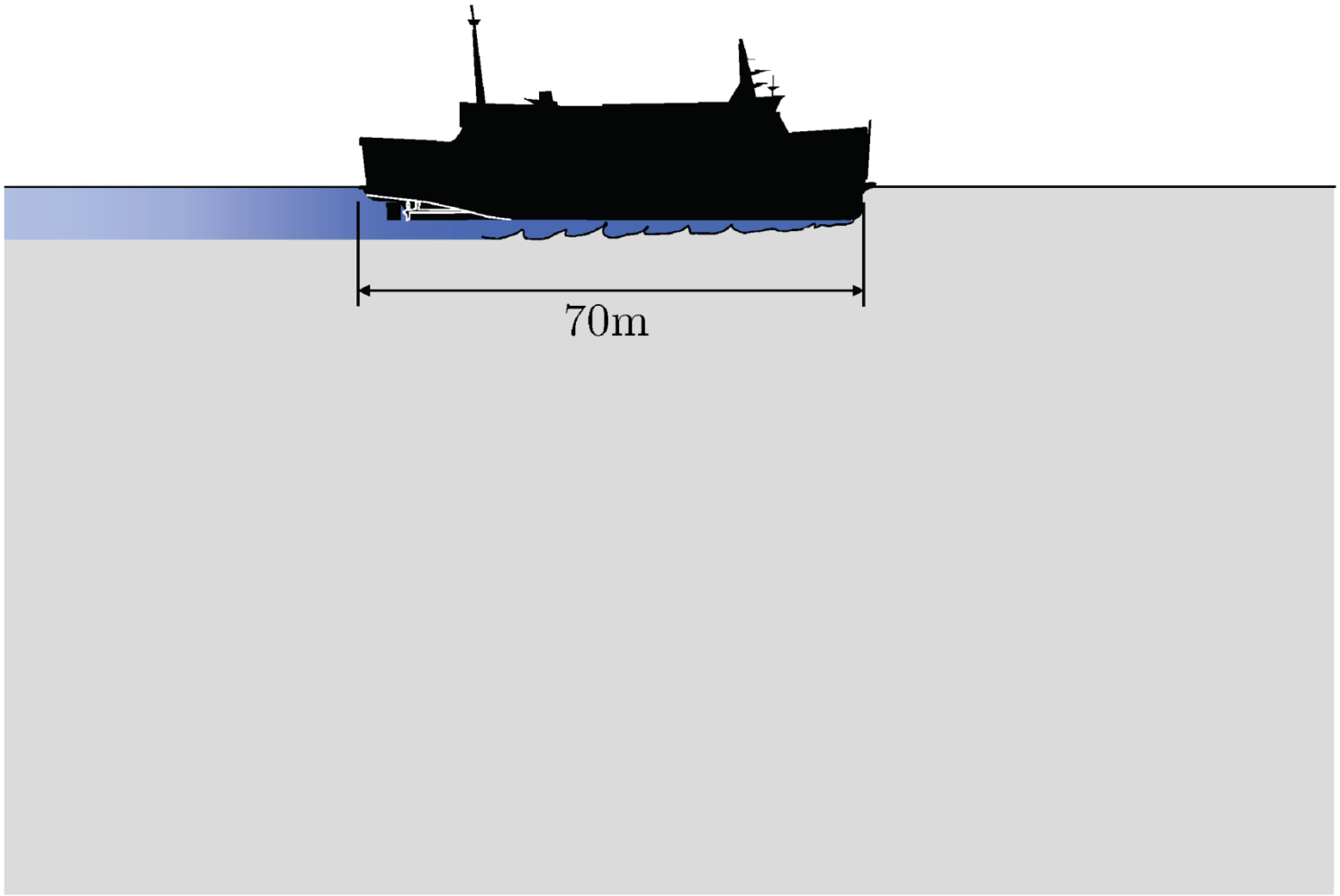

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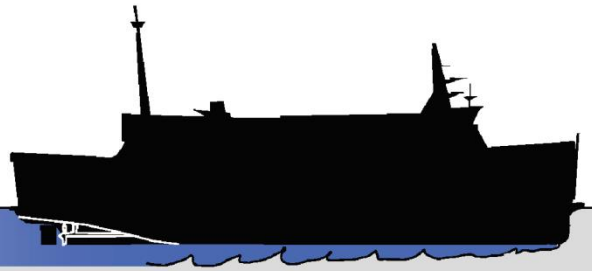

ITS
Institut
Teknologi
Sepuluh Nopember

PT. DHARMA LAUTAN UTAMA
armada pelayaran nasional

Dharma Kencana IX - RORO ferry

Direct ship board experiment

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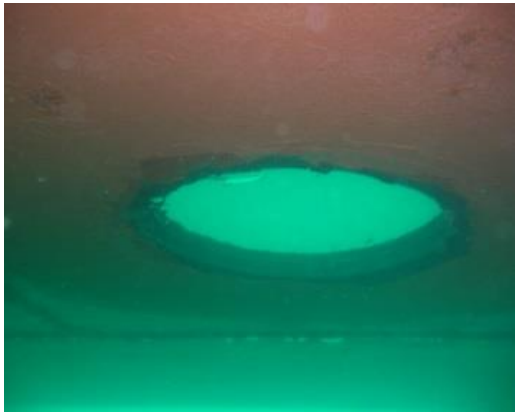

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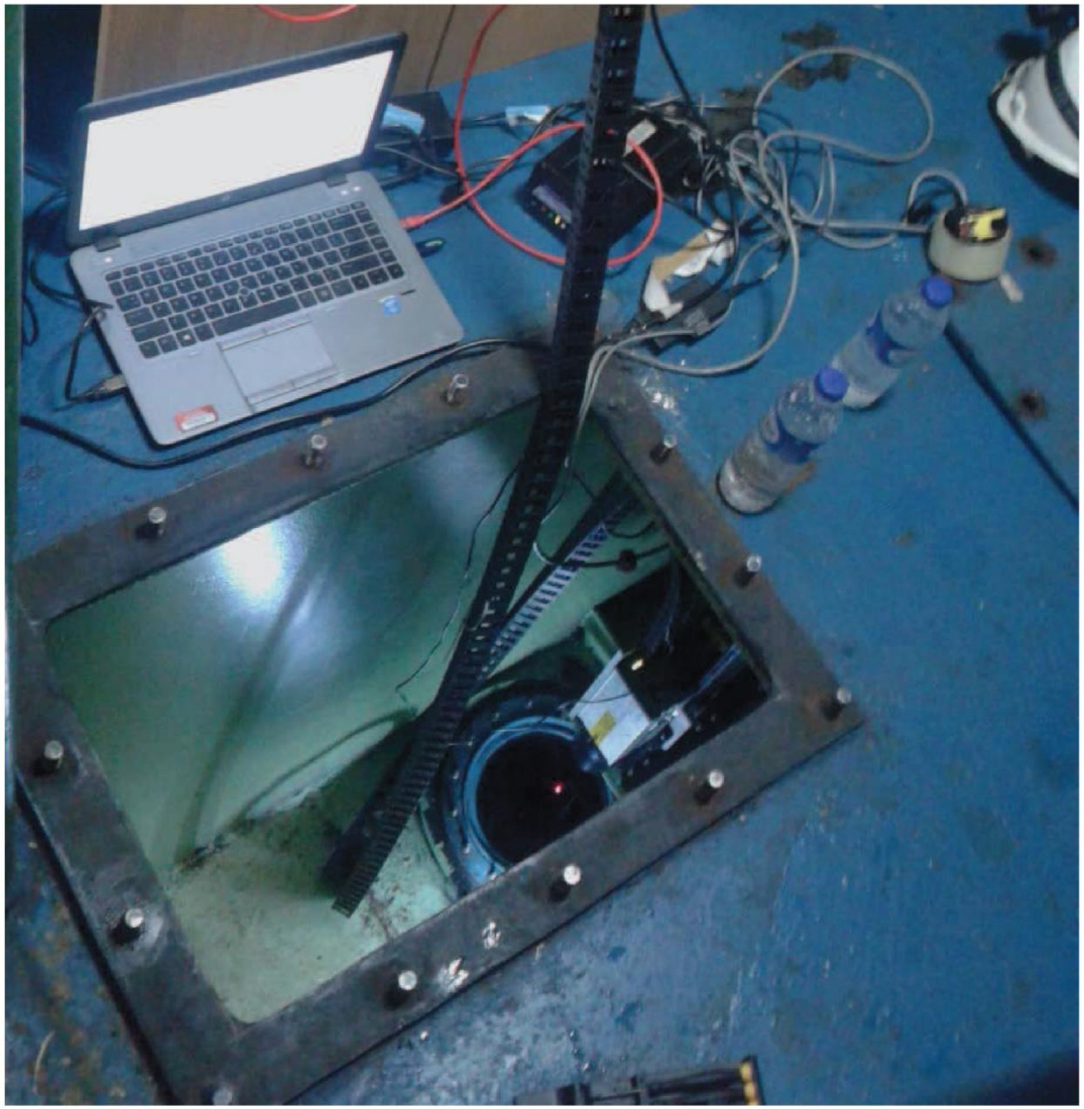

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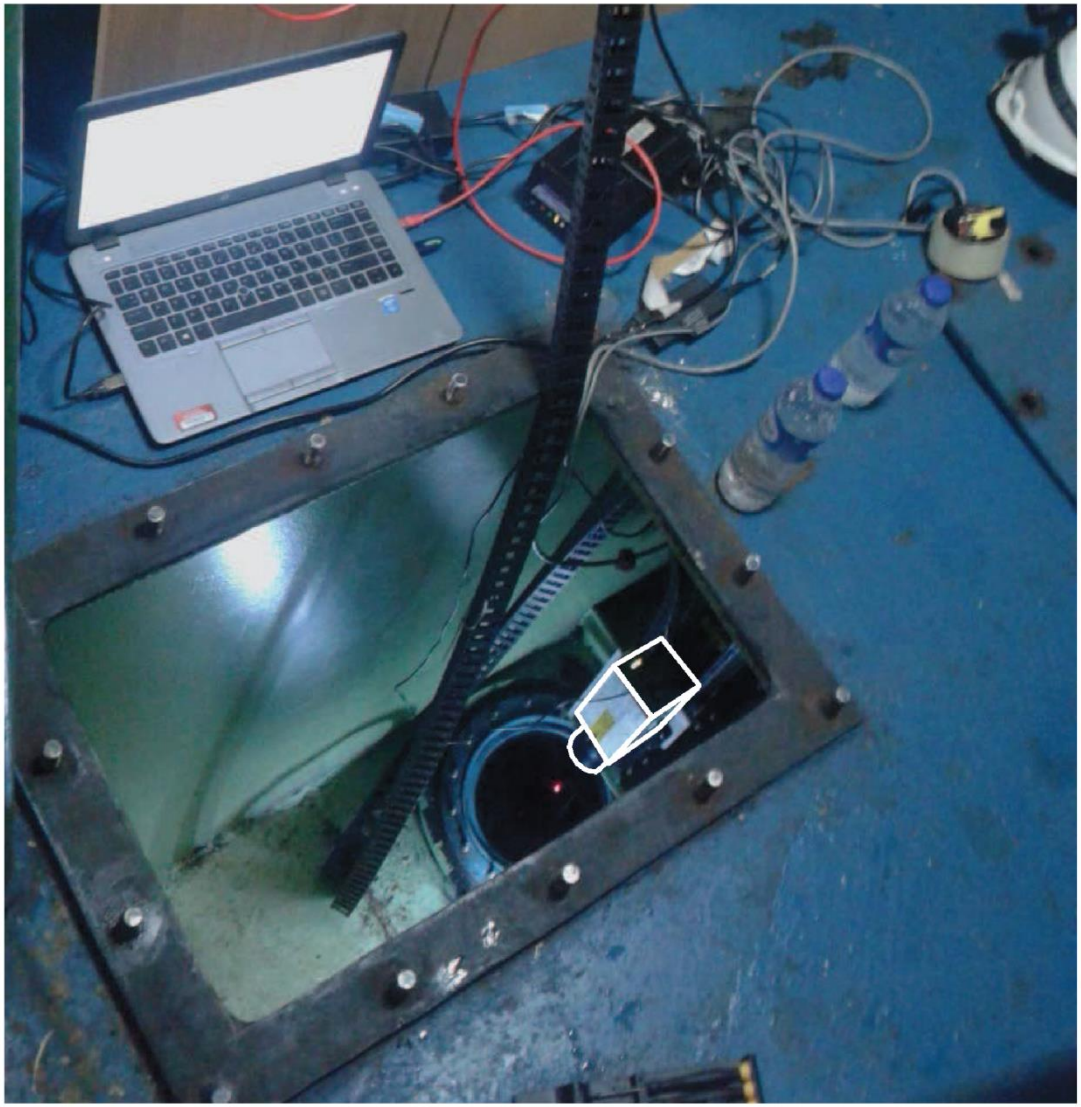

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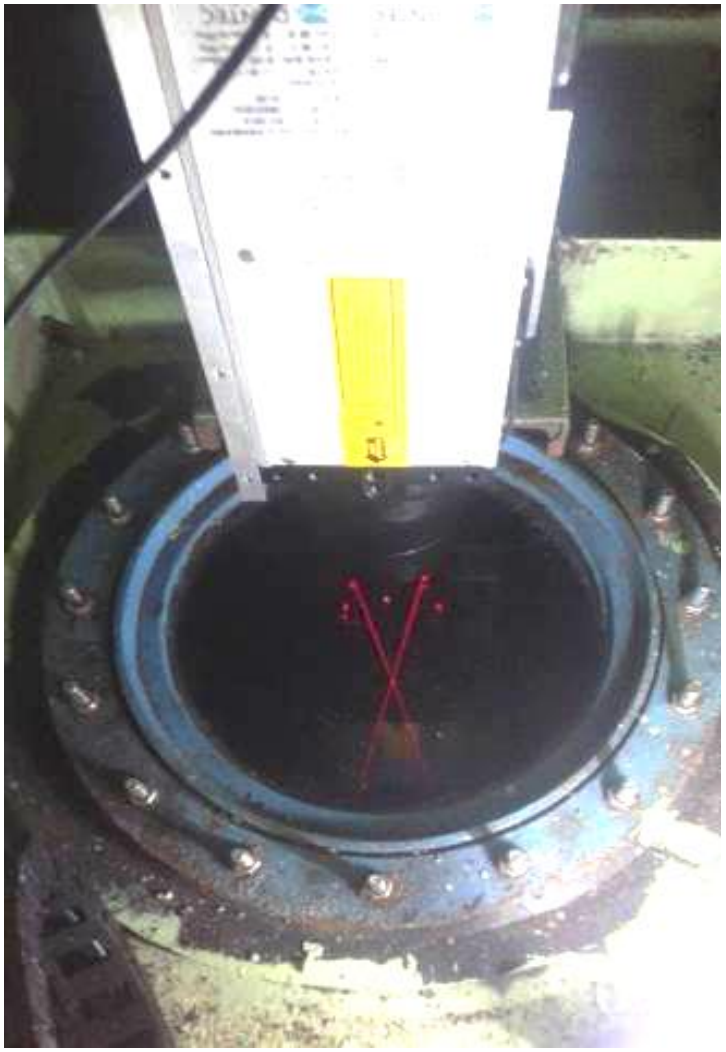
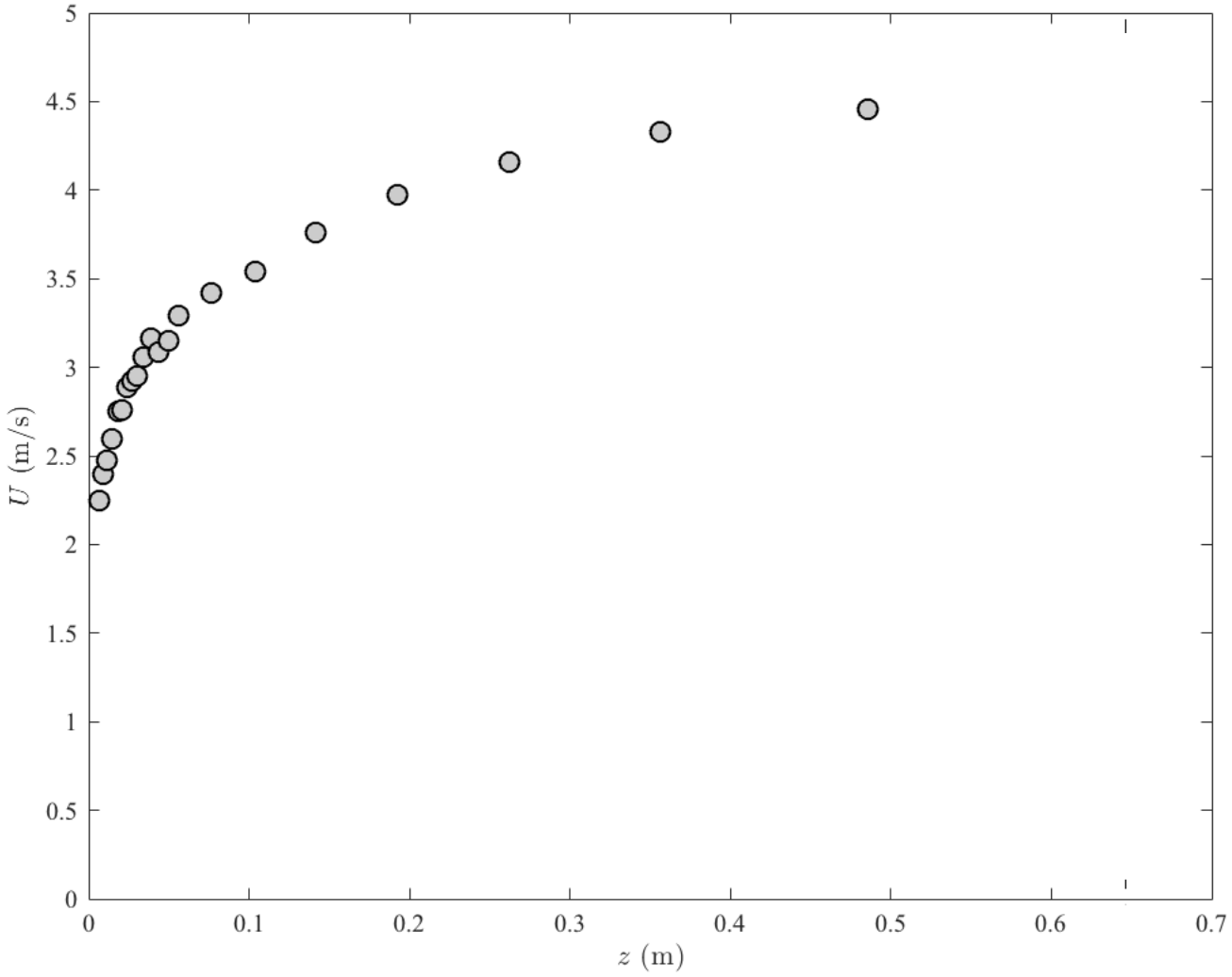


Direct ship board experiment

Mean velocity profile



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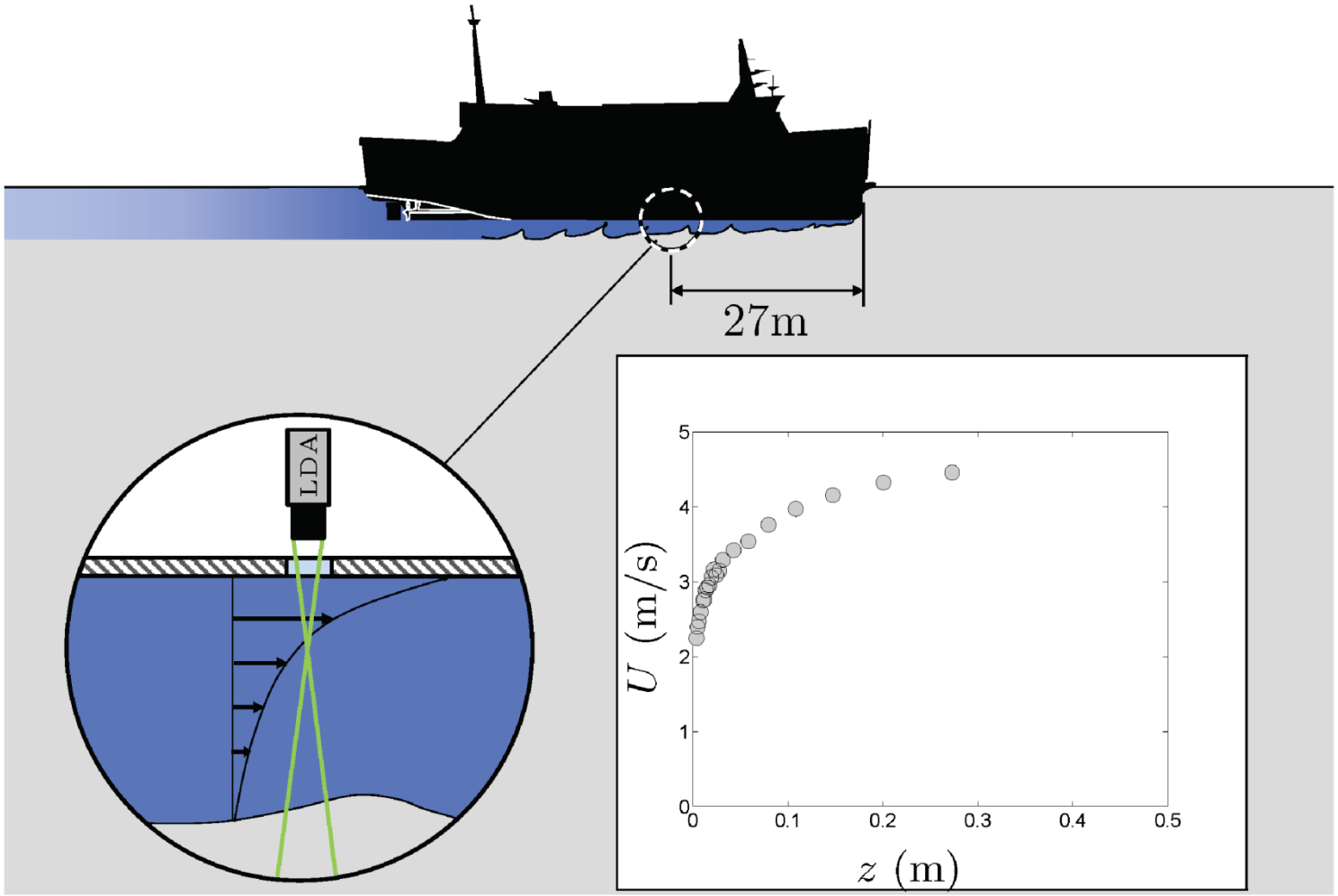

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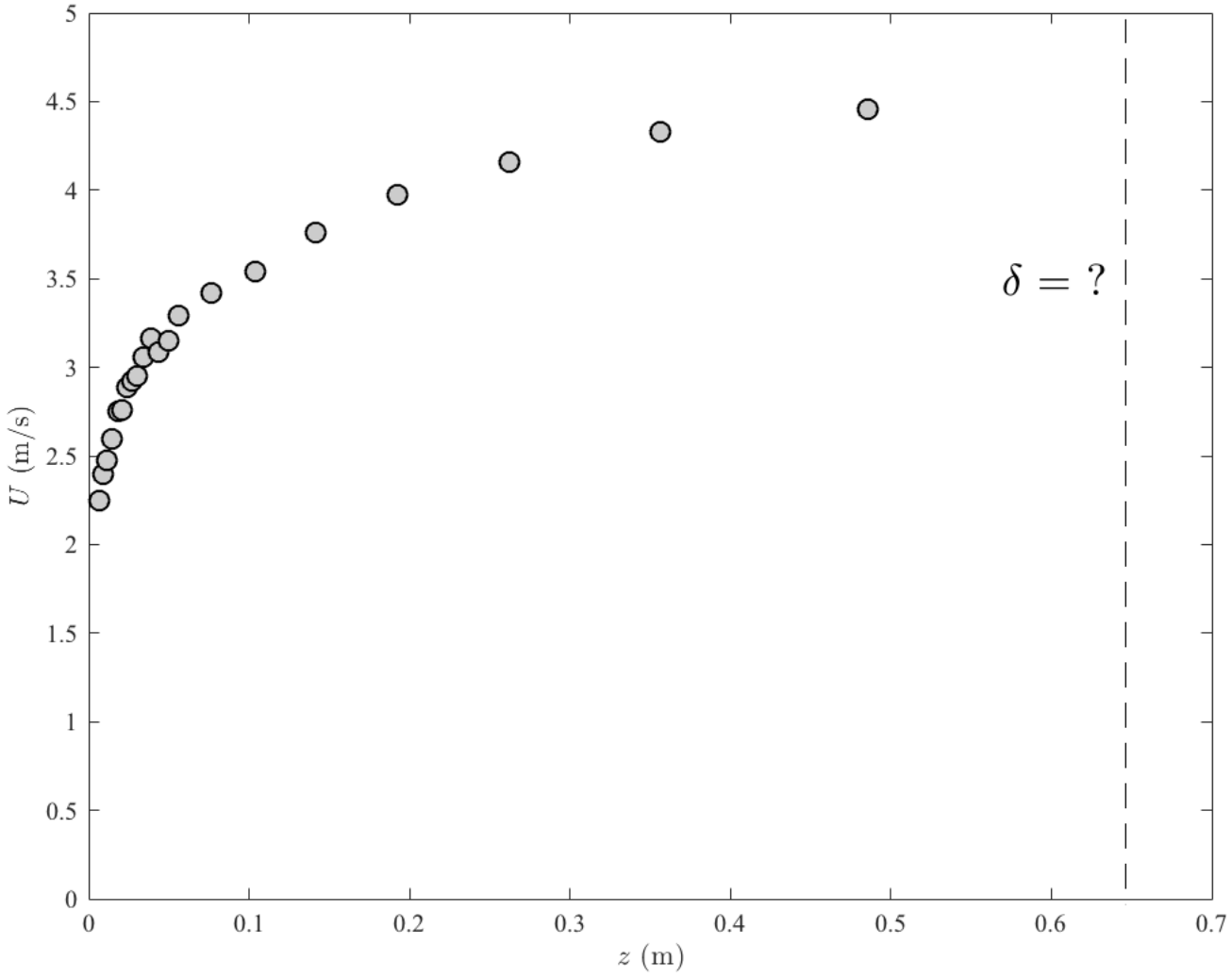

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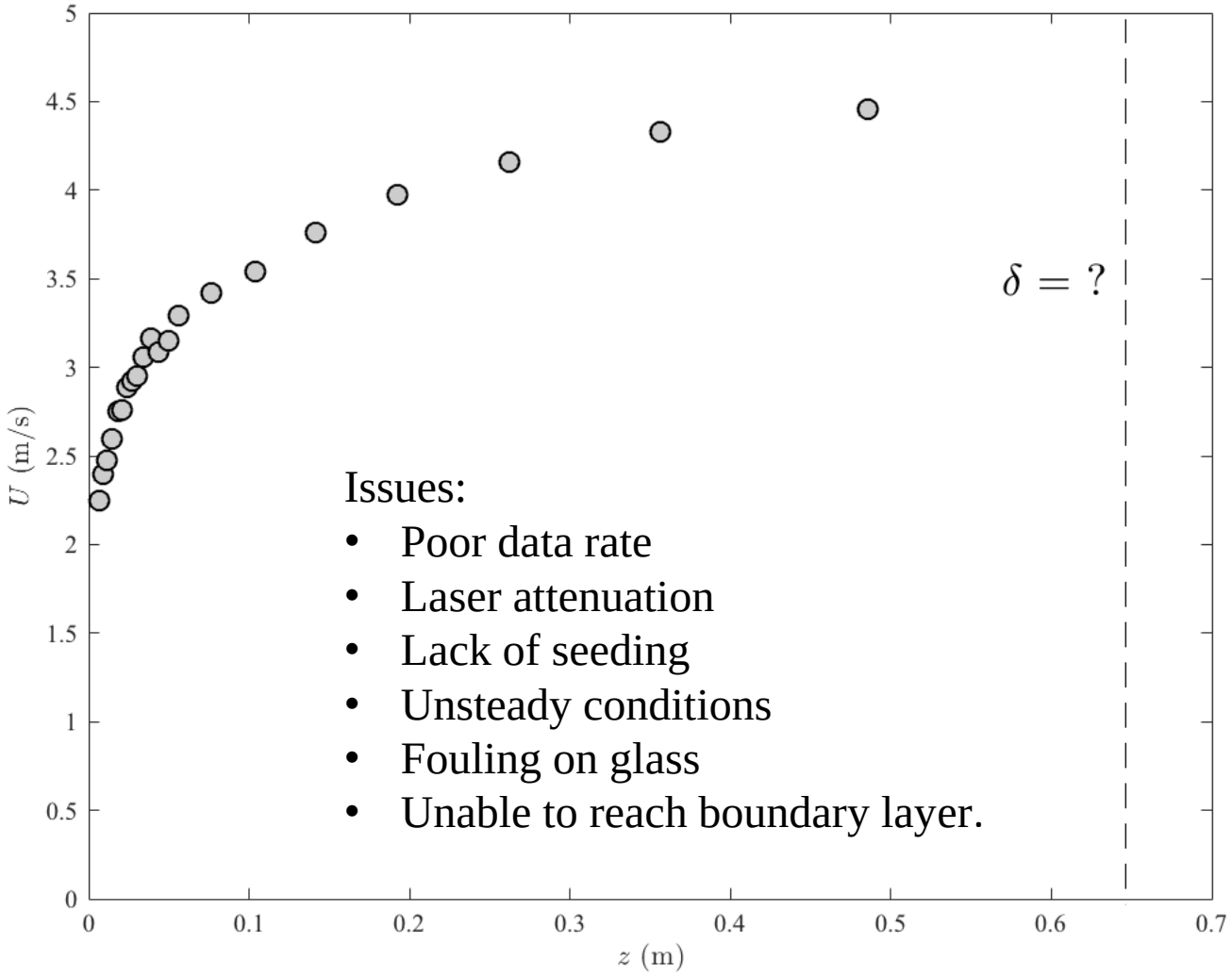
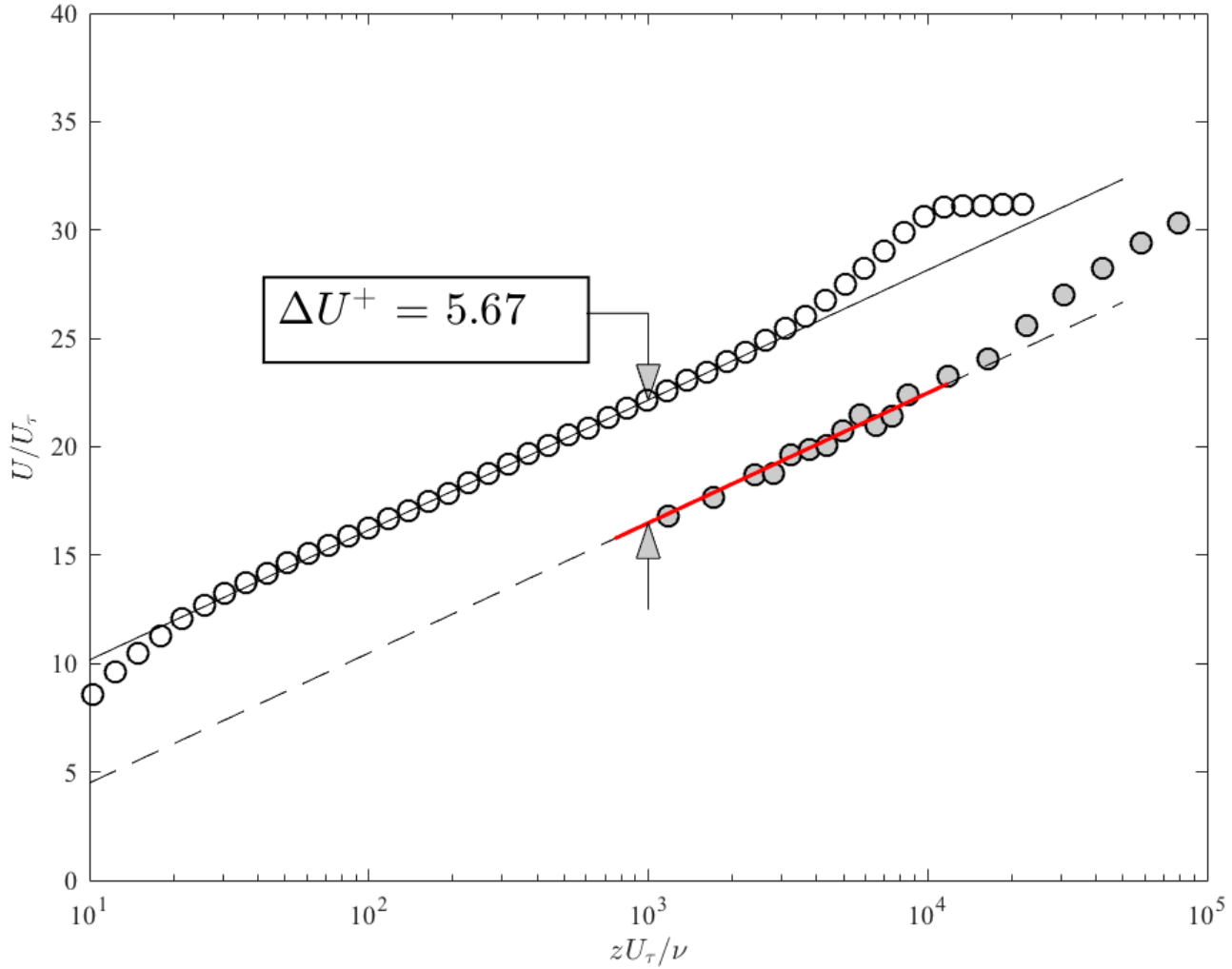


Issues:

- Poor data rate
- Laser attenuation
- Lack of seeding
- Unsteady conditions
- Fouling on glass
- Unable to reach boundary layer.

Direct ship board experiment

Mean velocity profile, normalised



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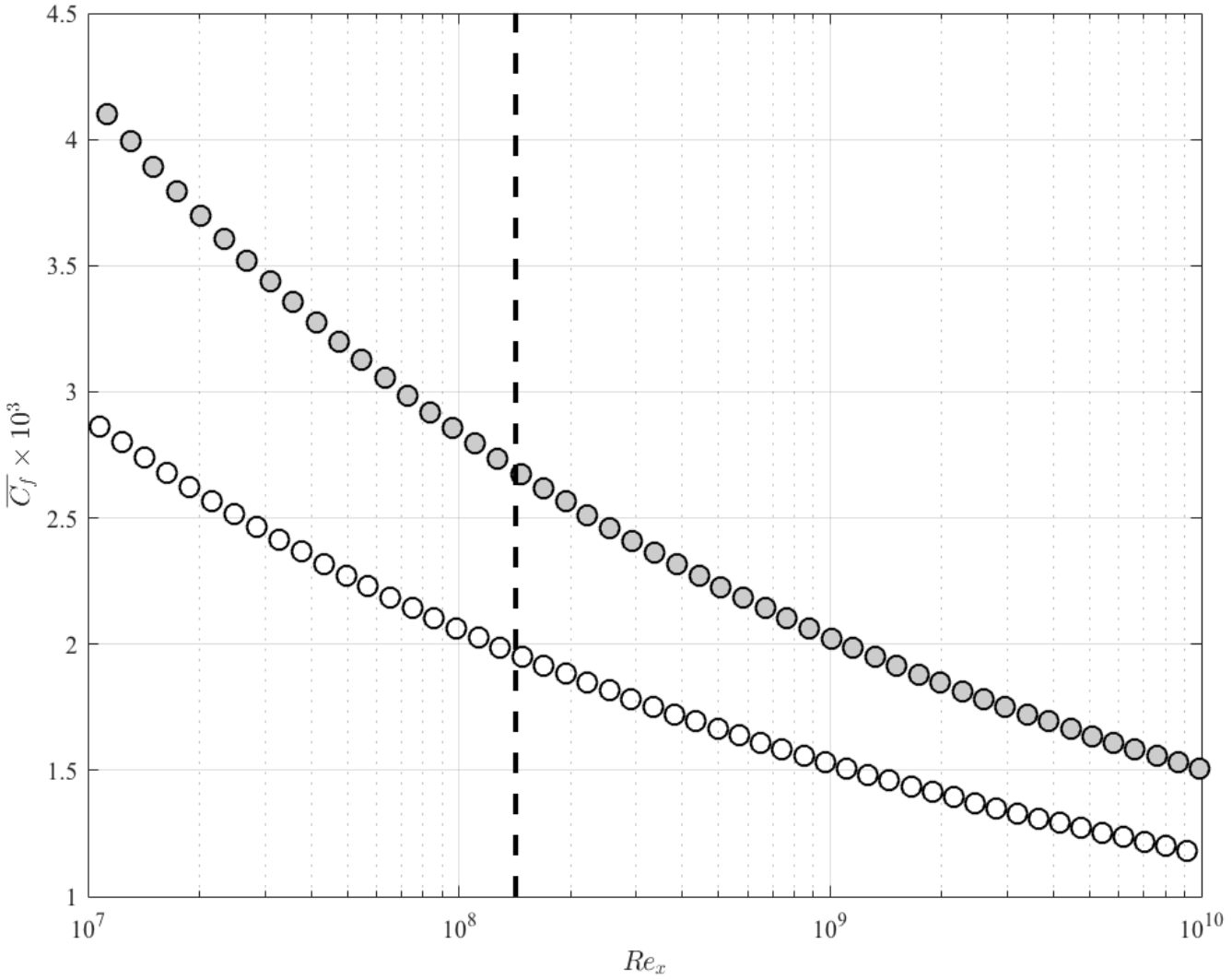

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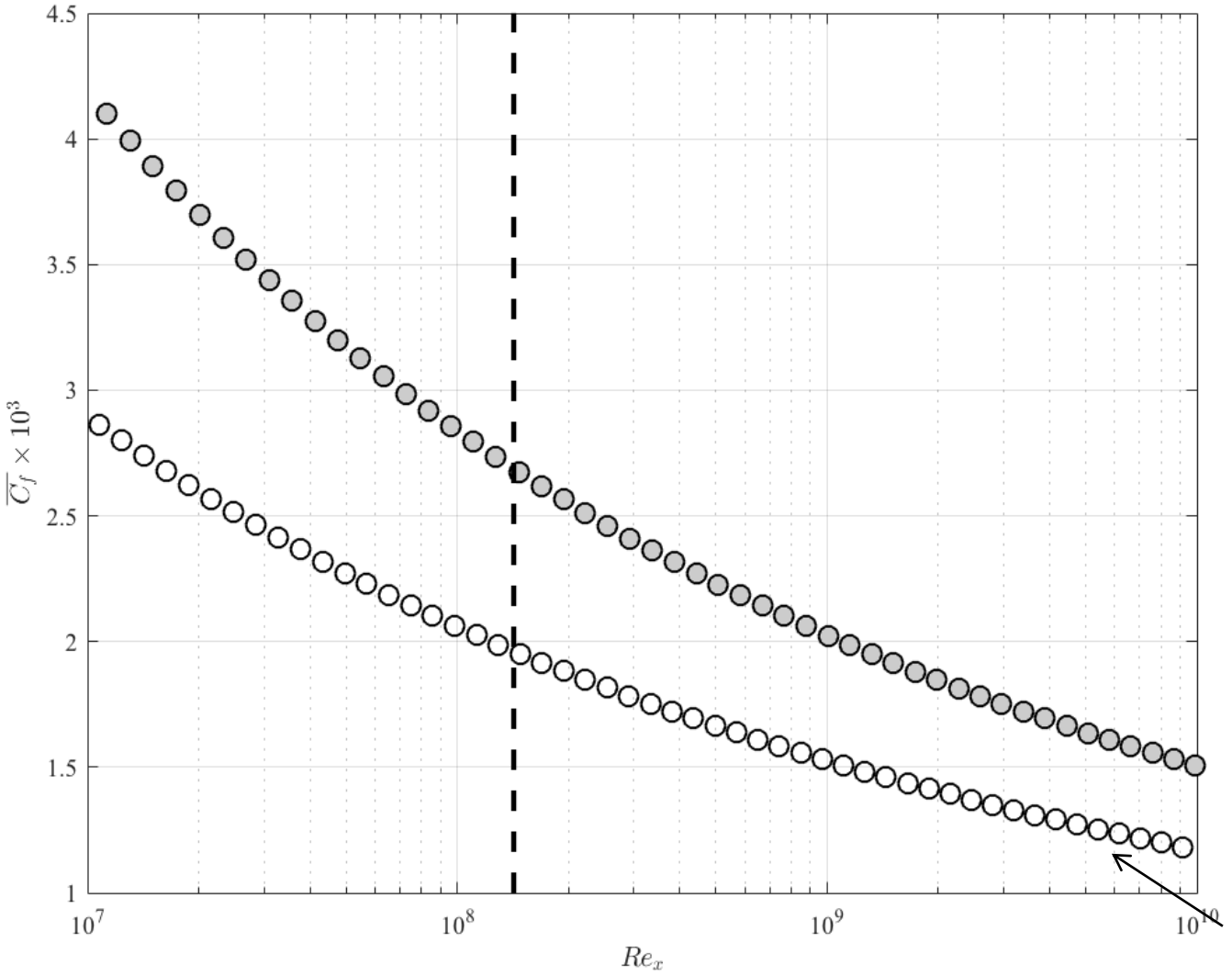

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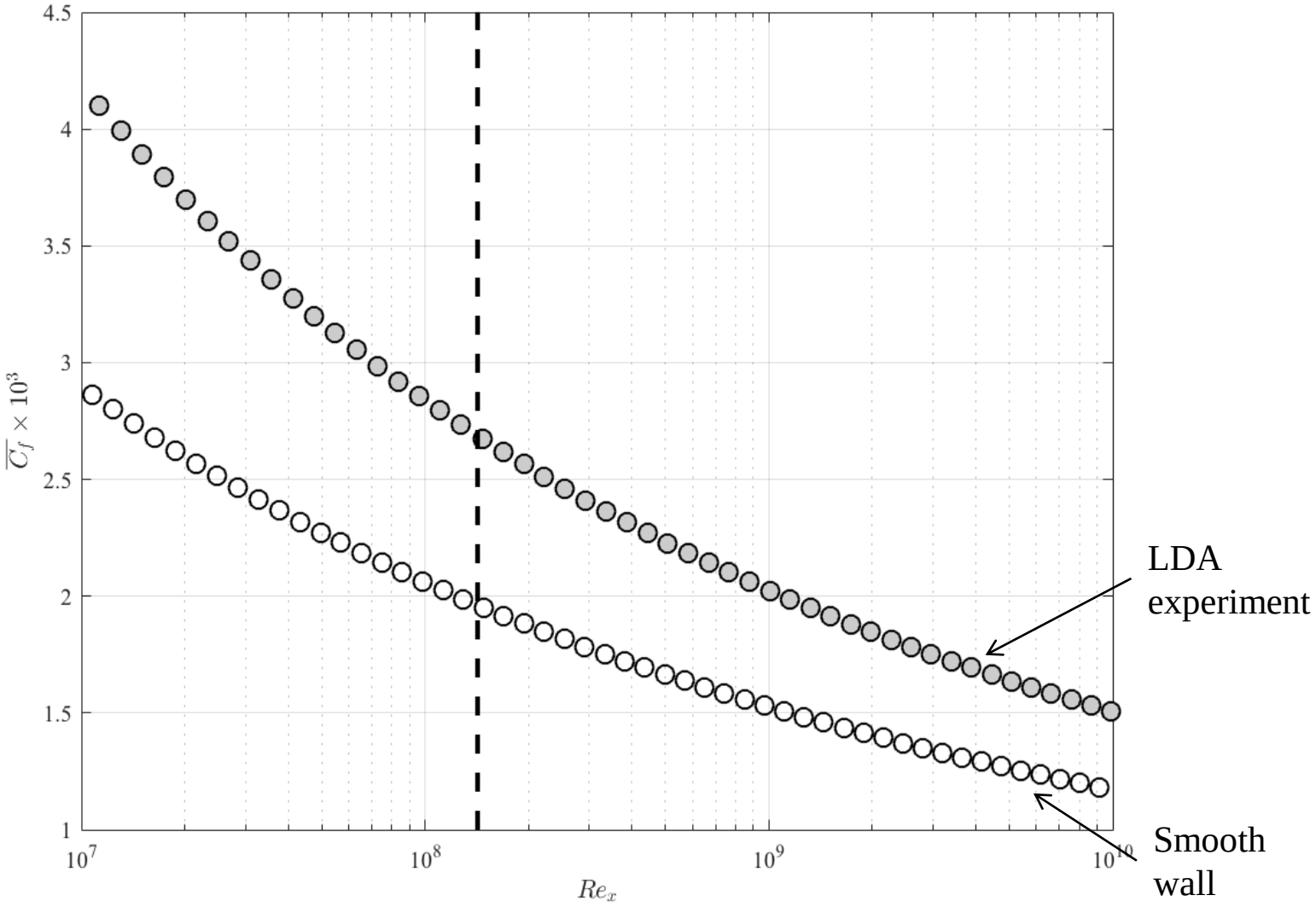

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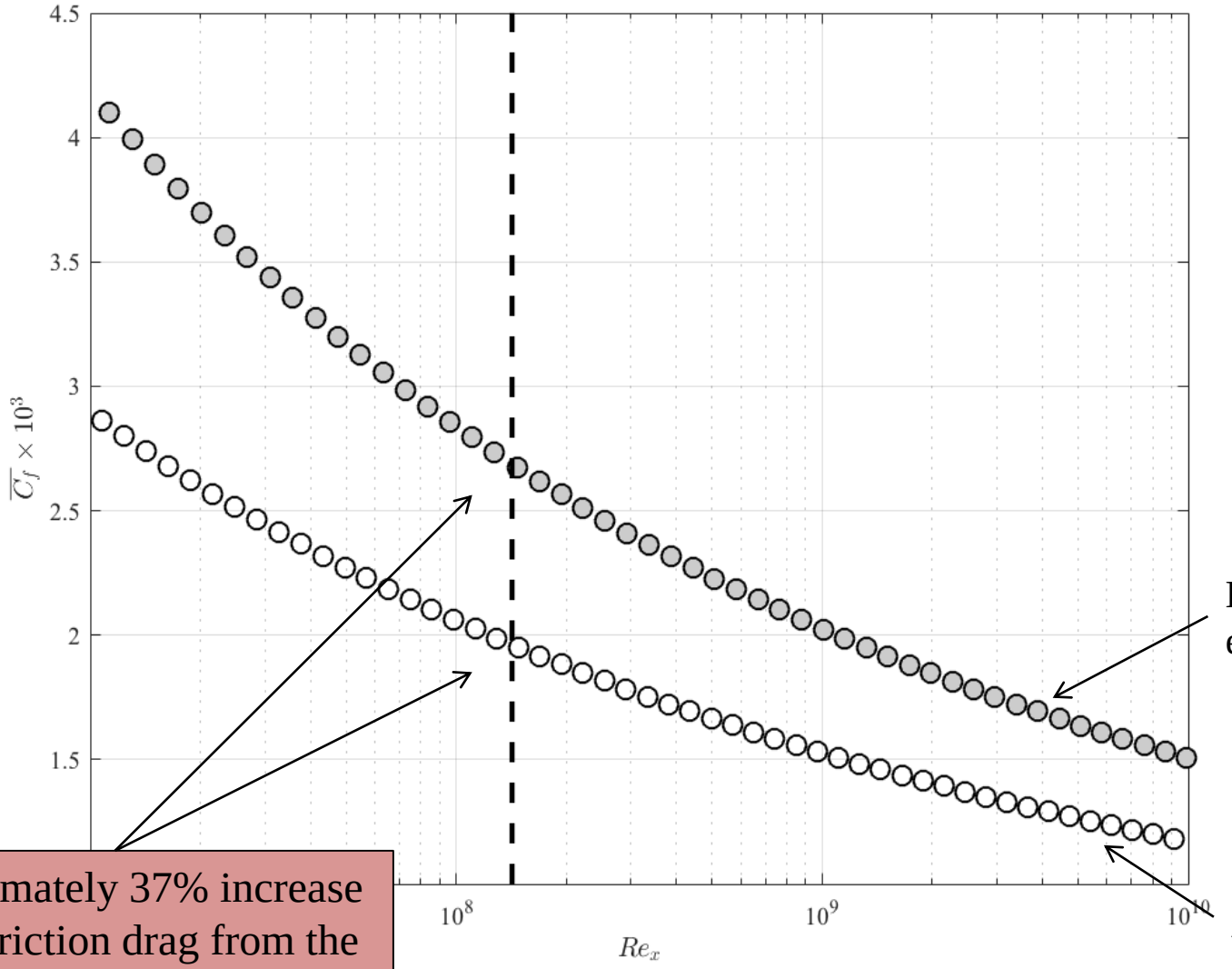
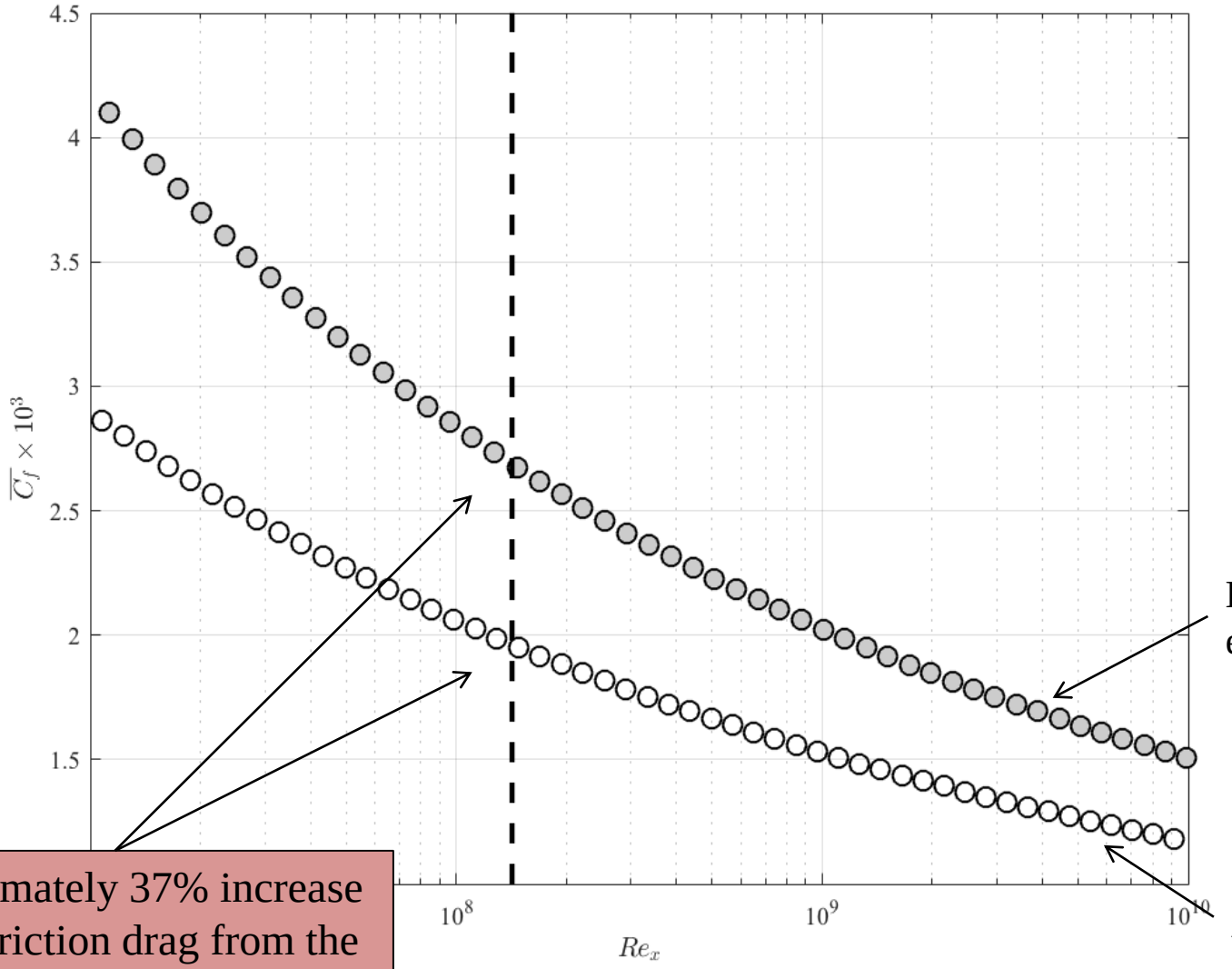


Approximately 37% increase in skin friction drag from the in-situ experiment

Direct ship board experiment



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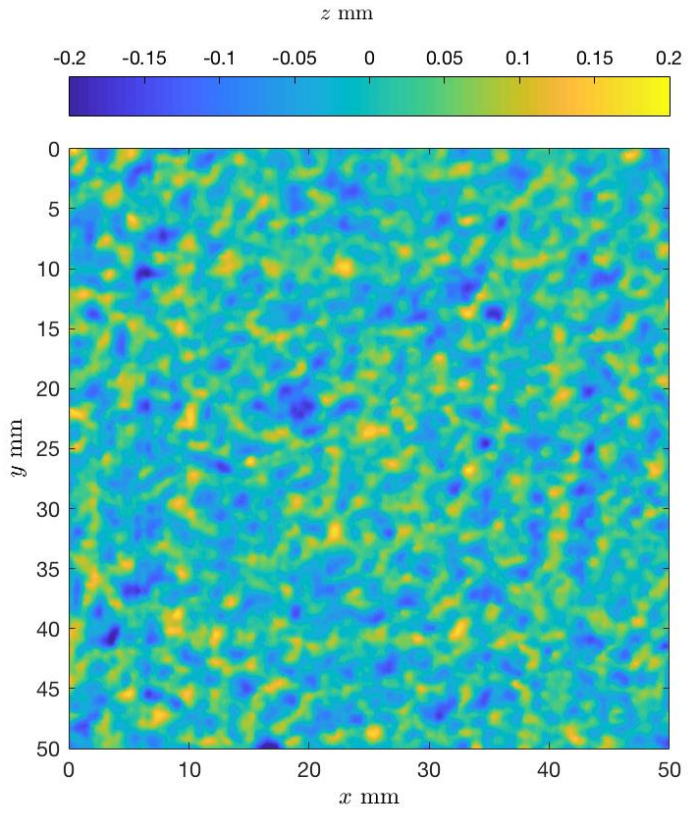
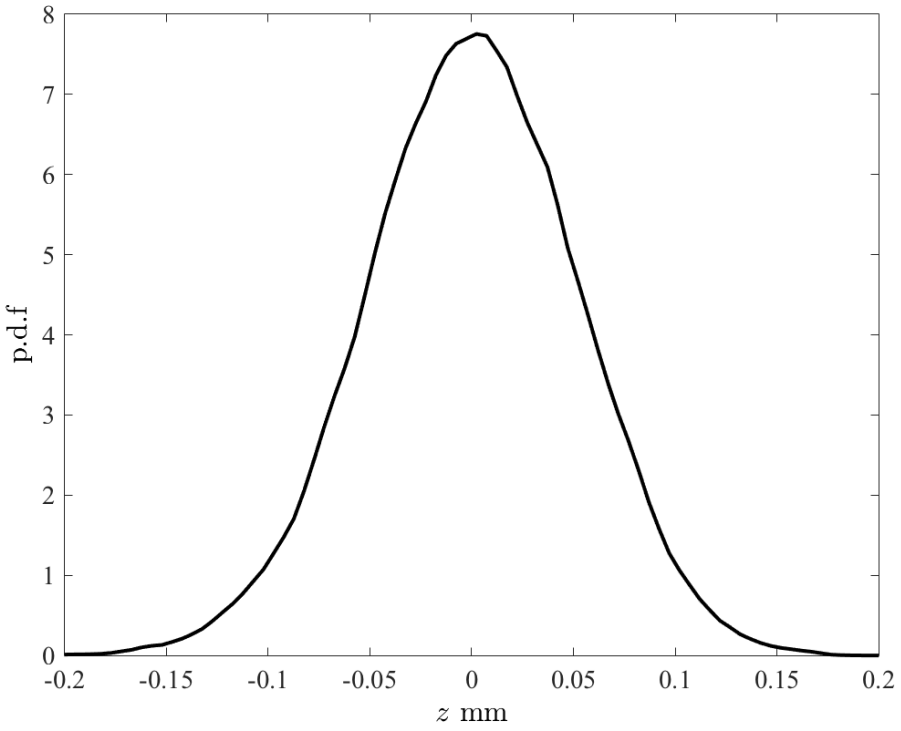


Direct ship board experiment

Parameter	Value	Units	Equation
k_a	0.0413	mm	$\overline{\lvert z' \rvert}$
k_{rms}	0.0519	mm	$\sqrt{\overline{z'^2}}$
k_p	0.4791	mm	$\max z' - \min z'$
k_{sk}	0.0868	-	$\overline{z'^3 / k_{rms}^3}$
k_{ku}	3.0712	-	$\overline{z'^4 / k_{rms}^4}$
ES_x	0.0890	-	$\overline{\lvert dz'/dx \rvert}$



Direct ship board experiment

Issue with heterogeneity

Outline

- Background
- An example of determining drag from laboratory testing of a given surface
- A direct shipboard in-situ method of measuring drag penalty due to surface roughness
- Regular monitoring of the hull state.

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Main issue with previous in-situ experiments in 50’s and 80’s :

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We do not know what kind of roughness characteristics that caused the increase in skin friction drag

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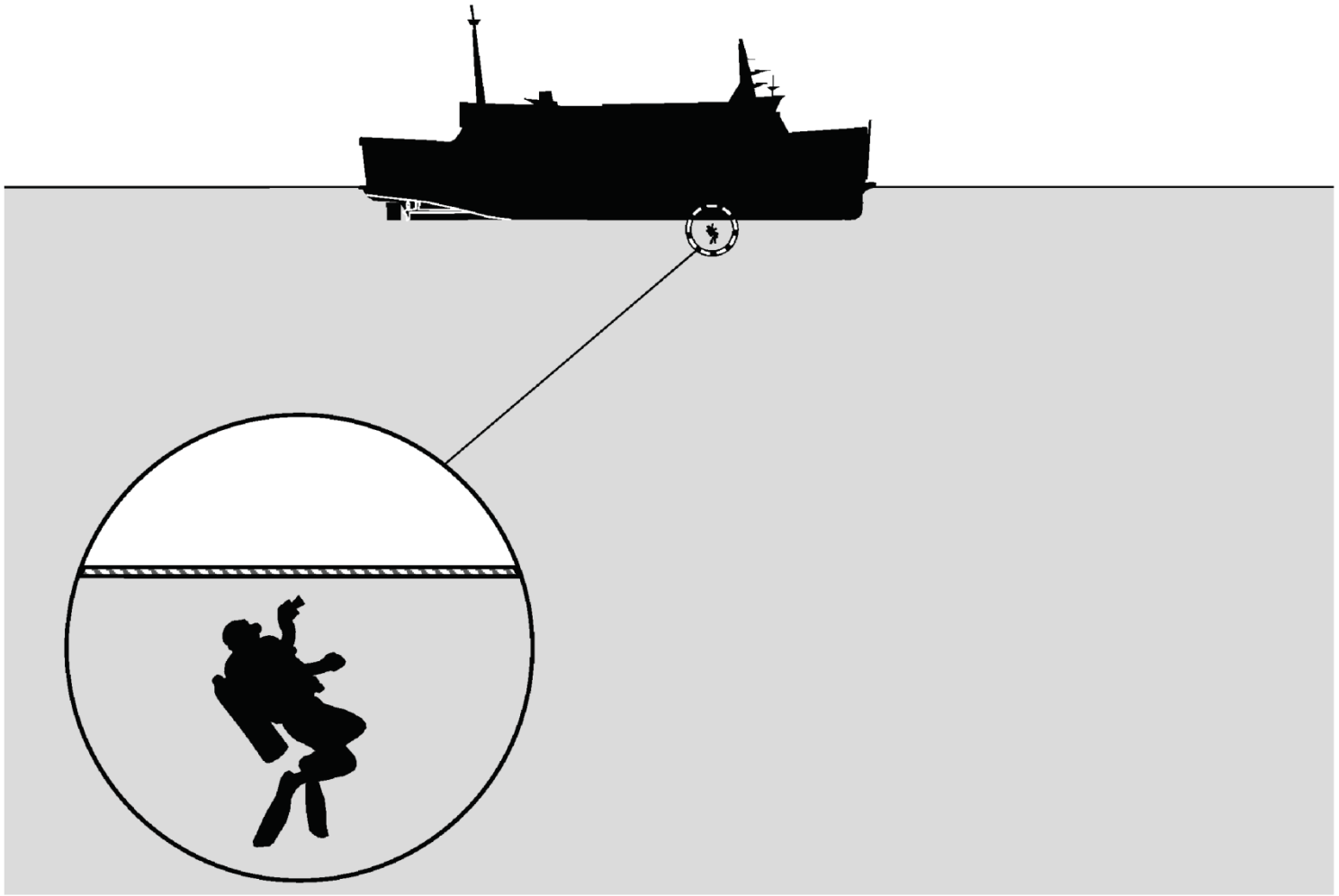

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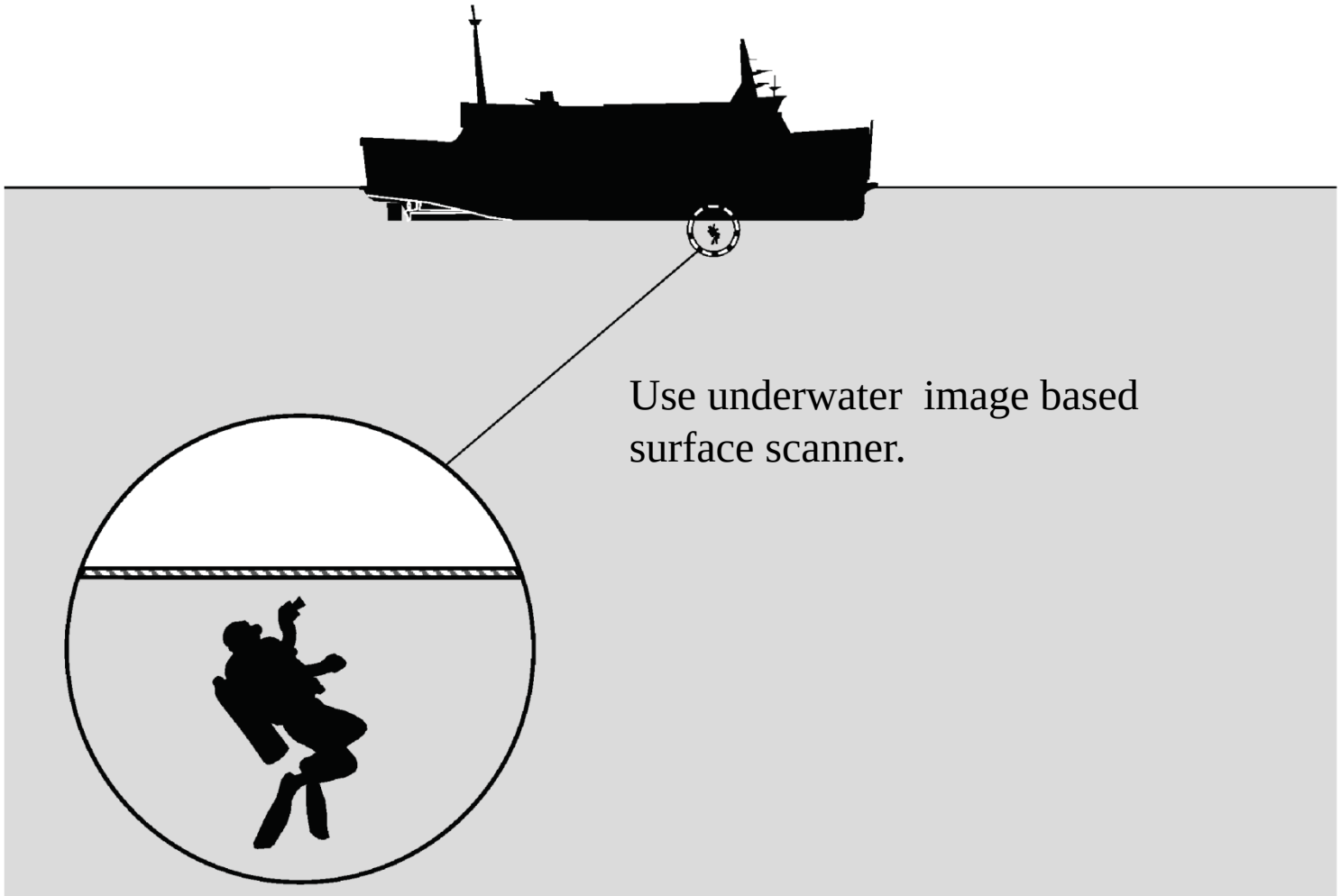

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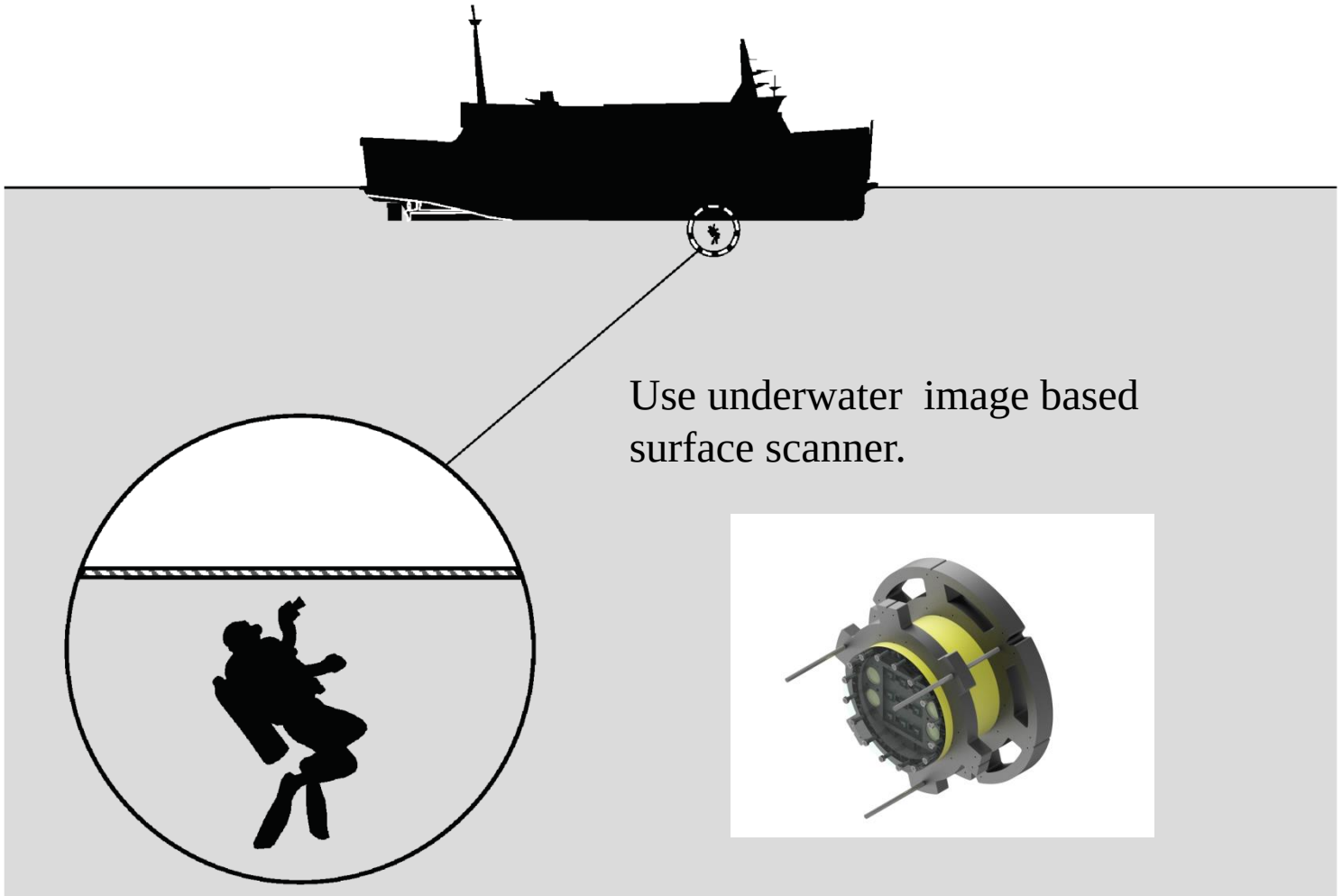
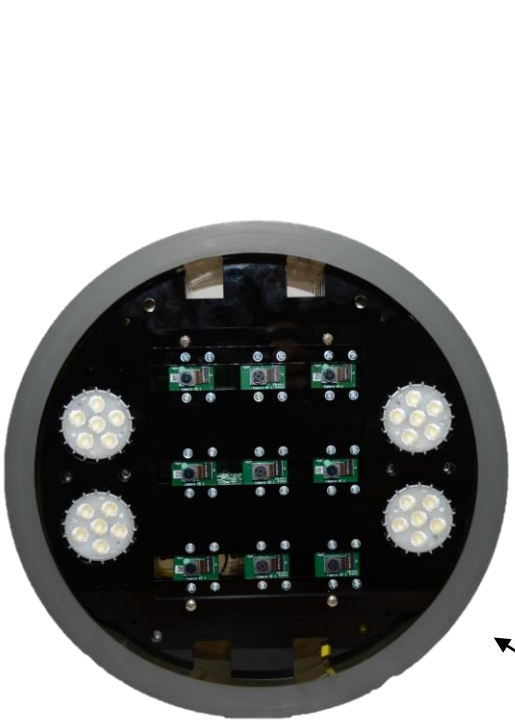
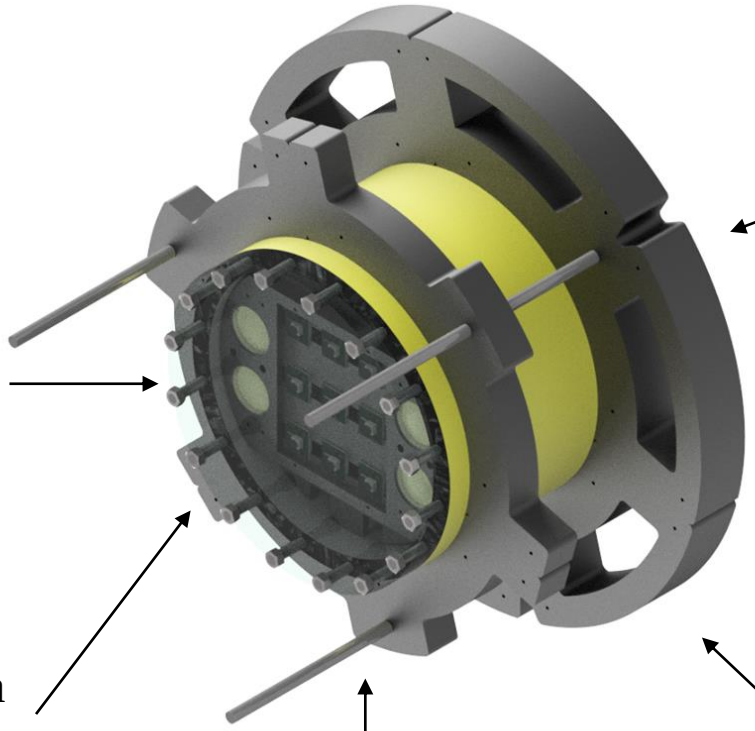


Use underwater image based surface scanner.

Regular monitoring of the hull state





Endcap

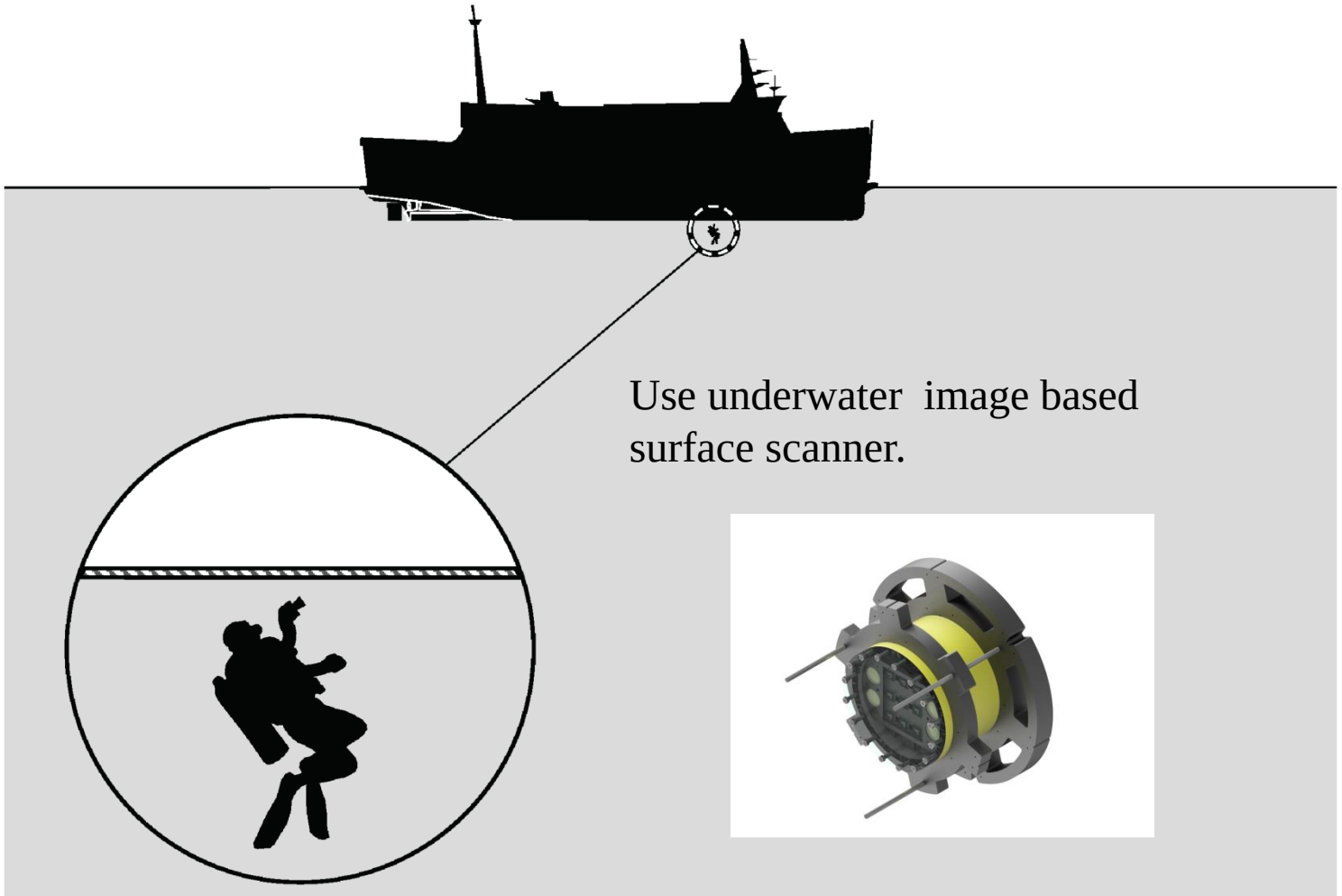
Lens

Camera
Array

Legs

Handles

Regular monitoring of the hull state



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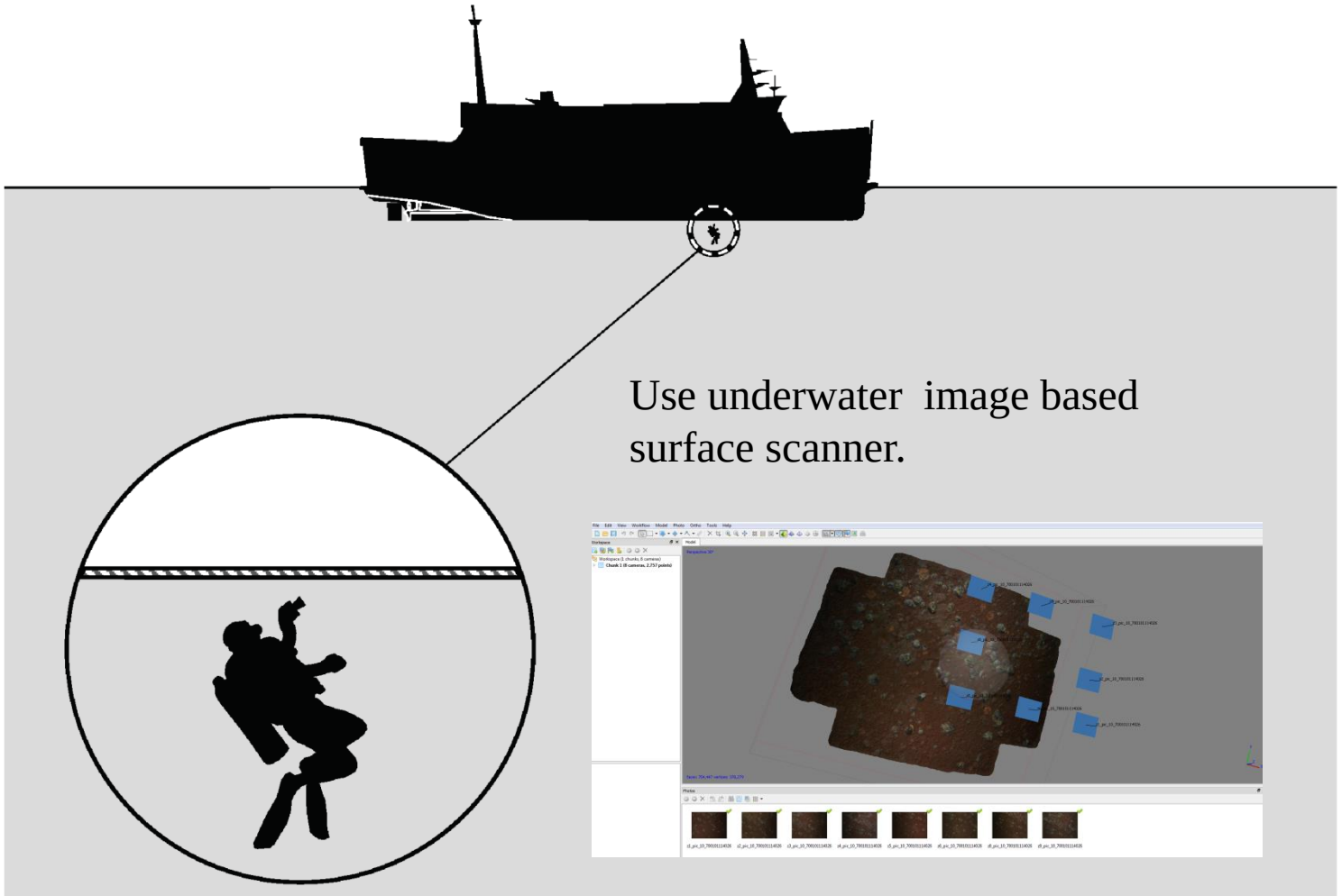

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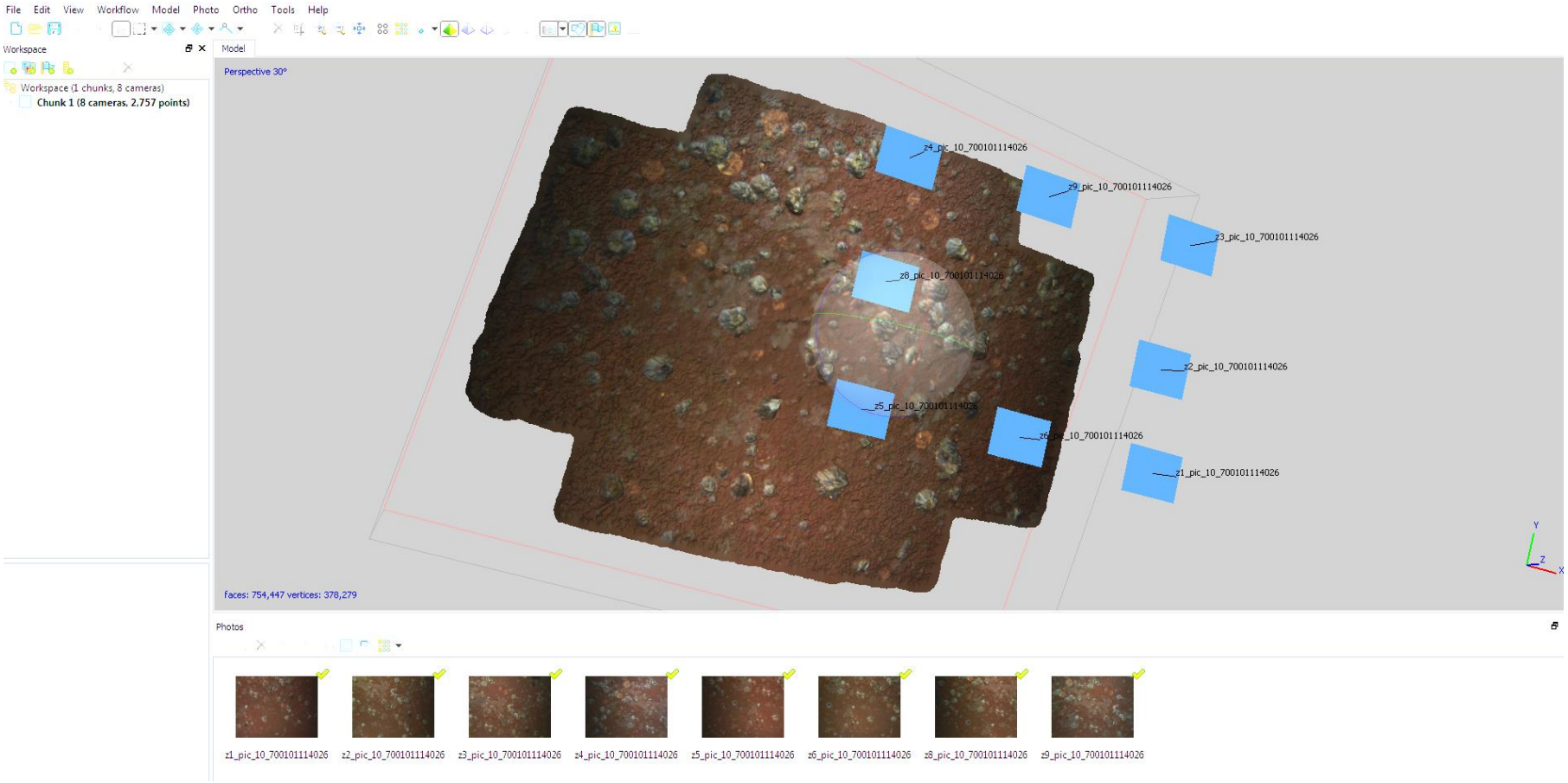
Using tomography techniques, multiple images are reconstructed to produce 3D surface scan data.



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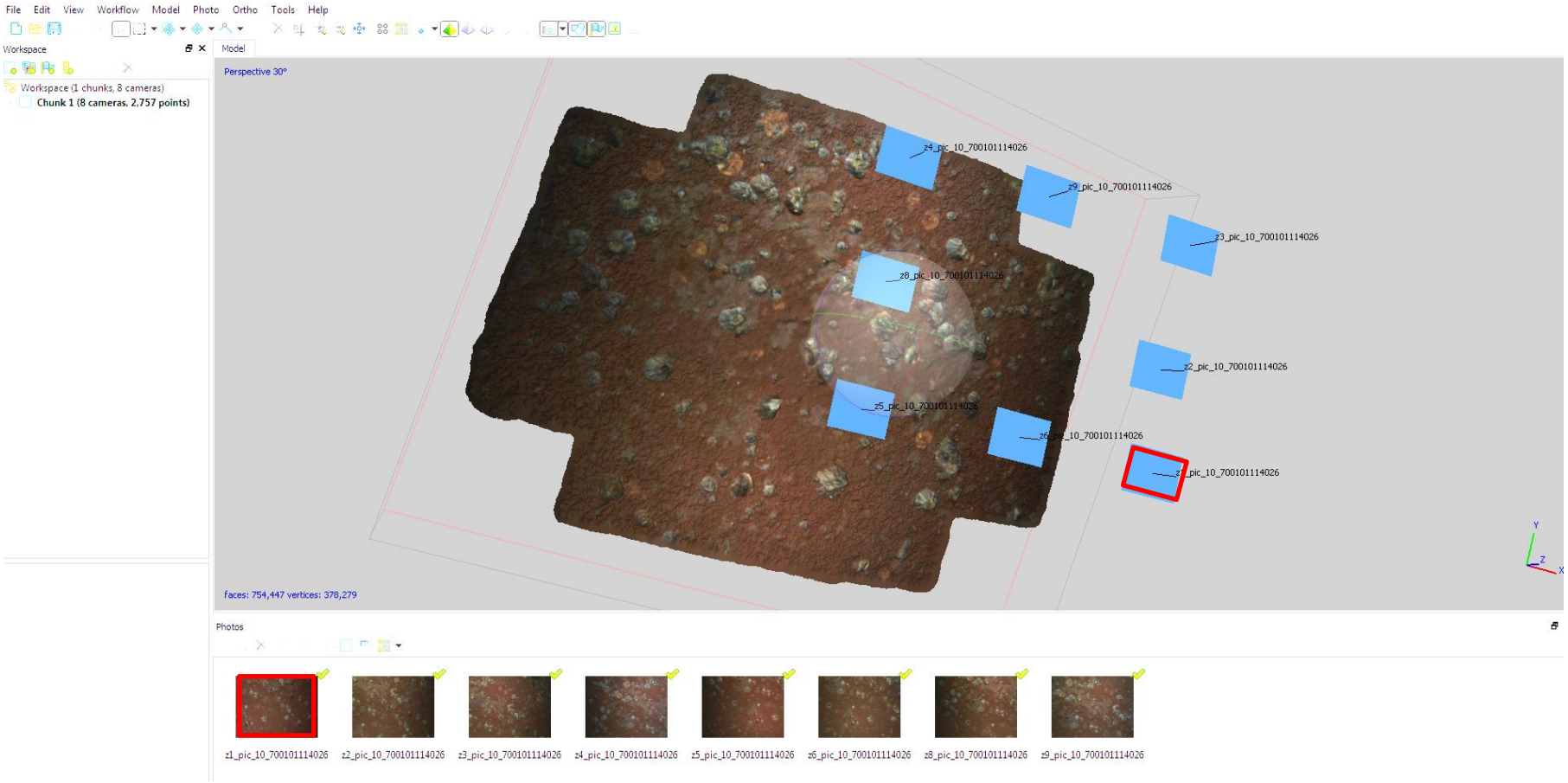

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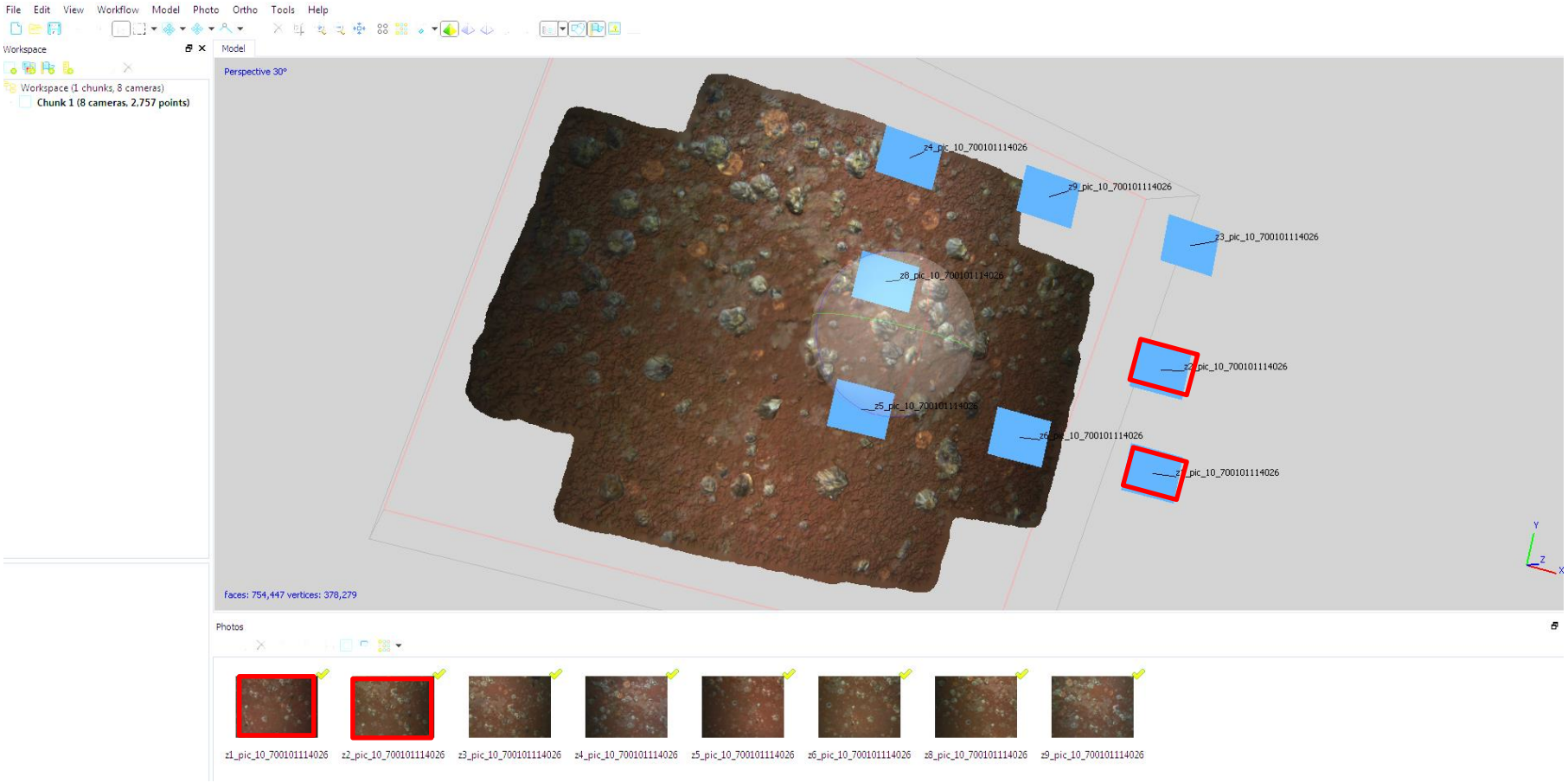

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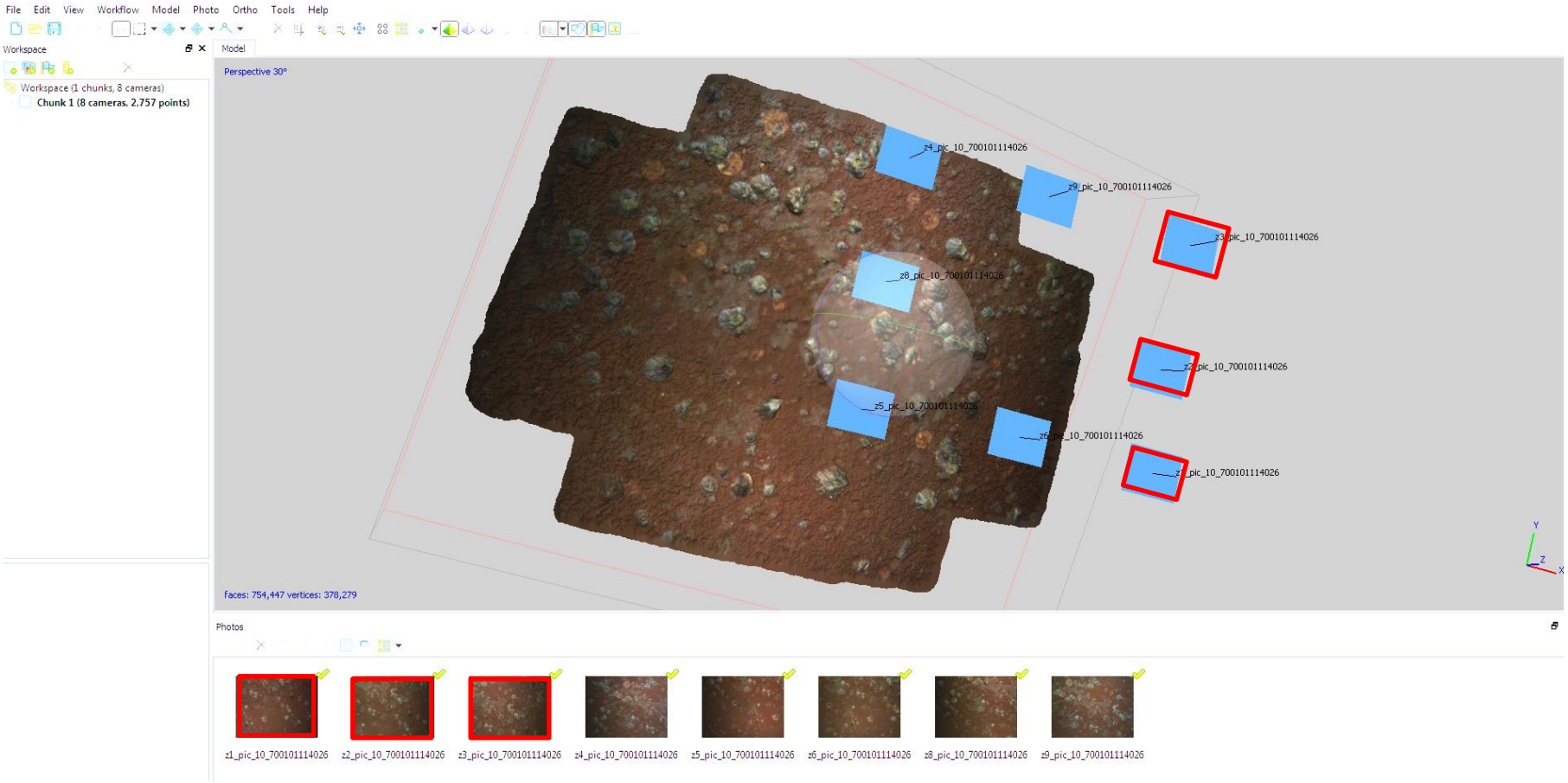

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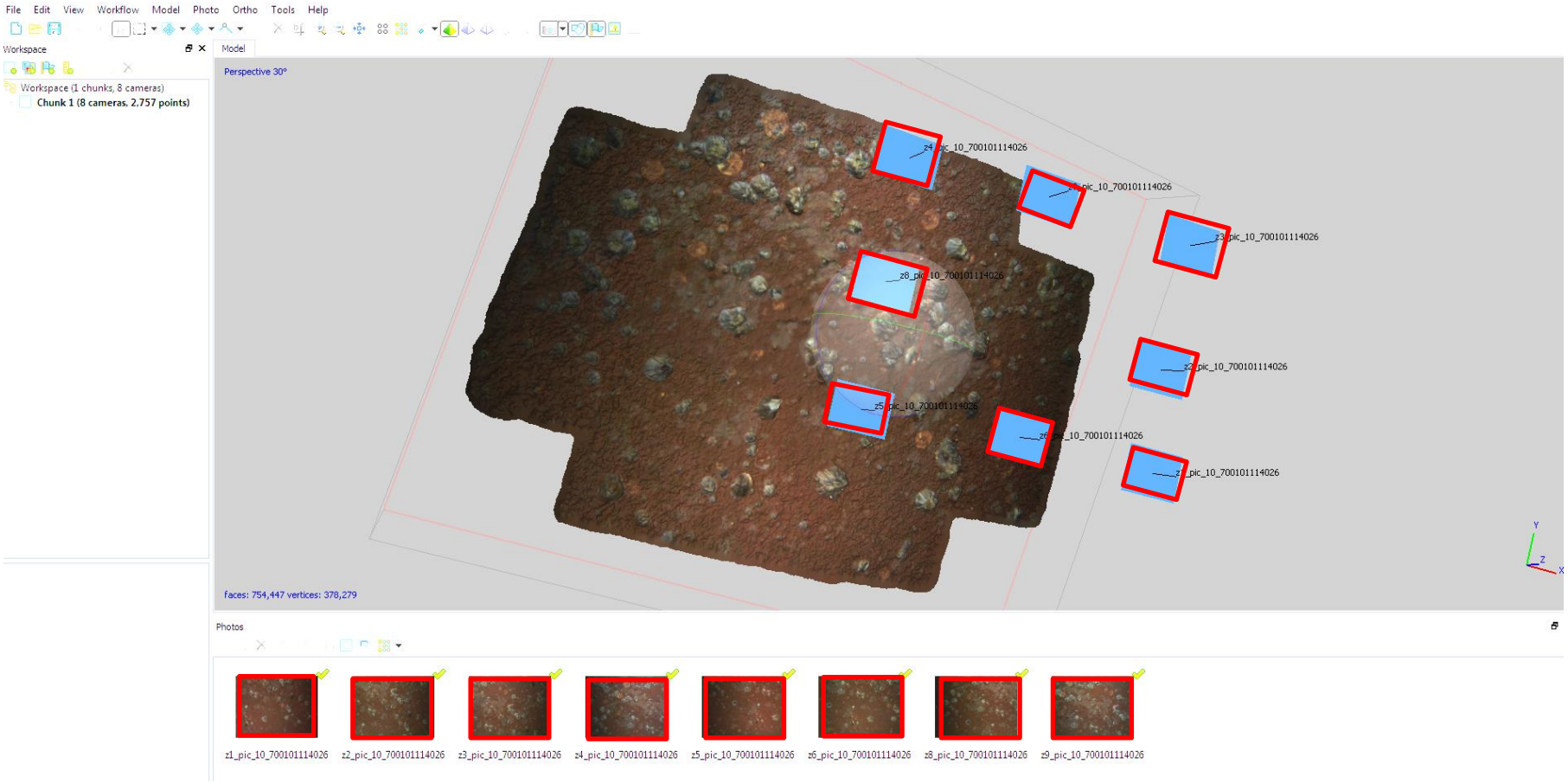

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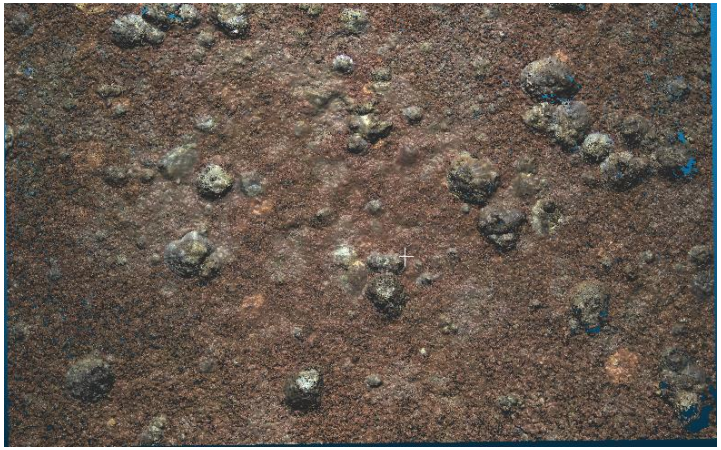

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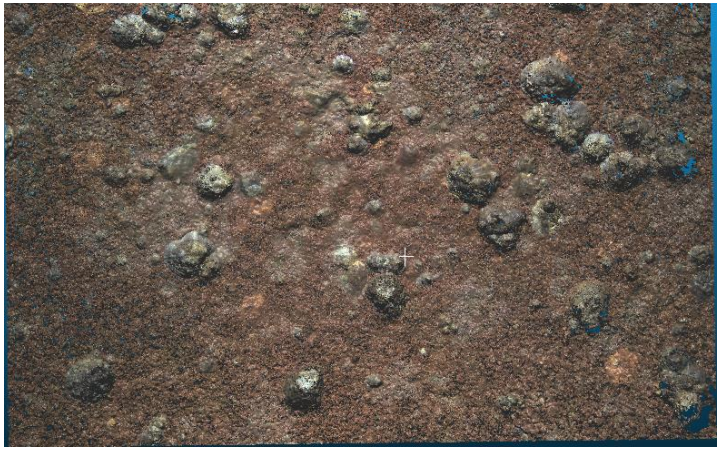
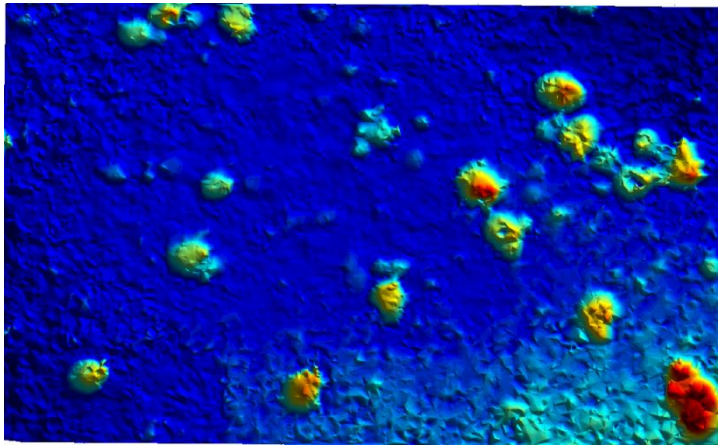


Roughness details



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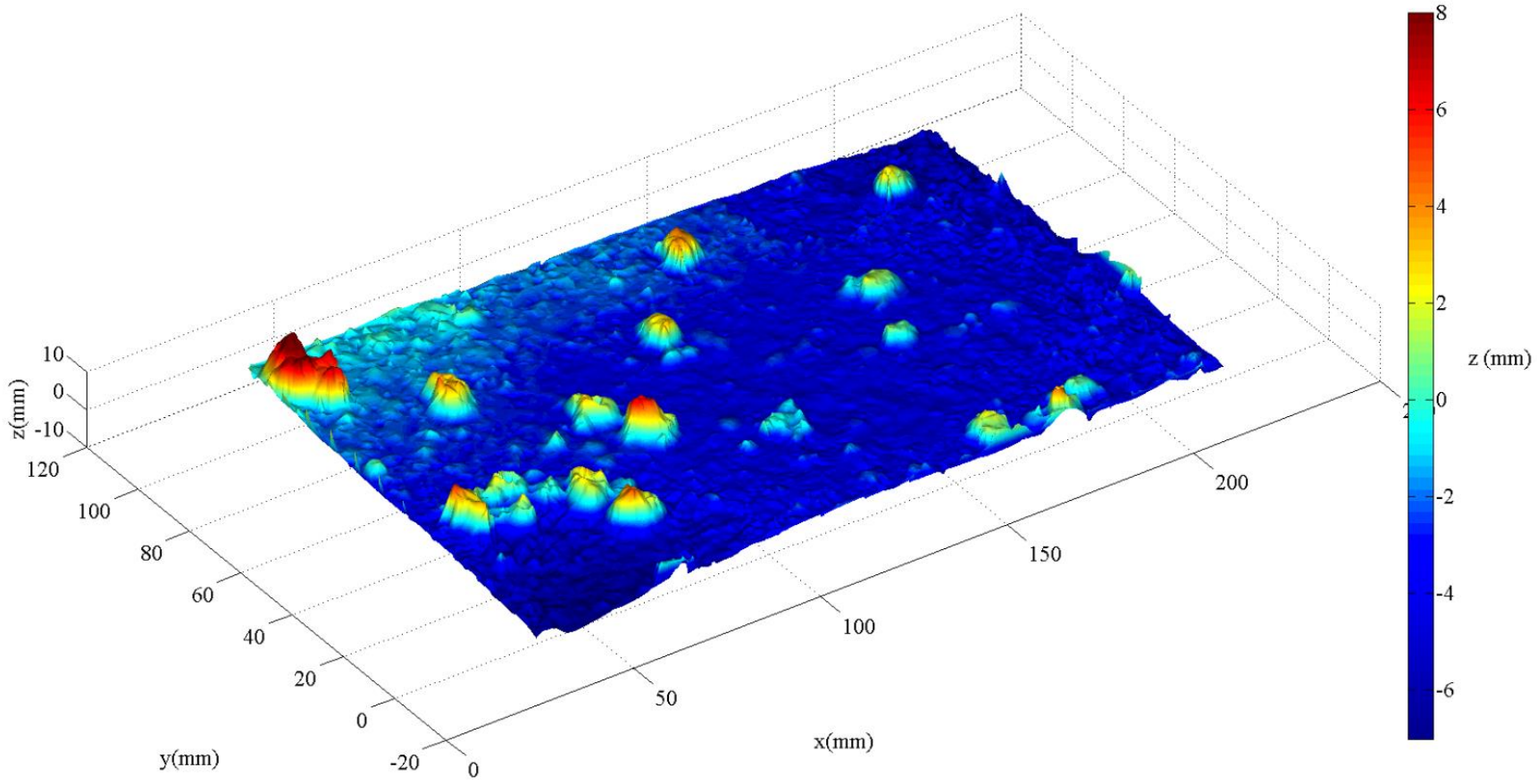

Future work

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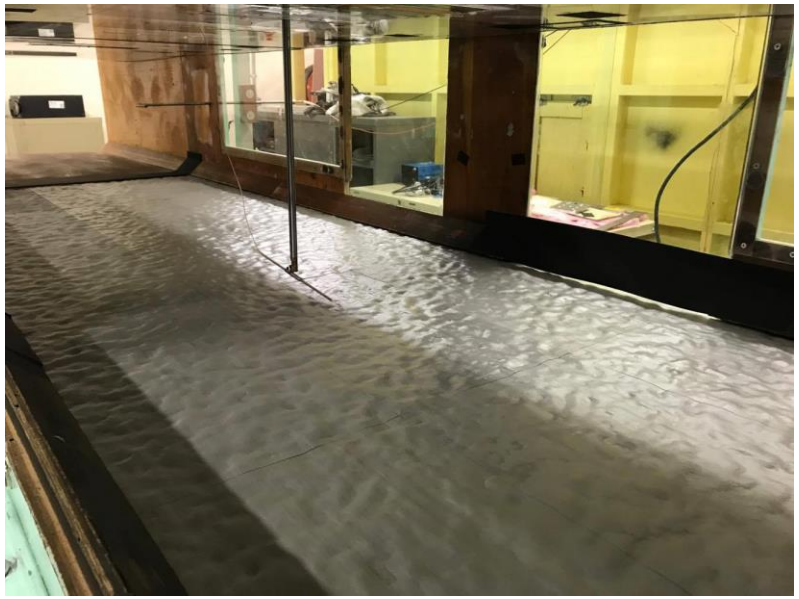

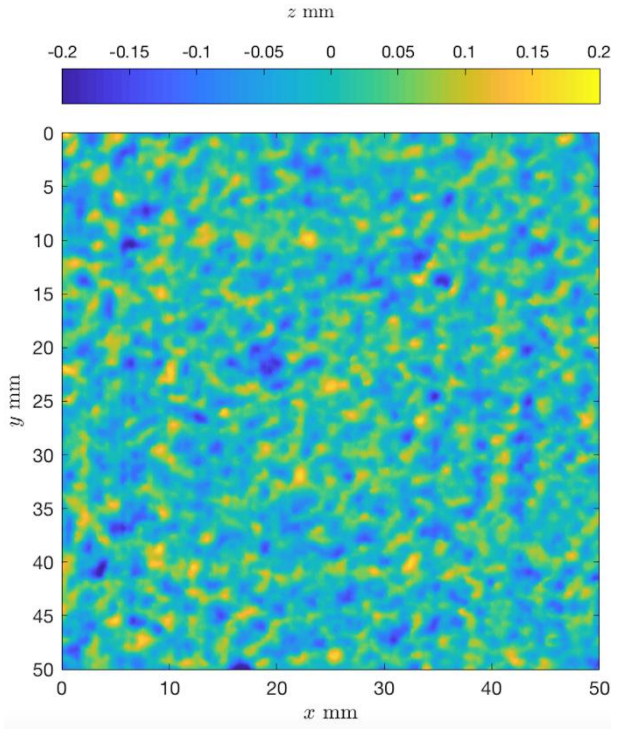

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4. Further improvement of the image surface scanner.

Conclusion

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4. Even a recently cleaned ship will experience severe drag-penalty.

Conclusion

B. Nugroho, I. K. A. P. Utama, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2018) *The influence of in-plane roughness wavelength relative to the boundary layer thickness.* 12th International ERCOFTAC Symposium on Engineering Turbulence Modelling and Measurements (ETMM). Montpellier, France. (under construction)

B. Nugroho, R. Baidya, M. N. Nurrohman, A. K. Yusim, F. A. Prasetyo, M. Yusuf, I. K. Suastika, I. K. A. P. Utama, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2017) *In-situ turbulent boundary layer measurements over freshly cleaned ship-hull under steady cruising*. Royal Institution of Naval Architects (RINA) Conference, International Conference on Ship and Offshore Technology (ICSOT). Jakarta, Indonesia.

I. K. A. P. Utama, B. Nugroho, C. Chin, M. L. Hakim, F. A. Prasetyo, M. Yusuf, I. K. Suastika, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2017) *A study of skin friction drag from realistic roughness of a freshly cleaned and painted ship hull.* International Symposium on Marine Engineering (ISME). Tokyo, Japan.

N. Hutchins, J. P. Monty, B. Ganapathisubramani, B. Nugroho, I. K. A. P. Utama (2016) *Turbulent boundary layers developing over rough surfaces: from the laboratory to full-scale systems*. Plenery speaker paper. 20th Australasian Fluid Mechanics Conference (AFMC). Perth, Australia.