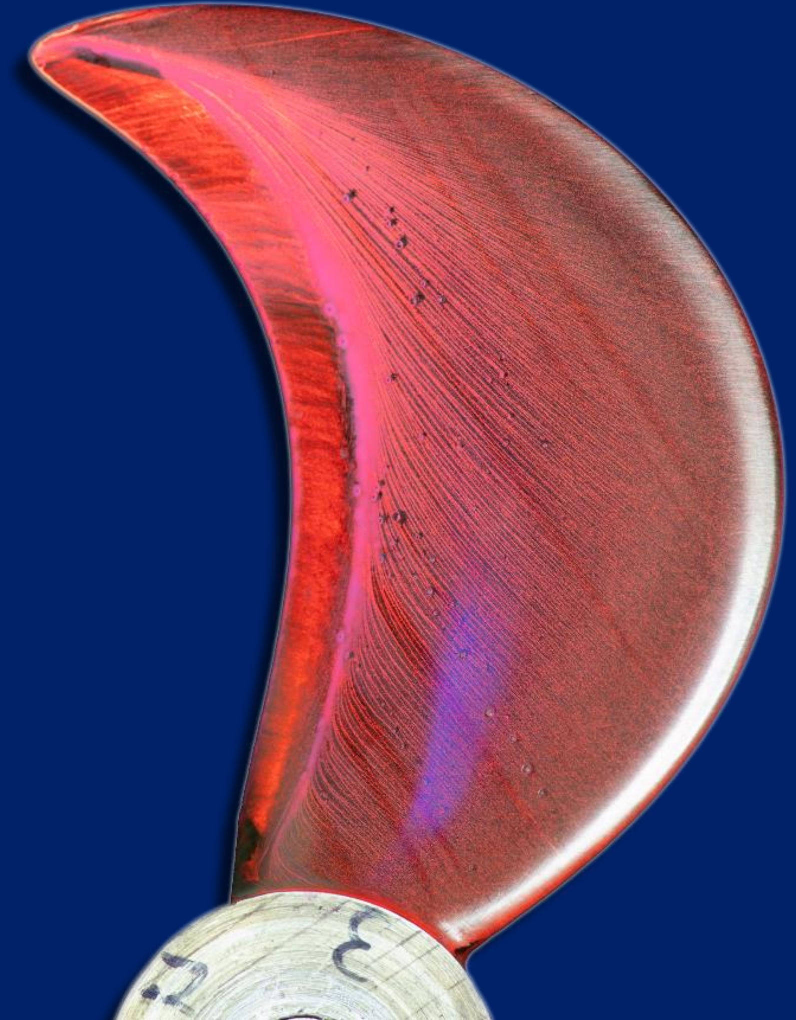
BETTER SHIPS, BLUE OCEANS

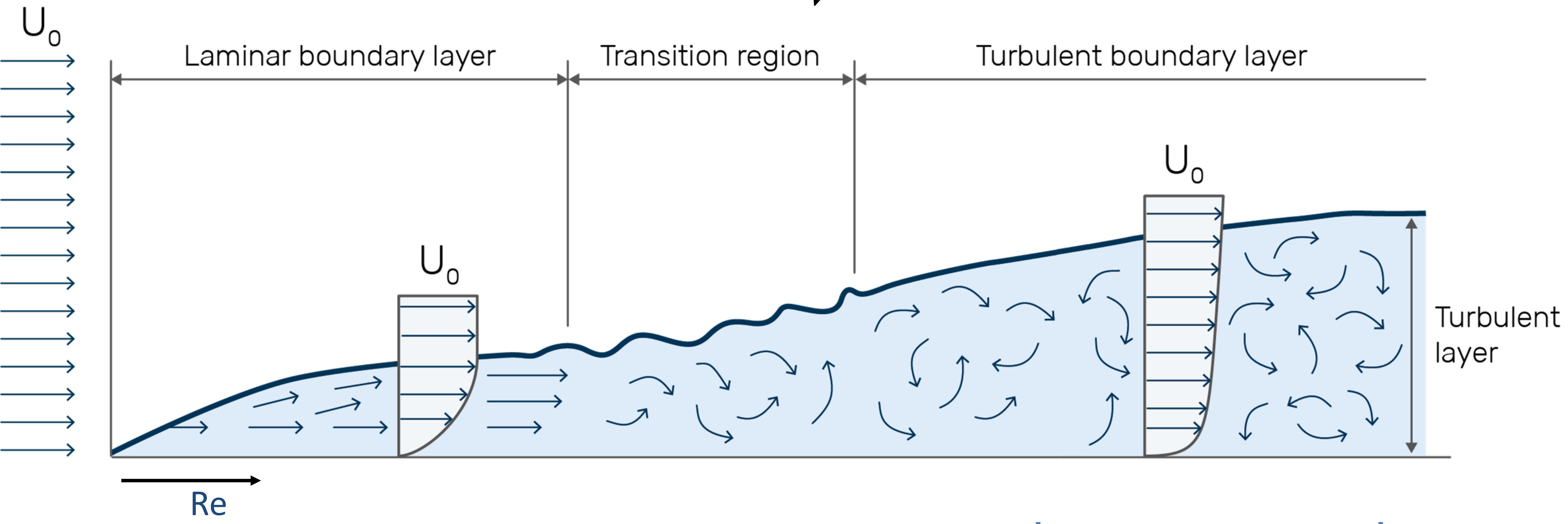


An Experimental Study on Visualisation and Passive Control of Model Propeller Boundary Layer

B.Schuiling, M.Kerkvliet and D.Rijpkema

Boundary Layer Flow Regime

$$Re = \frac{U_0 L}{\nu}$$



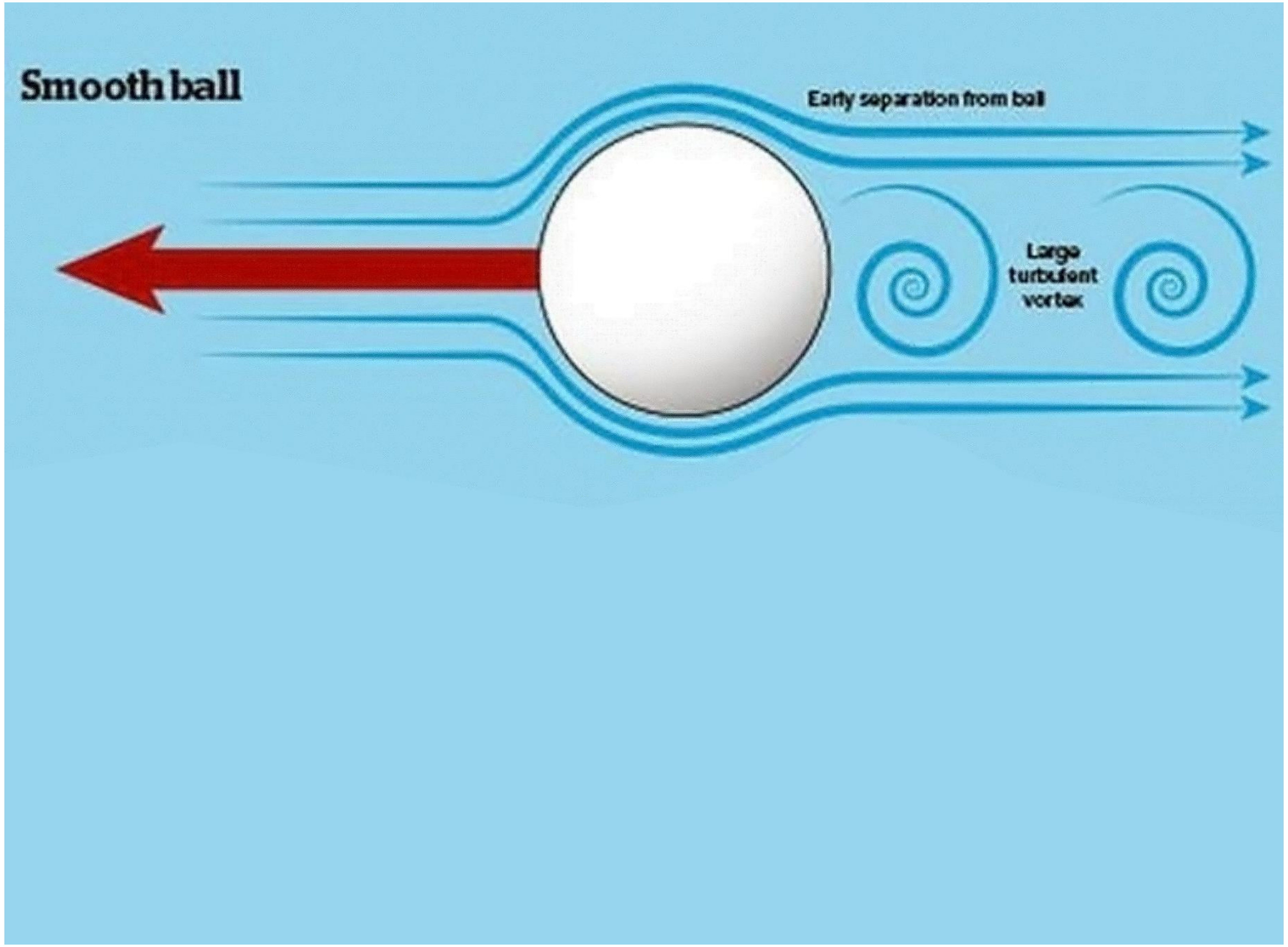
Model-Scale Flows

Ship-Scale Flows

Laminar versus Turbulent Flow

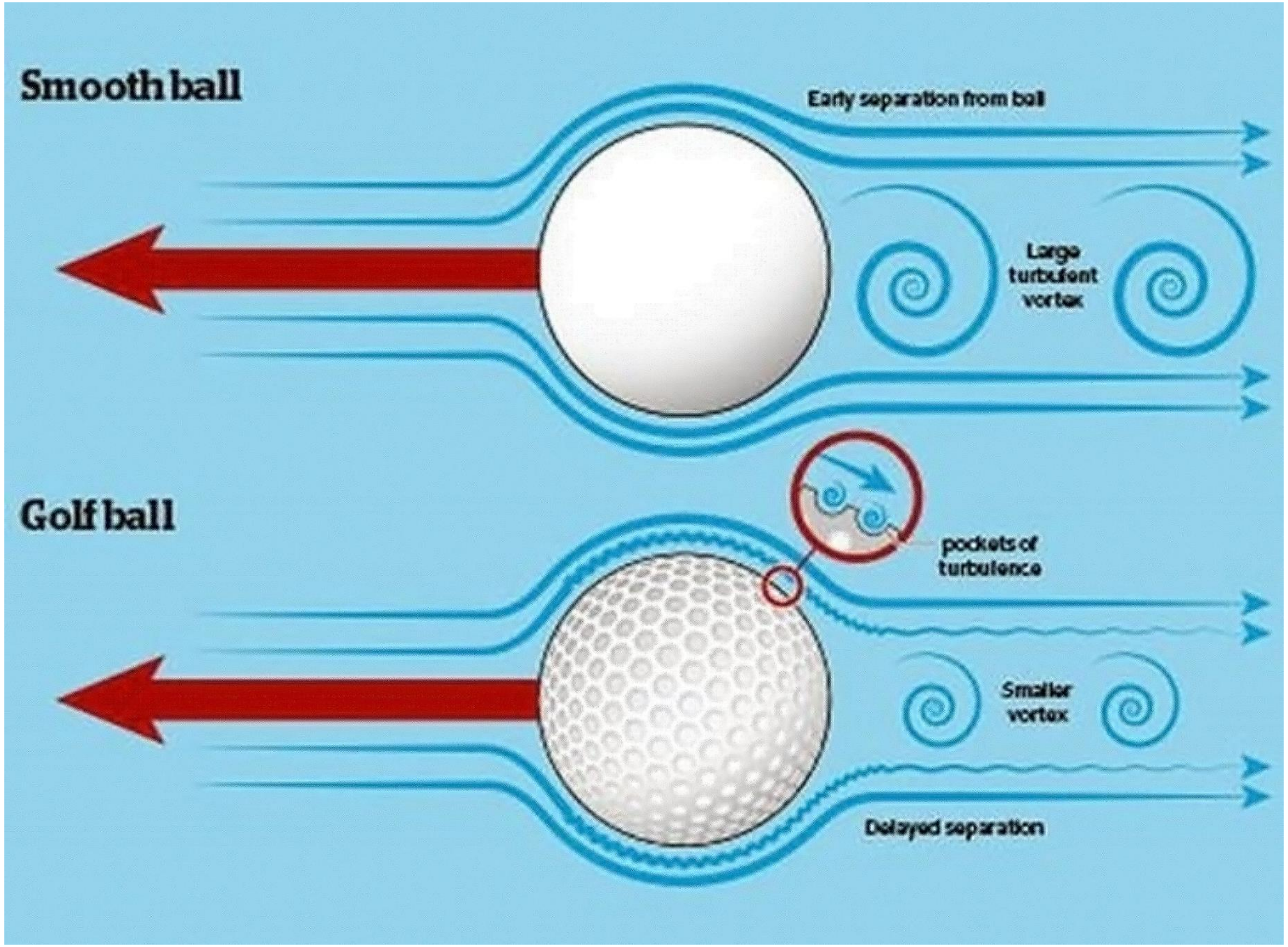
Boundary Layer Flow Regime

- Laminar boundary layer
  - Less frictional resistance
  - Prone to early separate

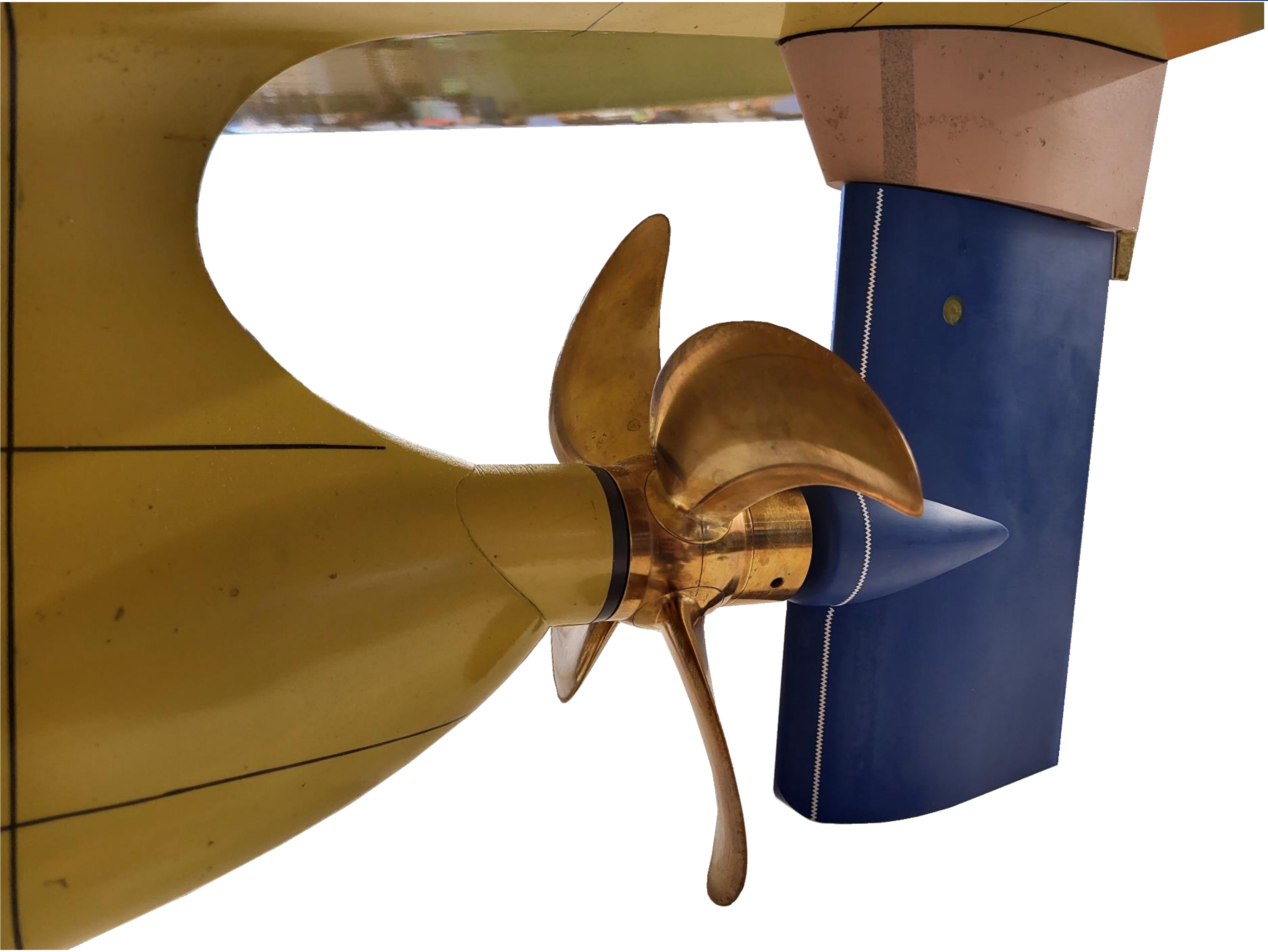


Boundary Layer Flow Regime

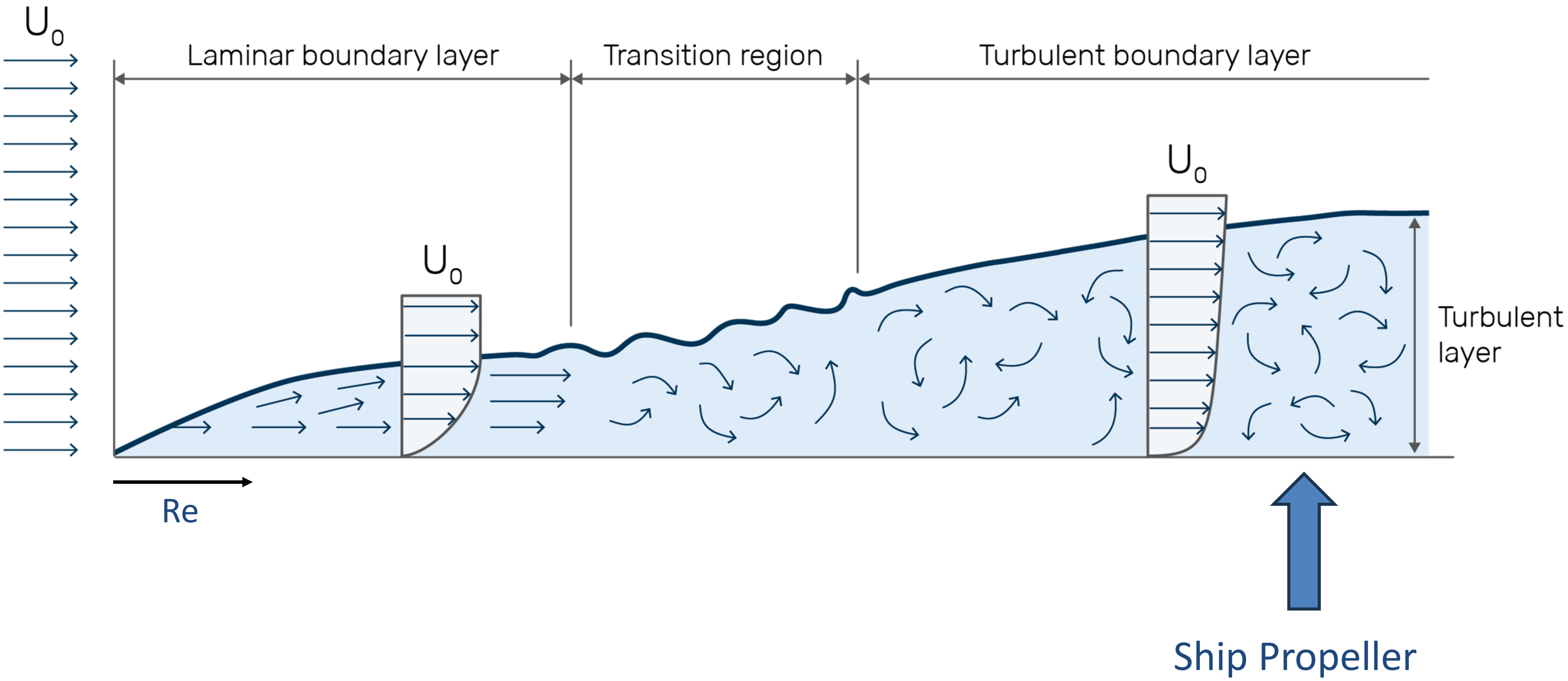
- Laminar boundary layer
  - Less frictional resistance
  - Prone to early separate
- Turbulent boundary layer
  - Increased frictional resistance
  - Energizing the boundary layer
  - Delayed separation



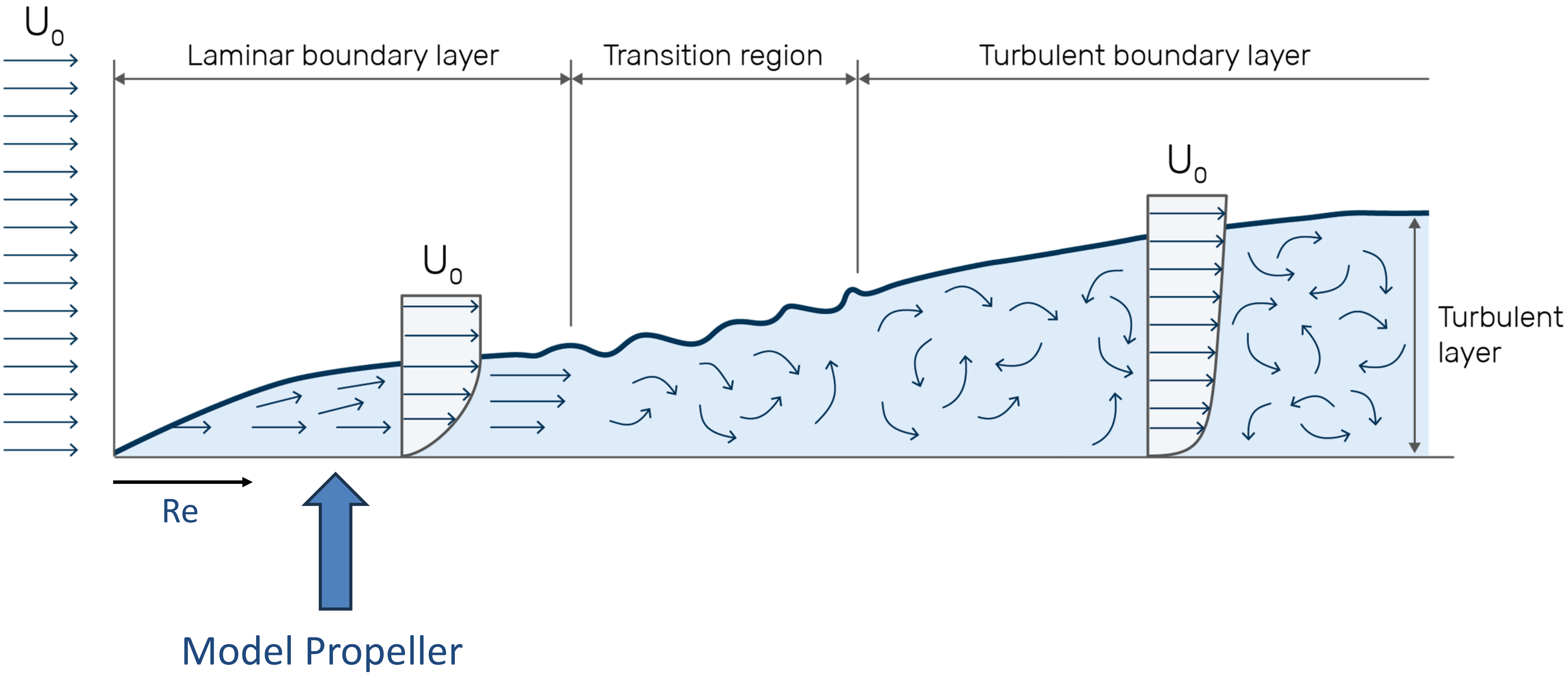
Boundary Layer Flow Regime



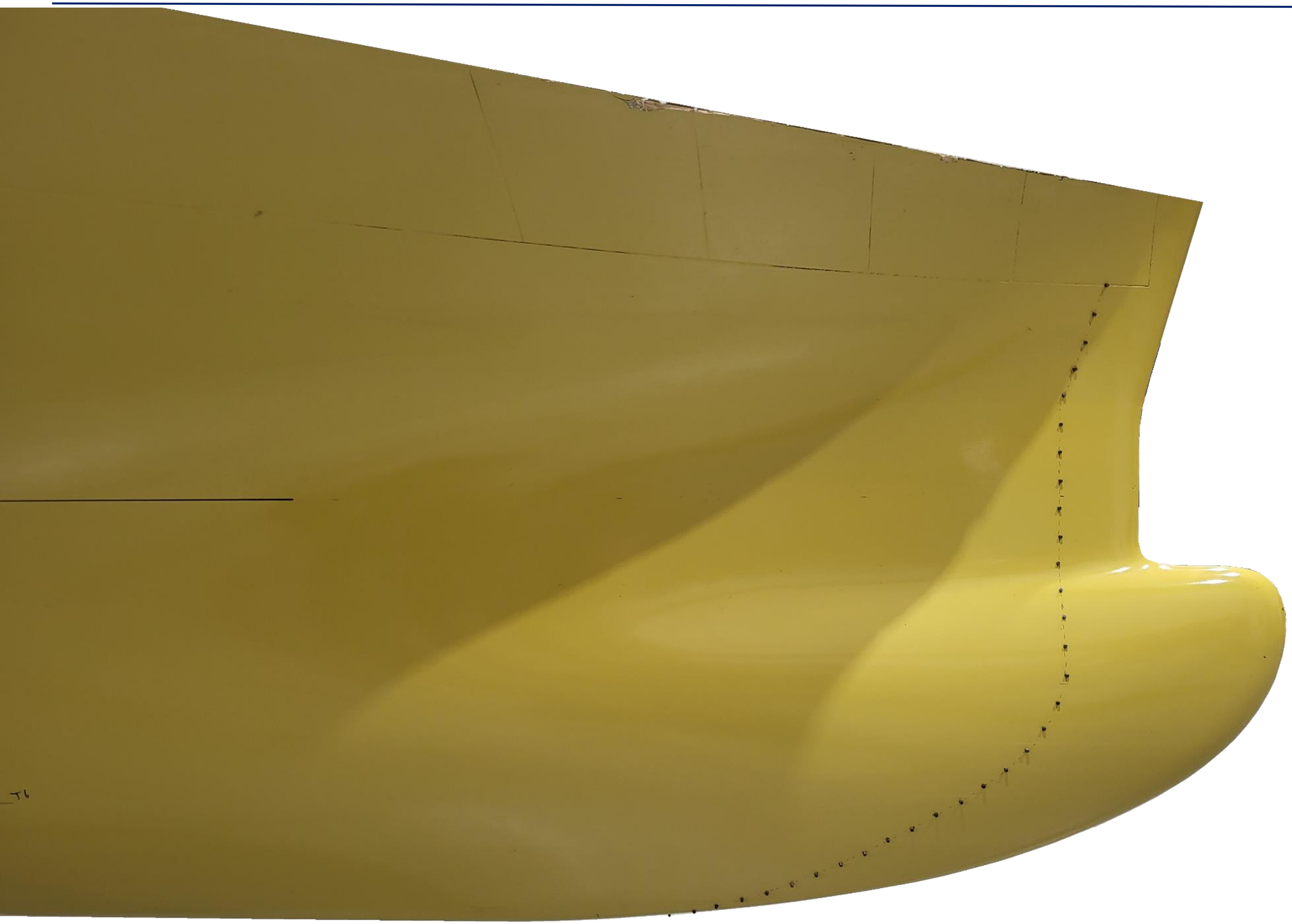
Boundary Layer Flow Regime



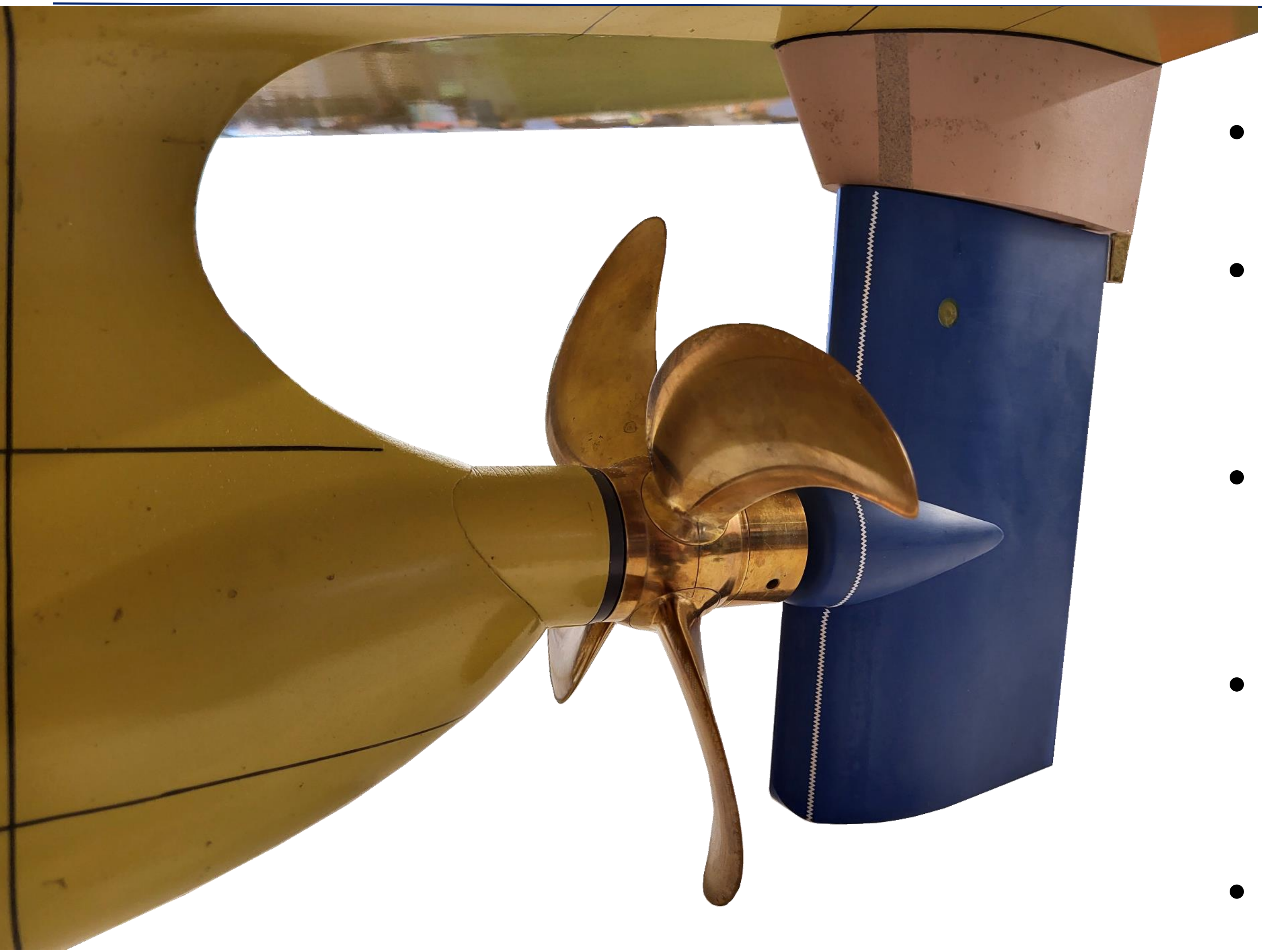
Boundary Layer Flow Regime



Introduction

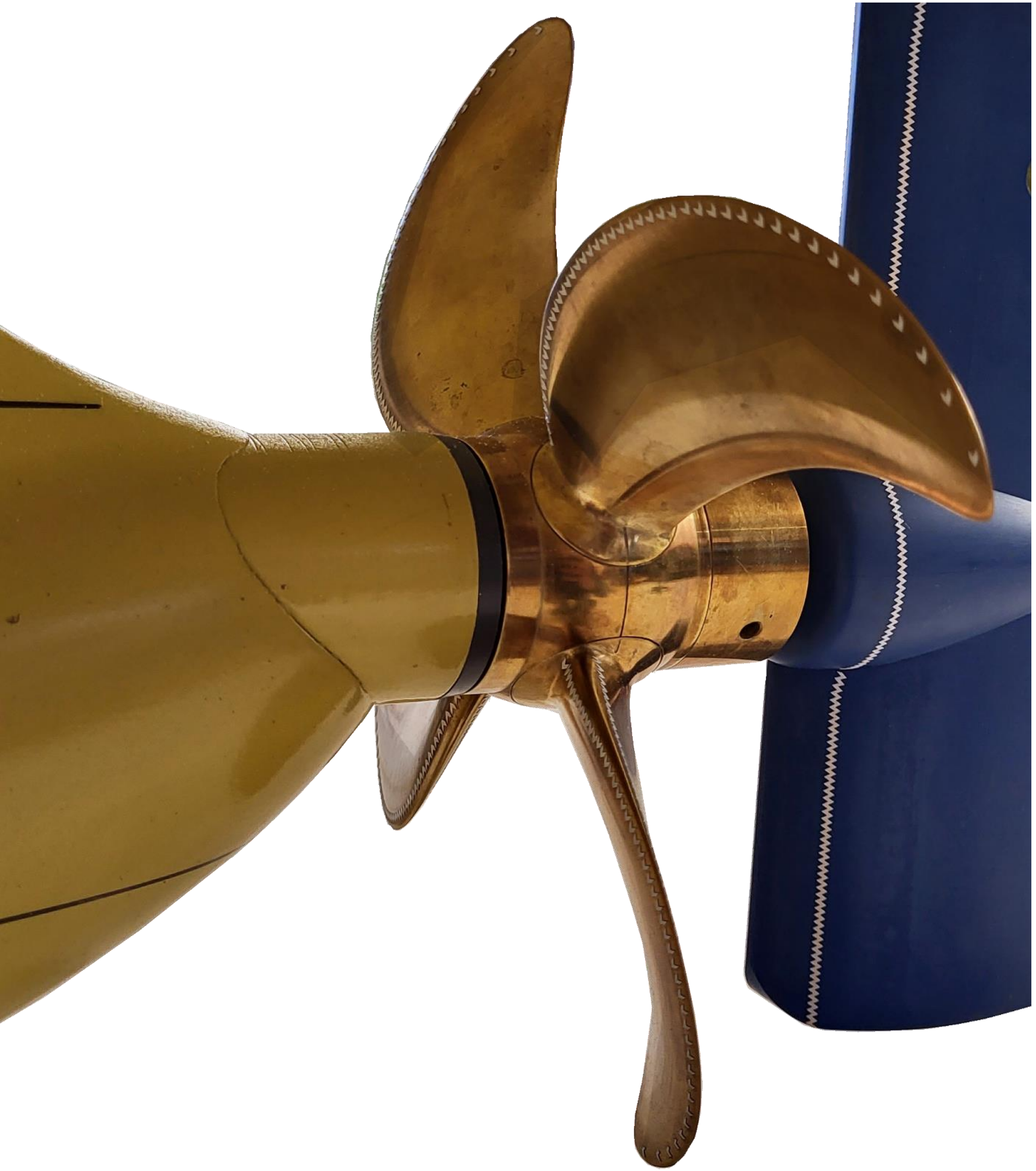


Introduction



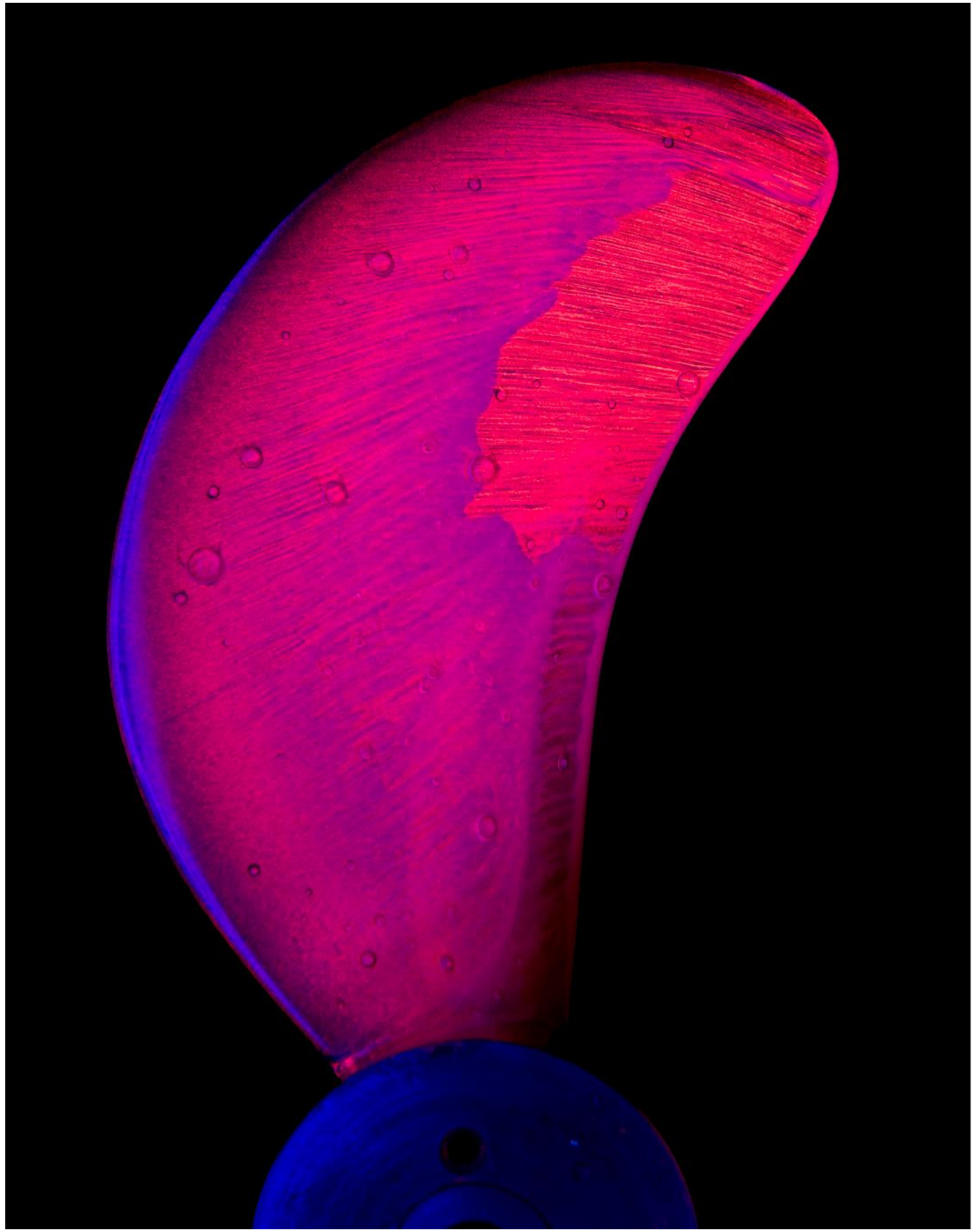
- Decades of experience
- Propeller performance decreases
- What is the penalty of the turbulence stimulation?
- The propeller geometry is changed
- The extrapolation procedure is not valid anymore

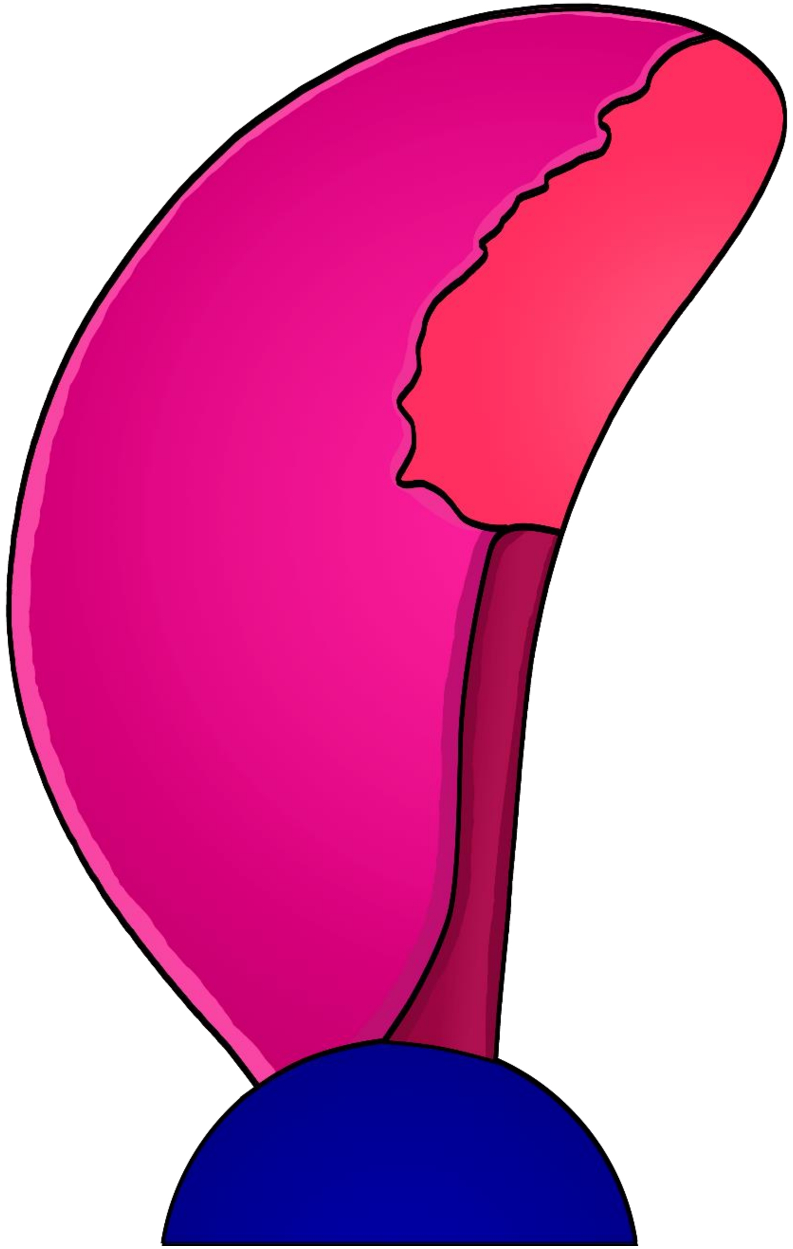
Introduction



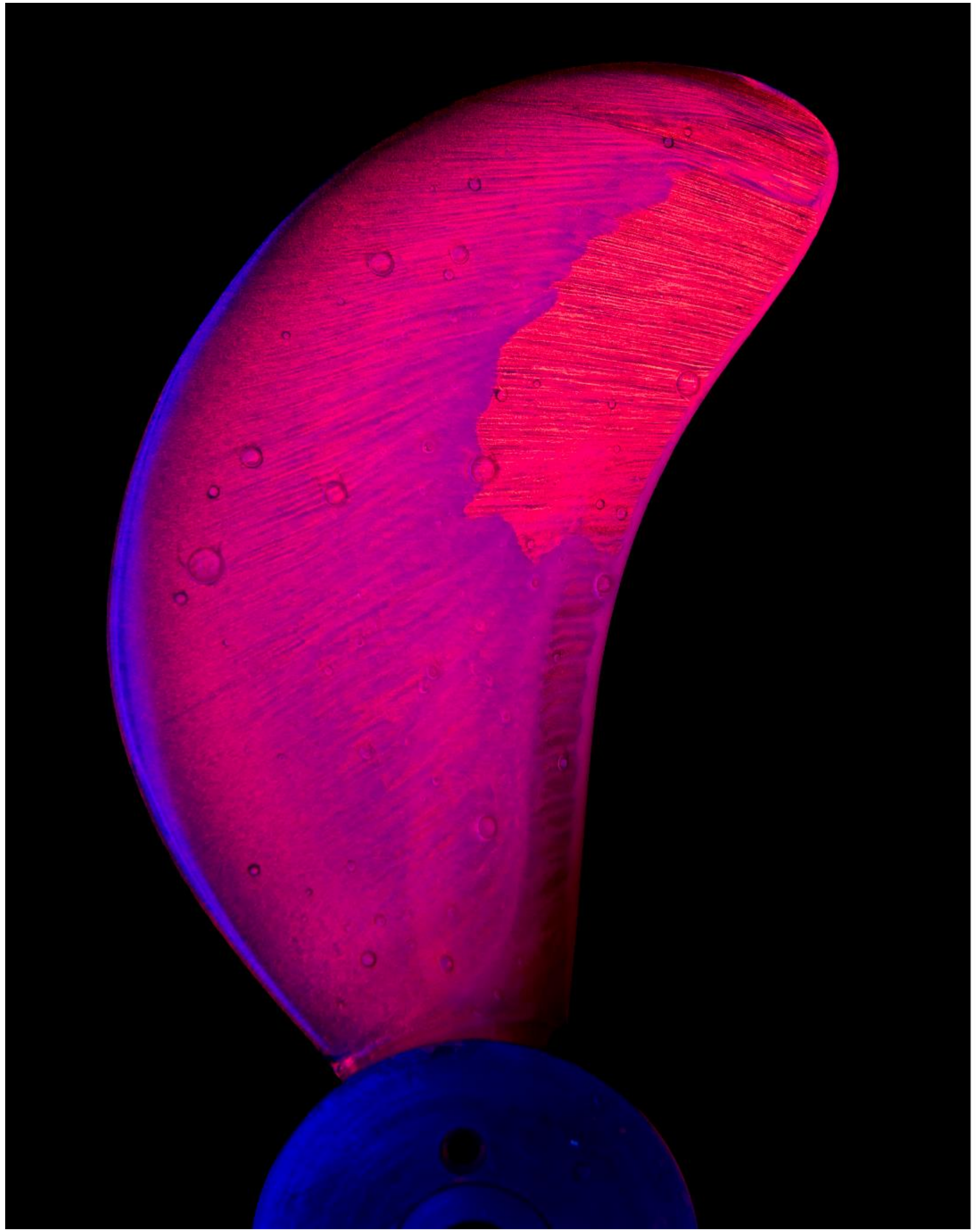
- High quality experimental boundary layer visualisation
- Simple, reliable and effective turbulence stimulation for model propellers

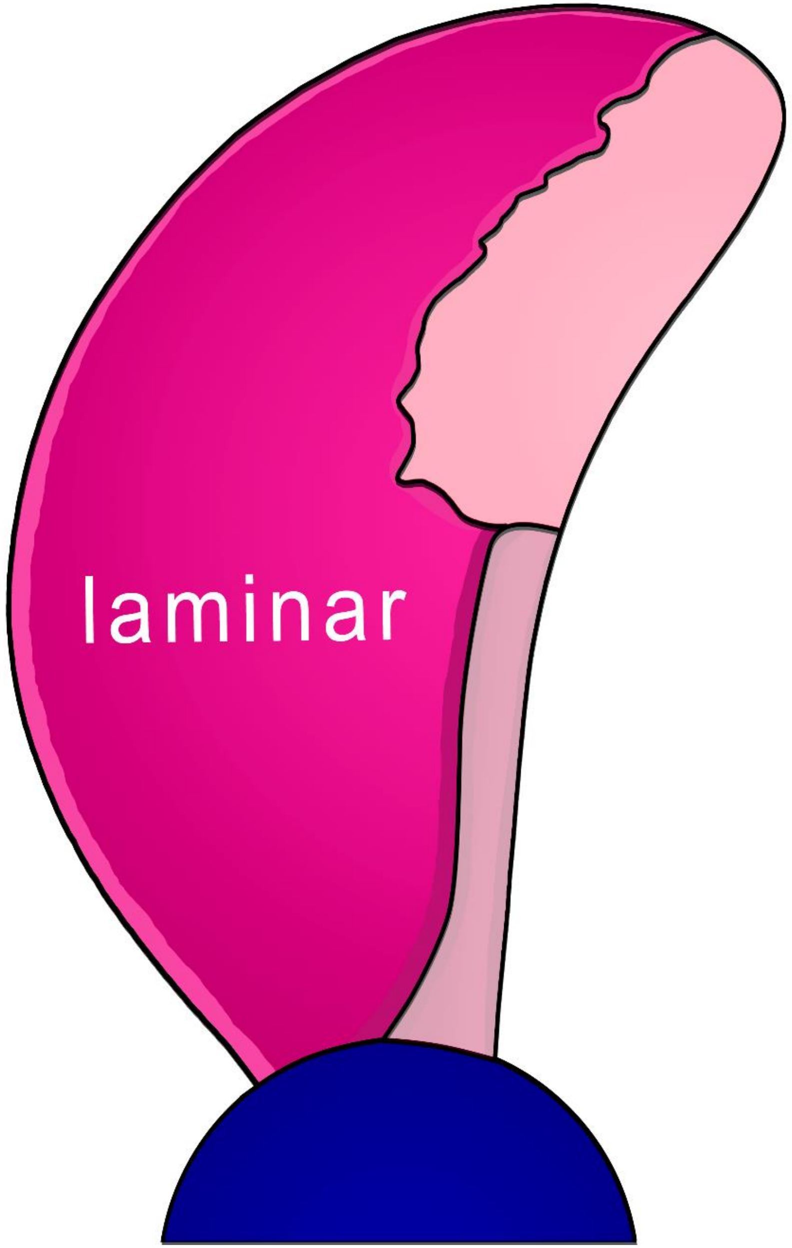
The Propeller Paint Test





The Propeller Paint Test





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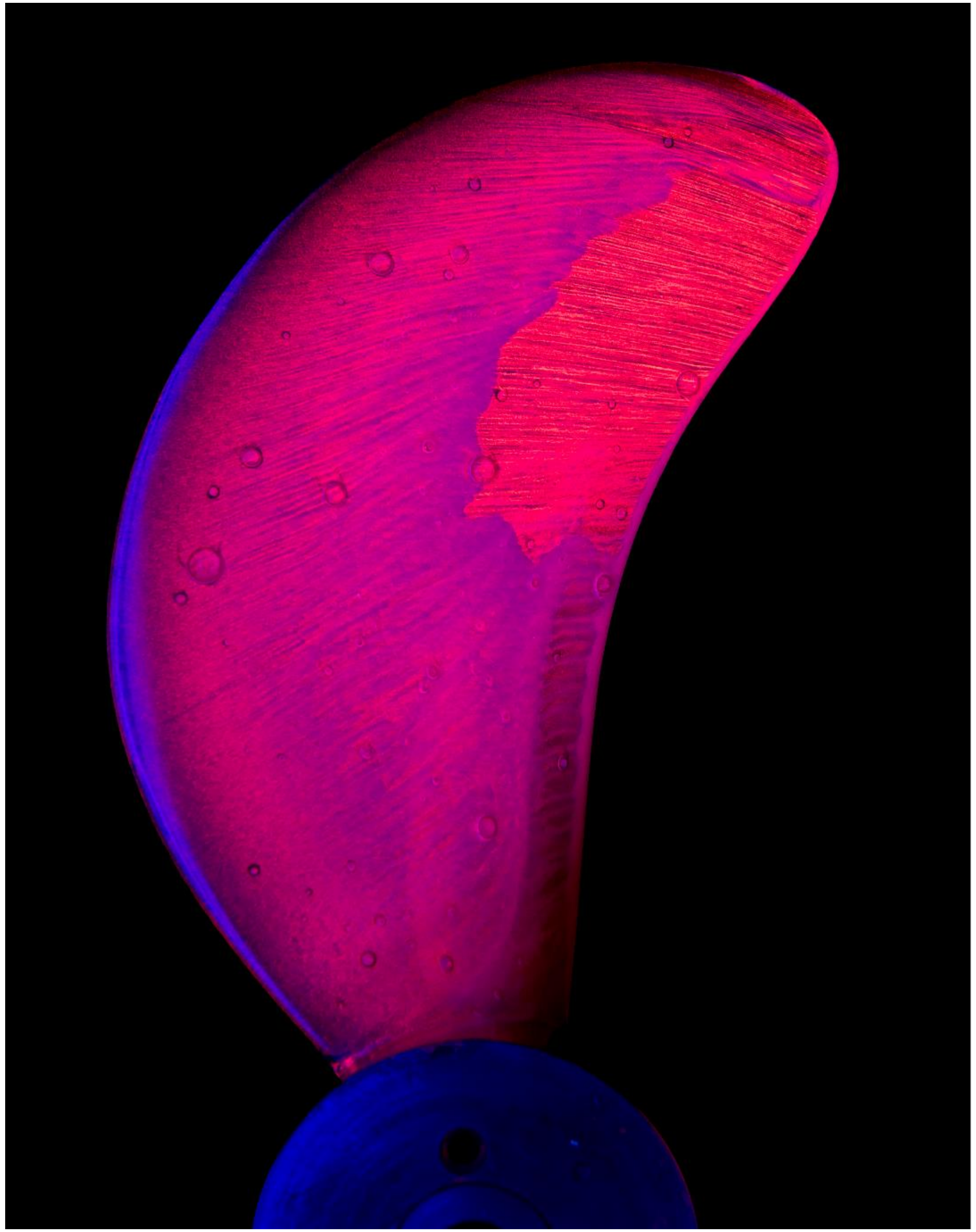

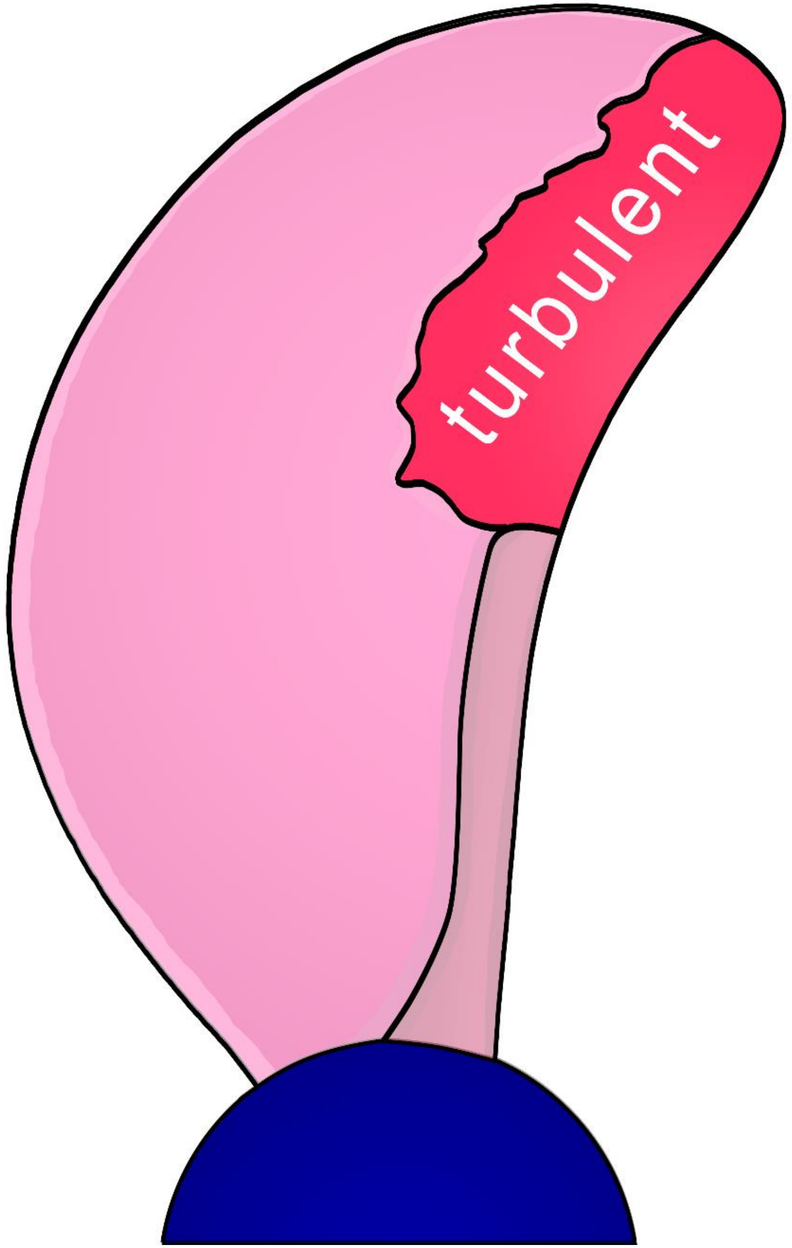

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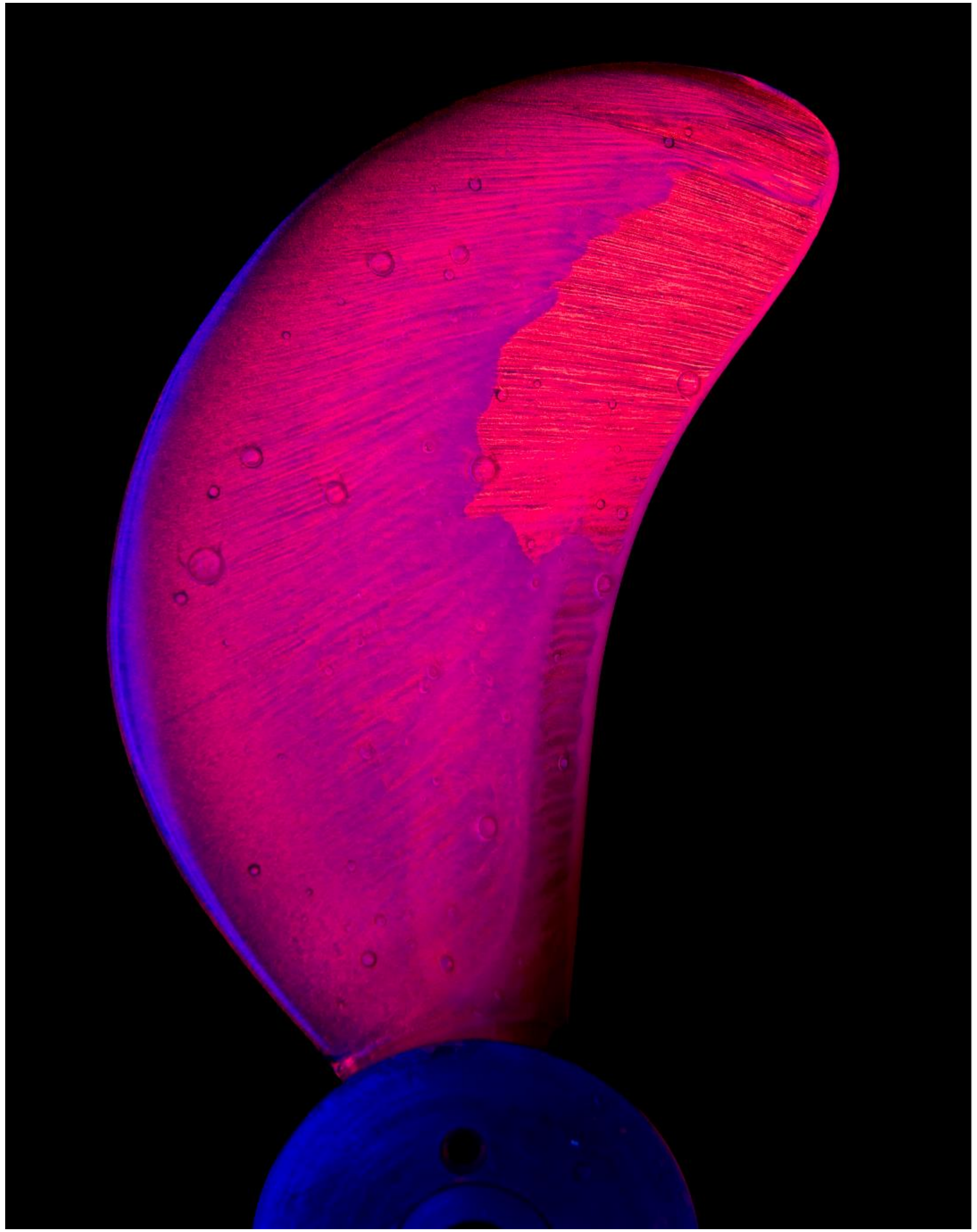

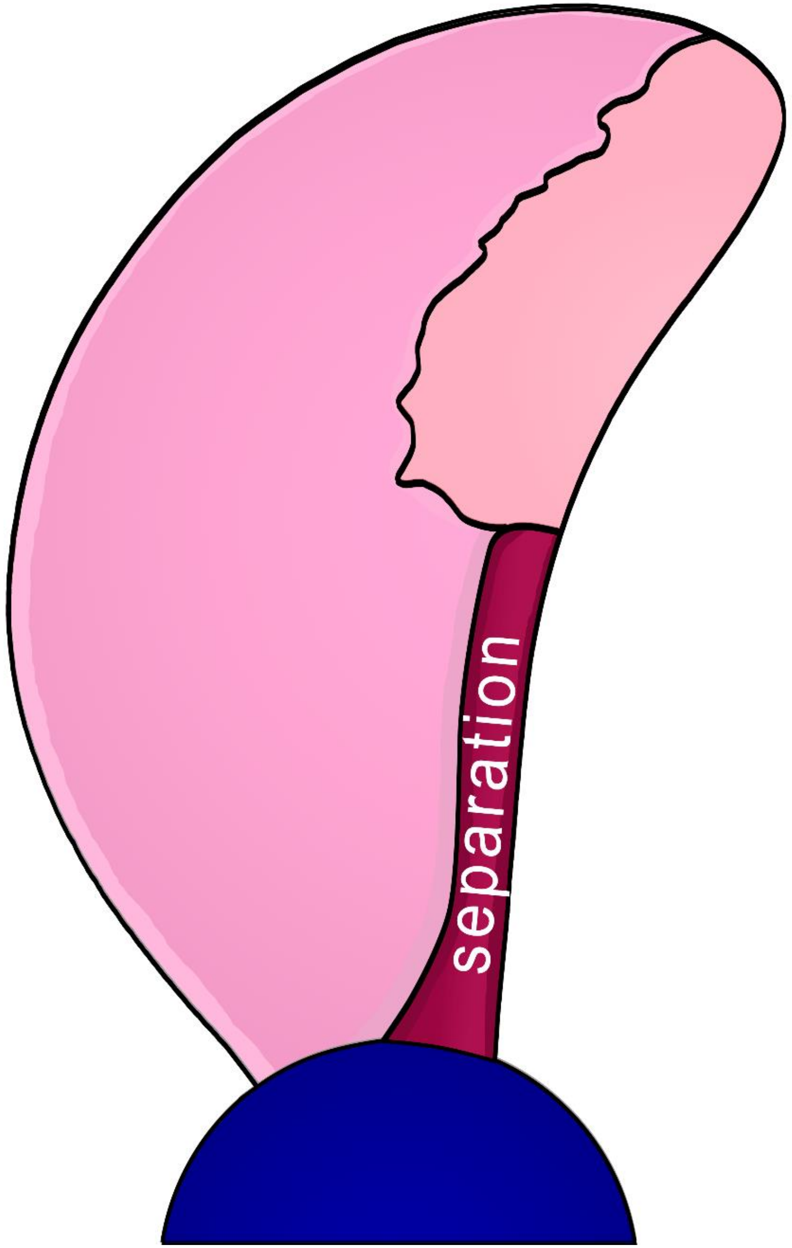

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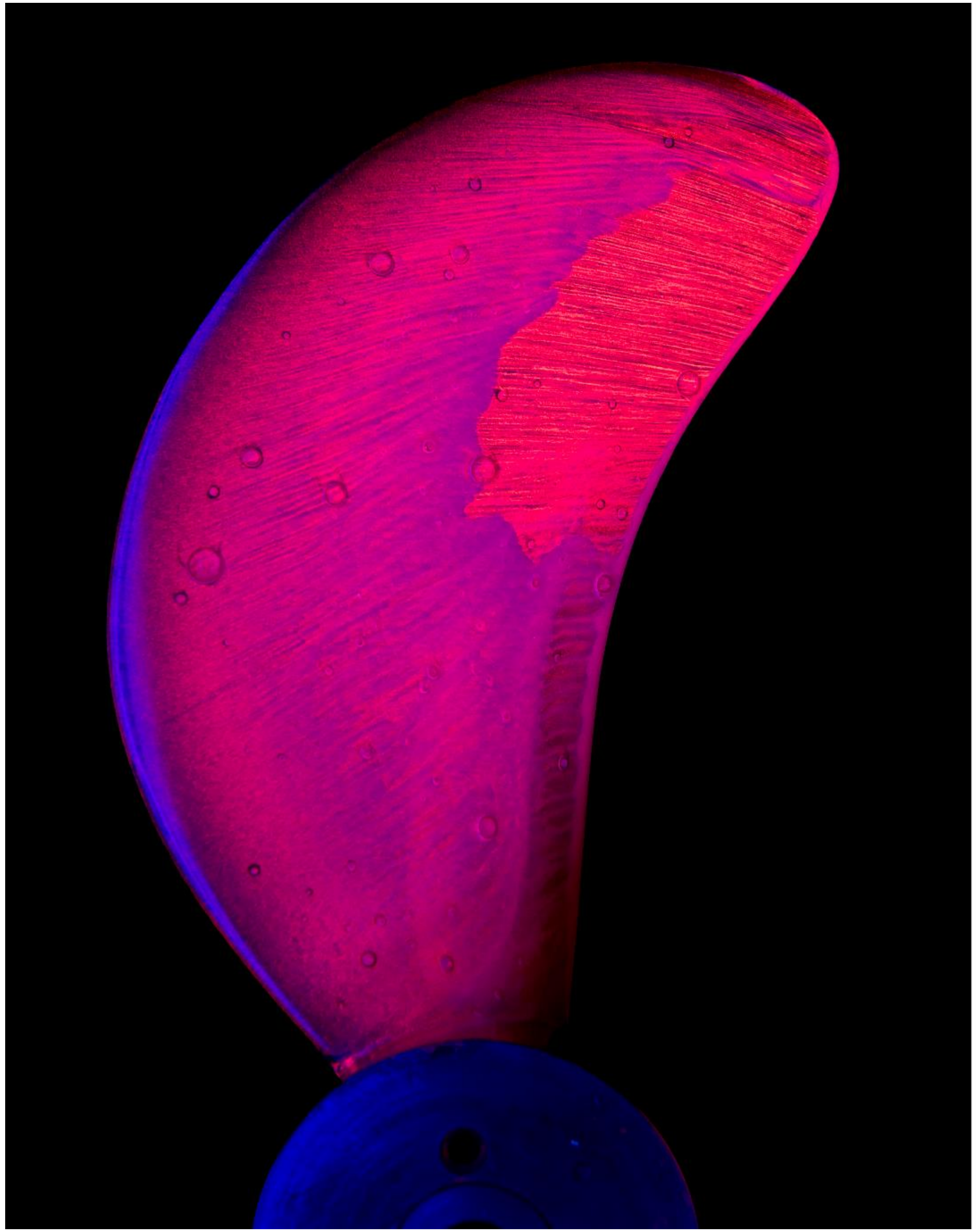

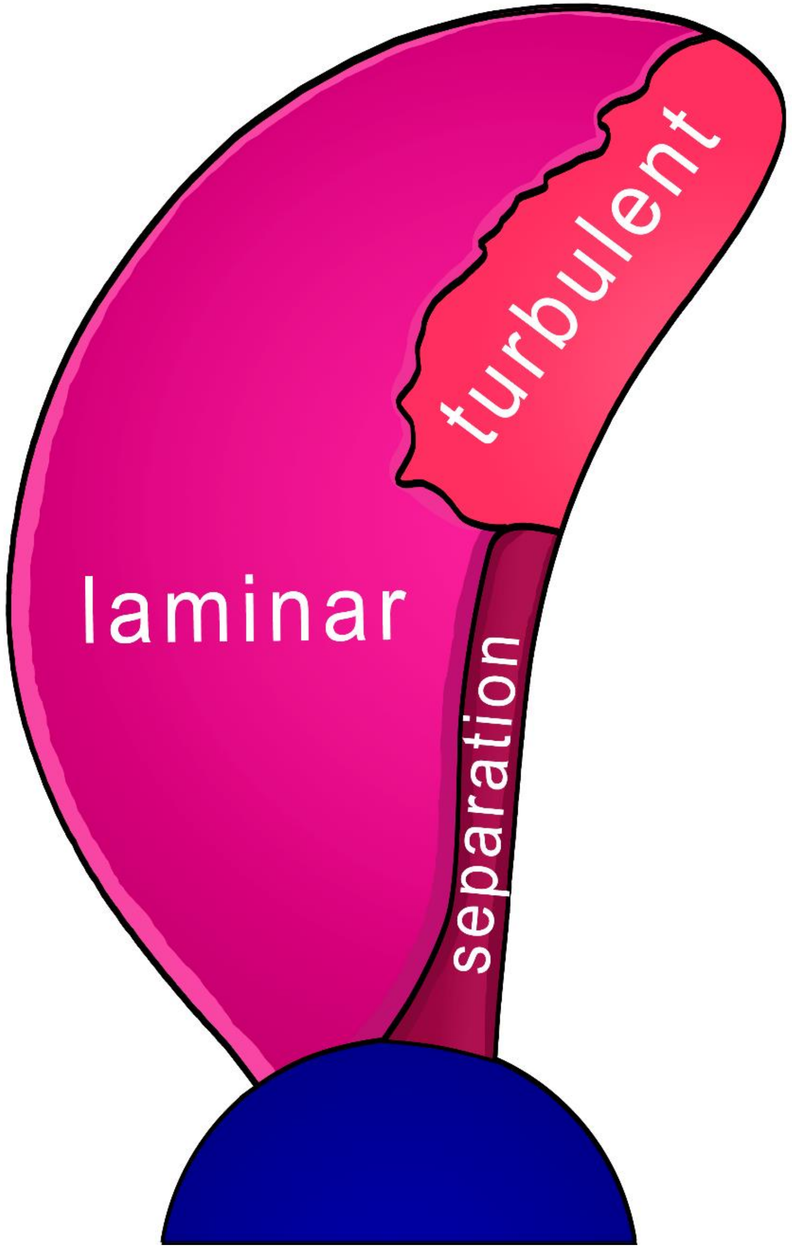

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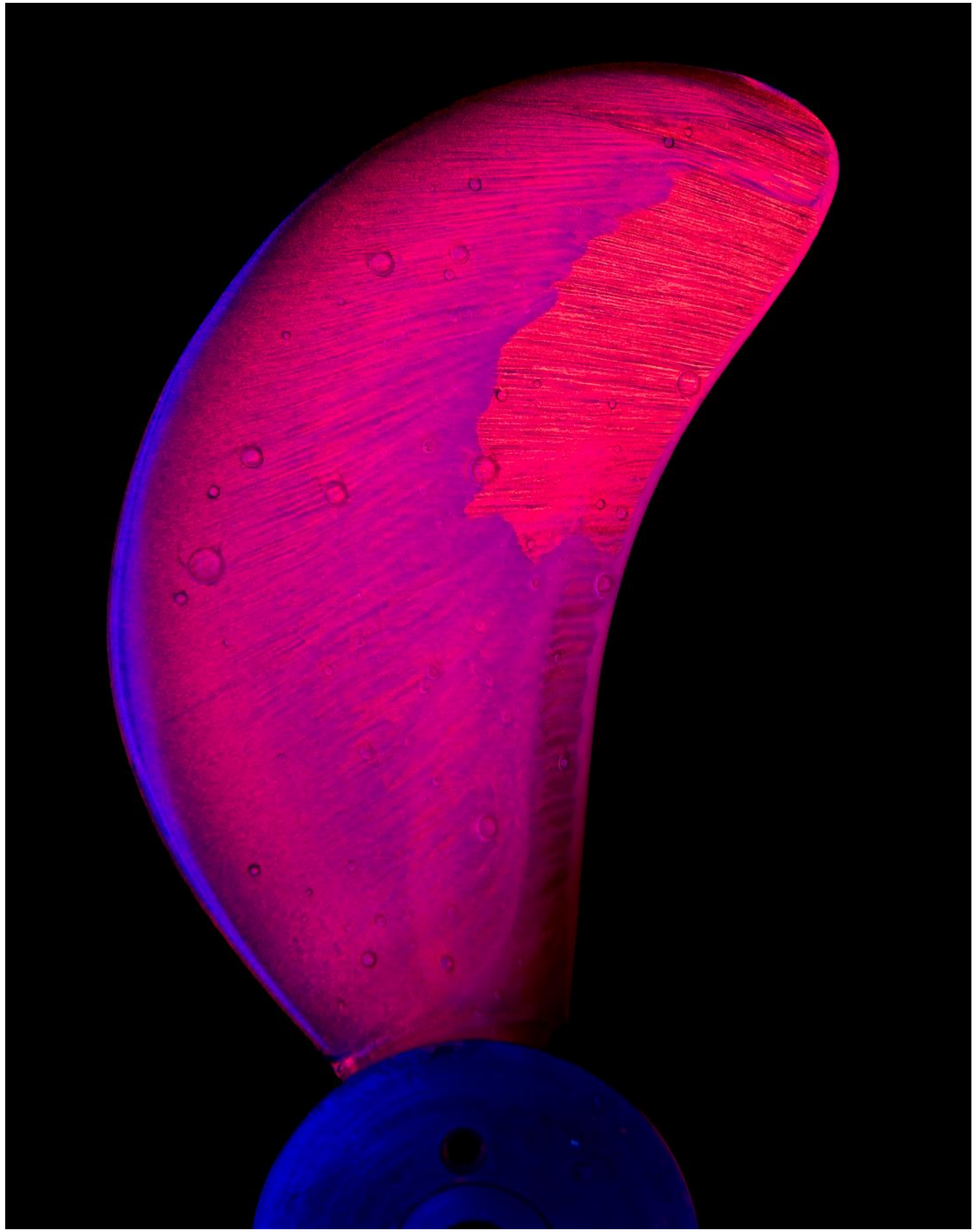
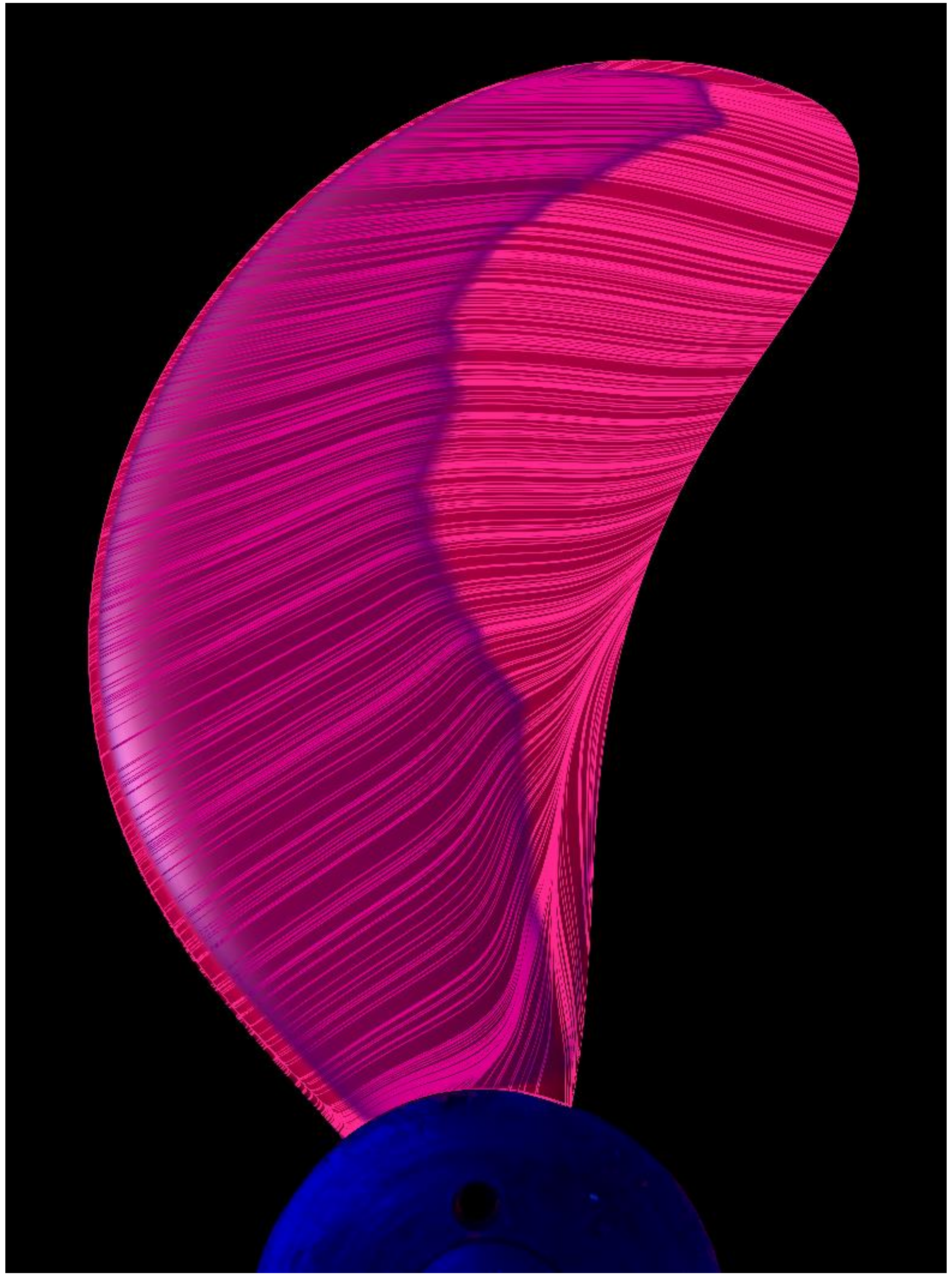
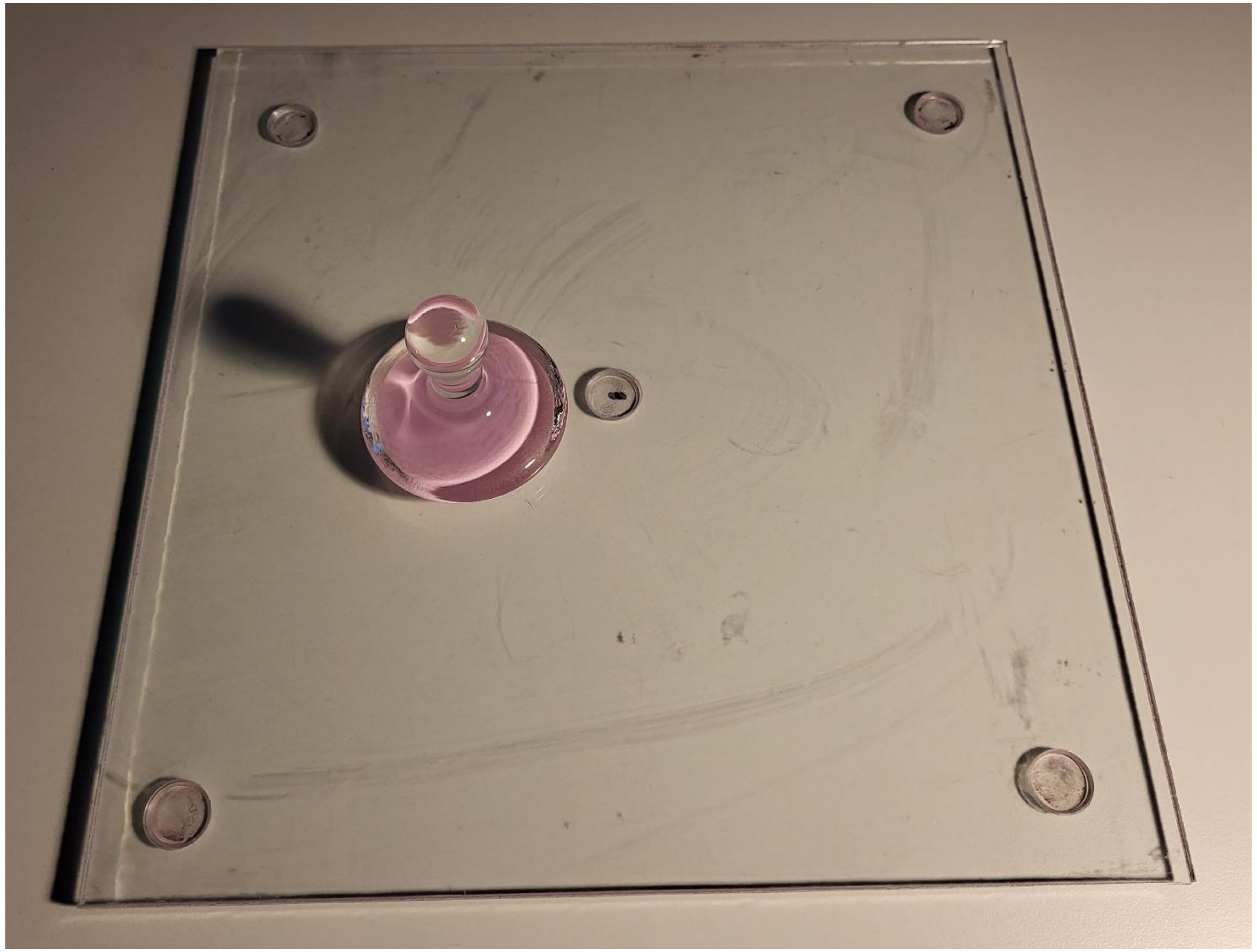




Paint Test Procedure

Step 1: Making the Paint



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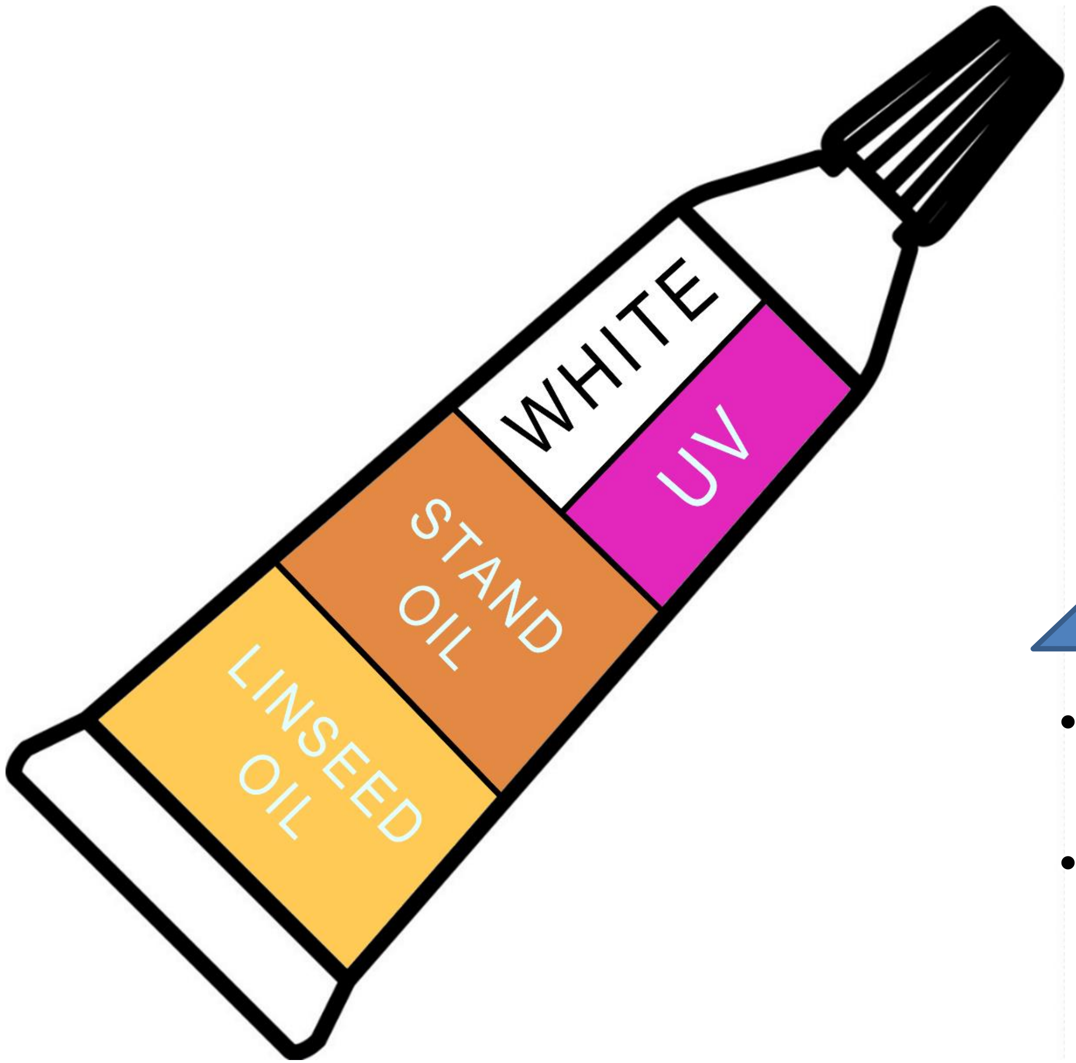


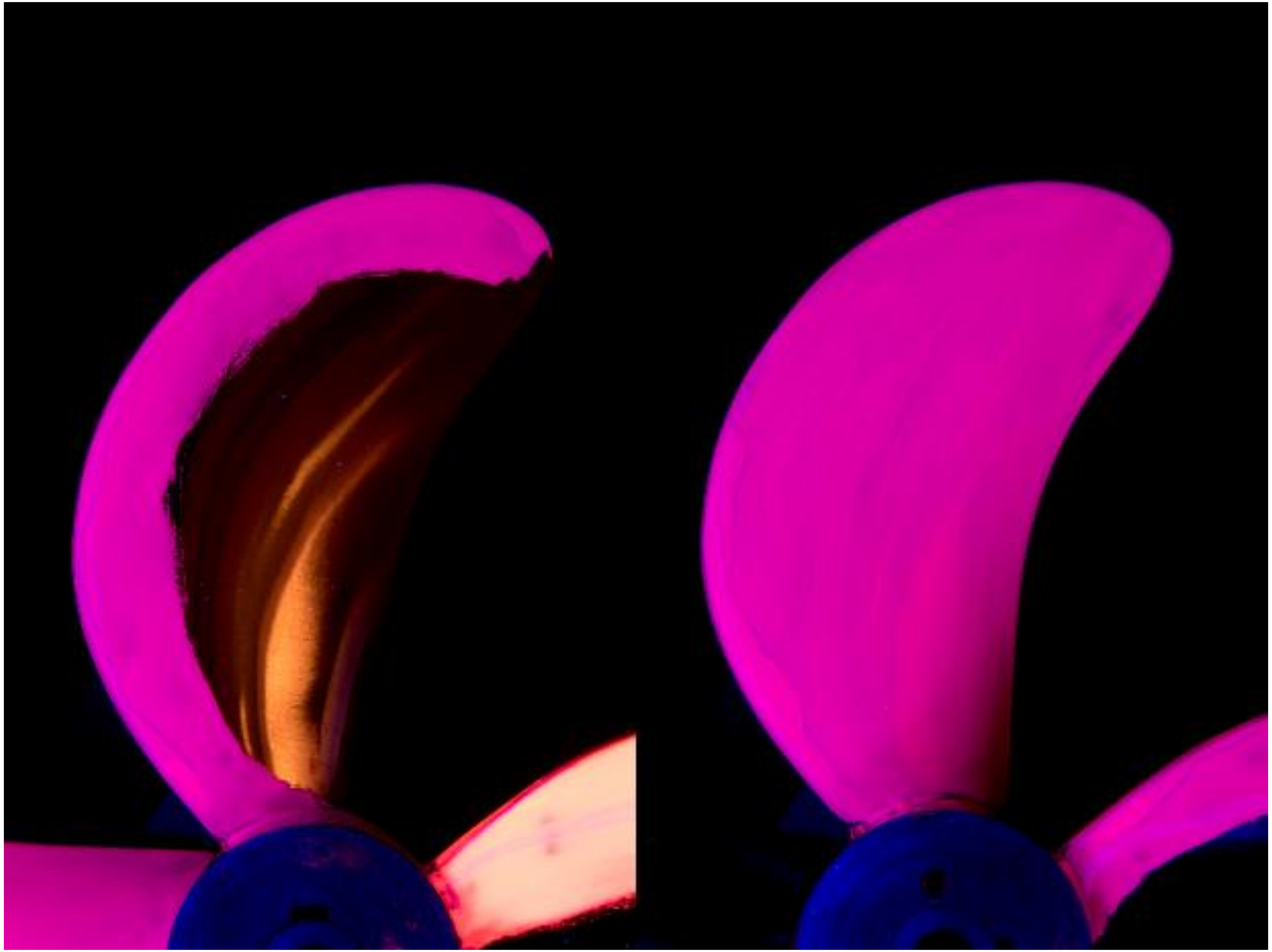
Viscosity

- The resistance to flow
- Sufficiently high

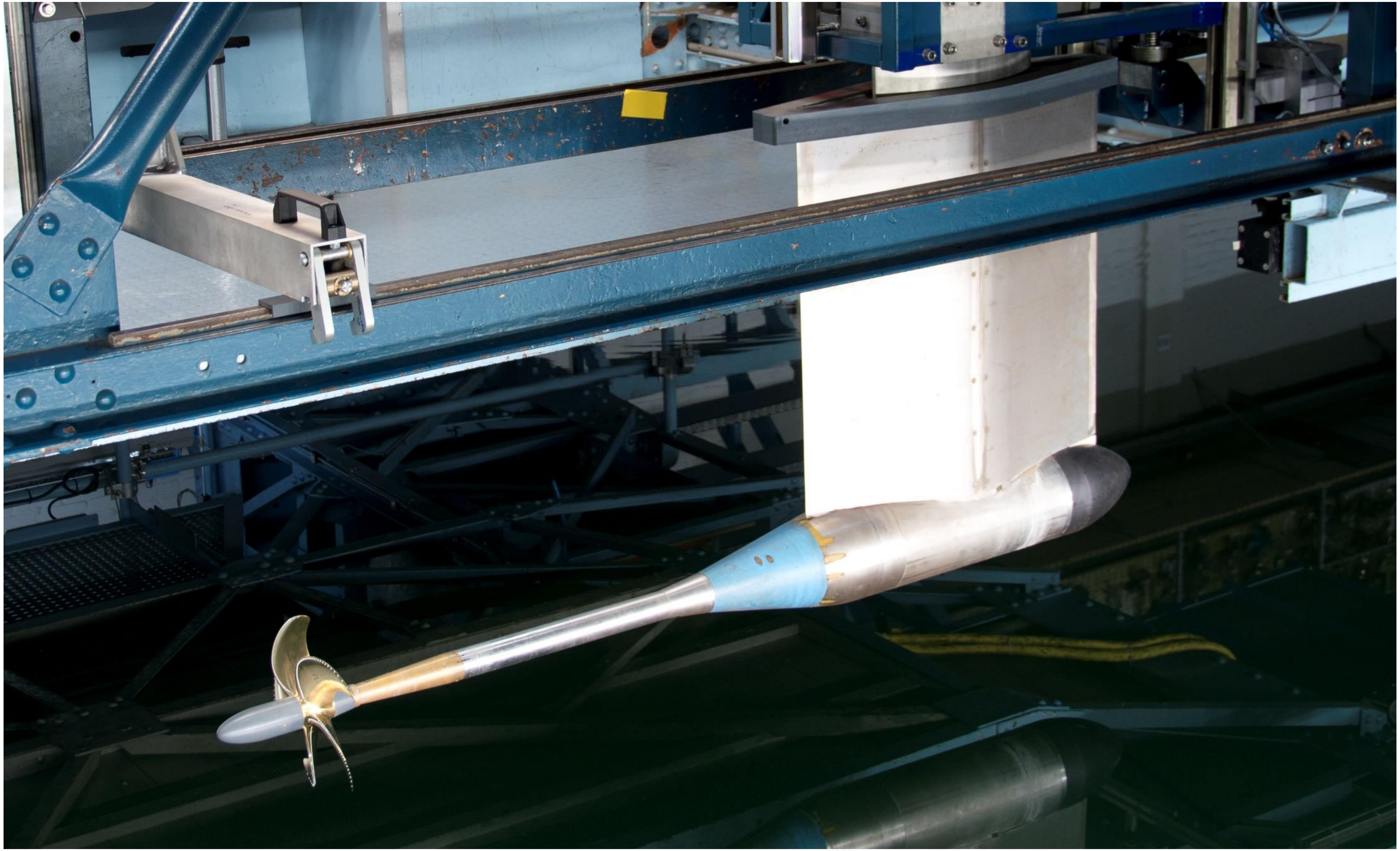
Yield Stress

- The amount of stress to permanently deform a material
- Preferably low

Step 2: Applying the Paint



Step 3: Performing the Model Test



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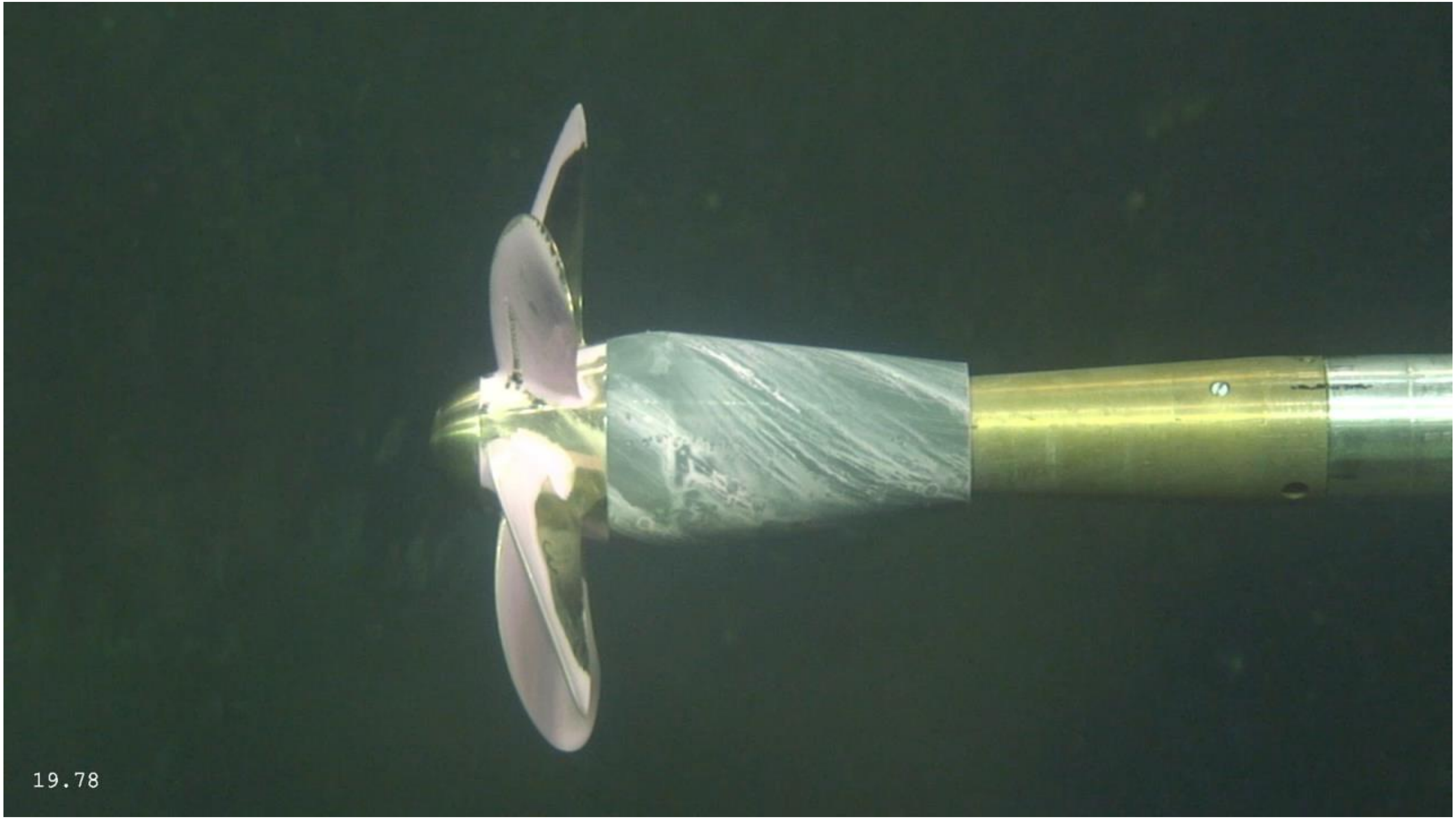
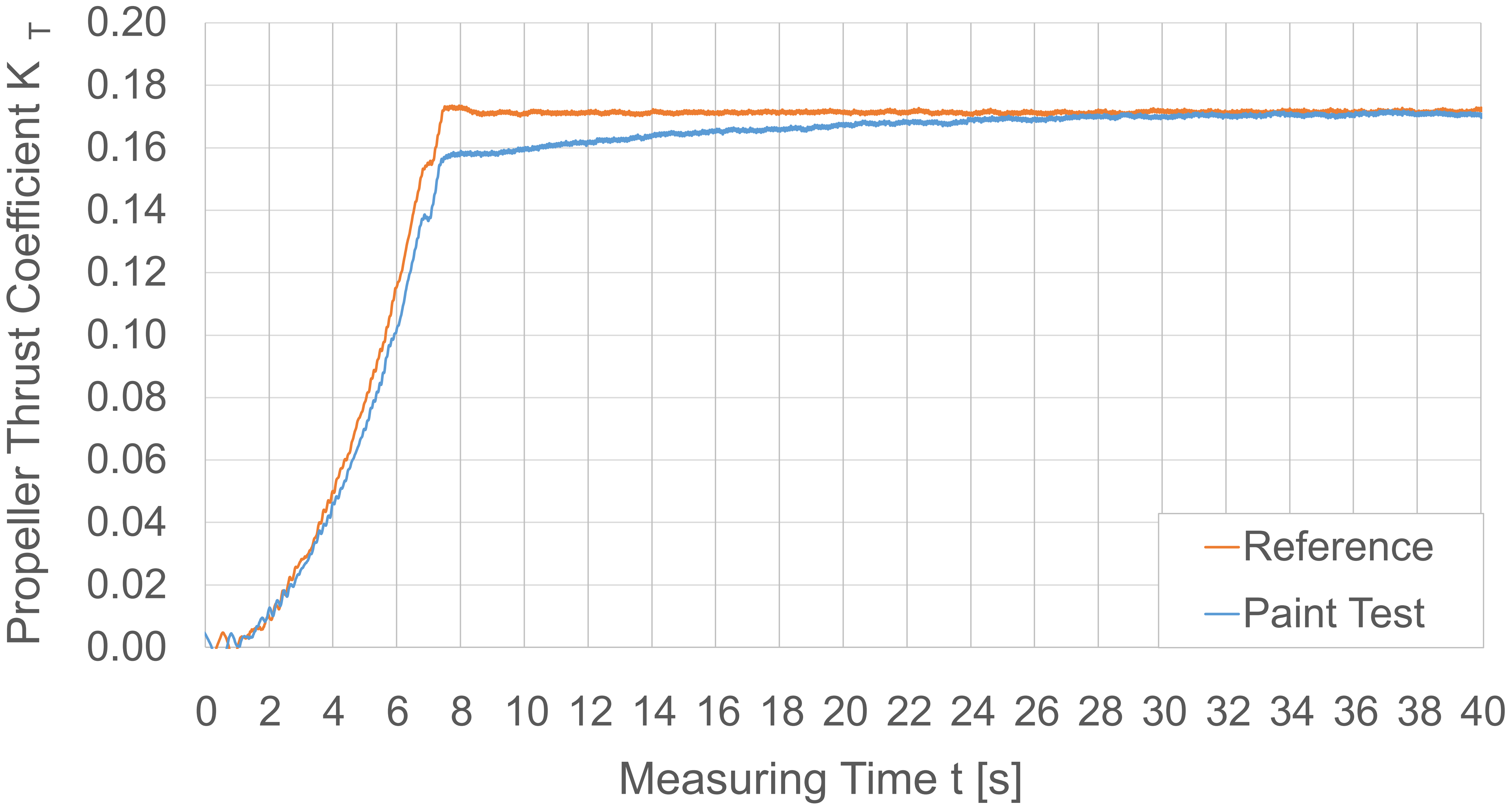
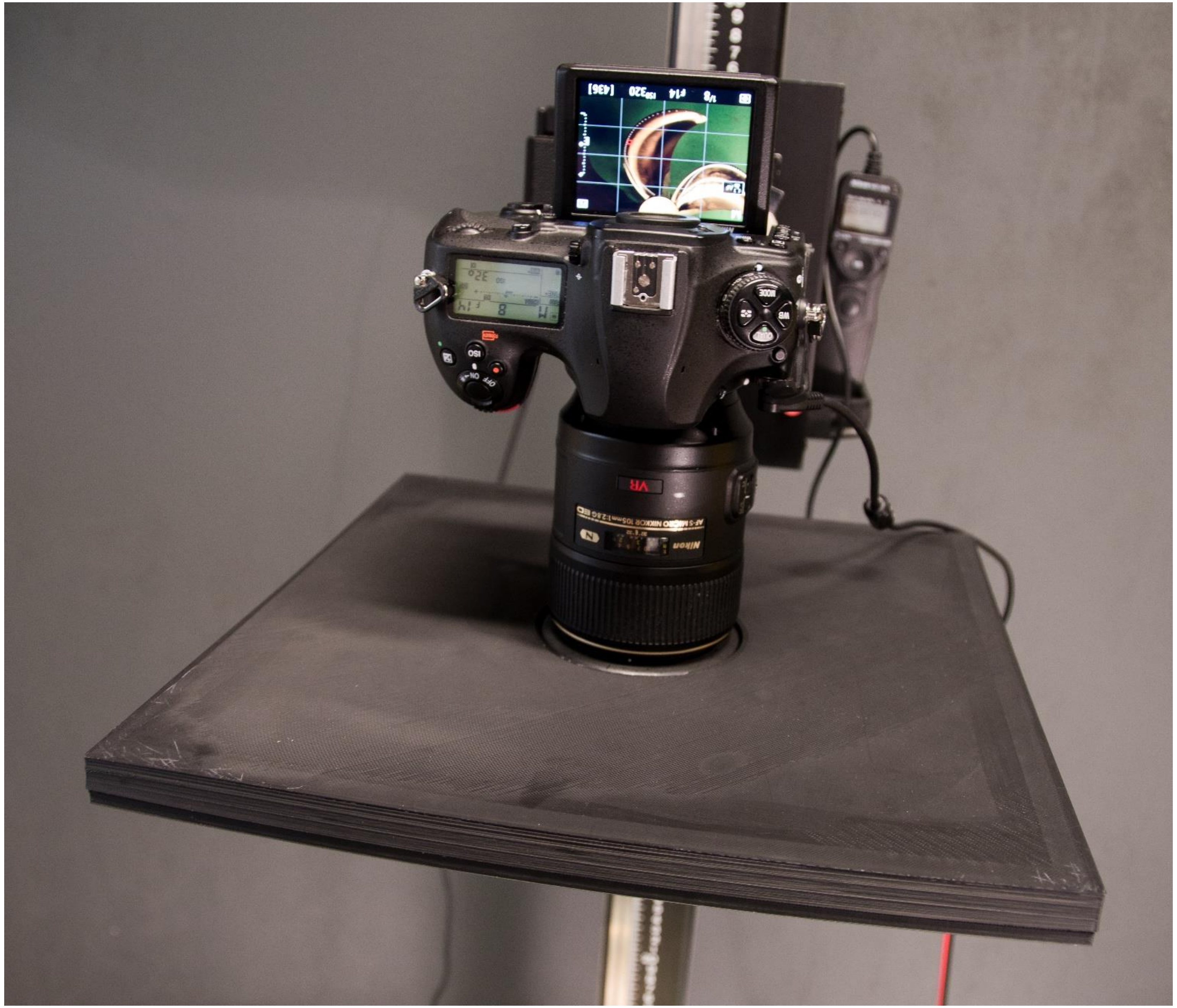


Step 4: Checking Propeller Force Convergence



Step 5: Taking the Picture-Perfect Photo



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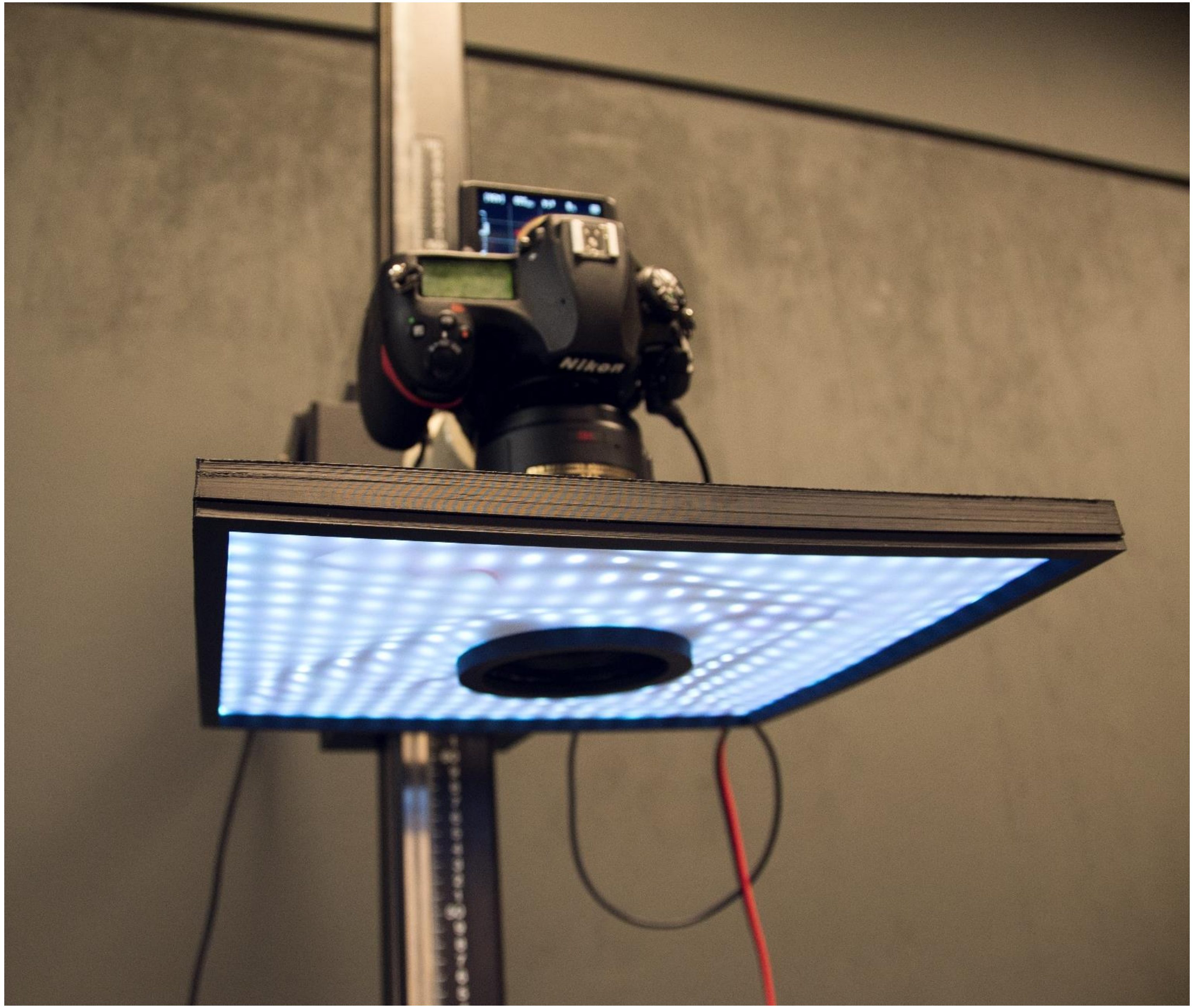

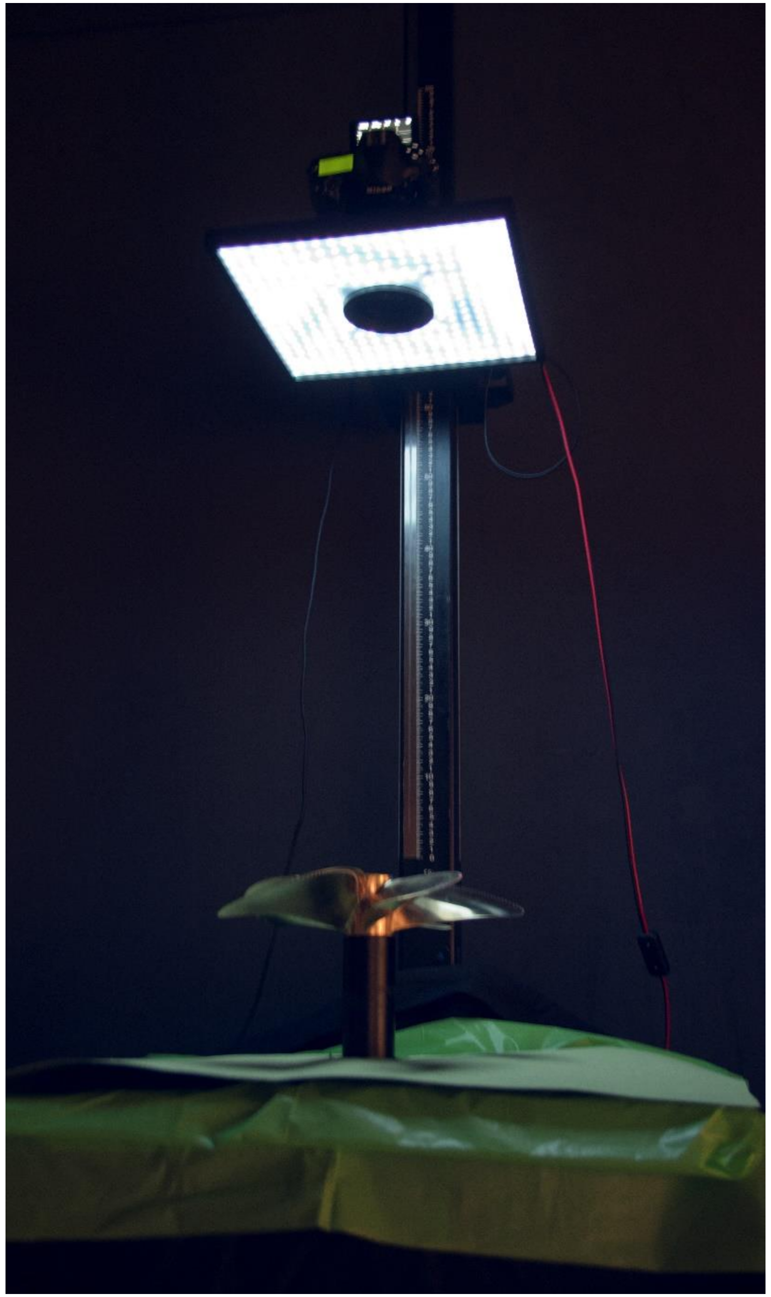

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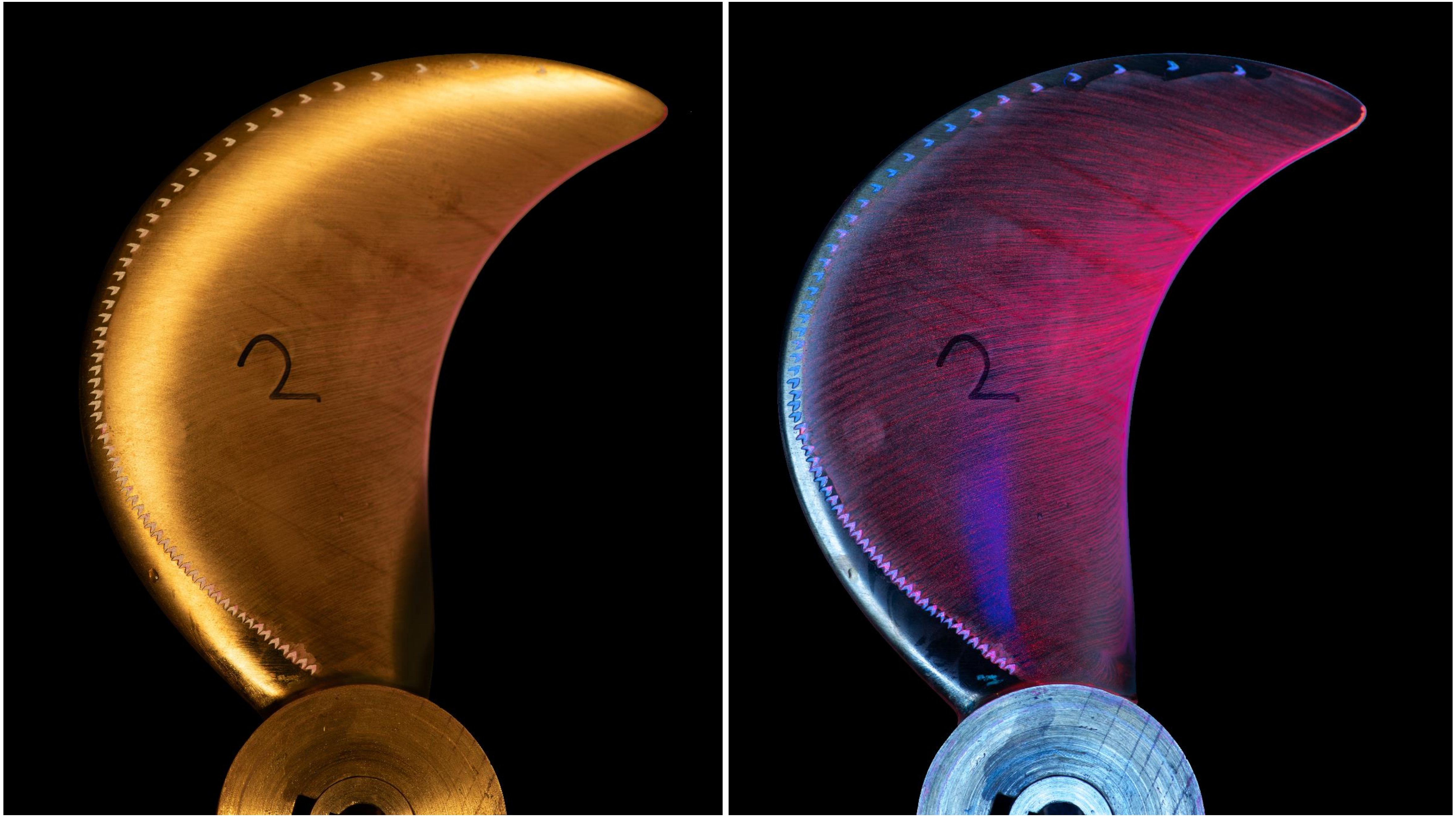
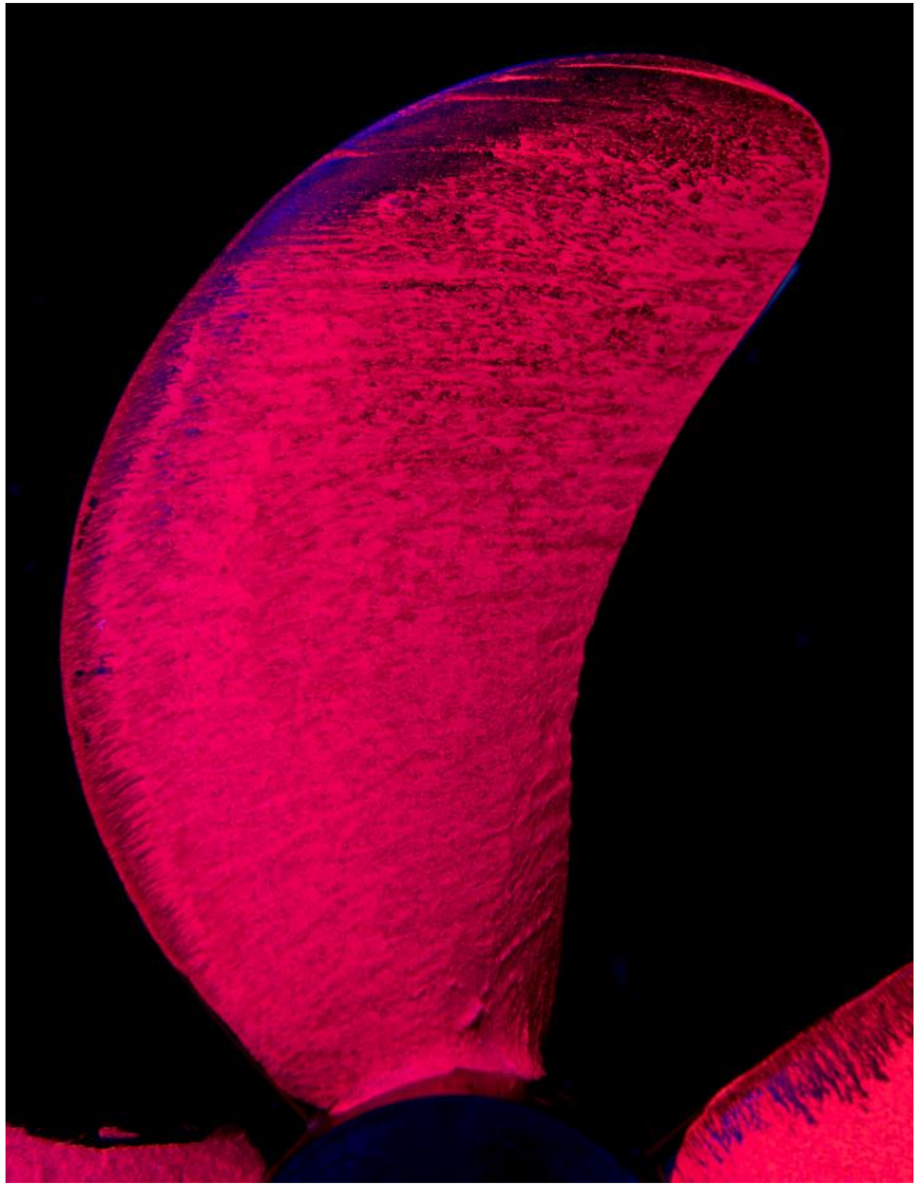


The Art of Propeller Painting

Boorsma (2000)



The Art of Propeller Painting

- Type: Forgotten Chroma
- Manufacturer: Unknown Corp.
- Pigment: Lead White

Cavitation inception on ship propeller models, G.Kuiper (1981)

Improving full scale ship powering performance predictions by application of propeller leading edge roughness, A. Boorsma (2000)

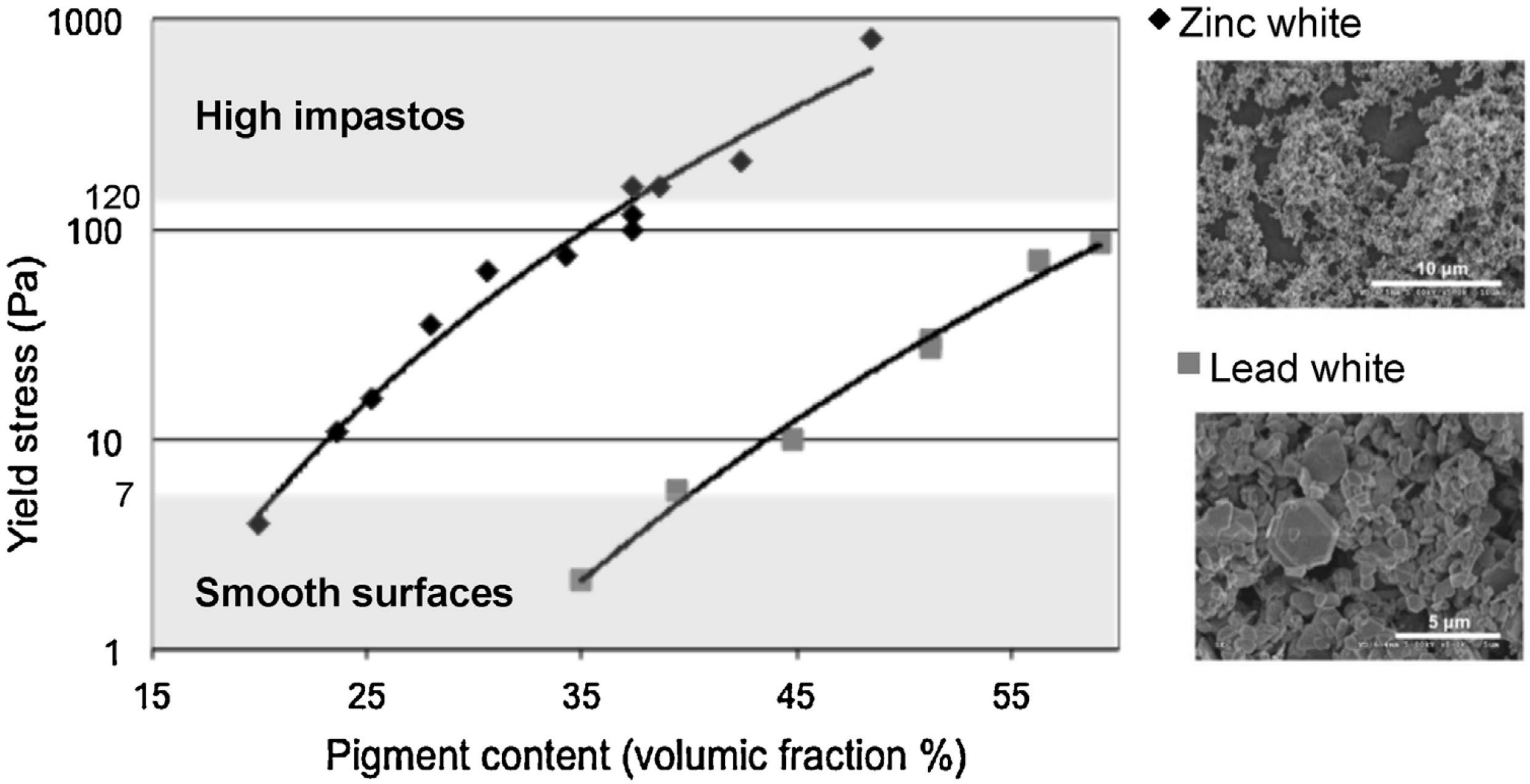
The Art of Propeller Painting

- Type: Artist oil
- Manufacturer: Van Gogh
- Color: Zinc White

Wageningen Propeller C4-40 Series; Two-Quadrant Open Water Test Results, J. Dang, M. Merkens and R. van Duijn (2015)

The Art of Propeller Painting

Salvant Plisson, J., de Viguerie, L., Tahroucht, L., Menu, M., Ducouret., G. (2014).
‘Rheology of white paints: How Van Gogh achieved his famous impasto’



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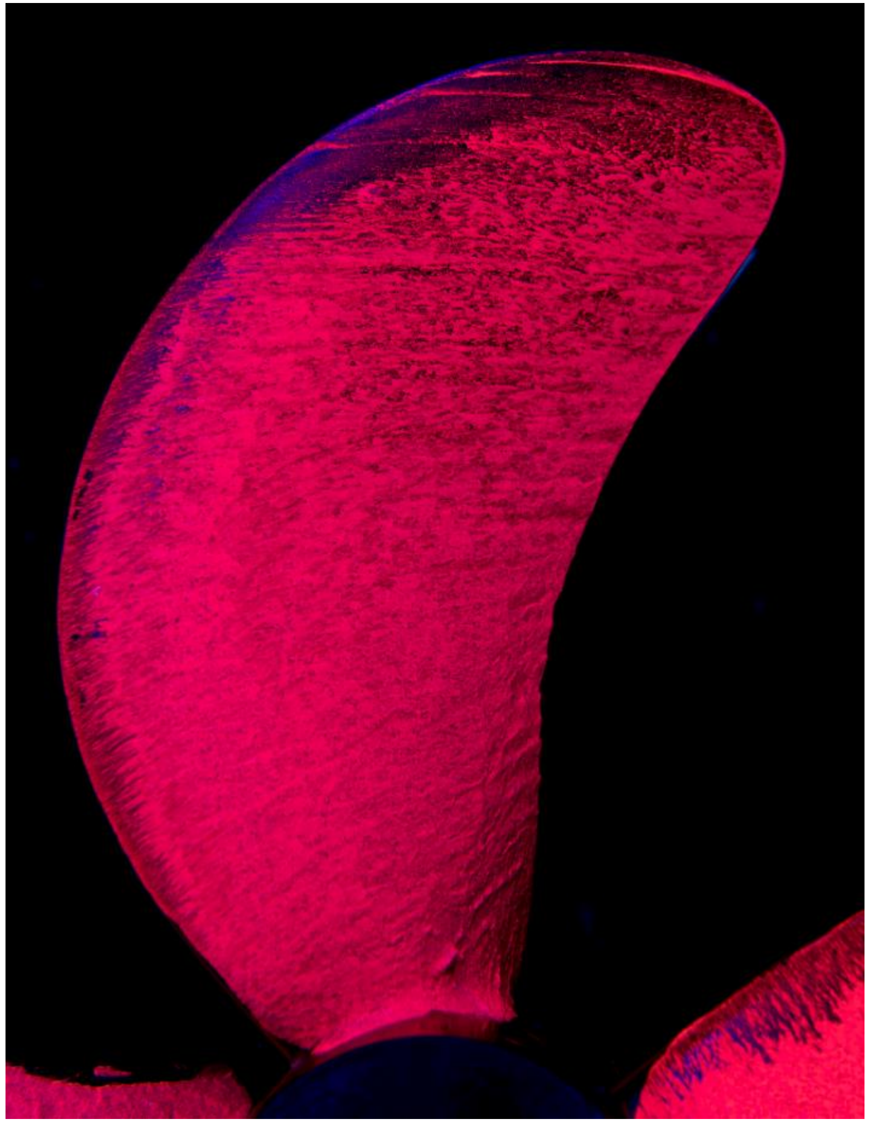

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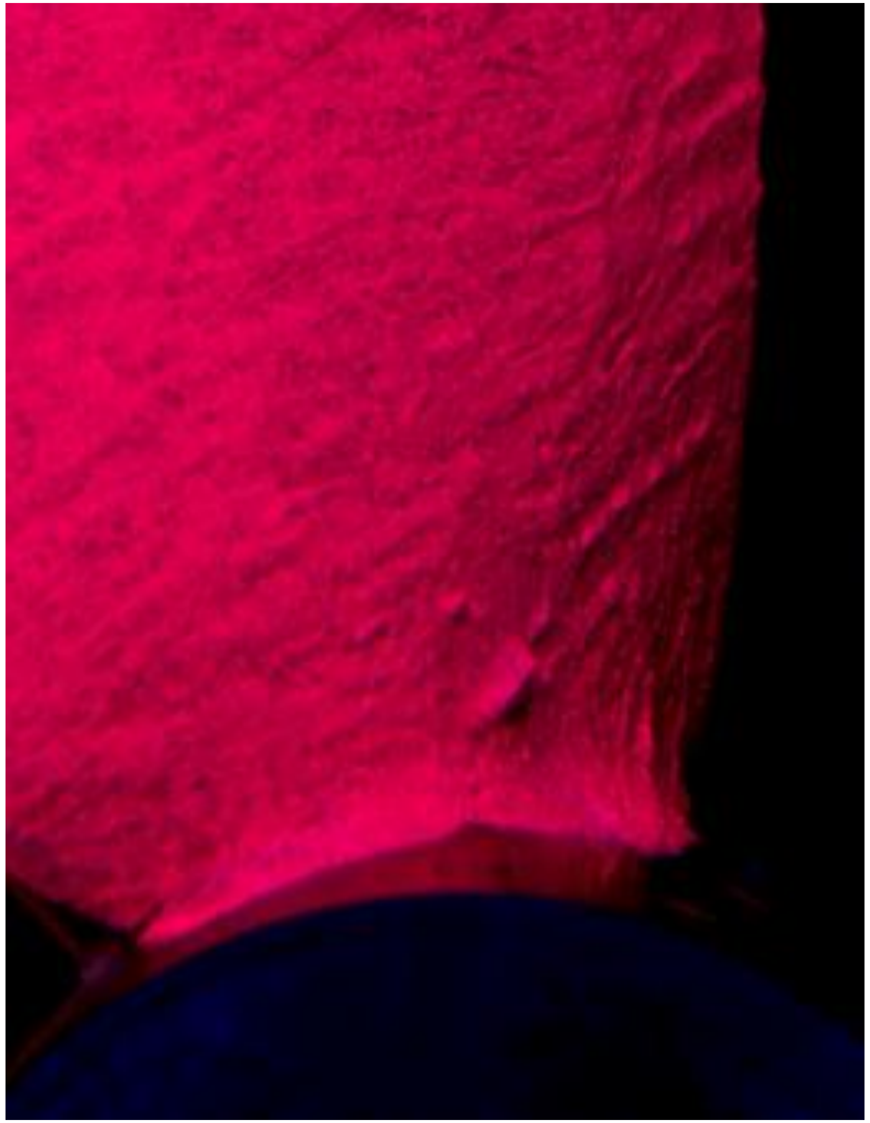

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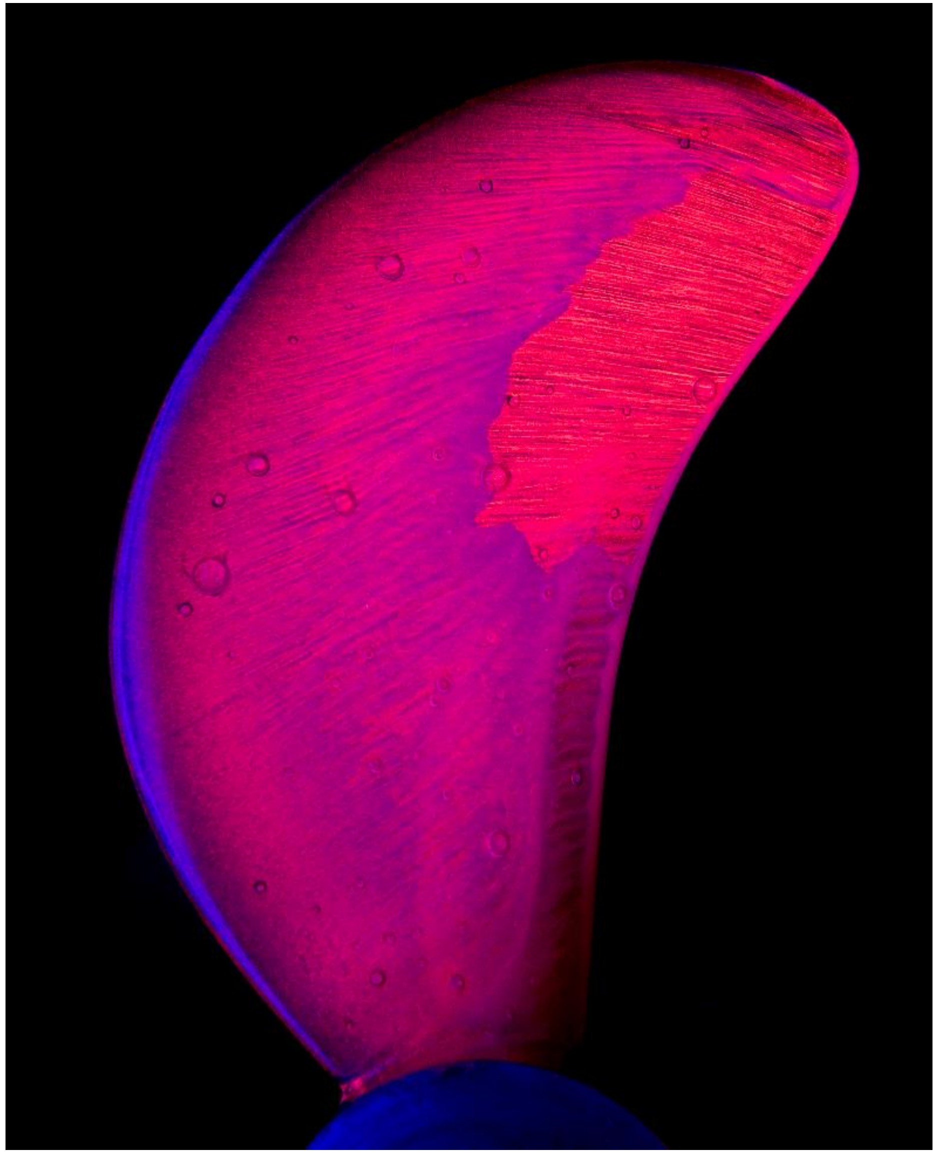
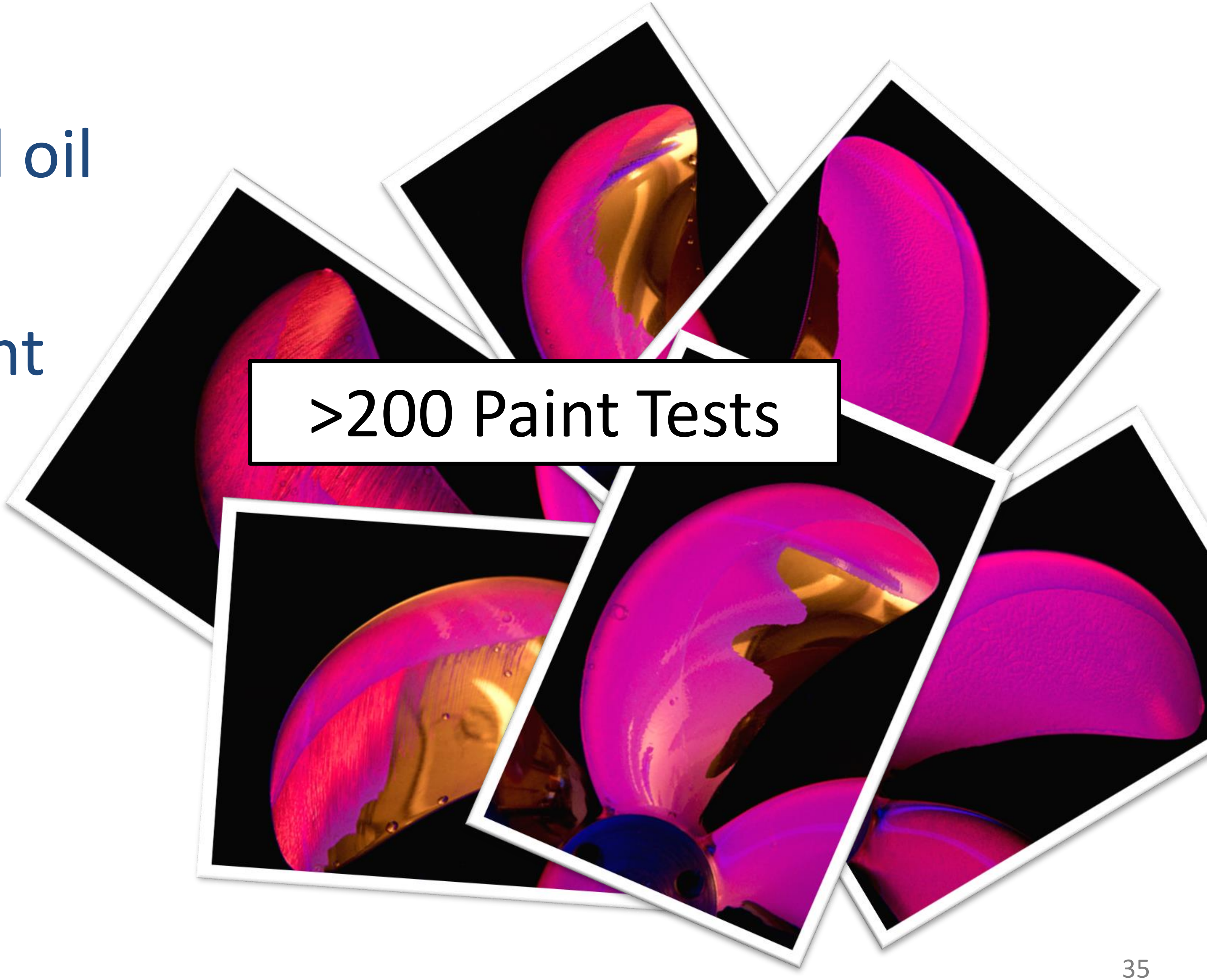


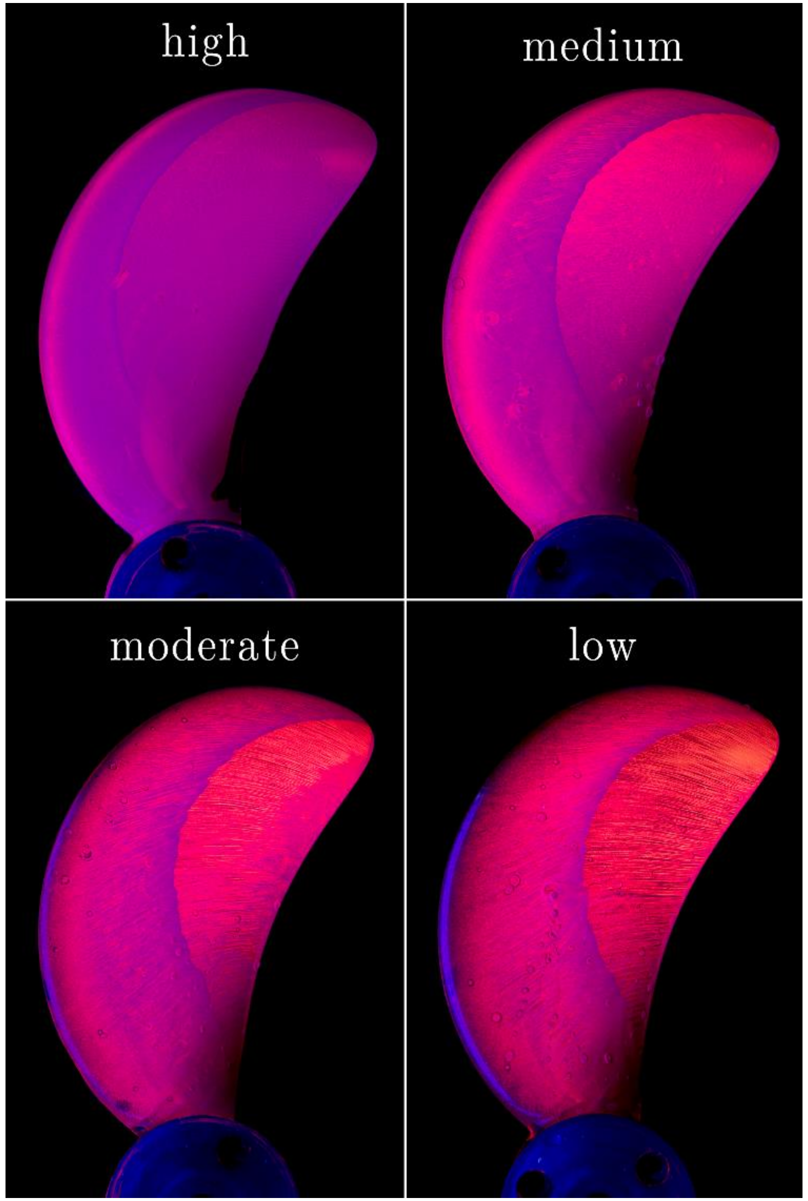
The Art of Propeller Painting

- Oil mixture: linseed / stand oil
- Volumetric Pigment Content
- Experimental Procedure
  - Total Test Time
  - Acceleration Phase Influence
  - Start-Up Procedure
  - Thrust and Torque Convergence

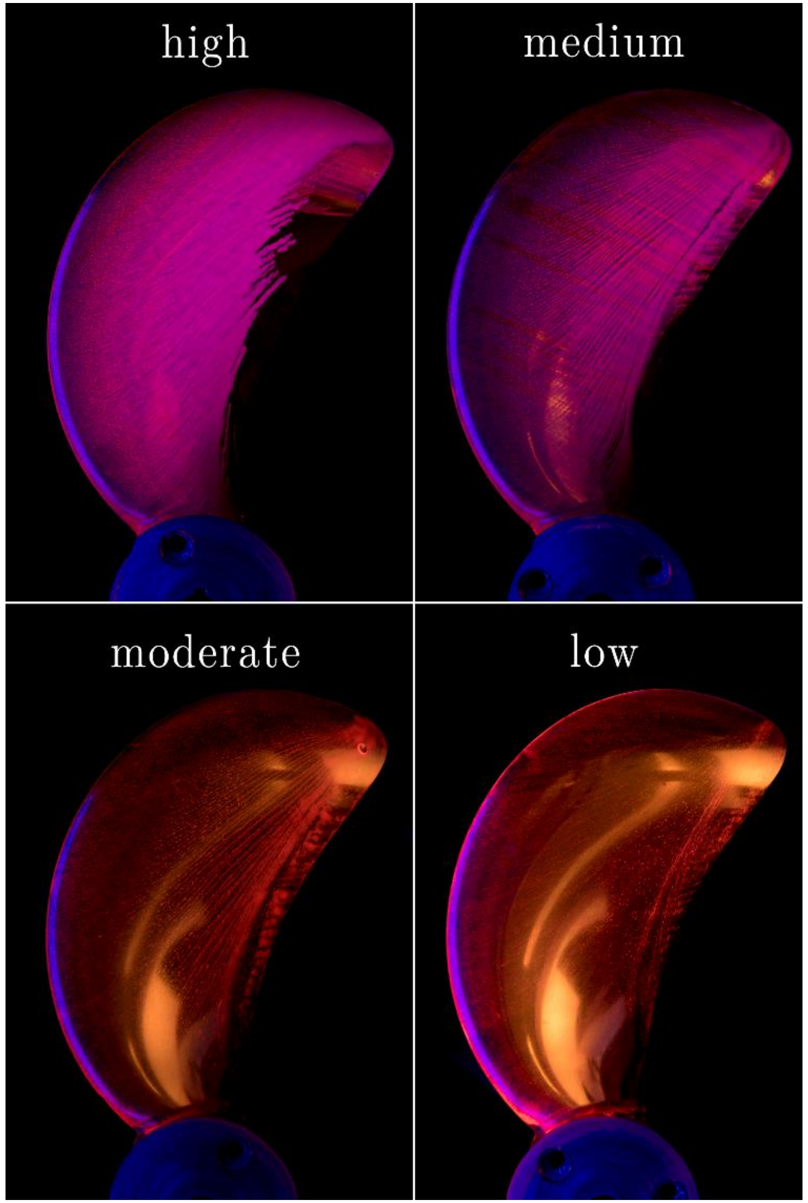


The Art of Propeller Painting

Volumetric Paint Content

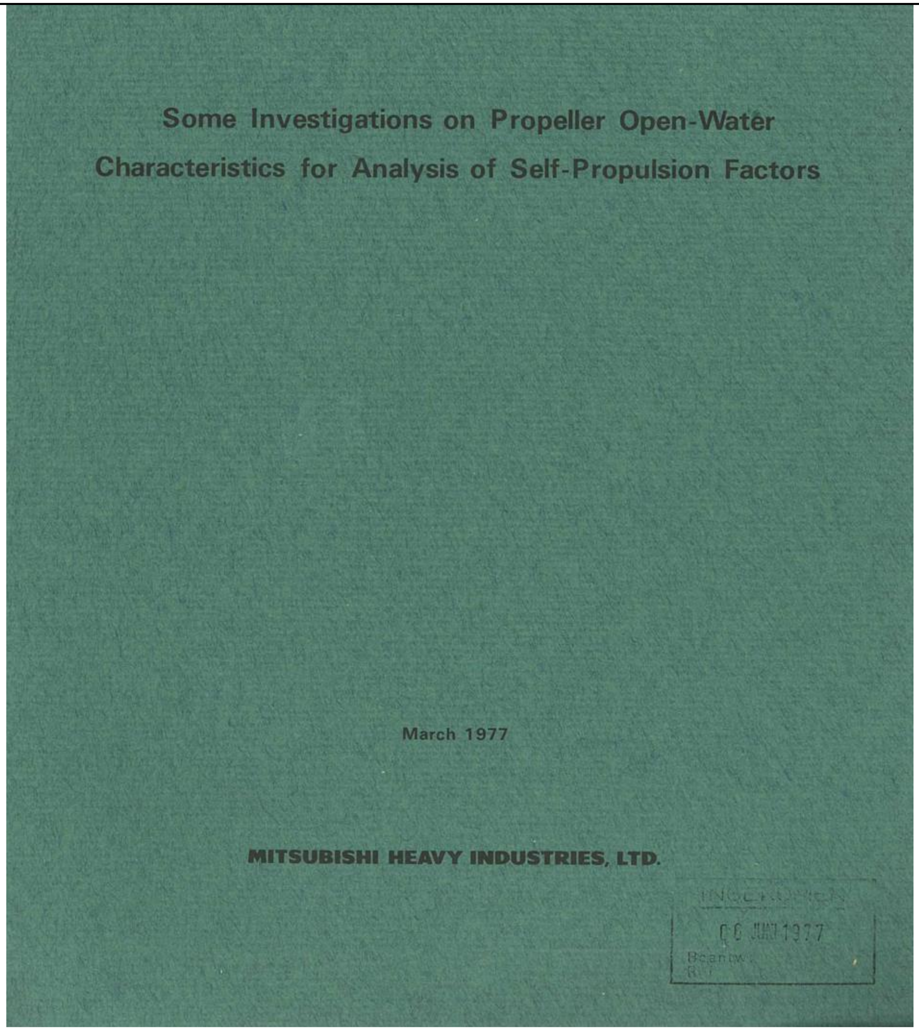


Oil Base Viscosity



Echoes of the Past

Tamura, K. & Sasajima, T (1977)
Some Investigations on Propeller Open-Water Characteristics
for Analysis of Self-Propulsion Factors,



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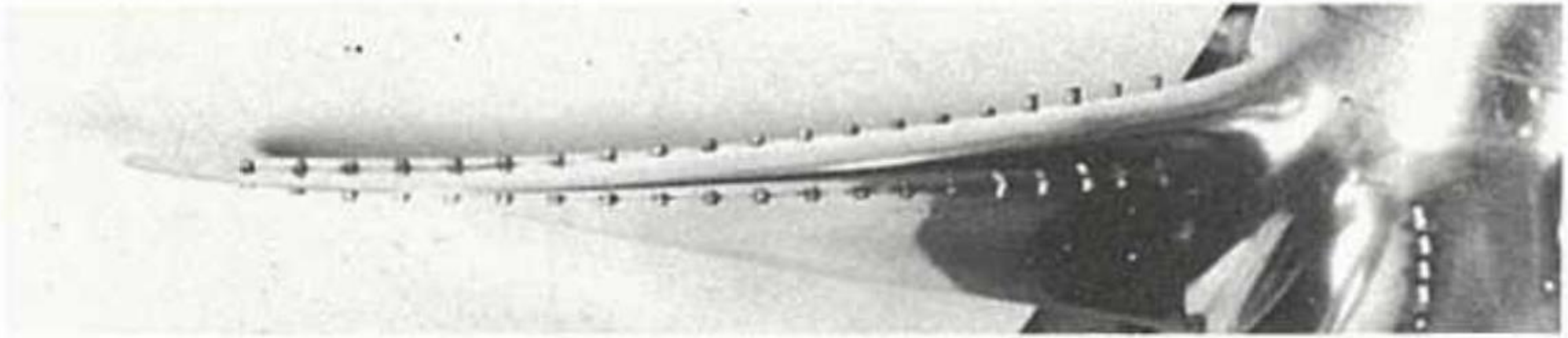
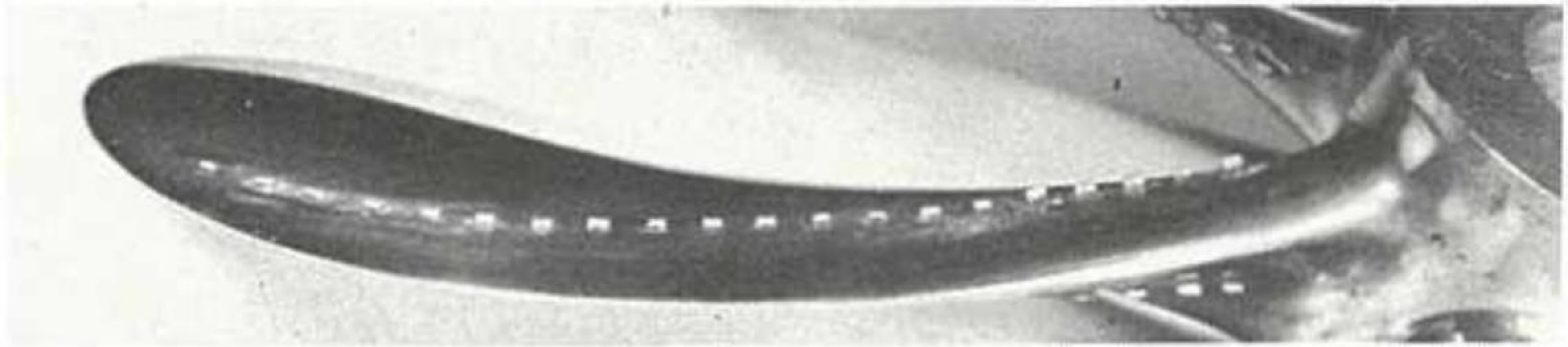


Cylindrical studs



Square studs

Modern Turbulence Stimulation

Critical Reynolds Number

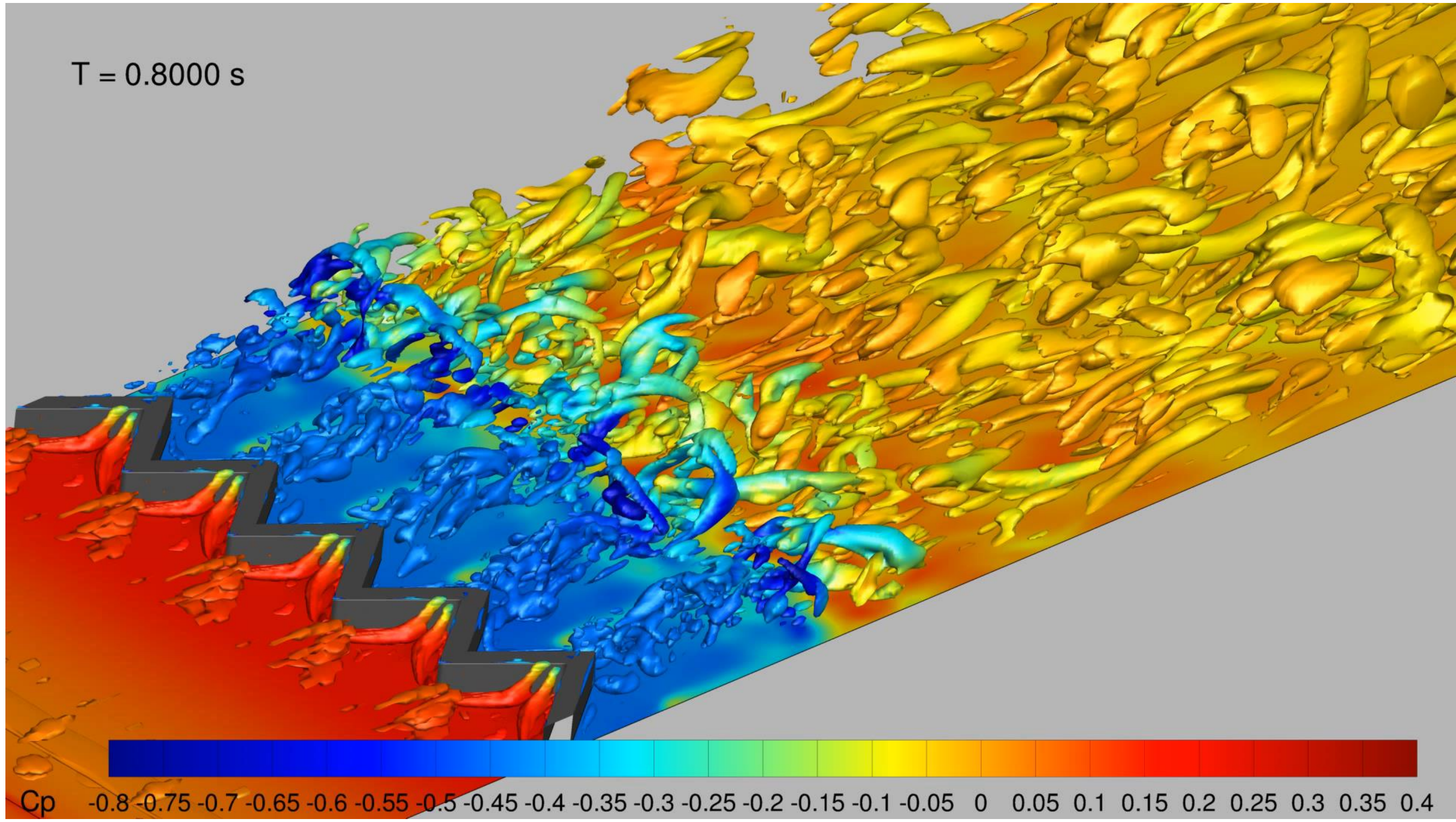
$$Re_h = \frac{u_h h}{\nu}$$

Zigzag strip

$Re_h \approx 200$ Rooij and Timmer (2003)

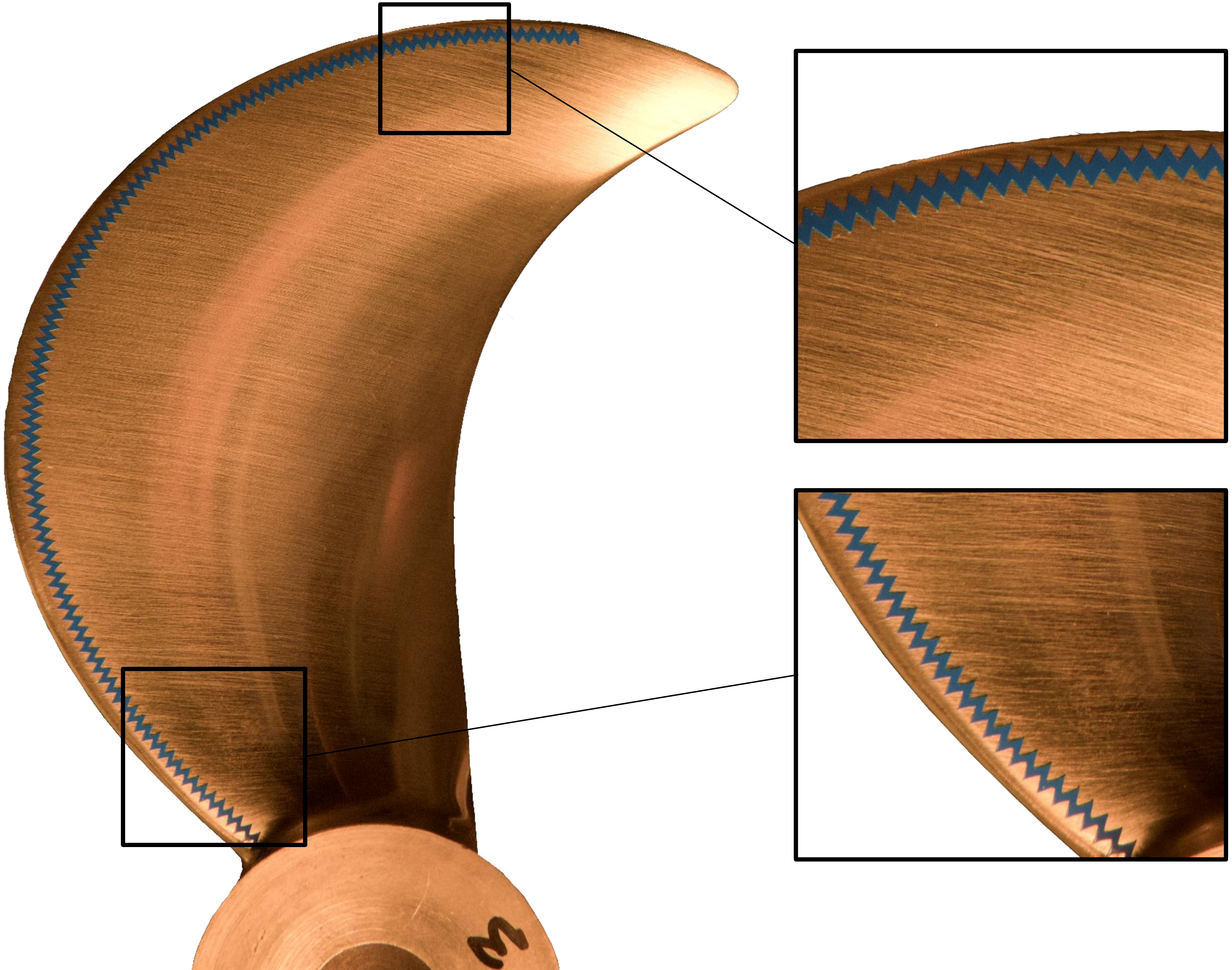
Sand Roughness

$250 \le Re_h \le 600$ Braslow and Knox (1958)

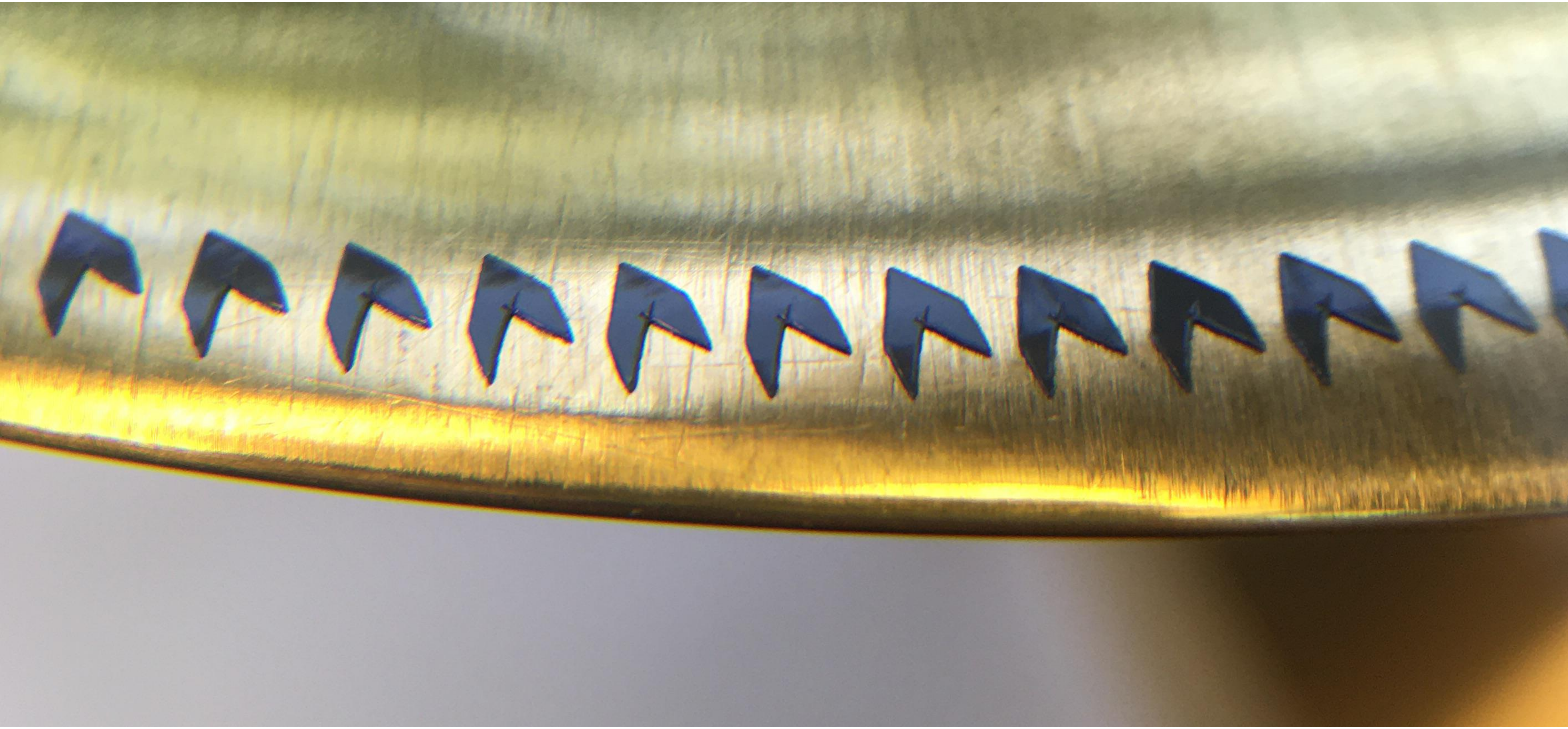


Kerkvliet (2022)

Modern Turbulence Stimulation

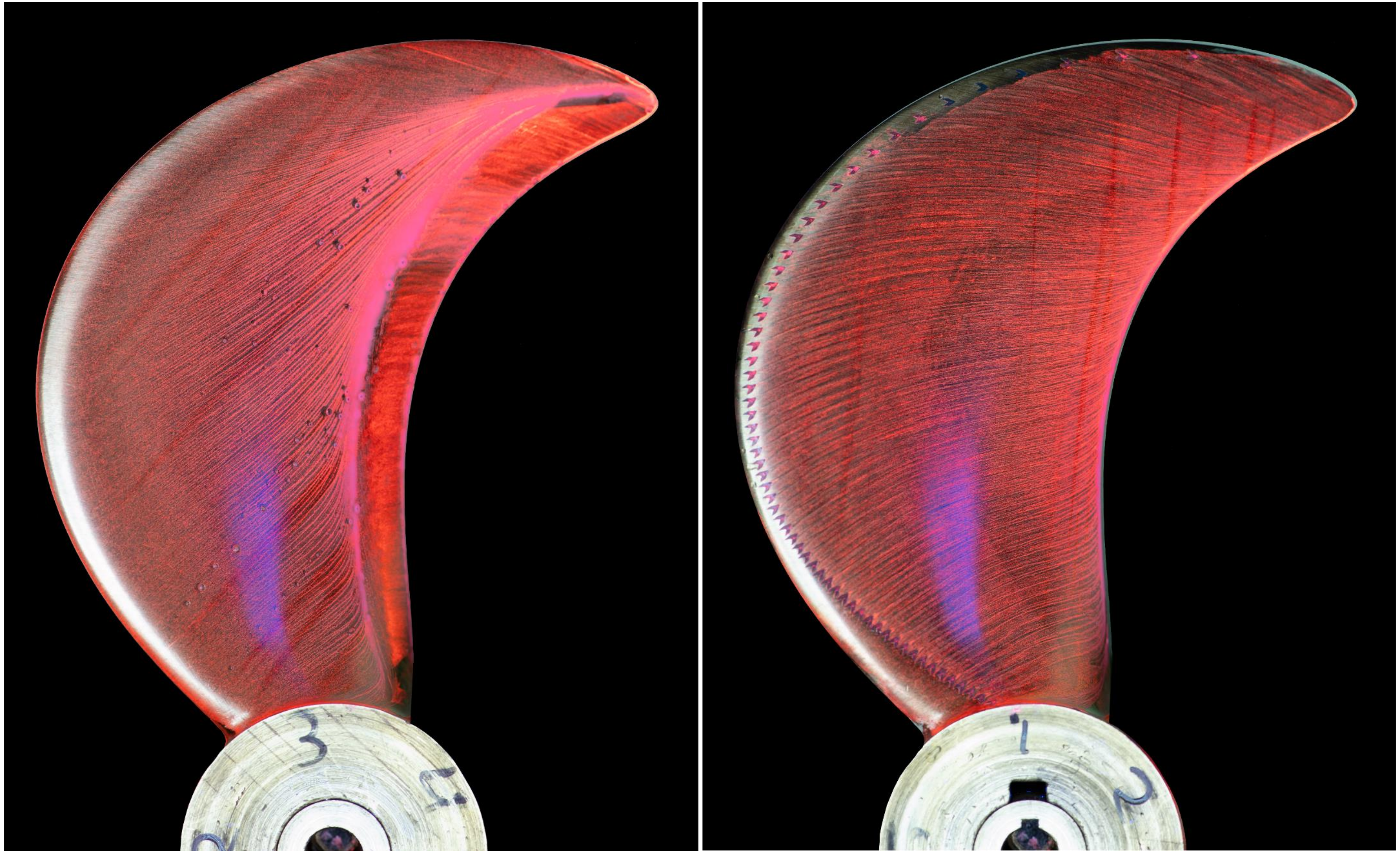


The Turbulators

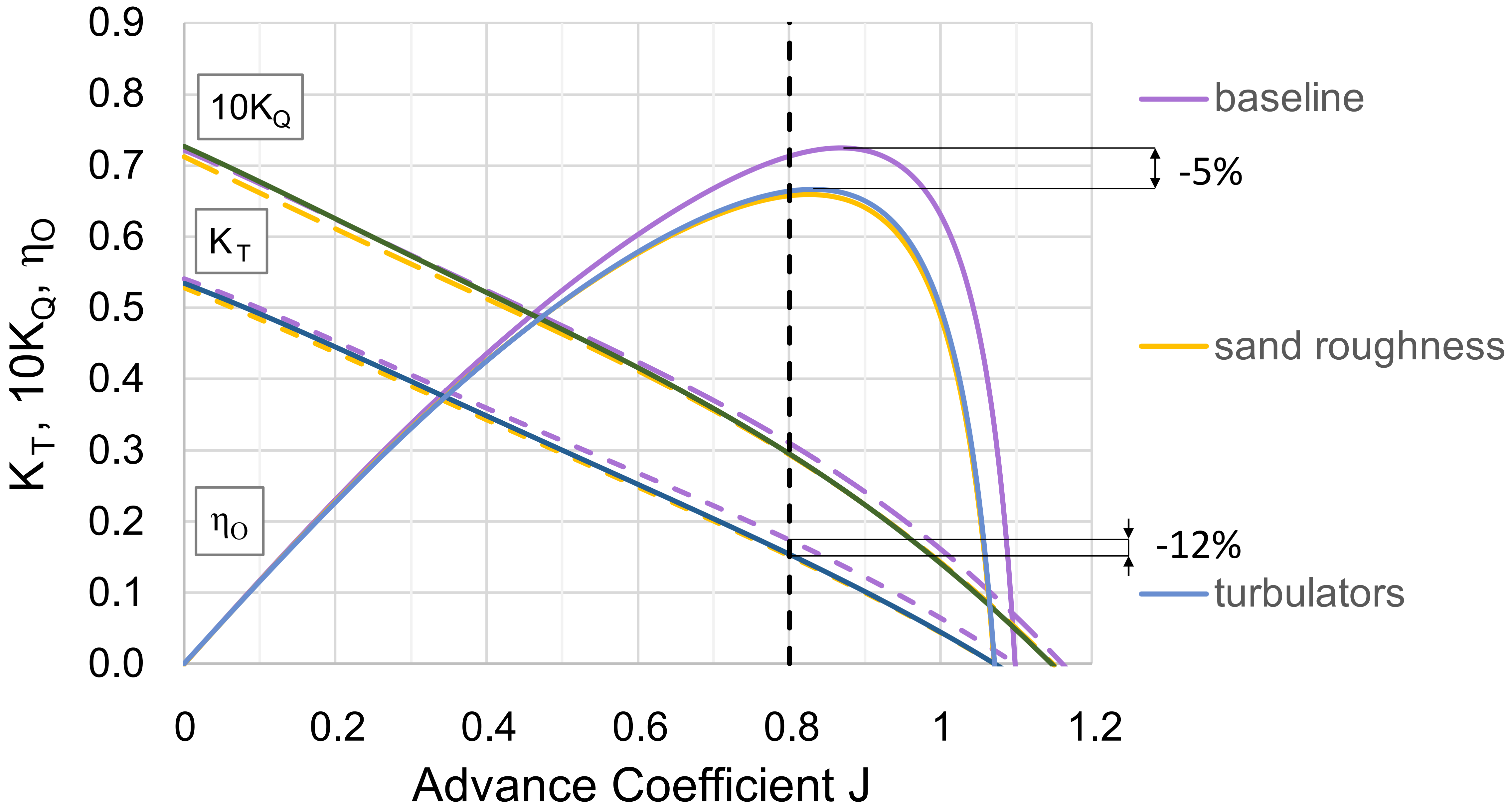


The Effect of the Turbulators on the Propeller Boundary Layer

D	300 mm
Z	5
$P_{0.7R}/D$	1.045
A_e / A_o	0.6362
J	0.8
n	800 rpm
$Re_{0.7R}$	7.5×10^5



The Effect of the Turbulators on the Propeller Performance



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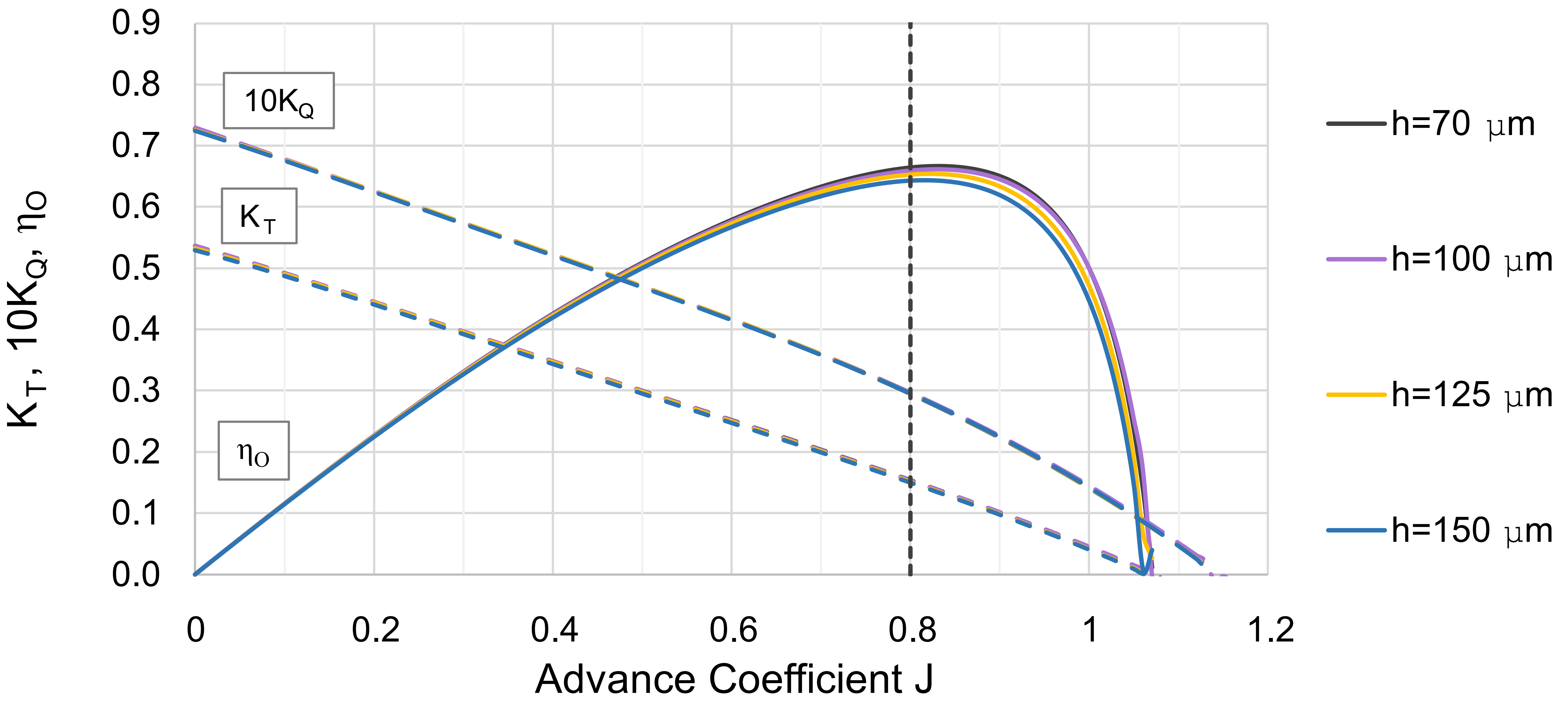

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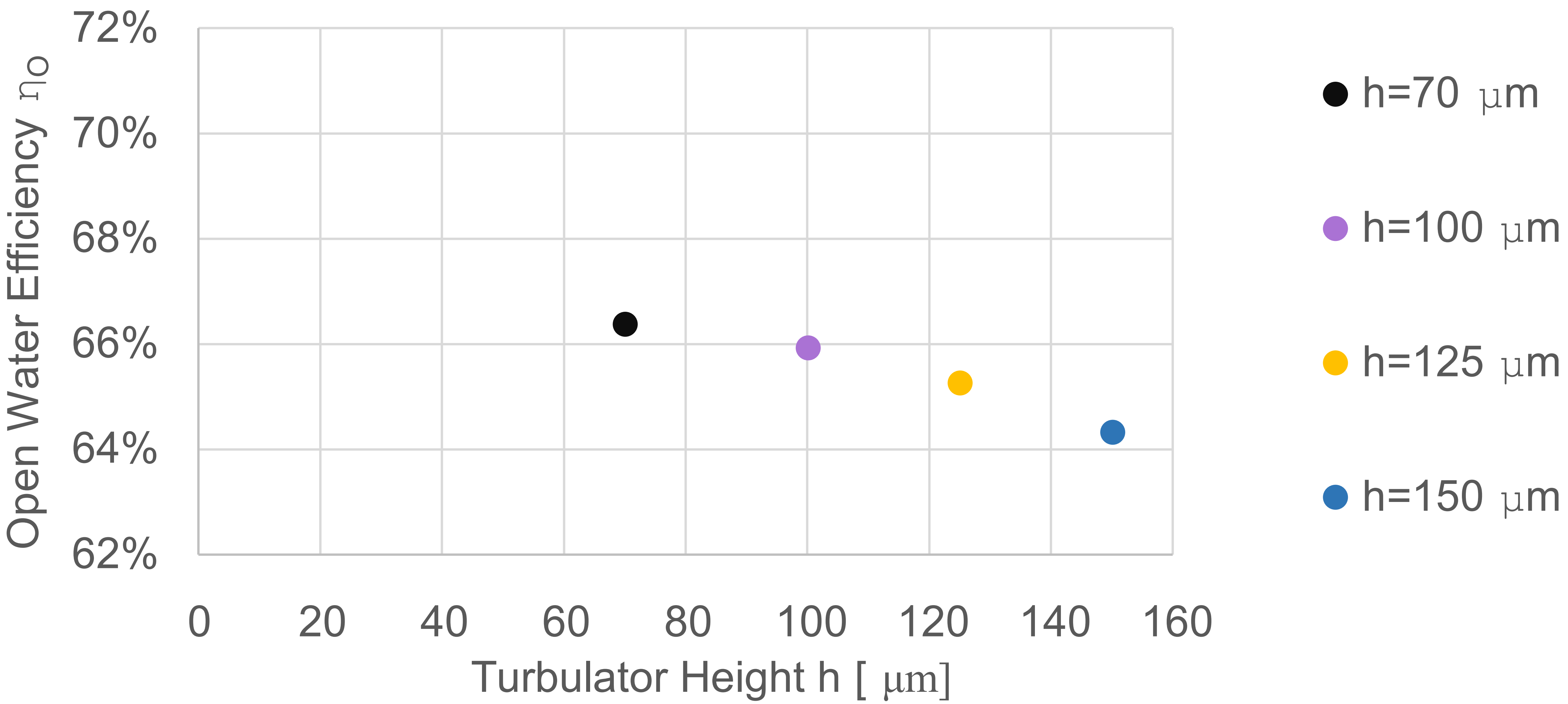

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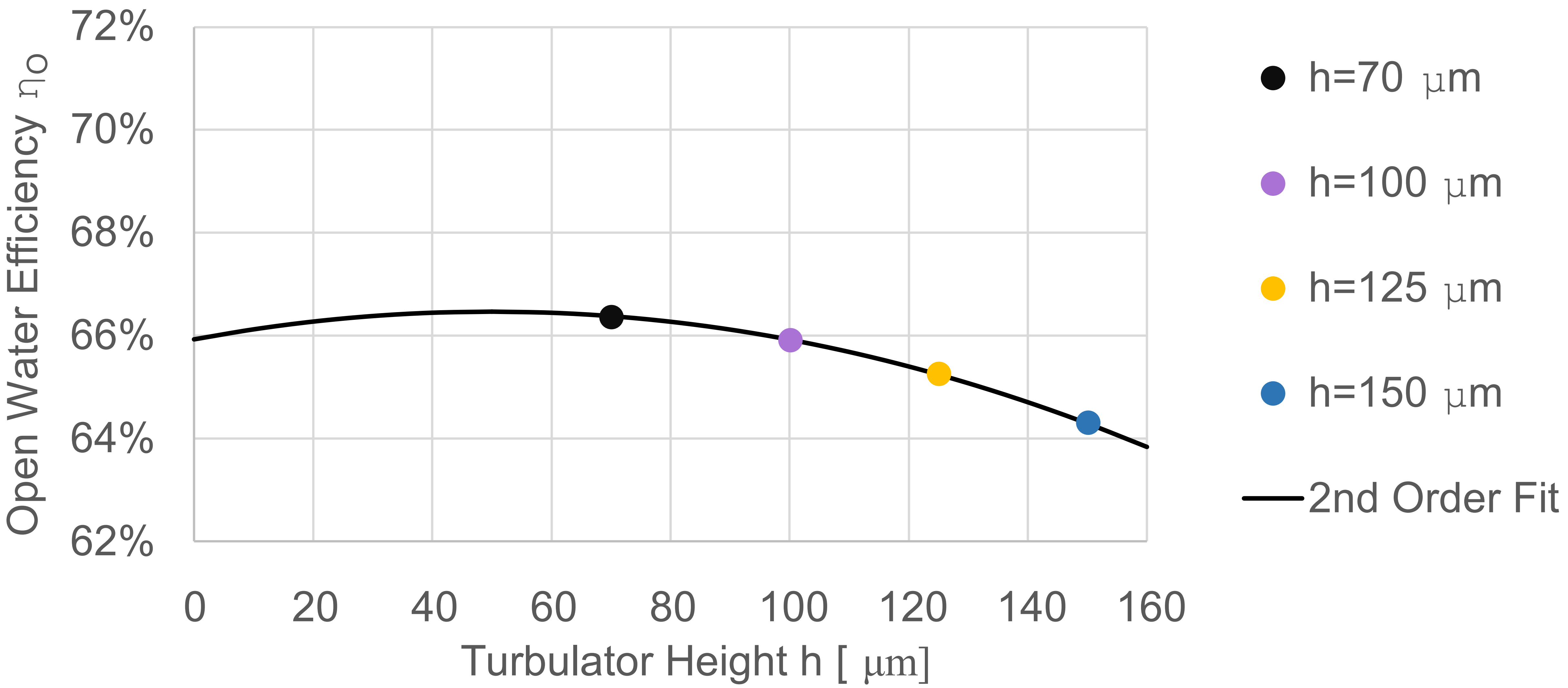

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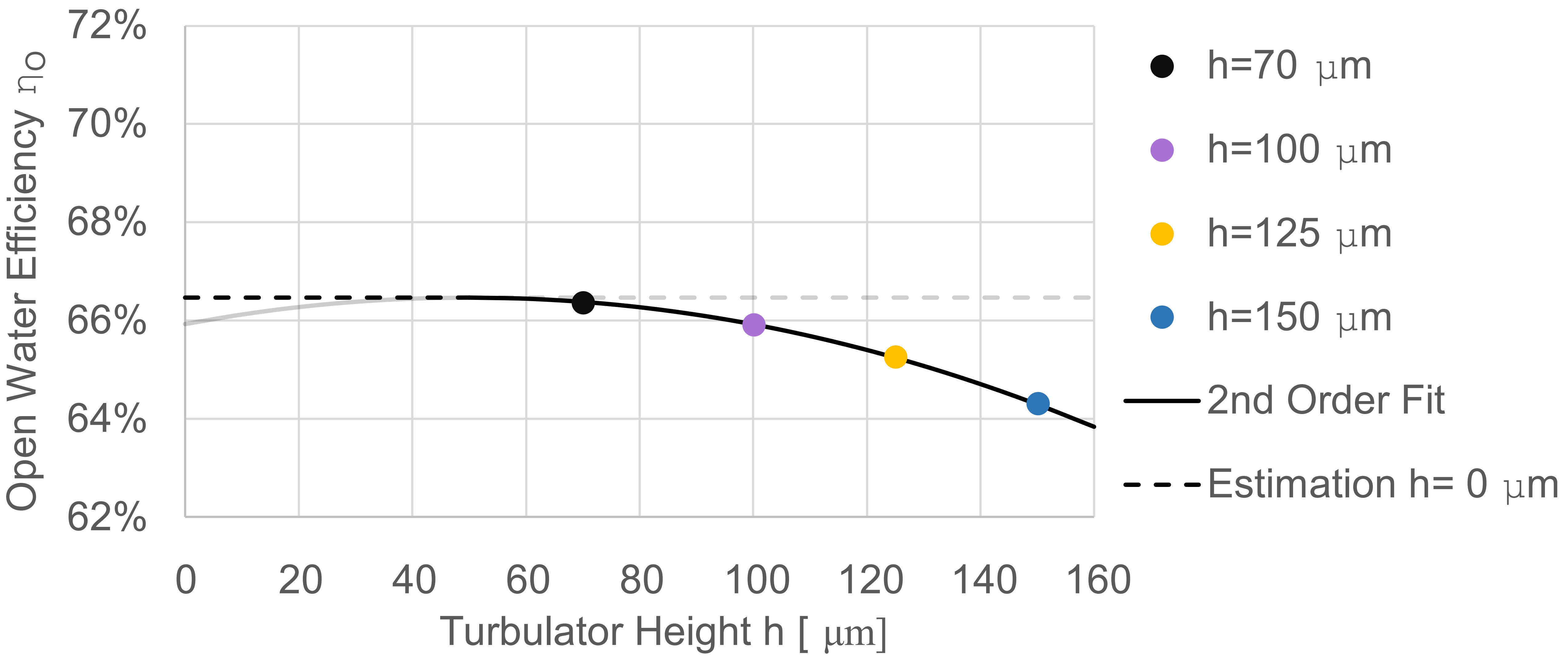

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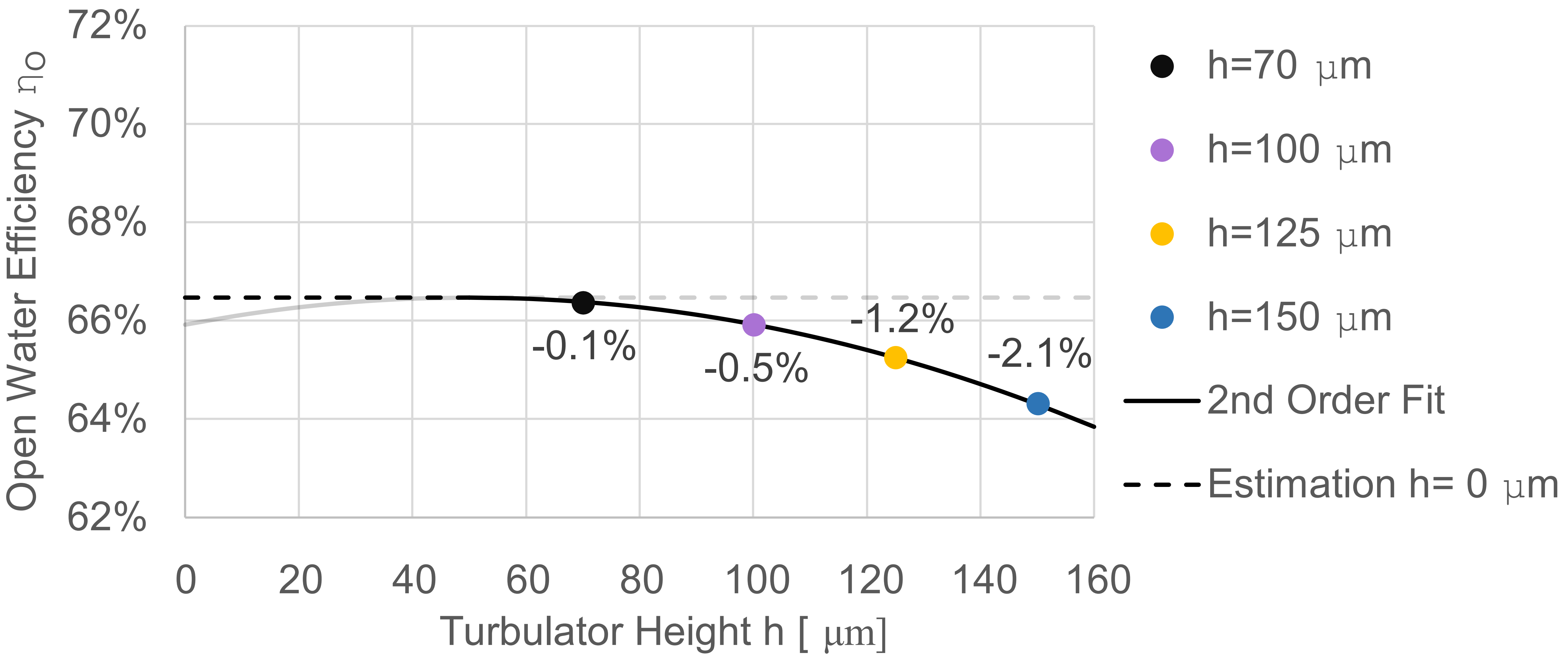

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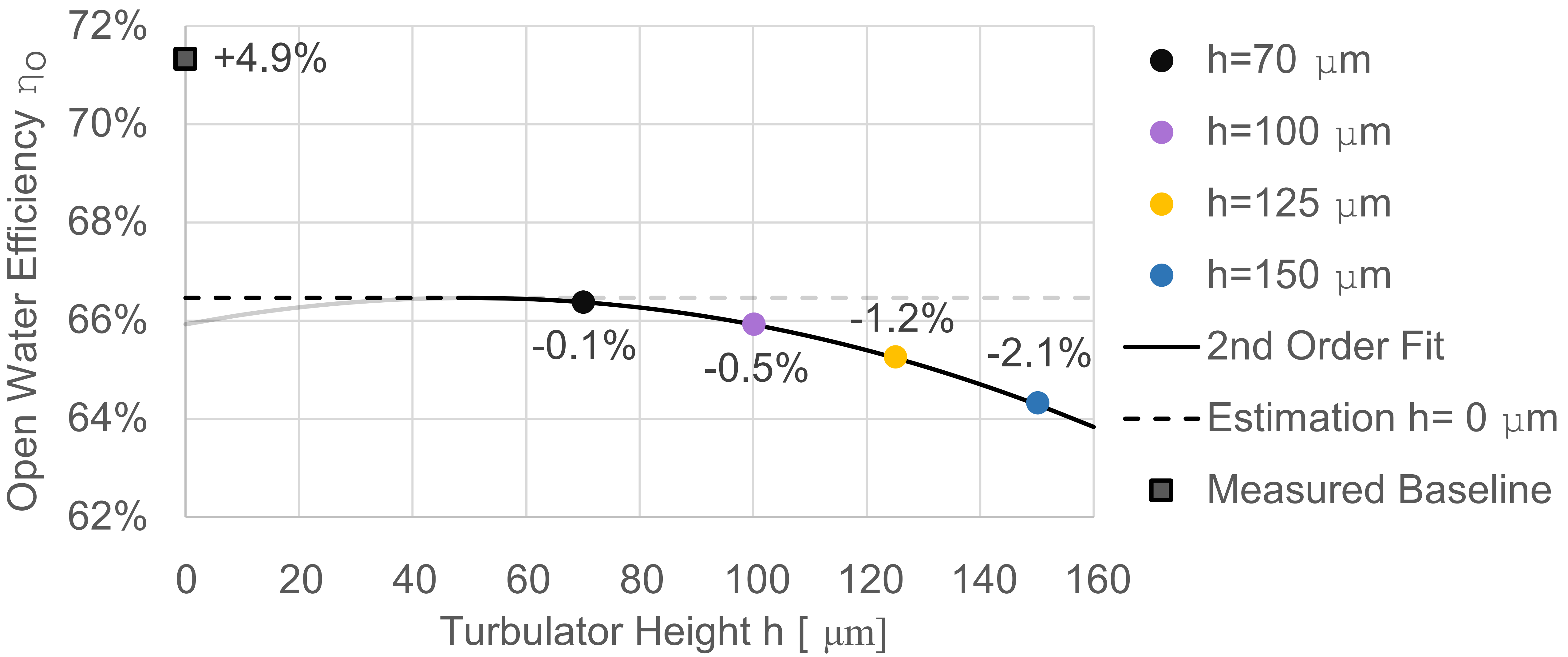

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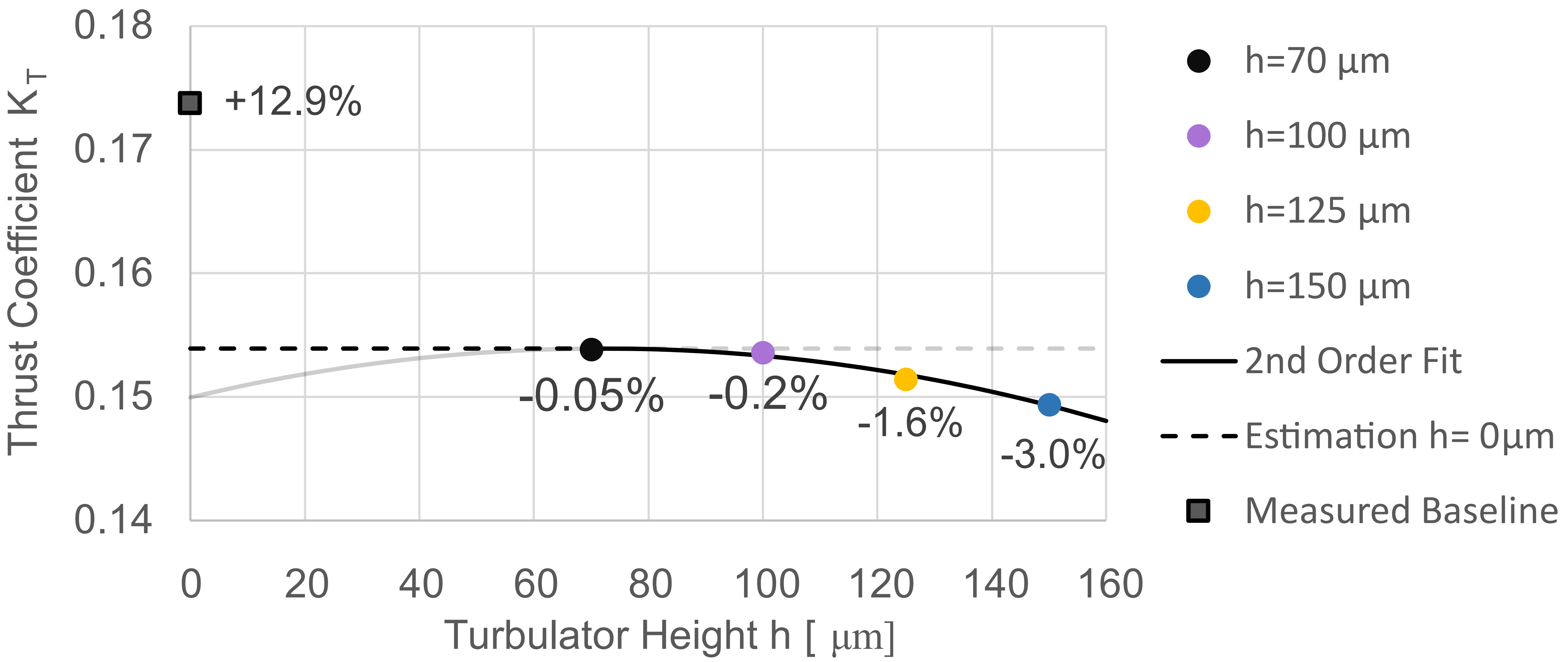

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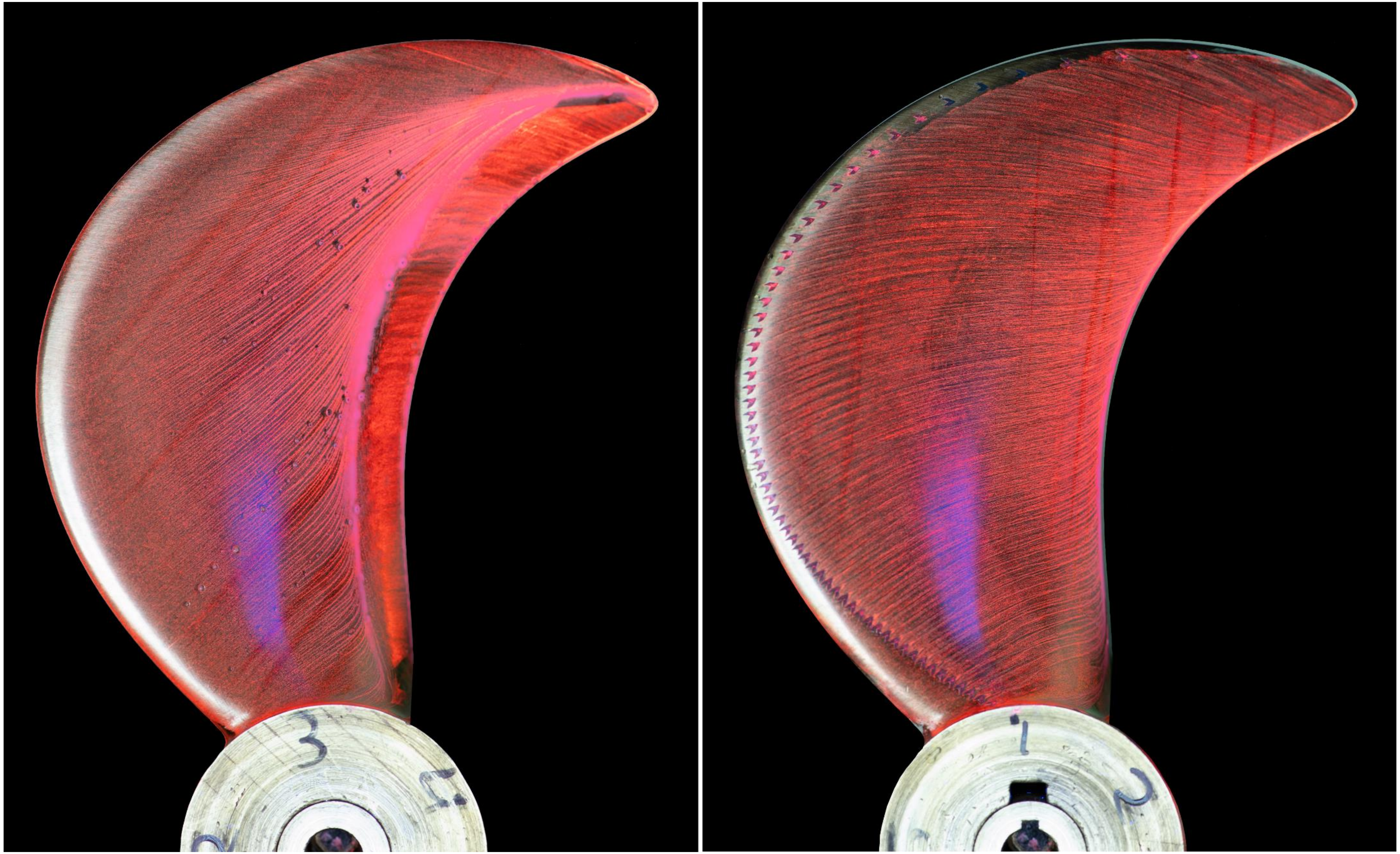
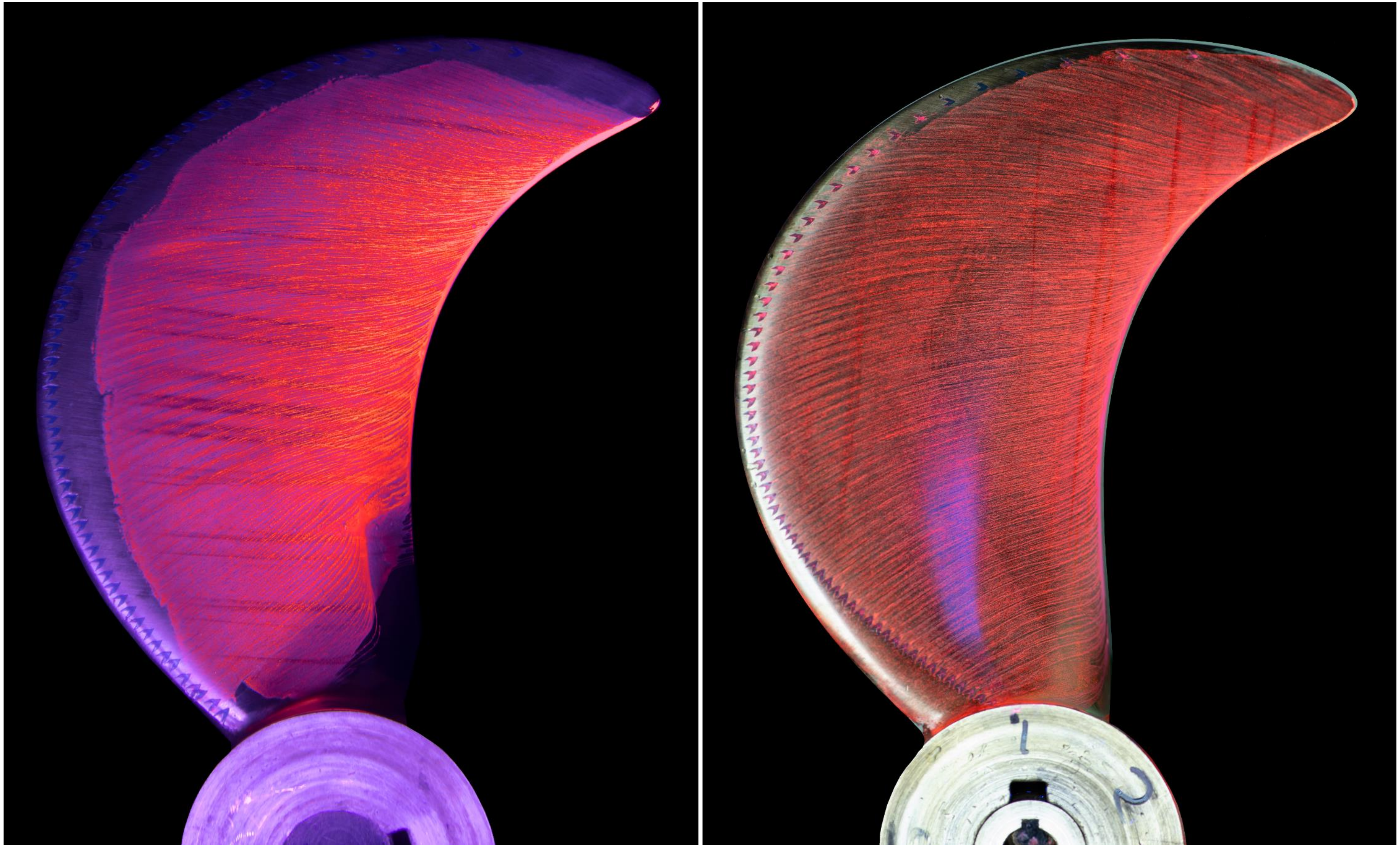


Positioning of the turbulators near the hub



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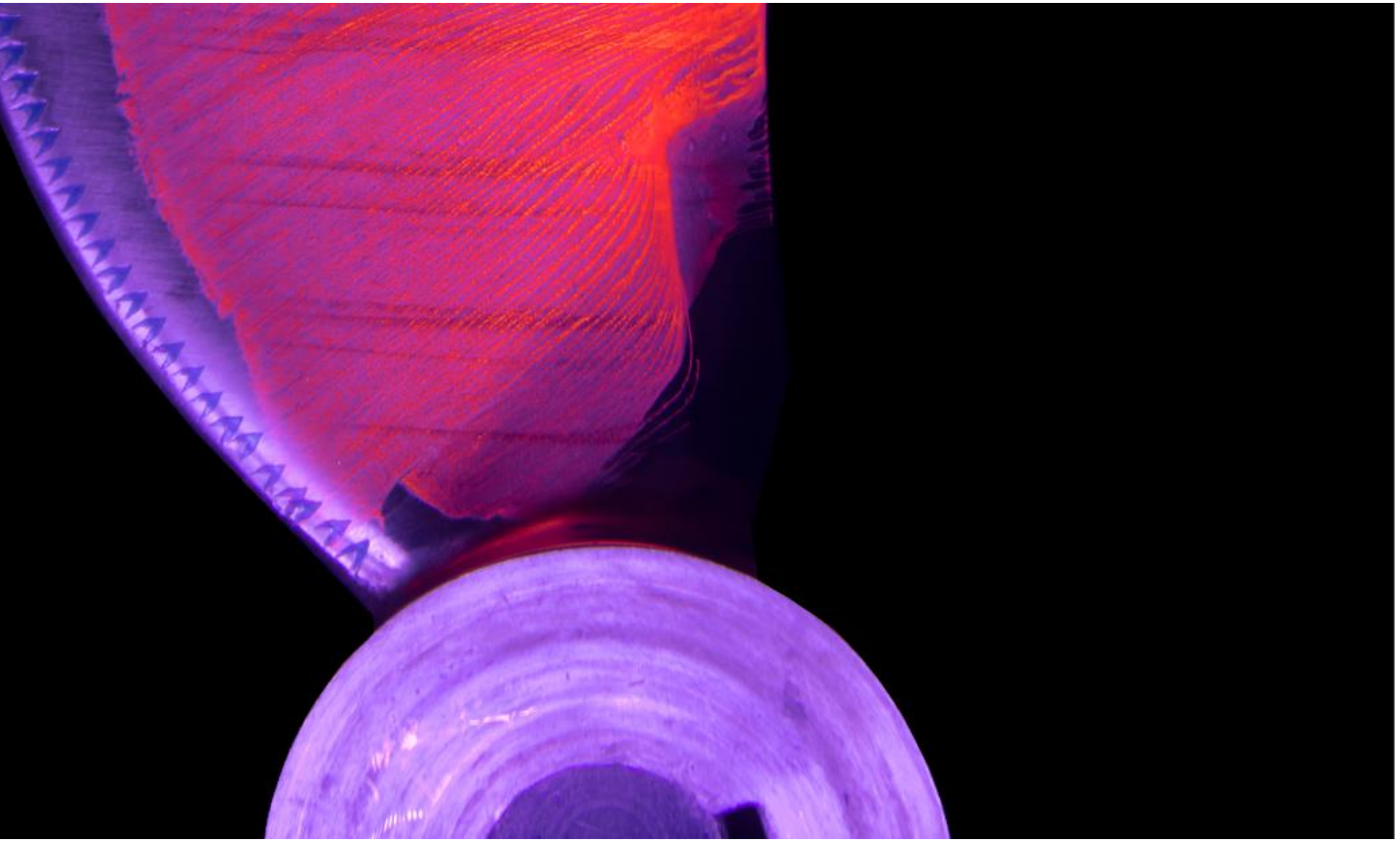
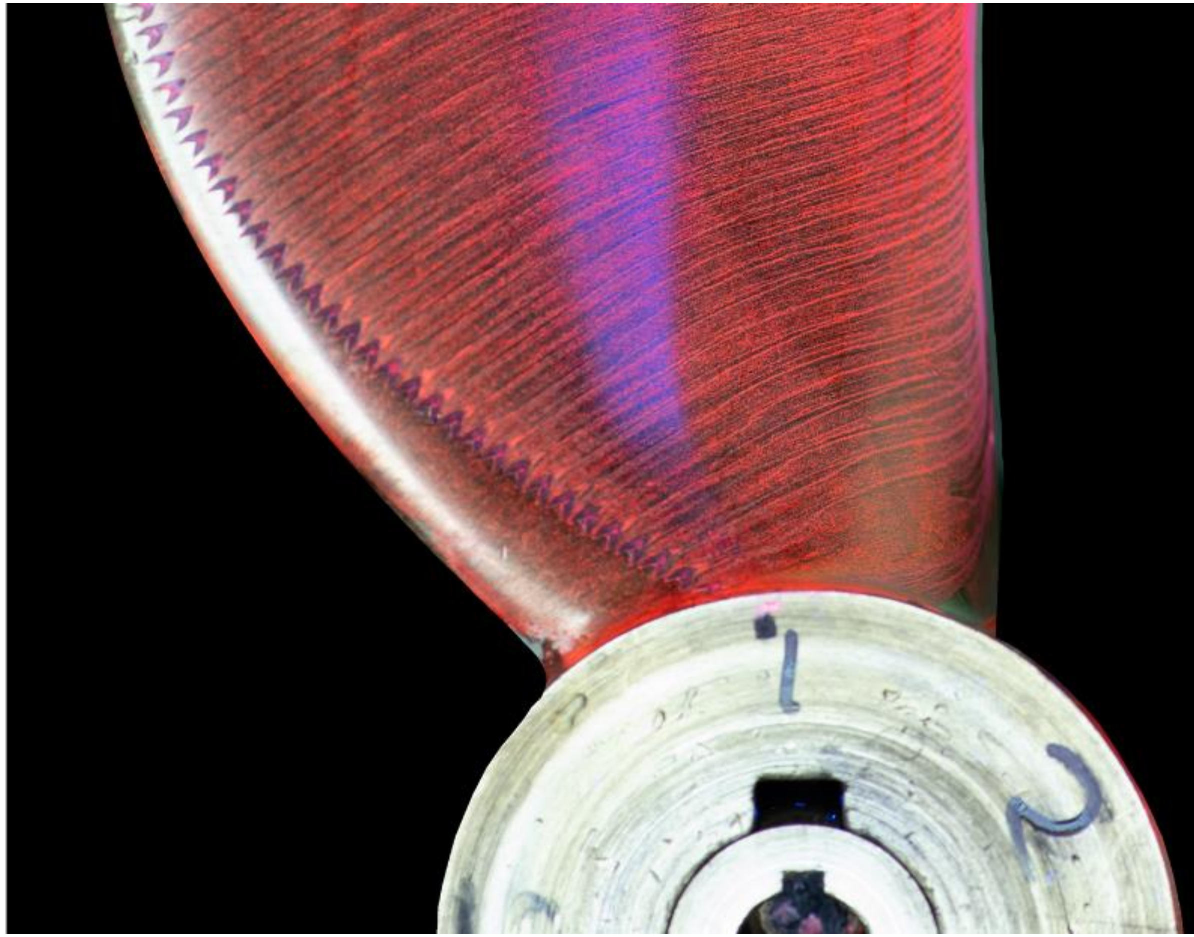


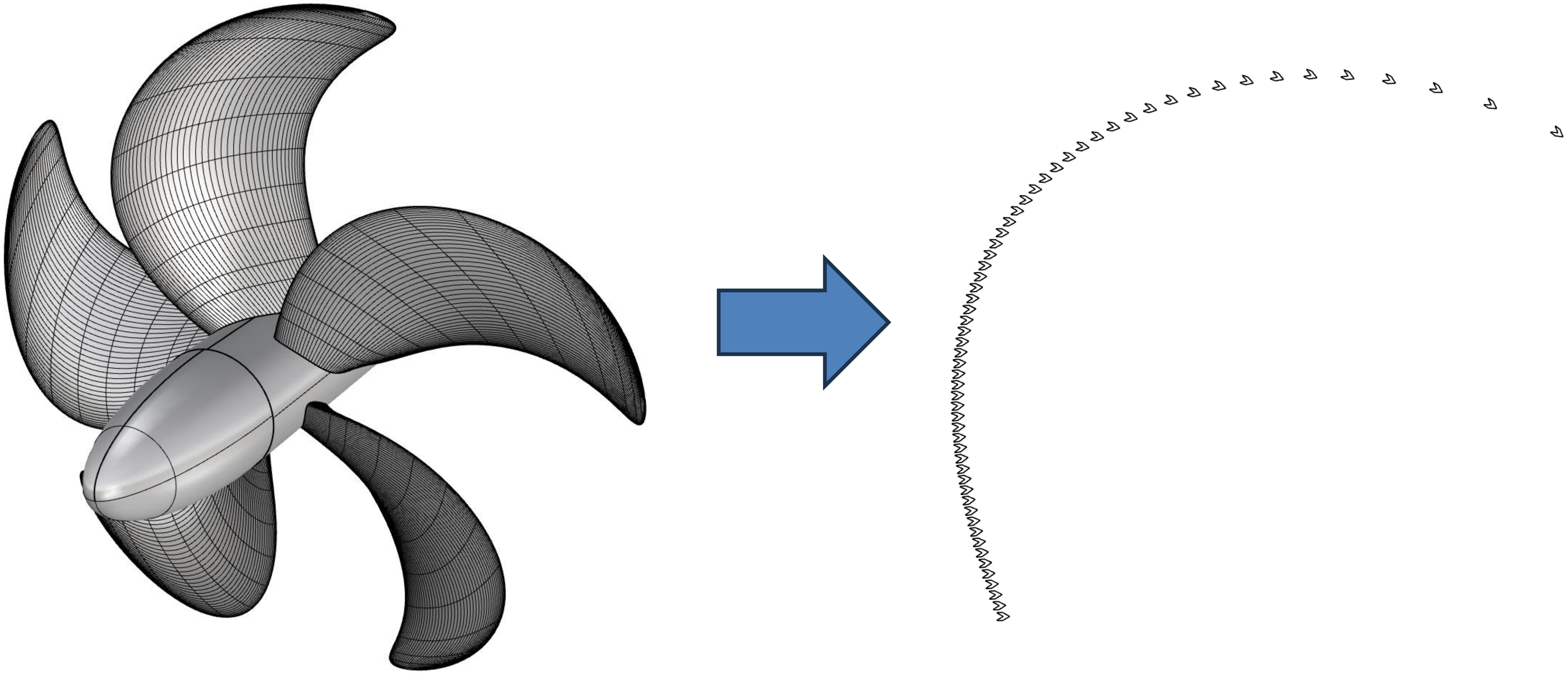


MARIN

How It's Made

The Turbulator

How It’s Made

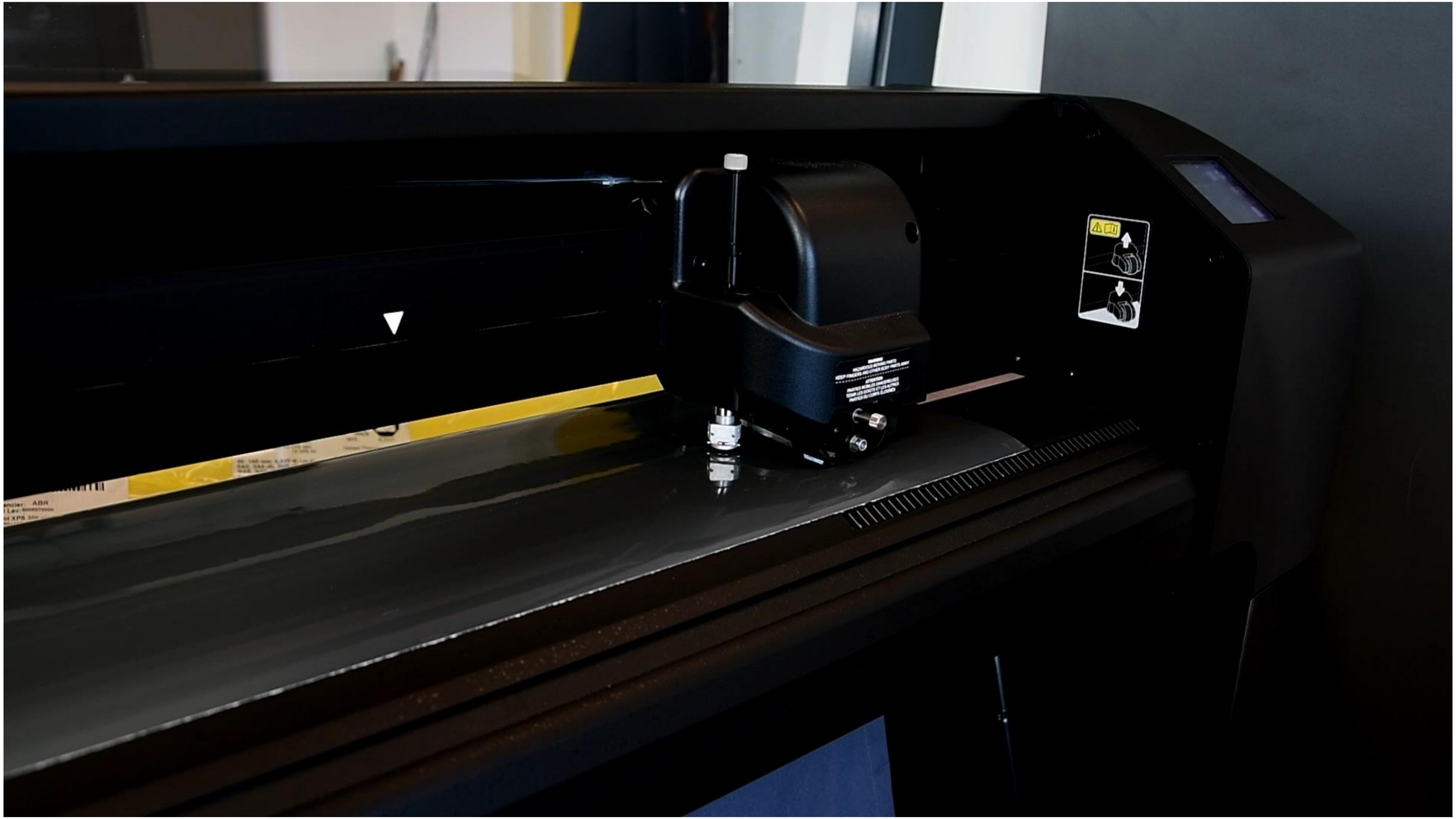


Rhinoceros

How It's Made

Adhesive Vinyl Foil
70 μm
90 μm
120 μm
150 μm
230 μm

How It's Made



How It's Made

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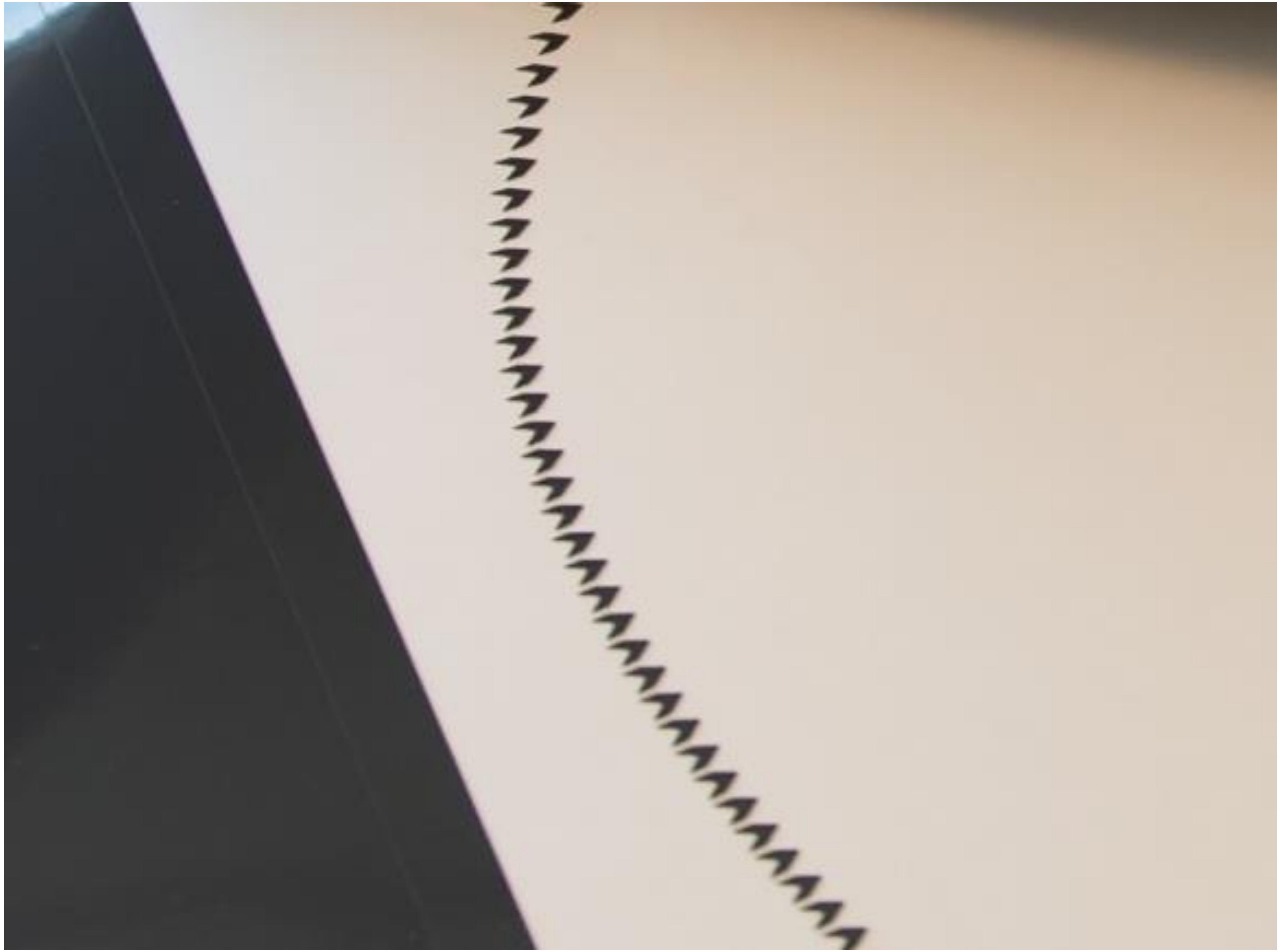

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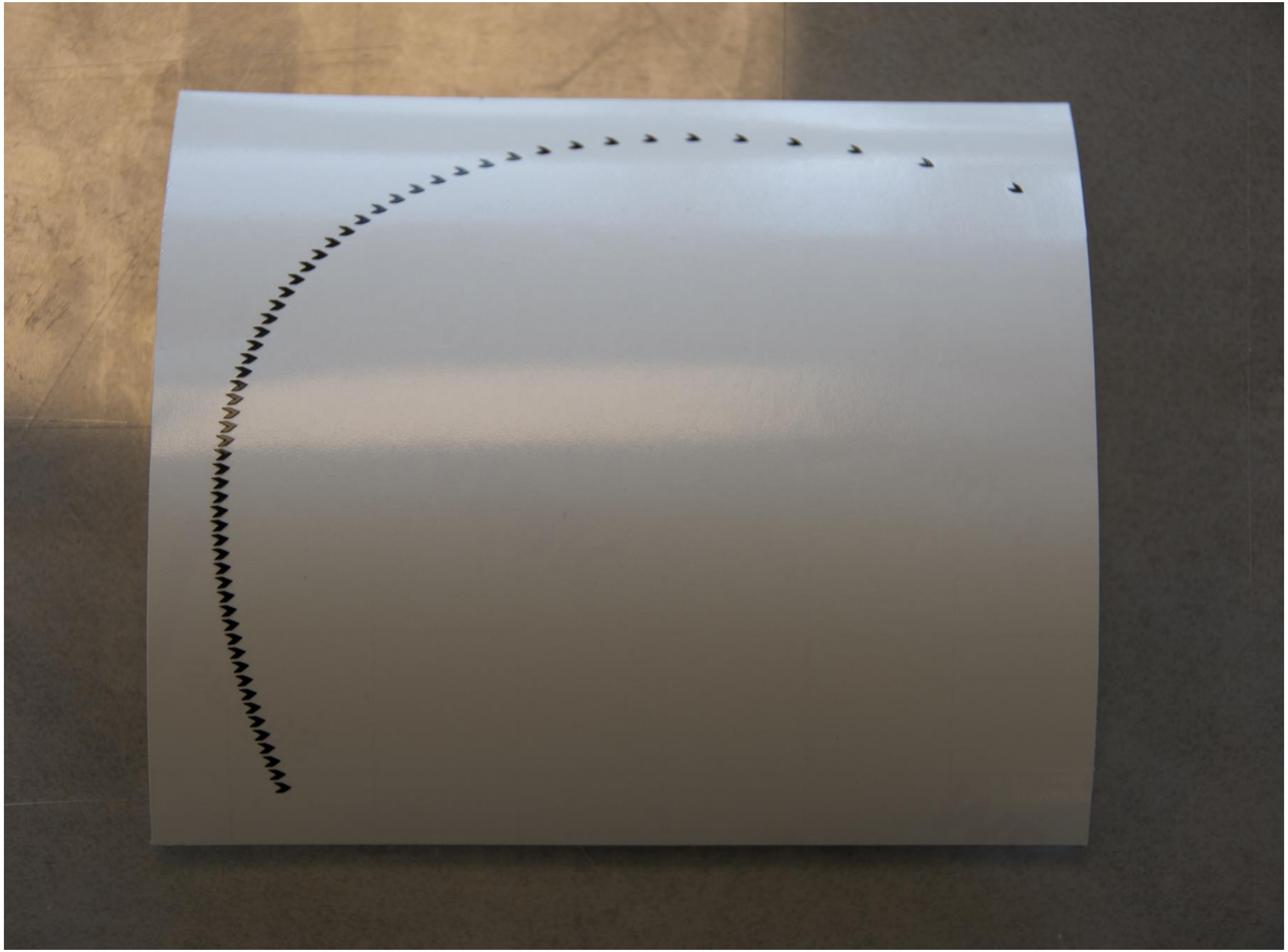
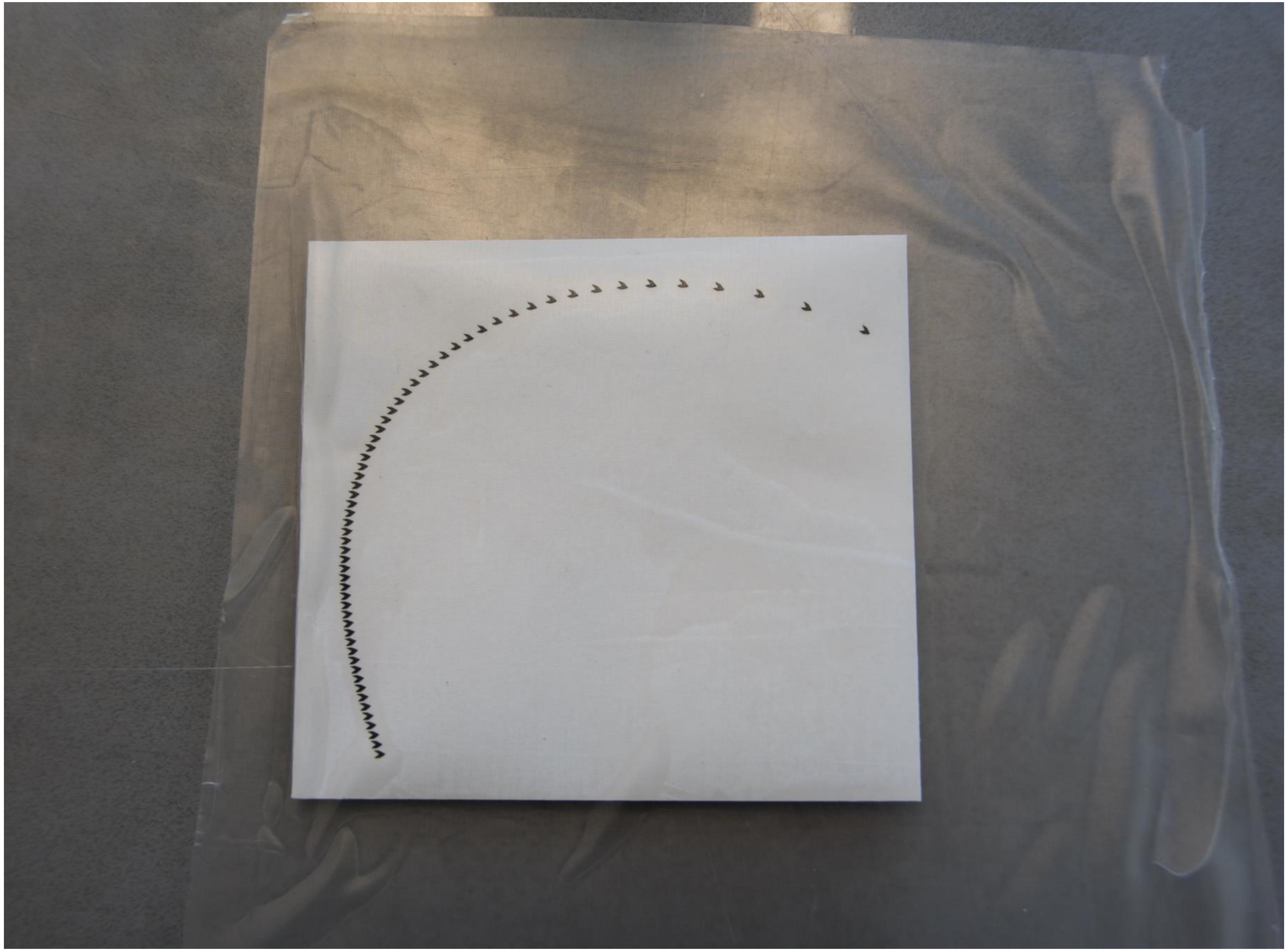


How It’s Made

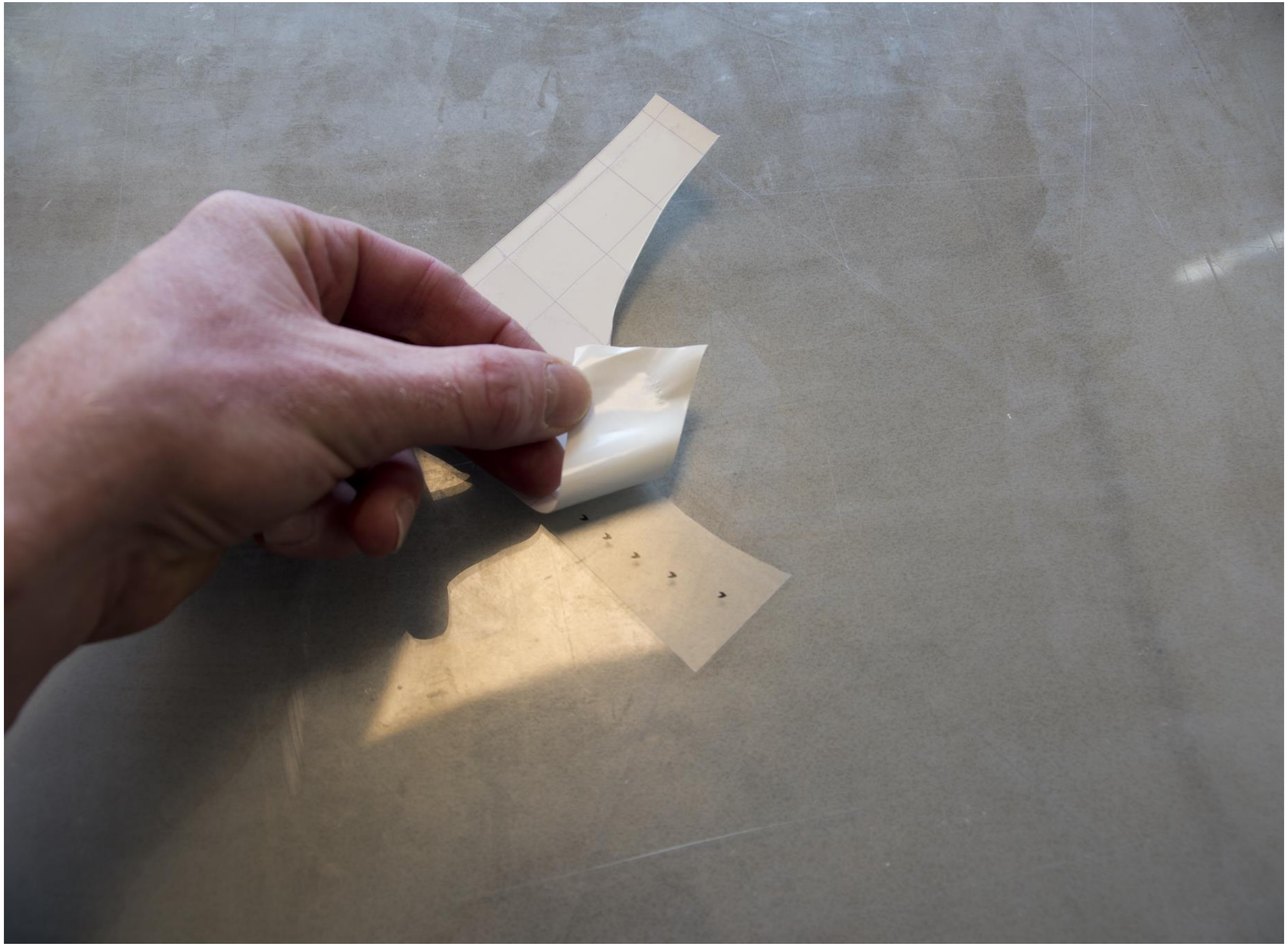
Transfer Foil

How It's Made

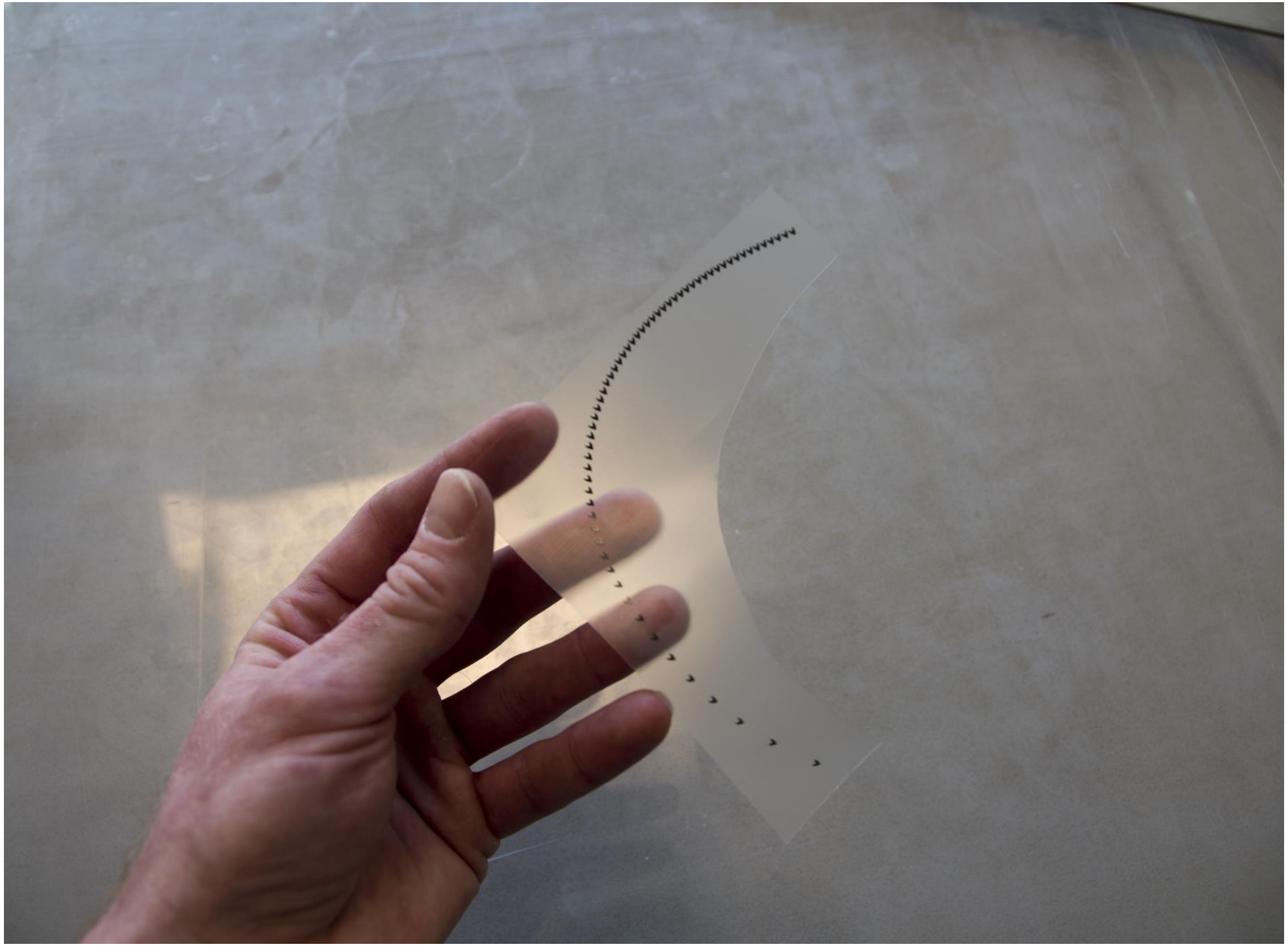


How It's Made

How It’s Made



How It's Made



How It's Made

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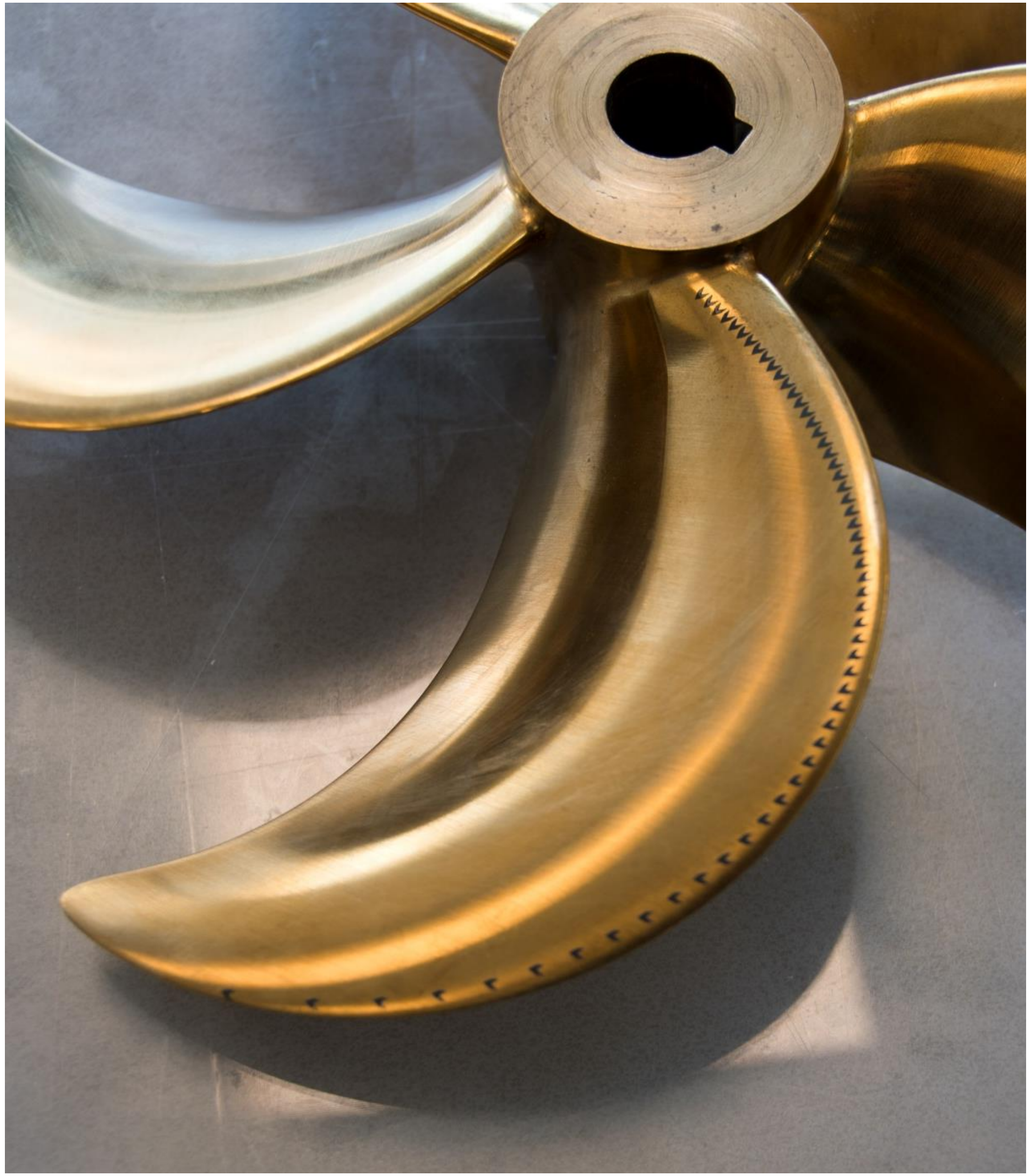
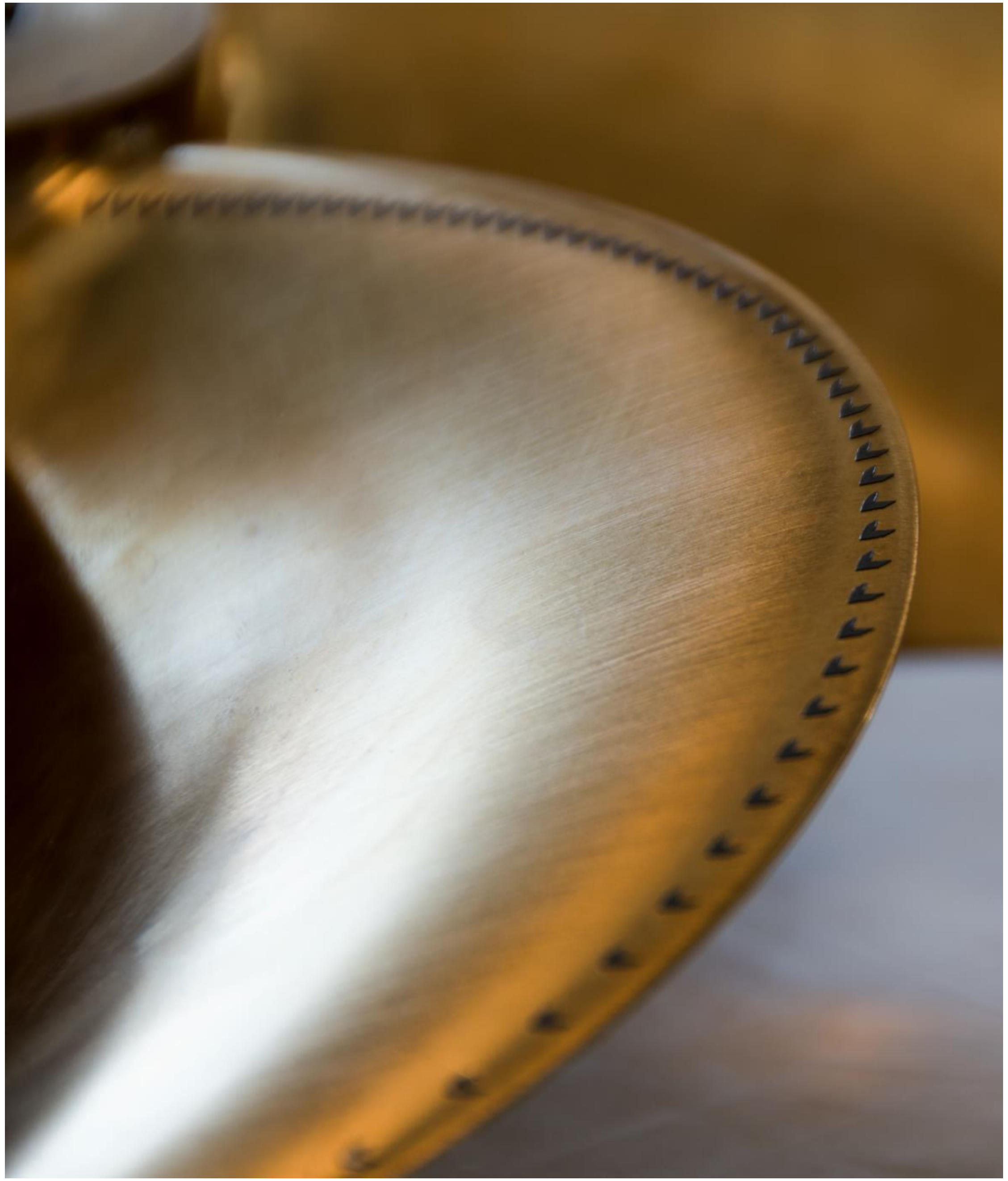




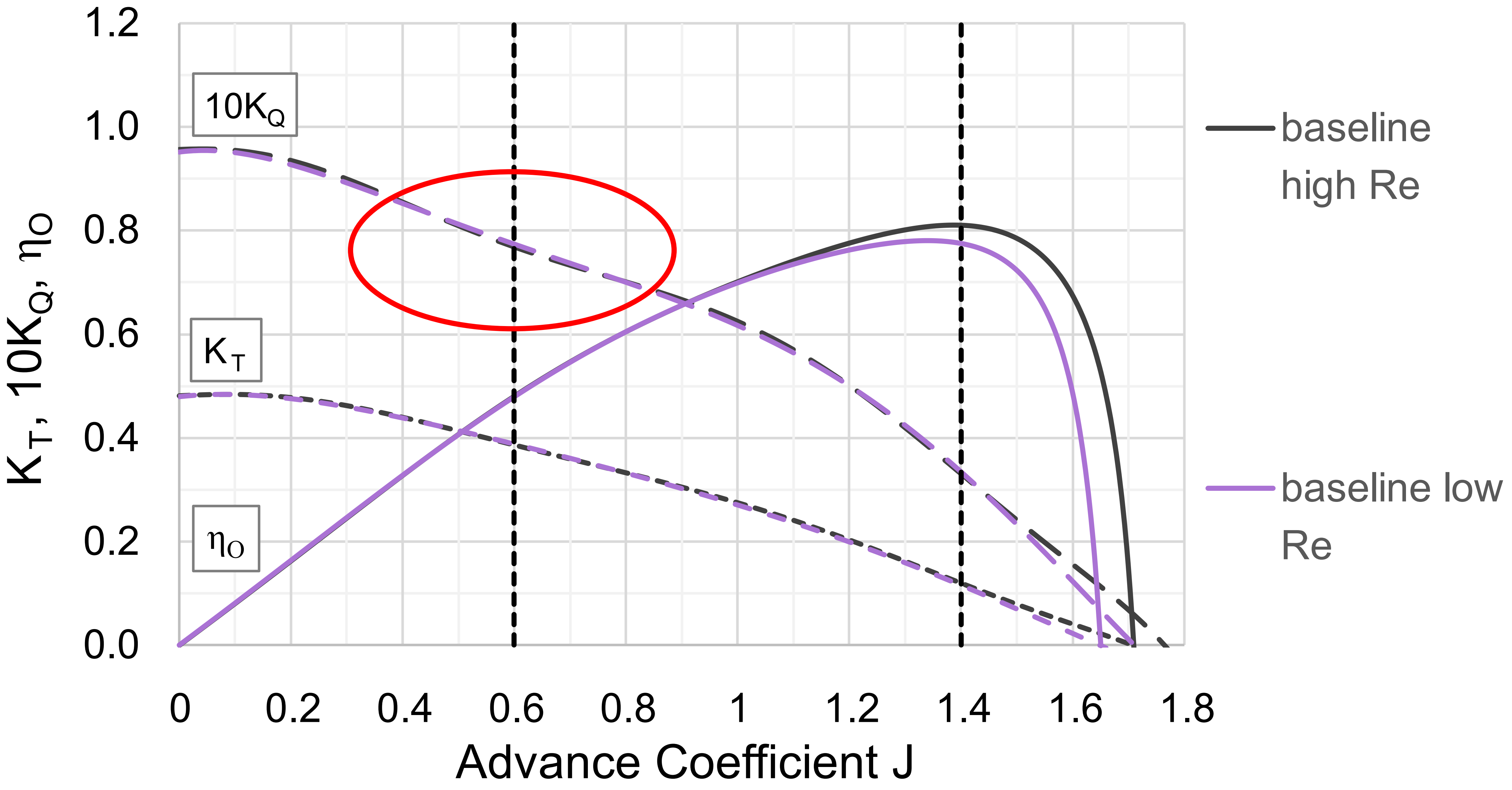
Small Blade Area Propeller

MARIN

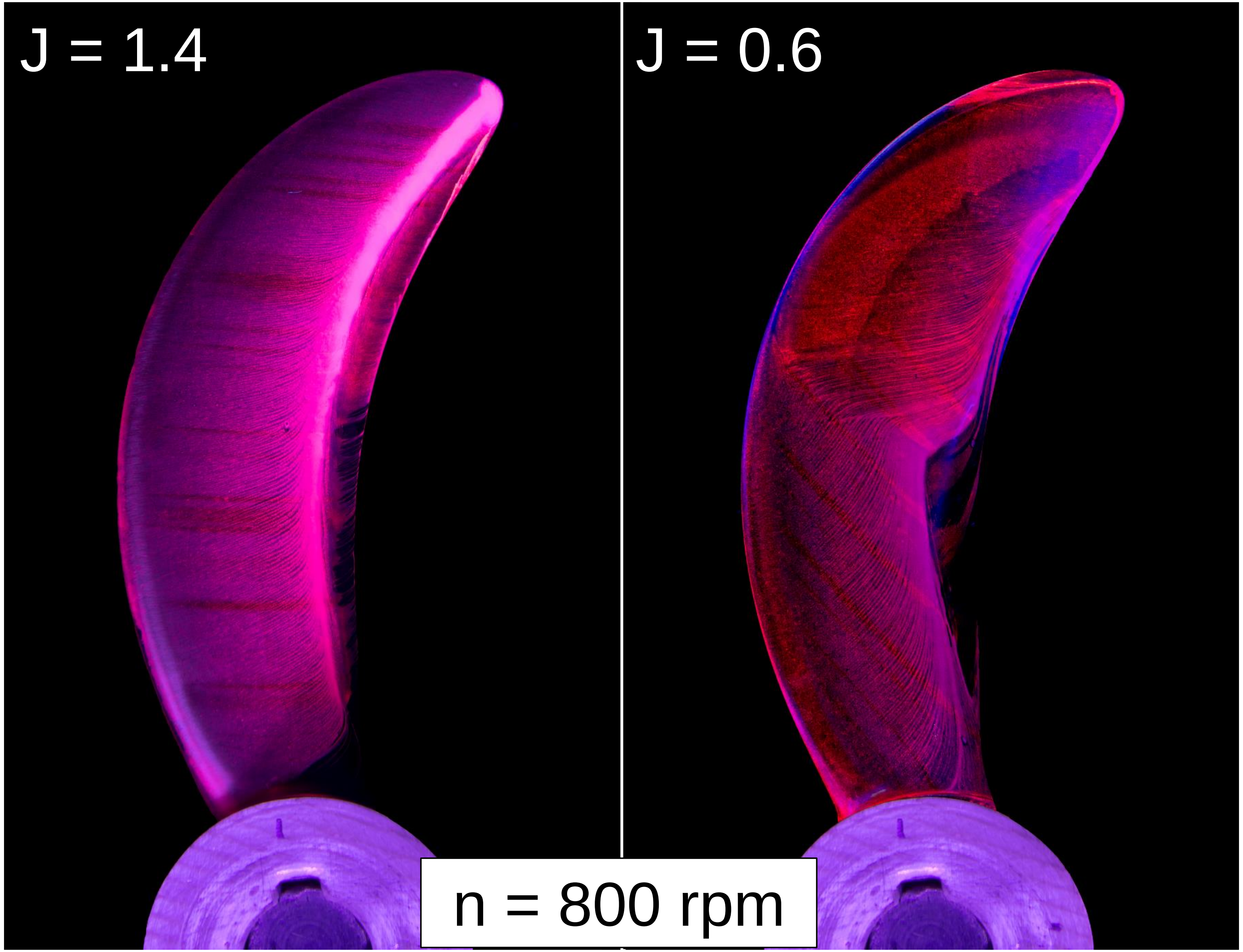
Propeller C

Diameter	D	290 mm
# Blades	Z	4
Chord	$C_{0.7R}/D$	0.1766
Pitch	$P_{0.7R}/D$	1.6
Expanded Area Ratio	A_e / A_o	0.35

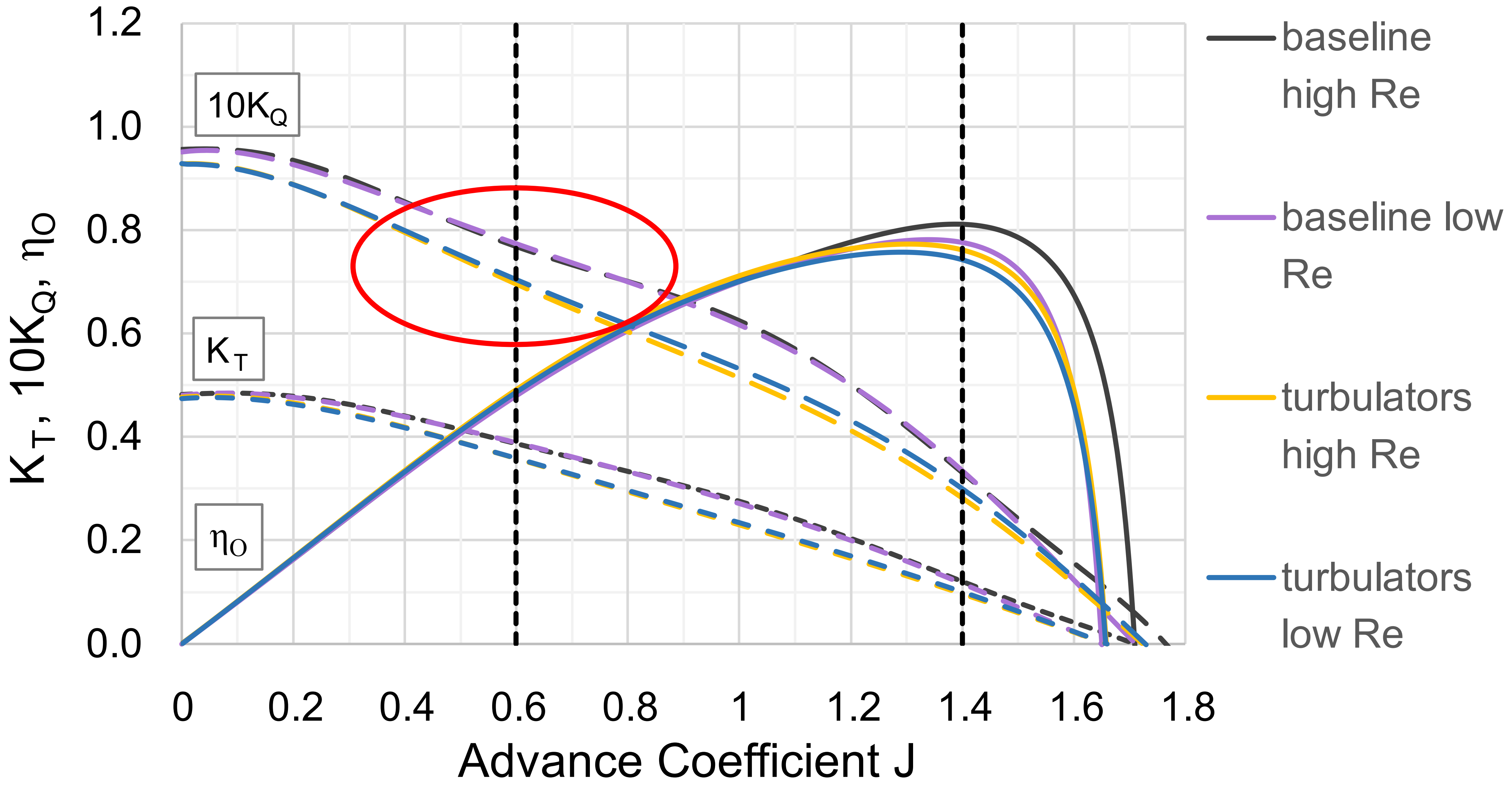
Small Blade Area Propeller



Small Blade Area Propeller



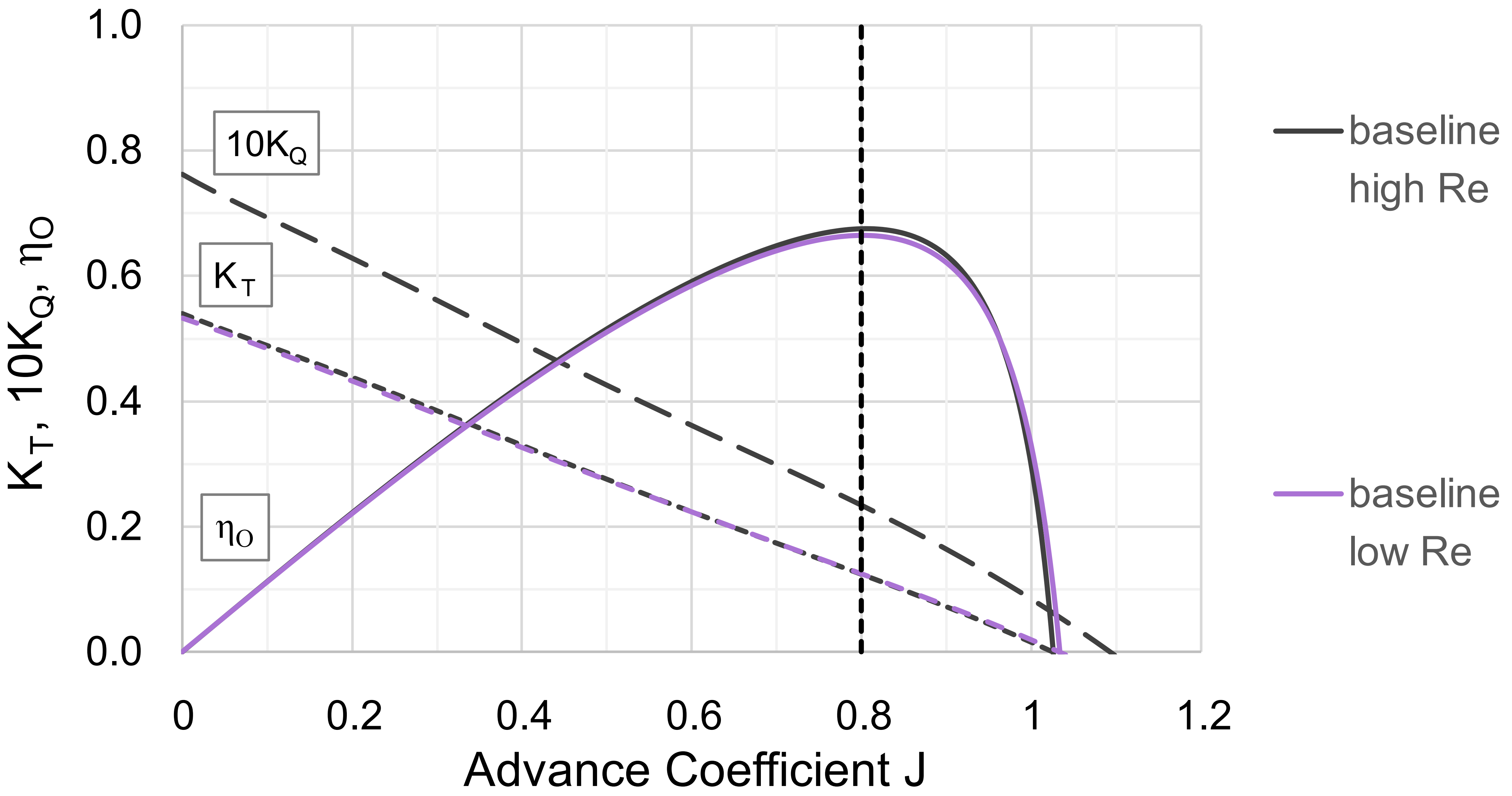
Small Blade Area Propeller



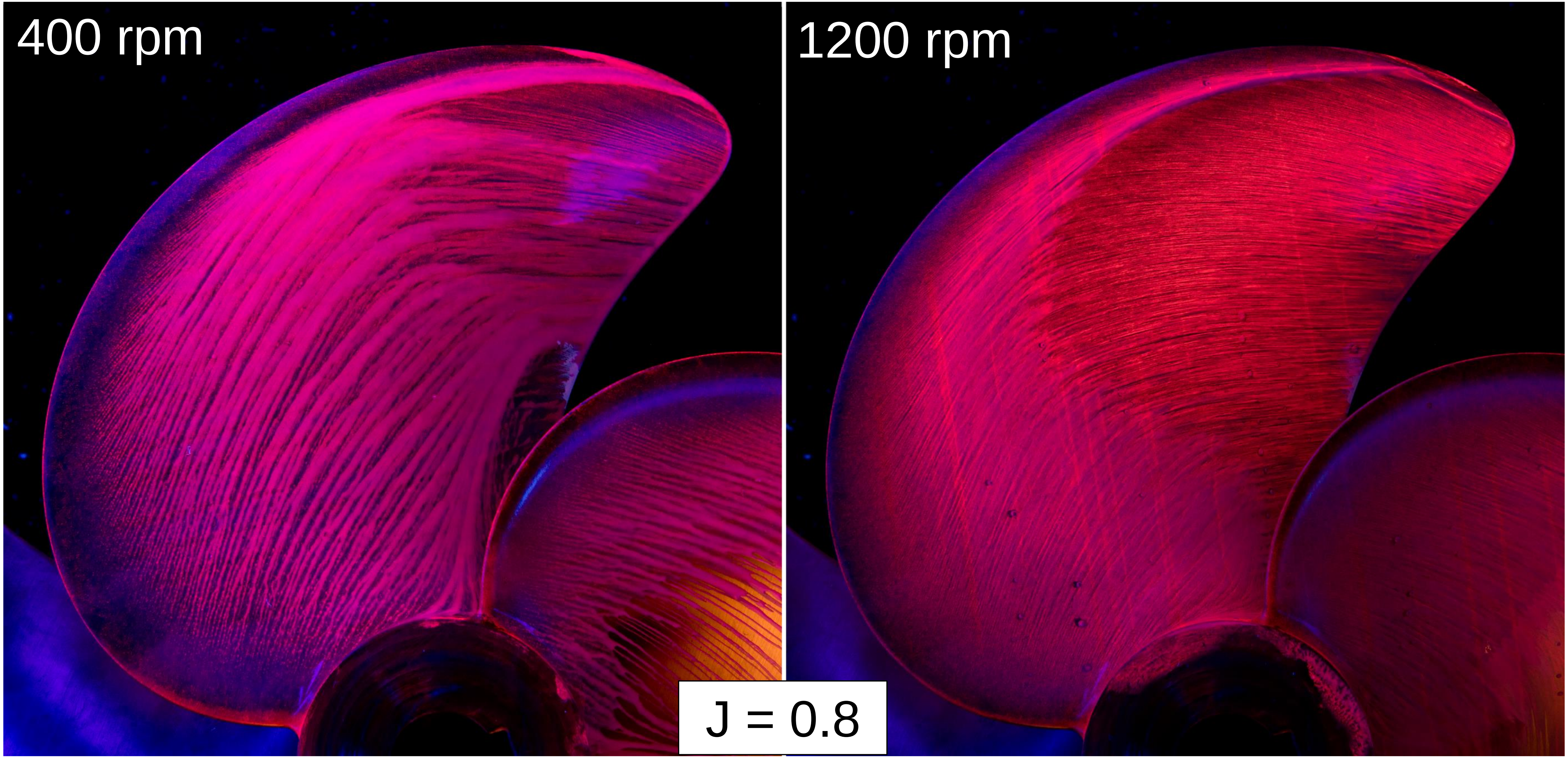
Propeller D

Diameter	D	290 mm
# Blades	Z	4
Chord	$C_{0.7R}/D$	0.4783
Pitch	$P_{0.7R}/D$	1.0
Expanded Area Ratio	A_e / A_o	0.85

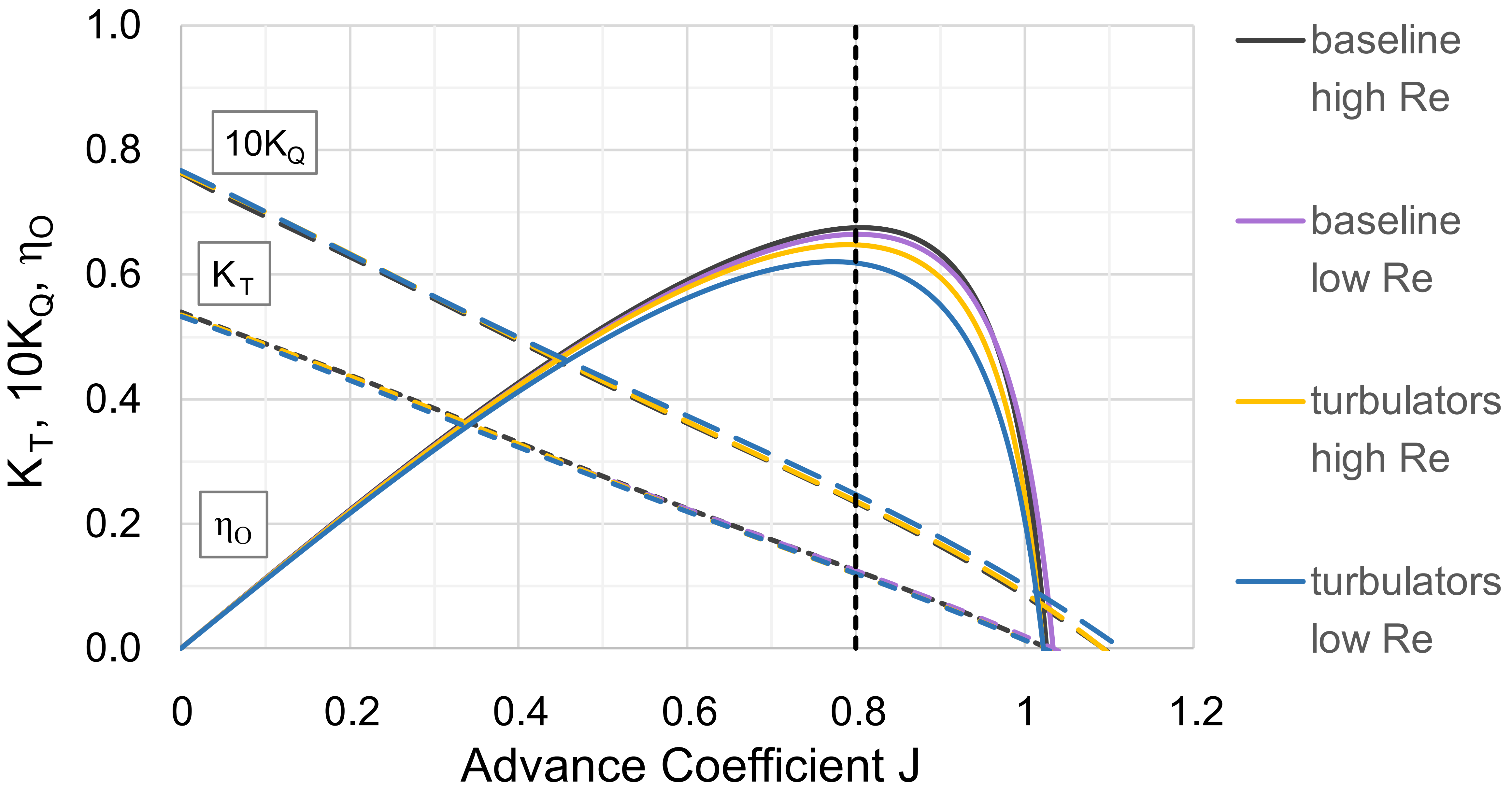
Large Blade Area Propeller



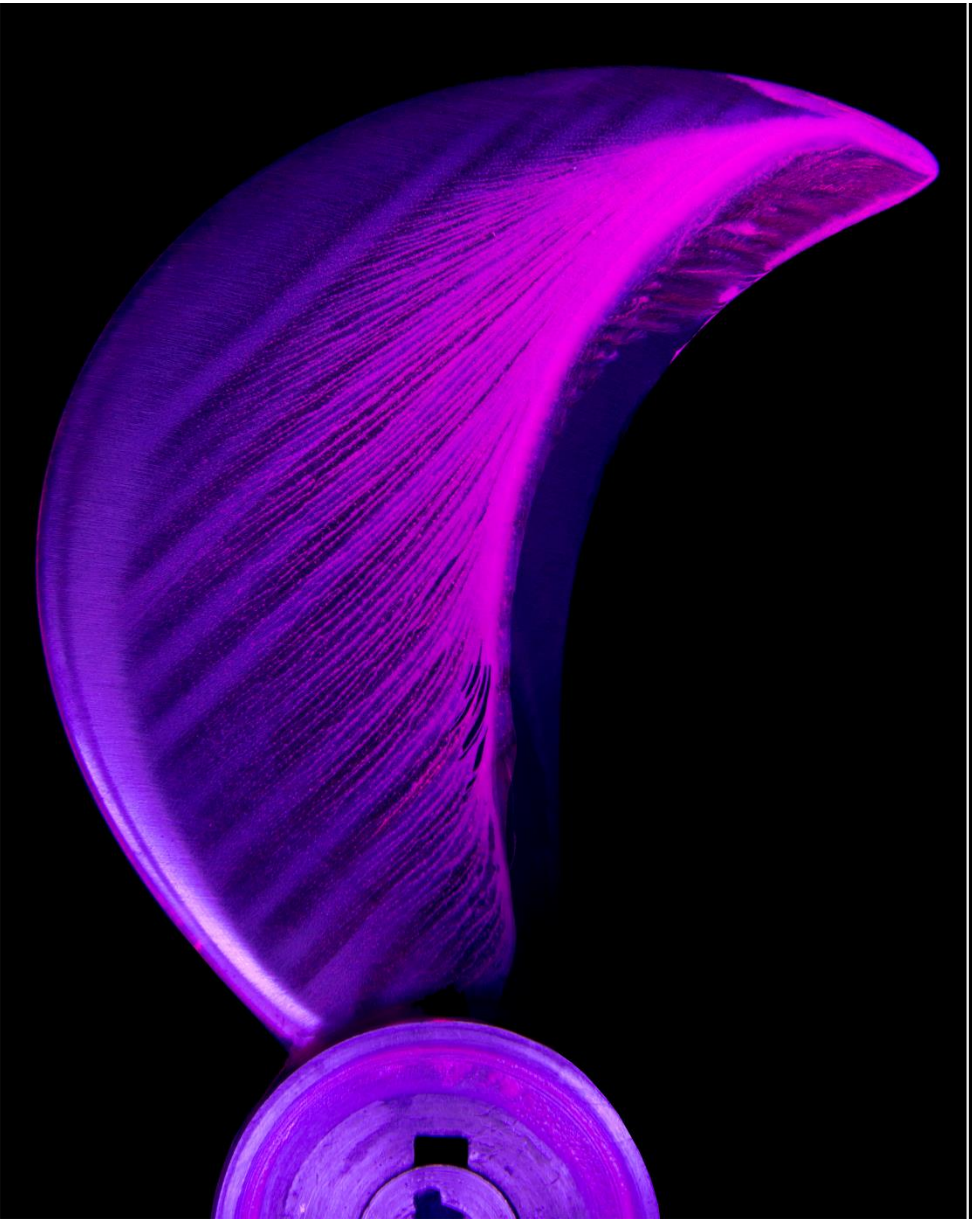
Large Blade Area Propeller



Large Blade Area Propeller



Behind Ship Model Tests



Open water

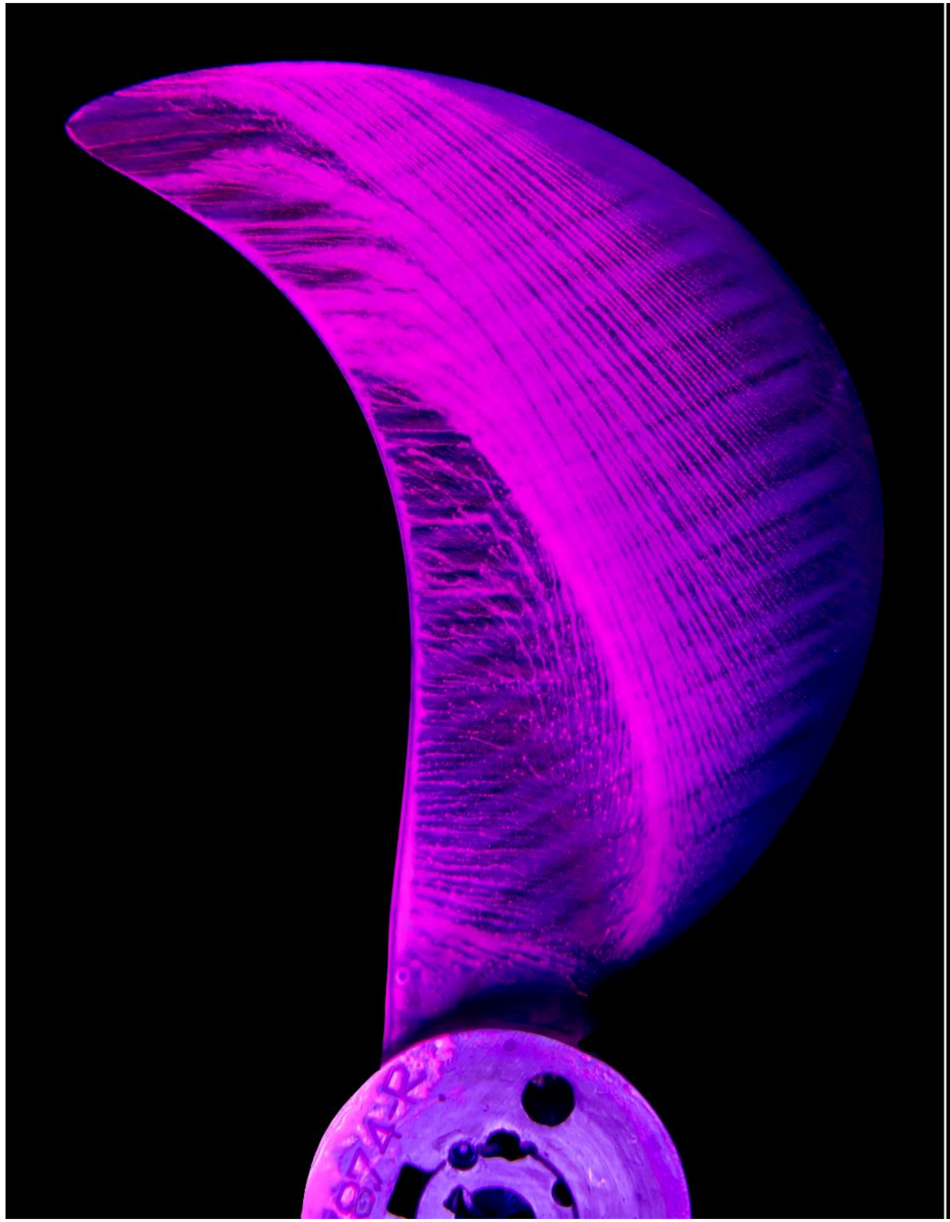
In behind ship model

Tamura and Sasajima (1977)

Lücke and Streckwall (2017)

Hasuike et al. (2018)

Li et al. (2019)



Open water

In behind ship model

Tamura and Sasajima (1977)

Lücke and Streckwall (2017)

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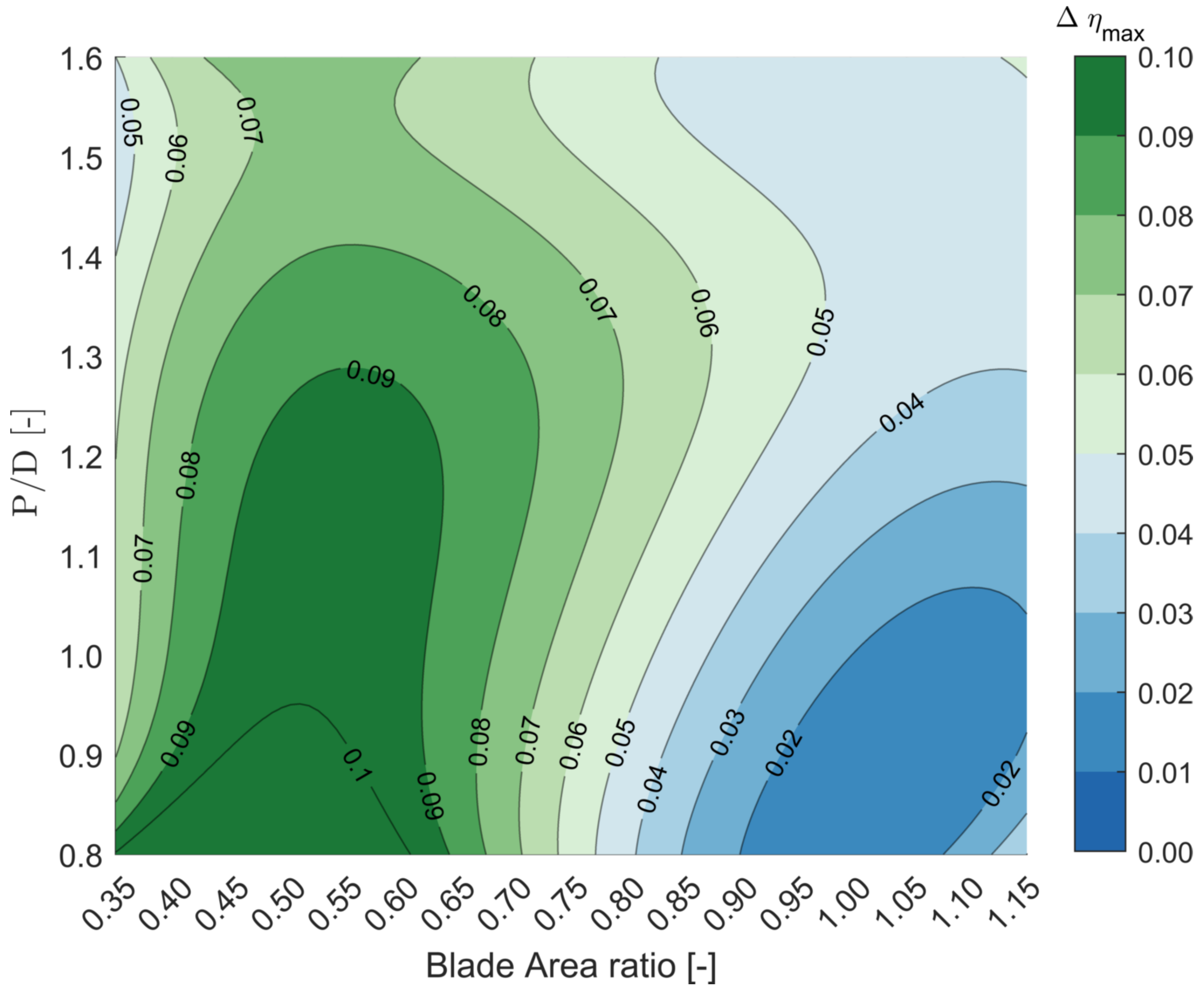
A Golden Opportunity

A Golden Opportunity

A Golden Opportunity



WAGENINGEN
F - SERIES | JIP

Conclusions

- Reinvented the propeller paint testing method and made it available to the maritime industry.

- Modern propeller designs tend to have (partially) laminar boundary layers and flow separation for the typical range of model test Reynolds numbers.

- The presence of low-Reynolds effects poses considerable challenges for the accuracy, interpretability and reliability of model tests and the extrapolation towards full-scale Reynolds numbers.

- An explorative study using the F-Series showed a large dependency on the propeller design.

- Our solution is the application of turbulators.
  - The isolated impact (parasitic drag) is small
  - They are easy to manufacture and apply
  - Low-Reynolds scale effects are no longer an issue