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Instituto Nacional de Técnica Aeroespacial

Cooperative Research Ships

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CEHIPAR CENTRO DE EXPERIENCIAS HIDRODINÁMICAS DE EL PARDO

PROJECT K2+

SCALING THE PEAKS OF SURFACE ROUGHNESS MODELLING

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INTRODUCTION

Who we are

The Cooperative Research Ships (CRS) is an organization that started in 1969 with the goal of obtaining general data about the hydrodynamics and related problems of large and high-powered ships.

24 member organizations and companies carrying out a joint work program, sponsored equally by all members.

What we do

PROJECT K2+
SCALING THE PEAKS OF SURFACE ROUGHNESS MODELLING

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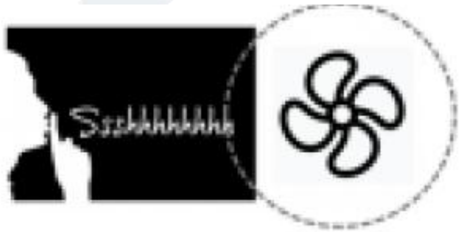
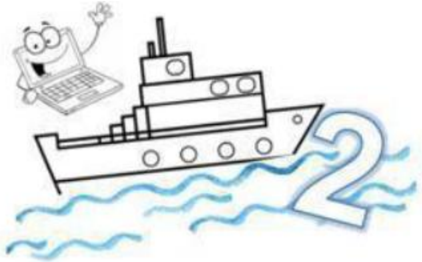




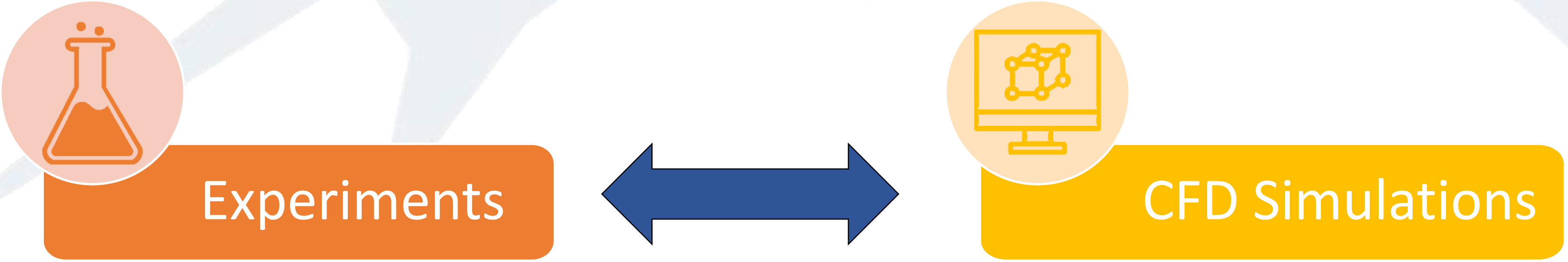
And more….!!!!

OBJECTIVE

Roughness (+fouling) on hulls and propellers has a ***significant*** impact on a ship performance over her lifetime.

- Reduce ship speed and increase fuel consumption and emissions.
- Influence on propeller inflow.
- Transom wet / dry.
- Local flow behavior / Boundary layer separation.
- Efficiency of appendages and control devices.

Accurately predicting these phenomena is crucial for shipping companies.



PROJECT OVERVIEW

- WP 1 State of the art
- WP 2 Rotating Disc: Manufacturing and Surface Measurement
- WP 3 Experimental Torque Measurements
- WP 4 Boundary Layer Profilometry using LDV
- WP 5 CFD Simulations
- WP 6 Experimental and Numerical Concordance

State of the Art

Roughness

Hagen, Darcy, Coolebrok, Moody, Nikuradse….

Boundary Layer

Schlichting.

Naval Industry (s.XX)

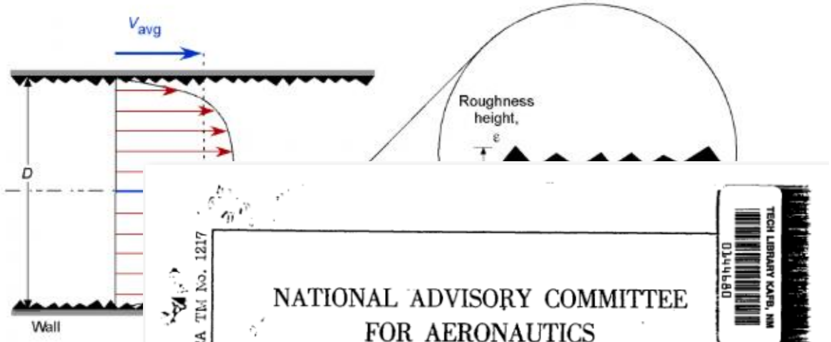
McEntee, U.S Navy, West, Granville.

Naval Industry (s.XIX)

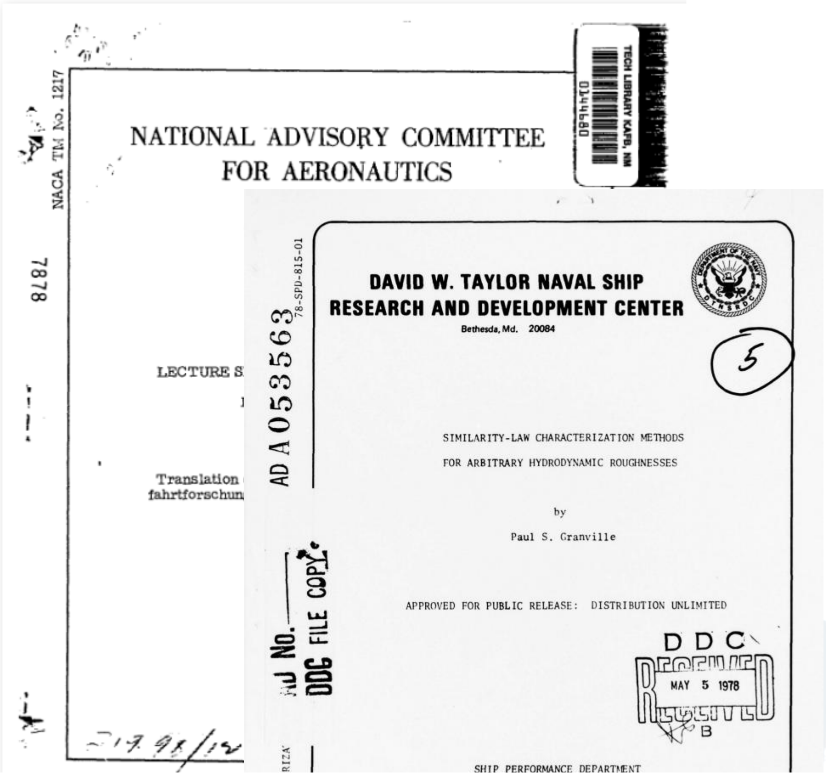
Song, Dai, Demirel, Atlar, Ravenna.

Schultz et al.

Mikkelsen.



Source: In Vehicles



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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

SIMILARITY-LAW CHARACTERIZATION METHODS FOR ARBITRARY HYDRODYNAMIC ROUGHNESSES

by

Paul S. Granville

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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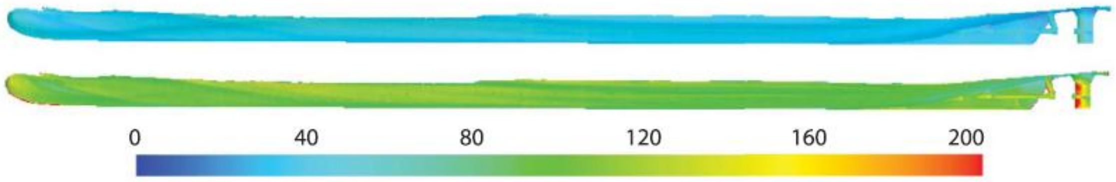
SHIP PERFORMANCE DEPARTMENT



Source: Mikkelsen, H., & Walther, J. H. (2020). Effect of roughness in full-scale validation of a CFD model of self-propelled ships

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Roughness Characterization

$\boldsymbol{R_a}$: Arithmetic average of the absolute height.

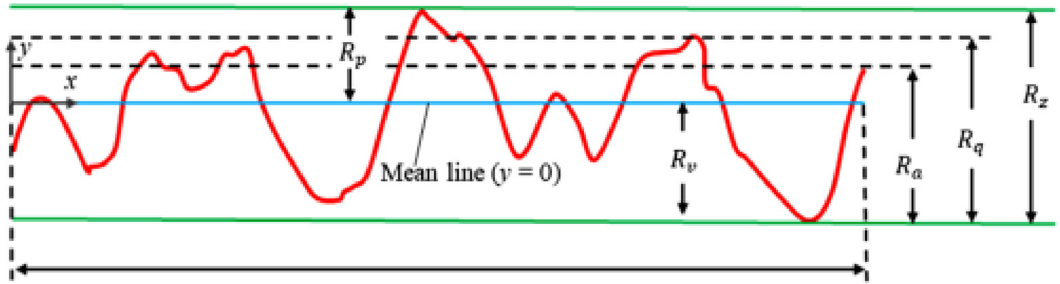
$$R_a = \frac{1}{L}\int_0^L |z(x)|dx$$

$\boldsymbol{R_z}$: Distance between the height of the maximum peak and the depth of the deepest valley.

$$R_z = \max\{p_i\} + \max\{v_i\}$$

$\boldsymbol{R_{RMS}}$ of height, sometimes named in the literature as $\boldsymbol{R_q}$ which is calculated as:

$$R_{RMS} = \sqrt{\frac{1}{L}\int_0^L z(x)^2 dx}$$



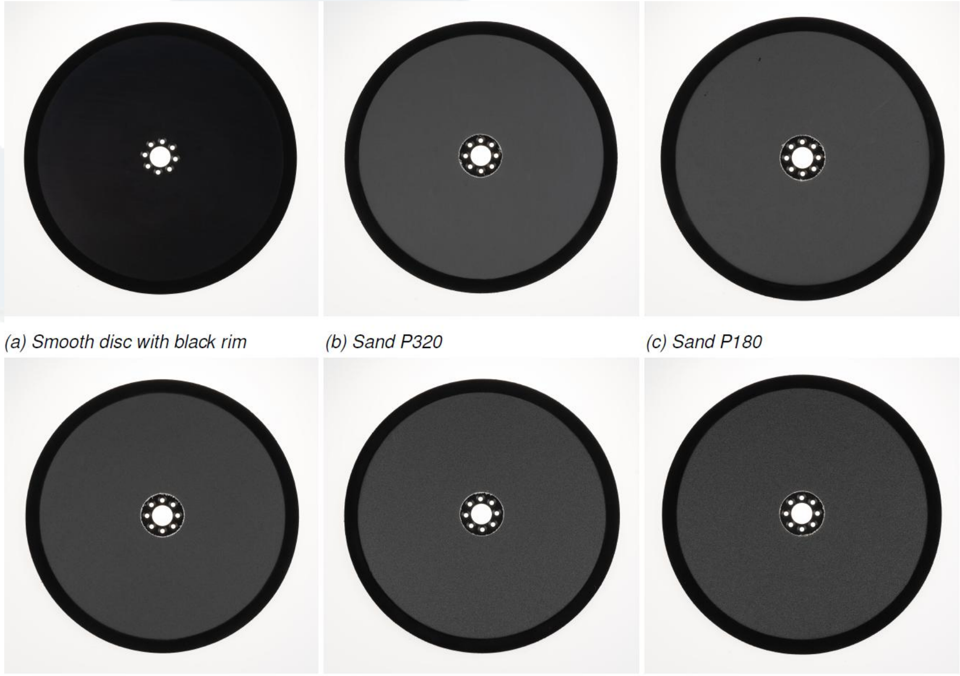
Schematic representation of roughness parameters (Kadivar el al, 2021)

Roughness values Ra micrometers (µm)	Roughness N ISO Grade Numbers	RMS	CLA (µin.) Center Line Avg	Surface Finish
0.025	N1	1.1	1	Superfinish
0.05	N2	2.2	2	-
0.1	N3	4.4	4	-
0.2	N4	8.8	8	Polish
0.4	N5	17.6	16	Ground
0.8	N6	32.5	32	Smooth
1.6	N7	64.3	63	Fine
3.2	N8	137.5	125	Semifine
6.3	N9	275.0	250	Medium
12.5	N10	550.0	500	Semirough
25.0	N11	1100.0	1000	Rough
50.0	N12	2200.0	2000	Cleanup

ISO 1302:1992 Roughness grade numbers and levels of surface preparation

Manufacturing and Roughnness Measurement

- Aluminium discs.
- Diameter = f(Rn) = 400mm.
- Thickness = 8mm.
- Artificial Fouling.



(a) Smooth disc with black rim
(b) Sand P320
(c) Sand P180
(d) Sand P120
(e) Sand P80
(f) Sand P60

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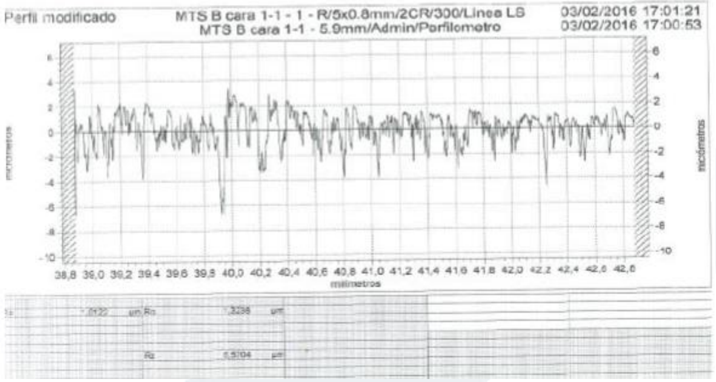
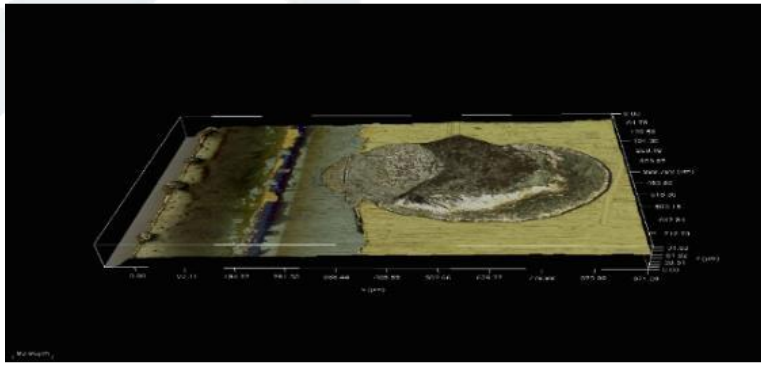
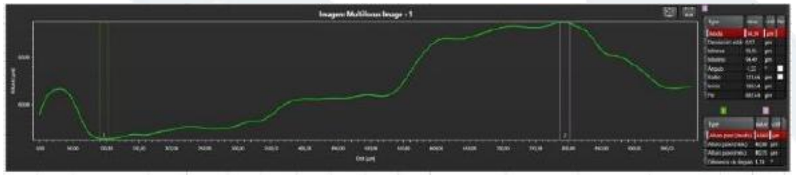
Manufacturing and Roughnness Measurement

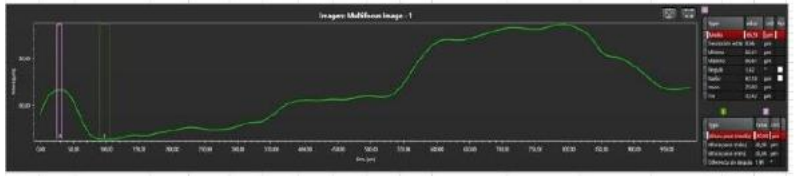
Profilometer



Digital microscope







Manufacturing and Roughnness Measurement

Hull Roughness Gauge

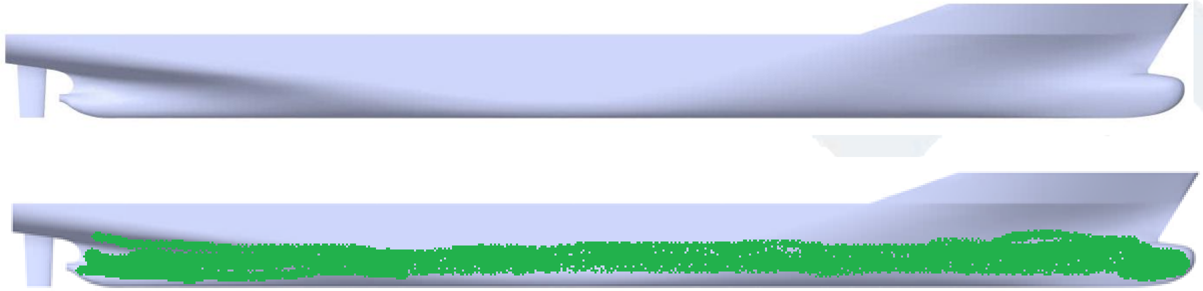
source https://industrialphysics.com/

- Mean Hull Roughness which is the average of Rt50.

$$\mathrm{MHR} = \frac{\sum Rt50}{n}$$

- Average Hull Roughness.

$$\mathrm{AHR} = \frac{\sum MHR}{m}$$



- ITTC Initial recommended value:
  - 120 – 150 microns
- Roughness after ten years....
  - 300 – 450 microns

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ROUGHNESS ESTIMATION

One approach is to estimate the roughness resistance using empirical formulas and apply it as a point force in the center of gravity. The first widely used correlation formula was proposed by Bowden and Davidson (1974).

$$\Delta C_{F,Bowden-Dav} = \left[105\left(\frac{AHR}{LWL}\right)^{\frac{1}{3}} - 0.64\right] 10^{-3}$$

ITTC recommends using AHR = 150µm.

$$\Delta C_{F,Townsin} = 0.044\left[\left(\frac{AHR}{LWL}\right)^{\frac{1}{3}} - 10\, Re^{-\frac{1}{3}}\right] + 0.000125$$

In the CFD simulations where the roughness resistance is empirically estimated, previous equations will be used with the recommended roughness height of 150µm.

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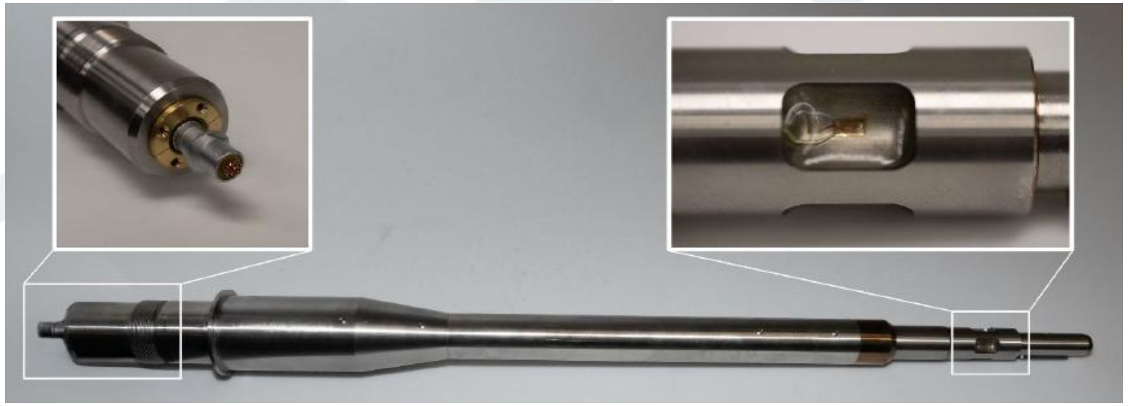
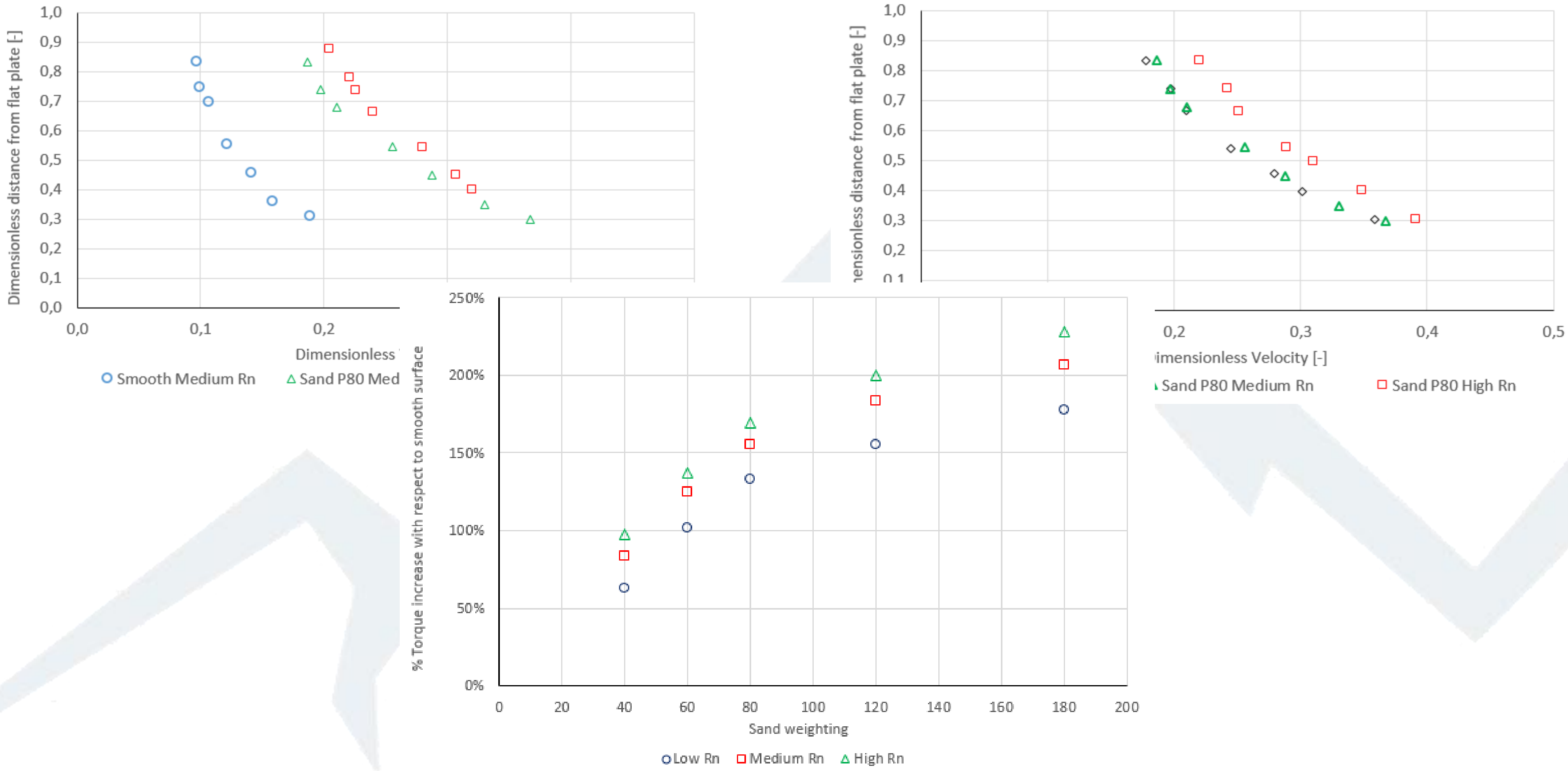
Roughness function experimental procedures

Before….

Now!!



EXPERIMENTAL RESULTS OBTAINED



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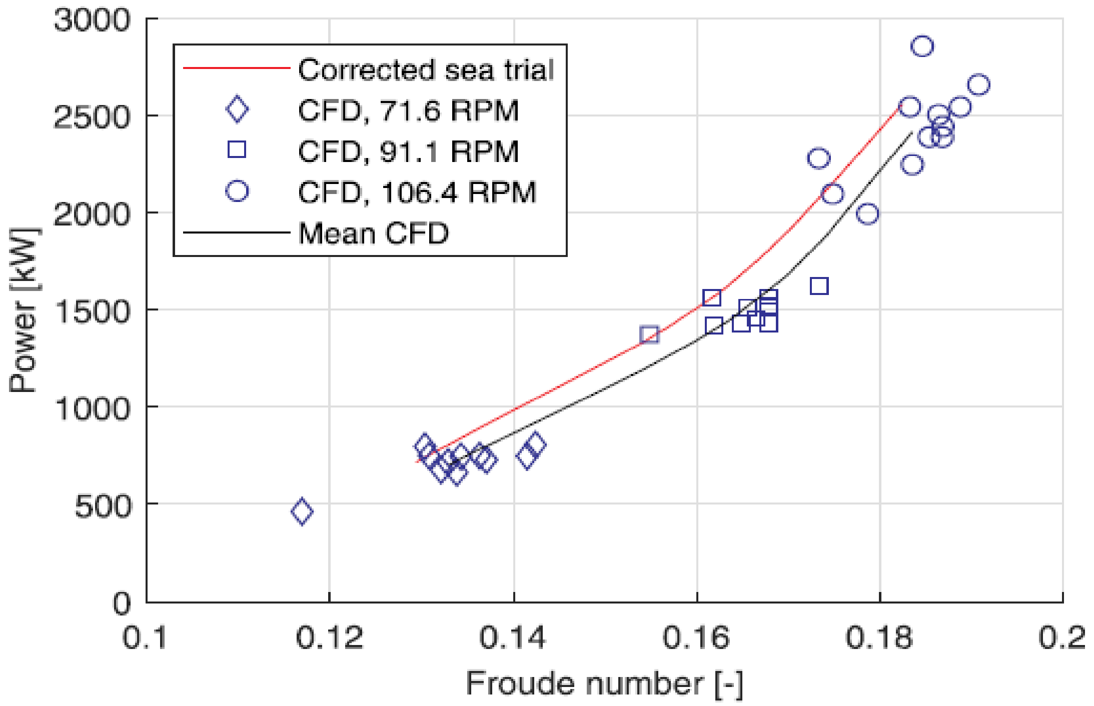
WALL ROUGHNESS IN NUMERICAL SIMULATIONS

CFD simulations underpredict the power in general.

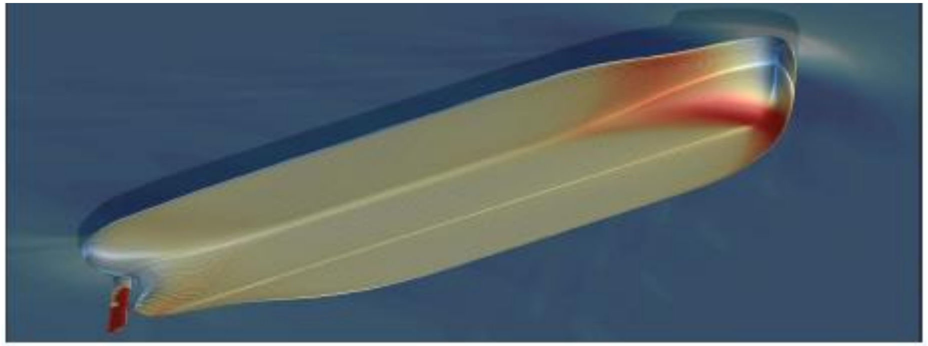
- Roughness of the hull and propeller.
- Wind loads on the superstructure.
- Reynolds number.



Comparison of CFD results from workshop participants and speed trial measurements for the LR workshop vessel REGAL. (Ponkratov 2016)

NUMERICAL TESTS

The end goal of the working group is to improve the prediction of the impact of roughness in ship performance by means of Full Scale simulations.



This will mean performing also Full Scale CFD predictions for a ship, based on the lessons learnt in previous correlation studies (disc).

However…..

- Is there some Full Scale Boundary Layer Measurement in different roughness conditions that could be used as full-scale verification?
- **Not all CFD codes model roughness in the same way.**
- Necessary knowledge so that users can use their codes in the most correct way possible.

ROUGHNESS BY CFD

An alternative method is to model the effects of roughness in the CFD calculation by applying a roughness function and modify the wall functions as proposed by Cebeci and Bradshaw.

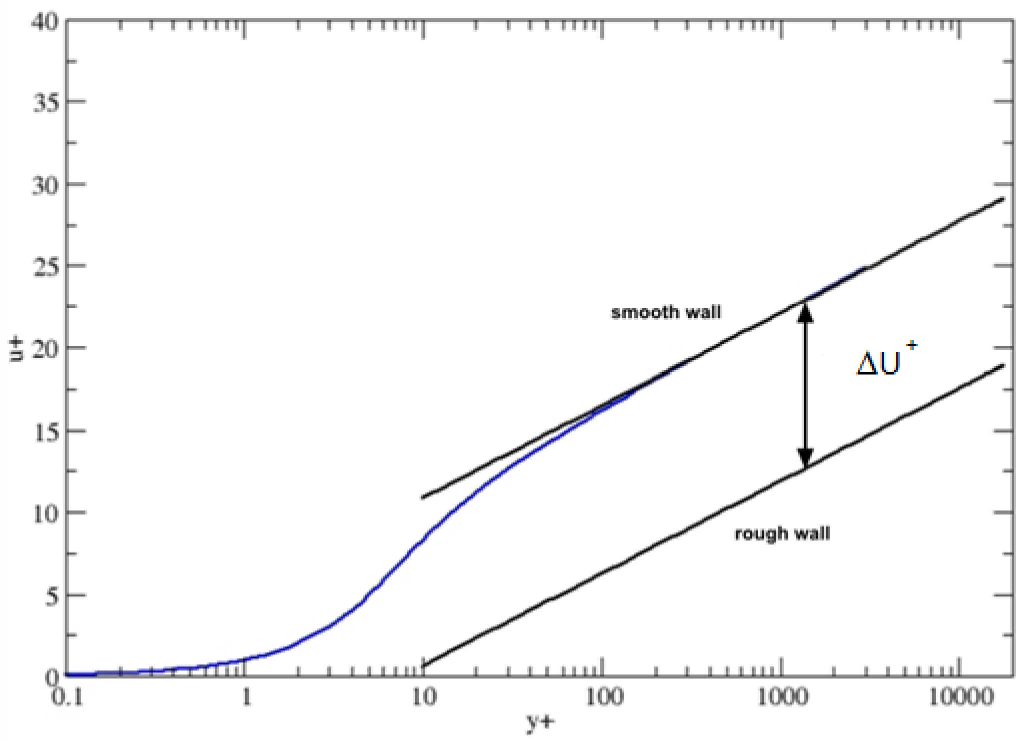
$$U^+ = \frac{1}{k}\ln y^+ + B$$

$$\Delta U^+ = f(k^+)$$

$$U^+ = \frac{1}{k}\ln y^+ + B - \Delta U^+$$

Source	κ	B
Schlichting (1979) Pipe Flow	0.4000	5.50
Schlichting (1979) Flat Plate	0.3900	5.56
CD Adapco (2016)	0.4200	5.23
ANSYS Fluent (2016)	0.4187	5.42

k von Karman constant



ROUGHNESS FUNCTION

The general form of Nikuradse-type roughness function can be written as:

$$\Delta U^{+} = \begin{cases} 0 & if\ k_s^+ < k_{Smooth}^+ \\ \frac{1}{k}\ln(C_s\, k_s^+)\ sin\left(\frac{\pi \ln(k_s^+) - \ln(k_{Smooth}^+)}{2\ln\left(k_{Rough}^+\right) - \ln(k_{Smooth}^+)}\right) & if\ k_{Smooth}^+ < k_s^+ < k_{Rough}^+ \\ \frac{1}{k}\ln(C_s\, k_s^+) & if\ k_s^+ > k_{Rough}^+ \end{cases}$$

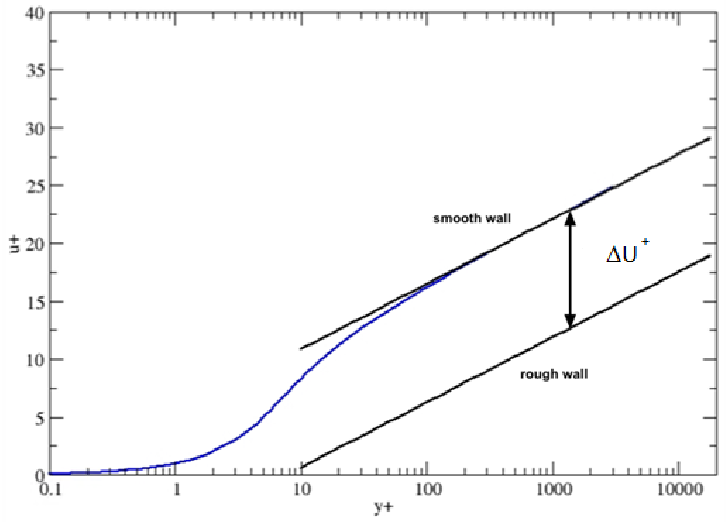
White suggested a Colebrook-type roughness function,

$$\Delta U^{+} = \frac{1}{k} ln(1 + 0.3\, k_s^+)$$

Grigson proposed

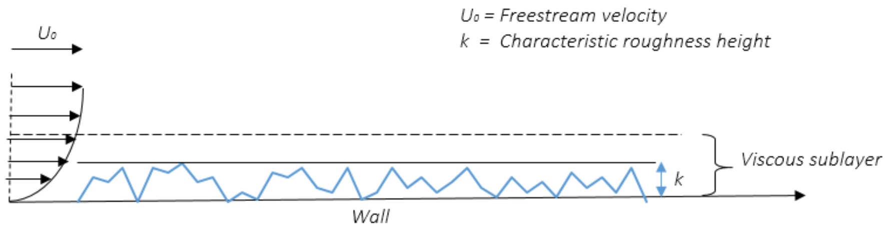
$$\Delta U^{+} = \frac{1}{k} ln\left(1 + \frac{k_s^+}{exp[k(8{,}5 - C)]}\right)$$

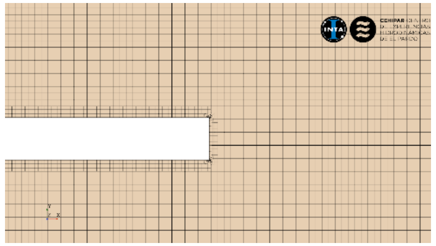
Where k=0.41 and C =5.25

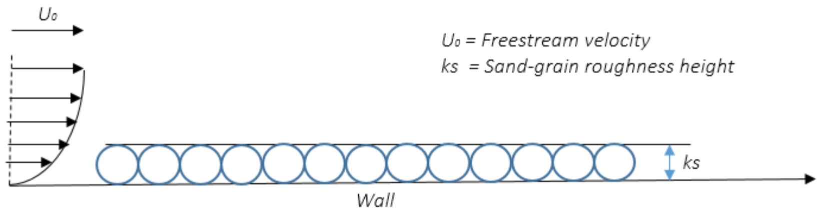


NUMERICAL TESTS

How to manage the information…..



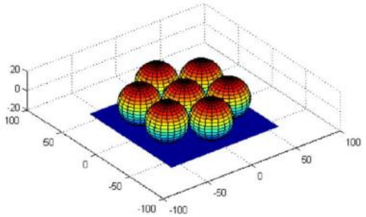




$$K_s = \frac{\rho k U_\tau}{\mu}$$

Researcher	Roughness type	K^+_{smooth}	K^+_{rough}
Nikuradse [33]	Uniform sand grain	5	70
Schultz and Flack [2]	Surface scratch	2.5	25
Lewkowitcz and Musker [34]	Ship hull roughness	17	40
Cebeci and Bradshaw [29]	Sand-grain roughness	2.25	90

$$K_s^+ = \frac{\rho k_s U_\tau}{\mu}$$



$$2D = k_s = 11.03\ R_a$$

$$3D = k_s = 5.863\ R_a$$

Adams, T., Grant, C., & Watson, H. (2012). "A simple algorithm to relate measured surface roughness to equivalent sand-grain roughness." International Journal of Mechanical Engineering and Mechatronics, 1(2), 66-71.

C_s is the roughness constant and depends on the type of roughness

The default roughness constant (C_s = 0.5) was determined so that, when used with turbulence models, it reproduces Nikuradse's resistance data for pipes roughened with tightly-packed, uniform sand-grain roughness.

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CONCLUSIONS

- The k2+ project is an on-going research that has significantly advanced our understanding of the effects of surface roughness on ship performance.

- Scientifically validated correlation between hull surface roughness and its equivalent sand-grain roughness value for Computational Fluid Dynamics (CFD) simulations will be established.

- Tests conducted at **high Reynolds number**, which are the interesting ones for full-scale models.

- The experiments conducted with rotating discs have provided a comprehensive and high-quality dataset.

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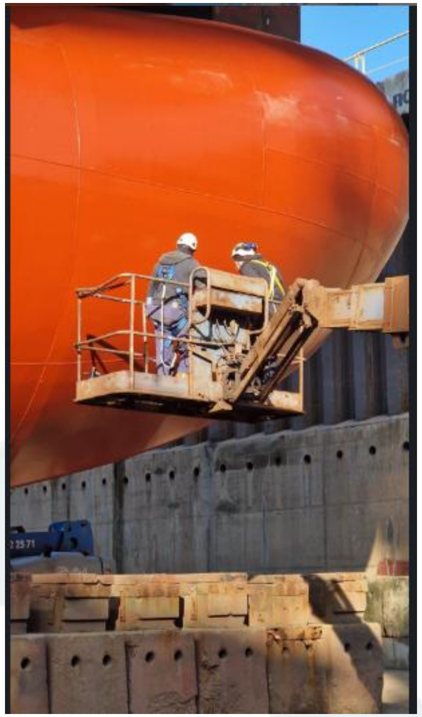
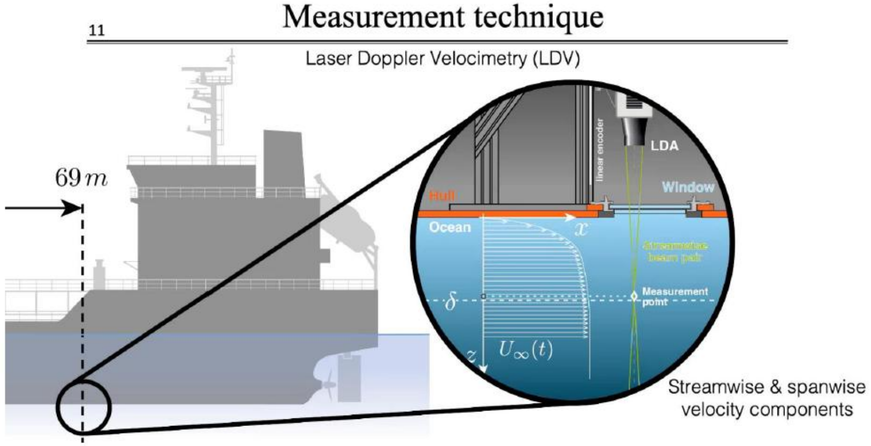
FUTURE WORKS

- Numerical investigations to validate our roughness models.
- Twelve CRS participants will participate in this numerical phase, what will enrich the value of the research bringing different codes and experiences.
- DAMEN shipyard will perform **full-scale roughness measurements** on ships.
- Partnership with the University of Melbourne, we will carry out long-term boundary layer measurements on an operational cargo ship.





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THANK FOR YOUR ATTENTION!!

QUESTIONS??

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