NTNU

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SMART MARITIME

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RESISTANCE OF SHIPS IN A SEAWAY

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SINTEF

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- **Total ship resistance**
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Introduction

- **Preliminary design of ships**
  - **Requirements:**
    - total hydrodynamic resistance and power

      Affected by the ship operational profile:

      - Average ship speed and heading
      - Ship loading conditions
      - Weather effects in open and deep water, coastal areas

- **Focus of the present work**
  - Development of *medium-fidelity methods* and tools for calculation of total ship resistance in waves and calm water
  - **Used approach:**
    - Application and development of modern, fast and reliable theoretical models capable to predict the total ship resistance in a seaway through the linear superposition of the calm water and added resistance in waves with accuracy compatible with common engineering/designer practice.

Total Ship Resistance - R_T

- **Modified Doctors and Day (1997) method**

$$R_T = R_F\left(1+k_1\right)+\Delta R_F + R_W + R_A + R_H + R_{AW}$$

R_F = frictional resistance; ITTC'57 formula
$1+k_1$ = hull form factor
ΔR_F = friction resistance due to hull roughness
R_W = wave making resistance in calm water
R_A = still-air resistance
R_H = hydrostatic resistance due to flow separation at (dry) transom stern, Faltinsen (2005)
R_{AW} = added resistance in waves (regular or irregular wave field)

- **Calm water wave resistance models (deep water)**
  - **Michell wave resistance theory with/without the viscosity effects**
  - **3D BEM**

- **Added resistance in waves models (deep water)**
  - **Short-wavelength asymptotic theories**

    Fujii and Takahashi(1975), Faltinsen et al. (1980), Takahashi (1987), NMRI (Tsujimoto et al. 2008; Kuroda et al. 2008)

  - **Long-wavelength theories (Hull pressure/Momentum conservation)**

    Maruo (1960), Salvesen (1974)

- Calm water wave resistance models (deep water)
  - **Michell water wave theory with/without the viscosity effects**

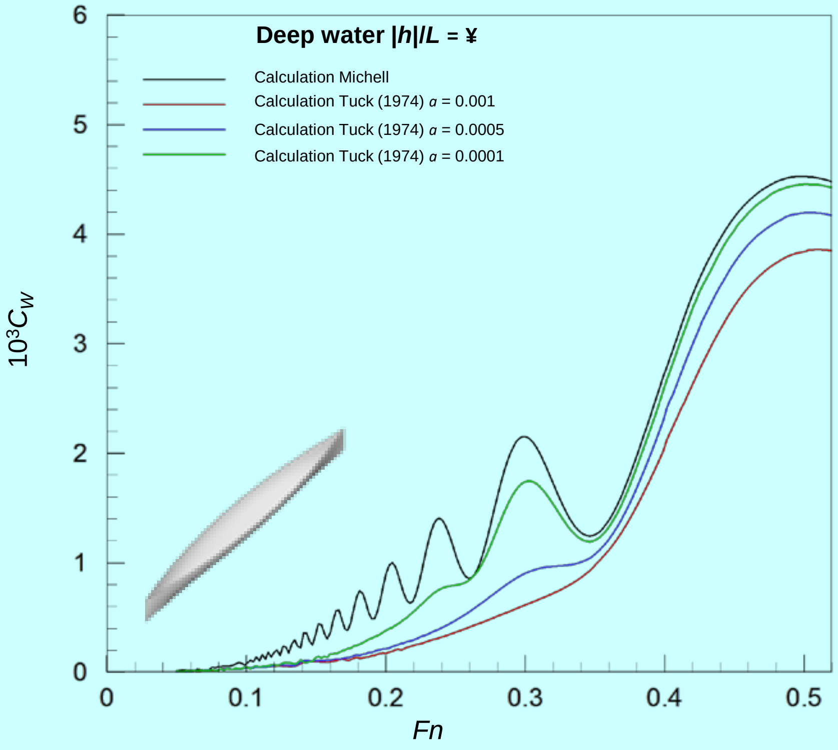
    (Tuck; 1974 and Lazauskas; 2009 models)
  - **3D BEM**

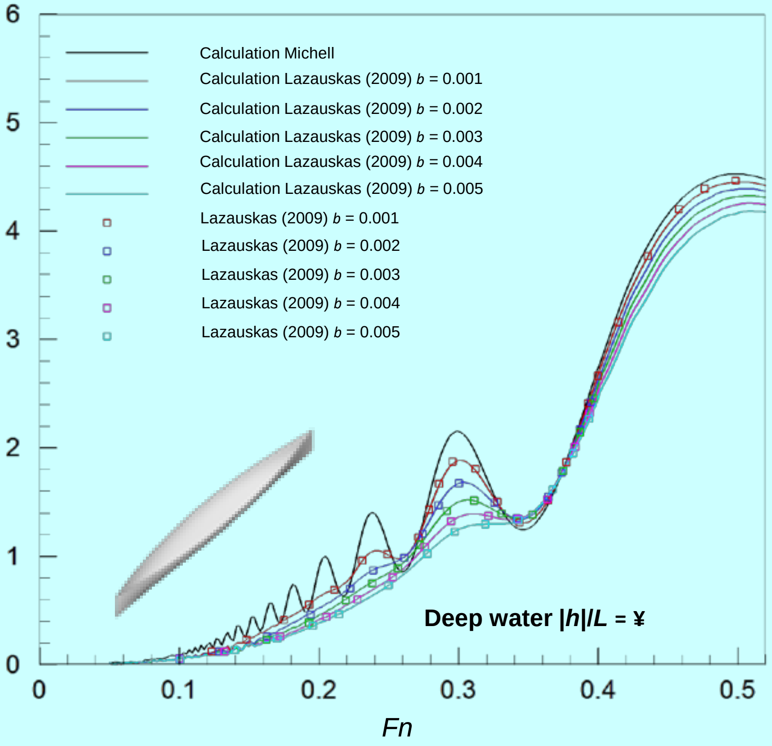
    (Dawson; 1977 model – double body fluid flow)

- **Wigley monohull**

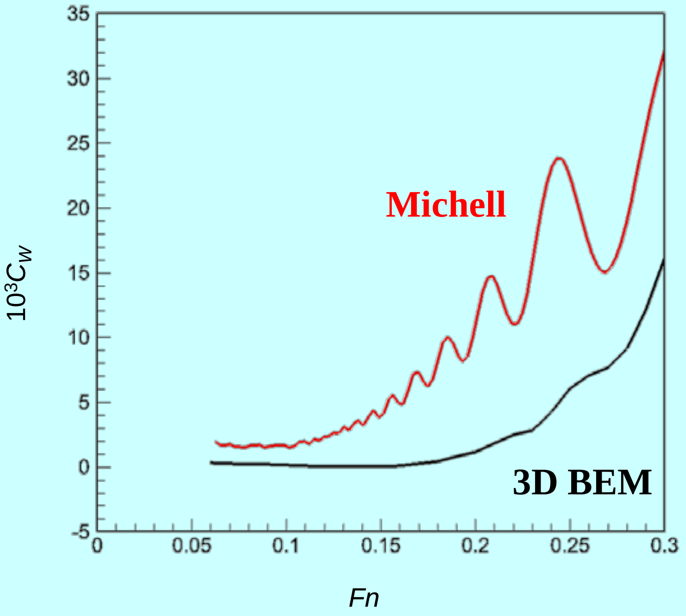
$B/T = 1.6$, $L/B = 10.0$,

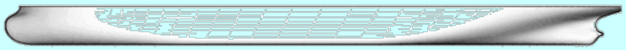
$C_B = 0.444$, $C_P = 0.667$

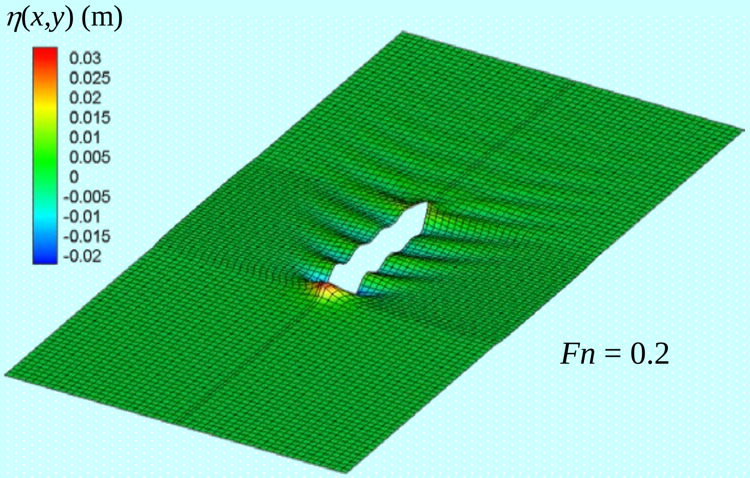




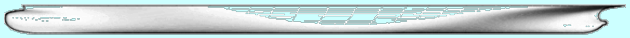
- **KRISO Very Large Crude Carrier 2 – KVLCC2 ($C_B = 0.8098$)**

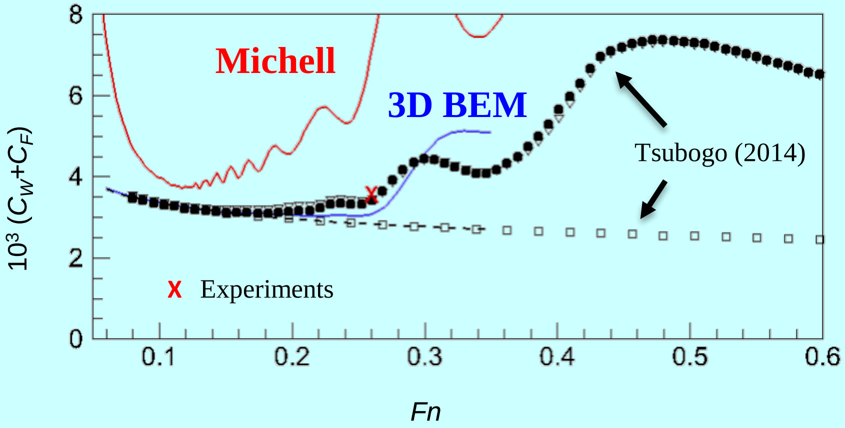


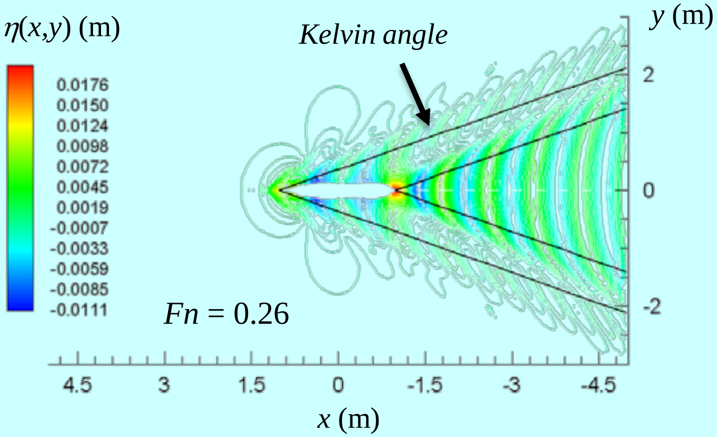




- **KRISO Container Ship – KCS ($C_B = 0.651$)**







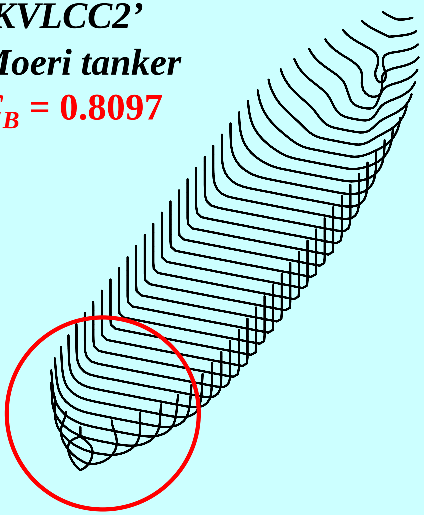
Added Resistance in a Seaway- R_{AW}

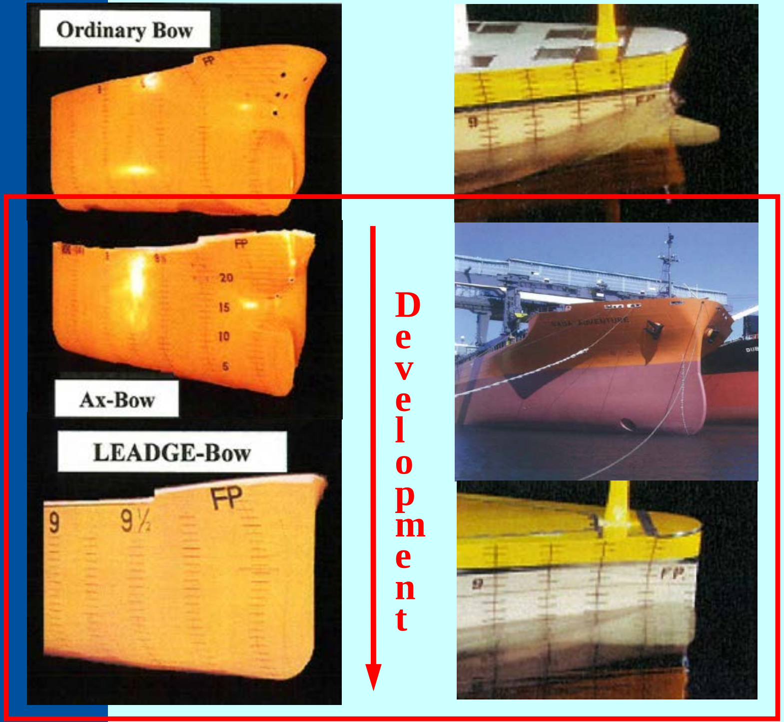
- **Short-wavelength asymptotic theories ($\lambda <\approx 0.5L$)**

  (importance of the ship bow shape effect)

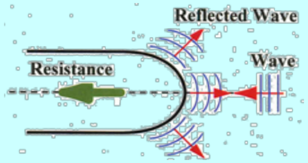
  Fujii and Takahashi(1975), Faltinsen et al. (1980), Takahashi (1987), NMRI (Tsujimoto et al. 2008; Kuroda et al. 2008)

'KVLCC2'
Moeri tanker
C_B = 0.8097





Ordinary (blunt)



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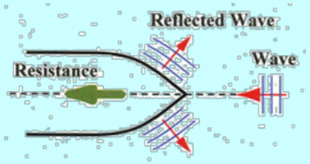
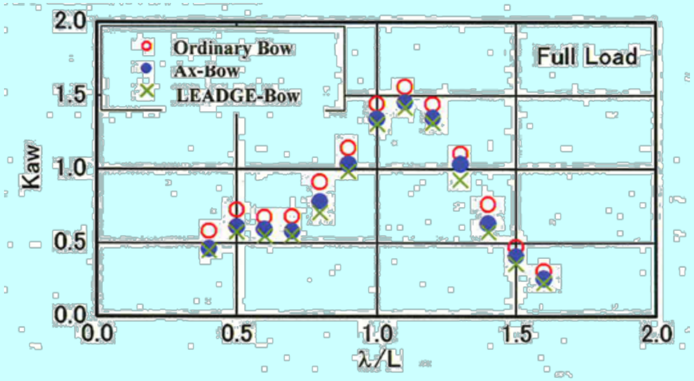




Reduced wave resistance : 20 ~ 30%

Influence of the bow shapes on added resistance - head (head beam) waves

Applicability of the NMRI method (Tsujimoto et al. 2008; Kuroda et al. 2008)

(NMRI – National Maritime Research Institute - Japan)

Faltinsen et al. (1980)

$$\bar{R}_X = -\int_L \bar{F}_n n_1 dl$$

$$\bar{F}_n = \frac{1}{2}\rho g \zeta_a^2 \left[\frac{1}{2}\frac{k_1}{k_0} - \frac{1}{2}\cos^2(\chi-\theta) + \frac{1}{2}\frac{k_2}{k_0}\sin(\chi-\theta)\right]$$

Kuroda et al. (2008)

$$\bar{R}_X = -\frac{1}{2}\rho g \zeta_a^2 B\left[B_f \alpha_d (1+\alpha_U)\right]$$

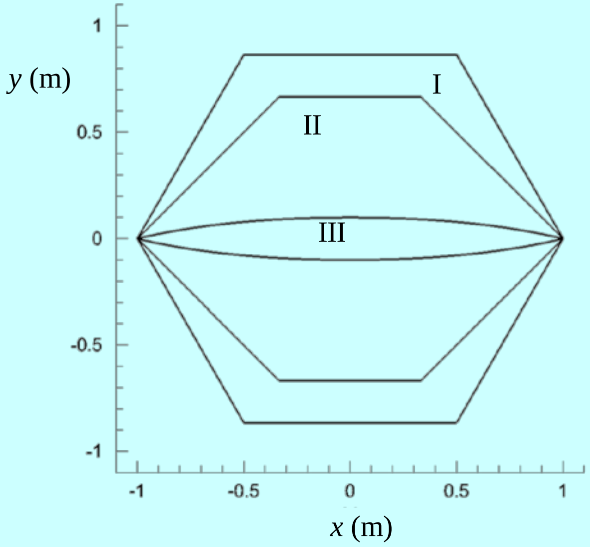
$$B_f(\theta) = \frac{1}{B}\left[\int_{\substack{\text{Non-shadow}\\ \text{region 1 - Type II}}} \sin^2(\chi-\theta)\sin\theta dl + \int_{\substack{\text{Non-shadow}\\ \text{region 2 - Type II}}} \sin^2(\chi+\theta)\sin\theta dl\right]$$

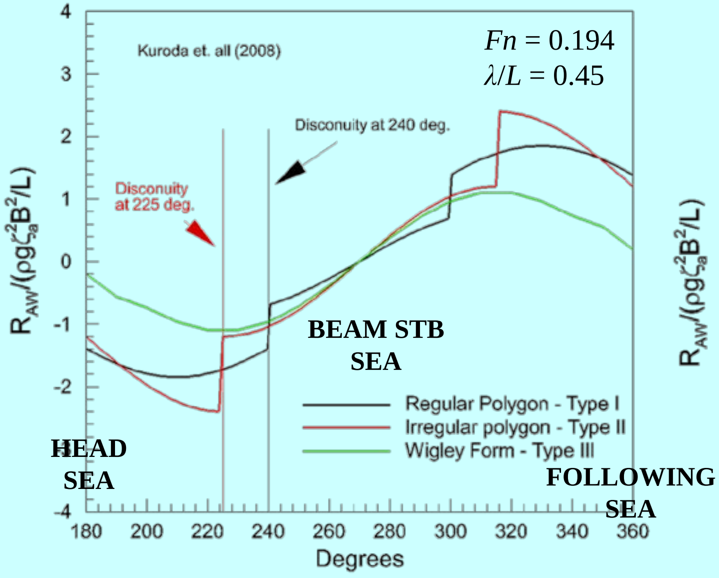
$$\alpha_d = \left[\pi^2 I_1^2(k_e T)\right] / \left[\pi^2 I_1^2(k_e T) + K_1^2(k_e T)\right]$$

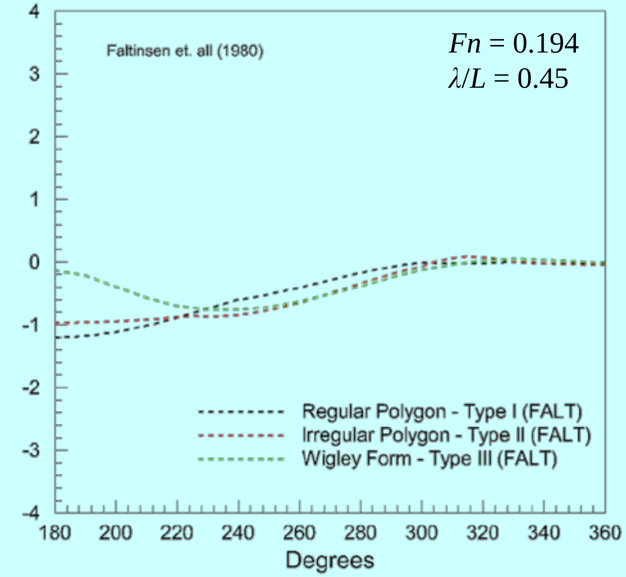
$$\alpha_U = \begin{cases} 1.0 + 5\sqrt{Fn} \\ 1.0 + 3.5\left(\sqrt{Fn}\right)\cos\chi \end{cases}$$

Type of the tested bodies:

I – Regular 6 sides polygon with the predominant waterline angle of 60°
II – Irregular 6 sides polygon with the predominant waterline angle 45°
III – Wigley form 1 or 3

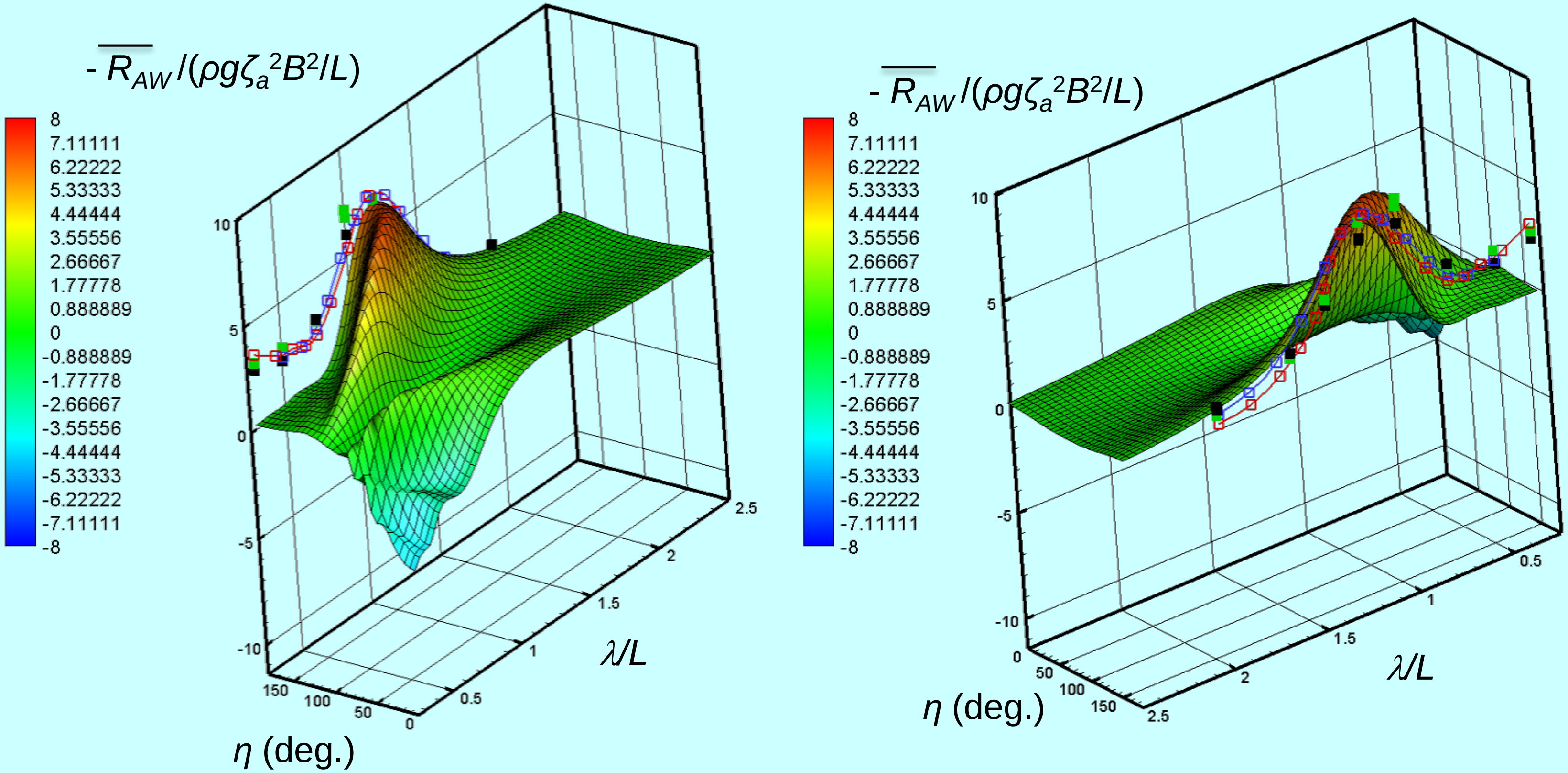






- **Long-wavelength theories (Hull pressure/Momentum conservation)**
  - Salvesen (1974)

KVLCC2 (C_B = 0.8098)



Added resistance waves for the 'KVLCC2' - Moeri tanker in range of the incident wave $\eta \in [0^\circ, 180^\circ]$ and wave length to ship length ratios $\lambda/L \in [0.29, 2.5]$ at Froude number at Froude number Fn = 0.142. Comparison with Lee et al. (2013) (squares; green and black) experimental results and Seo et al. (2014) (red and blue) computational results

▪ Maruo (1960)

$$R_{AW} = -\left\{ \frac{\rho}{8\pi}\left[\int_{\boxed{\theta_0}}^{\pi/2} - \int_{\pi/2}^{3\pi/2} + \int_{-\pi/2}^{\boxed{-\theta_0}} \right] \left|H\left(k_1,\theta\right)\right|^2 \frac{k_1(\theta)\left[k_1(\theta)\cos(\theta) - K\cos(\chi)\right]}{\sqrt{1-4\Omega\cos(\theta)}}\,d\theta \right.$$

$$\left. + \frac{\rho}{8\pi}\int_{\boxed{\theta_0}}^{2\pi-\boxed{\theta_0}} \left|H\left(k_2,\theta\right)\right|^2 \frac{k_2(\theta)\left[k_2(\theta)\cos(\theta) - K\cos(\chi)\right]}{\sqrt{1-4\Omega\cos(\theta)}} \right\} d\theta$$

$$\Omega = \frac{U\omega_e}{g} \qquad K = \frac{\omega^2}{g} \qquad \omega_e = \omega - KU\cos(\chi)$$

$\chi = 180°$ **Head Sea** (Incident wave angle)

$\chi = 90°$ Port Beam Sea (Incident wave angle)

θ_0 **Critical angle**

$$\boxed{\theta_0} = \begin{cases} \boxed{0 \qquad \text{for} \quad \Omega \le \frac{1}{4}} \\ \boxed{\arccos\left(\frac{1}{4\Omega}\right) \qquad \text{for} \quad \Omega > \frac{1}{4}} \end{cases}$$

$$k_{1,2} = K_0 \frac{\left[1 - 2\Omega\cos(\theta) \pm \sqrt{1-4\Omega\cos(\theta)}\right]}{2\cos^2(\theta)}$$

$$K_0 = \frac{g}{U^2}$$

Kochin fun

$$H\left(k_j,\theta\right) = \iint_S \Big($$

$$= \int_L \int_{C_x} \Big($$

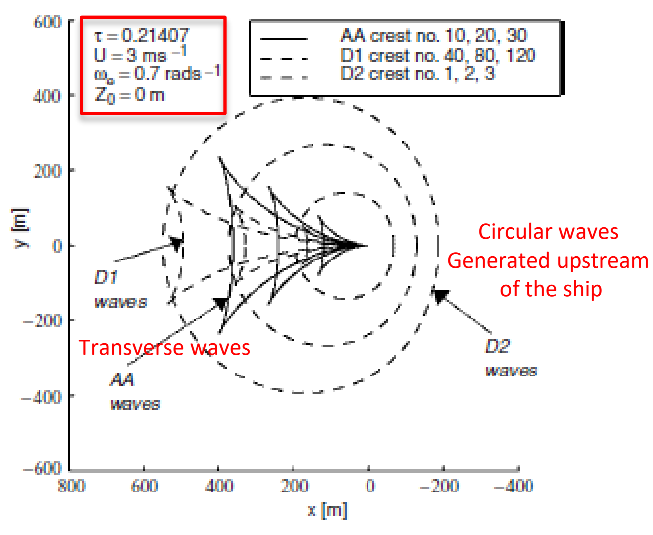
$G_j\left(\theta\right.$

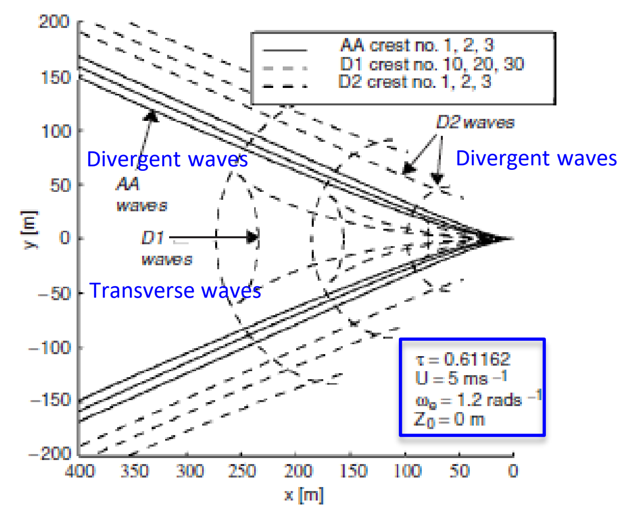
Formulatior **liffer** the ship

slenderness = d/B l have

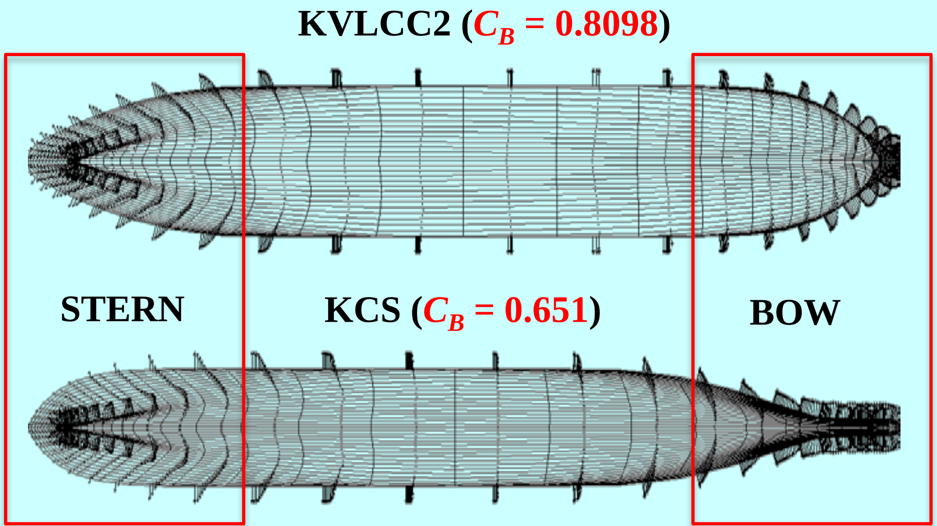
consequenc ion of 1960)

- Maruo (
- Loukaki
- Fujii anc
- Naito et





▪The Effect of Surge Motion Mode



Hull particulars	*'KVLCC2'*	*'KCS'*
$L_{PP}\ (\equiv L)$	320.0 m	230.0
B	58.0 m	32.2
T (even keel)	20.8 m	19.0
C_B	**0.8098**	**0.6505**
Ñ	3.12621*10⁵ m³	0.5203*10⁵ m³

$$\overline{C_{AW}} = -\overline{R_{AW}}/(\rho g \zeta_a^2 B^2/L)$$

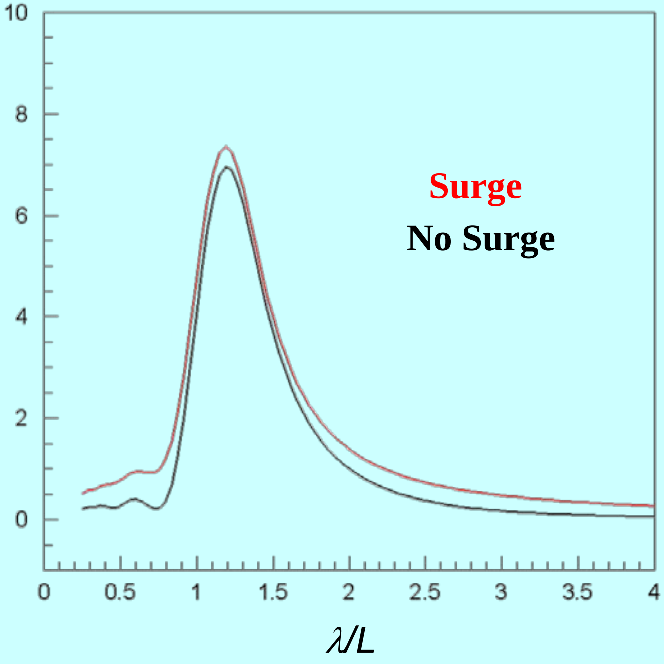
Ship surface F

$$F(x,y,z) = z - f(x,y) = 0$$

$$\vec{n} = n_x\vec{i} + n_y\vec{j} + n_z\vec{k}$$

$$n_x = -f_x/|\nabla F|$$

$C_B \uparrow \quad n_x \uparrow \quad C_W \uparrow \quad C_{AW} \uparrow$



Added resistance R_{AW} for KVLCC2 ship in regular waves for incident wave angle η = 180° (head sea) and wave length to ship length ratios $\lambda/L \in [0.29, 2.5]$ at Froude number Fn = 0.142.

Work in Progress

- Investigation of the Michell wave resistance integral with inclusion of the viscous effects for modern ship hull forms
- Investigation of the Maruo (1960) method for the estimation of the added resistance in waves (ITTC - Recommended Procedures and Guidelines, 2017)
- Investigation of the effect of surge motion mode upon the added resistance in waves for modern ship hull forms
- Preparation of the journal article in JSR
- Preparation of the conference article PRADS 2019
- Implementation of the developed methods for calculation of the added resistance in waves in the industrial software solutions