64th International Congress of Naval Architecture and Maritime Industry

26th ~ 28th March 2025

Gijón, Spain

Impact of Towing Tank Temperature on Model-Ship Extrapolation: Revisiting the ITTC Procedure

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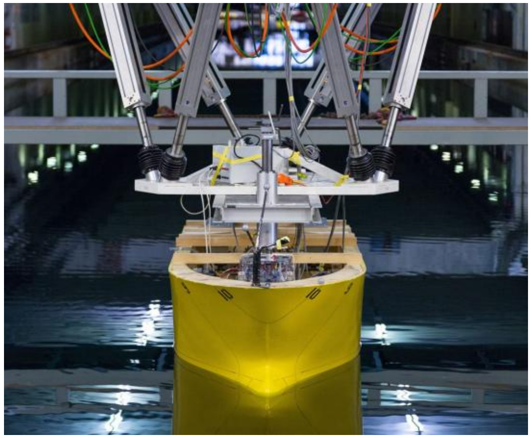
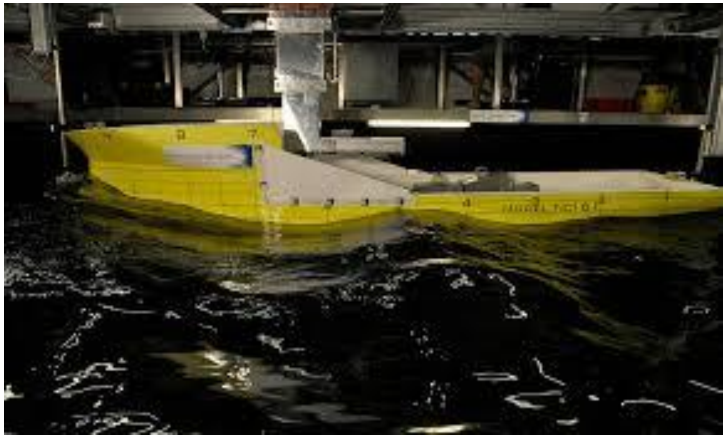
Introduction

- Towing tank facility
  - Importance of accurate ship performance estimation with IMO Net Zero initiative
  - Prediction of full-scale ship performance through model tests
  - Measurement of resistance, propulsion, and maneuvering characteristics in towing tank facilities





- Ship resistance test
  - Measurement of resistance encountered by ship models (i.e., KCS and KVLCC2)
  - Determining power requirements and evaluating full-scale ship resistance

Model-ship extrapolation

- Components of hull resistance
  - Total viscous resistance coefficient (C_V)
  - Total wave resistance coefficient (C_W)
  - Total resistance coefficient, $C_T = C_V + C_W = (1 + k)C_F + C_W$
- ITTC 1978 performance prediction
  - Assumes model and ship have equal wave resistance coefficient
  - Calculates ship's total resistance using parameters (i.e., wetted surface area, density and design speed)
- ITTC 1957 correlation line
  - Proposed solution to address the inconvenience of the ATTC curve's implicit equation
  - Standardized method to calculate frictional resistance coefficient (by ITTC)
  - Frictional resistance coefficient $(C_F) = \frac{0.75}{(\log Re - 2)^2}$

Discussion on the ITTC correlation line

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➤ Discussions

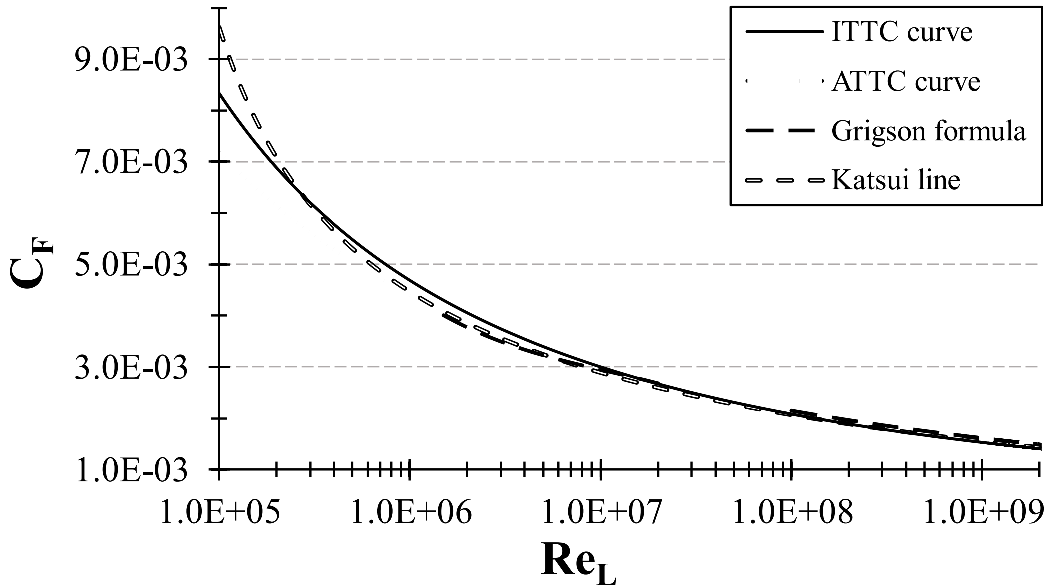
- Grigson (1993): Raised concerns about accuracy, proposed Grigson formula
- ITTC 23rd meeting (2002): Questioned friction curve validity (form factor)
- Katsui et al. (2005): Suggested Katsui line
- ITTC 25th meeting (2008): Recommend new friction formulas
- Wang et al. (2015), Zeng et al. (2019), Korkmaz et al. (2019, 2021): Proposed new numerical friction lines
- ITTC 29th meeting (2021): Concluded the need for further research before revising the friction curve

→ Issues with the ITTC correlation line have been consistently raised!

Research Gap and Research Motivation

- Research gap
  - Answer to the question, "Does the towing tank water temperature affect the model-ship extrapolation?"

- Research motivation
  - Investigating how variations in towing tank water temperature impact model-ship extrapolation across different friction curves



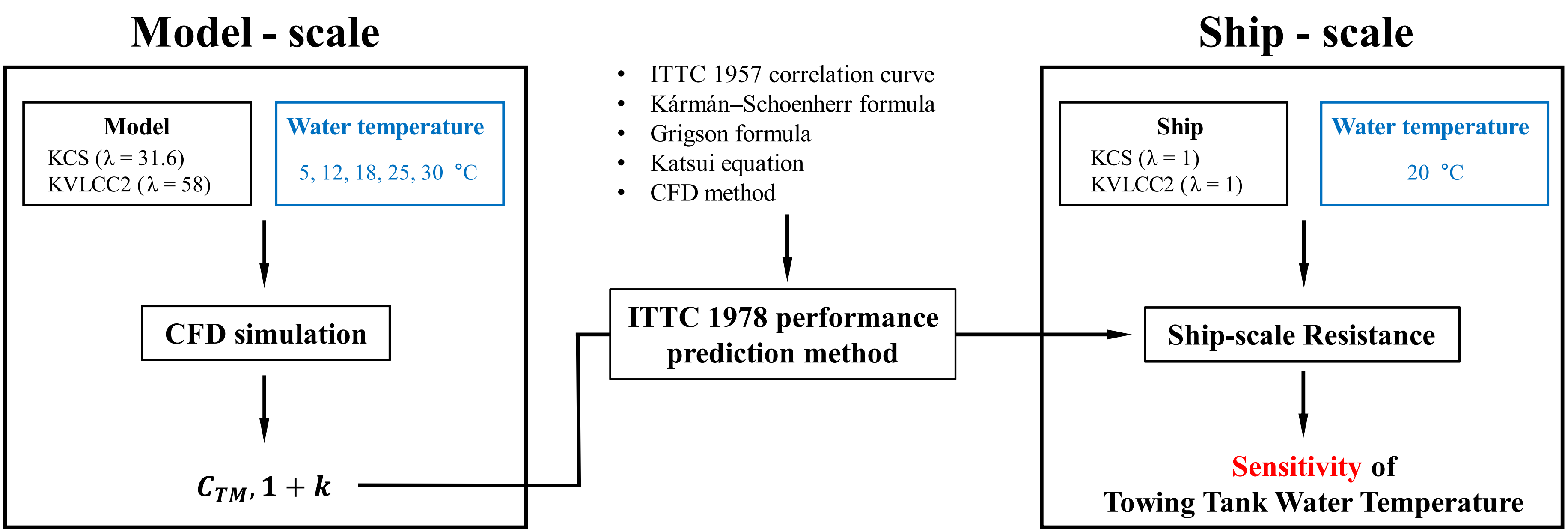
Aim and Objectives

- Aim:
  - To investigate how variations in towing tank water temperature affect the model-ship extrapolation using the ITTC 1957 correlation line

- Objectives:
  - To develop a resistance prediction model under different water temperature using CFD
    - Validation
    - Verification
  - To assess temperature-sensitivity of five different friction curves
    - ITTC 1957 correlation line
    - Kármán–Schoenherr formula
    - Grigson formula
    - Katsui equation
    - CFD method

Methodology

➢ Overview and methodology of current research



Methodology

- Target vessel: KCS and KVLCC2
  - Validation: model-scale
  - Scale factor
    - KCS: 31.6
    - KVLCC2: 58.0

Main particulars of KCS and KVLCC2 (SIMMAN 2008)

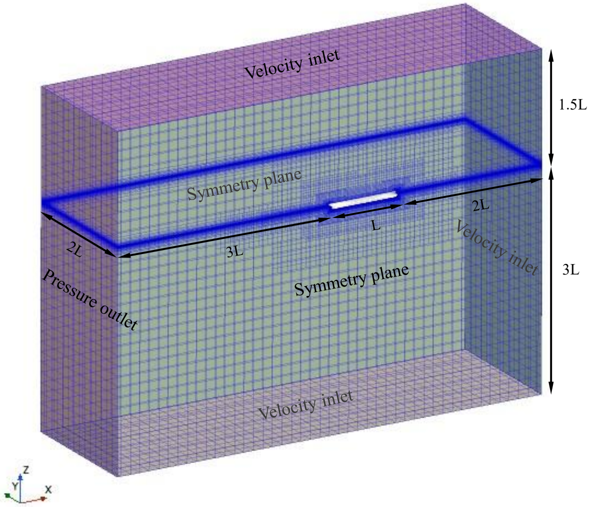
Main particulars	KCS		KVLCC2	
	Full-scale	Model-scale	Full-scale	Model-scale
Scale factor, λ	1	31.6	1	58.0
Length between the perpendiculars, L_{PP} (m)	230	7.279	320	5.517
Beam at the waterline, B_{wl} (m)	32.2	1.0190	58	1.00
Design draught, T (m)	10.8	0.3418	20.8	0.3586
Wetted surface area w/o rudder, S (m^2)	9530	9.5441	27194	8.0838
Displacement, Δ (m^3)	52030	1.6490	312622	1.6023
Block coefficient, C_B	0.651	0.651	0.8098	0.8098

Methodology

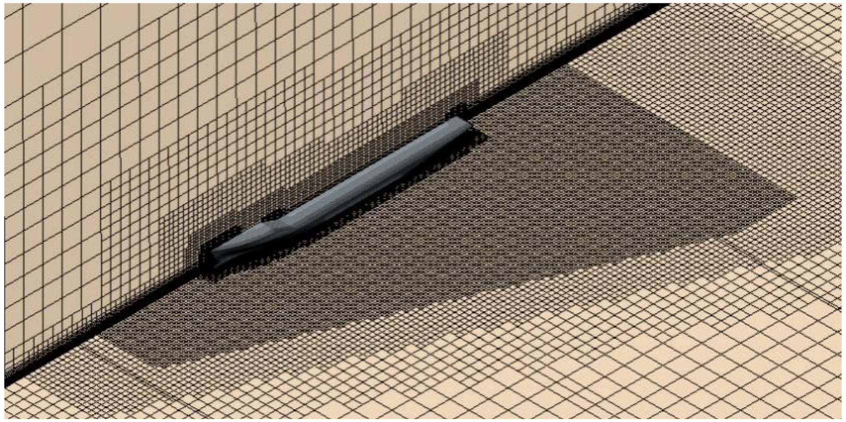
➢ Numerical modelling

- Star-CCM+ (ver. 18.06)
- Governing equation : Unsteady Reynolds Averaged Navier-Stokes (URANS)
- Turbulence model : Realisable k-ε turbulence model
- Trimmed cell mesh
- Prism layer
  - wall $y^+ \cong 50$ was set the same for all temperature conditions (i.e., 5 °C = 30 °C)

(a) Computational domain

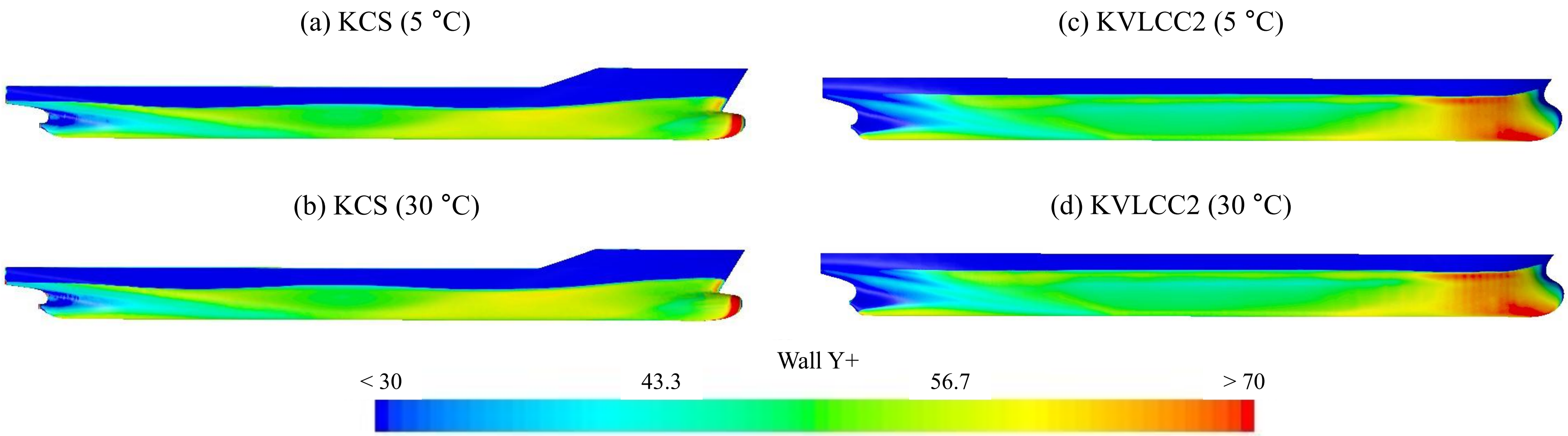


(b) Mesh generation of KCS



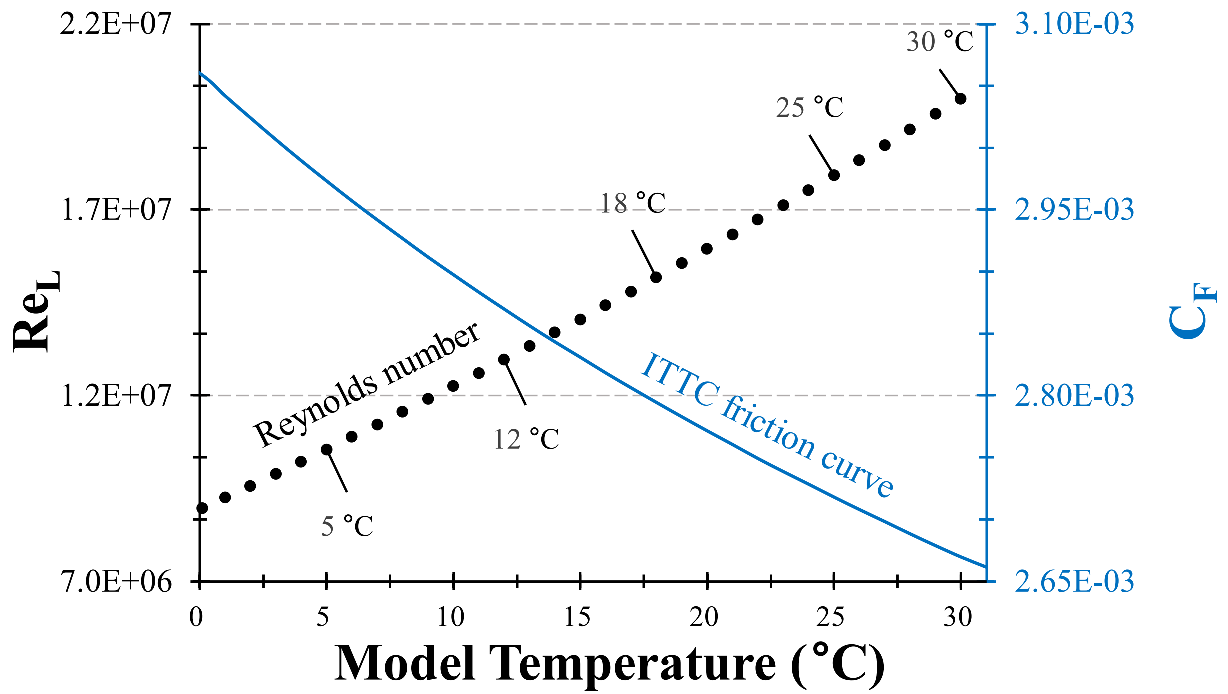
Methodology

- $Wall\ y^+$
  - $Wall\ y^+ = \frac{y u_\tau}{\nu} > 30$
  - $Mean\ Wall\ y^+$ is consistent with temperature for both KCS and KVLCC2
    - $y^+ \cong 50$
- $Wall\ y^+$ scene



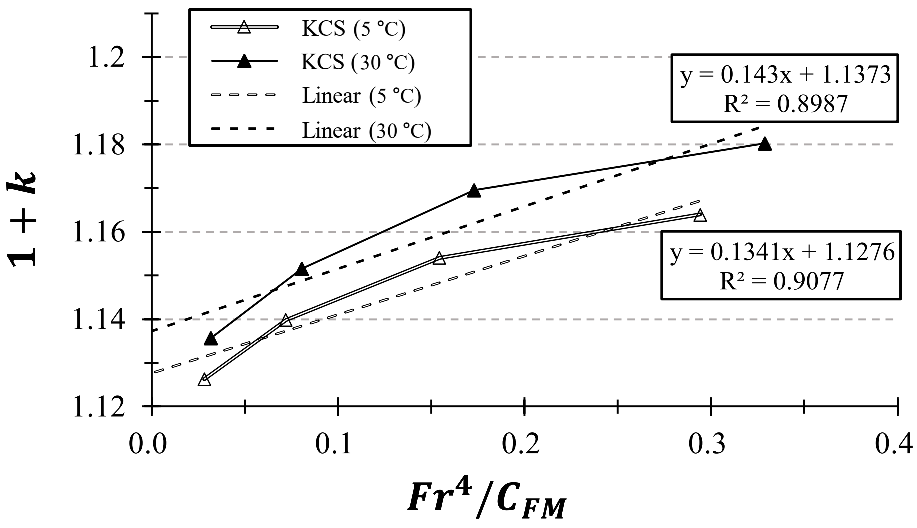
Methodology

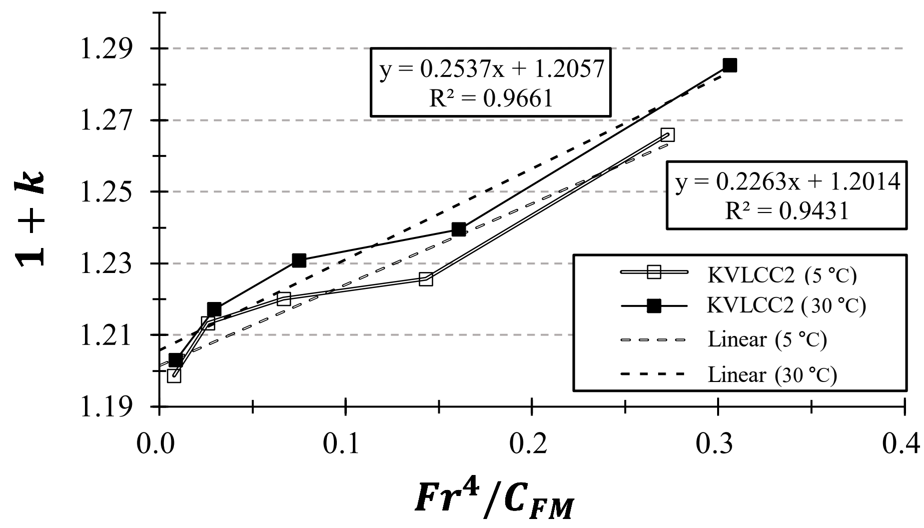
- Temperature conditions
  - Model-scale: 5, 12, 18, 25, and 30 °C
  - Full-scale: 20 °C
  - Water properties: ITTC Procedures (2011)



Methodology

- Form factor determination
  - Prohaska's Method (1966)
  - $C_T = C_V + C_W = (1+k)C_F + C_W$
  - $1 + k_M = C_{TM}/C_{FM}$
  - KCS: $Fr = 0.1, 0.125, 0.15,$ and 0.175
  - KVLCC2: $Fr = 0.075, 0.1, 0.125, 0.15,$ and 0.175

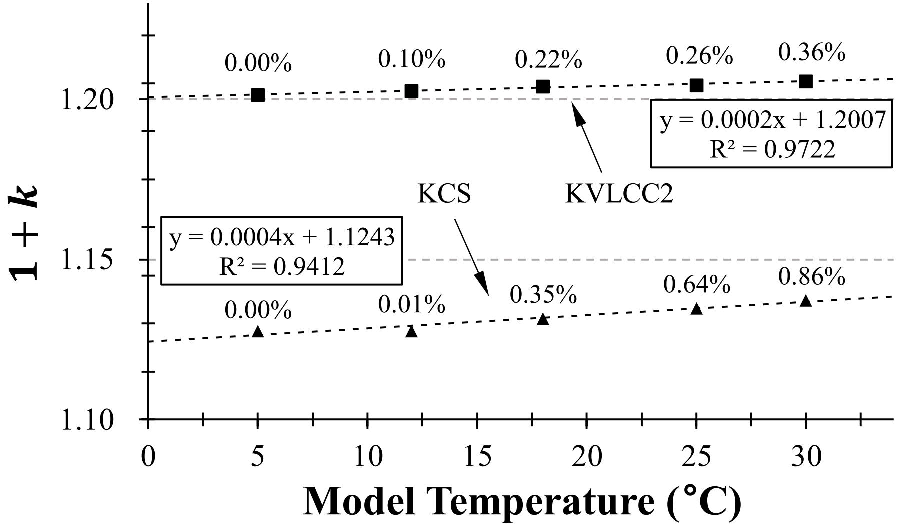




Methodology

- Temperature effects on form factor
  - Experimental conditions
    - Towing tank temperatures: 5, 12, 18, 25, and 30 °C
  - Application
    - Applied form factors in the ITTC 1978 model-ship extrapolation method.
    - $k_M = k_S$

Temperature (°C)	Form factor (k)	
	KCS	KVLCC2
5	0.1276	0.2014
12	0.1277	0.2026
18	0.1316	0.2041
25	0.1348	0.2045
30	0.1373	0.2057



Verification

- Verification study
  - Grid Convergence Index (Celik et al., 2008)
  - Performed at each operation speed for KCS and KVLCC2

- KCS

Spatial convergence		No. Cells	C_T
	Coarse	588,291	3.751E-03
	Medium	975,772	3.747E-03
	Fine	1,596,346	3.741E-03
$GCI_{Fine}^{21}(\%)$			0.376
Temporal convergence		$\Delta t\ (s)$	C_T
	Coarse	0.02	3.779E-03
	Medium	0.01	3.744E-03
	Fine	0.005	3.741E-03
$GCI_{\Delta t_1}^{21}(\%)$			0.007

- KVLCC2

Spatial convergence		No. Cells	C_T
	Coarse	597,623	4.271E-03
	Medium	1,061,000	4.227E-03
	Fine	1,886,772	4.218E-03
$GCI_{Fine}^{21}(\%)$			0.331
Temporal convergence		$\Delta t\ (s)$	C_T
	Coarse	0.02	3.779E-03
	Medium	0.01	3.744E-03
	Fine	0.005	3.741E-03
$GCI_{\Delta t_1}^{21}(\%)$			0.067

Validation

➢ Validation study

- Good agreement was achieved between CFD and EFD
  - KCS for Tokyo 2015
  - KVLCC2 for Gothenburg 2010

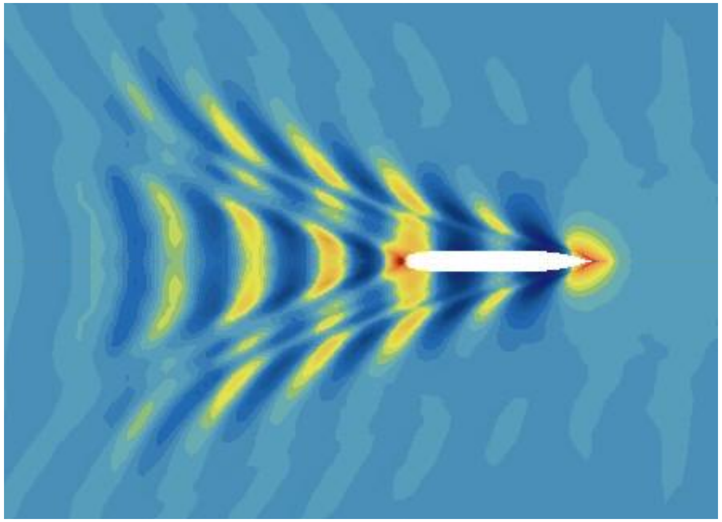
	CFD (present)	EFD	Relative difference
KCS	3.741E-03	3.711E-03 (Tokyo, 2015)	0.82%
KVLCC2	4.218E-03	4.180E-03 (Larsson et al., 2010)	0.91%

** With fine mesh (no.cell = KCS: 1.6 million, KVLCC2: 1.9 million) and fine timestep (dt =0.005s)*

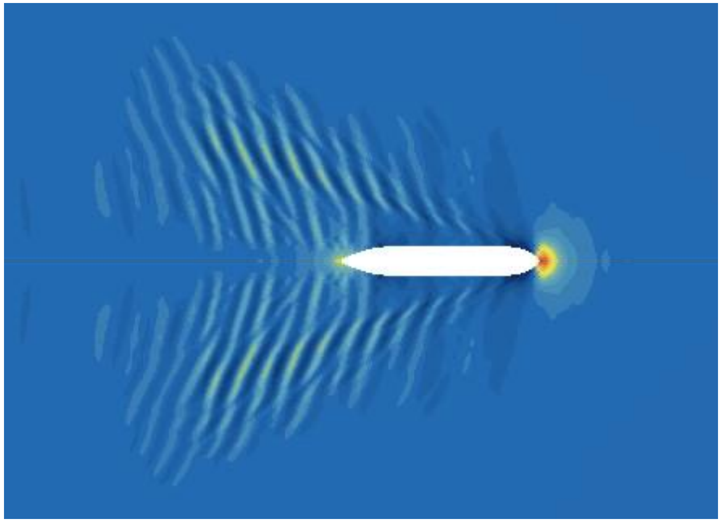
CFL number

- CFL number
  - CFL number = $\frac{U\Delta t}{\Delta x}$, ($U$: design speed, Δt: time step, Δx: cell distance)
  - Equal to 1 or less for stability in numerical solutions
    - KCS: 0.14
    - KVLCC2: 0.11
- Wave scene

(a) KCS



(b) KVLCC2



Results

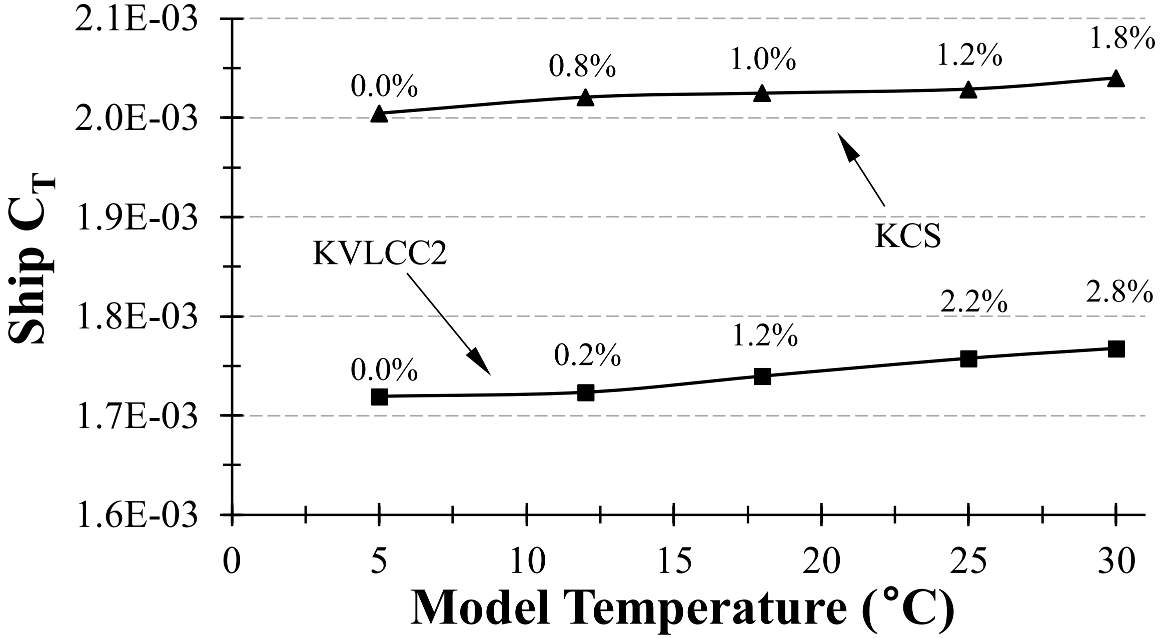
Results

➢ Model-Ship extrapolation

- Using different friction curves to compare temperature-sensitivity
  - ITTC 1957 correlation line
  - ATTC friction curve
  - Grigson formula
  - Katsui equation
  - CFD method
- Based on the ITTC 1978 model-ship extrapolation
- Identical water temperature conditions
  - Towing tank (Model): 5, 12, 28, 25, 30°C
  - Ship: 20°C
- Form factor (k)
  - Determined using Prohaska's method for each towing tank temperature

Results

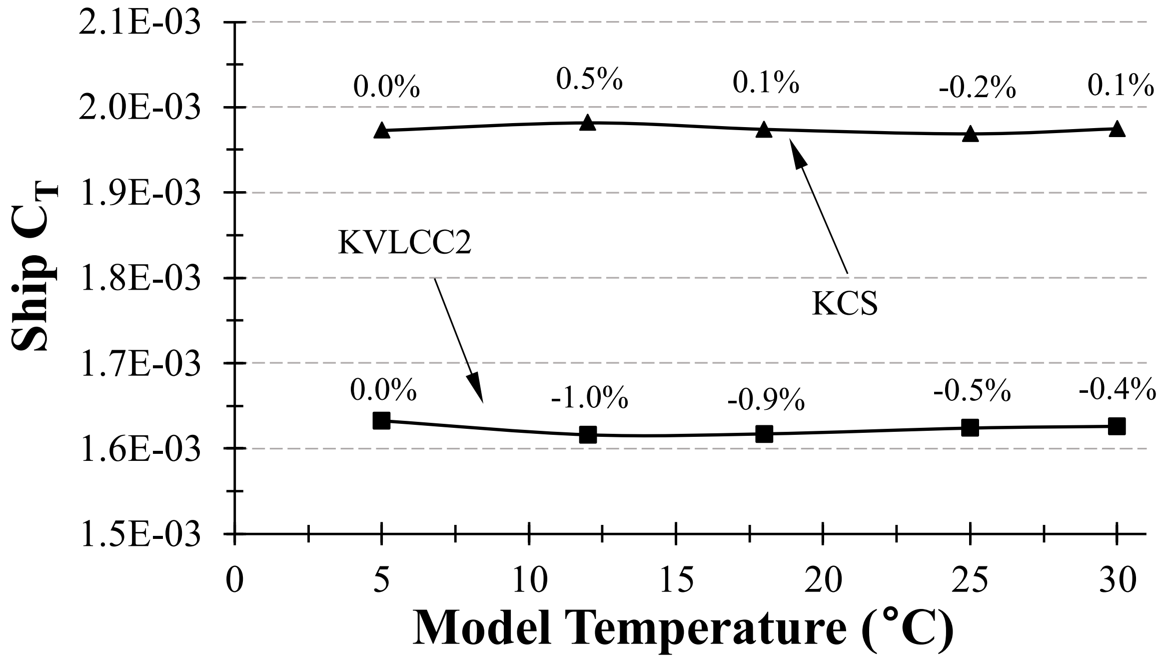
- ITTC correlation line-based model-ship extrapolation
  - Difference in C_T according to the ITTC 1957 correlation line
    - For KCS, the maximum difference is 1.8%, varying with temperature
    - For KVLCC2, the maximum difference is 2.8%, varying with temperature



Results

➢ Kármán–Schoenherr formula (a.k.a the ATTC friction curve)

- The Schoenherr line was adopted by the American Towing Tank Conference (1947)
- $\frac{1}{\sqrt{C_F}} = 4.13\log(Re \times C_F)$
- ATTC friction curve-based model-ship extrapolation



Results

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- Grigson formula (Grigson, 1993)
  - The most serious alternative to the ITTC correlation line and Schoenherr curve

    (Molland et al, 2011. *Ship Resistance and Propulsion*, 2^{nd} ed.)

  - $C_F = [0.93 + 0.1377(\log Re - 6.3)^2 - 0.06334\,(\log Re - 6.3)^4 \times \frac{0.075}{(\log Re - 2)^2}$

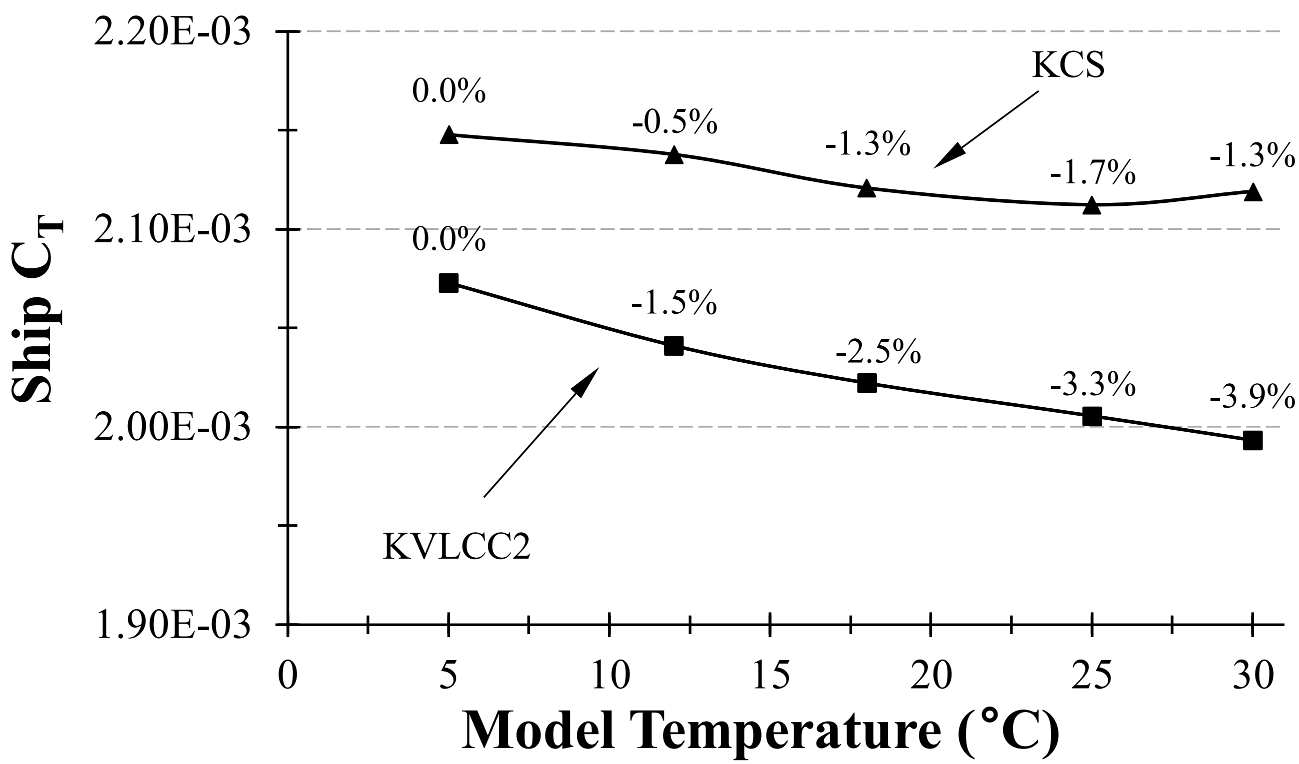
    (For low Reynolds number, specifically $1.5 \times 10^6 < Re < 2 \times 10^7$)

  - $C_F = [1.032 + 0.02816(\log Re - 8) - 0.006273\,(\log Re - 8)^2 \times \frac{0.075}{(\log Re - 2)^2}$

    (For high Reynolds number, specifically $10^8 < Re < 4 \times 10^9$)

Results

- Grigson formula (Grigson, 1993)
  - Grigson formula-based model-ship extrapolation



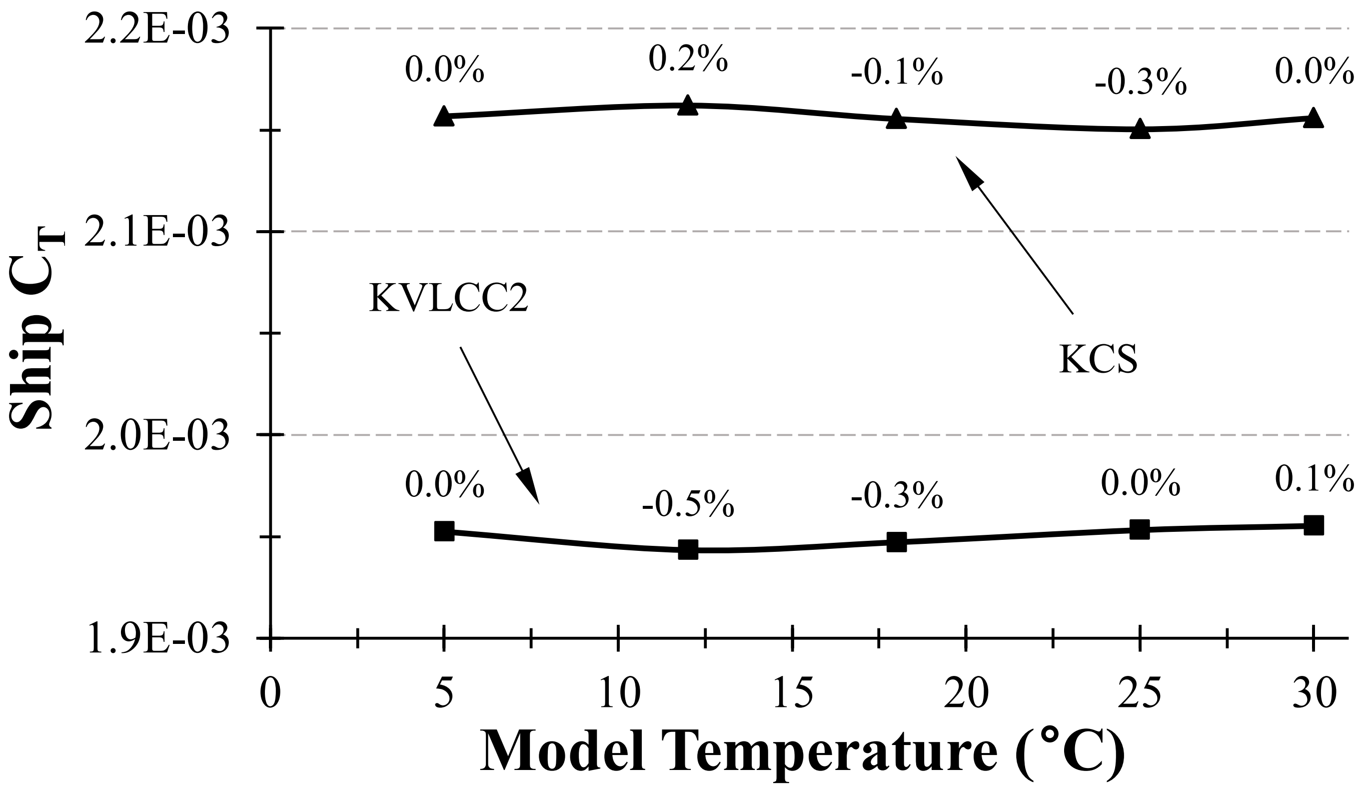
Results

- Katsui equation (Katsui et al., 2005)
  - Several studies have used a Katsui equation to compare various friction curves
    - Eça and Hoekstra (2008)
    - Wang et al. (2015)
    - Zeng et al. (2019)
    - Korkmaz et al. (2021)
  - $C_F = \frac{0.0066577}{(\log Re - 4.3762)^a}, a = 0.042612 \times \log Re + 0.56725$

Results

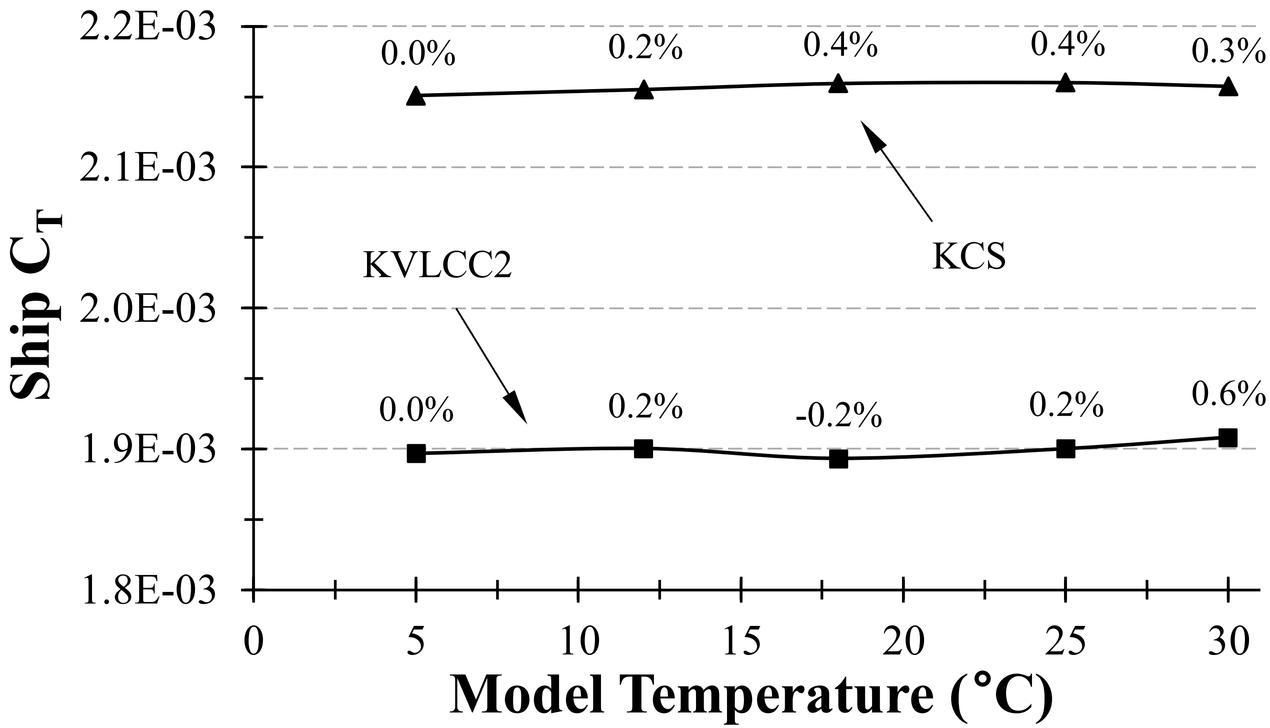
➢ Katsui equation (Katsui et al., 2005)

- Katsui equation-based model-ship extrapolation



Results

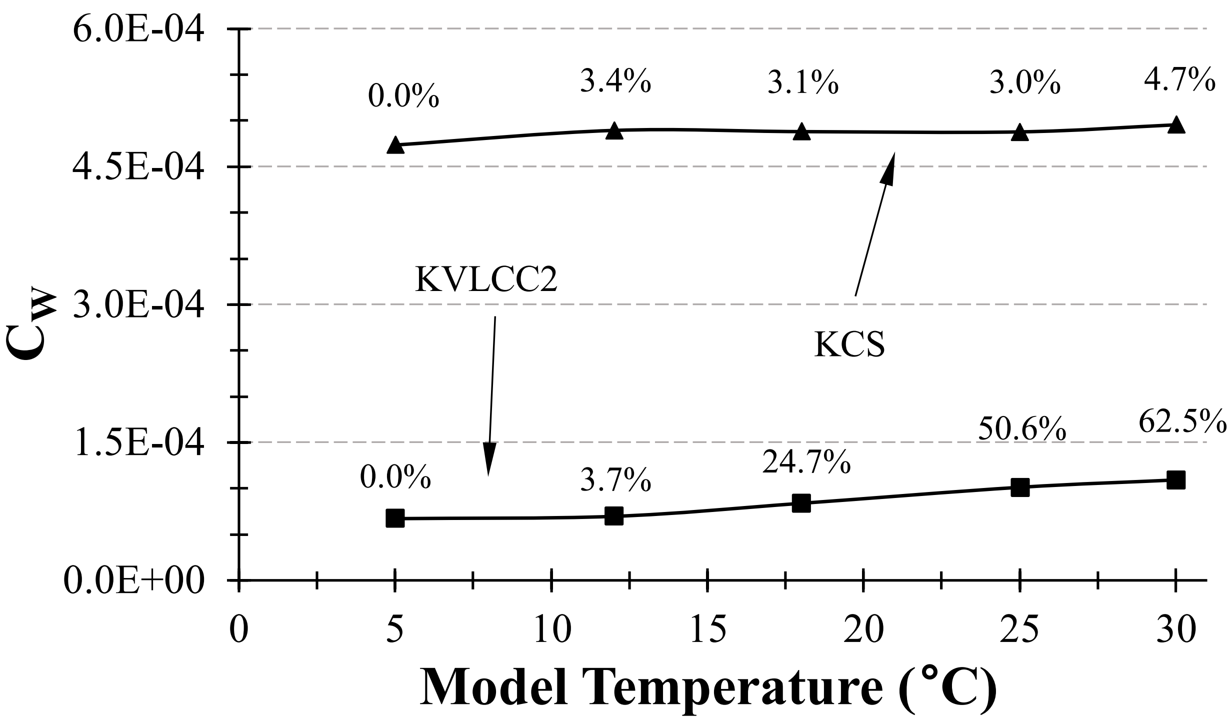
- "New" curve
  - Introduced an imaginary C_F curve matching CFD-derived C_F values
  - "New" curve-based model-ship extrapolation



Conclusion

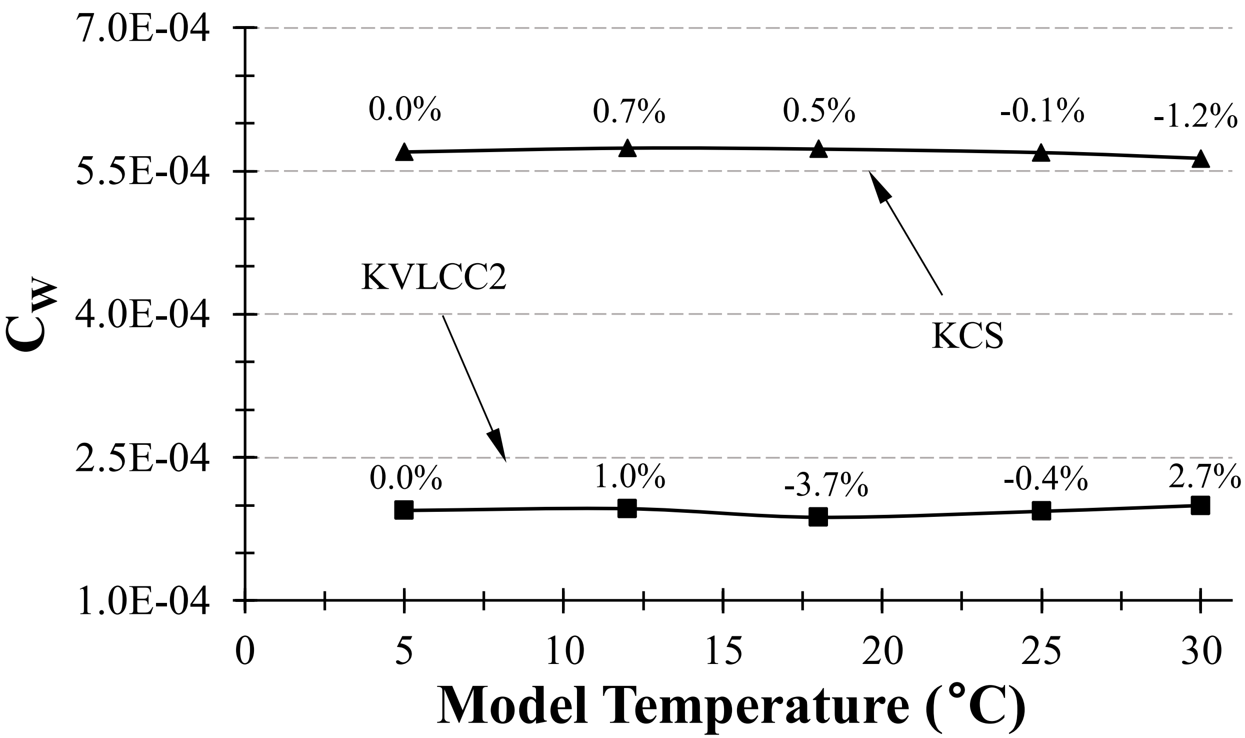
Conclusion

- ITTC correlation line-based model-ship extrapolation
  - Difference in C_W according to the ITTC 1957 correlation line
    - For KCS, the maximum difference is 4.7%, varying with temperature
    - For KVLCC2, the maximum difference is 62.5%, varying with temperature



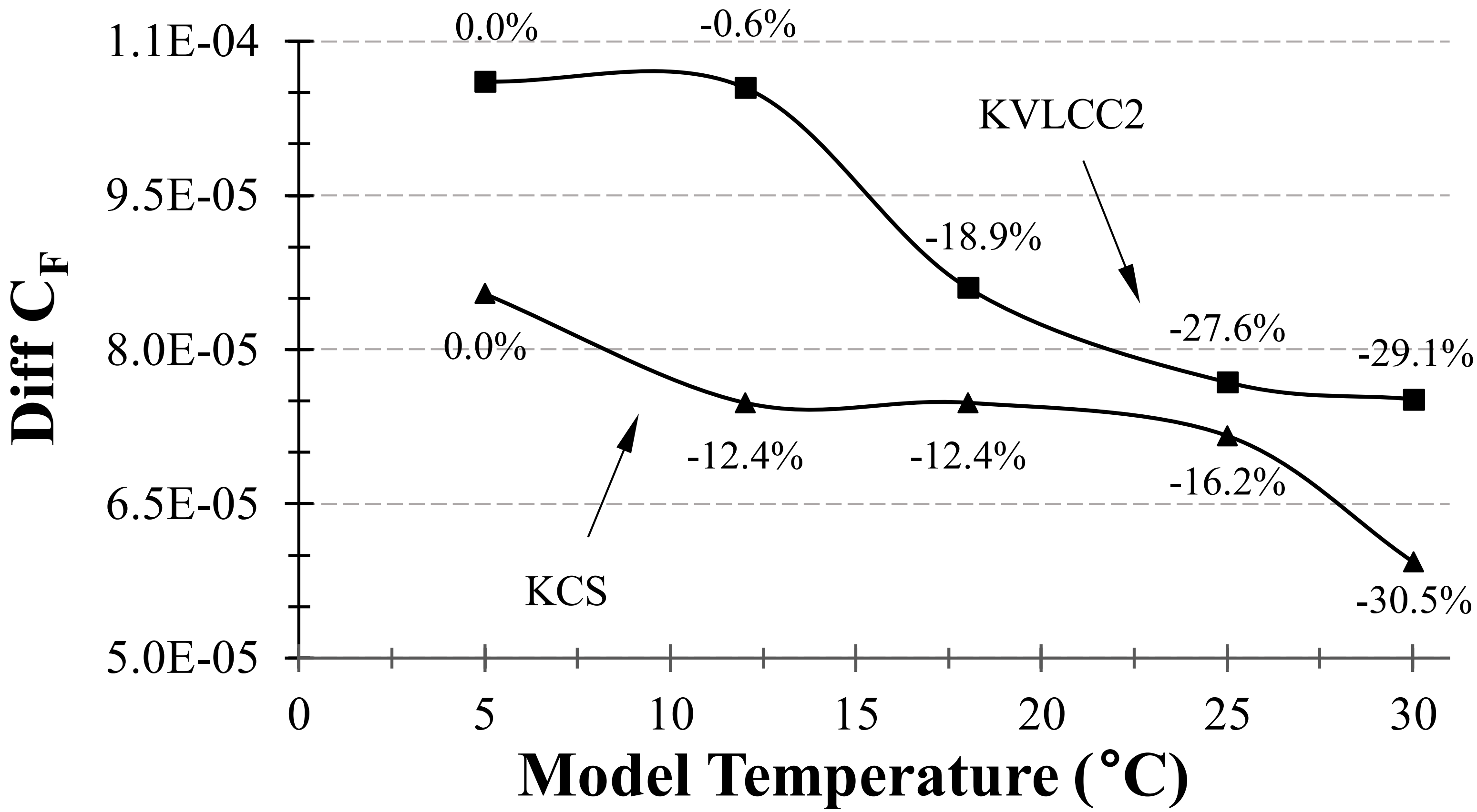
Conclusion

- “New curve”-based model-ship extrapolation
  - Difference in C_W according to the CFD method
    - For KCS, the maximum difference is 1.2%, varying with temperature
    - For KVLCC2, the maximum difference is 3.7%, varying with temperature



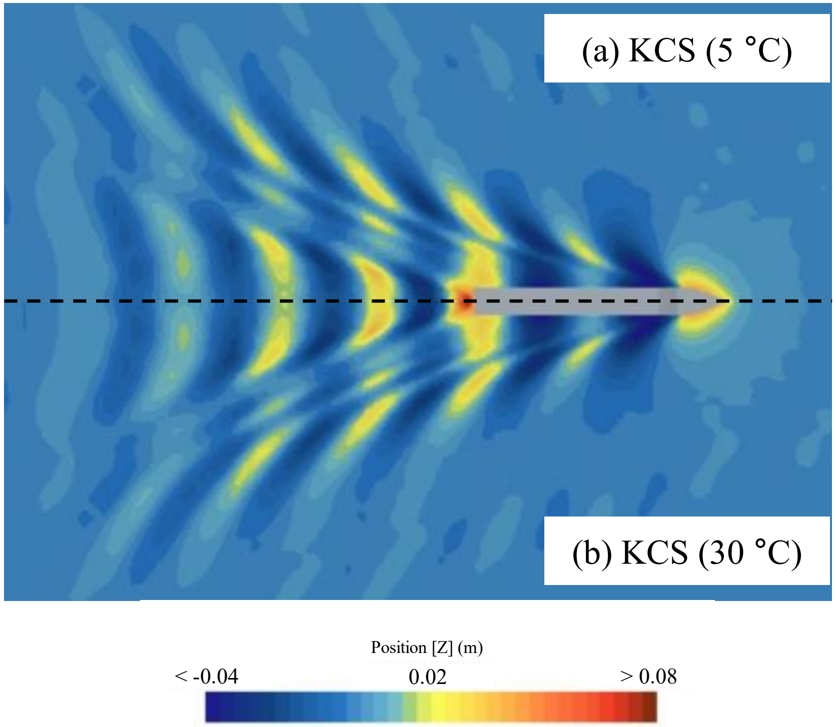
Conclusion

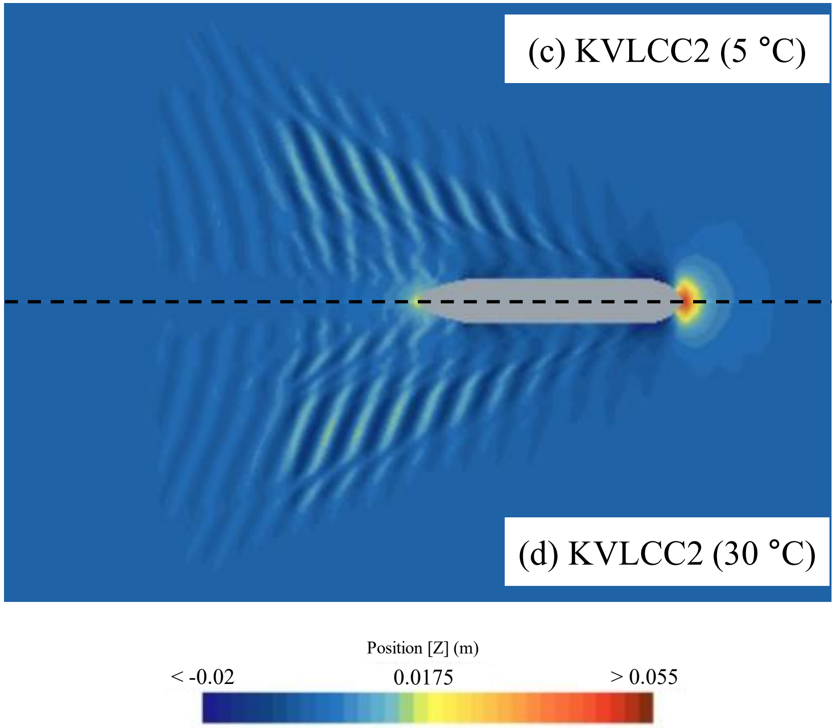
- $ITTC\ C_F - CFD\ C_F$



Conclusion

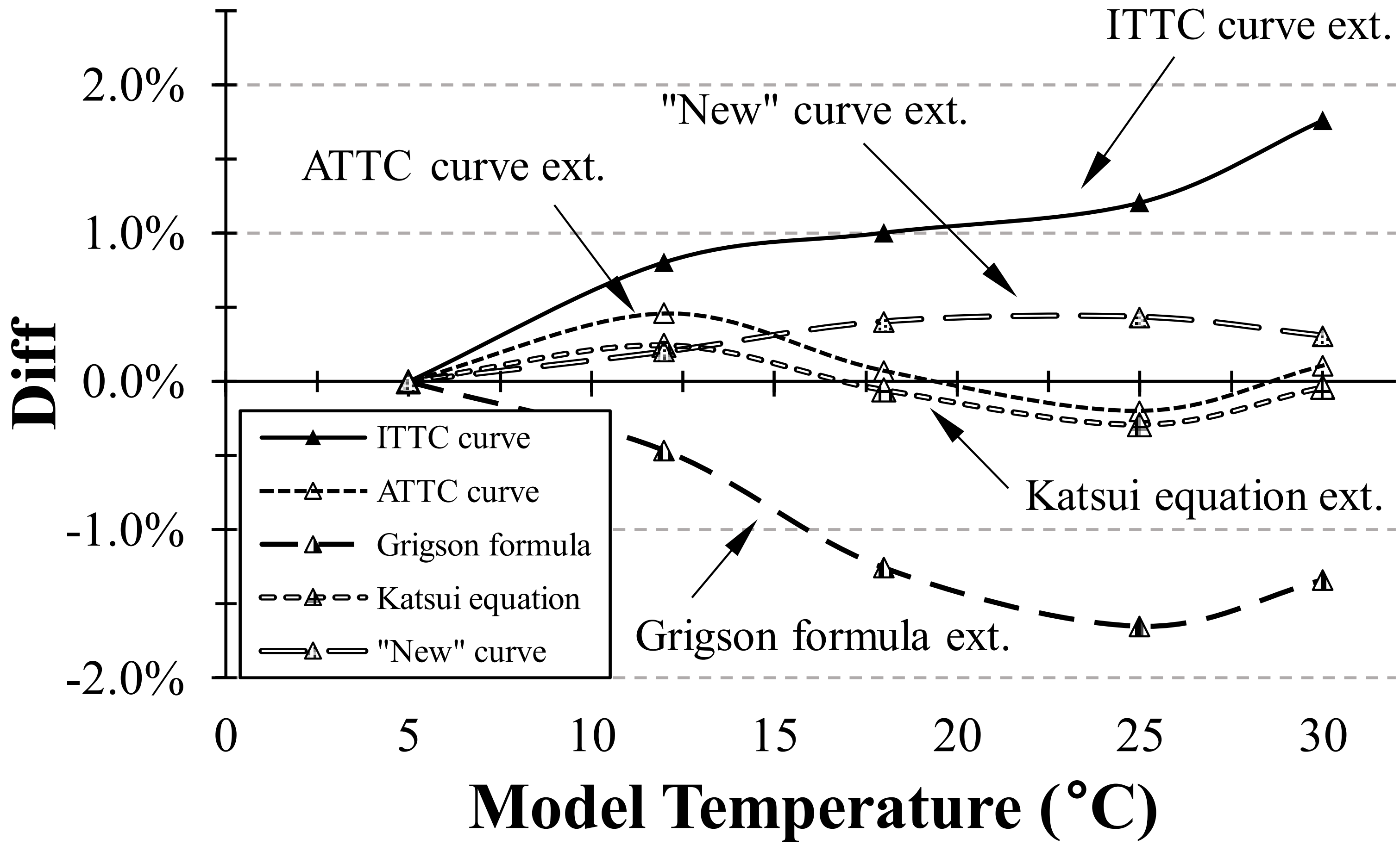
- Effect of towing tank temperature on wave making resistance
  - Wave-making resistance is unaffected by temperature (confirmed by consistent wave patterns).
  - CFD-based C_W stays constant, while the ITTC correlation line shows variation.
  - ITTC correlation misestimates frictional resistance, causing misleading C_W changes.





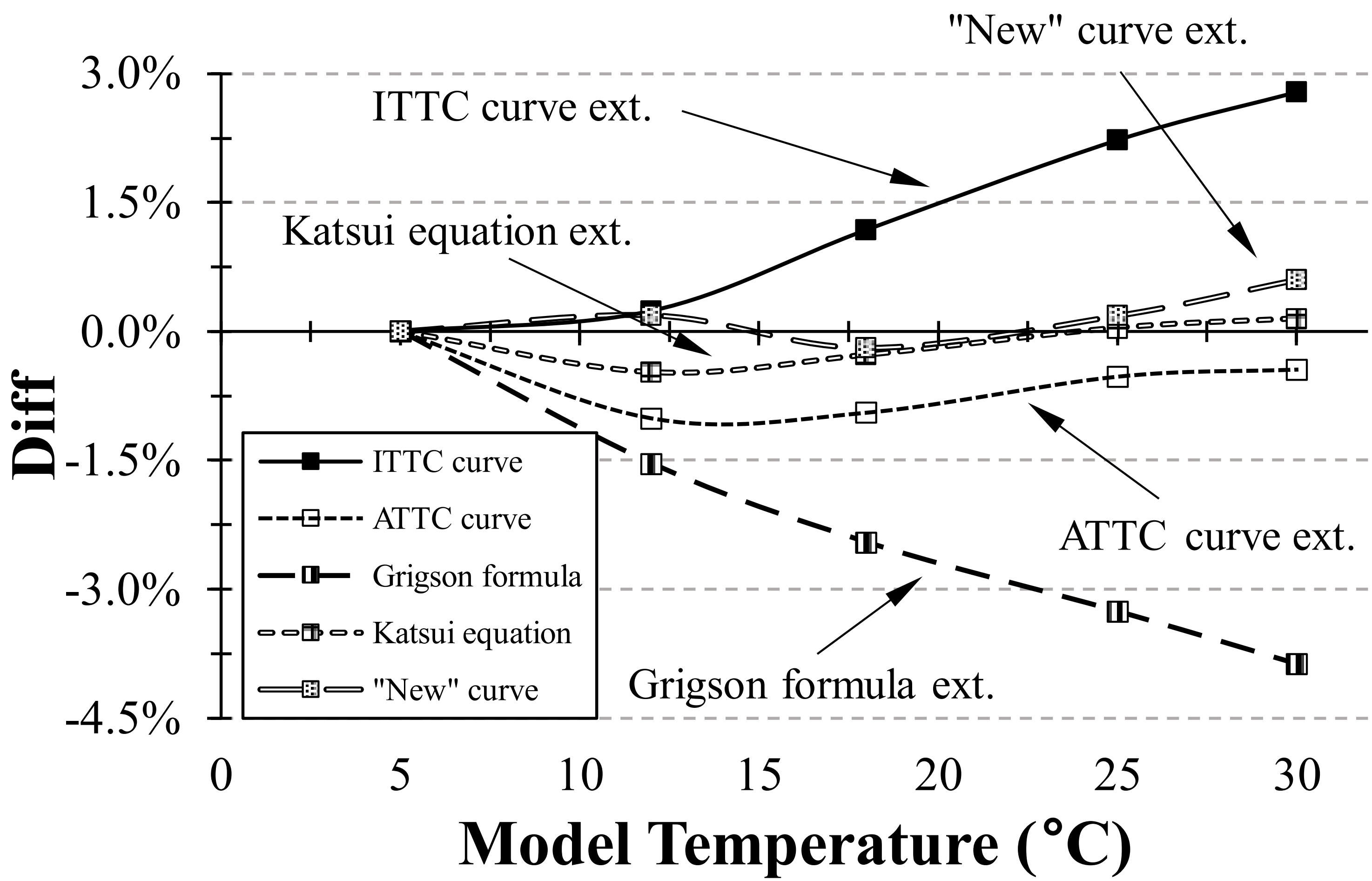
Conclusion

➢ Comparison of the extrapolation methods (KCS)



Conclusion

- Comparison of the extrapolation methods (KVLCC2)



Conclusion

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➢ Aim and Objectives

- To investigate how variations in towing tank water temperature affect the model-ship extrapolation using the ITTC 1957 correlation line
- To assess temperature-sensitivity of five different friction curves

➢ Implications

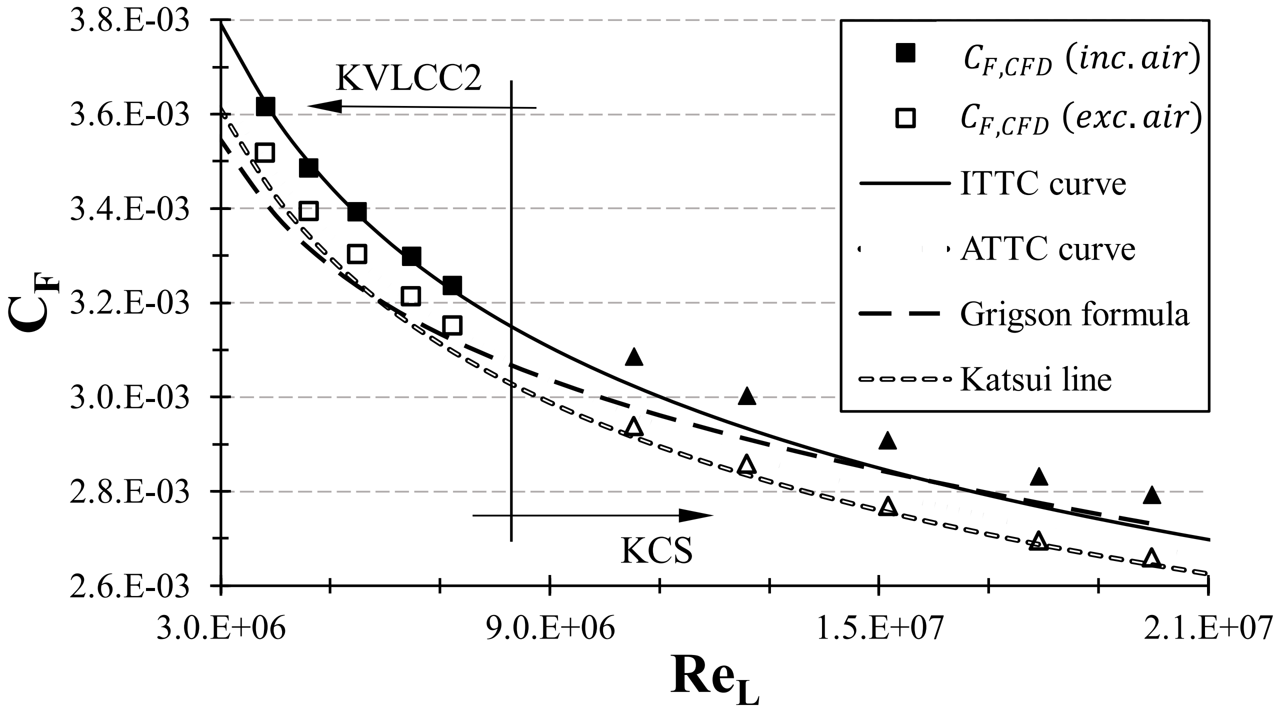
- The ITTC correlation line is significantly temperature-sensitive, affecting ship C_T predictions, by up to 2.8%
- The Grigson formula results in a maximum variation of 3.9% in ship C_T predictions
- The Katsui line and CFD method show minimal temperature-sensitivity, indicating more stable extrapolation, with a maximum difference of under 0.6%
- A new, accurate ITTC friction curve could improve extrapolation stability and reliability

Thank you for your attention!

Q&A

Results

- Frictional resistance coefficient, C_F
  - Compared different friction curves
    - i.e., ITTC curve, ATTC curve, Grigson formula, Katsui line and CFD method
  - Values were compared with those measured via CFD



Conclusion

➢ Limitations

- CFD simulations have numerical uncertainties that can affect result accuracy
- The "new" curve is hypothetical and doesn't realistically exist in terms of Reynolds numbers
- The influence of wave-making resistance was not considered
- Additional research using experimental fluid dynamics (EFD) is necessary