Name :__________________ **Quiz: No. 8** **Time: 15 minutes**

Student ID# : _____________ **Course: ME 5160, Fall 2022**

The exam is closed book and closed notes.

The KRISO Container Ship (KCS) was conceived to provide data for both explication of flow physics and CFD validation for a modern container ship with a bulbous bow. The ship is 230m long and designed to cruise at Fr=0.26.

Two different facilities need to simulate the ship resistance in towing tanks. The first facility (NMRI) has a model 7.2786m long and the second facility (IIHR-UIowa) has a model 2.7m long.

(a) Determine the cruise speed of the full-scale ship.

(b) For Froude scaling find the tow speed of the two models.

(c) For Reynolds scaling find the tow speed of the two models.

(d) Are the values you found in question (c) reasonable? Comment.

(e) The results of the experiments show that $C_D = 3.65 \cdot 10^{-3}$ for NMRI and $C_D = 5.203 \cdot 10^{-3}$ for IIHR. Determine the resistance of the two models using the tow speed obtained for Froude scaling.

Figure: KRISO Container Ship (KCS) geometry.

Hint: $Fr = \frac{U}{\sqrt{gL}}$, $Re = \frac{\rho UL}{\mu}$, $F_D = 0.5\rho L^2 U^2 C_D$

		Dimensions	
Quantity	Symbol	$MLT\Theta$	$FLT\Theta$
Length	L	L	L
Area	A	L^2	L^2
Volume	$\mathcal{V}$	L^3	L^3
Velocity	V	LT^{-1}	LT^{-1}
Acceleration	dV/dt	LT^{-2}	LT^{-2}
Speed of sound	a	LT^{-1}	LT^{-1}
Volume flow	Q	L^3T^{-1}	L^3T^{-1}
Mass flow	$\dot{m}$	MT^{-1}	FTL^{-1}
Pressure, stress	p, σ, τ	$ML^{-1}T^{-2}$	FL^{-2}
Strain rate	$\dot{\epsilon}$	T^{-1}	T^{-1}
Angle	θ	None	None
Angular velocity	ω, Ω	T^{-1}	T^{-1}
Viscosity	μ	$ML^{-1}T^{-1}$	FTL^{-2}
Kinematic viscosity	ν	L^2T^{-1}	L^2T^{-1}
Surface tension	Υ	MT^{-2}	FL^{-1}
Force	F	MLT^{-2}	F
Moment, torque	M	ML^2T^{-2}	FL
Power	P	ML^2T^{-3}	FLT^{-1}
Work, energy	W, E	ML^2T^{-2}	FL
Density	ρ	ML^{-3}	FT^2L^{-4}
Temperature	T	Θ	Θ
Specific heat	c_p, c_v	$L^2T^{-2}\Theta^{-1}$	$L^2T^{-2}\Theta^{-1}$
Specific weight	γ	$ML^{-2}T^{-2}$	FL^{-3}
Thermal conductivity	k	$MLT^{-3}\Theta^{-1}$	$FT^{-1}\Theta^{-1}$
Thermal expansion coefficient	β	Θ^{-1}	Θ^{-1}

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Solution

(a) For the full-scale simulation:

$$Fr = 0.26 = \frac{U}{\sqrt{gL}} = \frac{U}{\sqrt{9.81 \cdot 230}} \rightarrow U = 0.26\sqrt{9.81 \cdot 230} = 12.35\ m/s \quad \text{(+3)}$$

(b) Froude scaling:

$$Fr = Fr_m \quad \text{(+0.5)}$$

$$\frac{U}{\sqrt{gL}} = \frac{U_m}{\sqrt{gL_m}}$$

$$U_m = U\frac{\sqrt{L_m}}{\sqrt{L}} \quad \text{(+1)}$$

NMRI model:

$$U_m = 12.35\frac{\sqrt{7.2786}}{\sqrt{230}} = 2.197 m/s \quad \text{(+0.5)}$$

IIHR model:

$$U_m = 12.35\frac{\sqrt{2.7}}{\sqrt{230}} = 1.338 m/s \quad \text{(+0.5)}$$

(c) Reynolds scaling:

$$Re = Re_m \quad \text{(+0.5)}$$

$$\frac{\rho UL}{\mu} = \frac{\rho U_m L_m}{\mu}$$

$$U_m = U\frac{L}{L_m} \quad \text{(+1)}$$

NMRI model:

$$U_m = 12.35\frac{230}{7.2786} = 390.25 m/s \quad \text{(+0.5)}$$

IIHR model:

$$U_m = 12.35\frac{230}{2.7} = 1052.04 m/s \quad \text{(+0.5)}$$

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(d) The velocities values found in (c) are not reasonable since their value is too high. They are unrealizable in a towing tank facility. For this reason, towing tank experiment used the Froude number scaling, and it extracted the pressure force (including wave) component from the experiment to estimate the full-scale ship resistance. In case of friction force, the ITTC friction coefficient method is typically used to estimate the full-scale ship friction force because the Reynolds number similarity is hard to be achieved in towing tank experiment. (+1)

(e)

NMRI model:

$$F_D = 0.5\rho L^2 U^2 C_D = 0.5 \cdot 1000 \cdot 7.2786^2 \cdot 2.197^2 \cdot 3.65 \cdot 10^{-3} = 466.68N$$ (+0.5)

IIHR model:

$$F_D = 0.5\rho L^2 U^2 C_D = 0.5 \cdot 1000 \cdot 2.7^2 \cdot 1.338^2 \cdot 5.203 \cdot 10^{-3} = 33.95N$$ (+0.5)

(+0.5)