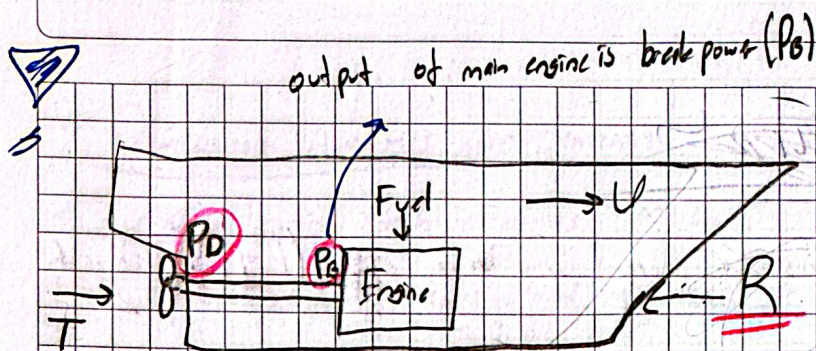




$$1 \text{ kn} = 0.5144 \text{ m/s}$$

$$1 \text{ HP} = 746 \text{ W} = 0.746 \text{ kW}$$

$P_B \rightarrow$ brake power (rpm)

Ship Hydrodynamics: Resistance of ships and Ship Propulsion (next to n)

propeller open water efficiency $\eta_0 \sim 0.6 - 0.7$

hull efficiency $\eta_H \sim 0.9 - 1$

transmission efficiency $\eta_{tr} \sim 0.95$

Relative efficiency η_r

efficiencies due to losses

$\eta_D =$ delivered efficiency
(includes all the above)

$$\text{Effective Power} = P_E = R \cdot U$$

it is not required engine power
engine power should be higher
due to losses.

$$P_E = \eta_D \cdot P_D$$

Break power P_B is transmitted to the propeller (with some mechanic losses due to gear box and/or bearings) called as delivered power P_D .

Propeller generates a thrust T. Because of the efficiencies of propeller and other losses due to propeller-hull interaction; T should be greater than R

$$T > R$$

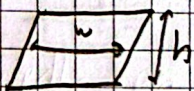
Dimensional Analysis and Similarity

3 fundamental units for hydrodynamics: M, L, T

$Q = f(p_1, p_2, \dots, p_n) \rightarrow n$ interrelated parameters $\rightarrow (n-3)$ non-dimensional quantities (including Q)

Buckingham

Pi Theorem:



$$D = f(u, h, \mu, \rho, \nu)$$

Drag force

① $D = M L T^{-2}$

$u = L T^{-1}$

$h = L$

$\rho = M L^{-3}$

$\mu = M L^{-1} T^{-1}$ (viskozite)

$\nu = L^2 T^{-1}$

② $6-3=3 \rightarrow$ bağımsız katları (π)

parametre sayısı $\rightarrow$ temel birimler (M, L, T)

π D için 3 değişken seç $\rightarrow u, \rho, \mu$

Aynı değişkenler içinde edilabilir seçilmemesi $\rightarrow$

tek bir değişken

$\frac{\nu}{h} = \frac{L^2 T^{-1}}{L} = L T^{-1} \times$

③ $\pi_1 = D \cdot u^a \cdot \nu^b \cdot \rho^c \rightarrow M L T^{-2} \cdot L^a \cdot (L T^{-1})^b \cdot (M L^{-3})^c = M^0 L^0 T^0$

$a+c=0$ (M)

$1+a+b-3c=0$ (L)

$-2-b=0$ (T)

$a=-2$

$b=-2$

$c=-1$

$\pi_1 = D \cdot u^{-2} \cdot \nu^{-2} \cdot \rho^{-1}$

④ Başka bir değişken seçilip tek bir değişkenle kullanılır.

$\pi_2 = h \cdot u^a \cdot \nu^b \cdot \rho^c = L \cdot L^a \cdot (L T^{-1})^b \cdot (M L^{-3})^c = M^0 L^0 T^0$

$c=0$ (M)

$1+a+b-3c=0$ (L)

$b=0$ (T)

$a=-1$

$b=0$

$\pi_2 = h \cdot u^{-1} \rightarrow \pi_2 = \frac{h}{u}$

⑤ Başka bir değişkenle kullanılır. Bu sırada sadece μ kaldı.

$\pi_3 = \mu \cdot u^a \cdot \nu^b \cdot \rho^c = M^0 L^0 T^0$

$\pi_3 = \frac{\mu}{u \cdot \nu \cdot \rho}$

⑥ $\pi_1 = f(\pi_2, \pi_3)$

$\frac{D}{\sqrt{2} u^2 \rho} = f\left[\left(\frac{h}{u}\right), \left(\frac{\mu}{u \cdot \nu \cdot \rho}\right)\right]$

π_1 bir insiz olduğundan tears çözümleri

Another way of solving

Expt 2: Resistance of a moving body. ($F = m \cdot g$) $\Rightarrow \frac{ML}{T^2}$



① $R_T = f(\rho, L, U, \mu, g)$ $5-3=2 \rightarrow$ başlangıç k. bası

$$M \cdot L \cdot T^{-2} = C [\underline{M \cdot L^{-3}}]^a \cdot (L)^b \cdot (L \cdot T^{-1})^c \cdot (M \cdot L^{-1} \cdot T^{-1})^d \cdot (L \cdot T^{-2})^e$$

$M \rightarrow 1 = a + d \rightarrow a = 1 - d$

② $L \rightarrow 1 = -3a + b + c - d + e \rightarrow b = 2 - d + e$

$T \rightarrow -2 = -c - d - 2e \rightarrow c = 2 - d - 2e$

③ $R_T = C \cdot (\rho)^{1-d} \cdot (L)^{2-d+e} \cdot (U)^{2-d-2e} \cdot (\mu)^d \cdot (g)^e$

$R_T = C \cdot \rho \cdot L^2 \cdot U^2 \cdot \left(\frac{\mu}{\rho U L}\right)^d \cdot \left(\frac{U^2}{g L}\right)^e$

④ $\frac{R_T}{\rho L^2 U^2} = C \underbrace{\left(\frac{\mu}{\rho U L}\right)^d}_{\text{Reynolds } (Re)} \underbrace{\left(\frac{U^2}{g L}\right)^e}_{\text{Froude } (Fr)} \Rightarrow \frac{R_T}{\rho L^2 U^2} = f(\underline{Re}, \underline{Fr})$

~ COMPONENTS OF SHIP RESISTANCE ~

$\propto ITTC \rightarrow$ International Towing Tank Conference

$\frac{R_T}{\rho L^2 U^2} = C_T (Re, Fr) \rightarrow (L^2 = S) \rightarrow \frac{R_T}{\frac{\rho}{2} S U^2} = C_T (Re, Fr)$

wetted surface area

$\rightarrow$ Yayılan yarıda jerganı da belgeler, ITTC dicituans

$\propto$ Inertial Force $\propto \rho U^2 L^2$
 $\propto$ Viscous Force $\propto \mu U L$
 $\propto$ Gravitational Force $\propto \rho g L^3$

$\frac{\text{Inertial } F_i}{\text{Gravitational } F_g} = \frac{U^2}{g L} = \underline{Fr}$

$\frac{\text{Inertial } F_i}{\text{Viscous } F_v} = \frac{\rho U^2 L^2}{\mu U L} = \underline{Re}$

$$\left(\nu = \frac{\mu}{\rho} \right)$$

$L_1, L_2 \rightarrow$ two models

$$\frac{R_T}{\rho L^2 U^2} = C_T \left(\frac{UL}{\nu} \right) \left(\frac{U}{\sqrt{gL}} \right)$$

$$Re \rightarrow \left(\frac{UL}{\nu} \right)_1 = \left(\frac{UL}{\nu} \right)_2 \rightarrow U_2 = U_1 \frac{L_1}{L_2}$$

$$Fr \rightarrow \left(\frac{U}{\sqrt{gL}} \right)_1 = \left(\frac{U}{\sqrt{gL}} \right)_2 \rightarrow U_2 = U_1 \sqrt{\frac{L_2}{L_1}}$$

$U_2 \neq U_1 \rightarrow$ Problem

W. Froude's hypothesis:

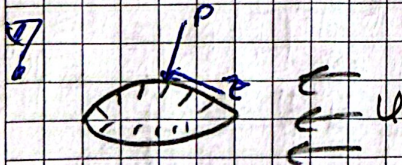
$$C_T(R_0, Fr) \approx C_F(R_0) + C_R(Fr)$$

3-dimensional effects due to the scales of the ship are neglected.

total resistance coefficient

frictional drag coefficient

residual drag coefficient



P : normal stress, pressure (normal direction)

τ : shear stress (tangential direction)

Frictional resistance coefficient

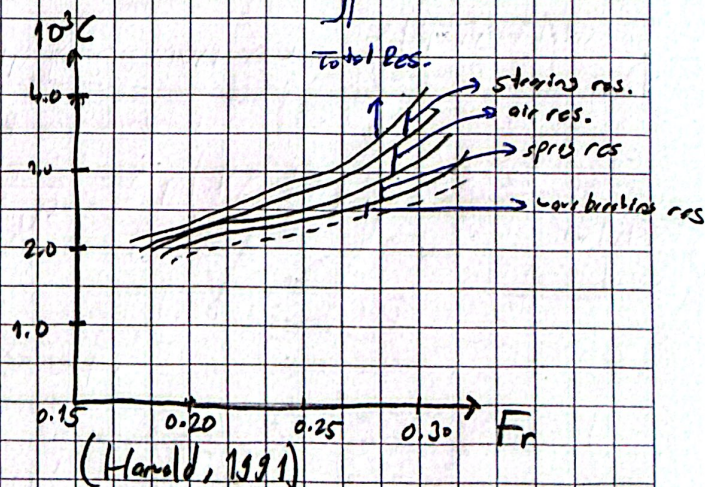
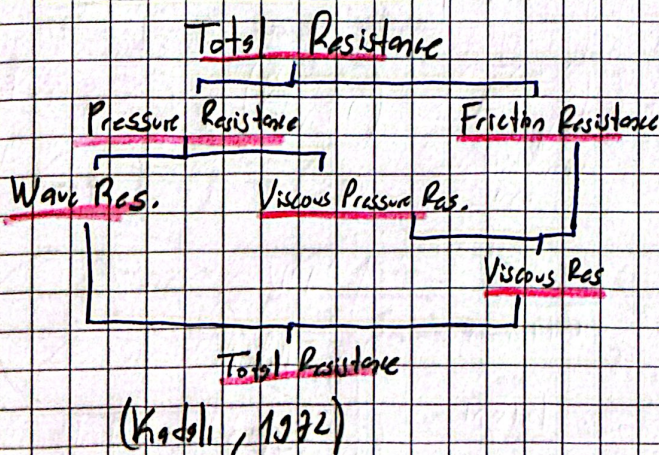
viscous pressure resistance coefficient

Definition of C_R

in Froude's hypothesis is questionable as

it is a function of Froude number but also contains a viscous related resistance

BASIC RESISTANCE COMPONENTS



Diagramın batıncı daha bir çok resistance içerir.

Ex 1 235 m bulk carrier, 16 knots speed

$1 \text{ knot} = 0.5144 \text{ m/s}$

A model with 7m length

1) $Fr = ?$ corresponding speed = ?

$Fr = \frac{U}{\sqrt{gL}}$

$\left(\frac{U}{\sqrt{gL}}\right)_1 = \left(\frac{U}{\sqrt{gL}}\right)_2 \rightarrow U_2 = U_1 \sqrt{\frac{L_2}{L_1}}$

$U_2 = 0.5144 \cdot 16 \sqrt{\frac{7}{235}}$
 $U_2 = 1.42 \text{ m/s}$
 $U_2 = 2.761$

$Fr = \frac{1.42}{\sqrt{9.81 \cdot 7}} = 0.7314$

2) What model speed is required to satisfy Reynold's Law at similitude?

$Re = \frac{UL}{\nu}$

$\nu_s = 1.103 \cdot 10^{-6} \text{ m}^2/\text{s}$
 $\nu_m = 1.055 \cdot 10^{-6} \text{ m}^2/\text{s}$

$\left(\frac{UL}{\nu}\right)_s = \left(\frac{UL}{\nu}\right)_m$

$16 \cdot 0.5144 \cdot 235 = \frac{U_m \cdot 7}{1.055 \cdot 10^{-6}}$

$U_m = 264.3 \text{ m/s}$

3) Test of the model in towing tank gives a trim moment of 39.5 Nm. Corresponding full scale moment according to Froude's law at similitude?

$\frac{R_T}{\frac{\rho}{2} S U^2}$ Keulegan-Gankovskiy

$\frac{M_T}{\frac{\rho}{2} S U^2 L}$ Momenti

$\left(\frac{R_s}{R_m} = 1.025\right)$
 $\left(\frac{S_s}{S_m} = 1\right)$

$C_{Ms}(Fr) = C_{Mm}(Fr)$

$\frac{M_{Ts}}{\frac{\rho_s}{2} S_s U_s^2 L_s} = \frac{M_{Tm}}{\frac{\rho_m}{2} S_m U_m^2 L_m}$

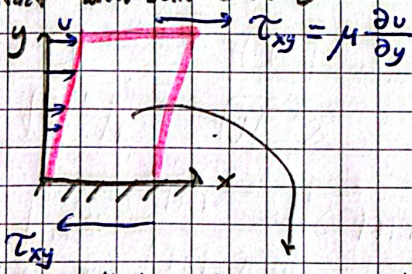
$M_{Ts} = M_{Tm} \cdot \frac{\rho_s}{\rho_m} \cdot \frac{S_s}{S_m} \cdot \frac{U_s^2}{U_m^2} \cdot \frac{L_s}{L_m}$
 $M_{Ts} = 39.5 \cdot 1.025 \cdot 1 \cdot \frac{(8.23)^2}{(1.42)^2} \cdot \frac{1}{1}$

$M_{Ts} = 51458 \text{ Nm}$

w.s.A

~ VISCOUS EFFECTS AND VISCOUS RESISTANCE ~

- Viscosity may be understood as friction between hypothetic layers of fluid which are in contact with solid boundaries.



- τ_{xy} is shear stress (kayma gerilmesi)
- $\frac{du}{dy}$ is rate of change of velocity as a function of y from solid boundary
- μ is dynamic viscosity coefficient.

Deformed fluid particle under viscous effects

In 3-D flow:

$$\tau_{ij} = -p \delta_{ij} + \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$$

Note: Pressure from wave-making effects are neglected

Frictional Drag (Skin Friction)

Viscous Pressure Drag

- Tangential
- Parallel to ship hull
- Causes a net force that opposes motion

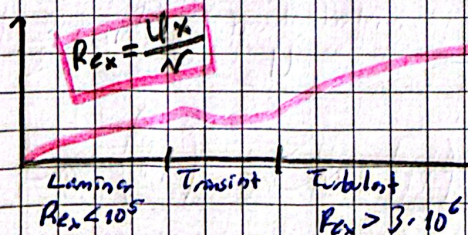
- Normal component causes a varying pressure distribution on hull

- High pressure area around the bow
- Low pressure zone at the aft
- Hull shape is effective
- Fuller forms have higher V.P.D

normal stress (pressure)
viscous pressure drag

frictional resistance

BOUNDARY LAYER



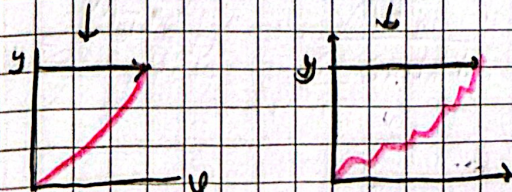
- Dümen geliştiği yerden itibaren hız azalır, duvara 0 olur.
- Dümen sönümlenmesi küçük bir alana sahiptir.
- Ayrıca hızın dış katman bölgesine ulaşması kadrolu bir süre boundary layer daha ve kalınlığı δ 'dir.

Laminar Boundary Layers

- well organized layers
- Steady or unsteady
- $Re < 10^5$

Turbulent Boundary Layers

- Mixing layers
- Unsteady
- $Re > 3 \times 10^6$
- 3-dimensional
- includes a random motion



$$\frac{\delta}{x} = \begin{cases} \frac{5.0}{Re_x^{1/2}} & \text{Laminar} \\ \frac{0.16}{Re_x^{1/4}} & \text{Turbulent} \end{cases}$$

Skin friction is described in terms of wall shear stress

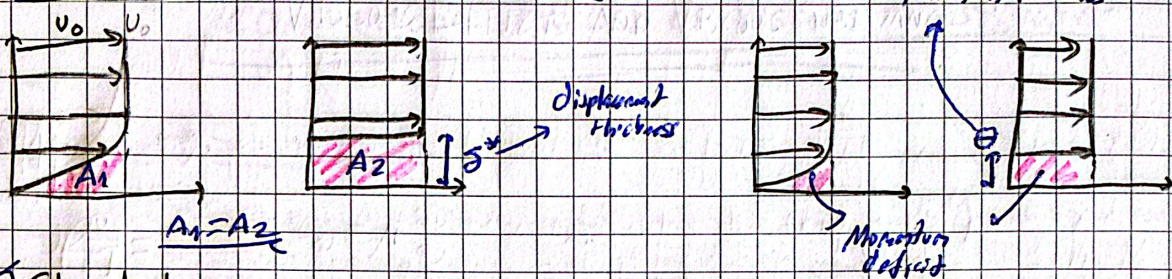
Skin Friction coefficient $C_f = \frac{\tau_w}{\frac{1}{2} \rho U_0^2}$

Well shear stress is the shear stress at solid boundary $\tau_w = \mu \left(\frac{\partial u}{\partial y} \right)_{y=0}$

Skin frictional Drag can then be obtained by integration along the flat plate

$$R_F(x) = b \int_0^x \tau_w(x) dx$$

DISPLACEMENT AND MOMENTUM THICKNESS



Skin friction drag can also be expressed in terms of the momentum thickness

$$R_{F(x)} = \rho b (U_0')^2 \theta$$

Shape Factor (Shape Parameter)

$$H = \frac{\delta^*}{\theta}$$

$H = 2.59 \rightarrow$ Laminar

$H = 1.3-1.4 \rightarrow$ Turbulent

ROUGHNESS EFFECT

$$k^+ = \frac{k_s}{l_v}$$

$$l_v = \frac{\nu}{\sqrt{\frac{\tau_w}{\rho}}}$$

roughness
Reynolds
number

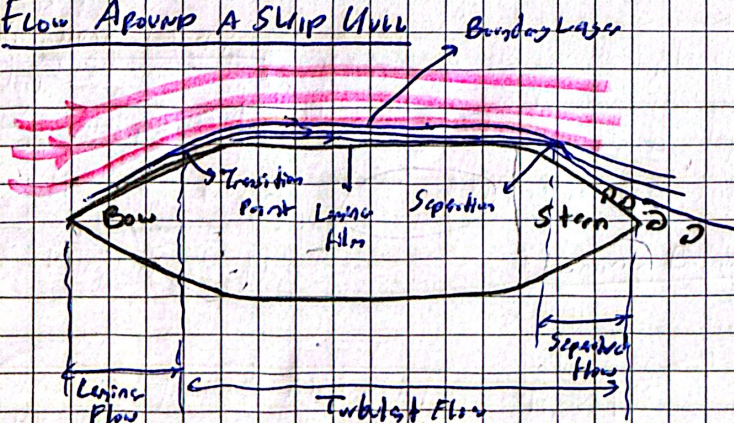
3 flow regimes:

1) $k^+ \approx 5 \rightarrow$ hydraulically smooth

2) $k^+ \approx 70 \rightarrow$ transitionally smooth

3) $k^+ > 70 \rightarrow$ fully rough

Flow Around A SHIP HULL



* Cadenas hesabı yaklaşık 3-4 saat

COMPUTATIONAL ANALYSIS OF VISCOUS RESISTANCE

✓ CADENCE → Sulu hacim yöntemi kullanılır.

Geometri: 1. Gemi simetrik olduğunda yarıda yarıya için hesap yapılır. (mesh sayısı azalır)
2. Tam gemi (200-300k) veya model ölçeğinde hesap yapılabilir.
→ daha kısa süren işler
→ Gölge seçilir.

Cadence'de iki model var → Hypermesh → mesh tanımlama

Box Creation → I.T.T.S'inde verdiğimizde daha yakın olursa duvara yakın atışta hesaplanır, daha uzak olursa giriz süratli olur.

✓ Domain Preparation

Maxing the ship faces → S. Adım çok önemli

✓ MESH GENERATION

Adapt to geometry → başta sadece max ribtae 12 yaa → sadece aynada 6 yaa gibi hesap bilginlere göre verilir.

Optimize ağırlığı nereden (cadence)'e atılır. Bu ağırlık ağırlığı dışı programlarda kısımlarda sıkı sıkıya → ilk doğrultması yapılır.

Viscous layer insertion → $30 < y^+ < 50$

✓ Flow Setting

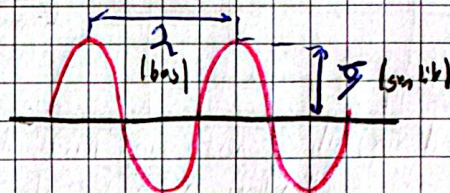
Domain → depleman ve aktif parametresi sulu hali hesaplar.

WAVE RESISTANCE

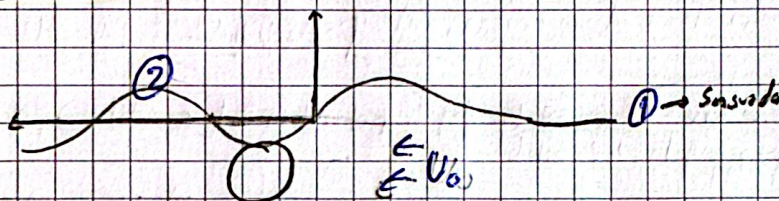
Total Resistance

Wave Res.

Viscous Res.



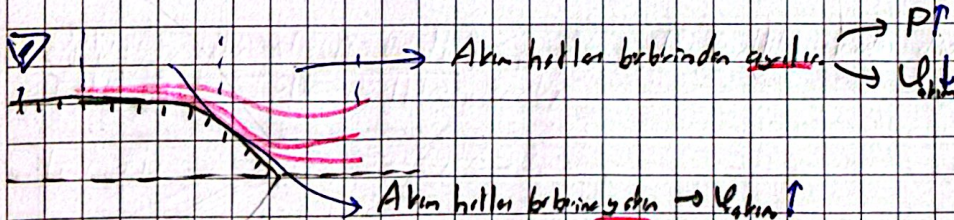
BERNOULLI



$$\left(\frac{P}{\rho} + \frac{1}{2} U_0^2 \right)_1 = \left(\frac{P}{\rho} + \frac{1}{2} U^2 + g\zeta \right)_2 \rightarrow \text{① u ② create Bernulli Diklari}$$

$$E = \frac{1}{2} \cdot \rho \cdot g \cdot \zeta^2 \cdot \lambda \rightarrow \text{dals. basu}$$

$$\lambda = \frac{2\pi U^2}{g}$$



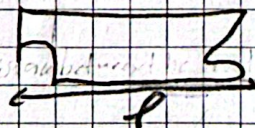
BOW AND AFT WAVE SYSTEMS

$$\text{Bow wave system} \rightarrow F_1 = F_{1a} \cdot \cos\left(\frac{2\pi x}{\lambda}\right)$$

$$\text{Aft wave system} \rightarrow F_2 = F_{2a} \cdot \cos\left(\frac{2\pi x}{\lambda} - \frac{2\pi f t}{\lambda}\right)$$

superpose two systems:

$$F_{12a} = \sqrt{F_{1a}^2 + F_{2a}^2 + 2F_{1a} \cdot F_{2a} \cdot \cos\left(\frac{2\pi f t}{\lambda}\right)}$$



THEORETICAL WAVE RESISTANCE ^{sinavda cok}

Takim calismasinda kullandiklar formulleri hoca dolduracak.

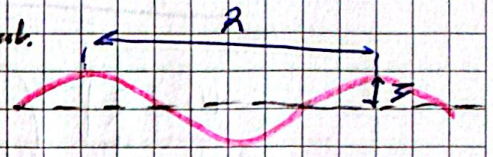
THW-SHIP THEORY → MICHELL'S INTERPOL

1) Linearization of free surface condition

$$\left[\frac{Fr}{2} \ll 1 \right]$$

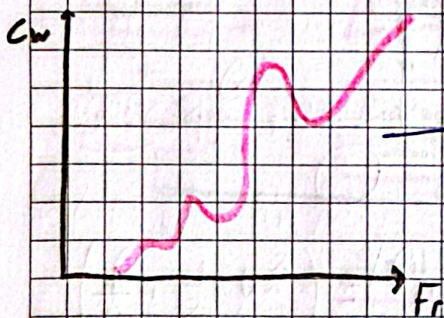
2) Linearization of ship surface condition

$$\left[\frac{Fr}{2} \gg 1 \right]$$



iki kabul

Ship is assumed to be thin.



Montroll bir geniclik tipik Mitchell's Integral sonucu

Low Froude Number Theory ^{Edende kullandiklar}

He tip genic isin linearizasyon yapmadan hirsizipta debrisi sonu vici.

~ COMPUTATIONAL WAVE RESISTANCE

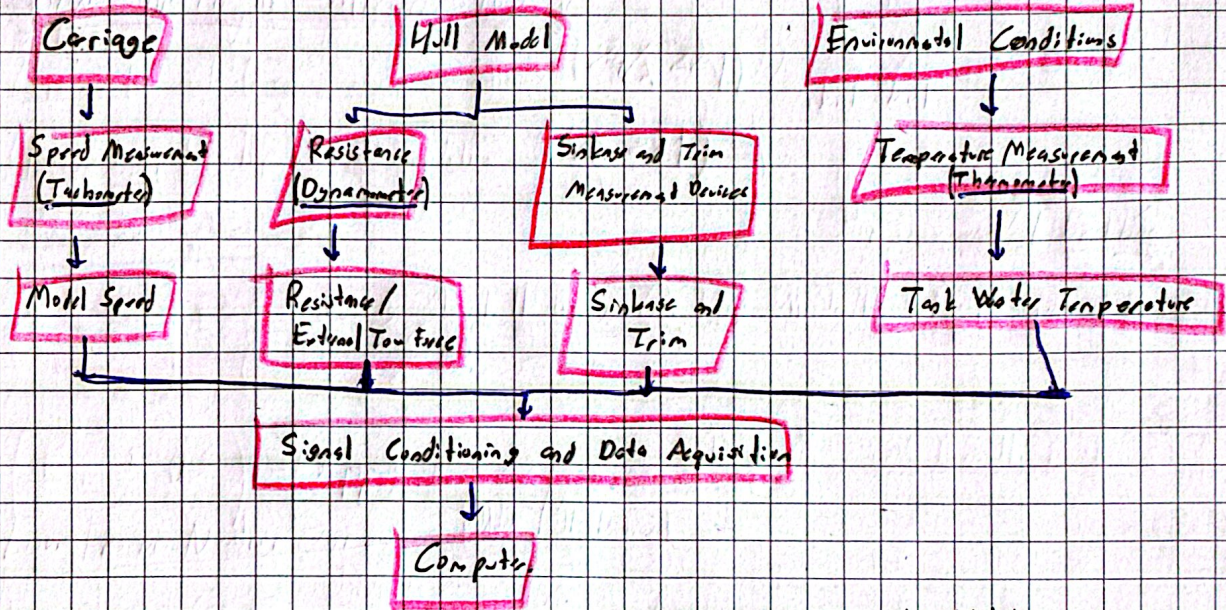
Bulb vass ile istesse e. kase



Bu konuyu iyi çözün, eksiklerinizle tamamlayın

RESISTANCE PREDICTION BY MODEL EXPERIMENTS

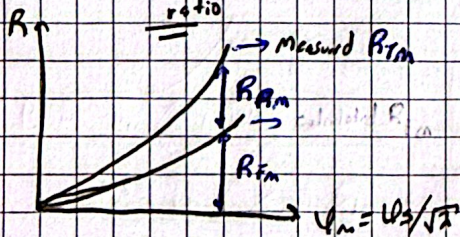
COMPONENTS OF A TYPICAL MEASUREMENT SYSTEM



FROUDE'S METHOD

$$\alpha U_m = \frac{U_s}{\sqrt{\lambda}}$$

Scale
ratio



$$\alpha R_{Tm} = R_{fm} + R_{rm}$$

Total Res. Frictional Res. Residual Res.

Residual res. component is extrapolated to ship scale

$$\alpha R_{Rs} = \lambda^3 \cdot R_{rm}$$

ITTC 1957 METHOD

$$\alpha C_F = \frac{0.075}{(\log_{10} Re - 2)^2}$$

Frictional
coefficient

$$\alpha C_{Tm} = C_{Rm} + C_{fm}$$

Total Res. is assumed to be the sum of frictional and residual components

At the same Froude number $\rightarrow C_{Rs} = C_{Rm}$

$$\alpha C_{Ts} = C_{Fs} + C_{Rm} + C_a$$

(C_{Rs} = C_{Rm})

Roughness coefficient $\rightarrow$ Sadece gemi üzerindeki hasarlar! (Only damage on the ship!)

▽ HUGHES METHOD

$$C_F = \frac{0.066}{(\log_{10} Re - 2.03)^2}$$

$$C_T = C_F + C_{up} + C_w$$

$$C_{TS} = (1+k) C_{FS} + C_w$$

extrapolation to full scale

years period: $(1.50 \cdot 10^6 \cdot \ln \text{militar})$

▽ ITTC 1978 METHOD

Improves Hughes' method.

$$C_A = \left[125 \left(\frac{k}{L_{wet}} \right)^{1/3} - 0.64 \right] \cdot 10^{-3}$$

$$C_{TS} = (1+k) \cdot C_{FS} + C_w + C_A + C_{AA}$$

$$C_{AA} = 0.001 \left(\frac{AvT}{s} \right)$$

Form Factor

Roughness allowance

Air Res.

C_A can be determined by Prandtl's method

▽ Prandtl's Method

$$\alpha \quad C_{Tm}(Re, Fr) = (1+k) \cdot C_{Fm}(Re) + C_w(Fr)$$

$$C_w = 5 Fr^{-1/4} \quad (\text{assumption})$$

$$\alpha \quad \frac{C_{Tm}}{C_{Fm}} = (1+k) + 5 Fr^{-1/4} / C_{Fm}$$

α $(1+k)$ can be determined as $Fr^{-1/4} / C_{Fm}$ goes to zero

$$1 + 0.15$$

~ VIZE SOLUARI ~

Ex 1

Analyze the experimental model data and extrapolate to full scale by ITTC-1958

$$1+k = 1.125$$

$\alpha = 20^\circ$, $V_m = 1.672 \text{ m/s}$, $R_{T,m} = 90.19 \text{ N}$, $W.S.A_m = 6.268 \text{ m}^2$, $L_m = 6.129 \text{ m}$, $V_m = 1.9347 \cdot 10^6$, $V_s = 1.1839 \cdot 10^6$

$$C_{T,m} = (1+k) C_{T,m} + C_{W,m}$$

$$C_{T,m} = \frac{R_{T,m}}{\frac{\rho}{2} V_m^2}$$

$$C_{F,m} = \frac{0.075}{(\log Re_m)^2}$$

$$V_s = \sqrt{1+k} \cdot V_m = 7.2535 \text{ m/s}$$

$$Fr = 0.208$$

$$C_{W,m} = C_{T,m} (1+k) \cdot C_{F,m} = 0.268 \cdot 10^{-3}$$

$$Re_m = \frac{V_m L_m}{\nu_m} = 8.877 \cdot 10^6$$

$$Re_s = \frac{V_s L_s}{\nu_s} = 0.756 \cdot 10^8$$

$$C_{F,s} = 1.58 \cdot 10^{-3}$$

$$C_{T,s} = (1+k) C_{F,s} + C_{W,s}$$

$$C_{W,m}(Fr) = C_{W,s}(Fr)$$

$$C_{T,s} = 1.124 \cdot 1.58 \cdot 10^{-3} + 0.268 \cdot 10^{-3}$$

$$C_{T,s} = 2.528 \cdot 10^{-3}$$

$$R_{T,s} = C_{T,s} \left(\frac{\rho}{2} V_s^2 \right) = 131.36 \text{ N}$$

CA design

$$P_E = R_{T,s} V_s = 124.36 \text{ kW}$$

Ex 2 (Tutorial 2)

$$F_T = \frac{\rho}{2} g \lambda^2 A$$

$$\lambda = \frac{2\pi v^2}{g}$$

Direct design
Reduction in wave resistance

$$= \frac{(\bar{F}_m)^2 - (\bar{F}_{m0})^2}{|\bar{F}_s|^2}$$

$$3.26$$

delta sink
upla qisi

Ex 3

0.23, 0.26 → favorable Froude Number? (considering interference of bow and stern wave systems)

$$\cos\left(\frac{1}{Fr}\right)$$

→ + gibasa wave interference dragi qidari
→ - gibasa wave interference dragi qidari

Ex 4

Scale = 1.25, $L = 100 \text{ m}$, $W.S.A = 2850 \text{ m}^2$, $V = 16 \text{ km/h}$, $C_w = 0.00123$, $C_d = 0.00136$, $R_e = 330 \text{ kN}$

What should be the corresponding speed of the smaller ship and what is the resistance coefficient and total res.? ($V = 1.1 \cdot 10^4$) Use Froude similarity and Hughes' method, form factor is same for both

$$\lambda = \frac{L_1}{L_2} = 1.25$$

$$V_2 = \frac{V_1}{\sqrt{\lambda}} = 7.36 \text{ m/s} = 14.3 \text{ km/h}$$

$$C_{T_1} = \frac{R_{T_1}}{\frac{\rho}{2} V_1^2} = \frac{330 \cdot 10^3}{\frac{1025}{2} \cdot 2850 \cdot (16 \cdot 0.5145)^2}$$

$$C_{T_1} = 0.00334$$

$$C_{T_1} = (1+k) \cdot C_{F_1} + C_{W_1} \rightarrow (1+k) = \frac{1.376}{C_{F_1}}$$

$$Re_2 = \frac{V_2 L_2}{\nu_2} = 6.9588 \cdot 10^7$$

$$C_{T_2} = (1+k) \cdot C_{F_2} + C_{W_2} = 0.00345$$

$$C_{F_2} = \frac{0.075}{(\log Re_2)^2} = 0.0016$$

R.T.

$$C_{W_1} = C_{W_2} = 0.00123$$

$$R_{T_2} = \frac{\rho}{2} S_2 V_2^2 \cdot C_{T_2} = \frac{1025}{2} \cdot 2850 \cdot (7.36)^2 \cdot 0.00345 = 136.71 \text{ N}$$

$$\frac{W.S.A}{\lambda^2}$$

Expt

$$[Re]_{ship} = \alpha^{scale} [Re]_{model}$$

(ship and model laminar viscousities are the same) (Froude similarity)

$$\alpha = ?$$

$$U_{ns} = \frac{U_s}{\sqrt{\alpha}} \Rightarrow \sqrt{\alpha} = \frac{U_s}{U_n}$$

C = cross sectional length of rudder

$$\frac{Re_s}{Re_n} = \alpha^x \Rightarrow \frac{\frac{V_s \cdot C_s}{\mu_s}}{\frac{V_n \cdot C_n}{\mu_n}} = \alpha^x$$

$$\left(\frac{V_s}{V_n} \right) \cdot \left(\frac{C_s}{C_n} \right) = \alpha^x$$

$$\frac{3/2}{\alpha} = \alpha^x \Rightarrow \boxed{x = 3/2}$$

with surface area

Expt 120 μm surface roughness, $R_T = 851 kN$ down speed = 20 km, $L_{ref} = 126 m$, $W.S.A = 5480 m^2$

overall propeller efficiency is predicted $\eta_D = 0.62$, $k_s = 220 \mu m$ above this kernel is not given by $\frac{220}{126}$?

$$C_A = \left[10.5 \left(\frac{k_s}{L_{ref}} \right)^{1/3} - 0.64 \right] \cdot 10^3$$

$$P_E = R_T \cdot V = 851 \cdot 20 \cdot 0.5144 = \dots$$

$$P_D = \frac{P_E}{\eta_D} = \dots \quad 0.0088$$

$$C_{A1} = \left[10.5 \left(\frac{220 \cdot 10^{-6}}{126} \right)^{1/3} - 0.64 \right] \cdot 10^3$$

$$\Delta C_A = C_{A1} - C_{A2} \rightarrow \Delta R = \frac{\rho}{2} S V^2 \Delta C_A, \quad \Delta P_E = \Delta R \cdot V, \quad \Delta P_D = \frac{\Delta P_E}{\eta_D}$$

$$\frac{P_{D1}}{P_{D2}} = 1.1$$

$$C_{A1} = \left[10.5 \cdot \left(\frac{220 \cdot 10^{-6}}{126} \right)^{1/3} - 0.64 \right] \cdot 10^3 = 0.104$$

$$C_{A2} = \left[10.5 \cdot \left(\frac{220 \cdot 10^{-6}}{126} \right)^{1/3} - 0.64 \right] \cdot 10^3 = \frac{10.5 \cdot 10^{-6}}{126} \cdot 0.104$$

$$0.000077$$

$$\frac{R_T}{\rho S V^2} = C_A$$

$$\Delta C_A = \frac{\Delta P_D}{\frac{\rho}{2} S V^2}$$

②

③

$R_{T,m} = 56.6 \text{ N}$, $U_m = 2.09 \text{ m/s}$, $R_{T,s} = ?$, $P_E = ?$

$\alpha = 20$

$W.S.A_m = 6.283 \text{ m}^2$

$L_{w,m} = 6.193 \text{ m}$

$V_m = 1.13902 \cdot 10^6 \text{ m}^3/\text{s}$

$V_s = 1.18831 \cdot 10^6 \text{ m}^3/\text{s}$

$C_{T,m} = (1+k) \cdot C_{F,m} + C_{w,m}$

$C_{T,m} = \frac{R_{T,m}}{\frac{\rho}{2} \cdot S_m \cdot U_m^2} = \frac{56.6}{\frac{1.025}{2} \cdot 6.283 \cdot (2.09)^2} = 0.004024$

$C_{F,m} = \frac{0.075}{(\log_{10} Re - 2)^2} = 0.002934$

$Re_m = \frac{U_m \cdot L_m}{\nu_m}$

$Re_m = 110746115$

$0.004024 = 2.3715 \cdot 0.002934 + C_{w,m}$

$C_{w,m} = -0.003$

$C_{w,m} = C_{w,s}$

$(1+k) = \frac{C_T}{C_F} = \frac{0.004024}{0.002934} = 1.3715$

$U_s = U_m \cdot \sqrt{\alpha}$

$U_s = 9.347$

$L_s = L_m \cdot \alpha = 120.38$

$Re_s = \frac{U_s \cdot L_s}{\nu_s}$

$Re_s = 325200986$

$C_{T,s} = (1+k) \cdot C_{F,s} + C_{w,s}$

$C_{T,s} = 2.3715 \cdot 0.0015354 - 0.003$

$C_{T,s} = 0.000641$

$C_{F,s} = \frac{0.075}{(\log_{10} Re - 2)^2} = 0.0015354$

$R_{T,s} = C_{T,s} \cdot \frac{\rho}{2} \cdot S_s \cdot U_s^2$

$S_s = S_m \cdot \alpha^2 = 2513.2 \text{ m}^2$

$R_{T,s} = 0.000641 \cdot \frac{1.025}{2} \cdot 2513.2 \cdot (9.347)^2 = 72131.25 \text{ N} = 72.13125 \text{ kN}$

$P_E = R_T \cdot U_s \rightarrow P_E = 647.21$

$$④ \Delta A = 4200 \text{ hrs}$$

$$U_A = 12 \text{ km} = \underline{6.1728 \text{ m/s}}$$

$$P_{B_A} = 850 \text{ kW}$$

$$\Delta B = 6000 \text{ hrs}$$

$$U_B = 12.6 \text{ km} = \underline{6.9814 \text{ m/s}}$$

$$P_{B_B} = ?$$

$$L_B = 0.3 \text{ m}$$

$$\lambda = \frac{6000}{4200} = \underline{1.27}$$

$$⑤ C_{T,5} = ?$$

$$(1+k) = \underline{1.116}$$

$$C_{T,m} = (1+k) \cdot C_{F,m} + C_{w,m}$$

$$0.00473 = 1.116 \cdot 0.00332 + C_{w,m} \rightarrow C_{w,m} = \underline{0.000969}$$

$$C_{T,5} = (1+k) \cdot C_{F,5} + C_{w,5} \rightarrow C_{T,5} = 1.116 \cdot 0.00139 + 0.000969 = \boxed{0.00252}$$

C_A : Roughness allowance, determined from comparison of model and full scale trial results.

$$U_s = U_m \cdot \sqrt{\lambda} \rightarrow U_s = 1.25 \cdot \sqrt{\frac{1.27}{3.4}} \rightarrow \boxed{U_s = 12.62 \text{ m/s}}$$

~ CALCULATION OF SHIP RESN

- I) a- Standart/Systematic Series
b- Res. Calculation Using Diagrams

II) Regression Equations (Statistical Methods)

III) Computational / Numerical Methods

- a- Potential Flow Solvers → Mitchell's Integral
b- Viscous Flow Solvers → Low Froude Number Theories

I(a) - STANDARD/SYSTEMATIC HULL SERIES

× L/O, O/T, LCO/L, CB gibi dezahı bınar olalı gıplı.

- × Series 60,
- × BSRA Cargo Ship Series
- × MARAD Series
- × SSPA Series
- × Taylor-Gettle Series
- × UBC Tractor Series
- × İTÜ Fishing Vessel Series
- × Series 64
- × NPL Series
- × Series 62
- × US Naval Academy YP Series

II - STATISTICAL METHODS (REGRESSION EQUATIONS)

α Simple Empirical Formulas:

Admiralty Coefficient (A_C) →

$$A_C = \frac{\Delta^{2/3} \cdot U^3}{P} \rightarrow \begin{matrix} \text{ton} \\ \text{HP} \end{matrix}$$

(additive) → P_E

Once the A_C is calculated for known type of ship, the necessary power for the new ship of same type →

$$P = \frac{\Delta^{2/3} \cdot U^3}{C} \rightarrow \begin{matrix} \text{m/s} \\ \text{HP} \end{matrix}$$

Harold (1985)

$$C = 3.7 \left(\sqrt{L} + \frac{75}{U} \right)$$

Break Power (Watson, 1960) →

$$P_B = \left[5 \Delta^{2/3} U^3 (40 - 0.017L + 400(K-1)^2 - 12CB) \right] / \left[1500 - \frac{11000}{\sqrt{P_E}} \right]$$

ton

m/s

m

$K = 1.06$ for $0.64 \leq CB \leq 0.80$

$K = 1.04$ for $CB < 0.64$

$K = 1.08 - 1.10$ for $CB > 0.80$

Potential speed (m/s)

For Naval Ships

$$1 \text{ HP} = 745.7 \text{ W}$$

α Effective Power (Brown, 1978)

$$P_E = \Delta \cdot U \left(\frac{0.0571 U}{\Delta^{1/6}} - 0.110 \right) \quad (\text{kW})$$

$\swarrow$ $\searrow$
 t_n k_n

α P_E (Kadali, 1987)

For ships similar to Seixago

$$P_E = C \cdot \Delta \cdot U \left(\frac{U}{L} \right)^2 \quad (\text{HP})$$

$\swarrow$ $\searrow$ $\swarrow$ $\searrow$
 t_n k_n m

$$C = \left(0.16 \frac{B}{T} + 0.55 \right) \left[0.05 - 0.00001 \left(\frac{0.120 - 4.30}{1000} \right) \left(\frac{U}{L} \right)^{10/5} \right]$$

α P_E (Kupras, 1980)

For Turks

$$P_E = C \frac{\Delta^{2/3} \cdot U^3}{128.1} \quad (\text{HP})$$

$\swarrow$ $\searrow$ $\swarrow$ $\searrow$
 t_n k_n m

$$C = 0.087 - 0.0004 L - 0.235 C_B$$

1. STATISTICAL METHODS OR A FAMILY REGRESSION FORMULA

α Doust (1962) is the pioneer, Holtrop and Mannes Method (1982) is the most popular and reliable

α Some other methods are:

- α Contreassen Small Ship Statistical Method
- α Sabit's Regression Analysis of BSRA Series
- α Sabit's Regression Analysis of SSRA Cargo Liner Series
- α Danahardt's Algorithm
- α Mecier and Smith's Numerical (1) Method
- α Modified Savitsky Method
- α Hollenbach Power Prediction Method
- α Fung's Method

$$C_F = 1.2$$

Cup line

Takumi

APPENDAGE RESISTANCE

1. TYPES OF APPENDAGES

- 1) Hydrofoil Type — Rudder, control surfaces, bilge keels
- 2) Streamlined Geometries — Sonar dome, side bulbs
- 3) Blunt Bodies — Shedd, shedd buckets, shedd basins
- 4) Openings on the Hull — Cooling water inlet and outlet, bow and stern thruster openings.

2. BASIC APPROACHES

* Reynold's similarity can not be satisfied by usual model experiments, appendage res. values may not be extrapolated to full scale propels

* An alternative method is calculating appendage res. by semi-empirical and semi-analytical formulas.

Sources of Appendage Res:

- * Surface friction
- * Res. due to pressure difference
- * Flow separation
- * Working in non-uniform flow regime

3. RES. OF CONTROL SURFACES

→ Rudders, hydrofoil sections, shedd buckets, roll stabilizers

² Assump: They may be treated as control surfaces (2-D) with zero angle of incidence with the oncoming flow.

∠ Frictional Res. coefficient for 2-D plate surfaces in turbulent flow (Schoenherr):

$$C_F = 0.4637 (\log_{10} Re)^{-2.6}$$

∝ Frictional Res.

in laminar flow (Blasius):

$$C_F = 1.323 \cdot Re^{-0.5}$$

For Appendages Having Hydrofoil Sections

→ Res. coefficient for laminar flow ($Re < 5 \cdot 10^5$)

thickness
chord
width

$t/c = 0$; $C_D = 1.46 Re^{-0.333}$

$t/c = 0.2$; $C_D = 0.446 Re^{-0.259}$

→ For transition regime ($5 \cdot 10^4 < Re < 5 \cdot 10^5$)

$t/c = 0$; $C_D = 0.132 \cdot Re^{-0.391}$

$t/c = 0.2$; $C_D = 0.181 \cdot Re^{-0.411}$

→ For turbulent regime ($Re > 5 \cdot 10^5$)

$5 \cdot 10^5 < Re < 5 \cdot 10^7$; $C_D = 2.03 \cdot 10^{-3} \cdot (1 + 2(t/c) + 60 \cdot (t/c)^{1/2})$

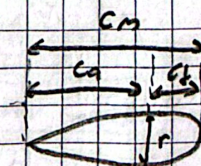
$> 5 \cdot 10^7 < Re$; $C_D = 0.003 \cdot Re^{-0.1928} \cdot (1 + 2(t/c) + 60(t/c)^{1/2})$

$R_T = 0.5 \rho S U^2 (C_D + C_{Dint})$; $C_{Dint} = 8.63 \cdot 10^{-3} \cdot (t^2/s) \cdot (0.25 \cdot (t/c) - 0.003(t/c)^2)$

Res. formula for rudders

$D_{rudder} = 0.5 \rho S U^2 C_F (1.25(C/C_F) + S/A + 40(t/c)^3)$

For thin rudders $\rightarrow S/A = 2c/b$ could be used

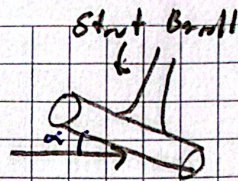


if surface appendage is causing spray

$D_{spray} = 0.24 \cdot 0.5 \rho U^2 b t^2$

t : max. thickness of the profile of control surface of water surface.

RES OF SQUARE, RECTANGLES, STEPS



Subcritical flow region $\rightarrow Re < 10^5$

Transitional regime $\rightarrow 10^5 < Re < 5 \cdot 10^5$

Supercritical flow regime $\rightarrow 5 \cdot 10^5 < Re$

- $0^\circ < \alpha < 40^\circ \rightarrow C_{DP} = 0.6 \cdot \sin^2(2.25\alpha)$
- $40^\circ < \alpha < 90^\circ \rightarrow C_{DP} = 0.6$

Frictional Res. coefficient:

$Re < 5 \cdot 10^5 \rightarrow C_F = 1.327 \cdot Re^{-0.5}$

$Re > 5 \cdot 10^5 \rightarrow C_F = (3.64 \log_{10} Re - 5.6)^{-2} - (1700/Re)$

Pressure Drag coefficient:

$Re < 10^5; \rightarrow C_{DP} = 1.1 \cdot \sin^3 \alpha$

$10^5 < Re < 5 \cdot 10^5; \rightarrow \alpha > \beta \rightarrow C_{DP} = -0.7154 \log_{10} Re + 4.677$

$\rightarrow \beta > \alpha \rightarrow C_{DP} = (-0.7154 \log_{10} Re + 4.677) \cdot (\sin^3(1.3882 \cdot \log_{10} Re - 7.29))$

$\beta = -21.54 \log_{10} Re - 14.42$

Total Res. of the sheet system:

$R_T = 0.5 \rho v^2 S_w (C_F + (C_{DP}/\pi) + C_{DLE} + C_{DAE})$

$C_{DLE} = 0.9 \cdot \cos^2 \alpha \rightarrow \text{sharp ends}$

$C_{DAE} = 0.1 \cdot \cos^2 \alpha \rightarrow \text{rounded ends}$

$C_{DAE} = 0.029 \cdot (C_F (S_w/S_s)^{0.5}) \cdot \cos^2 \alpha$

$S_B = \pi R^2 \rightarrow \text{Dike area at cylinder}$

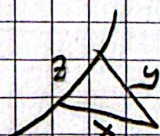
RES. OF BILGE KEELS

$Re < 5 \cdot 10^5 \rightarrow C_F = 1.327 \cdot Re^{-0.5}$

$5 \cdot 10^5 < Re \rightarrow C_F = (3.64 \log_{10} Re - 5.6)^{-2} - (1700/Re)$

$C_{cont} = 0.48 C_F$

$C_{cont} = 2(1 - 2/(x+y))$



Required Expressions

$\delta_s = 1.57 \cdot x \cdot Re^{-0.2662}$

δ_s → boundary layer thickness
 x → dist. between FIP and point of consideration

$\eta_L = \eta_s (y/\delta_s)^{1/3}$

$\eta = 2.901 \cdot Re^{0.0108} \cdot (x/L)^{-0.1212}$

Local velocity in boundary layer

0.521t

$$N_0 = 1.50 \cdot 10^5$$

Tutorial - RES N

$$① U_s = \sqrt{2} \cdot U_m = \sqrt{16} \cdot 15 = 6 \text{ m/s}$$

$$S_s = \alpha^2 \cdot S_m = 512 \text{ m}^2$$

In the wind tunnel: $C_T = C_V = C_F + C_{VP} \Rightarrow (1+k) = \frac{C_F + C_{VP}}{C_F} \rightarrow k = \frac{C_{VP}}{C_F}$

$$C_F = \frac{0.025}{(\log R - 2)^2} = 3.366 \cdot 10^{-3}$$

$R_{FW} = \frac{\rho_w \cdot L_w}{\mu_w} = \frac{\rho_a \cdot L_a}{\mu_a}$

$$U_a = U_w \cdot \frac{\mu_a}{\mu_w} \cdot \frac{L_w}{L_a} = 18.7 \text{ m/s}$$

$$C_V = \frac{\frac{1}{2} \rho U^2}{\frac{1}{2} \rho U^2} = 18.7$$

$$1+k = \frac{C_F + C_{VP}}{C_F} = \frac{C_V}{C_F} = 1.235$$

$$C_{T_m} = (1+k) \cdot C_{F_m} + C_{W_m} \rightarrow \frac{12.7}{\frac{1}{2} \rho U_m^2} = (1+k) \cdot C_{F_m} + C_{W_m} \Rightarrow C_{W_m} = 0.00135$$

$$C_{T_s} = (1+k) \cdot C_{F_s} + C_{W_s} + C_A$$

$$(C_{W_s} = C_{W_m})$$

$$R_{C_s} = \frac{\rho_s \cdot L_s}{\mu_s} = 3.220 \cdot 10^4, C_{F_s} = \frac{0.025}{(\log R - 2)^2} = 0.00182, C_A = \left(105 \cdot \left(\frac{k}{4}\right)^{1/3} - 0.64\right) \cdot 10^{-3}$$

$$C_{T_s} = (1.235) \cdot 0.00182 + 0.00135 + \dots =$$

$$C_{T_s} = \dots$$

$$\textcircled{2} \quad \alpha = \frac{L_s}{L_m} = \frac{120}{3} = 40$$

$$\frac{V_s}{V_m} = \alpha^3 \rightarrow V_m = V_s / \alpha^3 = 0.0781 \text{ m}^3$$

$$U_m = \frac{U_s}{\sqrt{\alpha}} = \frac{20}{\sqrt{40}} = 3.162 \text{ m/s}$$

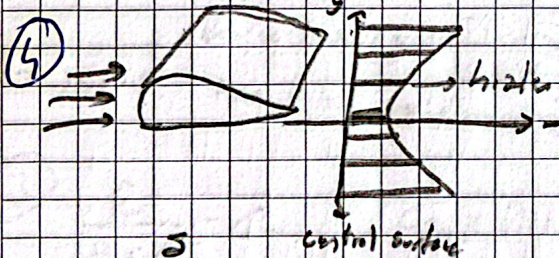
$$\frac{S_s}{S_m} = \alpha^2$$

$$\frac{P_{Es}}{P_{Em}} = \frac{R_s \cdot U_s}{R_m \cdot U_m}$$

$$R_s = C_{Ts} \cdot \rho_s \cdot S_s \cdot U_s^2$$

$$\frac{P_{Es}}{P_{Em}} = \frac{C_{Ts} \cdot \rho_s \cdot S_s \cdot U_s^2 \cdot U_s}{C_{Tm} \cdot \rho_m \cdot S_m \cdot U_m^2 \cdot U_m}$$

$$\frac{C_{Ts}}{C_{Tm}} \cdot \frac{\rho_s}{\rho_m} \cdot \alpha^2 \cdot \alpha \cdot \alpha^{1/2} = \boxed{\frac{C_{Ts}}{C_{Tm}} \cdot \frac{\rho_s}{\rho_m} \cdot \alpha^{3.5}}$$



$$\frac{y_1}{0.15} \quad \frac{u_1}{1}$$

$$\Theta = \int_0^5 \frac{u}{u_\infty} \left(1 - \frac{u}{u_\infty}\right) dy$$

$$\Theta = \int_{-0.15}^{0.15} \frac{u}{u_\infty} \left(1 - \frac{u}{u_\infty}\right) dy$$

Simpson

$$R = \rho U_\infty^2 \Theta = 2165 \text{ N/m}$$