İSTANBUL TEKNİK ÜNİVERSİTESİ

Naval Architecture and Marine Engineering – B.S.

GEM341E SHIP HYDRODYNAMICS

http://ninova.itu.edu.tr/Ders/2786

Appendage Resistance

Percentage of the appendage resistance in total resistance may reach considerable amounts depending on the ship type and appendage configuration and thus relatively gains importance as compared to other components of the total resistance.

Appendages may be classified and examined in 4 groups:

Hydrofoil type	Rudder, control surfaces (fins), bilge keels
Streamlined geometries	Sonar dome, side bulbs
Blunt bodies	Shaft, shaft bossing , shaft brackets
Openings on the hull	Cooling water inlet and outlets, bow and stern thruster openings

As an example, percentages of the appendages in total resistance of a frigate is given in the following:

Appendages	Appendage Resistance (% of naked hull)					
	Ship Speed (knots)					
	5	10	15	20	25	30
Single rudder	4.2	4.5	4.2	3.0	2.2	1.1
Sonar dome	6.2	5.7	4.6	4.1	2.8	1.9
Bilge keels	12.5	11.9	8.7	6.4	3.7	3.1
Shafts and brackets	16.6	15.9	13.6	11.5	9.0	6.7
Hull with all appendages	39.5	38.0	31.1	25.0	17.7	12.8

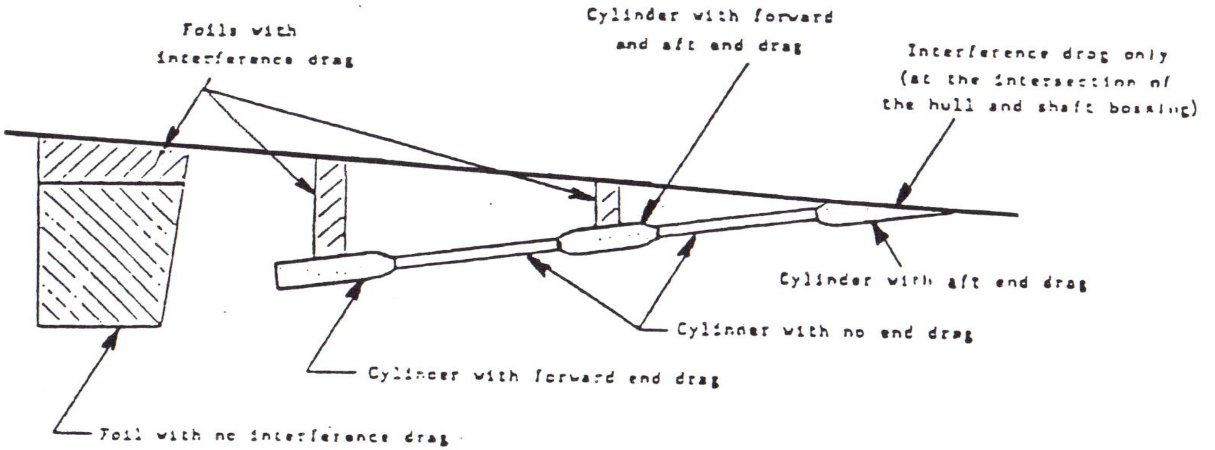
Percentages (appendage resistance) for various types of ships

Ship Type	Appendage Resistance(% of naked hull)		
	Froude Number		
	0.20	0.30	0.48
Large, fast, quadruple screw	10 to 16	10 to 16	-
Small, fast, twin screw	20 to 30	17 to 25	10 to 15
Large, medium speed, twin screw	8 to 14	8 to 14	-
Small, medium speed, twin screw	12 to 30	10 to 23	-
All single screw	2 to 5	2 to 5	-

Basic Approaches in the Calculation of Appendage Resistance

Since Reynolds similarity can not be satisfied by the usual model experiments, appendage resistance values as obtained from the model testing may not be extrapolated to full scale properly and with high accuracy.

An alternative to model experiment is to calculate the resistances of appendages by the use of semi-empirical and semi-analytical formulas (for foils, cylinders, plates etc.) including interference resistance with hull.



The sources of appendage resistance:

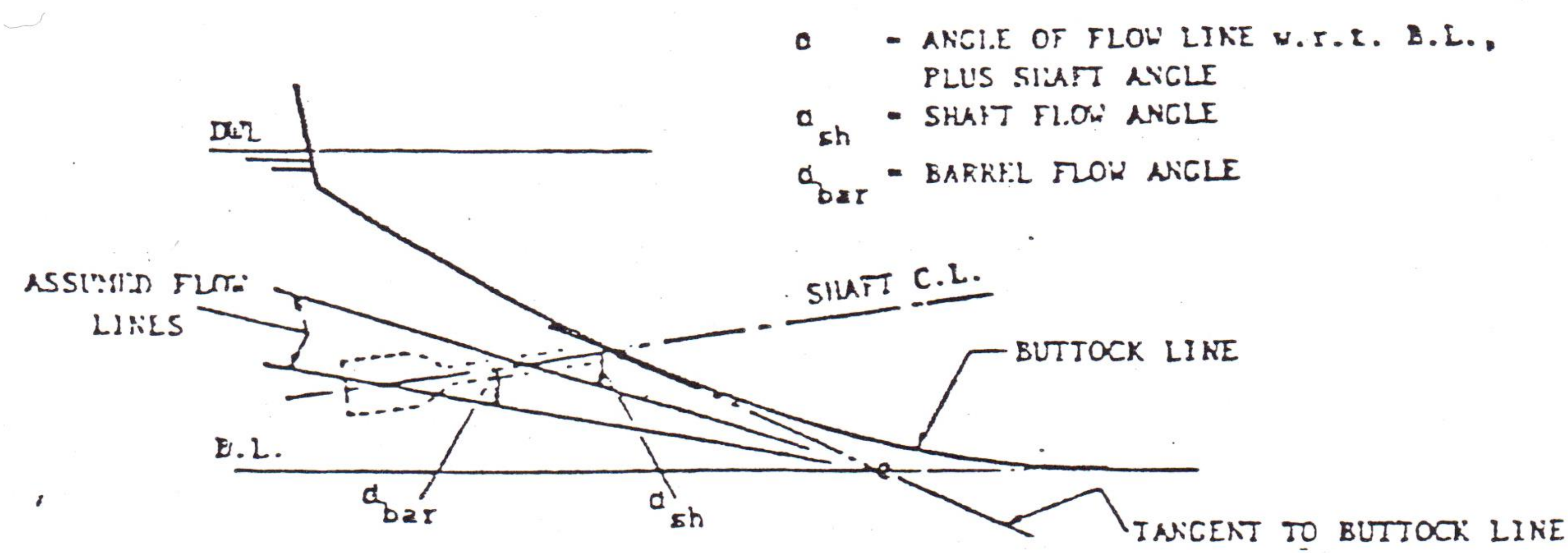
- Surface friction
- Resistance which occurs due to the pressure difference between the leading and the trailing edges of the element
- Flow separation
- Increase in boundary layer thickness due to discontinuities as a result of hull– appendage integration
- Cross flow evolution
- Working in a non-uniform flow regime (due to upstream disturbance of the uniform flow by other appendages generating vortex structures etc.)

Assumptions in the calculation of appendage resistance:

- In case of 2-D calculations, appendages are assumed to have high length/thickness and/or high length/ depth ratios.
- Additionaly, the following assumptions are valid:
  - Fluid is viscous. Cavitation and ventilation are disregarded in the calculations.
  - Appendages (rudders, bilge keels etc.) are installed with zero angle of incidence with the flow.
  - Cylindrical appendages may have an angle of incidence with the flow.
  - Effect of the cross flow is not considered.
  - The flow velocity around the appendages is predicted by taking the boundary layer velocity profile into account.
  - The mean flow velocity on appendages is accepted as the flow velocity at 2/3 of the boundary layer thickness if the appendage remains fully in the boundary layer.
  - Total appendage resistance is the sum of all the resistances of appendages.

Take water density for model 999 kg/m^3, for ship scale 1025.9 kg/m^3 and kinematic viscousity for model 1.13902 x 10- 6 m^2/s, and for ship 1.18831 x 10 – 6 m^2/s.

Angles with the flow to be determined are shown in the following:



Resistance of Control Surfaces:

Rudders (including plate rudders), hydrofoil section shaft brackets and roll stabilizers are regarded as control surfaces used in ships. They may be treated as 2-D control surfaces with zero angle of incidence with the oncoming flow. If rudders are mounted just behind the skegs, they may be considered as the continuation of skegs and in this case they may not be treated as appendages.

For 2-D plate surfaces in a turbulent flow, frictional resistance coefficient (Schoenherr's formula):

$$C_F = 0.4631(log_{10}Re)^{-2.6}$$

if in a laminar flow (Blasius' formula):

$$C_F = 1.327Re^{-0.5}$$

Reynolds number here should be taken according to the streamwise length of the plate .

For appendages having hydrofoil sections:

Note that in this type of appendages; resistance increases as the ratio of thickness/chord length (t/c) and flow separation may be observed for very high values of (t/c).

Resistance coefficient for laminar flow regime ($R_n<5 \times 10^{4}$);

$t/c = 0$; $C_D= 1.46\, R_n^{-0.507}$

$t/c = 0.2$; $C_D= 0.466\, R_n^{-0.259}$

In the transition regime ($5 \times 10^{4} < R_n < 5 \times 10^{5}$);

$t/c = 0$; $C_D= 0.172\, R_n^{-0.31}$

$t/c = 0.2$; $C_D= 0.181\, R_n^{-0.81}$

interpolation is used for intermadiate values of (t/c).

In the turbulent regime;

for $5 \times 10^{5} < R_n < 5 \times 10^{7}$; $C_D= 2.93 \times 10^{-3} \{1+2\,(t/c)+60\,(t/c)^{4}\}$

for $R_n > 10^{7}$; $C_D= 0.03 \times R_n^{-0.1428} \{1+2\,(t/c)+60\,(t/c)^{4}\}$

In addition to the above given resistance expressions, an interference resistance coefficient which takes into account the interference effect of appendage with the hull, is recommended to be employed in the calculations:

$$C_{Dint} = 8.63 \times 10^{-3} \times (t^2/S) \times \{ 0.75\,(t/c) - 0.003\,(t/c)^{-2} \}$$

Therefore the total resistance of appendage is given by

$$R_T = 0.5\,\rho\,S\,V^2\,(C_D + C_{Dint})$$

S: total wetted surface area
c: chord length (if variable use an average value)
V: speed
ρ: water density

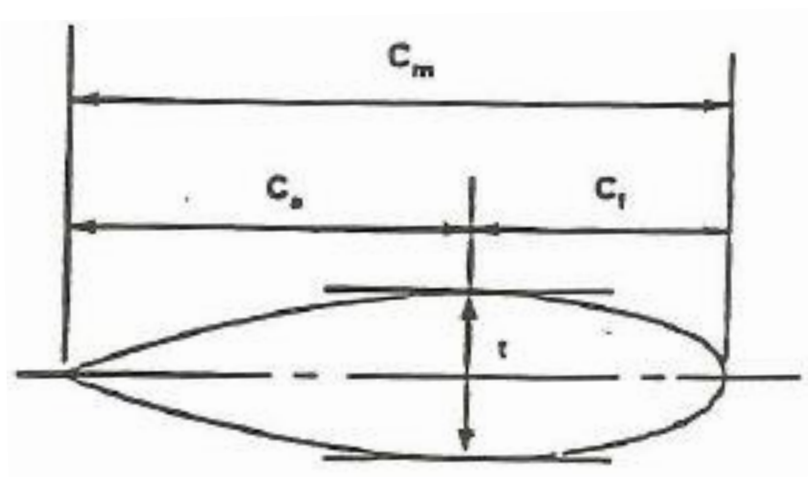
There is also resistance formula particularly for rudders:

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

For very thin rudders ; (S/A)=2c/t could be used.

(A is the maximum vertical cross-sectional area of the rudder)

Geometrical parameters in the formula:



If a control surface in consideration is a surface piercing appendage which causes spray in this case, it then results in an additional spray resistance:

$$D_{spray} = 0.24 \text{ x } 0.5\ \rho\ V^2\ t_w^{\ 2}$$

Here t_w : maximum thickness of the profile of the control surface at water surface.

Resistance of Shafts, Barrels, Struts

Cylinders which are mounted vertically, with longitudinal axis is perpendicular to the flow, are studied widely. But cylindrical appendages such as propeller shafts have non-zero angle of attacks with the flow, and this makes the flow around cylindrical appendages complicated. As a consequence, by making use of several assumptions, researchers developed empirical expressions to obtain the related resistance coefficients. The flow regimes defined for this purpose;

> Subcritical flow region ; $R_n < 10^5$

- Transitional regime; $10^5 < R_n < 5 \times 10^5$
- Supercritical flow regime ; $R_n > 5 \times 10^5$. (Relatively more stable flow is observed in this region).

Frictional resistance coefficient as function of Reynolds number:

$R_n < 5 \times 10^5$; $C_F = 1.327\, R_n^{-0.5}$

$R_n > 5 \times 10^5$; $C_F = (3.64 \log_{10} R_n - 5.6)^{-2} - (1700/R_n)$

Pressure drag coefficient (as function of Reynolds number) :

$R_n < 10^5$; $C_{Dp} = 1.1 \sin^3(\alpha)$

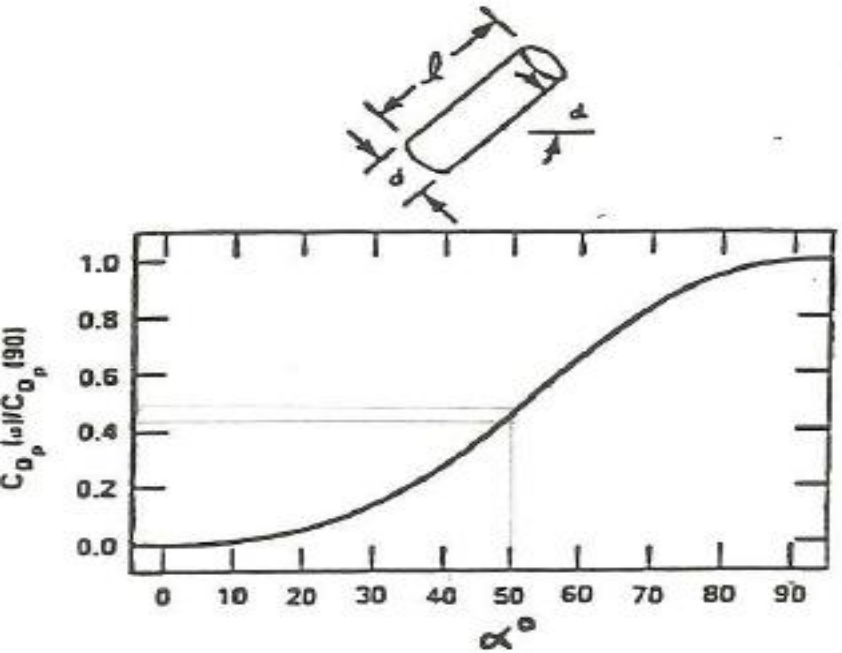
$10^5 < R_n < 5 \times 10^5$:

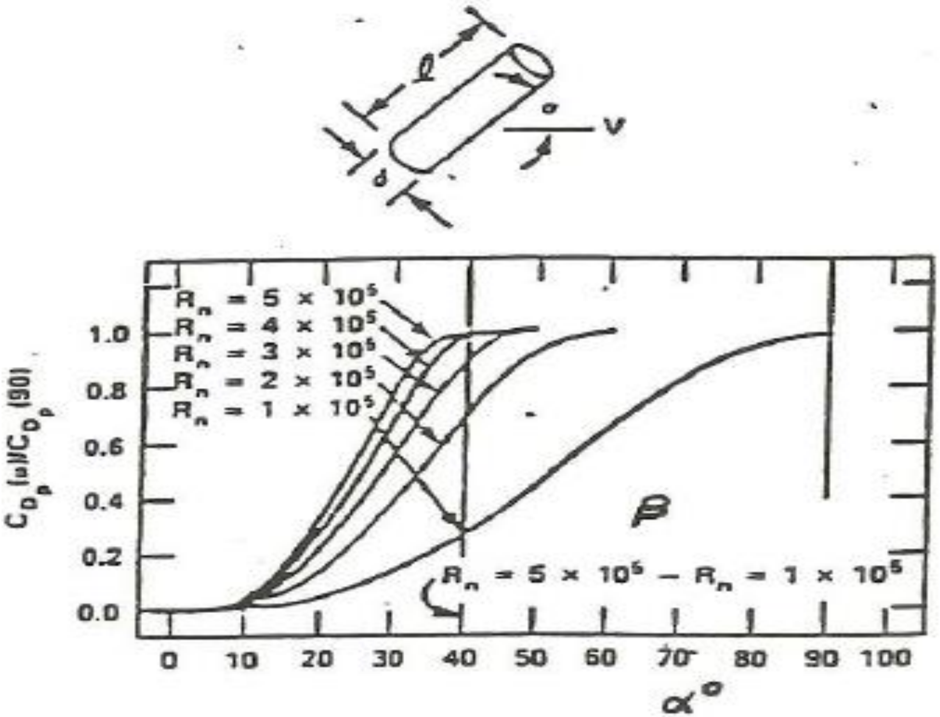
$\alpha > \beta$; $C_{Dp} = -0.7154 \log_{10} R_n + 4.677$

$\alpha < \beta$; $C_{Dp} = (-0.7154 \log_{10} R_n + 4.677)(\sin^3(1.7883 \log_{10} R_n - 7.9415))$

β (empirical); $\beta = -71.54 \log_{10} R_n + 447.7$

Graphs instead of the (previous) empirical formulae:



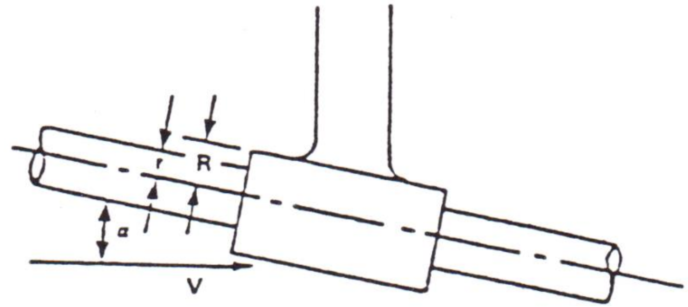


In supercritical regime ($R_n > 5 \times 10^{5}$);

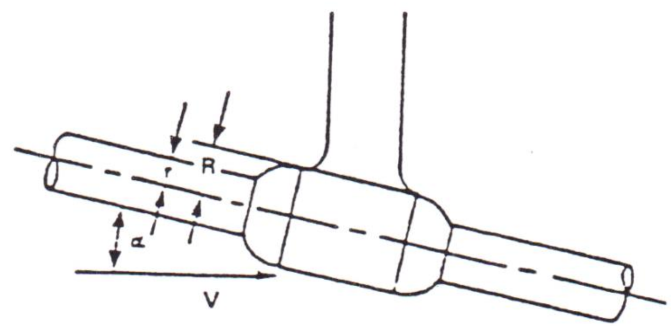
$0^{o} < \alpha < 40^{o}$; $C_{Dp} = 0.60 \sin^{3}(2.25\,\alpha)$

$40^{o} < \alpha < 90^{o}$; $C_{Dp} = 0.60$

Typical strut-barrel ends:



Strut Barrel Ends with Sharp Edges



Strut Barrel with Faired Ends

Strut-barrel ends introduce pressure difference drag coefficients as well.

Fore end pressure drag with sharp ends;

$$C_{Dfe} = 0.90 \cos^3(\alpha),$$

with faired ends;

$$C_{Dfe} = 0.10 \cos^3(\alpha).$$

Aft end pressure drag;

$$C_{Dae} = 0.029 \{C_F (S_W/S_B)\}^{0.5} \cos^3(\alpha).$$

where C_F frictional resistance coefficient of the cylindrical element, S_W; wetted surface of the cylinder, $S_B = (\pi R^2)$ is the base area of the cylinder.

Consequently the total resistance of the shaft system;

$$R_T = 0.5 \rho V^2 S_W (C_F + (C_{Dp}/\pi) + C_{Dfe} + C_{Dae})$$

Resistance of Bilge Keels

Frictional resistance coefficient for bilge keels and flat (retrofitted) skegs;

$R_n < 5 \times 10^5$; $C_F = 1.327\, R_n^{-0.5}$

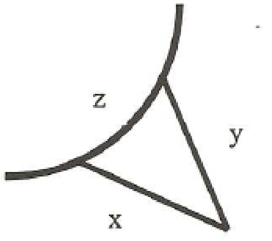
$R_n > 5 \times 10^5$; $C_F = (3.64 \log_{10} R_n - 5.6)^{-2} - (1700/R_n)$

Interference resistance coefficient:

$$C_{Dint} = 0.48\, C_F$$

Total resistance is the sum of frictional and interference resistance components. If a wedge type bilge keel is used instead of a flat bilge keel, the following expression for interference resistance is recommended:

$$C_{Dint} = 2\{1 - z / (x+y)\}$$



Some expressions and quantities required in the calculations

Boundary layer thickness; $\delta_s = 1.57\ (x)\ R_n^{-0.2667}$

(x is the distance between F.P. and the point of consideration)

Local velocity taken in the boundary layer $V_L = V_S\ (y / \delta_s)^{1/n}$

Here the power n; $n = 2.901\ R_n^{0.0478}\ (x / L)^{-0.1217}$.