Offshore Hydromechanics Module 1

Dr. ir. Pepijn de Jong

6. Real Flows part 2

Introduction

Topics of Module 1

• Problems of interest	Chapter 1
• Hydrostatics	Chapter 2
• Floating stability	Chapter 2
• Constant potential flows	Chapter 3
• **Constant real flows**	**Chapter 4**
• Waves	Chapter 5

Learning Objectives

Chapter 4

- *To understand basic real flow concepts, flow regimes in real flows, vortex induced vibrations*
- *Understand the concepts of lift and drag in real and in potential flows*
- *To apply scaling laws to analyze hydromechanic model experiments*
- *To understand the concept of ship resistance and resistance components*
- To perform basic computations on wind and current loads on floating structures
- To understand the basic concepts of ship propulsion

Ship Resistance

Resistance Extrapolation

$$R = C \cdot \frac{1}{2}\rho V^2 \cdot S$$

$$Fn = \frac{V}{\sqrt{gL}} \qquad Rn = \frac{VL}{\nu}$$

- Method of Froude

$$Rn_{model} \neq Rn_{prototype}$$
$$Fn_{model} = Fn_{prototype}$$
$$V_{prototype} = \sqrt{\alpha_L} V_{model}$$

1 measure

2 calculate: $C_f = \frac{0.075}{(\log_{10}(Rn_{model}) - 2)^2}$

3 calculate: $C_r = C_t - C_f$

$$C_{t\,model} = C_{f\,model} + C_{r\,model}$$

4 extrapolate: $C_{r\,prototype} = C_{r\,model}$

$$C_{t\,prototype} = C_{f\,prototype} + C_{r\,prototype}$$

5 calculate: $C_f = \frac{0.075}{\left(\log_{10}\left(Rn_{prototype}\right) - 2\right)^2}$

6 calculate: $C_t = C_f + C_r$

TU Delft

Ship Resistance

Resistance Extrapolation

$$R = C \cdot \frac{1}{2}\rho V^2 \cdot S$$

$$Fn = \frac{V}{\sqrt{gL}} \qquad Rn = \frac{VL}{\nu}$$

- Method of Hughes

$$Rn_{model} \neq Rn_{prototype}$$
$$Fn_{model} = Fn_{prototype}$$
$$V_{prototype} = \sqrt{\alpha_L} V_{model}$$

1 measure

2 calculate: $C_f = \frac{0.075}{(\log_{10}(Rn_{model}) - 2)^2}$

3 calculate: $C_w = C_t - C_f(1+k)$

$$C_{t_{model}} = (1+k)C_{f_{model}} + C_{w_{model}}$$

4 extrapolate: $C_{w_{prototype}} = C_{w_{model}}$

$$C_{t_{prototype}} = (1+k)C_{f_{prototype}} + C_{w_{prototype}}$$

6 calculate: $C_t = C_f(1+k) + C_w$

5 calculate: $C_f = \frac{0.075}{\left(\log_{10}\left(Rn_{prototype}\right) - 2\right)^2}$

Wind and Current loads

Forces and moments

- Forces and moments calculated using drag coefficients:

$$X = C_X(\alpha_r) \cdot \frac{1}{2}\rho V_r^2 \cdot A_T$$

$$Y = C_Y(\alpha_r) \cdot \frac{1}{2}\rho V_r^2 \cdot A_L$$

$$N = C_N(\alpha_r) \cdot \frac{1}{2}\rho V_r^2 \cdot A_L \cdot L$$

- X, Y, N Longitudinal, lateral and horizontal wind/current moment
- C_X, C_Y, C_N Drag coefficients dependent on relative wind angle
- ρ Density (of air for wind, of water for current)
- A_T, A_L Frontal and lateral projected area (above water for wind, below for current)
- L Length of ship
- V_r, α_r Relative wind speed and angle

Wind and Current loads

Apparent Wind and True Wind

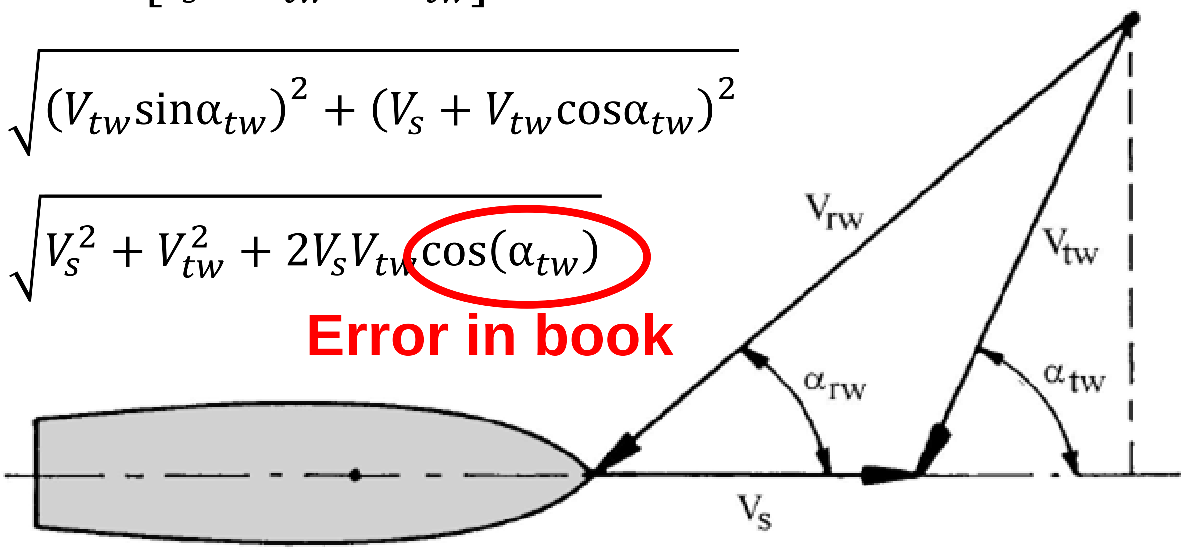
- Take into account ship's own velocity (for instance important for sailing yachts or cruise vessels)

$$\alpha_{rw} = \arctan\left[\frac{V_{tw}\sin\alpha_{tw}}{V_s + V_{tw}\cos\alpha_{tw}}\right]$$

$$V_{rw} = \sqrt{(V_{tw}\sin\alpha_{tw})^2 + (V_s + V_{tw}\cos\alpha_{tw})^2}$$

$$V_{rw} = \sqrt{V_s^2 + V_{tw}^2 + 2V_sV_{tw}\cos(\alpha_{tw})}$$

Error in book



Wind and Current loads

Values for Drag Coefficients

- Difficult to calculate: viscous effects significant, as well as flow separation
  - Wind loads: done with wind tunnel model testing
  - Current loads: done with towing tank testing or testing in basin with current simulation
- Based on previous performed model testing:
  - Empirical estimation methods available (for instance Remery and Van Oortmerssen, 1973)

Wind and Current loads

Wind Shear Profile

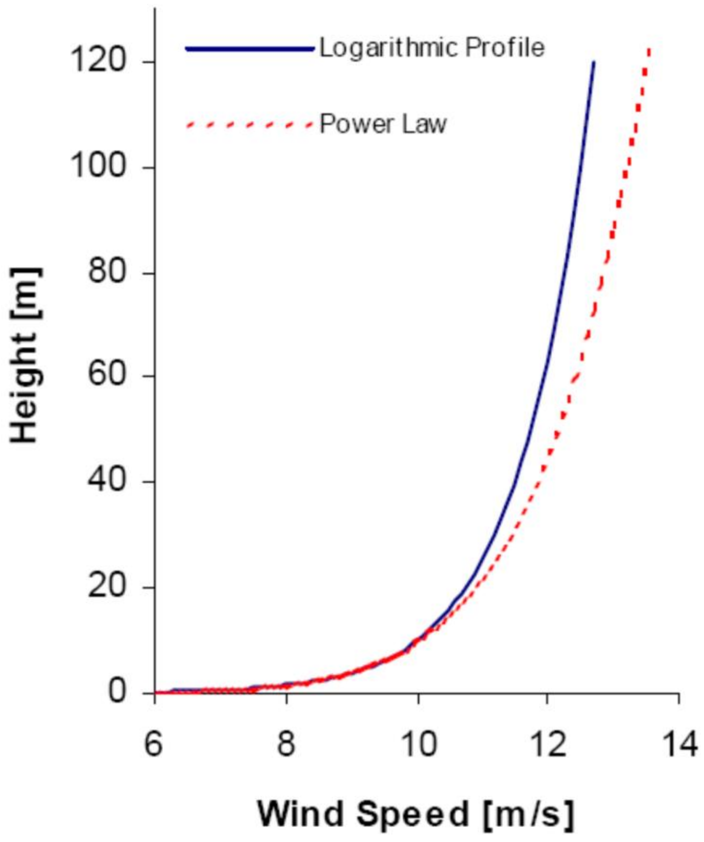
$$V_w(z) = V_{wrefheight} \cdot \left(\frac{z}{z_{refheight}}\right)^{\alpha_{shear}}$$

- Typical values:

$$z_{refheight} = 10m$$

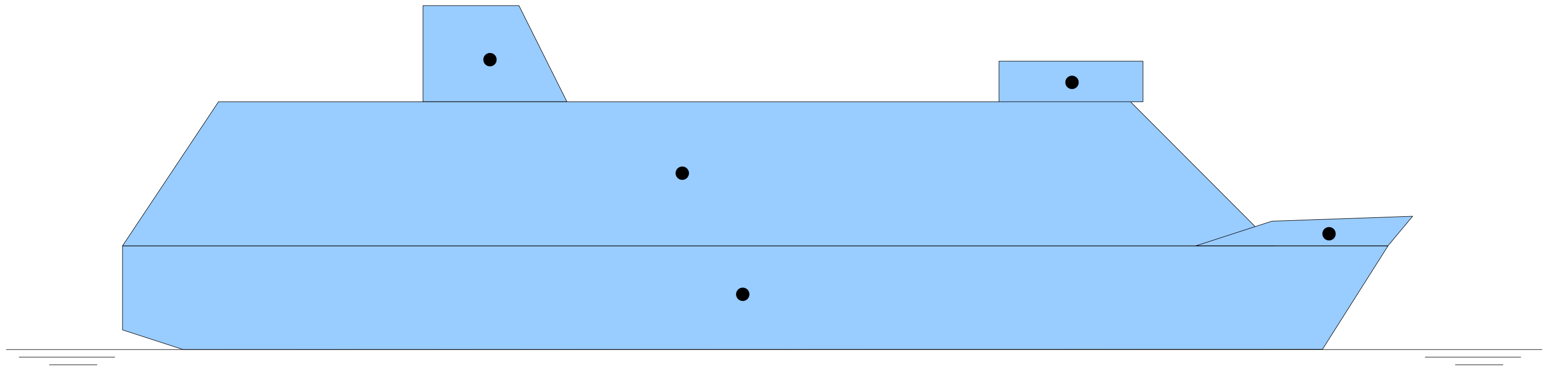
$$\alpha_{sea} = 0.11$$

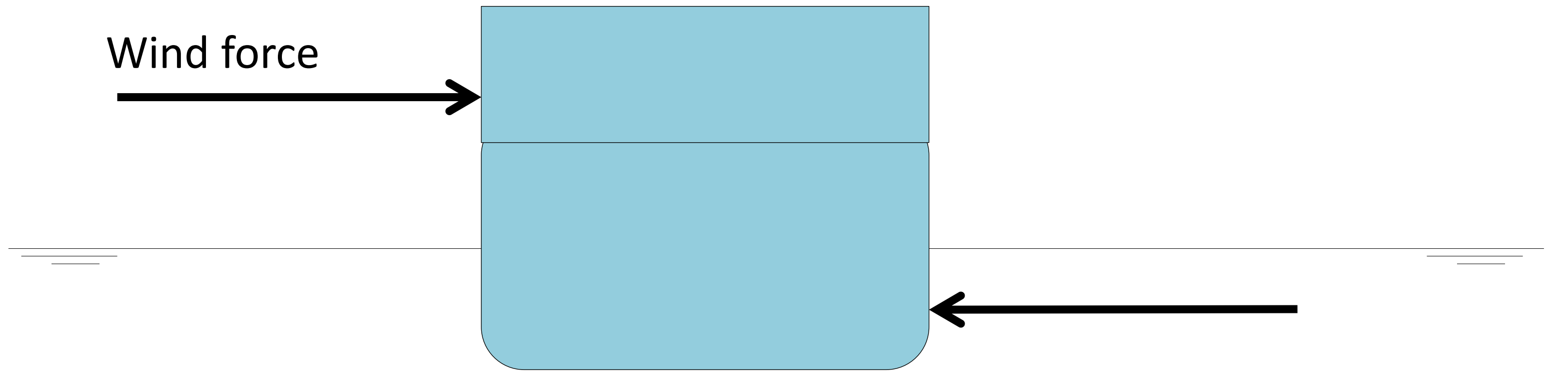
$$\alpha_{land} = 0.16$$



Wind and Current loads

Lateral area and force balance





Thrust and Propulsion

Topics

- Propulsor and propulsion efficiency
- Propulsion systems
- Propeller geometry and flow around blades
- Propeller in open water
- Interaction propeller and ship
- Cavitation
- Propeller design

Thrust and Propulsion

Propulsor

- Converts energy delivered by engine into thrust
- Engine:
  - Diesel
  - Electric
  - Steam turbine
  - Nuclear (combined with steam turbine)
  - Gas turbine
- Generally propulsor converts **torque** and **rotation** into **thrust** and **translation**

TU Delft

Thrust and Propulsion

Propulsor

- Efficiency of Propulsor:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_E}{P_D} = \frac{T \cdot V_e}{Q \cdot 2\pi n}$$

  - η Efficiency propulsor
  - P_D Delivered power (by shaft to propulsor)
  - P_E Effective power (power effectively used for propulsion)
  - Q Delivered torque (by shaft to propulsor)
  - n Revs. per time of propulsor
  - T Thrust delivered by propulsor
  - V_e Mean water velocity entering at propulsor

Thrust and Propulsion

Propulsion Systems – Fixed Pitch Propeller

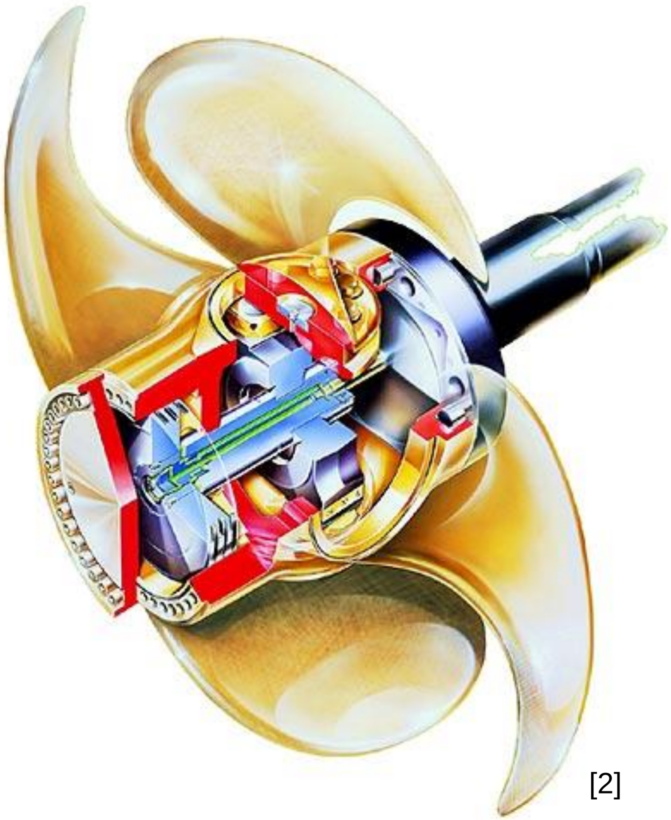
- Lift is generated on the rotating blades (like airfoil sections)
- Part of the lift produces a longitudinal force: thrust
- Rotation and torque → Thrust
- Geometry determined by:
  - Efficiency
  - Available space
  - Cavitation and resonance
- Most common type of propeller


[1]

Thrust and Propulsion

Propulsion Systems – Controllable Pitch Propeller

- Works identical to FPP
- Added benefit: efficient operation at more than one design condition
  (For instance free running and towing of tug)
- Also: enables the use of a constant shaft rotational speed
- Also: easier maneuvering (easy reversal of thrust)
- Still one optimum design condition
- Efficiency losses due to larger hub



[2]

Thrust and Propulsion

Propulsion Systems – Ducted Propeller

- Works identical to FPP
- Increases efficiency at high propeller loadings (large thrust at low forward speed)
- Often used on tugs, fishing ships, etc.
- Sometimes used to modify inflow on propeller

[3]

Thrust and Propulsion

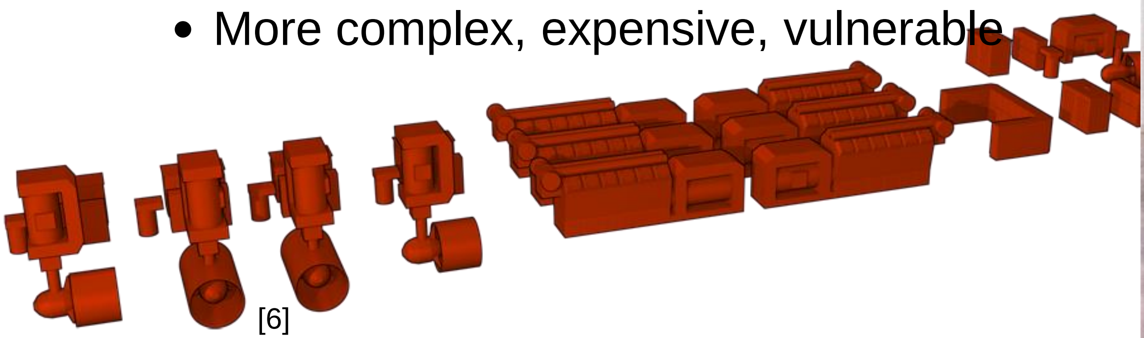
Propulsion Systems – Thrusters and podded propellers

- Works identical to FPP
- Increased flexibility
- Added functionality for steering
- Dynamic Positioning
- More complex, expensive, vulnerable
- Less efficient?

Thrust and Propulsion

Propulsion Systems – Thrusters and podded propellers

- Works identical to FPP
- Increased flexibility
- Added functionality for steering
- Dynamic Positioning
- More complex, expensive, vulnerable



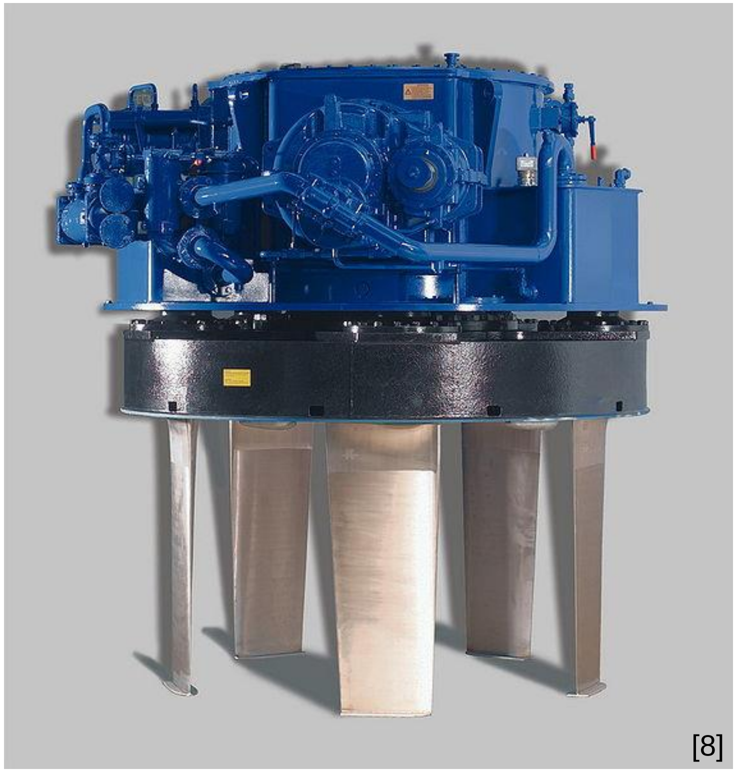
[6]

[7]

Thrust and Propulsion

Propulsion Systems – Voith-Schneider Propellers

- Set of vertical foils mounted on a circular rotating disk
- By controlling the angle of attack of each blade during the rotation a thrust force can be generated in any direction in horizontal plane
- Very maneuverable at the cost of complexity and lower efficiency
- Used mostly in harbor tugs



[8]

Thrust and Propulsion

Propulsion Systems – Voith-Schneider Propellers

- Set of vertical foils mounted on a circular rotating disk
- By controlling the angle of attack of each blade during the rotation a thrust force can be generated in any direction in horizontal plane
- Very maneuverable at the cost of complexity and lower efficiency
- Used mostly in harbor tugs


[9]

Thrust and Propulsion

Propulsion Systems – Voith-Schneider Propellers

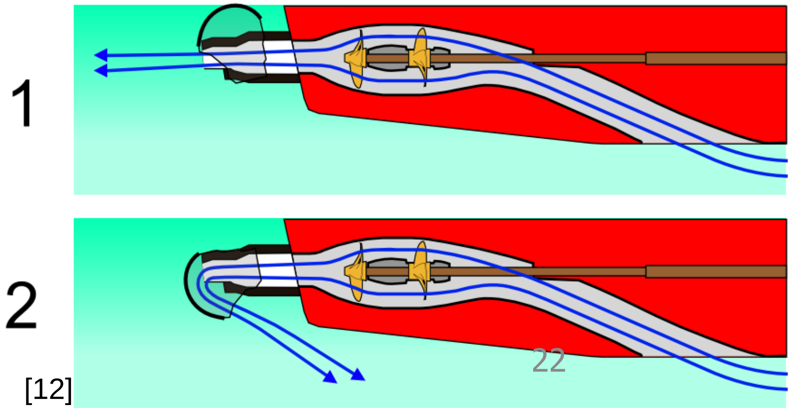
- Se
  ci
- By
  ea
  fo
  in
- Ve
  co
- Us


[10]

Thrust and Propulsion

Propulsion Systems – Water Jets

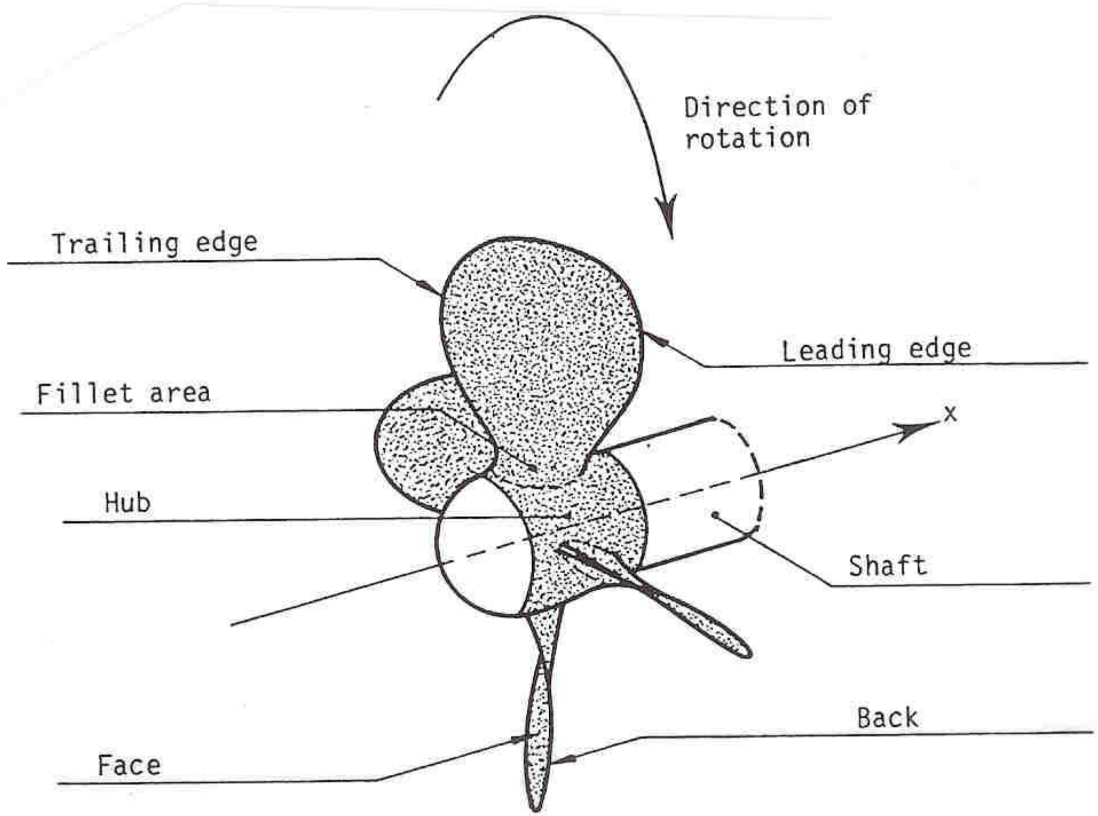
- Basically pump inside ship, or propeller mounted in a tunnel
- Advantages when propeller is too vulnerable (shallow water or lots of objects in the water)
- Or when propeller is dangerous (rescue vessels picking up people)
- Nozzle can be steered: no rudders
- Viscous losses in tunnel: lower efficiency
- At very high speeds more practical and efficient than propeller



[12]

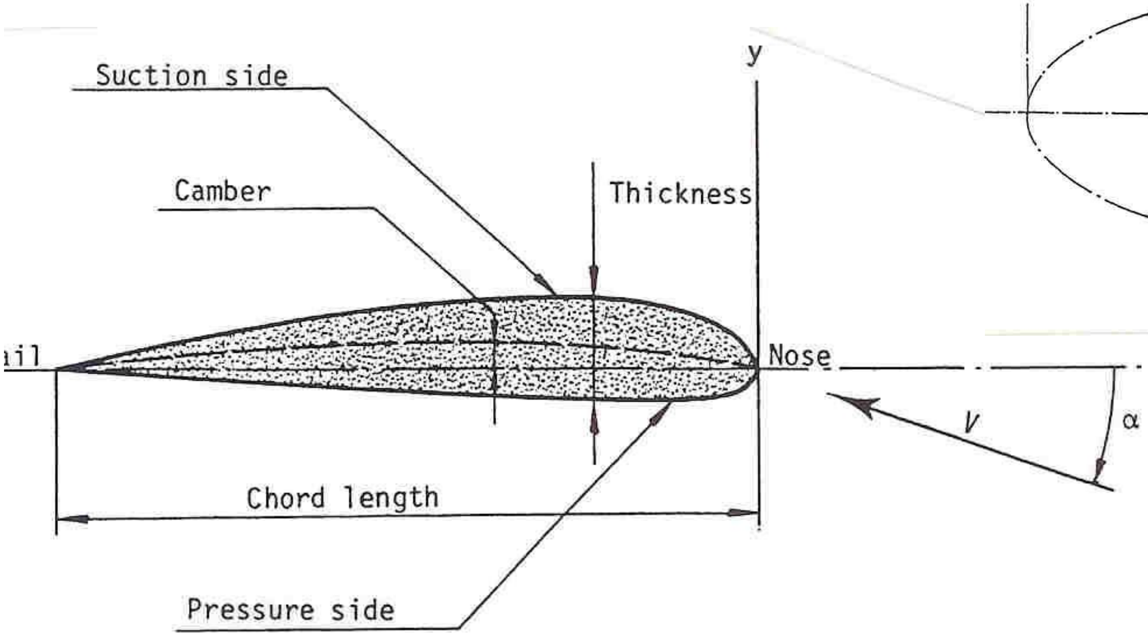
Thrust and Propulsion

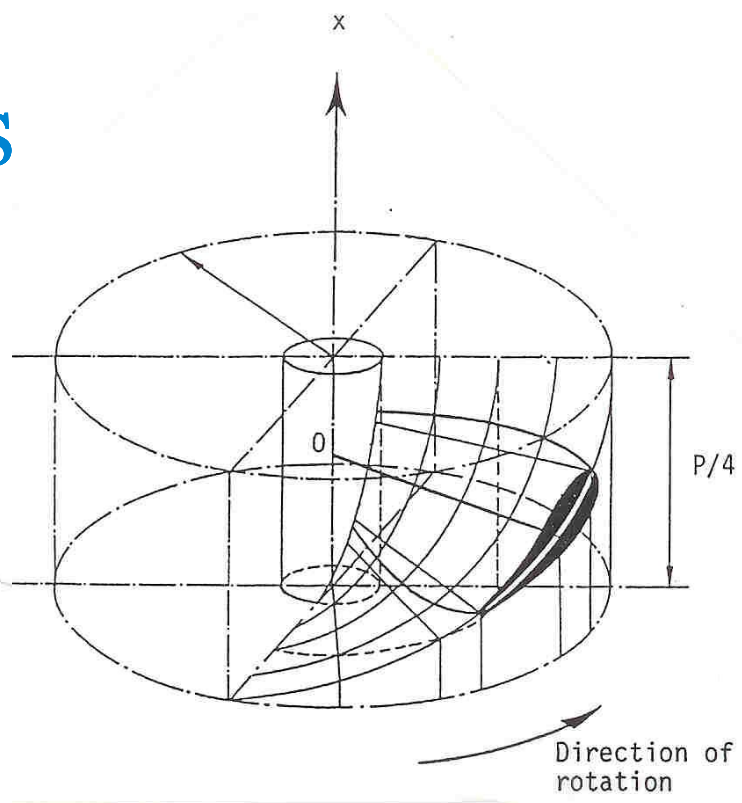
Propeller Geometry



Thrust and Propuls

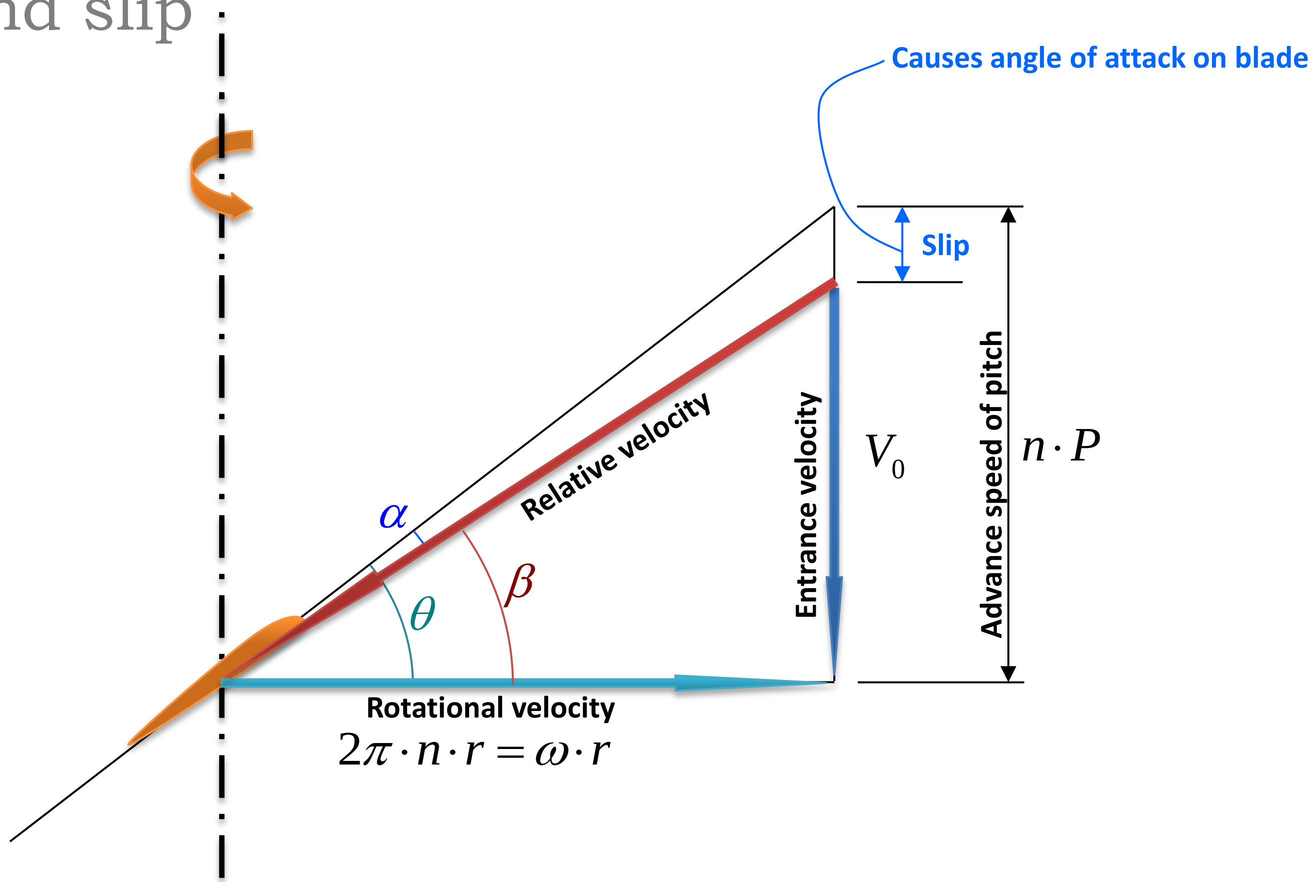
Propeller Geometry





Thrust and Propulsion

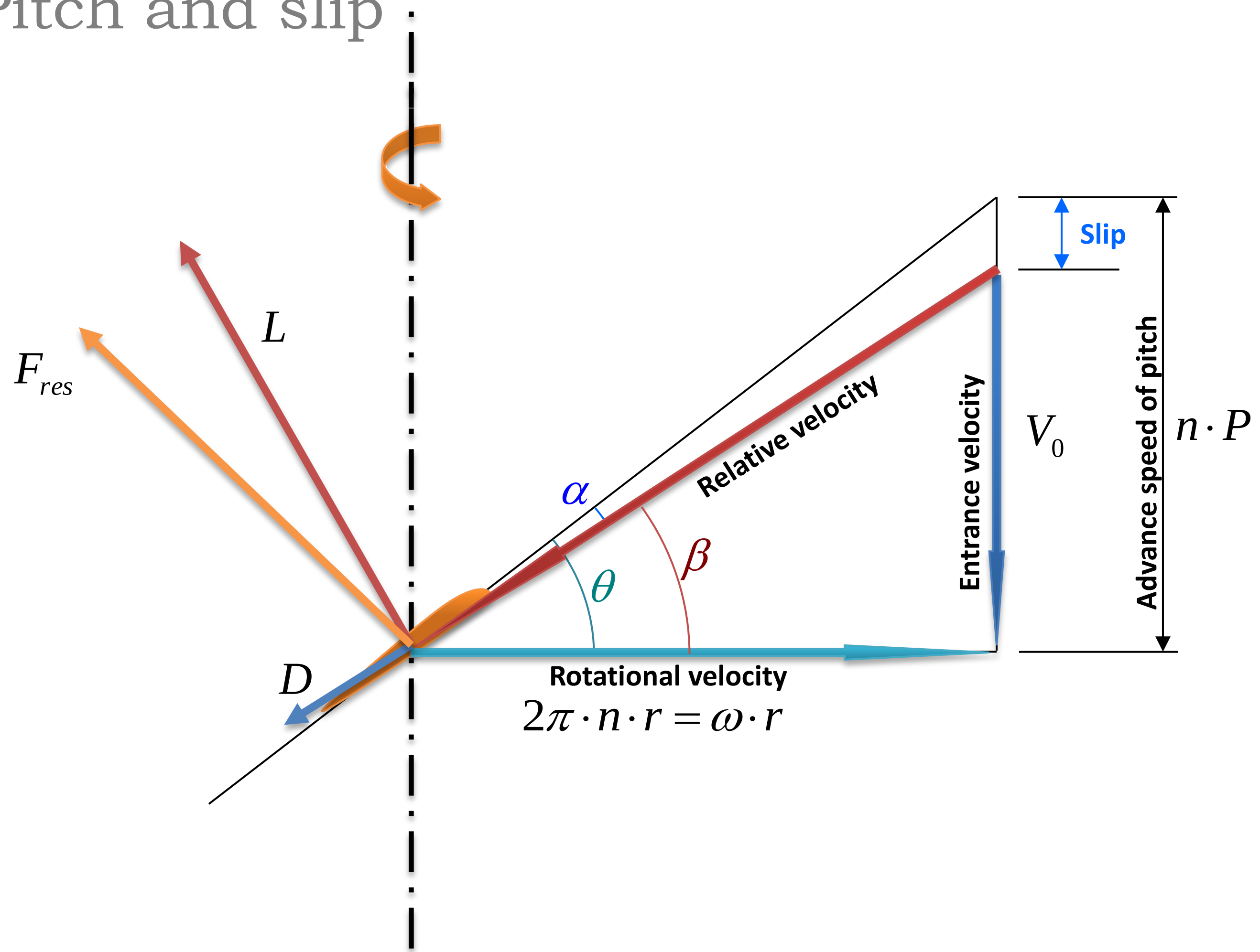
Pitch and slip



- Definition pitch angle: $\theta = \arctan \frac{P}{2\pi r}$ Significant radius: $r_{sig} = 0.7\text{R}$

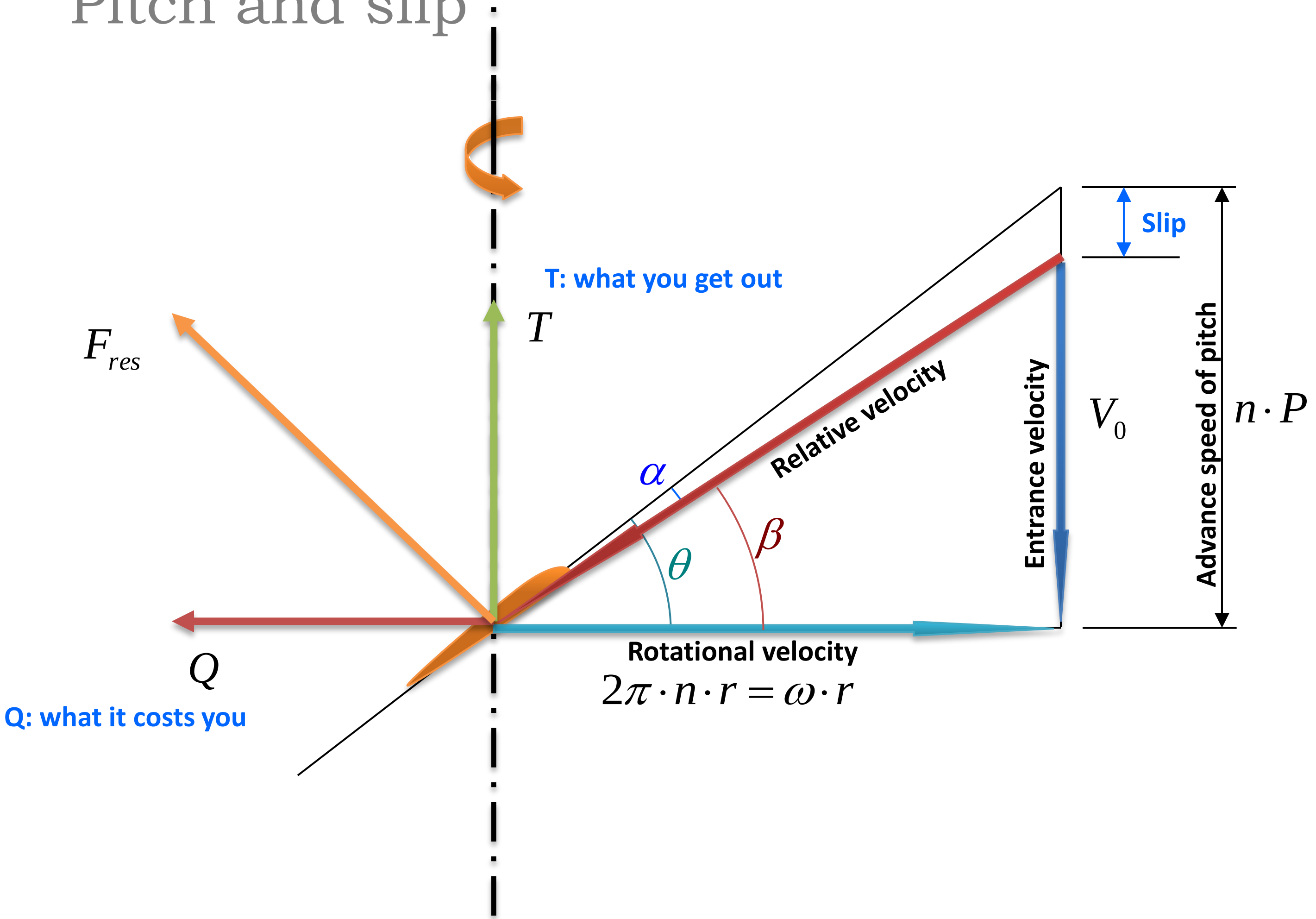
Thrust and Propulsion

Pitch and slip



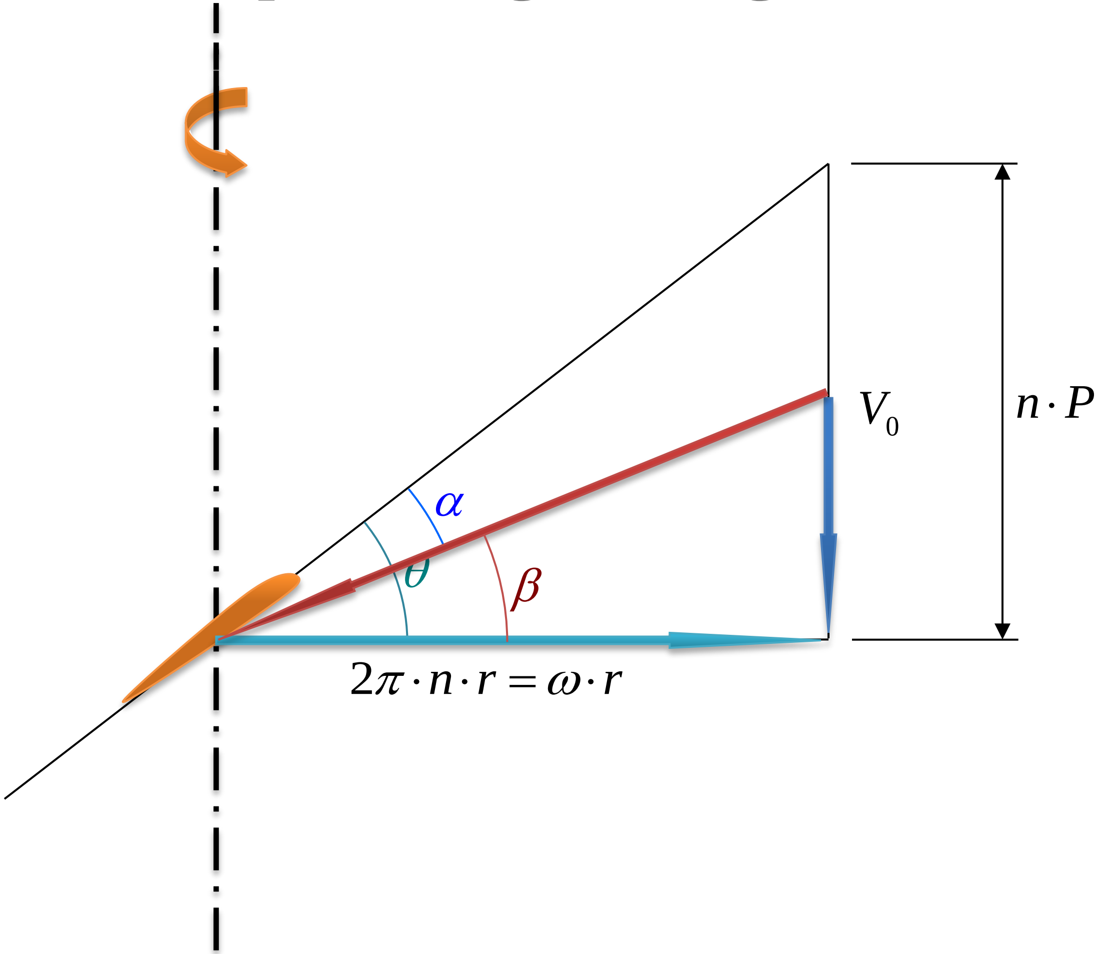
Thrust and Propulsion

Pitch and slip



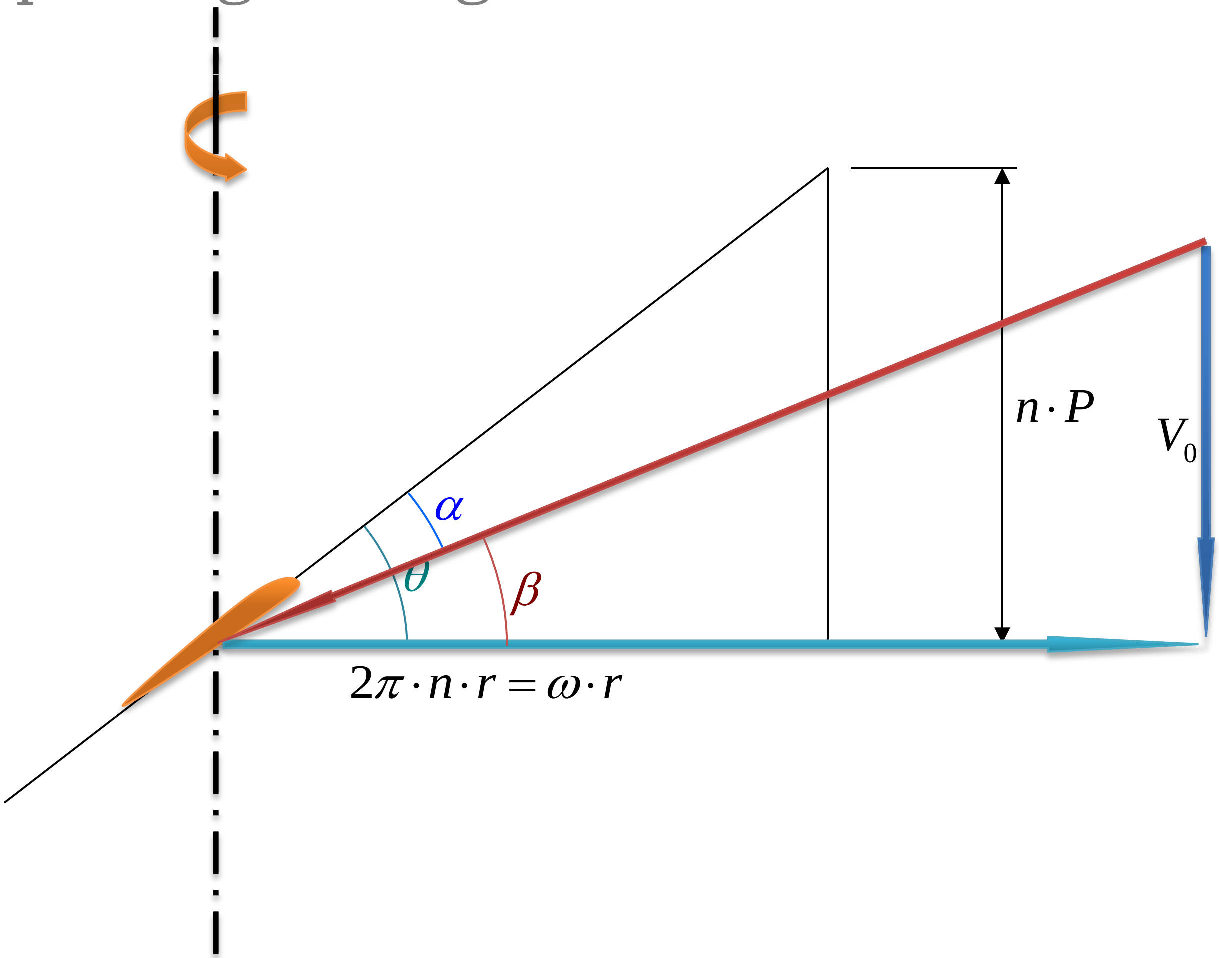
Thrust and Propulsion

Lower forward speed: higher angle of attack



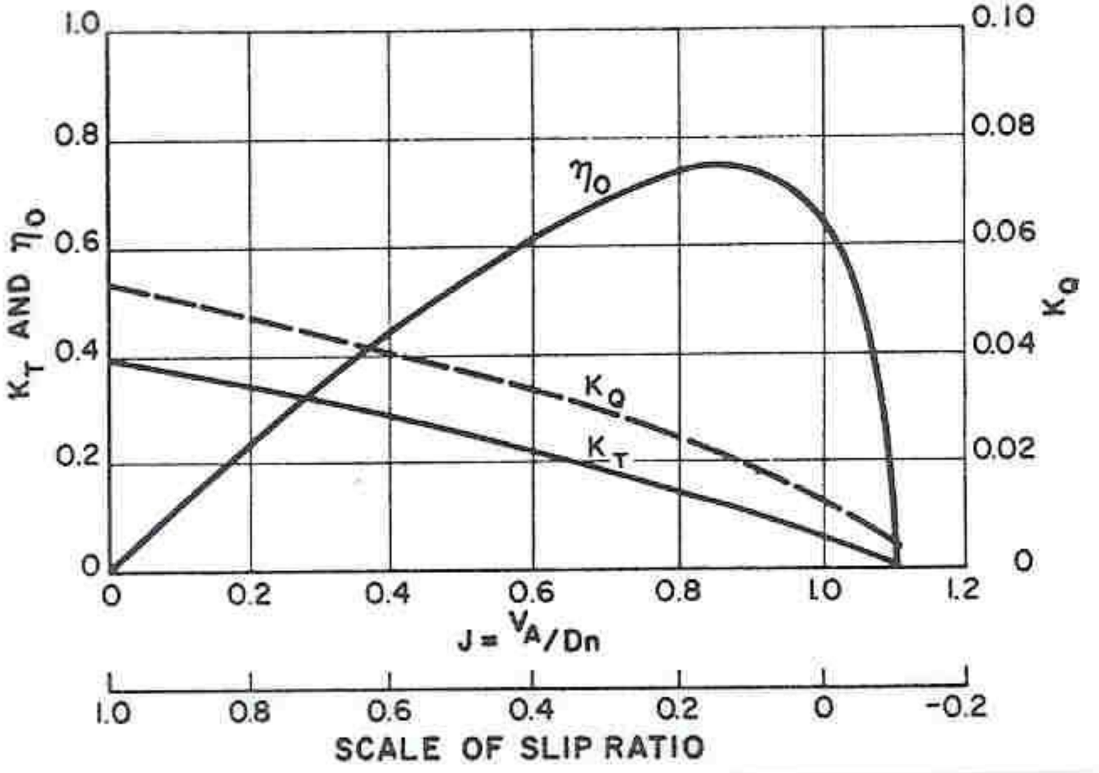
Thrust and Propulsion

Higher rpm: higher angle of attack



Thrust and Propulsion

Open Water Characteristics



- Hydrodynamic pitch angle:

$$\beta = \arctan \frac{V_e}{0.7\pi \cdot nD}$$

- Advance Ratio:

$$J = \frac{V_e}{nD}$$

- Thrust coefficient:

$$K_T = \frac{T}{\rho D^4 n^2}$$

- Torque coefficient:

$$K_Q = \frac{Q}{\rho D^5 n^2}$$

Thrust and Propulsion

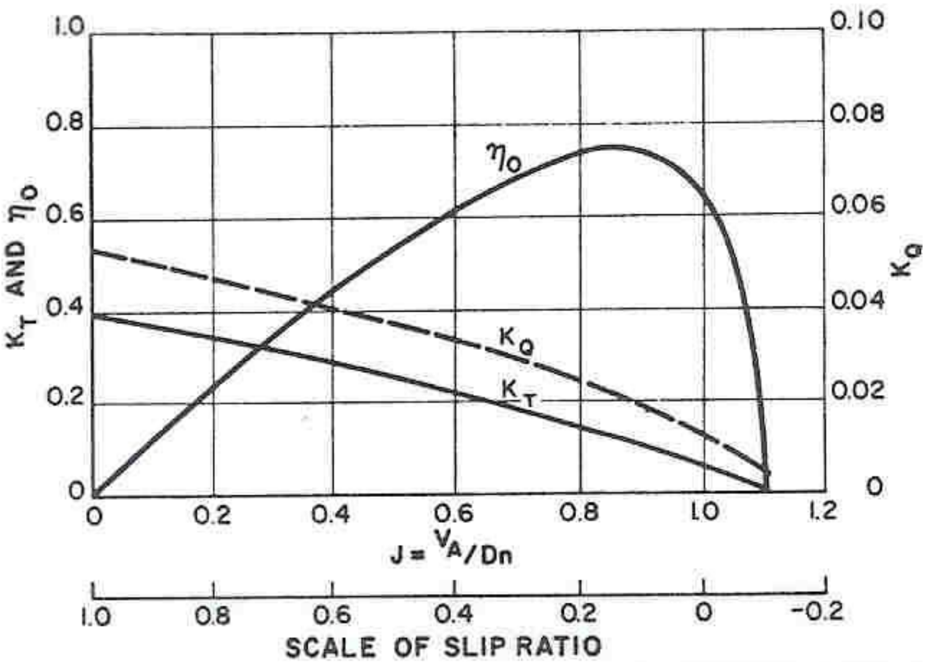
Open Water Characteristics

- Obtained in open water tests with propellers in towing tank

- Open Water Efficiency:

$$\eta_0 = \frac{P_{out}}{P_{in}} = \frac{P_E}{P_D} = \frac{T \cdot V_e}{Q \cdot 2\pi n}$$

$$\eta_0 = \frac{K_T}{K_Q} \cdot \frac{J}{2\pi}$$



Thrust and Propulsion

Interaction Propeller-Hull

1. Influence ship on inflow propeller:
   - Nominal inflow less than ship speed
   - Expressed by nominal wake fraction:

$$V_e = (1 - w_n) \cdot V_s$$

- V_s is the ship speed, V_e the nominal inflow velocity on the propeller

- Typical values:

$$w_n \approx 0.5 \cdot C_B - 0.05$$

Thrust and Propulsion

Interaction Propeller-Hull

2. Influence propeller on pressure on ship:
   - Relative reduction of pressure behind ship
   - Expressed in thrust deduction fraction:

$$R = (1 - t) \cdot T$$

- T is the necessary thrust force, R the ship resistance without prop

- Typical values:

$$t \approx 0.6 \cdot w_n$$

TU Delft

Thrust and Propulsion

Interaction Propeller-Hull

3. Relative Rotative Efficiency:

$$\eta_R = \frac{Q_0}{Q}$$

- Difference in torque in wake behind ship and in open water
  - 0.98 – 1.00 for single-screw ships
  - 1.00 – 1.02 for twin-screw ships

Thrust and Propulsion

Interaction Propeller-Hull

- Total Propulsive Efficiency:

$$\eta_T = \frac{R \cdot V_s}{Q \cdot 2\pi n}$$

$$\eta_T = \frac{T(1-t) \cdot \dfrac{V_e}{(1-w_n)}}{\dfrac{Q}{Q_0} \cdot Q_0 \cdot 2\pi n}$$

$$\eta_T = \frac{T \cdot V_e}{Q_0 \cdot 2\pi n} \cdot \frac{1-t}{1-w_n} \cdot \frac{Q_0}{Q}$$

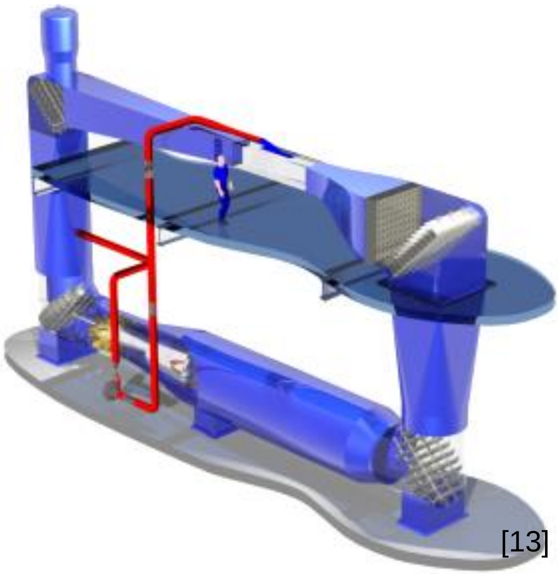
$$\eta_T = \frac{K_T \cdot J}{K_Q \cdot 2\pi} \cdot \frac{1-t}{1-w_n} \cdot \frac{Q_0}{Q} = \eta_0 \cdot \eta_H \cdot \eta_R$$

Thrust and Propulsion

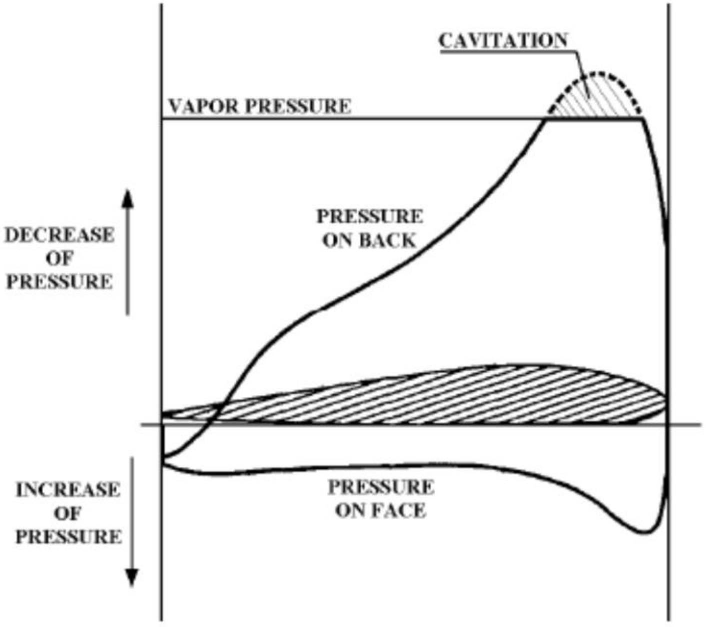
Cavitation

- Cavitation occurs when:

  local pressure < vapor pressure



[13]

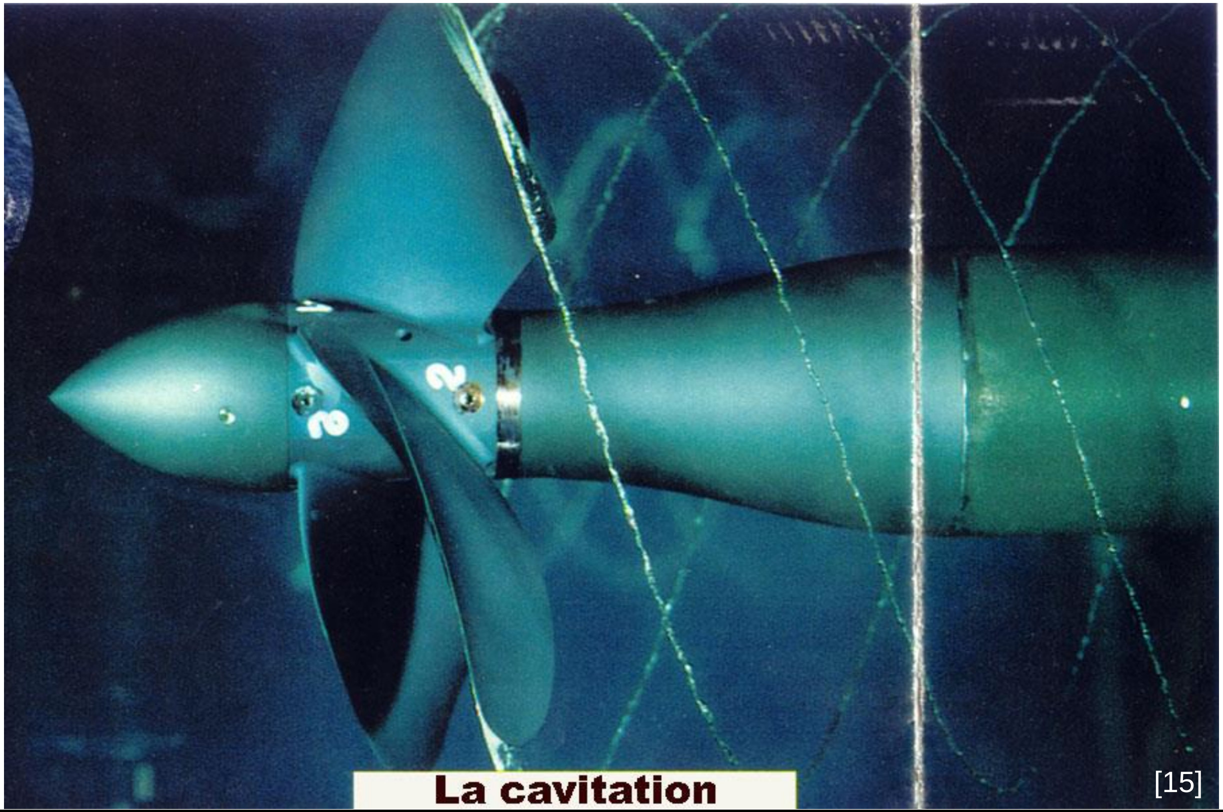


[14]

Thrust and Propulsion

Cavitation

- Cavitation can cause noise, vibration and damage



Thrust and Propulsion

Cavitation

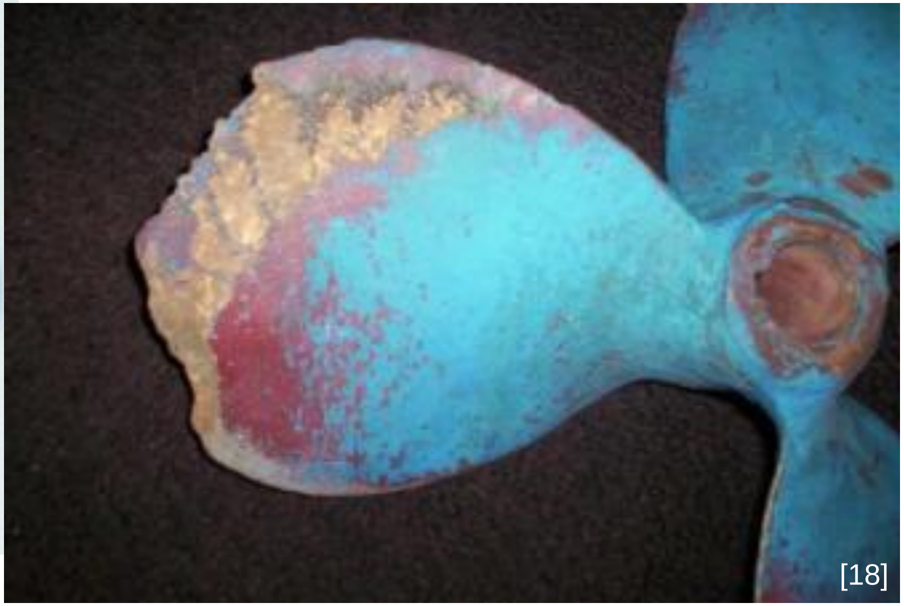
Thrust and Propulsion

Cavitation


[13]

Thrust and Propulsion

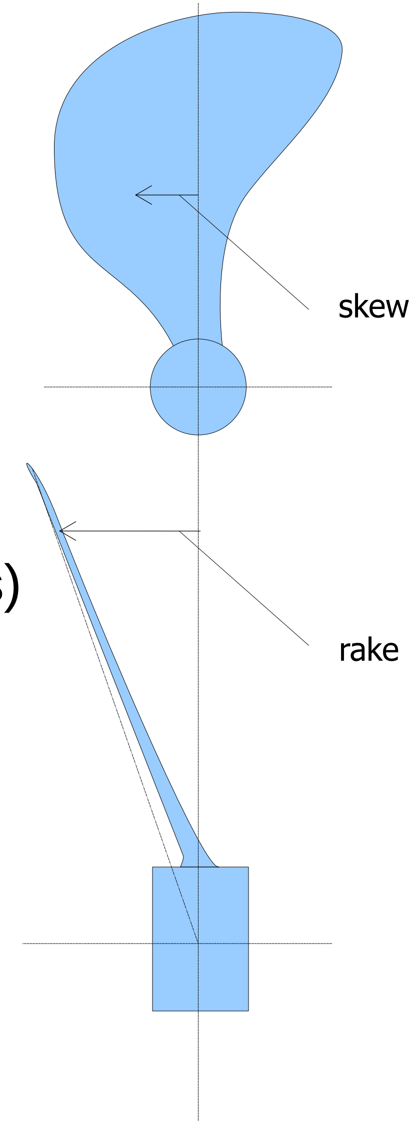
Cavitation



Thrust and Propulsion

Design considerations Propellers

- Necessary thrust (dependent on resistance, hull design)
- Blade loading (dependent on thrust, blade area, pitch, strength)
- Space (dependent on hull design, design restrictions)
- Resonance frequency (dependent on structural design, number of blades, rotation rate)
- Cavitation
- Parameters: diameter, blade area, rotation rate, number of blades, blade shape (pitch, skew, rake)



Sources images

[1] Fixed Pitch propeller, source: unknown
[2] Controllable pitch propeller, source: unknown
[3] Kort Nozzle, source: Langemachinery Co. Ltd
[4] Four 250 ton Rolls-Royce Mermaid™ electric propulsion pods, source: unknown
[5] The podded propulsion system on the ferry Nils Holgersson, source: ship-technology.com
[6] Helix Producer I propulsion system, source: ntd-offshore.com
[7] Full rotating propeller, source: Hiroaki International (HK) Co., Ltd.
[8] Voith Schneider Propeller (VSP), source: Voith Turbo Pte Ltd., Singapore
[9] Voith Turbo, source: heidenheim.voith.com
[10] Non-virtual Voith Schneider propeller, source: Voith Schneider
[11] Kamewa waterjets employed by Rolls-Royce, source: Naval Technology
[12] Hydrojet scheme 1- Ahead 2- Astern, source: Tosaka/Wikimedia Commons
[13] Source: unknown
[14] Propeller Dynamometers, source: Cussons Marine
[15] La cavitation, source: http://zone.sousmarins.free.fr/Sous-marins%20et%20cavitation.htm
[16] Cavitating propeller in a water tunnel experiment at the David Taylor Model Basin, source: Wikimedia Commons
[17] Cavitation damage evident on the propeller of a personal watercraft. Note the concentrated damage on the outer edge of the propeller where the speed of the blade is fastest, source: Axda0002/Wikimedia Commons
[18] Cavitation, source: unknown