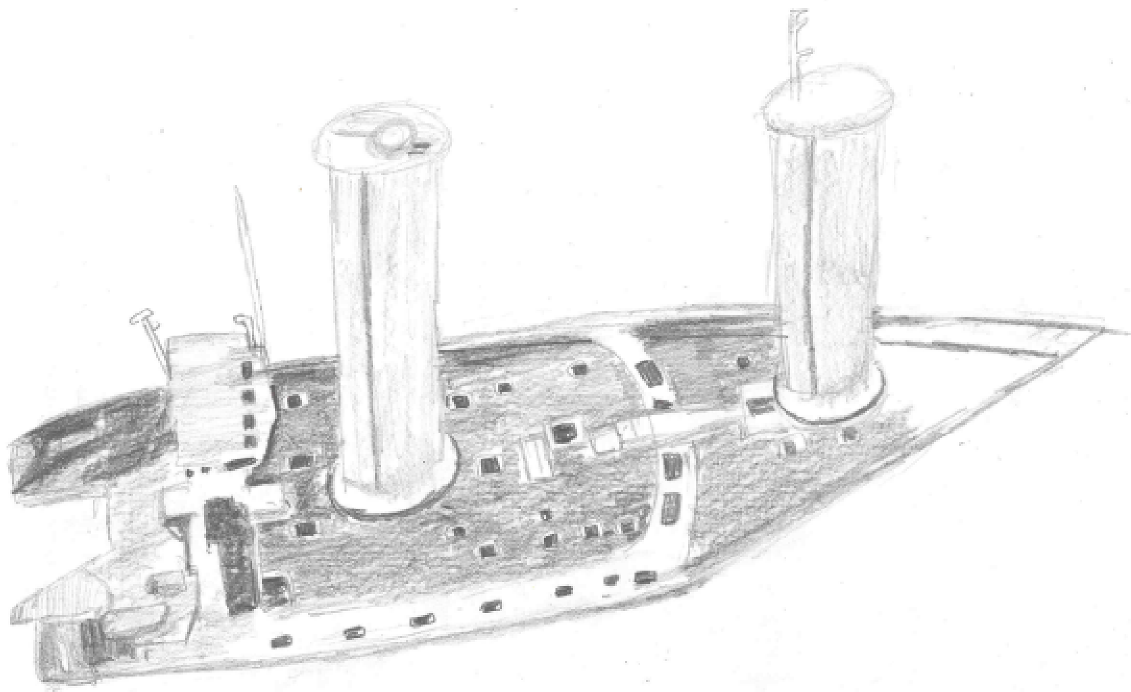
ASSIGNMENT A - APPLICATION OF IRROTATIONAL FLOW MOTION OF IDEAL FLUID TO THE DESIGN OF THE ALCYONE 2

Fig. 1 - Sketch of the Alcyone at sea



Introduction

The assignment includes 2 parts : a study of an auxiliary propulsion system for a ship, and the analysis of the hydrofoil system of the same boat. It is based upon the characteristics of a real ship, the "Alcyone", built by the Equipe Cousteau (see Chapter 4, section 3.7) (Fig. 1 & 2). It is proposed to design a new version of the ship, called the "Alcyone 2". Appendix 1 provides information on naval hydrodynamics (drag on ship, vocabulary, units). Appendix 2 gives the characteristics of and summarises the principle of the turbosail of the first "Alcyone".

You consider the design of the new ship "Alcyone 2" that will be built on the Gold Coast for the Jacques COUSTEAU Foundation. The new boat will be 25 meters long, 7 meters wide and the maximum draught (or draft) will be 1.5 meters (excluding the foils). The maximum weight will be 260 tonnes. The ship is designed with two hydrofoils below the hull to reduce the drag force (Fig. 3). Each foil is a flat plate with a inverted T-shape. Auxiliary propulsion is supplied by 2 masts, each being a rotating cylinder of radius 0.75 m and 9 metres height. The first mast is located 4 metres from the bows and the second mast is 6 metres from the stern. The maximum speed is expected to be 25 knots.

Figure 2 - The Alcyone arriving in New York, USA (Courtesy of Equipe Cousteau, France)

Hypothesis

You will assume that the flow around the hull of the ship is a two-dimensional and irrotational flow of ideal fluid. Typical sea temperature is 15 Celsius.

You will assume that the wind flow around the masts is a two-dimensional and irrotational flow of ideal fluid. The atmospheric conditions are : $P = P_{atm} = 10^5$ Pa ; T = 20 Celsius.

<u>Question 1 - Design of the hull</u>

You will design the hull with a shape of a Rankine body (obtained for the maximum speed).

(a) Apply the theorem of superposition to obtain the stream function and the velocity potential of the resulting flow pattern. Explain the basic flow patterns used to obtain the Rankine body. Define the complete characteristics of the Rankine body. Give the numerical results of these main parameters, in SI units. On a sketch, explain the origin and the directions of the axes used to define the flow pattern. Show the direction of motion of the ship on the sketch.

(b) On graph paper, draw the complete flow net. Indicate **<u>clearly</u>** on the sketch the location of the free surface and the contour of the hull. Using the scale : 1 cm = 1 m, draw the flow net with the appropriate value of $\Delta\psi$. Indicate the values of ψ and ϕ of each streamline and equipotential line.

(c) What is the maximum velocity on the hull ? Explain and justify your answer.

(d) Neglecting the Drag force due to the waves, compute the drag force on the ship hull. Explain your calculations in detail. Justify your choice(s).

Note : A formula for the drag coefficient is given in Appendix 1.

Question 2 - Design of the hydrofoils

Two identical hydrofoils will be installed 3 metres below the bottom of the hull. Each hydrofoil is a flat plate of 0.9 m chord length[1]. You will design the foils for the maximum speed.

The effects of the hull on the flow past the foils will be neglected.

(a) In a text book on hydrofoils, you read that a hydrofoil is mounted with an angle of attack varying from 5 to 20 degrees. You will study the flow past a flat hydrofoil at angle of attack[2] **15 degrees**. On a sketch, show the hull of the ship, the position of the foils, the direction of motion of the ship and the angle of attack of each foil.

(b) On graph paper (A4 size), draw the complete flow net for the flow past a flat plate at angle of attack 15 degrees. Assuming that the discharge between two streamlines is $\Delta q = 3$ m^2/s, indicate what value you choose for $\Delta\psi$. Using the scale : 1 cm = 0.1 m, draw the flow net with the appropriate value of $\Delta\psi$. Indicate on the graph the direction of motion of the foil (i.e. the flat plate).

(c) Far away (from the foil), the pressure is equal to the atmospheric pressure plus 4.5 metres of water. Using the flow net construction, determine the velocity and pressure distributions on each side of the foil : i.e. the velocity and the pressure at the locations **0.1125, 0.3375, 0.5625 and 0.7875 metres** from the leading edge of the foil. Explain carefully in words your method.

(d) Using the flow nets, compute the Lift force per unit width of hydrofoil. Explain your calculations and use the appropriate SI units.

(e) The hydrofoils are introduced to lift the hull totally above the water surface at maximum speed. (i) Compute the width of each foil required to lift the ship at maximum speed and maximum weight. (ii) What is the total lift force resulting from the two hydrofoils ? Neglect the drag induced by the foils.

The hydrofoils are replaced by two NACA2415 profiles with the performances shown in Figure 6-5.

(f) Calculate the total lift force at maximum speed for a 3º angle of incidence. What is the drag force on the foils ?

(g) Calculate the optimum angle of incidence and the foil width to lift the hull totally above the water surface at maximum speed. That is, the optimum angle of incidence is that for which the ratio of lift to drag forces is maximum.

Question 3 - Auxiliary propulsion

You will now consider the auxiliary propulsion system consisting of two circular rotating cylinders.

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[1] Length of the straight line connecting the nose to the trailing edge of the foil.

[2] Angle between the approaching flow velocity vector and the chordline.

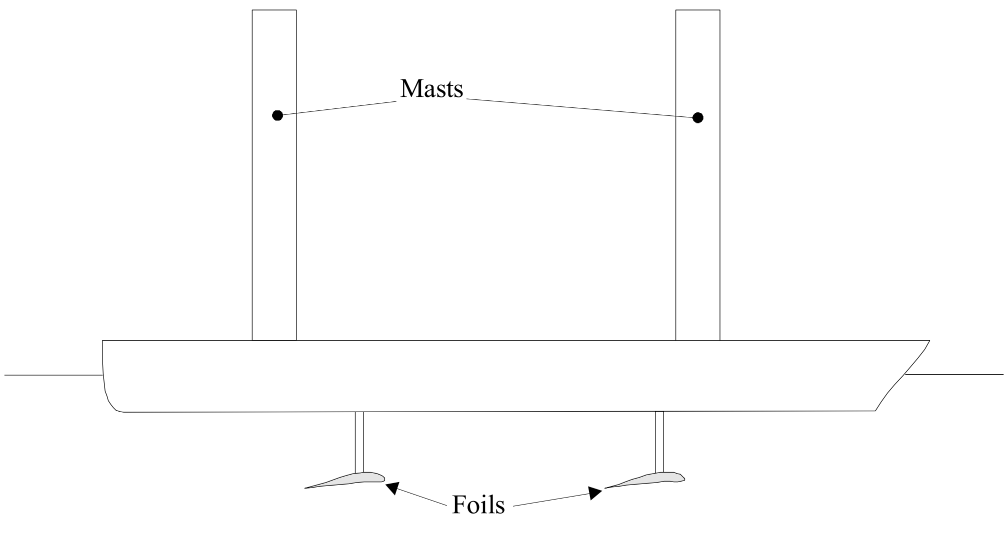
(a) Apply the theorem of superposition to describe the flow past a rotating cylinder. Give the stream function and velocity potential of the flow around a rotating cylinder as a function of the uniform flow velocity V_o, the cylinder radius R and the speed of rotation of the cylinder ω.

(b) Give the expression for the velocity at any point on the surface of the cylinder as a function of the uniform flow velocity V_o, the cylinder radius R and the cylinder's rotational speed ω. What is the pressure distribution at any point on the surface of the cylinder as a function of the uniform flow velocity V_o, the cylinder radius R and the speed of rotation of the cylinder ω? Integrate the pressure distribution around the cylinder to obtain the expression of the lift force and drag force as a function of the uniform flow velocity V_o, the cylinder radius R and the speed of rotation of the cylinder ω. Detail and justify your calculations.

(c) Sketch the flow pattern(s) of the flow past a rotating cylinder. Indicate the location of the stagnation point(s). If there are several cases, sketch the flow pattern for each case and indicate the flow conditions.

(d) In operation, the speed of rotation of the cylinder will be 50 revolutions per minute. Assume that the absolute wind speed is 30 knots, blowing perpendicularly to the ship direction, and that the ship is at maximum speed. On a sketch, show the direction of the absolute wind as well as the apparent wind direction, ship motion direction and the sense of rotation of each cylinder. Considering the first cylinder (i.e. the forward mast), sketch the flow pattern and indicate the ship motion direction, the sense of rotation of the cylinder and the wind velocity. How many stagnation point would occur at the surface of the first cylinder ? Explain what wind speed and direction you will use. Neglect the interference between the masts. Explain and justify your calculations.

Figure 3 - Cross-section of the Alcyone 2



Appendix 1. Naval hydrodynamics

Drag on a ship hull - Drag coefficient

Dimensional analysis shows that the drag on a ship hull can be written as :

$$\text{Drag} = \frac{1}{2} * C_D * A_W * V_o^2$$

where C_D is the drag coefficient, A_W is the wetted-surface area, V_o is the ship velocity. The drag coefficient is a function of both the Reynolds and Froude number.

To a first approximation, it is assumed that the drag coefficient can be expressed as the sum of a frictional-drag coefficient, depending on the Reynolds number only, plus a residual-drag coefficient which depends on the Froude number only (NEWMAN 1977, pp. 27-29).

Neglecting the residual-drag coefficient, the drag coefficient equals the frictional drag coefficient. This may be estimated as the flat plate drag coefficient. Experiments showed that the frictional-drag coefficient of a flat plate is determined by SCHOENHERR's correlation (NEWMAN 1977, pp. 16-18) :

$$\frac{0.242}{\sqrt{C_D}} = \log_{10}(Re * C_F)$$

where Re is the Reynolds number : $Re = V_o * L/\nu$, L is the ship length, ν is the fluid kinematic viscosity.

Units

knots	1 knot =	1 nautical mile per hour
nautical mile	1 naut. mile =	1852 m

Glossary

Angle of attack : angle between the approaching flow velocity vector and the chordline.

Bows : the forward part of a ship (often plural with singular meaning).

Chord (or chord length) : length of the chordline.

Chordline : straight line connecting the nose to the trailing edge (of a foil).

Drag : force component (on an object) in the direction of the approaching flow.

Draught : the depth of water a ship requires to float in.

Hydrofoil : a device that, when attached to a ship, lifts (totally or partially) the hull out of the water at speed.

Lift : force component (on a wing or foil) perpendicular to the approaching flow.

Mast : a tall pole or structure rising from the keel or deck of a ship.

Stern : the rear end of a ship or boat.

Tonne : a metric unit of weight equal to 1000 kg.

Appendix 2. The Alcyone

The propulsion system of the Alcyone was developed by the Frenchman L. MALAVARD for Jacques-Yves COUSTEAU (Chapter 4, section 3.7). Its consists of two identical fixed masts (i.e. Turbosail™). Boundary layer suction is generated on one side of the cylinder by a suction fan installed inside the mast, while a flap controls flow separation downstream (Fig. 4-17B). The resulting effect is a large

fluid circulation around the sail and a significant lift force ($C_L \sim 5$ to 6). Optimum performances are obtained when the angle between wind and ship directions ranges between 50 and 140º.
Dimensions and characteristics of the ship are listed in Table 2-1.

Table 2-1 - Characteristics of the Alcyone ship

Section (1)	Characteristics (2)	Remarks (3)
Hull	Built in 1984-85. Overall length: 31.1 m. Maximum draught: 2.34 m. Maximum width: 8.92 m. Half-load displacement: 76.8 t. Cruise speed: 10.5 knots	Designed by A. MAURIC and J.C. NAHON (Fra.)
Turbosails™	2 identical fixed masts equipped with a boundary layer suction system. Height: 10.2 m. Maximum chord: 2.05 m. Width: 1.35 m. Surface area: 21 m^2 (each). Suction fan: 25 hp. Performances : $C_L = 5$ to 6.5 and $C_D = 1.2$ to 1.8.	Developed by L. MALAVARD. Cousteau-Pechiney system built in aluminium.