<u>Topic</u>: Ship resistance and propulsion

<u>Synthesising information from different sources</u>

- **Using information from <u>all</u> excerpts, write a paragraph of not more than 170 words discussing <u>Froude's contribution to ship resistance</u>.**

Remember that you need to:
- **Use information from <u>all sources</u>.**
- **C<u>ite</u> your sources appropriately.**
- **Use your own words! You must not plagiarise!**

Excerpt 1

Froude's work was influenced by a particularly expensive mistake [8]. He had been consulted by his old boss Brunel and the mistake involved the design of a huge iron-clad ocean liner, the *Great Eastern*, which was the largest ship in the world at that time. Even though the designers had included paddle wheels and a screw propeller, as well as auxiliary sails (Fig. 2a), the sheer size of the ship meant that it had insufficient power. Its speed was so slow that there was no way the ship could earn enough to pay for the cost of its fuel [8], a significant shortcoming, since the *Great Eastern* laid the undersea telegraph cable between Co. Kerry, Ireland and Newfoundland, Canada in 1869, linking the continents of Europe and North America for the first time. Although Froude was involved with the engineering of the *Great Eastern* in only a minor capacity, he clearly appreciated how poorly naval architects in the mid-19th century understood wave resistance and the effects of size.

Froude's own approach to science, and indeed religion, is summed up in a phrase that he often quoted: "Our sacred duty [is] to doubt each and every proposition put to us including our own" [9]. He turned his attention to experimentation in the River Dart on two scale models, called *Raven* and *Swan*, in which he demonstrated that there was no ideal form and that performance varied with speed. With this evidence he persuaded the government to fund the building in the early 1870s of a towing tank, almost 100m long, across the road from his house. With the assistance of his third son Robert Edmund, born in 1846, he was able to tow his models at a known speed through still water using a steam-powered winch that pulled the carriage along a track suspended over the tank (Fig. 2b). The drag force acting on the models was monitored by a custom-designed dynamometer [10].

What Froude observed was that large and small models of geometrically similar hulls produced different wave patterns when towed at the same speed (Fig. 2c). However, if the larger hull was pulled at greater speeds, there was a speed at which the wave patterns were nearly identical. This occurred when the ratio of the velocity squared to the hull length was the same for both large and small hulls. He had thus demonstrated that geometrically similar hulls would also be dynamically similar, in terms of wave resistance, when this ratio—now known as the Froude number—was constant. In his own words [6]: That "Law of Comparison" is that if the speeds of the ships are proportional to the square roots of their dimensions, their resistances at those speeds will be as the cubes of their dimensions [1, p. 351]

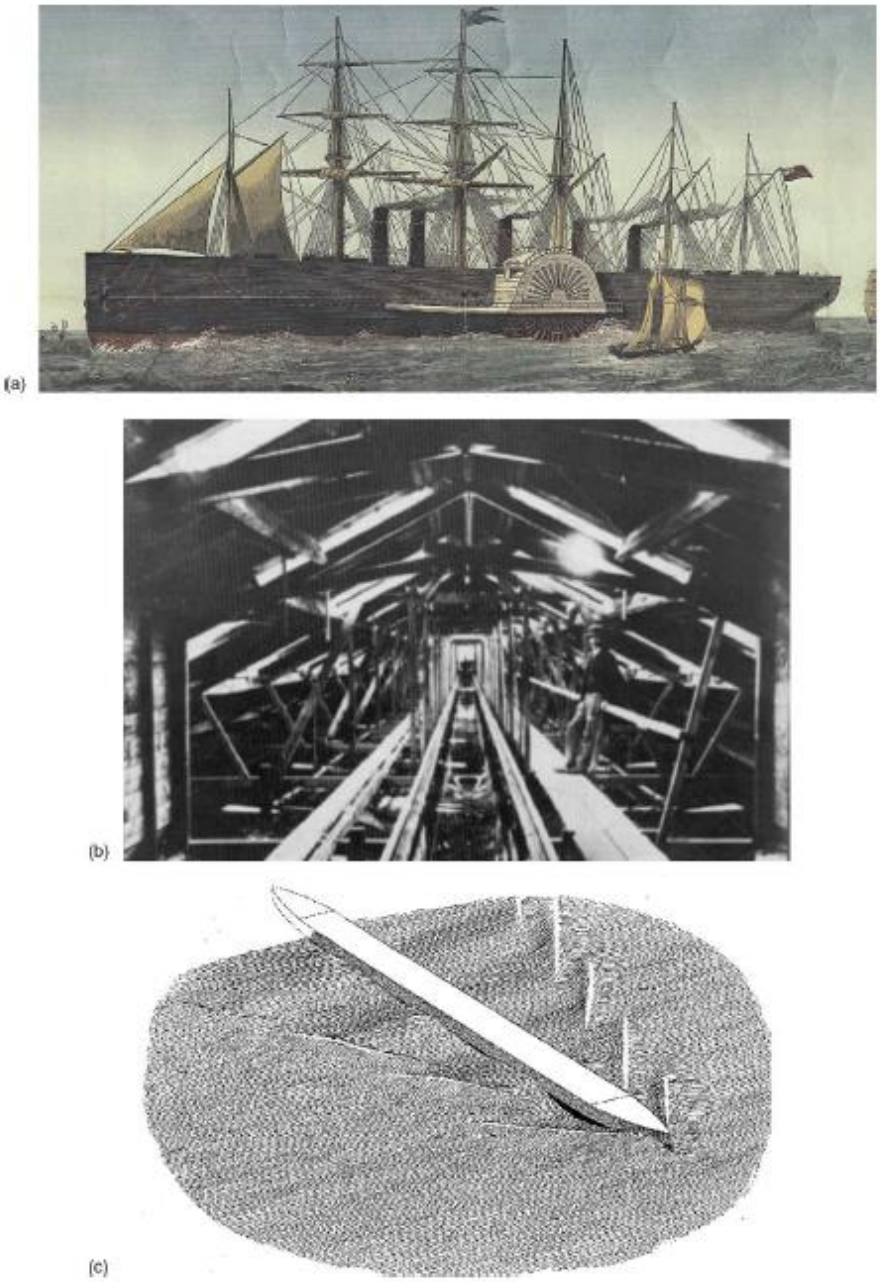

Fig. 2. (a) The *Great Eastern* was a ship which convinced William Froude that naval architects of the mid-19th century did not understand wave resistance and the effects of size. Reproduced with the permission of the Maritime Museum, Valentia Island, Co. Kerry, Ireland. (b) The towing tank built by William Froude in the early 1870s where he conducted hydrodynamic experiments on scale models. Reproduced with the permission of Russell [7]. (c) William Froude conducted experiments on the resistance of model boats of different lengths, allowing him to study diverging bow waves [12]. Reproduced with permission of the Royal Institution of Naval Architects.

Excerpt 2

Up to the early 1860s, little was really understood about ship resistance and many of the ideas on powering at that time were erroneous. Propeller design was very much a question of trial and error. The power installed in ships was often wrong and it was clear that there was a need for a method of estimating the power to be installed in order to attain a certain speed.

In 1870, W. Froude initiated an investigation into ship resistance with the use of models. He noted that the wave configurations around geometrically similar forms were similar if compared at corresponding speeds, that is, speeds proportional to the square root of the model length. He propounded that the total resistance could be divided into skin friction resistance and residuary, mainly wave-making, resistance.

He derived estimates of frictional resistance from a series of measurements on planks of different lengths and with different surface finishes. Specific residuary resistance, or resistance per ton displacement, would remain constant at corresponding speeds between model and ship. His proposal was initially not well received, but gained favour after full-scale tests had been carried out. HMS *Greyhound* (100 ft) was towed by a larger vessel and the results showed a substantial level of agreement with the model predictions. Model tests had been vindicated and the way opened for the realistic prediction of ship power. In a 1877 paper, Froude gave a detailed explanation of wave-making resistance which lent further support to his methodology.

In the 1860s, propeller design was hampered by a lack of understanding of negative, or apparent, slip; naval architects were not fully aware of the effect of wake. Early propeller theories were developed to enhance the propeller design process, including the momentum theory of Rankine [1.5] in 1865, the blade element theory of Froude [1.6] in 1878 and the actuator disc theory of Froude [1.7] in 1889.

In 1910, Luke [1.8] published the first of three important papers on wake, allowing more realistic estimates of wake to be made for propeller design purposes. Cavitation was not known as such at this time, although several investigators, including Reynolds [1.9], were attempting to describe its presence in various ways. Barnaby [1.10] goes some way to describing cavitation, including the experience of Parsons with *Turbinia*. During this period, propeller blade area was based simply on thrust loading, without a basic understanding of cavitation.

By the 1890s the full potential of model resistance tests had been realised. Routine testing was being carried out for specific ships and tests were also being carried out on a series of models. A notable early contribution to this is the work of Taylor [1.11], [1.12] which was closely followed by Baker [1.13].

The next era saw a steady stream of model resistance tests, including the study of the effects of changes in hull parameters, the effects of shallow water and to challenge the suitability and correctness of the Froude friction values [1.14]. There was an increasing interest in the performance of ships in rough water. Several investigations were carried out to determine the influence of waves on motions and added resistance, both at model scale and from full-scale ship measurements [1.15] [2, pp. 2-3]

Excerpt 3

Theoretical methods to predict the action of propellers began to develop in the latter part of the nineteenth century. Perhaps the most notable of these early works was that of Rankine, with momentum theory, which was then closely followed by the blade element theories of Froude. The modern theories of propeller action, however, had to await the more fundamental works in aerodynamics of Lanchester, Kutta, Joukowski, Munk and Prandtl in the early years of the nineteenth century before their development could begin… [3, p. 137]

Rankine proposed a simple theory of propeller action based on the axial motion of water passing through the propeller disc. The theory did not concern itself with the geometry of the propeller which was producing the thrust and, consequently, his work is not very useful for blade design purposes. It does, however, lead to some general conclusions about propeller action which have subsequently been validated by more recent propeller theoretical methods and experiment….

In contrast to the work of Rankine, W. Froude developed a quite different model of propeller action, which took account of the geometry of the propeller blade. In its original form the theory did not take account of the acceleration of the inflowing water from its far upstream value relative to the propeller disc. This is somewhat surprising, since this could have been deduced from the earlier work of Rankine; nevertheless, this omission was rectified in subsequent developments of the work.

Although Froude's work of 1878 failed in some respects to predict propeller performance accurately, it was in reality a great advance, since it contained the basic idea upon which all modern theory is founded. It was, however, to be just over half a century later before all of the major problems in applying these early methods had been overcome. [3, pp. 171-72]

Excerpt 4

William Froude (1810–1879) was the first to champion and prove the validity of scale model testing in the design of ocean going vessels. He is also known for his pioneering work in the rolling of ships, helping Brunel to stabilize the *Great Eastern* and explaining for the first time the behavior of a ship experiencing waves and what could be done to minimize their impact. His *Froude Number*, still in use today, is a dimensionless number that measures resistance. It is calculated as the ratio of a body's inertia to gravitational forces. The greater the Froude Number, the greater is the resistance [18].

One of Froude's greatest contributions was his Law of Similitude. According to this, the results obtained on a scale model would be applicable to a full-sized vessel or vehicle. This law is at the basis of all model testing. It is an integral part of the design process for vehicles and vessels of all types and led to the use of model basins worldwide for the testing of designs for the first metal ships.

William John Macquorn Rankine (1820–1872) was the Scottish civil engineer who developed the *streamline theory* that replaced John Scott Russell's wave-line system. The work in Rankine's paper, "On the mathematical Theory of Streamlines, especially those with four Foci and upwards," published in 1871, was described in an abstract: "A stream-line is the line that is traced by a particle in a current of fluid. In a steady current each individual streamline preserves its figure and position unchanged, and marks the track of a filament or continuous series of particles that follow each other. The motions in different parts of a steady current may be represented to the eye and to the mind by a group of stream-lines [4, p. 80].

References

[1] Vaughan, C. L. and o' Malley, M. J. 2005. "Froude and the contribution of naval architecture to our understanding of bipedal locomotion". Gait and Posture, **21**, pp. 350–362
[2] Molland, A. F., Turnock, S. R. and Hudson, D. A., 2011, *Ship Resistance and Propulsion*, Cambridge University Press: Cambridge.
[3] Carlton, J. S. 2012. *Marine Propellers and Propulsion*. Butterworth-Heinemann: Oxford.
[4] Hagler, G. 2013, *Modeling Ships and Space Craft.* Springer-Verlag: New York.

(Selected) Glossary

Actuator disc = δίσκος άνωσης
Cavitation = σπηλαίωση
Displacement = εκτόπισμα
Drag force = οπισθέλκουσα δύναμη
Skin = κέλυφος
Slip = ολίσθηση
Slipstream = ρεύμα ολίσθησης
Thrust = ώση
Tow= ρυμουλκώ
Wake = ομόρρους
Winch = βαρούλκο