**Hull Resistance**

A ship differs from land based large engineering structures in that, in addition to all its other functions, it must be designed to move efficiently through the water with a minimum of external assistance.


The resistance offered by a ship to movement through water may be resolved into two principal components: frictional resistance and residual resistance. The frictional resistance arises from frictional forces set up by the flow of water along the surface of the hull, and is consequently influenced by fouling and the coatings of paint used for its prevention. The residual resistance is due to pressures developed in pushing the water aside, and arises from the form of the hull.

https://darchive.mblwhoilibrary.org/bitstream/handle/1912/191/chapter%202.pdf

Total Hull Resistance ($R_T$) is the force that the ship experiences opposite to the motion of the ship as it moves.

\[ R_T = R_W + R_V + R_A \]

where:

- $R_W$ = wave making resistance
- $R_V$ = viscous resistance
- $R_A$ = air resistance

Wave-Making Resistance ($R_W$) is caused by waves generated by the motion of the ship. Wave-making resistance is affected by beam to length ratio, displacement, shape of hull, (ship length & speed).

Viscous Resistance ($R_V$) is the resistance due to the viscous stresses that the fluid exerts on the hull (i.e. due to friction of the water against the surface of the ship). Water viscosity, ship’s velocity, wetted surface area and roughness of the ship generally affect the viscous resistance.

Air Resistance ($R_A$) is the resistance caused by the flow of air over the ship with no wind present. Air resistance is affected by projected area and shape of the ship above the water line and is typically 4 ~ 8 % of the total resistance.

https://www.usna.edu/Users/naome/phmiller/courses/index.php
Components of Total Hull Resistance

- Low speed: *Viscous R*
- Higher speed: *Wave-making R*
- Hump (Hollow): location is function of ship length and speed.

*Components of Total Hull Resistance*

http://cflymarine.com/services/
William Froude
Froude (pronounced Frude) was the sixth son of Archdeacon Richard Hurrell Froude, rector at Dartington, and Margaret Spedding of Cumberland. He studied seven years at Oriel College, Oxford, where he was tutored in mathematics by his oldest brother, Robert Hurrell. (The latter was also a leader of the Oxford Movement, and it is noteworthy that William was the only member of the family who did not follow Newman into Roman Catholicism.) While subsequently occupied as a civil engineer, Froude came under the influence of I. K. Brunel, builder of both railways and oceangoing steamships, who stimulated his interest in naval architecture.

Froude retired from active civil engineering practice at the age of thirty-six, but he continued to give attention to various aspects of ship behavior, both recreational (he was an avid yachtsman) and technical. At Brunel’s request he undertook in 1856 a resistance and rolling study of the Great Eastern, and his analytical and experimental work on the subject, at full as well as reduced scale, extended to many ships over many years. Of even greater importance than his control of rolling by use of bilge keels was his promotion of resistance studies on scale models. His efforts to secure the support of the Admiralty for
the construction of a model towing tank at first aroused the opposition of John Scott Russell and other members of the Institution of Naval Architects, and it was not till 1870 that the sum of £2,000 was granted for this purpose. The original tank, 250 feet in length, was built on Froude’s own land at Torquay only eight years before his death; he was ably assisted by his son, Robert Edmund Froude, who later built the Admiralty tank at Haslar.

William Froude’s great manual skill was of inestimable value in the construction and operation of the tank, and many of his model and prototype processes and instruments continue to be employed: the use of paraffin and waterline cutting machines for models; resistance recorders; governors; roll indicators; and propeller-engine dynamometers. Use of the scale model for resistance studies was based upon his hypothesis that the total resistance could be considered the sum of wave formation and skin friction and that each could be scaled independently. He showed that the wave effects would be similar in model and prototype if the velocity were reduced in proportion to the square root of the length. This is known as Froude’s law of similarity, even though it had been published by Ferdinand Reech, a professor in the school of naval architecture at Paris, in 1852 and purportedly introduced in his lectures as early as 1831. Froude formulated the law of skin-friction similarity after towing streamlined catamaran planks of various lengths and surface finishes through water over a wide range of speeds. The resistance of the smooth surfaces was found to vary with no more than the 1.85 power of the velocity, and only for the roughest did the power reach 2.0. His perceptive understanding of the effect of surface length was in close accord with present-day boundary-layer theory.

Froude was elected a fellow of the Royal Society of London in 1870. In 1876 he received both the honorary degree of LL.D. from the University of Glasgow and a Royal Medal of the Royal Society. His many writings are to be found in the Transactions of the Institution of Naval Architects and in reports to the British Association for the Advancement of Science. Froude’s last paper, published a year before his death, was on the subject of screw propulsion, one of his early interests. While on a holiday trip to the Cape in 1879 he succumbed to dysentery just before his scheduled return to England.


Viscous flow around a ship
http://www.slideshare.net/adsokant/basics-ofshipresistance
Air Flow behind Deck House


http://www.vos.noaa.gov/MWL/apr_06/winds.shtml
Resistance
Generally the resistance of a boat is made from the following components: Surface friction, Form resistance, Surface roughness, Wave resistance, Air resistance & Appendage drag. Obviously, these will also change with the speed of the boat.

The graph below shows the general resistance components for different type of hulls.

http://www.humphree.com/learn-more/how-it-works/
**380 foot Towing Tank at US Naval Academy**

This tank is equipped with two towing carriages, a dual flap wavemaker and a wave-absorbing beach. The smaller carriage is lighter and capable of towing smaller models at higher speeds. The larger carriage is heavier and used to tow larger models at lower speeds. Both carriages are set up with platforms to carry ten or more students, allowing close-up observations of the test subject underway. A center section of the tank’s beach can be lowered to allow access to a finger pier for ballasting and setting up experiments while the tank is being used for other tests. Measurements from sensors on towed models are monitored and recorded using an onboard computer. Digital measurement records and live HD video signals are transferred to the shore-based control room using wireless networks. Measurement records can be evaluated and analyzed onboard the carriage and on shore.

This facility has been used to test a wide variety of models, including: ships, submarines, planing boats, hydrofoils, surface effect craft, SWATH's, sailboats, offshore platforms, wave buoys, divers, mine arrays, pilings, etc. It is also used to study wave motions and forces, without the use of models.

**Length = 380 ft (116 m)**
**Breadth = 26 ft (7.9 m)**
**Depth of Water = 16 ft (4.9 m)**
**Carriage Travel = 270 ft (82 m)**

**DESCRIPTION OF CARRIAGE:**

1) High speed – 11,000 lb box girder, steel wheels, round rails; max speed 32 ft/s (9.8 m/s)
2) Low speed – 22,000 lb box girder towed by high speed carriage; max speed 25 ft/s (7.6 m/s)

**TYPE OF DRIVE SYSTEM AND TOTAL POWER:**

Shore-mounted motors with twin tow cables; two motors @ 200 hp (150 kw) with 400% overload capability; controlled from shore using computer driven touchscreen

**OTHER CAPABILITIES:**

Large and small horizontal planar motion mechanisms

Open water propeller testing

Water current turbine testing

**WAVE GENERATION CAPABILITY:**
Regular, irregular, and transient water waves, wave frequency range 0.25 to 1.4 Hz

WAVEMAKER TYPE:
Dual flap servo-hydraulic control with dry back

BEACH TYPE AND LENGTH:
4 layers of 2 inch (5 cm) square tubes, 60 ft long (18 m), nominal slope 1:5

INSTRUMENTATION:
Sensors and amplifiers for measuring: force, moment, distance, angle, rotation rate and position, velocity, acceleration, inertial motion, wave elevation, water particle motion, pressure; multiple 16 bit analog-to-digital USB-based data collection systems with sample rates of 20KHz+

TESTS PERFORMED:
Resistance, self-propulsion, seakeeping, open water propeller, horizontal planar motion, various tests of fixed and moored ocean structures, hydrodynamic forces on submerged bodies, foils, etc., capsize and dynamic stability tests, flow visualization, basic ocean wave mechanics