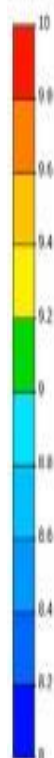




**Why should you keep your
hull free of marine growth,
surface irregularities and
anti-fouled regularly?**

**(Hull Resistance and the
Boundary Layer)**

All Velocity (node) (m/s)

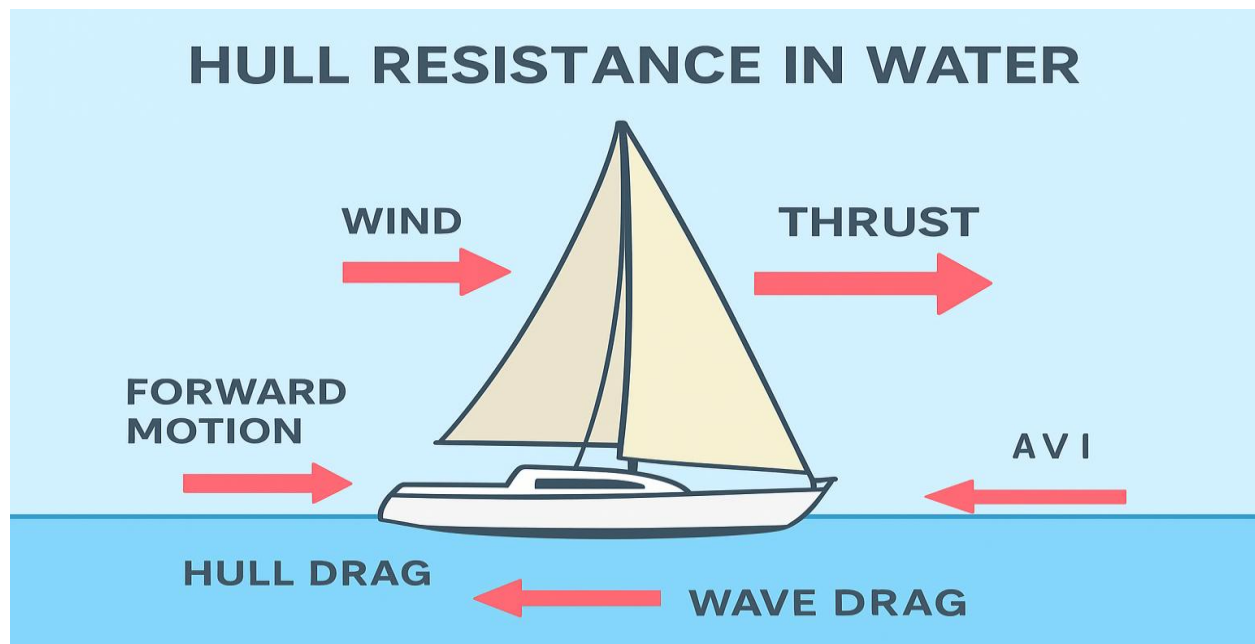


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© Image from SIMSSCALE)

Why should you keep your hull free of marine growth, surface irregularities and anti-fouled regularly?

If you minimise hull resistance, the flow of water at the boundary layer with the hull, will be optimal for the hull design. This essay explores hull resistance and the interaction of a hull surface with water at the boundary layer, where they meet and as the distance from the hull grows.



In Europe, the sailing season draws to a close for most sailors, as the autumn and winter seasons with their unpredictable weather, arrives. Boat owners will be making vessels ready for the harsher conditions. Some may choose to sail on in 'white sails'. Some may choose to haul out and winterise. Most will as a matter of routine turn thoughts to maintenance. Some will have been ensuring the condition of their hull is optimal to ensure best (racing) performance.

This note explores the reasoning behind such attention to detail, of the condition of a hull, is a good preoccupation. We discuss the related topics of 'hull resistance' and the 'boundary layer' and how these two come together to influence performance.

Hull Resistance

Hull resistance is the force opposing a vessel's motion through water. It can be decomposed into several components:

- **Frictional Resistance (R_f)** – due to viscous drag along the hull surface. This depends on hull wetted area, speed, and Reynolds number.
- **Form (or Pressure) Resistance (R_p)** – due to flow separation around the hull shape.
- **Wave-Making Resistance (R_w)** – energy lost creating waves as the vessel moves.
- **Air Resistance (R_a)** – generally small unless superstructure is large.

For moderate to high speeds, wave-making resistance dominates.

Effect of Wave Patterns on Resistance

The environment plays a huge role. Different wave conditions change how the hull interacts with water:

a) Calm Water

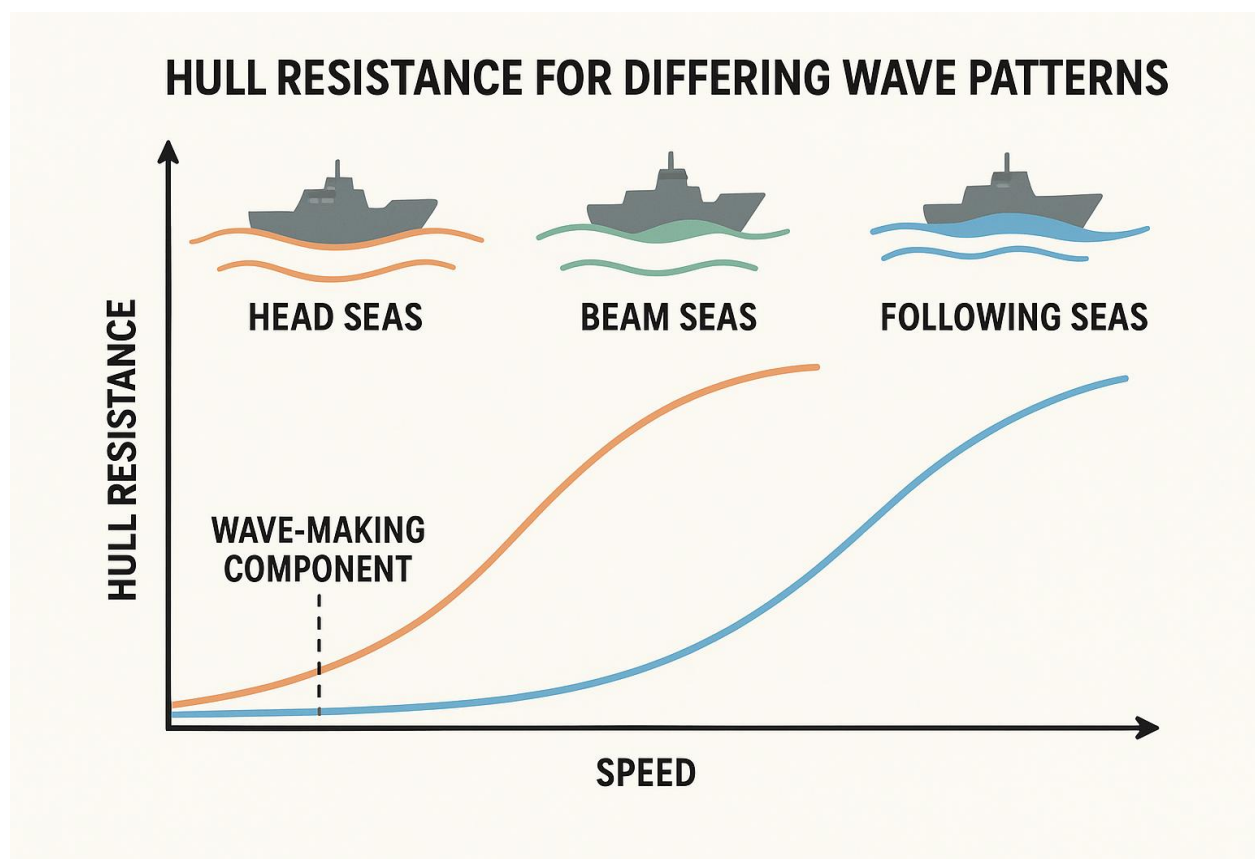
- A classic resistance curve can be applied.
- Wave-making resistance depends mainly on hull speed (V) and Froude number:

$$(Fr = \frac{V}{\sqrt{gL}})$$

where L is the waterline length.

b) Regular Waves (Sinusoidal)

- Resistance is oscillatory: sometimes the ship is going downhill along a wave, sometimes uphill.
- Key effects:
 - Added resistance in waves (RAW): extra resistance compared to calm water.
 - Peaks at certain wave frequencies relative to ship speed and hull length.
 - This depends on wave steepness (H/λ), wave encounter frequency, and heading angle.



c) Irregular Sea (Realistic Ocean Waves)

- Characterised by superposition of multiple wave components with random amplitudes and frequencies.
- Added resistance is often higher on average than calm water but fluctuates.
- Computed using statistical methods, like spectral analysis of sea states (Pierson–Moskowitz or JONSWAP spectra).
- Resonance effects: Certain hull lengths and speeds amplify pitching/rolling, increasing resistance.

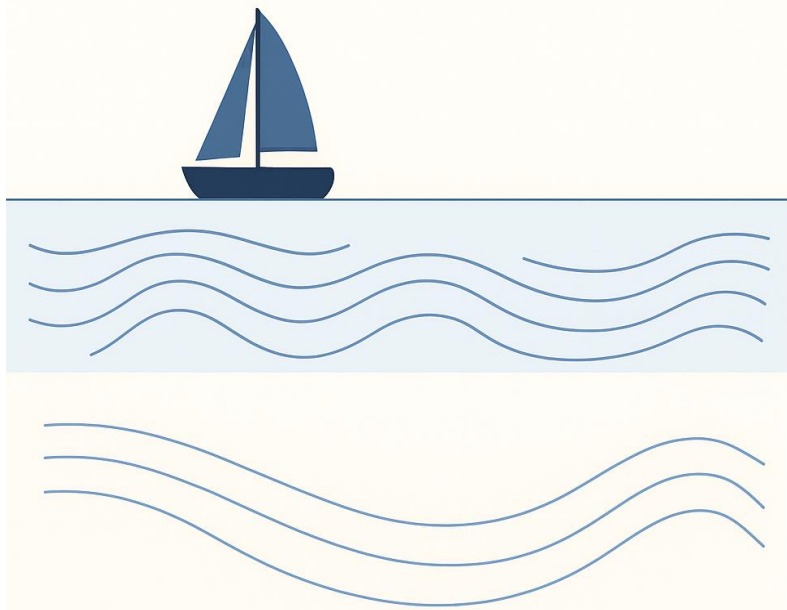
d) Head Seas vs Following Seas

- **Head Seas (waves against the ship's motion):**
 - Increased resistance due to hull climbing waves.
 - Pitching can exacerbate drag.
- **Following Seas (waves in the same direction):**
 - Can reduce resistance if the wave slope assists motion (the hull is “surfing” downhill).
 - But can also induce bow slamming or green water loads, creating spikes in resistance.

e) Beam Seas (waves from the side)

- Usually increases resistance due to leeway, rolling, and added drag.
- Not just forward resistance: dynamic effects like roll damping affect effective resistance.

HULL RESISTANCE AND ENERGY DISSIPATION



Very near the hull

Strong velocity gradients (boundary layer).
High turbulence and eddies
→ most energy is dissipated here

Moderate distance

Wake spreads laterally and vertically. Velocity deficit decreases (water speed recovers toward free-stream velocity)

Far field

Viscous wake merges with surrounding flow → turbulence mostly dissipated as heat
The only major surviving resistance effect is wave making

3. Quantifying Hull Resistance in Waves

1. **Added Resistance in Waves (RAW)** is often expressed as:

$$R_{\text{wave}} = R_{\text{total in waves}} - R_{\text{calm water}}$$

2. **Methods of calculation:**

- Empirical formulas (e.g., Hollenbach, SSPA, ITTC methods)
- Numerical simulation: CFD with free surface waves
- Model tests: towing tank experiments with controlled waves

3. Key Dependencies

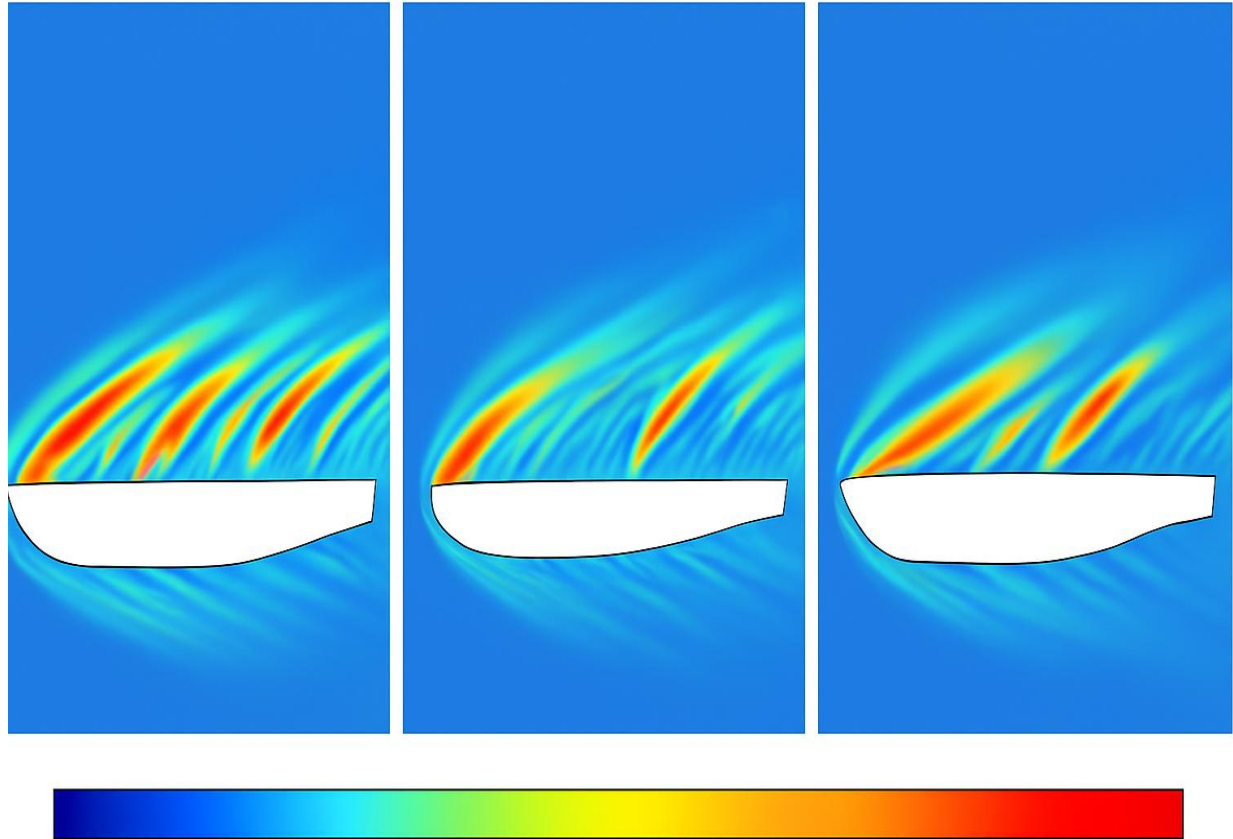
In quantifying Hull Resistance in Waves these dependencies should be addressed:

- Hull form: fine vs full hull, bulbous bow, transom stern
- Speed and Froude number
- Wave parameters: height, length, steepness, heading
- Sea state spectrum

The second area to be covered here is the Boundary Layer which is critical in understanding hull resistance.

The Boundary Layer

WAVE PATTERNS FROM RANS CFD



Above – A schematic example of a comparative figure, showing 3 different hull designs with RANS-simulated wave patterns, which are similar to what you'd get in CFD post-processing.

Note the significant waves at the bow across all hull shapes which have varying rates of dissipation along the hull dependent on the specific hull.

Note: Computational Fluid Dynamics (CFD) uses numerical methods and computers to simulate and analyse fluid flow, heat transfer, and mass transfer in complex systems, enabling engineers to predict and understand phenomena like turbulence, optimize designs, and reduce costs for physical prototypes.

What is a boundary layer?

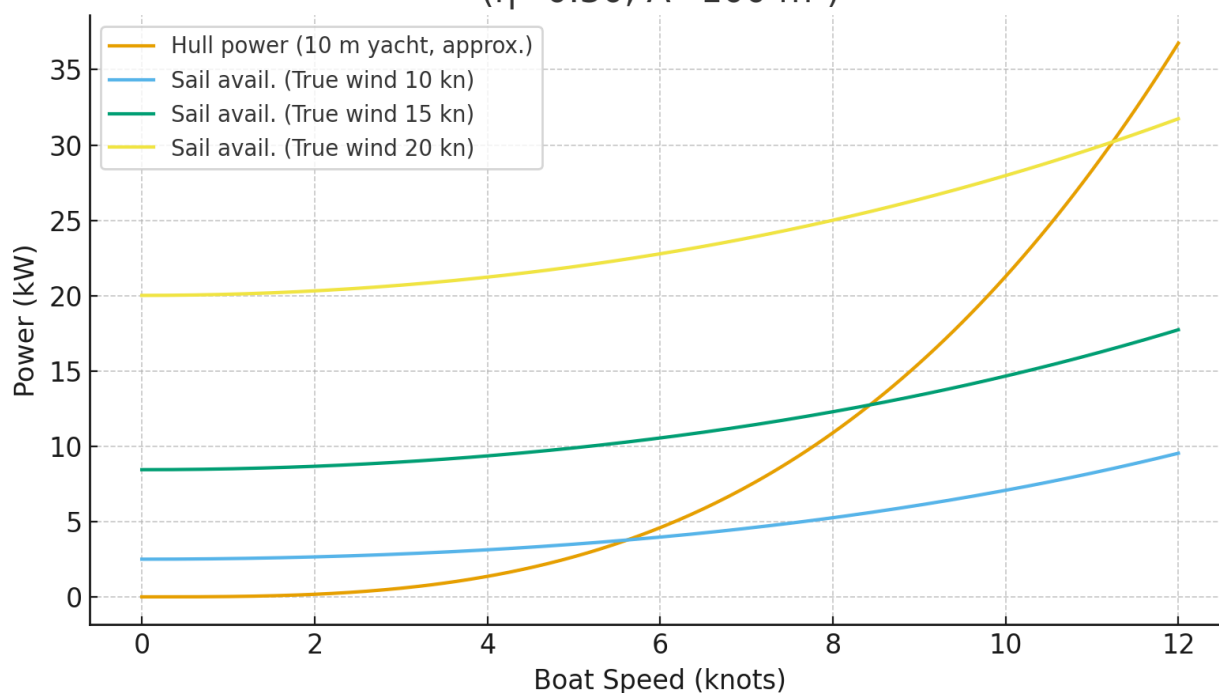
The hull boundary layer refers to the layer of fluid (usually water) in immediate contact with the surface of a ship's hull where viscous effects are significant. It's a key concept in fluid dynamics and naval architecture, because it directly affects drag, fuel efficiency, and flow characteristics around the vessel.

A boundary layer is the thin region of fluid close to a solid surface (here, the vessel's hull) where the fluid velocity changes from zero at the wall (no-slip condition) to the free-stream velocity of the surrounding fluid. These are defined as:

☐ **At the hull surface:** $v=0$ $w=0$ $u=0$

☐ **Outside the boundary layer:** $\mathbf{v} \approx \mathbf{V}_{inf}$. (speed of water from the hull)

Sail Available Power (beam reach) vs Hull Power — 10 m Yacht ($\eta=0.30$, $A=100 \text{ m}^2$)



Above - Graph of hull resistance/power curve – This models the relationship between the available sail power on a beam reach of a 10m yacht and the effect of hull resistance on boat speed. Note: these results are particular to the chosen scenario.

Types of hull boundary layers

The boundary layer can be laminar or turbulent:

- Laminar boundary layer: Smooth, orderly flow. Lower skin friction, but unstable at high Reynolds numbers (common in ships).
- Turbulent boundary layer: Chaotic flow with eddies. Higher skin friction, but more resistant to separation, which can reduce pressure drag.

Thickness of the boundary layer

The boundary layer grows along the hull in the direction of flow. For a flat plate approximation:

- Laminar boundary layer thickness:

$$\delta \approx 5\nu x \sqrt{V} \approx 5V\nu x$$

- Turbulent boundary layer thickness:

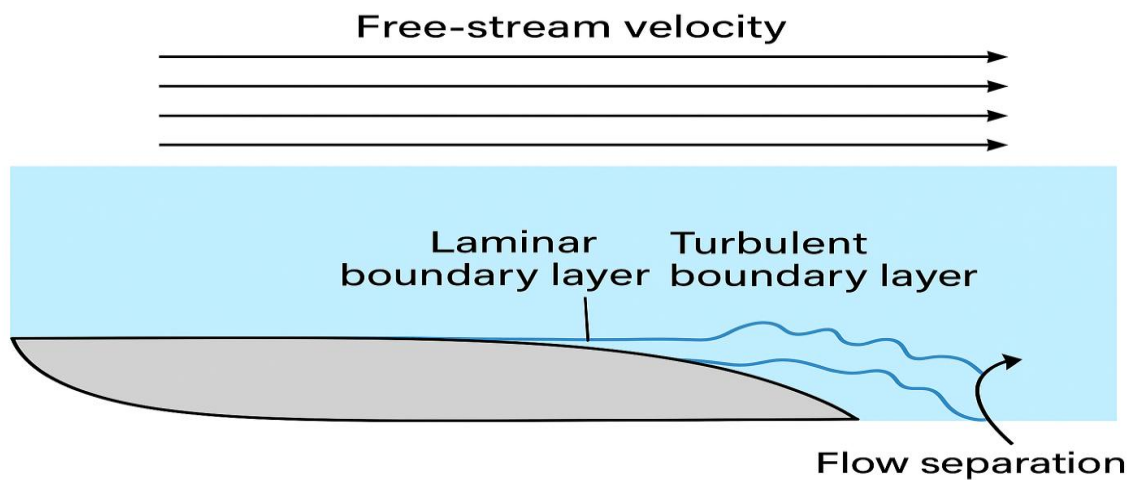
$$\delta \approx 0.16x \text{Re}_x^{-1/7}$$

Where:

- x = distance from the leading edge of the hull
- ν = kinematic viscosity of water
- V = ship speed
- $\text{Re}_x = \frac{Vx}{\nu}$ = Reynolds number at position x

Effects on ship performance

- **Skin friction drag:** The boundary layer contributes to viscous drag along the hull, which can be 50–80% of total resistance for displacement ships.
- **Flow separation:** If the boundary layer separates, it increases pressure drag and can cause turbulent wake.
- **Propeller inflow:** A thick boundary layer modifies the flow into the propeller, affecting efficiency.
- **Hull coatings:** Special coatings (e.g., anti-fouling paints) reduce boundary layer roughness and drag.



Above - Figure showing the hull, laminar and turbulent boundary layers, and flow separation, which makes it visually much easier to grasp.

Boundary layer control

Naval architects often aim to delay transition from laminar to turbulent flow or control separation through:

- Hull shaping: Smooth, streamlined surfaces
- Air lubrication: Injecting bubbles to reduce friction
- Riblets or coatings: Micro-grooves that reduce turbulent drag

In conclusion, hull resistance and the hull boundary layer are key to understanding a vessel's overall (hull) resistance in water and is central to designing efficient, high-speed, and fuel-saving vessels.