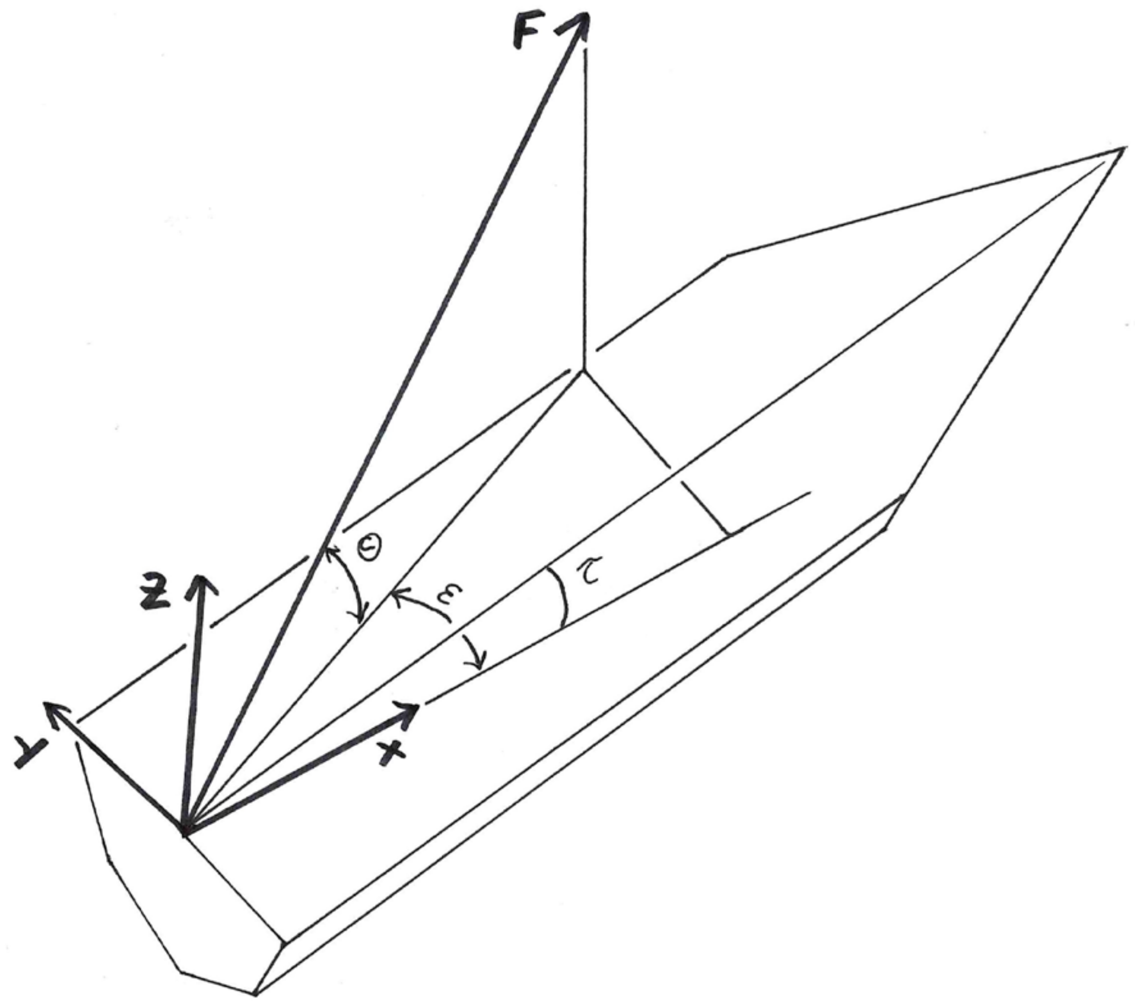
This section is intended to be read in conjunction with:

3. The *WINDFLY Rig* – Theory
4. The *WINDFLY Rig* – Use of combined 'keel-rudders' to avoid leeway
7. The *WINDFLY Rig* – Mounting on a planing boat – Rudder and hydrofoil
8. The *WindFly Rig* – Planing upwind



τ is the trim angle

Figure 6.1.1 Axes

6. Mounting the *WINDFLY Rig* on a planing or semi-planing boat – Simple keel-rudder

At speeds corresponding to a Froude number of up to around 0.4 a hull operates in the displacement mode.

At speeds corresponding to Froude numbers above about 0.45 a hull gains some support from hydrodynamic lift and the hull begins to plane.

6.1 Axes and kite lines alignment

Figure 6.1.1 shows a set of orthogonal axes:

- a set X, Y, Z in which X is horizontal and parallel to the longitudinal axis of the hull, Y is parallel to the transverse axis of the hull, and Z is vertical.

The kite force F can be considered to act as the three orthogonal vectors, $\mathbf{F_X}$, $\mathbf{F_Y}$ and $\mathbf{F_Z}$ acting parallel to the X, Y and Z axes respectively. The component of F acting in the XY plane ($F_{XY} = F\ \cos\theta$) is offset from the X axis by angle ε.

$$F_X = F\ \cos\theta\ \cos\varepsilon \qquad F_Y = F\ \cos\theta\ \sin\varepsilon \qquad F_Z = F\ \sin\theta$$

$$\tan\theta_{XZ} = \frac{F_Z}{F_X} = \frac{\tan\theta}{\cos\varepsilon}$$

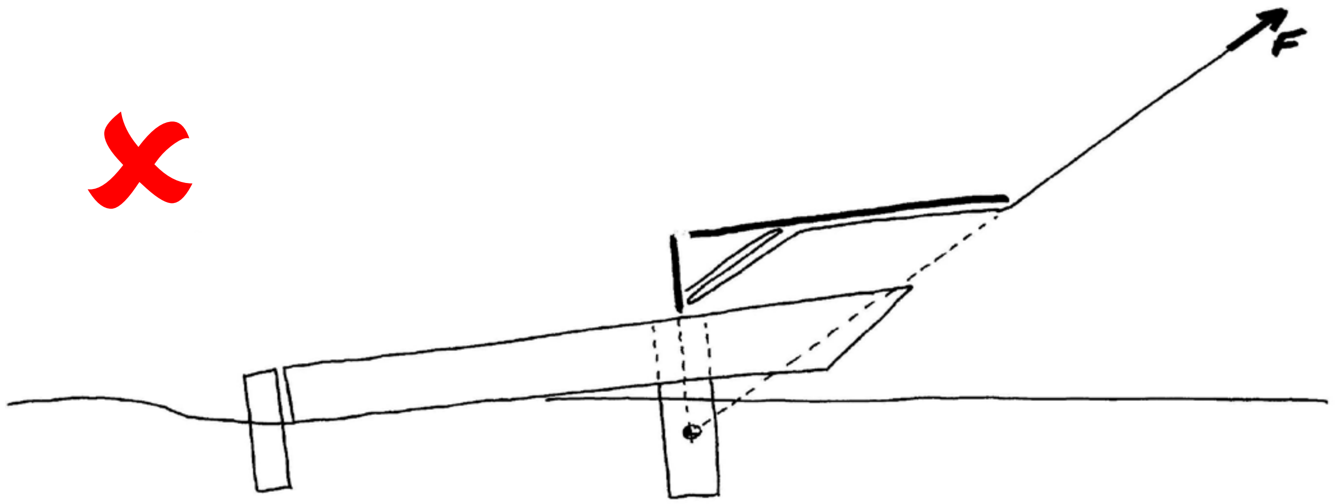


Figure 6.2.1

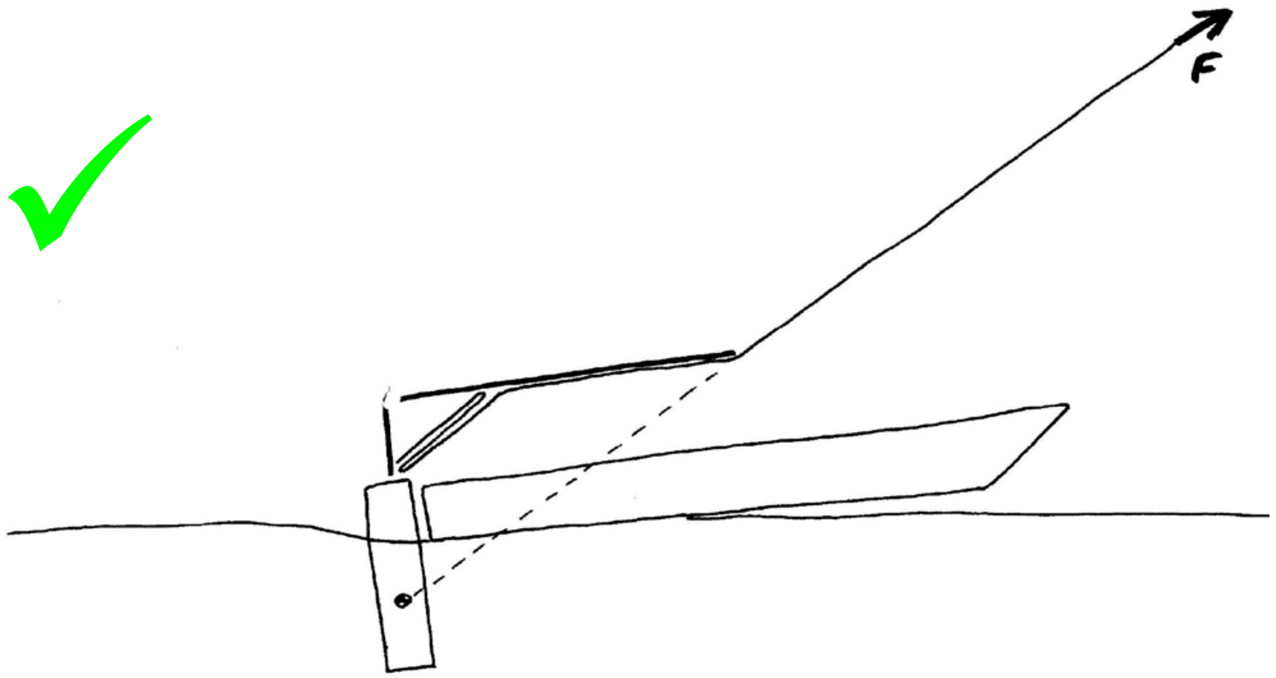


Figure 6.2.2

6.2 Preferred placement of the WINDFLY Rig on a planing boat

A centreboard or keel is required below the *WINDFLY Rig* to resist the lateral load $\mathbf{F_y}$. Ideally the centreboard / keel is located directly below the *WINDFLY Rig* so that the lateral load $\mathbf{F_y}$ does not cause the boat to rotate around the centreboard or keel

If the *WINDFLY Rig* is placed forward on the boat then as the trim angle increases, at the point where the *WINDFLY Rig* is located the hull lifts clear of the water. As the hull lifts clear of the water the centreboard or keel is drawn out of the water, this reduces the resistance to lateral load and lowers the centre of lateral resistance **CLR** which results in a rolling moment causing the boat to heel.

Therefore the *WINDFLY Rig* is ideally located so far back on the boat that the hull below the *WINDFLY Rig* never lifts clear of the water. This can be achieved by fixing the *WINDFLY Rig* to the stern of the boat. If the *WINDFLY Rig* is fixed to the stern the keel and rudder may be combined in a single foil.

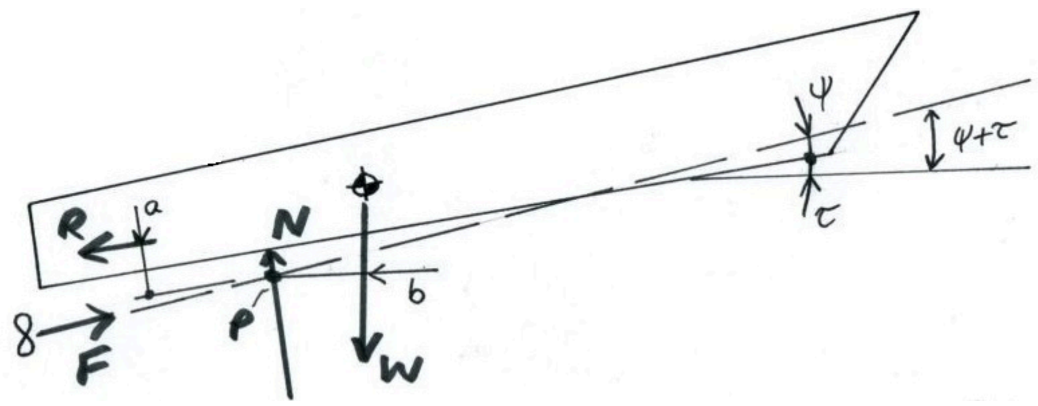


Figure 6.3.1

6.3 Theory of planing hulls (motor boats)

As a boat travels through water, water is moved to make way for the hull. In order to be moved, the water is accelerated to have a velocity and momentum. A force is applied by the hull to accelerate the water and an equal and opposite force is applied by the water on the hull. At high speed and with suitable hull geometry this hydrodynamic force is sufficient to support the boat. When this happens the boat is planing.

The component of the hydrodynamic force acting perpendicular to the hull baseline is referred to as the hydrodynamic lift, the component of the force acting parallel to the hull baseline is referred to as the hydrodynamic resistance or hydrodynamic drag. The hydrodynamic lift **N** can be represented as a vector passing through a point on the hull, the position of this point varies along the length of the hull baseline as the boat speed and trim angle vary. Similarly the hydrodynamic resistance can be represented by a vector **R** passing through a point on the hull, the distance of **R** from the hull baseline varies as the boat speed and trim angle vary.

As the trim angle increases the hydrodynamic lift increases, the hydrodynamic resistance increases, and the frictional resistance of water on the hull becomes less significant since the wetted area reduces. At low trim angles frictional resistance dominates; at high trim angles hydrodynamic resistance dominates. Generally total resistance falls as the trim angle increases, however the greater the trim angle the more the bow is lifted and the more the hull slams into waves; typically motor boats are designed to operate with a trim angle of around 4 degrees which provides a sensible balance between limiting frictional resistance and lifting the bow.
It is usual to take moments about the point **P** where the vectors representing the propeller thrust **F** and the hydrodynamic lift **N** intersect. To establish the trim angle and power required the moments due to water resistance on the hull and appendages must be balanced by the moments due to the self weight of the vessel. This principle is illustrated in figure 6.3.1.

For equilibrium:

$$aR = bW \qquad \text{[equation 6.3.1]}$$

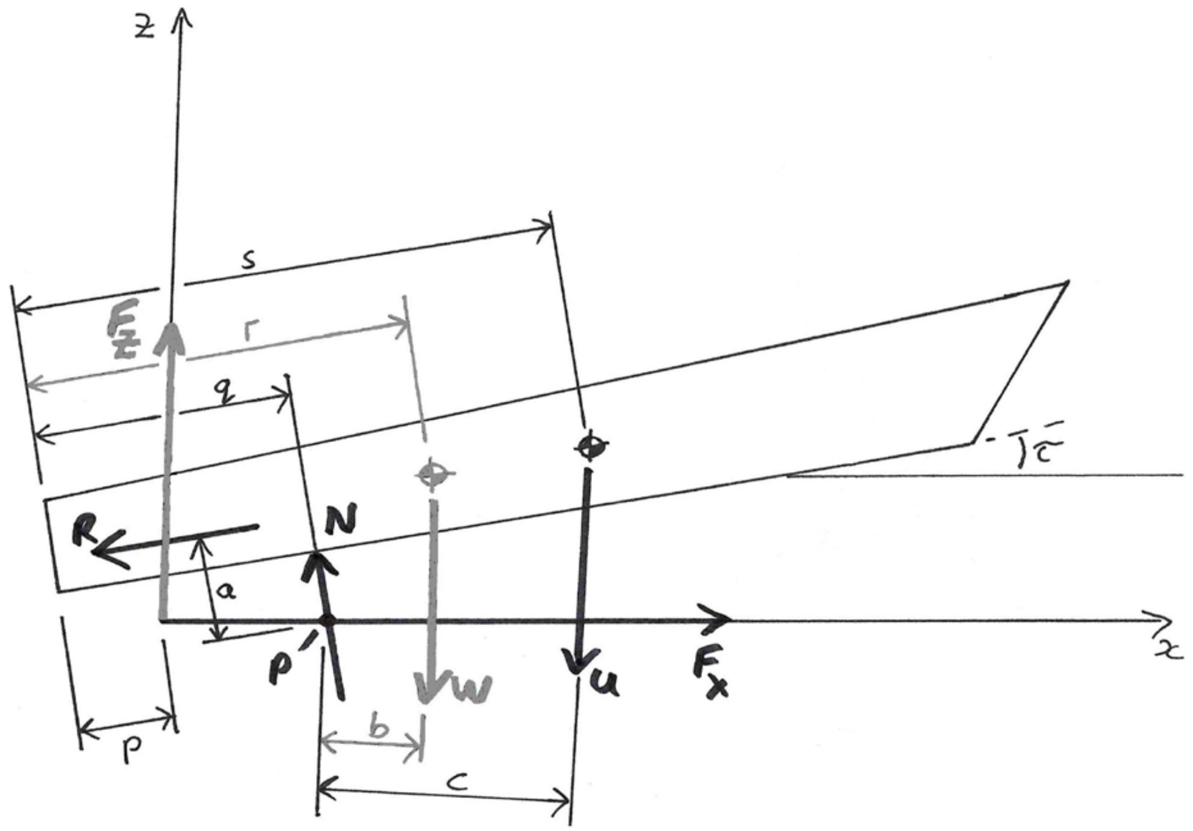


Figure 6.4.1

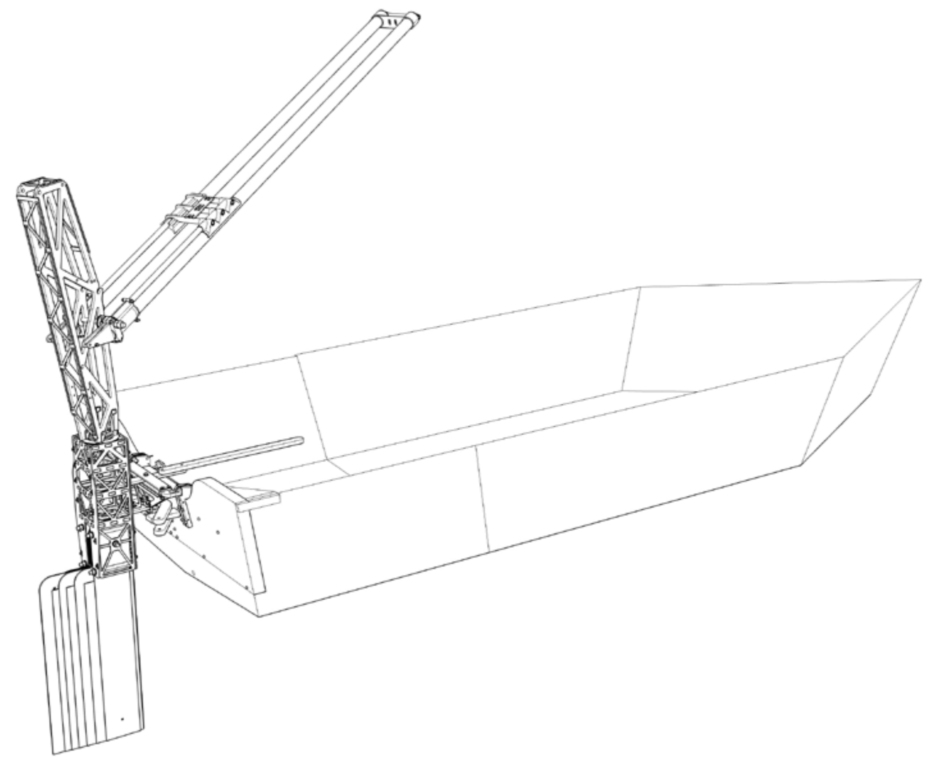


Figure 6.4.2

6.4 Theory for the analysis of planing hulls using the WINDFLY Rig

The same theory that is used to analyse a planing motor boat is suitable for analysis of a planing boat using the *WINDFLY Rig*.

The weight of the vessel **W** and the position of the centre of gravity are modified to take account of the vertical component of the kite load, $\mathbf{F_z}$.

$$U = W - F_Z \qquad \text{[equation 6.4.1]}$$

$$s = \frac{Wr - F_Z p}{U} \qquad \text{[equation 6.4.2]}$$

$$a = f + (q - p)\sin\tau + e \qquad \text{[equation 6.4.3]}$$

$$c = (s - q)\cos\tau \qquad \text{[equation 6.4.4]}$$

$$F_X = R\cos\tau + N\sin\tau \qquad \text{[equation 6.4.5]}$$

When taking moments about P the moments due to water resistance on the hull and appendages must be balanced by the moments due to the self weight of the vessel. For equilibrium:

$$aR = cU \qquad \text{[equation 6.4.6]}$$

If p < q the vertical component of the kite load reduces the trim angle and lowers the bow, while if p > q the vertical component of the kite load increases the trim angle and raises the bow.

If the *WINDFLY Rig* is fixed to the stern the kite load reduces the trim angle and the position at which the hydrodynamic lift N acts moves forward on the boat. The following measures may be taken to mitigate this effect:

- The centre of mass may be placed further aft than it would be for a motor boat.
- The kite may be flown at a low angle, close to the water, to limit the vertical component of the kite load.
- A more slender (longer, narrower) hull may be used to limit the effect of movements in the position of the hydrodynamic lift. While this increases the resistance of a planing hull it improves sea keeping and can provide an efficient 'high speed displacement' (or 'semi-planing') hull for operation with Froude numbers in the range 0.4 to 1.1.