Orca3D

Planing Craft Analysis: **Static vs. Dynamic Trim**

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A question that often arises for Orca3D users is whether or not the "Static" and "Running" Trim of a fast planing craft are somewhat "geometrically" related to each other. The quick answer is "No," but it is worth studying the question more closely to understand the answer.

Static Trim

Whether it's about a slow displacement vessel or the fastest planing "Hot Rod" boat, the "Trim" angle, as reported by Orca3D when performing a hydrostatic analysis, is related to a "Static" condition of the hull only. That is, throughout the analysis performed the hull is considered to be "at rest," or in physics terms, "in static equilibrium." No dynamic effects (i.e., speed/acceleration-related forces) are taken into account under this type of hydrostatic analysis.

More specifically, when performing a "Free-Float" hydrostatic analysis in Orca3D, the reported "Trim" angle corresponds to the longitudinal (i.e., Fore-Aft) hull orientation in 3D space that results from the balance of the simple system of forces considered by this analysis, that consists of two forces only. These are the "Weight" of the craft, acting through its "CG" (Center of Gravity), and the "Buoyancy" force that acts through the "CB" (Center of Buoyancy[1]).

As we all know from basic engineering mechanics, for any "structure" (i.e., our craft, yacht, or vessel) to be in a "static equilibrium" condition, it has to be verified that net the sum[2] of all acting forces must be zero (i.e., the net resultant force is zero), and also that the moment is zero. This is known as "pure" static analysis.

Orca3D, through its built-in algorithms, is capable of finding the final hull orientation in 3D space, after finding the solution to this both "simple" and "complex" problem.

Given a hull geometry for analysis, once a craft's weight and CG are specified by the user, the software solves the system of equations for static equilibrium with the hull free to trim, heel, and translate vertically, until an orientation is found that results in an immersed volume, and its corresponding buoyancy force, that counteracts (i.e., is equal and opposite to) the craft's weight.

Furthermore, the resulting solution is such that the relative position between the CG, which is "fixed" to the craft, and the CB that results from the "immersed geometry" is such that no net moment will result from this situation. In other words, this also means that Weight and Buoyancy forces are also acting through the same line of action, or that their directions are mutually coincident.

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[1] The CB, or Center of Buoyancy, is the centroid of the wetted volume.
[2] Here we refer to a "Vector" sum.

Figure 1 illustrates a typical situation before performing a "Free-Float" hydrostatic analysis. That is, the boat's geometry is modeled with reference to a known "Baseline" (usually a horizontal, or the "x" axis line[3]). The boat's weight and CG[4] are known by the designer's preliminary estimations, and a "preliminary" Design Waterline is drawn, usually parallel to the Reference Line at a height (or Draft) that produces a displacement (buoyancy force) that equals the boat's weight.

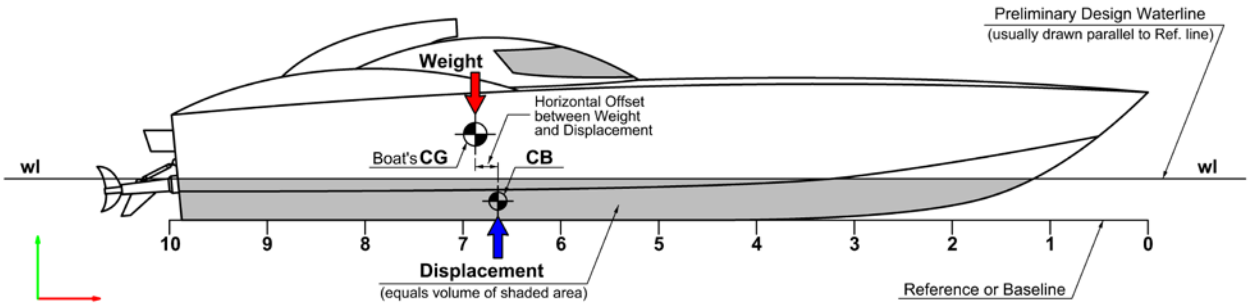

Figure 1

Notice that in this condition what usually happens is that, even when the boat's weight and displacement for the given preliminary Design Waterline are equal, both forces are not aligned, since, as we can see in Figure 1, there is a horizontal "Offset" between their corresponding directions.

The craft's weight is usually assumed to be acting along the Vertical direction, or "-z" in Rhino World coordinates, whereas the Buoyancy force is considered to be acting along the "+z" direction.

Figure 2 shows the boat's final attitude (i.e., hull orientation) after performing a Free-Float hydrostatic analysis of the case shown in Figure 1.

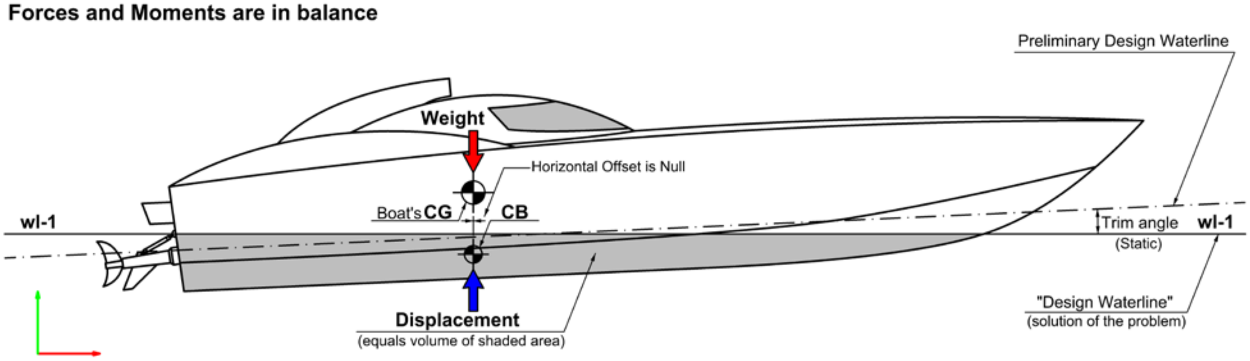

Figure 2

[3] The default coordinate system is positive X aft, positive Y to starboard, and positive Z up. However, Orca3D can accommodate any right-hand rule coordinate system that the user chooses.
[4] Remember that Orca3D's Weight & Cost module provides an excellent tool for weight and CG estimation on your 3D model.

As can be seen in Figure 2, a new “Waterplane” was found (“wl-1”) that represents the craft’s actual attitude for the given weight value and CG position. This is the “Design” waterline (“wl-1”)
Thus, it can be said that, with reference to the previous situation (Figure 1), the hull is now trimming by the stern by the calculated “Trim” angle; and, since the hull is considered to be “at rest,” this is also called a “Static Trim” angle.

Remember that, as the boat is rotated and moved to find an equilibrium, the CG also rotates and moves with the craft, since it always remains fixed to the hull geometry. For this kind of hydrostatic analysis it is always assumed that the CG remains fixed to the hull geometry. On the other hand, we cannot assume the same behavior with the CB, since the CB corresponds to the centroid of the wetted volume; because the shape of this volume changes at each iteration in the analysis, the CB position will change.

So, in this condition (Figure 2), we can see that the net force acting on the craft is zero (i.e., Weight = Displacement) and the net moment is also zero (the horizontal offset between these forces is zero). The boat is in “Static” equilibrium.

Note that for this simplified analysis, it is assumed that the CG lies in the Vertical center plane of the craft (usually the “x-z” plane in Rhino World coordinates), and that the hull shape is port-starboard symmetrical. To find the final vessel attitude the hull was rotated about its transverse axis (trimmed) and moved vertically, until a new wetted volume was found, such that the Buoyancy force it generates equals the boat’s Weight, and its CB is aligned vertically with the CG. Orca3D will compute the resultant static heel angle as well if the hull is not symmetric or if the transverse location of the CG is not in the centerplane.

Another simplification for the sake of this discussion is whether the final equilibrium condition of the vessel is “Stable” or not. The requirements for the “Static” equilibrium of the craft discussed so far are necessary, but not sufficient, to guarantee a “Stable” equilibrium. Once a valid “Static” equilibrium condition is achieved, the next question to ask is what would happen if we apply a small perturbation (e.g., a very small angular displacement) to the craft in the “Static” equilibrium configuration found. Will it return to the “pre-perturbation” condition, or it will adopt a new equilibrium attitude? If it will return, it is a stable equilibrium. An example of an *unstable* equilibrium is a cone, balanced point-down on a table. When perfectly balanced, it is in equilibrium, but if disturbed, it will not return to that equilibrium. Reference 3 provides further explanation of this subject, in the context of hydrostatics.

Dynamic Trim

When performing a Resistance calculation on a planing hull with the aid of the Planing Analysis module available in Orca3D, the “Trim” angle that is reported, also called “Dynamic or Running Trim Angle,” comes from a similar static equilibrium analysis, but for a different kind of problem.

We say “similar,” because one of the tasks that the algorithms within the Planing Analysis module has to perform is, again, to find a balance of forces and moments; but the difference here comes from the very nature and origin of the forces to be considered acting over the craft.

Figure 3 illustrates this new problem and shows the new forces that come into play on this type of analysis.

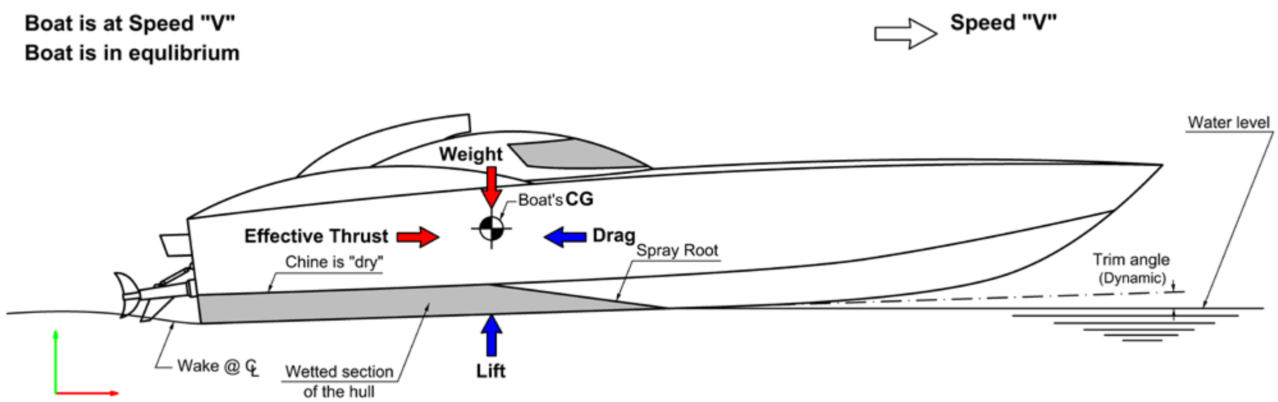

Figure 3

On a planing craft, considering that is running on calm waters at a steady speed, apart from its Weight, three (3) new forces have to be considered for its equilibrium analysis, which are “Lift,” “Drag,” and “Thrust.”

Lift is the “Vertical” component of all acting forces over the hull (e.g., buoyancy, dynamic lift), except Weight, whose principal purpose is to balance the craft’s Weight.

Drag, also known as Resistance, is the “Horizontal” component of all acting forces over the hull that, for the craft to be running at a steady speed, has to be balanced by the “effective” Thrust; otherwise, the craft will slow down. Usually, the “effective” Thrust is to be provided by the propellers, or any other propulsion system under consideration, such as waterjets, etc.

Figure 3 shows the craft in a static equilibrium condition, where the Vertical and Horizontal forces are in balance, and there is zero net moment for the present system of forces acting on the craft.

This is, again, a simple static analysis, since we have reduced a complex dynamic problem into a simple static one. Notice also that, for this equilibrium condition to be achieved, the craft has to maintain a “Trim” angle. The assumption made here to simplify the analysis is to neglect any dynamic effects due to things like waves and wind (i.e., the boat is assumed as running on “calm waters”).

The Savitsky Method

The Planing Analysis module available in Orca3D, developed and licensed by HydroComp, Inc., is based upon the very popular “Savitsky” method.

The Savitsky method relies upon a 2D “Static” representation of the problem; that is, all forces are considered lying in the Vertical centerplane of the craft. For each speed to be analyzed, the method first makes an estimation of the dynamic forces acting over the hull, mainly friction and pressure forces (magnitude, direction, and location) and, second, finds the equilibrium condition among them, including the Weight and Thrust.

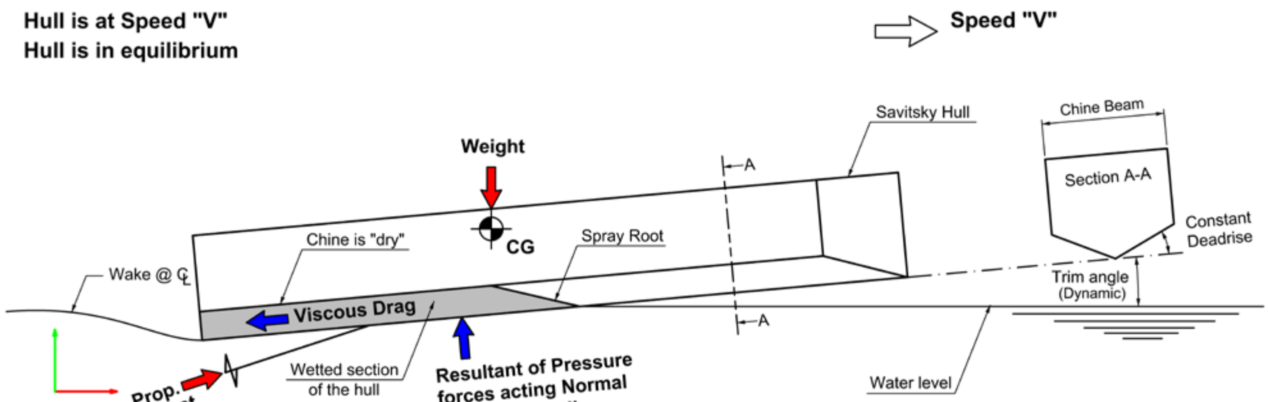

Figure 4

As we can see in Figure 4, the system of forces considered by the Savitsky method is slightly different from the one shown previously in Figure 3. However, the system of forces in Figure 4 can easily be resolved into components parallel to those in Figure 3. Once the equilibrium condition is found, both representations are equivalent and the Trim angle is the same as well.

We can see here that, apart from craft's Weight, the Savitsky method considers (in fact predicts) the resultant of the Pressure forces acting Normal to the hull bottom, the Viscous Drag acting along the hull's bottom (both of them acting within the wetted section of the hull), and it also considers the direction of the Propulsion Thrust, usually the shaft angle for the Propeller thrust.

One "key" aspect of the Savitsky method to keep in mind is that the hull under analysis is not the "actual" hull (i.e., the 3D modeled hull in Rhino). Instead, the Savitsky method creates an "equivalent" prismatic V-type hull, with a constant deadrise angle and chine beam over the entire length of the hull. Even with this simplification the method is very reliable, if used for the analysis of similar hull types, i.e., single monohedron hulls with nearly constant deadrise extending, at least, over the wetted portion of the hull at running speed. Some corrections for warped hulls are available in the implementation of the Savitsky method used in Orca3D.

Figure 5 shows a correlation between the ideal Savitsky hull and our analysis case.

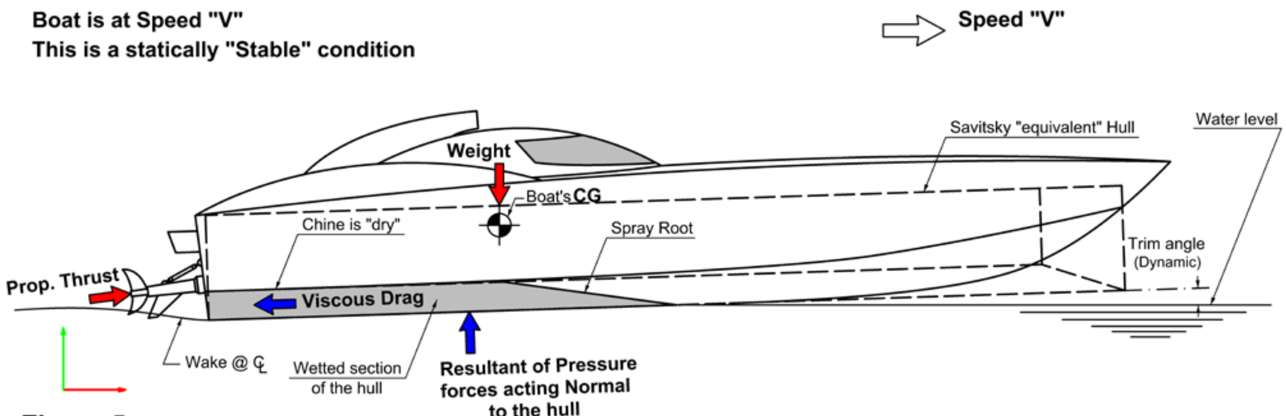

Figure 5

For further details of the Savitsky Method, please see Reference 1 and/or Reference 2.

Conclusion

Coming back to the initial question, we can understand now why the "Static" and the "Running" trim of a planing boat are not directly tied to each other, since each of them are the consequence of a different type of problem and analysis.

However, we have also shown that this is just a simple interpretation of such an answer, since, as explained and shown in the previous sections, it is now easy to identify Weight and CG as common factors that influence both the "Static" and "Dynamic" trim calculations.

But, again, remember that the Savitsky method doesn't take into consideration anything about the "Static" attitude of the hull when it's at rest. It simply has no means to know anything about the hull in this condition. The Savitsky method only attempts to bring us a "snapshot" of the hull, and the main forces acting over it, when the craft is running at the "steady" speed of analysis.

Since the implementation of the Savitsky method in Orca3D gets shape information from the hull in the "as-modeled" condition, it is good practice to have the model oriented so that stations give a good representation of the deadrise. In a hull without rocker in the keel, this simply means having the keel parallel to the longitudinal axis.

References:
1) Lewis, E.V., "Principles of Naval Architecture, Vol. II: Resistance and Propulsion," SNAME 1988
2) Savitsky, D., "Hydrodynamic Design of Planing Hulls," SNAME Marine Technology, Oct 1964
3) Orca3D Help file, in Hydrostatics & Stability/Output.