SCALE HULLFORMS

The purposes of testing the prismatic series were to extend the documented research to higher deadrise angles and to validate the predictive method based on the simple planing shape these hulls projected into the water. Since perfectly prismatic boats are very rare, the next planned step was to expand the testing program to include actual scale hullforms. One of the most important questions the experimenter had in mind from the very beginning of the project was whether or not the stability of a real semi-prismatic hullform, complete with the most common bottom features such as lifting strakes, a keel pad, and a transom notch could be adequately predicted using the same method as for fully prismatic forms. Hull enhancements such as these are usually placed with the intention of improving speed and performance by increasing lift to reduce wetted area and drag.

The first of the two models that was available for this purpose was a 40' modern offshore "deep-V" hullform built to $\lambda=7$ and pictured in Figure 12. This boat is among the most modern of high-deadrise hullforms.

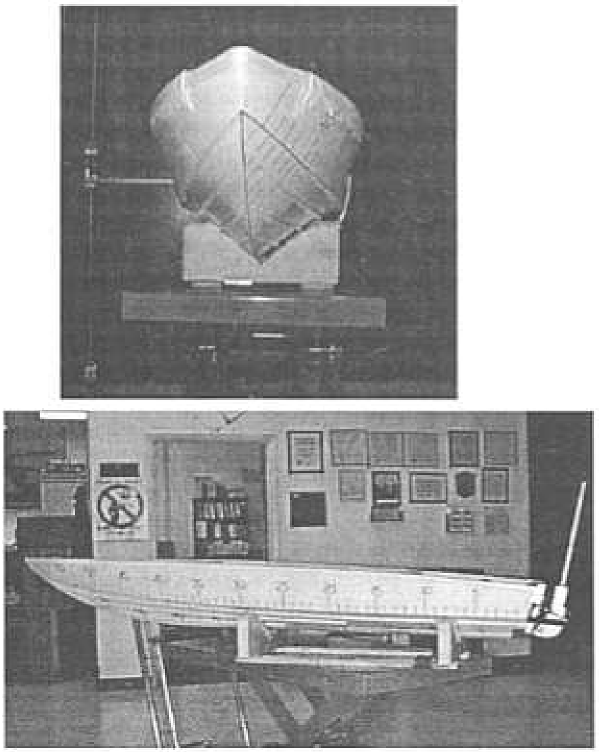

Figure 12 – Modern Offshore Planing Hull

It had been determined during testing with the NAHL prismatic series that the porpoising condition could be avoided at any speed achievable in the 380' high-speed tank by progressively moving the CG of the craft forward. In order to achieve stability at the higher speeds, however, the required LCG for all three deadrise hulls was so far forward that the boat would float statically with a negative trim angle (bow down). From experience, no one would ever configure a speedboat in this manner, not just from an aesthetic perspective, but because it would cause the boat to be highly dangerous in a following seaway. The potential for submarining would become very great, and the boat could take a great deal of water aboard. During testing in this condition, a safety line made of parachute chord was tied to the bow of the model to prevent submarining from occurring. Since it is not practical to move the CG of a full-scale craft underway, except for very small boats where people are a large fraction of the total load, another means must be implemented to control running trim.

When considering the seakeeping abilities of planing hulls, deadrise is very important. Increased deadrise angles lower the severity of impacts with the water's surface associated with the extreme vertical excursions and possible airborne trajectories which can result from driving the boat fast in heavy seas. While Drs. Sottorf and Savitsky had developed an equation to account for the reduction in lift due to deadrise angle, the question arose of how to evaluate the lifting and porpoising properties of a hull with performance enhancing lifting strakes and reverse chines. As a first approximation, the experimenter chose to characterize the lifting surface with an effective deadrise angle, based on the numerical weighted average of the different deadrise surface areas over the after third of the boat. This method seemed reasonable. Later, it was determined that the lifting strakes and reverse chines actually produced much more lift than predicted by simple methods due to cross flow and flow separation, warranting further analysis and an attempt at modeling the strakes using swept wing lifting theory. It was found that as the loading increased on the model, the critical porpoising trim angle suggested that the effective deadrise angle was decreasing, possibly due to the increased wetting of the running strakes, which are truncated well forward of the transom. The inboard pair terminate at 27" forward of the transom, the second pair terminate at 19", and the third pair and the reverse chine extend all the way to the transom. Therefore, as more of the forebody of the model comes in contact with the water, the ratio of the strake area to the normal deadrise planing surface increased dramatically. Not only was more lift being produced by the increased running strake area, but the center of pressure of the strake lift was well forward of the center of gravity of the model, producing bow up moment, and further degrading the porpoising stability of the craft.

Approximately seven months prior to testing, a pair of Kiekhaefer 30" K-Planes, shown in Figure 13 were constructed to one-seventh scale. These trim tabs were made of $^{3}/_{32}$" carbon fiber plates and a single stiffener was epoxied down the centerline of each surface, both to cancel any possible deflection under hydrodynamic loads, and to provide a mounting surface for the adjustable turnbuckle. The turnbuckles were intended for installation as suspension links on a high performance radio-controlled car, but were perfect for the present purpose. They were modified by soldering a nut to the shaft to facilitate manual adjustment while in the water.

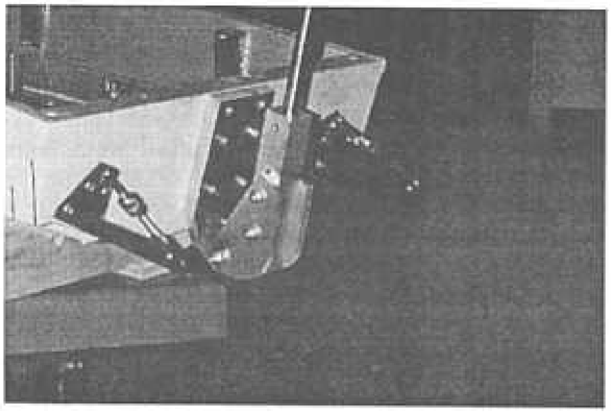

Figure 13 – $\lambda = 7$ Kiekhaefer K-Plane Trim Tabs

The experimenter was faced with devising an accurate method for determining and setting the trim tab deflection while the model was attached to the towing rig. After several ideas were evaluated, it was clear that the most reliable and accurate method was to measure the length of the turnbuckle. At each end of the turnbuckle was a ball joint, which was mounted to the carbon fiber flange, and not on the axis of the trim tab's plates. Since the trim tabs had been designed using AUTOCAD LT, it was a simple matter to confirm the actual positions of each turnbuckle, then actually rotate the bottom plate of the trim tab with respect to the transom plate about the hinge axis. AUTOCAD's measure function was used to find the required turnbuckle length for each tab angle. Since subtle differences existed in the positions of the mounting holes for each tab's turnbuckle, each tab was analyzed separately. The trim tab deflection was defined as the angle with respect to the local buttock line in the vicinity of the tab. The available range of tab deflections when mounted to this model was –1 to 19 degrees with respect to the water flow.

The K-Planes are mounted to the full-scale hull with a one inch vertical offset, meaning that when trimmed parallel to the bottom of the boat, the step up between the boat's bottom and the trim tab surface is one inch, which ensures that the flow does not attach to the tabs when they are in the retracted position, and not needed. The offset is visible as the small strip of transom visible between the bottom of the trim tab and the transom/hull bottom intersection. The goal of these experiments was to determine the required tab deflections to achieve stability. Therefore, it was necessary to learn how to quantify not only the force generated by these very low aspect ratio trim tabs acting on the surface of the water in the boat's wake, but also the effects of installation variations, such as the aforementioned vertical offset, which was expected to produce a reduction in the dynamic pressure acting on the trim tab. Trim tab aspect ratio is defined as span divided by chord.

It was immediately apparent that due to the nature of lifting surfaces, the force generated by trim tabs should be a function of the square of the speed of the water across the trim tab. The potential lifting force on four square feet of tab area traveling at full-scale speeds of 100 ft/sec would be very great indeed. Avoiding porpoising at high speeds requires a large bow down moment, and the (negative) bow down moment created by the vertical component of the trim tab lifting force was expected to produce a similar effect. Offshore speedboat operators have long used these large trim tabs to stabilize their boats which are generally configured with multiple heavy engine blocks mounted just forward of the transom, forcing CG extremely far aft.

In addition to the negative trimming moment generated by the tabs, the experimenter expected the magnitude of the lifting force itself to have an effect on the running characteristics of the craft. At high speeds, the trim tabs would have the potential to generate a lifting force equal to almost one quarter of the weight of the craft itself. In order to maintain an equilibrium planing condition, lift produced by trim tabs lessens the planing load the remainder of the hull is expected to carry. Remembering that the loading of the hull is a major factor in the determination of porpoising stability, the experimenter set out to prove from experimentation and calculation that the porpoising stability characteristics would be affected by both the trim moment and the lifting forces produced by the trim tabs.

The testing procedure used to test the scale model with trim tabs was as follows: the boat was ballasted to typical running conditions. Rather than shifting the position of the center of gravity, as was done for the previous tests, LCG was held constant for each setup, and tests were run at varied speeds and trim tab angles. Initially, the model was run with the trim tabs set at zero deflection, and speed was increased until porpoising occurred. Once operating in the porpoising regime, the trim tab deflection was adjusted on subsequent runs until the porpoising oscillations disappeared completely or were below one degree amplitude, which is just noticeable. The results generally were as expected. Just above the critical porpoising speed for the model without trim tabs, the required trim tab angle to steady the model increased very quickly to the maximum value. As the model was run at higher speeds, less trim tab deflection was required to stabilize the model. This observation was made from full-scale testing data prior to running the model tests, which is the reason it did not come as a surprise. As mentioned earlier, as speed increases, the force imparted by the water on the trim tabs increases as a square function of speed, resulting in the moment produced by the tab "catching up" with the required moment to stabilize the model at high speeds. The normal trends observed during testing of the prismatic series applied to testing the semi-prismatic form with trim tabs as well.

The results of testing with the scale model are summarized in Figure 16 and Table 4, which gives the required trim tab deflection for each porpoising inception point. The predictive curves for this graph were developed by setting the effective deadrise according to the zero tab porpoising inception point, since all other parameters required for the prediction of porpoising trim angle could be predicted. These angles worked out to be 14 degrees for the lightest load through 8 degrees for the heaviest load. The critical porpoising trim angles thus become the "fingerprint" of the hull, allowing its effective deadrise to be determined. In addition, the trim tab deflection was recorded at each critical porpoising point, and the vertical lifting force was calculated, then subtracted from the model's loading coefficient. Equation (1) is still used to calculate the critical porpoising trim angle, except the lift generated by the trim tabs is subtracted, and the effective deadrise value is used.

$$\sqrt{\frac{C_L}{2}} = \frac{\sqrt{\dfrac{\Delta - \text{TabLift}}{\rho * g * b^3}}}{C_V} = \sqrt{\frac{C_\delta}{C_V}} \qquad (7)$$

Equation (7) is to be used in conjunction with Equation (1). The load coefficient in the radical of Equation (7) accounts for lift due to trim tabs, and is also referred to as C_δ in this study. The load coefficient has been adjusted by subtracting from the model's actual weight the lift generated by the trim tabs, and appears as C_δ in Table 4.

V, condition ft/sec	TabDef deg (down)	Cδ	Effective Deadrise
17.5 A	14	0.397	14
20 A	14	0.386	14
24 A	14	0.366	14
27 A	12	0.360	14
30 A	10	0.358	14
32 A	8	0.365	14
17.5 B	4	0.522	10
20 B	14	0.486	10
24 B	18	0.447	10
27 B	19	0.418	10
30 B	18	0.399	10
32 B	15	0.406	10
17.5 C	0	0.564	8
20 C	14	0.518	8
24 C	18	0.479	8
27 C	17	0.462	8
30 C	17	0.438	8
32 C	15	0.438	8

Table 4 – Scale Model Test Data

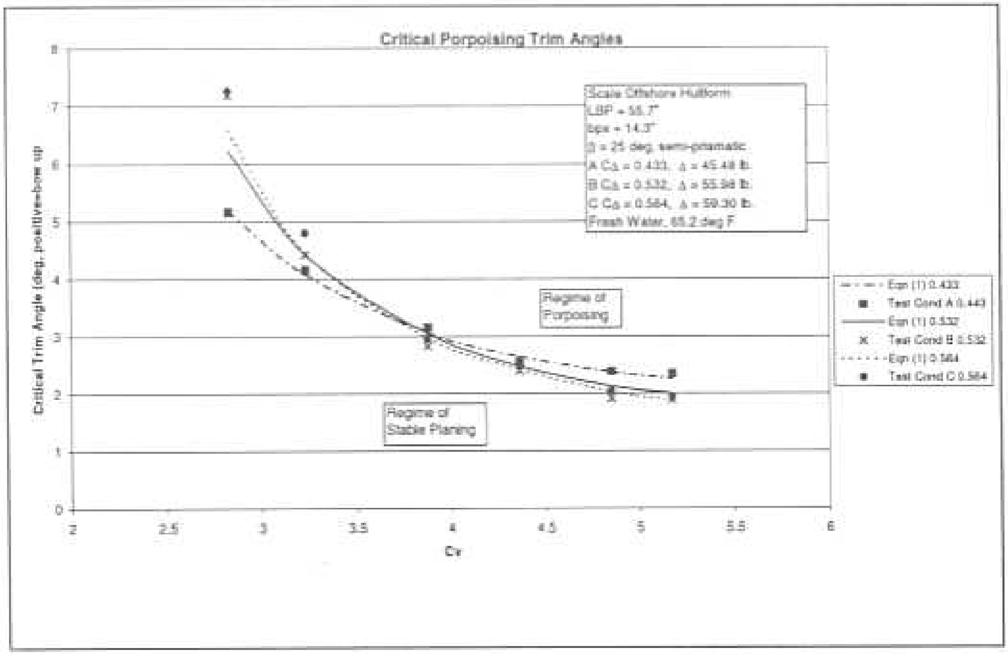

Figure 16 – Experimental Porpoising Inception Boundary for λ=7 Scale Hull form