TESTING PART II

Following the reproduction of Day & Haag's cable towed experiments, the next challenge was to implement a prototype outdrive towing rig, which would apply thrust to the model in a manner more similar to a full scale craft. This effort was considered necessary to quantify the effect of thrust vector location and direction on porpoising inception. The design for the new towing setup evolved over a period of several months. Given that the program's intent was the search for the porpoising inception boundaries, the following criteria were established for the design of a new towing rig:

1. The rig must allow freedom in both pitch and heave with minimal damping.
2. The rig must not interfere with the inception of porpoising.
3. The location of thrust application should simulate typical stern and surface drives.
4. The angle of the applied thrust must be variable, while still satisfying #1.
5. The rig must be stiff to minimize deflections due to loading, which would skew the angle of applied force.
6. The rig must be easily transferable between models, and installation must not cause irreparable damage to the models.

A ½" diameter hardened steel rod, sliding though a precision linear ball bearing block, mounted to a transversely oriented hinge mechanism, was selected for the towing rig because it satisfied all of the above requirements. During initial testing, the pillow block and rod were loaded in the normal direction with a 20lb weight, with the rod suspended between two platforms, causing the worst possible deflection of the rod. It was determined that the static friction could be overcome by applying 0.8 ounces of force, yielding a coefficient of static friction of 0.0025. Version A of the rig saw the ½" rod anchored to the adjustable towing post, and the linear bearing bolted to the hinged plate on the back of the model. This configuration required that the rod be immersed approximately 7" below the surface of the water in order to ensure that the linear bearing would not slide off the bottom of the rod under acceleration to the planing condition, when the stern temporarily sinks very deeply into the water. This setup resulted in several undesirable effects, both due to the immersion of the ½" rod. First, since the rod was less than 3" behind the transom of the model, it was producing a positive pressure field in front of it of unknown magnitude. Second, water flowing up the rod at high speed would impact the bottom of the bearing block, providing an unquantifiable lifting force. Considerable spray was also formed which impacted both the rig and the model transom. It may have been possible to account for this vertical force, except for the fact that the presence of the model operating at

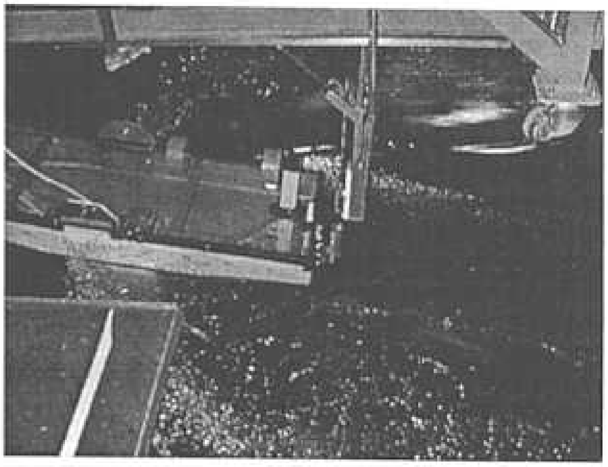

Figure 6 – Towing Rig B with β=20 Model

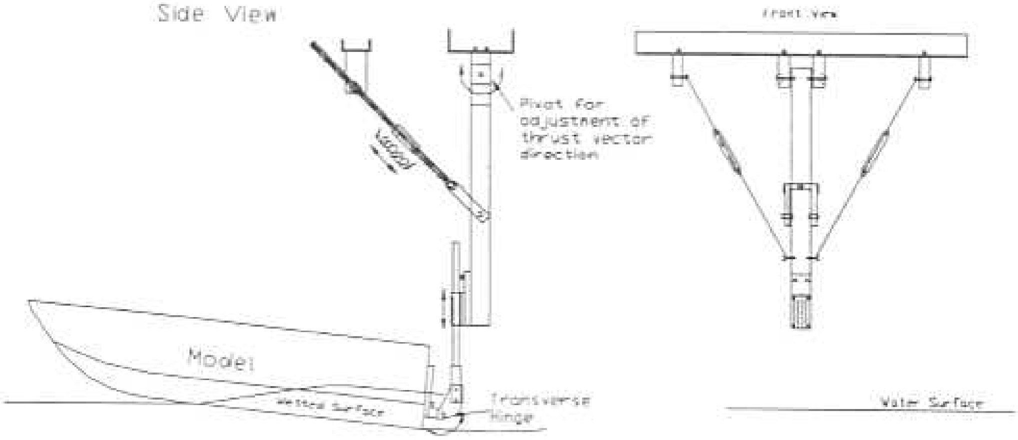

Figure 7 –Towing Rig B

varying displacements, trim angles and speeds in front of the rod would change the amount and speed of the water flowing up the rod. These effects would both result in a lower running trim angle than the model would naturally assume, and would have likely skewed the conditions for the inception of porpoising.

A total of six trial runs were made with the Rig A before the decision was made to dismantle it and use many of the same parts to construct Rig B. The principle of operation remained the same, but the parts were rearranged. A ½" hole was bored longitudinally into a 1" x 1" x 6" aluminum block. The rod was force-fit into it, and secured with set screws. This block was fastened to a plate to which was attached the hinge which would allow pitching freedom.

The vertical height of the transverse hinge axis was the point at which the thrust was taken to act, the values for which are given in Table 1. This hinge point was determined by mounting the towing bracket on each model hull in the lowest possible position without any portion of the rig extending below the expected flow path of the water, eliminating the need to quantify the very complex dynamic forces mentioned above. If any part of the hinge mechanism touched the water, it would be readily apparent because of the spray and wake patterns produced. The angle of deadrise of the different boats controlled the vertical position of the hinge axis. Rig B, shown in Figure 6, clearly results in clean and undisturbed flow from the model transom.

Table 1 – Vertical Location of Thrust Point

Model	Height Above Keel (in)
15 Degree Deadrise	1.5"
20 Degree Deadrise	1.6"
25 Degree Deadrise	2.0"

In addition to the apparatus mounted at the transom, it was necessary to provide yaw restraint since the linear block bearing would not provide any yaw restraint itself. To accomplish this, a fork-like device was constructed by boring parallel ½" holes in a PVC block, and mounting it to the bow of the boat. A 1" rod was fastened to lockable bushings and centered on the vertical rail module in front of the boat, so that the fork mechanism straddled the 1" rod. The spacing of the parallel rods was chosen so as to leave a total of $^{1}/_{10}$" of play laterally to prevent any binding. The yaw restraint kept the boat aligned with the tank during the test runs, and the minimal surface contact between the two hardened steel rods did not appear to apply any significant unwanted damping to the system. Figure 8 shows a model at speed with the bow yaw restraint clearly visible. On several occasions, either the model's bow or the cap placed on the end of the yaw restraint impacted the 1" vertical rod. This occurred mainly on runs with extreme porpoising amplitudes, and did not affect the conditions present at the inception of porpoising. The longitudinal position of the restraining rod was adjustable to suit different models, and different testing conditions.

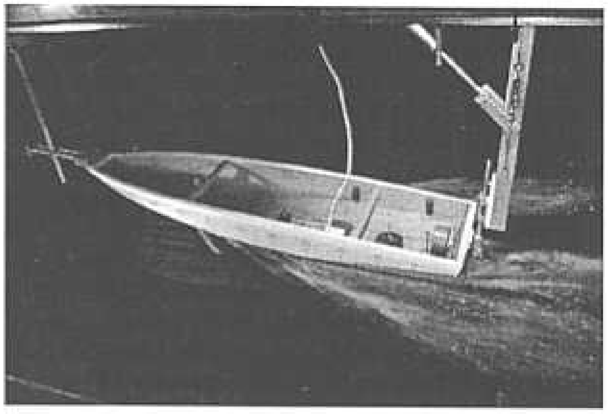

Figure 8 – Towing Rig B, Showing Yaw Restraint and Towing Bracket.

Testing was begun with the 20-degree deadrise hull for immediate comparison with the testing done with the Day & Haag style cable rig. As expected, the application of the propulsive force at a point low on the transom raised the running trim angle for the same LCG setup. For the NAHL deadrise series, the drive angle was set to a value so as to provide a force perpendicular to the transom, and parallel to the keel; however, drive angle variations were made on several runs to analyze their effects. Drive trim angle adjustments were accomplished by turning the ½" threaded tie-rod, visible in Figures 7 and 8. The threaded rod was anchored but free to rotate at the vertical post end. The other end was threaded into a tapped aluminum block attached to the vertical rail module of the towing carriage. Adjusting the length of this tie-rod varied the angle of the towing post. The linear block bearing, due to its very low friction was only capable of providing a force perpendicular to the ½" rod. Therefore, when angled, the rod and bearing combination would provide driving force perpendicular to the rod.

As was done for the first testing series, LCG changes were made to the model for each speed. Pre-test estimates of the LCG values were made by calculating the change in trim moment due to moving the thrust point. The resistance values from the first series of tests were used, and the change in moment was accomplished by moving LCG forward. The LCG and trim angle were recorded at the inception of porpoising for two different loadings for each of three different deadrise models. In general, a porpoising inception point could be determined in three to four runs in the towing tank. The results were compiled and plotted using the method established in the previous section. The LCG values required to achieve stability using Towing Rig B corresponded to G being up to four inches further forward than for the cable rig. Figure 9 clearly indicates that the trim angle was responsible for determining whether or not porpoising would occur for a given load. This observation confirms the popular presumption that the inception of porpoising is a function of the geometry of the water flow beneath the boat's hull, due to the running trim angle. For each run, beginning with the original cable towed runs, the time histories of all data signals were saved, enabling spectral analysis to be performed on the trim signals for selected runs. By using Quattro Pro's Fourier Analysis function, the oscillations of the model could be broken down into their characteristic frequencies and amplitudes. Because the angle of the propulsive force did not follow the model as it pitched, the rig did not dynamically scale a real boat, but the purpose of the spectral analysis was to quantify the inception of porpoising, and not to measure large motion amplitudes, far beyond inception. The experimenter initially characterized porpoising by "feel" by drawing on experience with full scale planing boats. Because this was not a scientific approach to the problem, the spectral analysis was used to determine for a given test run whether or not porpoising had occurred. By comparing the experience-based pitch amplitude threshold for porpoising inception with amplitudes determined using spectral analysis, the experimenter concluded that a spectral density equivalent to a one-degree amplitude at a given frequency constituted porpoising inception. Quite coincidentally, it was found in Day & Haag's report that they had determined porpoising to begin when the double amplitude of the pitching motion equaled two degrees! This showed that the "gut feel" for the inception of porpoising was similar for different naval architects, separated by 46 years.

When operating just at the boundary of porpoising inception, the model would respond to small waves in the tank by oscillating several times after encountering them. This motion, no matter how subtle, was immediately distinguishable. If the model encountered several waves in series of the same wavelength, it would produce repeated oscillations similar to porpoising, except that the characteristics of the motion were noticeably different. During testing, wave driven oscillations never appeared to occur exactly at the model's natural porpoising frequency, and when encountering a series of waves, the model would usually impact one harder than the others. A similar, but abbreviated battery of tests was performed for both the 25 and 15 degree deadrise models, using Towing Rig B. The results were plotted in a similar fashion and appear in Figures 10 and 11. The three prismatic hulls performed quite differently, especially when subject to heavy loads.

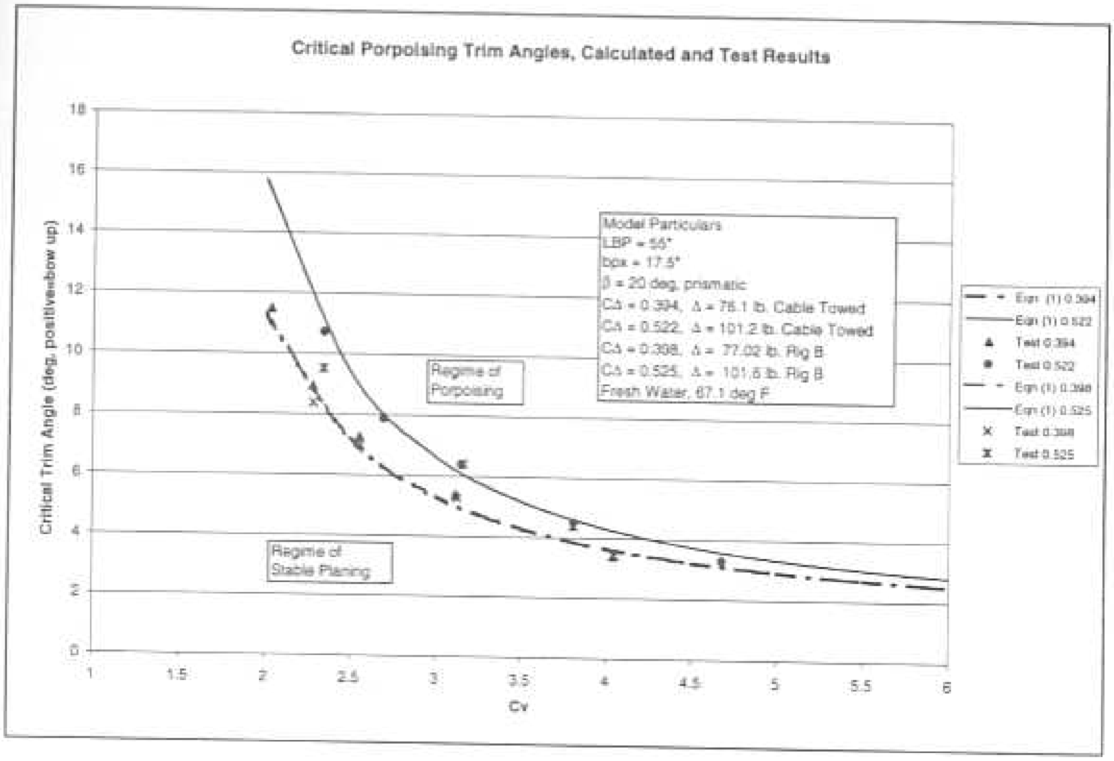

Figure 9 -- Experimental Porpoising Inception Boundary for Prismatic Hull Forms , $\beta = 20°$

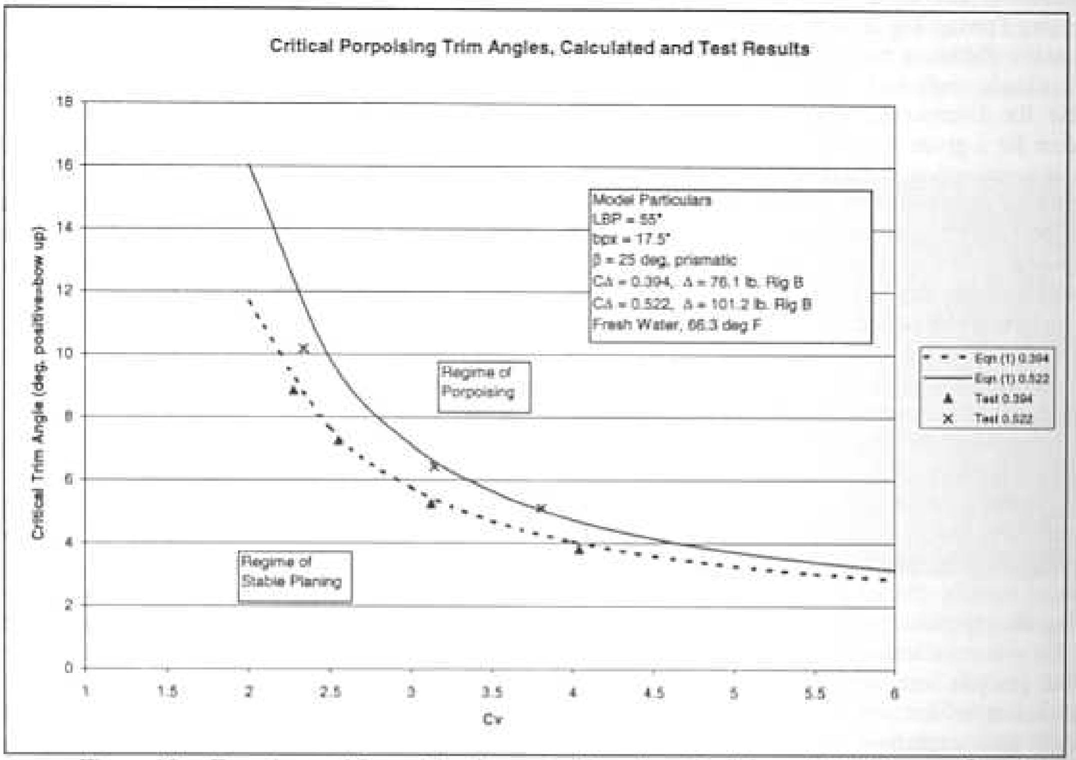

Figure 10 -- Experimental Porpoising Inception Boundary for Prismatic Hull Forms , β = 25°

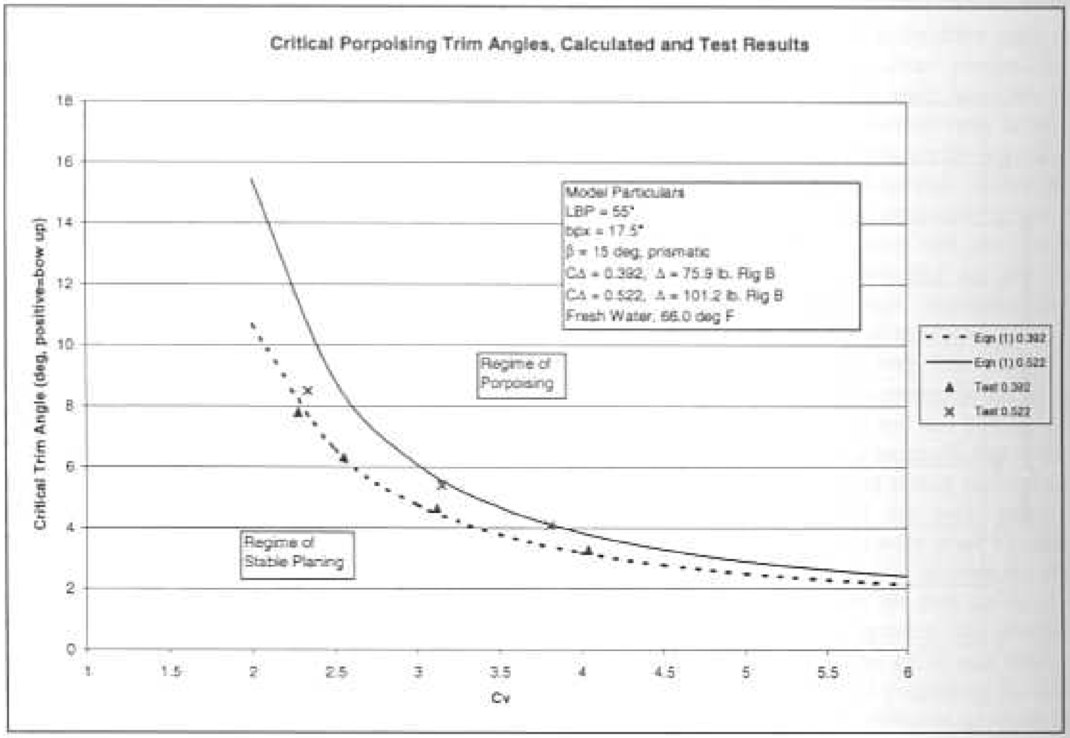

Figure 11 -- Experimental Porpoising Inception Boundary for Prismatic Hull Forms , β = 15°