The Dynaplane Planing Motorboat Design

Eugene P. Clement*, John Hollingsworth** and Robert Scher**

*David Taylor Model Basin (Retired)
**Alion Science and Technology, Alexandria, VA

ABSTRACT

A significantly improved design for motorboats can attain planing speeds with approximately half the power required by conventional planing hulls. Accordingly, Dynaplane craft can offer significant savings in fuel consumption, produce correspondingly reduced environmental impacts, and potentially can take advantage of lower-powered alternative propulsion concepts. The Dynaplane is a stepped craft with a planing region near amidships, and a hydrofoil at the stern. At planing speeds, approximately 90 percent of the weight of the boat is supported by the planing region. Significantly, the planing surface incorporates camber and can take advantage of efficient trim control provided by the hydrofoil. As a result of these features, the required planing lift is developed with a minimum of wetted area and frictional resistance, while the curvature of the cambered surface also results in reduced pressure drag, which constitutes the other major component of resistance.

Keywords: planing boats, resistance, powering

1 INTRODUCTION

From the purely environmental standpoint there is an inherent difficulty confronting the designers and users of powered boats. Obviously, pleasure craft (and to some extent small commercial vessels as well) tend to operate in the most environmentally desirable and often the most *sensitive* areas. At the same time, a usefully high speed is a key attribute for most boat owners: this drives the vast majority of small-craft designs into the planing boat design regime. In turn, utilizing conventional planing hull designs, the need for high speed drives designers in the direction of high installed power.

With a given engine technology, and assuming that engine condition and maintenance are comparable, a higher power requirement inevitably results in increased fuel consumption. As boat owners are painfully aware, at this time in particular, costs of operation (and importantly, uncertainties regarding costs) are increasingly related to fuel. Consequently, differences in planing boat powering performance are an increasingly important element in operating decisions (for the owner), and design and marketing decisions (for the boat designer and builder).

Moreover, with stringent prohibitions on waste-water, oily bilge water, and non-power-related discharges, the environmental effects of pleasure or small commercial craft are often dominated by powering levels. Environmental impacts that are directly related to power include:

- Engine-related emissions (that is, exhaust products), both airborne and residual into the water
- Noise
- Wave wakes

The desire to reduce the powering requirements of planing craft has never been stronger than now, with both economic and environmental incentives. Dynaplane represents an opportunity to achieve a significant improvement in planing craft powering performance.

2 DYNAPLANE

Dynaplane, a radical improvement in the design of planing motorboats, has been brought to a significant stage of development. The basic elements of the concept include the following:

1. Planing surface, near amidships, optimized with high aspect ratio and camber, with its aft edge in the form of a shallow, re-entrant (chevron) step.
2. Hydrofoil (surface-piercing or fully submerged) serving as an aft lifting surface and as a stabilizer.
3. Afterbody (aft of the step) arranged so as to remain entirely unwetted once the craft is on plane.

Based on this design, craft of a considerable range of sizes can reach and maintain planing speeds on approximately half the power required by conventional planing hulls. This improvement in planing hull performance has been developed through extensive theoretical and experimental work in hydrodynamics – the extremely low drag has been verified accurately by model tests, performed in the towing tanks of the U.S. Navy and at the Stevens Institute of Technology, as reported in [1] and [2].

A potential application of the concept, a special-purpose patrol craft, is illustrated in Figure 1. This application makes use of several advantages that arise from the Dynaplane configuration, apart from its substantially reduced power at planing speeds. Above all, though, it is the dramatic reduction in required power that gives Dynaplane the important potential of improving the fuel economy and environmental character of small craft, across a wide range of the industry.

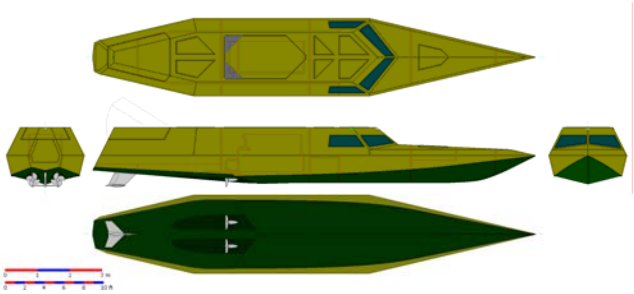

Figure 1: Dynaplane application example: 45-ft special purpose patrol craft.

2.1 Basic Planing Boat Powering

To understand the powering advantage of Dynaplane, a brief overview of planing boat resistance and powering terminology may be useful for the general technical reader.

The propulsion power of a boat can be expressed as:

$$P_t = V\,R_t \,/\, \eta \qquad (1)$$

where P_t is power (measured, for example, at the engine coupling), V is the speed of the boat, R_t is the total (calm-water) resistance, and η is the over-all propulsive efficiency. The resistance of a craft, R_t, is expressed as the sum of several components which, for practical design purposes in the planing regime, can be examined and treated separately:

$$R_t = R_{fric} + R_{press} + R_{append} + R_{air} \qquad (2)$$

Here, R_{fric} is the resistance due to skin friction acting on the wetted surface of the boat; R_{press} is the so-called pressure drag, which results from the horizontal component of the summation of forces acting normal to the wetted hull surface. The drag associated with underwater appendages, such as rudders, exposed shafting, brackets, or other hull fittings is grouped in the term R_{append}; R_{air} is the air resistance of the above-water portions of the boat.

Of these components, R_{fric} and R_{press} typically account for most of the total calm-water resistance of most high-speed craft. Generally, R_{fric} can be reduced significantly only by reducing the area of the wetted surface. The pressure drag R_{press} can be reduced, for a given lift, by favorable variations in the distributions of pressures over the surfaces.

For a Dynaplane, in principle, R_{press} may be defined to include the induced drag of all the lifting surfaces, that is, both the planing surface and the hydrofoil. Similarly, R_{fric} may be defined to include the frictional drag of the hydrofoil as well. Struts supporting the hydrofoil, to the extent that they do not develop useful lift themselves, can reasonably be considered as appendages: their contribution to drag is essentially parasitic.

The propulsive efficiency η in Eq. (1) is the product of the efficiencies of all components that introduce losses between the power supplied at engine coupling and the power actually imparted to the motion of the boat through the water. These components include the propulsor (waterjet or propeller, in which the losses are essentially hydrodynamic), the transmission, and other system losses such as shaft bearings and seals. (In general, η also includes a factor which captures the effects of hydrodynamic interactions between the hull and the propulsor: however, in high-speed planing boat designs this factor is often quite close to unity.)

It is to be noted that reduced resistance generally permits a higher propulsive efficiency as well. Consequently, a design with lower resistance at a given speed obtains an additional benefit in required power.

2.2 Dynaplane Resistance

At planing speeds, approximately 90 percent of the weight of a typical Dynaplane boat is carried by the planing surface and about 10 percent by the hydrofoil. Because the planing surface incorporates optimal sweepback of the step, the planing surface can operate at a relatively high aspect ratio (ratio of span to mean wetted length) compared with conventional unstepped hulls, as shown in Figure 2.

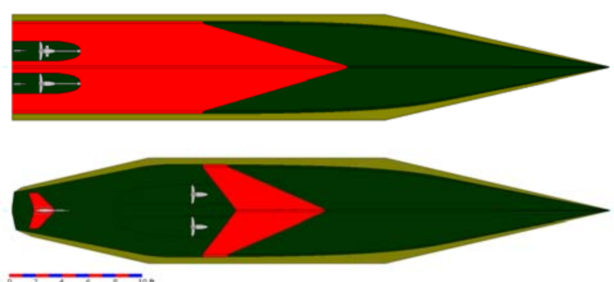

Figure 2: Comparison of planforms of Dynaplane and conventional planing boat lift-producing surfaces.

Apart from wetted surface reduction, which directly reduces the frictional resistance, the high aspect ratio and cambered planing surface produces lift more efficiently than a conventional planing hull, for reasons that are analogous to the corresponding efficiency of high aspect ratio wings in aircraft design.

It is instructive to compare the planing wetted areas of a Dynaplane boat and a comparable conventional planing boat. Consider a typical case: the design of a 32-ft craft weighing 13,500 lb, for a design speed of 45 mph. The wetted area of the Dynaplane design (including the upper and lower surfaces of the hydrofoil) is 40 ft² and of a typical conventional design about 136 ft². Accordingly, running at the same speed and weight, the Dynaplane will have approximately one-third as much frictional resistance as the conventional design. With frictional resistance typically representing about half of the boat's total drag, the wetted surface reduction alone would indicate a saving of over 30 percent on total resistance. The reduction in pressure drag due to the efficiency of a higher aspect ratio planing area, along with camber, increases the over-all powering benefit to the neighborhood of 50 percent, as indicated in Figure 3.

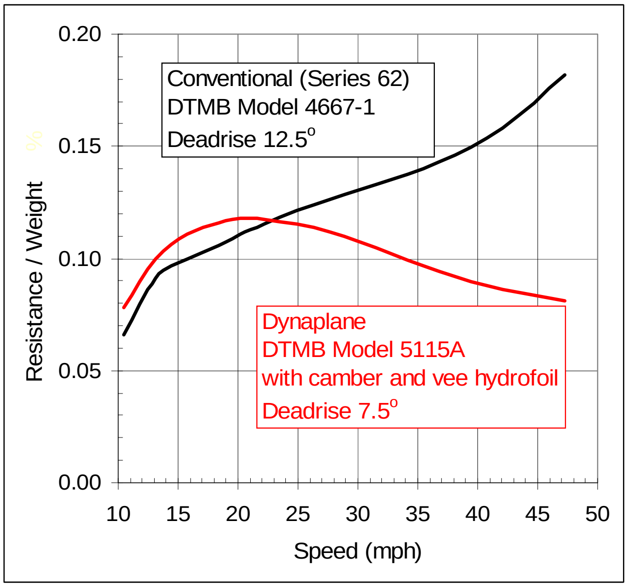

Figure 3. Typical resistance/weight curves for comparable conventional and Dynaplane motorboat hulls, boat weight 13,500 lb, adapted from [1].

Camber, that is, the concave curvature of the surface in the longitudinal direction, improves the distribution of pressures on the planing surface and reduces losses (induced drag) for a given lift. Optimum camber shapes for a high-aspect ratio planing surface were originally derived based on hydrodynamic analyses of supercavitating foils operating near the free surface, as described for example in [3]. Modern analytical tools can make it possible to derive ideal camber distributions (both longitudinally and spanwise) which will achieve further pressure drag reductions over a range of loading conditions.

With the hydrofoil acting as a stabilizer, Dynaplane can take advantage of the swept, high aspect ratio planing surface without encountering longitudinal instabilities (porpoising) which often affects very fast, lightly loaded unstepped planing boats. Furthermore, adjusting the incidence of the hydrofoil makes it possible to trim the boat to achieve optimum running angles for different speeds and loads. Because of its relatively long moment arm the hydrofoil has considerable trim authority. Thus, rather small changes in its angle of attack are sufficient to trim the boat, and consequently the foil does not impose excessive drag penalties of its own.

The ability to change trim efficiently permits the boat to adapt running angle to various wave conditions. In calm water, for example, the hydrofoil incidence can be set for a trim giving minimum drag. Running in a head sea, trim angle can be reduced to mitigate wave impact accelerations and provide a more comfortable ride. In a following sea, trim angle can be increased to reduce immersion of the bow in the backs of waves; this aids over-all controllability as well as reducing wetness and spray forward.

3 ENVIRONMENTAL BENEFITS OF REDUCED POWER

As mentioned above, important environmental impacts that are directly related to small-craft powering include the following:

- Engine-related emissions
- Noise
- Wave wakes

Other considerations aside, engine emissions and airborne noise levels are directly attributable to *total* power, as these environmental effects originate from the power-plant itself. Depending on propulsion system configuration, underwater radiated noise levels may be dominated by engine exhaust-system or propulsor sources, or both (varying with speed) but again these effects are determined by total power.

By contrast, the wave system generated by a boat is especially related to the pressure drag of a hull rather than the frictional component. Accordingly, wave wakes are strongly influenced by the length and trim angle of the planing surface. Wave wakes impinging on shoreline property, or on other watercraft nearby, are a particularly noticeable influence of motorboats on the environment, especially in sensitive areas. Reducing pressure drag, with effective trim provided by the hydrofoil, it is reasonable to suppose that a prudent operator would be able to reduce this particular environmental effect over a wider range of boat speeds and loads.

In short, motorboat environmental impacts are significantly reduced if the boats themselves are more efficient from the standpoint of powering.

4 ENABLING APPLICATIONS OF ALTERNATIVE POWERING TECHNOLOGIES

Not surprisingly (in view of today's fuel prices, not to mention environmental concerns) the search for alternative powering technologies is continually gaining in importance, technical and financial resources, and numbers of active participants. The emergence of promising battery and electric motor technologies, especially in the automotive field, is a case in point. Fuel cells of various types (using hydrogen or other fuels) have also been under development and developers are in search of potential applications, including the marine field, although not yet for small boat propulsion.

However, the application of battery-electric or hybrid drives for small watercraft, apart from electric trolling-motor applications (very low powers and speeds) and a few other specialty boat types, has not kept pace with recent automotive developments. There are several reasons why this is so. Of course, regenerative braking (for example) cannot be taken advantage of in typical marine duty applications, as it can in city driving or when descending hills. But more to the point, battery-electrics are still down on power, and even more so on range, when compared to gasoline or diesel power, while initial costs have been significantly higher, at least so far.

This is not to say that battery-electric boats are incapable of achieving planing speeds. That has certainly been accomplished, at relatively small scales, even without extremely sophisticated or costly batteries, or the most advanced motor technologies [4]. However, battery-electric power has not yet emerged as a practical alternative to gasoline or diesel power for motorboats in the pleasure craft market, and the principal reason is energy-storage density and, as a result, range and endurance. With further advances in battery and electric motor technologies, of course, this situation may ultimately change. If and when it does, it is reasonable to expect that it will happen first for boat designs with unusually favorable powering characteristics at cruising speeds, such as Dynaplane.

In any case, there are significant economic and environmental advantages in a design that yields more efficient powering for motorboats, even with present propulsion technologies, and which also helps open the door to possible future innovations in small boat power systems. Among the advantages that can be achieved immediately are dramatic savings in fuel consumption, along with reduced engine emissions and noise. Ultimately, a more efficient planing hull type may reduce our reliance on higher-powered gasoline or diesel engines, while still attaining small craft performance that meets the needs of the majority of motorboat owners.

REFERENCES

[1] E.P. Clement and J.G.Hoyt III, “A Parametric Study of Dynaplane-Type Planing Motorboats,” First Chesapeake Power Boat Symposium, Annapolis, MD, March 2008.

[2] E.P. Clement, *A Configuration for a Stepped Planing Boat Having Minimum Drag (Dynaplane Boat)*, 2nd ed, 2005, (published by the author).

[3] V.E. Johnson, Jr., "Theoretical and Experimental Investigation of Supercavitating Hydrofoils Operating Near the Free Water Surface," NASA Technical Report R-93, 1961.

[4] See, as an example, the results of solar electric boat competitions at http://www.solarsplash.com