Technical Note

Aerodynamic Characteristics of a Hybrid Trimaran Model

Konstantin I. Matveev[a], Victor A. Dubrovsky[b]

[a] Corresponding author

Address: Art Anderson Associates
202 Pacific Avenue
Bremerton, WA 98337
USA

Phone: 360-490-3586

Fax: 360-479-5605

E-mail: matveev@hydrofoils.org

[b] Independent ship designer, Russia

Abstract

Ultra fast marine vehicles can substantially benefit from aerodynamic unloading. The subject of this study is aerodynamics of a hybrid trimaran that comprises three wave-piercing planing hulls and a wing-shaped superstructure. This configuration is characterized by high efficiency and good seaworthiness at speeds about twice those of contemporary fast ferries and combat ships. Aerodynamic coefficients of the above-water structure of the hybrid trimaran were measured in a wind tunnel. A computer code based on the vortex lattice method is applied for modeling steady aerodynamics of this structure in a range of attack angles. The application of an interceptor at the pressure side of the wing is shown to produce significant increase in aerodynamic lift.

Keywords: Aerodynamic lift, trimaran, wing-in-ground, planing hull, scale effect, CFD.

Introduction

The speed range of modern fast commercial and naval ships does not differ significantly from the speeds achieved by advanced marine vehicles several decades ago. High-speed motion in the water, which is much heavier and more viscous than the air, results in significant friction and wave resistance. Applications of planing surfaces and hydrofoils to lift most of the ship hull out of water with a purpose to increase the speed had limited success. Cavitation phenomena on hydrofoils and restricted seaworthiness, reduced efficiency, and stability problems of planing hulls are the main barriers for the growth in speed.

Aerodynamic support can undoubtedly benefit marine craft in higher speed range, because of significant augmentation of aerodynamic lift in the motion near the water (ground) surface. Wing-In-Ground (WIG) vehicles have proven to work well at speeds several times higher than those of fast ships. However, the complexity of WIG structure and dynamics, which leads to high cost and safety issues, still limit WIG's application to either experimental or small commercial craft. The WIG concept differs so much from traditional ships that WIG's can be considered as an intermediate class between ships and airplanes. Less drastic growth in speed and more gradual development of marine craft is achieved by using hybrid systems that comprise elements of both conventional marine vessels and WIG's. Such craft can be classified as ships with aerodynamic support.

Only aerodynamic properties of one such vehicle are the subject of this study. The main components of a hybrid trimaran under our consideration are three planing hulls, an above-water platform of aerodynamic shape, and struts connecting the platform with the planing hulls. A schematic view of one possible configuration of the hybrid trimaran is shown in Fig. 1, and an artist impression of such a craft as a large car-passenger ferry is presented in Fig. 2.

Some concept designs of this vehicle and specifications projected to the full scale have been reported (Dubrovsky & Lyakhovitsky, 2001, Dubrovsky, 2002, Dubrovsky & Matveev, 2004). In previous publications, this craft was also named as a wave-piercing trimaran to contrast it with the wave-piercing catamarans, a well-known concept in the fast ferry community.

A motivation for using three planing hulls with relatively low length-beam ratio comes from higher efficiency of such hulls in the planing regime, larger overall deck area, and dynamic stability achieved by a planing trimaran configuration with a central hull displaced forward. The above-water platform has a wing shape, so a significant aerodynamic lift is produced on this platform. More than half of the total ship weight can be supported aerodynamically near the high speed limit; and this limit is imposed mainly by the power of available propulsion systems. The aerodynamic platform also improves ship's dynamic stability and ride quality in rough seas.

The above-water superstructure of the hybrid trimaran on the model scale has been tested in a wind tunnel. Experiments are briefly described in the next section. A Computational Fluid Dynamics (CFD) code, based on the vortex lattice method, has been applied for studying steady aerodynamics of the hybrid trimaran. Numerical results are presented and discussed in the following sections.

Model tests

Aerodynamic experiments with the hybrid trimaran model were conducted in the wind tunnel of Krylov Shipbuilding Research Institute. Aerodynamic lift, drag, and moment characteristics of the above-water superstructure were determined. Measured aerodynamic coefficients are presented in the Results section, where these data are compared with numerical results.

The part of the hybrid trimaran model that stays underwater was cut off. The model was placed above the solid floor that imitated the water surface. Aerodynamics of the craft in the ground effect may depend on the ground surface type (e.g., water or solid surface), but only if the wing trailing edge is in the extreme proximity to the ground. In early-stage design, the difference between the water and solid surfaces can be neglected for most operational conditions.

The model schematic was similar to that shown in Fig. 1 but with slightly different planform proportions and taller and thinner struts. The platform can be approximated by a wing with a variable chord, similar to a CFD model shown in Fig. 3. The horizontal and vertical location of the trailing edge relative to the ground is constant along the span. The relative thickness of the wing section at the tip is about 17%. The aft parts of the wing longitudinal sections are the same as that at the tip. The fore parts of longitudinal sections are also the same as at the tip profile, except for the sections near the centerplane where the fore part becomes slightly blunter. The lower side of the wing is mainly flat, except for a small region near the leading edge. The effective aspect ratio of this wing is about 0.53.

Lift coefficients were measured at two representative attack angles, 0.35 and 3.5 degrees. The attack angle is defined as the angle between the horizontal plane and the flat part of the lower wing surface. The relative clearances corresponding to these attack angles were $h/c \approx 0.064$ and 0.038, respectively, where h is the distance between the trailing edge and the ground, and c is the wing chord at the centerplane. In the tests, Reynolds number based on c was in the range $1-3 \cdot 10^6$.

Additional tests were conducted with an interceptor placed on the lower platform surface at the trailing edge. An interceptor is a short plate that is pulled out the lifting surface perpendicularly to the flow with a purpose of augmenting aerodynamic lift and changing aerodynamic moment. In the ground vicinity, this effect becomes even stronger when interceptors are placed on the wing lower surface. Similar in spirit interceptors are being used to control hydrodynamics and dynamics of some fast ships. The size of an interceptor applied in the model tests was variable in the span-wise direction; and its height was approximately equal to 1% of the local chord.

Computational approach

The potential-flow computer code Autowing (Kornev et al, 1998) based on the vortex lattice method is applied for numerical investigation of the hybrid trimaran aerodynamics. This program was thoroughly and extensively validated for steady and unsteady motions of various WIG craft (e.g., Kornev & Treshkov, 1992, Benedict et al, 2002, Kornev & Matveev, 2003). An important feature of the code version we use is the placement of filaments of vortices and sources on the wing chord surface, in contrast to the horizontal plane. This results in significant nonlinearity of aerodynamic forces in the ground effect that cannot be neglected in practical WIG design (Benedict et al, 2002).

The vertical structural elements are modeled using thin plates. For relatively thick struts of the hybrid trimaran, and especially for comparison with tests at the model scale, this substitution certainly leads to errors due to some exaggeration of the actual wing area and viscous effects, such as flow separation. Viscous solvers may produce more accurate results (e.g., Hirata & Kodama, 1995, Wu & Rozhdestvensky, 2001), but their complexity for realistic configurations of aerodynamically supported fast craft makes vortex lattice methods more attractive practical tools (Benedict et al, 2002). Another simplifying assumption made in our study is neglecting the vortex-wake roll-up.

The first step in our computational approach is to generate a virtual model of the hybrid trimaran, which is shown in Fig. 3. The strut parts below the ground plane are cut off, so the strut sizes depend on the ground clearance and attack angle. Only one half of the model is used in computations, assuming symmetry of the flow with respect to the centerplane. Inviscid lift, drag and moment are calculated by the code. After that, the contributions of viscous forces, including drag of the upper parts of the hulls that appear above the ground surface, are added to the drag and moment using empirical formulae (Hoerner, 1965, Kirkman & Kloetzli, 1980). The addition of viscous forces in an empirical form is simple, but it reduces the accuracy of computations.

For modeling a configuration with an interceptor applied on the lower wing surface at the trailing edge, the aft part of the wing section (3% of the chord) was bent to generate the trailing edge downward displacement by 1% of the chord (as in tests). The resulting scheme is, of course, only a rough approximation of the interceptor-augmented system for aerodynamic analysis.

Results and discussion

The results are presented in the form of lift, drag, and moment coefficients that are defined as follows

$$C_L = \frac{2L}{\rho U^2 A}, \tag{1}$$

$$C_D = \frac{2D}{\rho U^2 A}, \tag{2}$$

$$C_M = \frac{2M}{\rho U^2 Ac}, \tag{3}$$

where L and D are the aerodynamic lift and drag, M is the aerodynamic moment (defined here relative to the wing trailing edge), ρ is the air density, U is the incident flow velocity, A is the characteristic area (taken as a wing planform area), and c is the wing chord at the centerplane.

Convergence studies were undertaken to determine the number of panels (for half of the trimaran configuration) necessary for accurate calculation of inviscid forces. The dependence of computed aerodynamic coefficients of inviscid forces on the number of panels for two test conditions (without interceptor) is shown in Fig. 4. The number of panels 9100 was considered to be sufficient for this study, and this panel discretization was used in all other calculations.

Numerical results and available experimental data for three aerodynamic coefficients are presented in Figs. 5-6. First, let us discuss a configuration without an interceptor. There is a satisfactory agreement for the lift coefficient at clearance 0.038 and attack angle 3.5 degrees and some overpredicting at clearance 0.064 and attack angle 0.35 degrees. This overpredicting may be due to unaccounted flow separation at the upper wing surface, which becomes less important at lower clearances to the ground. The drag coefficient is significantly underpredicted. This is most probably due to unaccounted (by calculations) additional viscous effects, such as flow separation, viscous interaction between system elements, and the boundary layer at the ground in the wind tunnel (e.g., Basin & Shadrin, 1980). These effects can be especially significant at low Reynolds numbers on the model scale. The moment coefficient is underpredicted with lower error, since more accurately determined lift is considerably higher than drag. The sign of this discrepancy indicates that the net force is applied further upstream in reality than in calculations, which may be due to the viscous and volumetric effects of the stern struts.

Both experimental and numerical results demonstrate that a significant increment in the lift (40-80% in the range of studied attack angles) can be achieved in the system with an interceptor, showing the effectiveness of using such a small device. This is naturally accompanied by the increase in the drag coefficient. The correspondence between predicted and measured lift coefficients is similar to that of the configuration without an interceptor. The drag coefficient seems to be in much better agreement with experiments. However, this is probably the effect of overpredicting drag in the vicinity of insufficiently accurately modeled interceptor that compensates for unaccounted viscous drag. The calculated moment coefficients are considerably smaller than experimental values, which can be caused by inaccurate modeling of the interceptor, interceptor-strut interaction, and experimental uncertainties.

It should be noted that the role of viscous effects will be less significant on the full-scale vehicle. Also, the configuration can be modified to have more aerodynamically streamlined structural elements. Therefore, the full-scale craft performance predictions by the vortex lattice method are expected to be more accurate than at the model scale.

The aerodynamic lift-drag ratio above 5 is achievable for this configuration on the full scale. Although this value is not so high in comparison with high-aspect ratio wings, it corresponds to planing hulls that operate at much lower speeds than those of aerodynamically supported craft.

The speed of conventional planning boats in realistic sea conditions cannot be significantly increased due to their seakeeping and longitudinal stability problems, so the hybrid trimaran concept can take the speed niche between fast ships and WIG’s.

Concluding remarks

Experimental and numerical results for steady aerodynamic characteristics of a trimaran with aerodynamic support demonstrate a viable performance of this concept for ultra-fast marine transportation. Generally, model test results can be used for rather conservative prediction of the required power for such craft, bearing in mind the importance of viscous effects on the model scale. Potential-flow vortex-lattice codes can be more reliable and convenient means than small-scale model tests for estimating steady and especially unsteady performance of full-scale aerodynamically supported vehicles without significant flow separation.

References

Basin, M.A., Shadrin, V.P., 1980. Hydroaerodynamics of a Wing near the Boundary between Media. Sudostroenie, Leningrad.

Benedict, K., Kornev, N., Meyer, M., Ebert, J., 2002. Complex mathematical model of the WIG motion including the take-off mode. Ocean Engineering 29(3), 315-357.

Dubrovsky, V. A., Lyakhovitsky, A. A., 2001. Multi-Hull Ships. Backbone Publishing, Fair Lawn, NJ.

Dubrovsky, V.A., 2002. Motion of wave-piercing trimaran: test data and a comparison with the motion of the other vessels. Proc. International Conference on High Speed Craft: Technology and Operation, RINA, London, UK, pp. 133-137.

Dubrovsky, V.A., Matveev, K.I., 2004. Some aspects of the growth in speed of future combat ships. International Journal of Maritime Engineering 146, Part A1.

Hirata, N., Kodama, Y., 1995. Flow computation for three-dimensional wing in ground effect using multi-block technique. Journal of the Society of Naval Architects of Japan 177, 49-57.

Hoerner, S.F., 1965. Fluid-Dynamic Drag. Hoerner Fluid Dynamics, Bricktown, NJ.

Kirkman, K.L., Kloetzli, J.W., 1980. Scaling problems of model appendages. Proc. 19th General Meeting of the American Towing Tank Conference, Vol. 1, pp. 129-154.

Kornev, N.V., Treshkov, V.K., 1992. Numerical investigation of non-linear unsteady aerodynamics of the WIG vehicle. Proc. Intersociety High Performance Marine Vehicle Conference, Arlington, VA, pp. ws38-ws48.

Kornev, N.V., Taranov, A.E., Treshkov, V.K., 1998. Efficient software for numerical calculation of ekranoplans (WIG craft) and hydrofoils. Proc. Workshop WISE up to Ekranoplan GEMS, The University of New South Wales, Sydney, Australia, pp. 263-266.

Kornev, N.V., Matveev, K.I., 2003. Complex numerical modeling of dynamics and crashes of wing-in-ground vehicles. 41st Aerospace Sciences Meeting & Exhibit, Reno, NV, AIAA paper No. 2003-0600.

Wu, C.-K., Rozhdestvensky, K.V., 2001. High-Reynolds-number flow computations for wings in ground effect. Proc. 6th International Conference on Fast Sea Transportation, Southampton, UK, Vol. III, pp. 7-17.

Figure captions

Fig. 1. Front and plan view of hybrid trimaran.

Fig. 2. Artist impression of 125-knot, 1000-ton car-passenger hybrid trimaran ferry.

Fig. 3. Birdeye and fisheye view of CFD model of hybrid trimaran.

Fig. 4. Convergence of aerodynamic coefficients of inviscid forces with increasing number of panels.

Fig. 5. Lift, drag, and moment coefficients for $h/c = 0.038$. Symbols, experimental data; curves, numerical results. Dashed curves and symbols Δ correspond to interceptor-augmented configuration.

Fig. 6. Lift, drag, and moment coefficients for $h/c = 0.064$. Symbols, experimental data; curves, numerical results. Dashed curves and symbols Δ correspond to interceptor-augmented configuration.

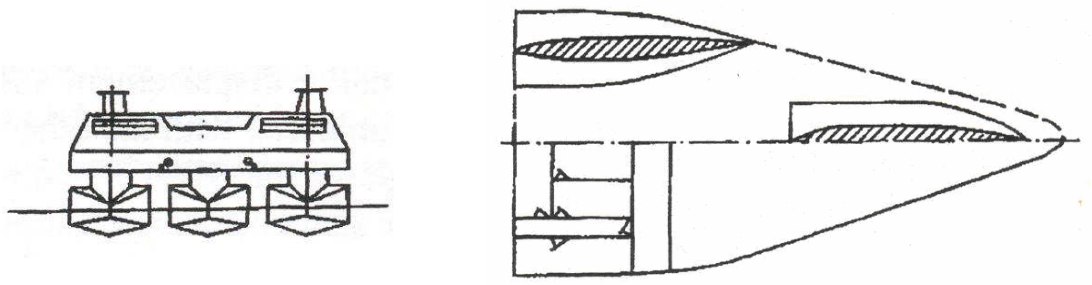

Figure 1.

Figure 2.

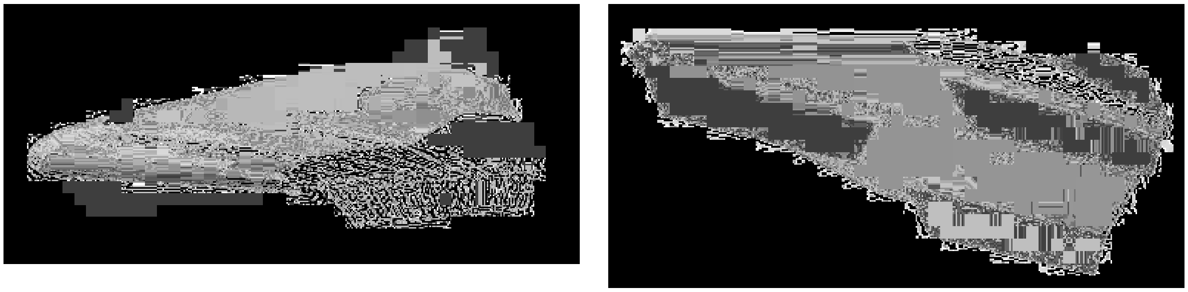

Figure 3.

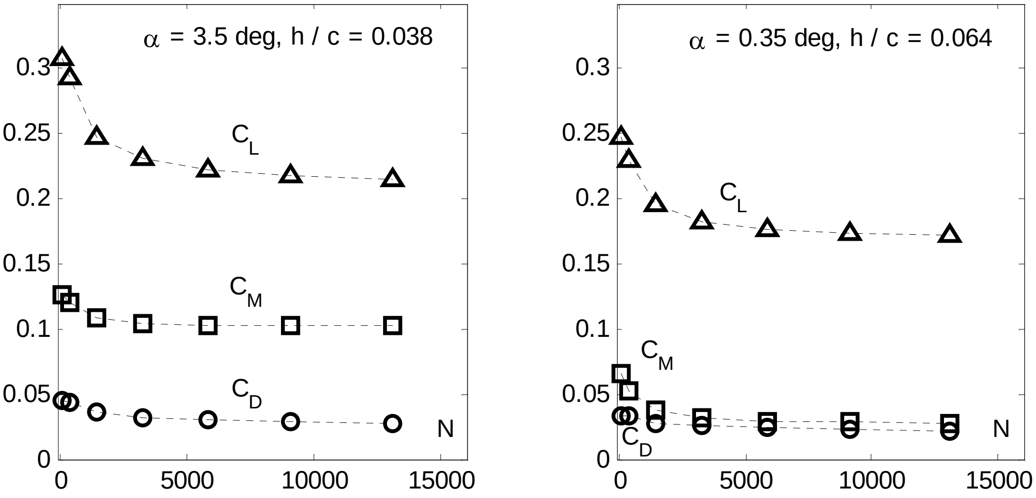

Figure 4.

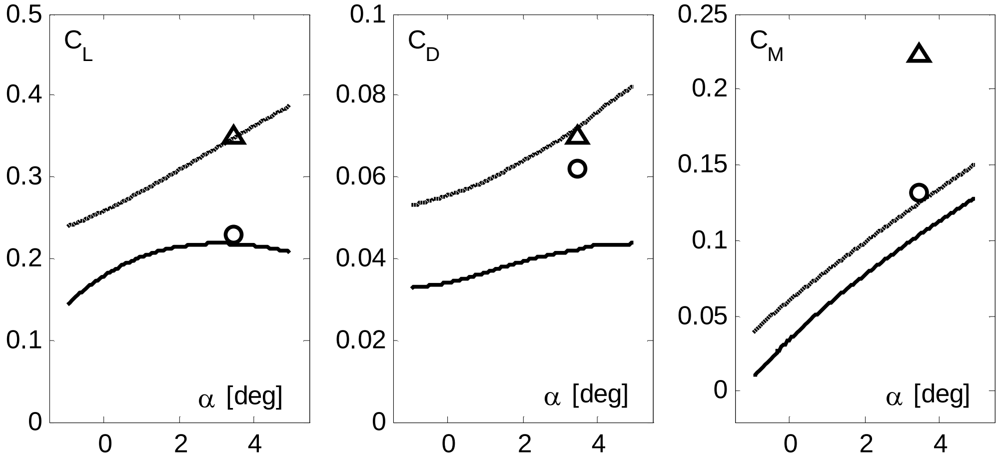

Figure 5.

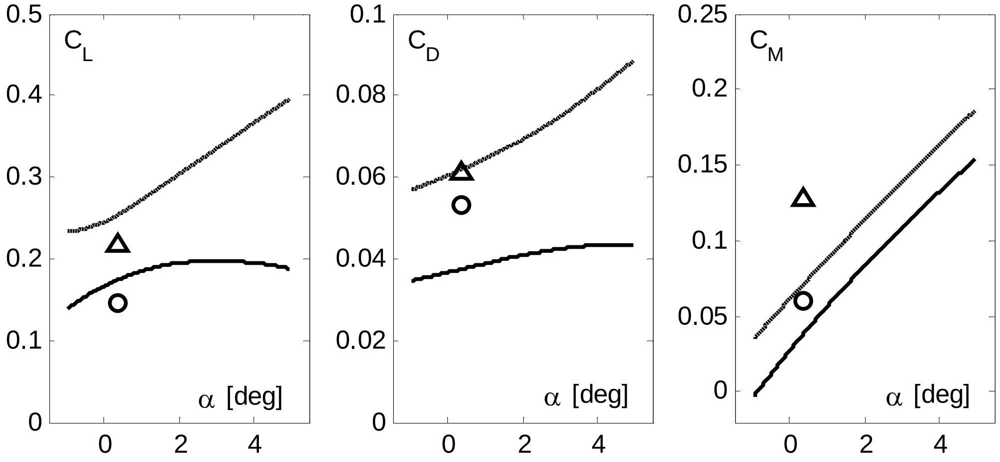

Figure 6.