AERODYNAMIC LIFT FORCES ON MULTIHULLED MARINE VEHICLES

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SUMMARY

The need for high-speed high-payload craft has led to considerable efforts within the marine transport industry towards a vehicle capable of bridging the gap between conventional ships and aircraft. One such concept uses the forward motion of the craft to create aerodynamic lift forces on a wing-like superstructure and hence, reduce the displacement and skin friction. This paper addresses the specific aerodynamic design of multihull for optimal lift production and shows that significant efficiency can be achieved through careful shaping of a ducted hull, with lift-to-drag ratios of nearly 50 for a complete aerodynamic hull configuration. Further analysis is carried out using a hybrid vehicle stability model to determine the effect of such aerodynamic alleviation on a theoretical planing hull. It is found that the resistance can be halved for a fifty metre, three hundred tonne vehicle with aerodynamic alleviation travelling at 70 knots. Results are presented for a candidate vessel.

NOMENCLATURE

C_L	Coefficient of lift
C_D	Coefficient of drag
C_m	Coefficient of moment
WIG	Wing In Ground Effect
WISE	Wing In Surface Effect
ACV	Air Cushion Vehicle
SES	Surface Effect Ship
AAMV	Aerodynamically Alleviated Marine Vehicle
B	beam (width) of the hull at transom (m)
HV	Hybrid Vehicle, with aero- and hydrodynamic lift
HV1	First HV configuration, not optimized
HV2	Second HV configuration, developed to have the optimum amount of weight sustained by aerodynamic lift
H	height of the axis system origin, as shown in Figure 8, above the mean water surface
Fr	Froude number, $V/\sqrt{(gL)}$
F_b	beam based Froude number $V/\sqrt{(gB)}$
g	gravitational acceleration (m/s^2)
L	waterline length (m)
V	vehicle speed (m/s)
k	turbulent kinetic energy, k-ε model
ε	rate of dissipation of turbulent kinetic energy k

1. INTRODUCTION

The modern transport market may be thought of as existing in two distinct sections: that of high-speed, low-payload vehicles, such as aircraft, and that of low-speed, high-payload vehicles, such as cargo ships. Constant pressure to carry more load and at greater speed, combined with environmental concerns over fuel efficiency has led companies and researchers to look for hybrid technologies capable of closing this gap in the market. Shorter transit time for commercial produce is obviously a valuable asset, as indeed is the case for passenger ferries, where speed comes at a premium. More critical pressure for high-speed high-payload comes from the military and humanitarian aid organizations, where speed often means the difference between life and death.

The benefits of a vehicle capable of sustaining high speeds over vast stretches of open ocean whilst carrying significant weight in cargo are extremely tangible. Financial, tactical and humanitarian needs warrant a considerable amount of research into the field. A significant amount of work has been done by the Russians on WISE craft, being aircraft capable of utilizing ground effect whilst flying close to the sea. Many subsequent studies such as Moore *et al* [1] have shown the aerodynamic advantages of WIG configurations. Few WIG craft have been produced (most notably in Russia) and design studies have shown that the advantages of ground effect are largely outweighed by the difficulties of flying close to the sea [2]. In particular, the need to perform banked turns and maintain wing strength against potential water collision reduces the practical length of the wings and thus the aspect ratio, which reduces efficiency. Equally, to avoid collisions in even moderately rough seas the WIGE must fly at greater heights, and since ground effect diminishes rapidly with increased height, the combined effect of low aspect ratio wings and greater cruising height often mean that any advantages are lost altogether.

Perhaps the most promising variety of high-speed high-payload vessel are aircushion vehicles, and in particular the SES which have reached speeds of nearly 100knots in calm seas [3]. An SES, having rigid side hulls is better able to maintain cushion pressure in rough seas, however, wave slamming on the front seal results in a significant increase in drag and heavy loading on the vessel, which reduces the speed considerably in even moderate swells. A partial SES described in [26] and [27] explores this concept as well.

Lazauskas [4] presents a detailed comparison of theoretically optimised vessels with regard to speed. Figure 1 shows the resistance to weight ratio plotted against speed for a catamaran vessel with varying degrees of cushion support. This plot shows the catamaran with no cushion pressure (or associated skirt drag etc.), with 50% and 85% cushion pressure, where it acts as an SES, and with total cushion support, where it may be considered as an ACV. The plot clearly shows the difference in resistance with speed. At low speeds, up to around 25knots, the catamaran is the obvious winner and is not noticeably beaten until about 35knots where the two SES ships become favourable. Above 60knots the level of air support can be seen to be inversely linked to the resistance.

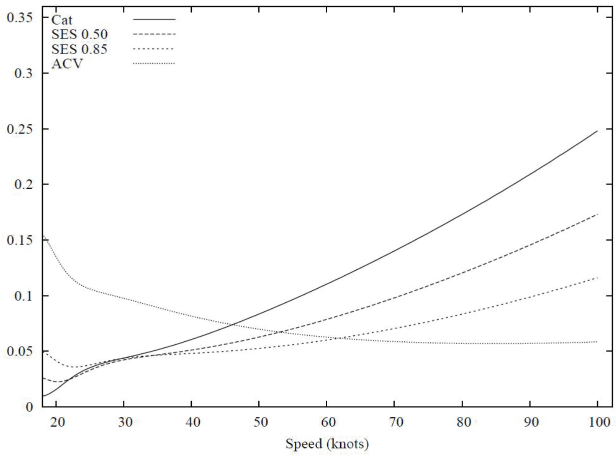


Figure 1: Optimal resistance curves for a catamaran with varying degrees of aerostatic support [4].

Clearly the ACV is the best for high speeds; however, in reality the presence of waves limits the speed of ACVs severely. This can mean that they are operating at far less efficiency than other vessels, and indeed in particularly rough seas they are often not able to cope at all.

This plot clearly demonstrates the potential for a hybrid vehicle configuration to achieve much better performance than any of the existing solutions, provided the attributes of each can be successfully combined. It is apparent that a hybrid vehicle capable of performing as a catamaran at low speeds whilst attaining greater aerodynamic lift with increasing forward speed could follow the line of least resistance of all of these vessels. Such a vessel should have negligible lift at low speeds of up to 20knots, partial aerodynamic lift at 40 to 60knots and almost total aerodynamic lift above 70knots. This can be achieved by changing the cushion pressure of an SES, however it is the aim of this work to explore the possibility of utilizing aerodynamic lift for this purpose. It is proposed that a vehicle which can maintain adequate lift from aerodynamic forces would have lower profile drag than an SES, require far less engine thrust to achieve the high pressure and would cut though the waves unimpeded by a front or rear seal. If feasible, such a vehicle could provide a significant advancement in marine transport. Vehicles which use forward motion for aerodynamic support will be referred to as AAMVs for the purpose of this work.

2. AAMV

The basic concept for the AAMV is not new, and aerodynamic lift has already appeared in the literature many times. Perhaps most notably the *Ekranocat* (a portmanteau from the French word Ekranoplan and catamaran) which refers to the use of a wing-like structure to join the hulls of a catamaran. The name was proposed by Doctors [5], Nebylov [25], but the concept has already been suggested elsewhere by Trillo [6]. These vehicles do not use any engine thrust to trap or channel air, only the forward motion of the vessel is used to generate lift. Doctors proposed a catamaran, whilst Walker *et al* [7] and later Matveev *et al* [8] suggest using a trimaran. The theory is quite simple. As the boat speed increases the wing generates lift which reduces the hull displacement and hydrodynamic drag at the expense of the far smaller aerodynamic drag. This theory is perfectly sound; however, it has been difficult to propose a vehicle to provide sufficient aerodynamic lift at realistic speeds, especially since the wings are very low aspect ratio. As McKesson points out in [9], if stagnation pressure could be achieved for a vehicle of comparable size and footprint to a 6000tonne SES it would have to be travelling at around 200knots to achieve total aerodynamic lift. A lively speed indeed for a 6000tonne ship, but even SES ships do not usually run on full air support and can achieve significant drag reduction at much lower cushion pressure ratios; although around eighty percent air lift seems to be the best for most air cushion type vehicles [4] & [10].

The AAMV design has some distinct advantages, particularly in that it does not require any front or rear skirt, which eliminates a lot of drag and wave impact problems as well as not needing any extra engines to provide cushion pressure. This means that any aerodynamic lift created by fairing the deck area into a wing shape is effectively free, since the profile drag should be much the same, and indeed may even be reduced. Tunnel hull racing boats have effectively been using this principle on a smaller scale for some time [11] & [12]. It is to be noted that they can achieve very high speeds, the world record being 275knots, but even at much lower speeds the aerodynamics can be significant and boats can become fully airborne at speeds closer to 100knots. On a slightly larger scale the KUDU II [13] is an 11m long 4m wide twin hull ram wing planing craft capable of speeds as high as 85knots, with open ocean cruise speeds of around 69knots. This speed is only achievable through considerable amounts of aerodynamic alleviation from the ram wing joining the hulls.

An interesting report by Hockberger [14] describes the performance of a quadrimaran ship with aerodynamic lift capabilities. The vessel's four hulls are almost identical and form three channels along the wetted deck. Conventional wisdom would most likely lead to a dismissal of such a design as it appears to have an unnecessarily large surface area. Indeed both Doctors

[15] and Tuck [16] argue that fewer hulls are almost always preferable. The quadrimaran, however, produced some interesting results. Along with its natural stability provided by the relative width of the vessel it has additional stability from the time averaged effects of the hulls. This is caused by the hulls sitting atop a variety of wave peaks at any one time without descending into the troughs. Of course, this is largely dependant on the relative size of the vehicle and the waves. Furthermore, the hulls are designed to create dynamic lift and as such, much of the hull area is lifted from the water, significantly reducing the wetted area drag. The most remarkable aspect however, was unanticipated and is due to the aerodynamic effects of the hulls. It was found during trial runs of the 17.5 metre test model *Alexander* that at full throttle the ship would go noticeably faster into a strong head wind. From this it was realised that the air flow between the hulls was actually creating a ram wing effect and lifting the hulls. Reports from riders who lay down near the bow suggest that a visible depression caused by the air pressure could be seen, and that this actually helped not only to reduce frictional resistance by lifting the vessel out of the water, but also helped to dampen the motion in rough seas. It is also claimed to have reduced the wash height and thus, the wave drag. Unfortunately, the test model *Alexander* was used as a demonstrator and not as a proper test model, meaning that although reports are generally consistent they must be read with caution. For example, some speeds were calculated by riders who measured approximate distances and timed them on their wrist watches.

Theoretical analysis of wing-ship configurations has largely been limited to combining a two dimensional wing with an existing hull shape, such as the work by Doctors [5]. The two dimensional approach simplifies the evaluation and is justified on the grounds that the hulls will act as end plates. It should be noted that wing hull configurations are inherently low aspect ratio and as such, any unbound wing would most likely be very inefficient. However, end plates do not generally allow a low aspect ratio wing to perform as well as its 2D counterpart [17] & [18] making this seem like an over estimate. Furthermore, experimental analysis such as [7] & [8] shows that low aspect ratio triangular wings in the trimaran configuration are not very efficient. This makes the wing ship look like an untenable option, since the wing will only provide a very small fraction of the vessel support. However, the configuration of a low aspect ratio wing bound by demihulls over a water surface is a reasonably complex geometry and, if it is to be simplified, seems more akin to a duct than a 2D wing. For this reason, it was decided that the geometry of a ducted hull configuration should be studied so that a more thorough understanding of the aerodynamic forces on multihulled vessels could be gained, and from this, a reassessment of the viability of aerodynamic alleviation for marine vehicles.

3. AERODYNAMIC DESIGN

3.1 INITIAL TESTING

The AAMV aerodynamics is a complex and coupled phenomena, being the interaction of the upper deck wing with the side hulls and the free surface. The ducted shape which is created will result in a pressure difference through the duct which will affect the free surface shape, which in turn will alter the duct aerodynamics. However, at higher Froude numbers the free surface deformation will become less significant and for cruise conditions it may be fair to assume an infinite Froude number to simplify calculations [19]. It is the aim of this initial study to use a generic hull form to investigate whether there are any significant advantages to using a fully ducted geometry.

The initial model uses a ducted shape shown in Figure 2, where the cross deck is a Clark Y airfoil as shown in Figure 3(a) and the hulls are made of a variety of shapes to provide a comparison. There is extensive data for the Clark Y foil in two and three dimensions in extreme ground effect [20] and it was considered that this could be used to validate the initial CFD model and then provide a comparison when in a ducted form. The Clark Y cross deck was studied with Clark Y hulls, symmetrical foils, and a highly cambered foil.

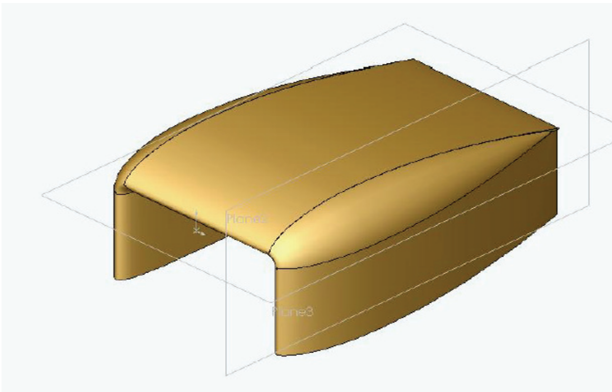
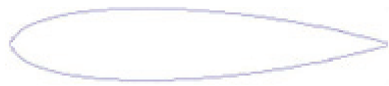


Figure 2: Solid model of the Clark Y wing-hull combination.

(a)



(b)

(c)

Figure 3: Profiles of the various hull geometries used, showing the Clark Y (a), ‘Hull shape’ (b) and the ‘Diff hull’ (c).

The symmetric shape labelled 'Hull shape' in Figure 3(b) is representative of a possible aerodynamic hull shape, constructed purely to reduce aerodynamic drag on the hulls. The highly cambered hull labelled 'Diff hull' in Figure 3(c) is designed to create a diffuser shape though the hulls which should increase the pressure. The Clark Y shape was specifically chosen for its flat under side, which gives neutral ducting for comparing with the convergent and divergent ducting created by the other foils.

A CFD model was run in Fluent using the k-ε turbulence model. This turbulence model would seem the most appropriate choice due to its wide acceptance in industry and its ability to handle a variety of turbulent flows. In particular the rapid length scale changes associated with backwards facing steps, such as the transom of a ship's hull. For specific cases it may be better to use more computationally expensive methods such as Reynolds Stress Model (RSM) or a simpler method such as Spalart-Allmaras, but in order to lend consistency to the results, it is desirable that only one model, for which the limitations are well understood, should be used. Accepting that the drag is likely to be slightly over predicted due to the k-ε model's inability to account for transitions from laminar to turbulent flow, there will at least be a uniform over-prediction for all cases, allowing for a fair comparison. That is to say, accuracy over precision may be chosen. The accuracy of the k-ε model has proved to be more than adequate throughout much of industry. The k-ε model is considered to be robust, stable, versatile and accurate, and as such, is used for all of the computations in this analysis.

Validation of the CFD was done in prior work and is presented in detail in [21] with mesh independence found over 100,000 nodes. The model hull is 50m long and has a beam of 25m with the leading edge at a height of 5m and at zero angle of attack. This gives an effective cross deck clearance of 3m for the Clark Y wing. The model was run at 36m/s which corresponds to about 70knots.

3.2 RESULTS

The results from the CFD model are shown in Figures 4 to 6. The lift and drag coefficients for each configuration are shown as a bar chart to give a comparison of their relative values. The final configuration, marked Diffuser hull, is a combination of the diff hulls with the same diff hull cross deck. That is, all parts were constructed from the cambered profile shown in Figure 3(c) instead of having the Clark Y cross deck. This configuration provides a complete divergent convergent duct, with the exception of the free surface which remains flat.

3.3 DISCUSSION OF RESULTS

The results for the different hulls in conjunction with the Clark Y wing clearly show that the shape of the hull has a dramatic effect on the pressure distribution between the hulls. The results for coefficients of lift and drag demonstrate the change in performance clearly. Figures 4 and 5 show the lift and drag for the various hulls in combination with the Clark Y as well as the complete diffuser shape outlined above. From this it can be seen that although the drag remains quite constant for all of the configurations, the lift varies dramatically from 0.31 up to 1.15. The lift-to-drag ratio shown in Figure 6 is also very dependent on the hull shape with considerably better results for the diffuser hull, which has about four times more lift than the hull shape for approximately the same level of drag. Figure 7 shows the effect of the various hulls as a percent change from a theoretical two dimensional wing.

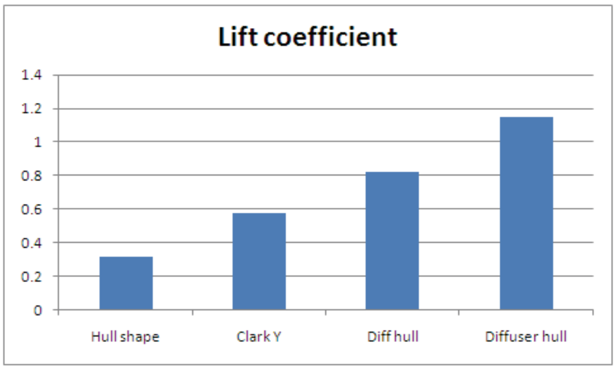


Figure 4: Coefficient of lift for the four hull configurations.

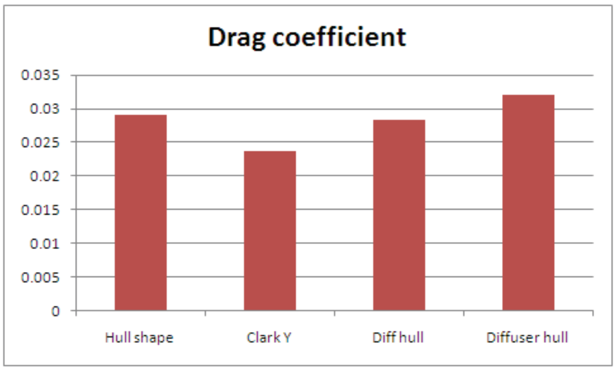


Figure 5: Coefficient of drag for the four hull configurations.

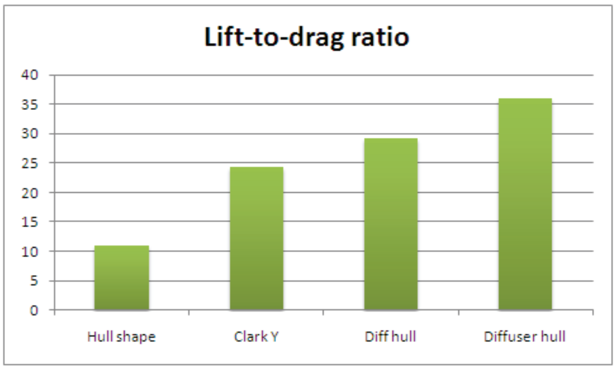


Figure 6: Lift-to-drag ratio for the four hull configurations.

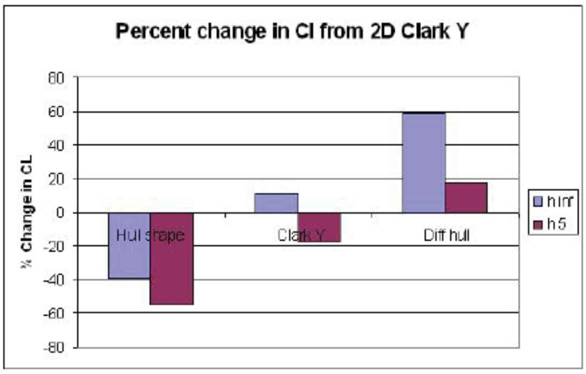


Figure 7: Relative effect of the various hulls on an infinite Clark Y wing.

In previous papers, such as that by Doctors [5], the hulls are assumed to act as end plates and allow two dimensionality to be applied to the aerodynamics. Figure 7 shows the percentage error of the hull data compared to two dimensional experimental data for a Clark Y wing at infinite height and at a height of 5metres taken from [20]. It can be seen that the effect of the symmetrical Hull shape is extremely detrimental and that assuming the effect is two dimensional and still in ground effect leads to an error of around 55%. By shaping the hulls as Clark Y foils however, the assumption of two dimensionality becomes more reasonable. The actual value lies between that of the ground effect and infinite height, that is to say, the end plate effect of the hulls has not produced as high a value as for an infinite wing in ground effect, but it is better than that of an infinite wing out of ground effect. This is a considerable achievement, since end plates do not usually have such a pronounced effect. They are of course not usually airfoil shaped or in contact with the ground, and this must account for much of the difference. In the case of the diff hull, the hulls have improved the coefficient of lift of the low aspect ratio wing in ground effect beyond that of an infinite wing in ground effect by nearly 18%. This means that the assumption of two dimensionality and dismissal of the effects of the side hulls on a low aspect ratio wing can lead to errors of over 100%. Indeed, since much of the criticism of aerodynamically alleviated catamarans is based on the proposed difficulty of providing sufficient lift with a low aspect ratio wing in ground effect, which, it is suggested, will not achieve the two dimensional lift proposed, may in fact be an under estimate if the hulls are designed properly.

It is confirmed that the standard hulls will not allow the assumption of two dimensionality by quite a margin, but the adapted hulls presented here are able to significantly do better than the 2D wing. The final test, using the complete diffuser shaped hull, gives a total C_L of 1.151 and a lift-to-drag ratio of 35.9, this can be compared to a low aspect ratio wing of the same dimensions where the C_L is only around 0.07 and the L/D as low as 3. This clearly illustrates the importance of hull design in conjunction with wing design when considering aerodynamically alleviated hull designs. It is also worth noting that the diffuser hull has four times more lift than the hull shape with very little increase in drag, and that most likely any such shape would already be a significant improvement over the original aerodynamic drag. Usually, also for high speed craft, the hull is optimized from a hydrodynamic point of view, therefore from an aerodynamic point of view great improvement can be reached, as demonstrated here.

4. COMPLETE AERODYNAMIC HULL FORM

The previous section demonstrated that efficient lift can be generated by suitably shaped ducted hull geometry and that lift values may be much higher than expected. This section aims to provide a complete ship design which accounts for the hydrodynamic constraints as well as the aerodynamic requirements.

To achieve a complete aero-hydrodynamic design for the hybrid vehicle it is necessary to consider the transition states of the vehicle. That is, the at rest requirements, the take-off requirements and the cruise requirements. The static requirements are that the vehicle must float. But beyond this it must float such that the hydrodynamic and aerodynamic surfaces are able to perform once motion has begun. From basic calculations of a prismatic hull using the Archimedean principle of displacement, we can find that a 200tonne planing hull will rest at a maximum draft of about 1.5m. This is based on a 10degree deadrise and 2degree trim angle predicted from the hybrid stability model used in previous work [22]. It may be beneficial to consider the possibility of greater loading, since the aforementioned model gave reason to believe that a greater load may be supported if correctly designed. As such, a maximum draft of 3metres is suggested to accommodate greater static loading.
The transitory, or take-off stage, will require the hull to have a good water piercing bow for low speeds as well as a greater trim angle in the bow section to encourage the hull out of the water at lower speeds.

The precise design of such a hull for optimal performance is beyond the scope of this paper and is not considered further here. The proposed design is a best guess at what may be required and is shown below in Figures 8 & 9.

4.2 RESULTS

The results for coefficient of lift, drag and moment are shown below in Figures 11 to 13. The various coefficients are plotted against the angle of attack (alpha) and are presented for a range of heights (H) between 3 and 7m where H is the height of the origin, as shown in Figure 8, above the mean water surface. The origin is located at the quarter cord point.

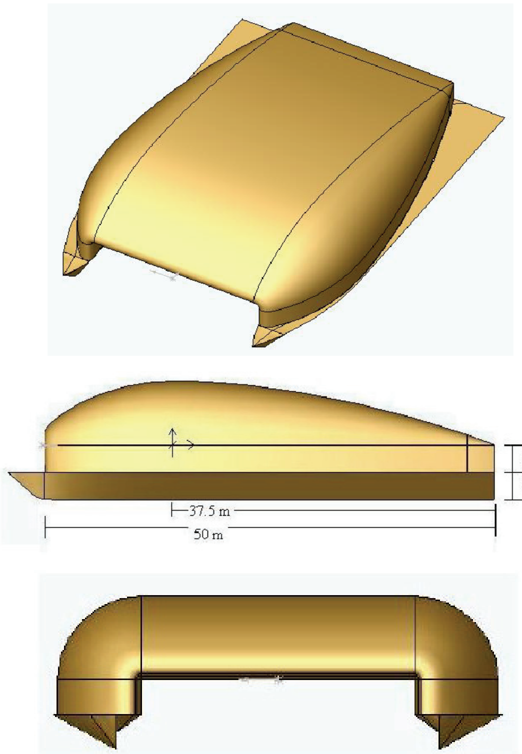


Figure 8: Complete hull form geometry.

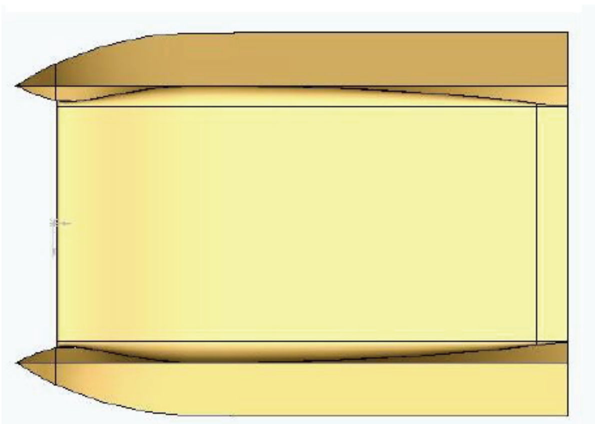


Figure 9: Hull geometry seen from below. Note the diffuser shape integrated with straight planing hulls.

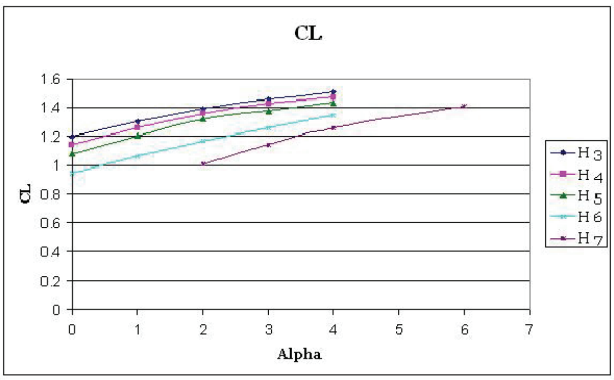


Figure 11: Coefficient of lift verses alpha for various heights and angles of attack.

The lift results shown in Figure 11 are highly encouraging, with values of between 1 and 1.5 for all heights and at only moderate angles of attack.

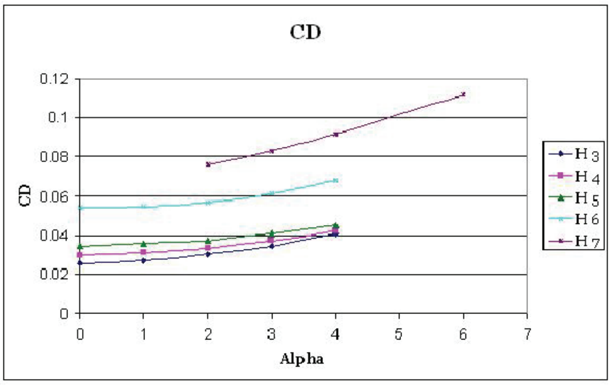


Figure 12: Coefficient of drag for various heights and angles of attack.

Figure 12 shows the drag results, which are also quite encouraging for lower heights but increase rapidly as the hydrodynamic portion of the hull becomes fully exposed. Likewise, Figure 13 shows the calculated moment coefficient.

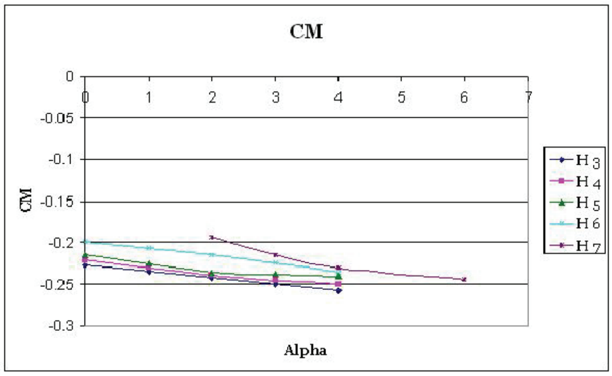


Figure 13: Coefficient of moment verses alpha for various heights and angles of attack.

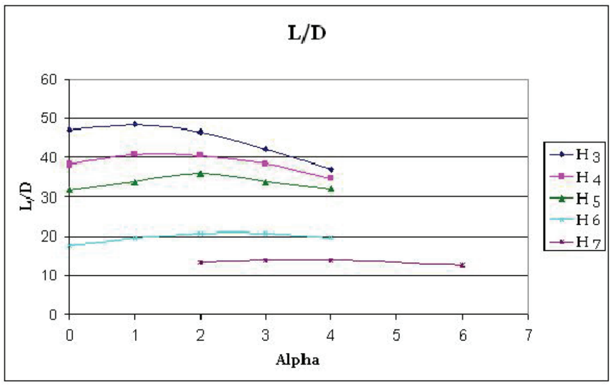


Figure 14: Lift to drag ratio for various heights and angles of attack.

Figure 14 shows the lift to drag ratio for the various heights. At the lowest height, H_3, the L/D is nearly 50, which is an extremely good value. And for the subsequent heights the decrease is initially quite small.

However, as the hydrodynamic portion is exposed the drag increases rapidly and thus the L/D decreases correspondingly.

Since the aerodynamic drag is likely to be a much less significant factor than the hydrodynamic drag and the aerodynamic lift should affect the hydrodynamic drag, it is reasonable to hope that the higher aerodynamic drag for this configuration will be more than compensated for by the superior aerodynamic lift. However, it should be noted that both the aero and hydrodynamic design of this model are purely demonstrative at this stage and it is anticipated that many improvements could be made to reduce the aerodynamic drag. Significantly, the drag is still quite high at running attitudes where the transom is mostly submerged, suggesting that there is quite a lot of drag arising from the bow design, and that there is much room for improving this. None the less, these initial results show much promise for producing significant levels of aerodynamic support.

5. STABILITY ANALYSIS

The proposed structure has proved that the simple wing in ground effect analysis is not suitable for studying the aerodynamics of multihulls and that significant lift can be provided through careful shaping of ducted hull geometry. However, the question still remains as to whether this aerodynamic lift will reduce the total drag sufficiently to warrant further study. The following section is an analysis of the performance of the proposed configuration combining a basic planning model with the measured aerodynamic properties.

5.1 STABILITY MODEL

The proposed configuration is studied using a Hybrid Vehicle (HV) stability model, developed by Collu [22] specifically for the analysis of AAMV. The model has already been used to study previous aerodynamic configurations in conjunction with the author [23].

The model uses a hybrid stability model combining a Savitsky planing hull [24] with the computed aerodynamic forces which allows it to estimate a running attitude and find the static equilibrium through iterative refinement. This approach allows the vehicle to be studied through a range of speeds, from take off to cruise. The model is only valid for planing speeds and thus is not appropriate at beam based Froude numbers (F_b) lower than 1, which limits the current model to speeds above 20knot. Equally, the model is not able to cope with full air support and returns a null value if the hull leaves the water.

The model is once again 50m long and 25m wide, weighing 300tonnes and having a centre of gravity approximately one third of the ship's length from the transom, being a distance of 17m from the stern.

The model is run in comparison to a planing hull, having exactly the same hydrodynamic properties but without the aerodynamic contribution.

5.2 RESULTS

Results from the static stability model are shown below. From Figure 15 it can be seen that the aerodynamic lift gradually takes over from the hydrodynamic lift and that the cross over point occurs at just after 75knots. It is interesting to note that even at much lower speeds such as 30knots there is still about a 10% aerodynamic contribution.

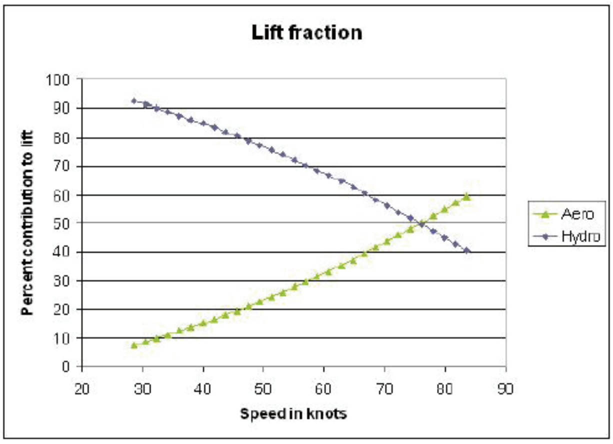


Figure 15: Shows the lift fraction for the AAMV as a function of speed.

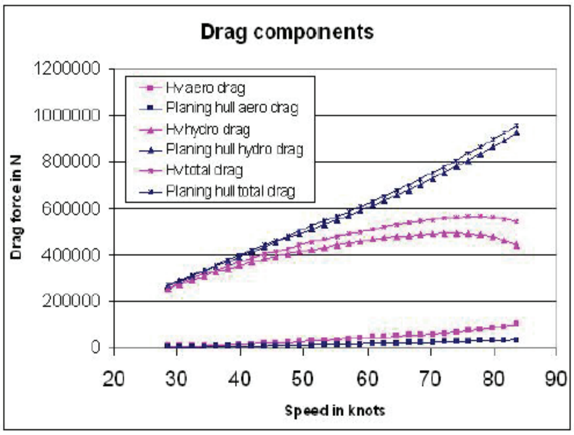


Figure 16: Shows a comparison of the various components of drag for the planing hull and hybrid vehicle.

Figure 16 shows the various contributions to drag for both the Hybrid Vehicle and the planing hull. It can be seen that above speeds of 50knots the hydrodynamic drag of the HV is significantly reduced. This is at the cost of only a very small increase in aerodynamic drag. This model assumes that the planing hull has very little surface above the water, which is why the aerodynamic drag is so small. In reality, if the above water portion of the planing vessel is of comparable size to that of the HV, then the aerodynamic drag of the HV may be smaller than that of a corresponding planing vessel, especially if its aerodynamic design has been given little consideration.

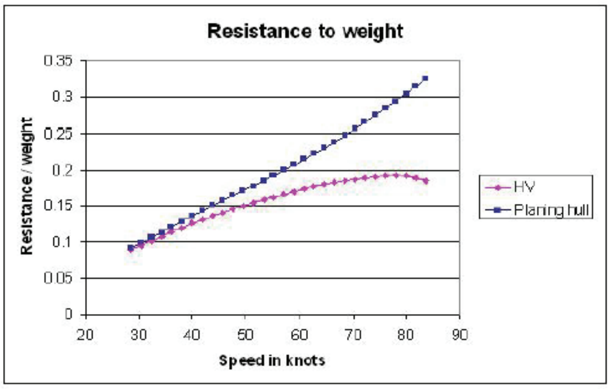


Figure 17: Comparison of resistance to weight ratio for the planing hull and hybrid vehicle.

Both Figures 16 and 17 show the characteristic 'hump drag' for the hybrid vehicle. Above 30knots the total drag starts to reduce compared to the planing hull and by about 75 knots the maximum drag is reached. Where the planing hull drag increases constantly, the hybrid vehicle drag actually begins to diminish beyond 75knots. This is also the point where the aerodynamic lift becomes greater than the hydrodynamic lift, as is illustrated in Figure 15.

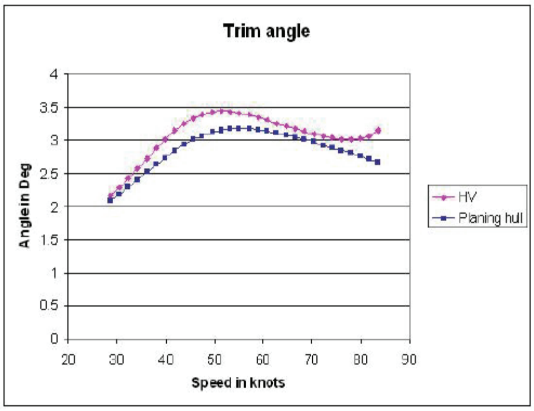


Figure 18: Trim angle in degrees for the planing hull and hybrid vehicle.

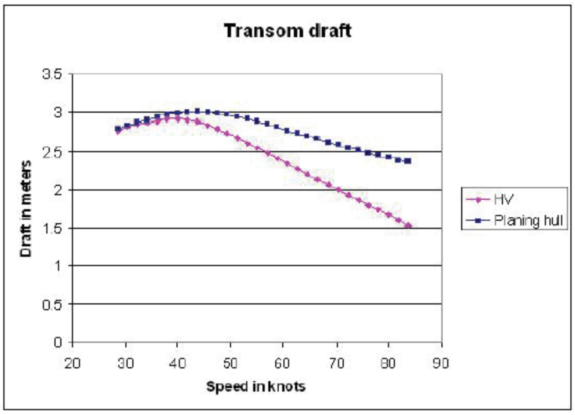


Figure 19: Draft of the transom for the planing hull and hybrid vehicle.

Figures 18 and 19 show the trim angle and the draft of the transom for the planing hull and hybrid vehicle as predicted by the static stability model.

6. THEORETICAL OPTIMUM

The previous results have shown that significant aerodynamic lift can be produced by a hybrid vehicle design, and that the total drag can be reduced by over 45%. However, the analysis was performed without any control over stability. It can be seen that the vehicle was not analyzed beyond 85knots and that at this point the vehicle trim angle was beginning to increase rapidly. The program evidently predicted that the vehicle would flip over at this point. As such, it would be essential to provide the final AAMV with control surfaces. This is perfectly logical and even simple planing hulls will often have control surfaces to determine the trim angle. Further research will focus on the dynamics of the AAMV with control surfaces.

The purpose of this section is to consider what may be achievable with control surfaces, and thus to identify the real potential of the AAMV concept. The AAMV will be compared to the theoretical results of Lazuskas shown in Figure 1 above, from [4]. The vehicle studied by Lazuskas is the 1200tonne INCAT86, which is 76.41m long and 26m wide with a maximum draft of 3m. Versions of this ship are in use around the world and are capable of sustaining speeds of around 40knots. An estimated payload for ships of this size would be 480tonnes. As discussed above, the INCAT is studied with various levels of aerostatic support to compare the benefit of cushion pressure at various speeds. However it was seen that a variable cushion pressure would allow a hybrid vehicle to out perform all of the individual designs proposed.

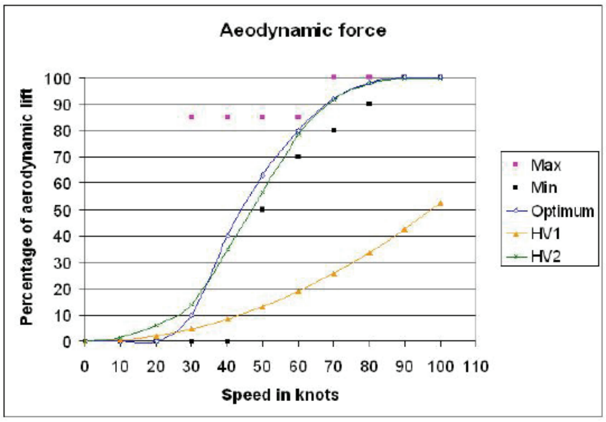


Figure 20: Optimum aerodynamic lift fraction as a percentage, shown against speed for a 1200 tonne vessel based on the INCAT.

Figure 20 shows the estimated percent of aerodynamic lift which would follow the line of least resistance for a hybrid vehicle. The minimum and maximum markers show the upper and lower limits of cushion support at the given speed, which match Lazuskas' minimum drag. The optimum curve is an estimate of the smooth line through these points. HV1 shows the lift produced by the equivalent size and weight of hybrid vehicle as calculated by the stability model. It can be seen that HV1 does not produce enough aerodynamic support to be at optimum drag.

The HV2 is a version of the hybrid vehicle using optimised lift coefficients and a modification to the geometry. For this vehicle it was assumed that the lift coefficient could be controlled at each speed via control surfaces. The lift coefficients used are shown in Table 1. To achieve these optimum values a maximum lift coefficient of 1.45 was used at 50knots. This should be entirely achievable given that slightly higher values have already been achieved without further optimisation or the use of control surfaces or trailing edge flaps. One difference with the modified coefficient of lift is that the value is reduced in the latter stages to prevent total take-off.

Speed in knots	C_L	Cushion pressure %
0	1	0
10	1	1.6
20	1	6.2
30	1	13.9
40	1.4	34.8
50	1.45	56.4
60	1.4	78.4
70	1.2	91.5
80	0.98	97.6
90	0.79	99.5
100	0.64	99.6

Table 1: Lift coefficients used to obtain an optimal aerodynamic support curve.

Unfortunately, the most effective way to achieve the desired optimum lift fraction was to change the geometry of the ship. HV2 has an increased length of 150m, with the same length to beam ratio of 2 used for the previous hybrid AAMV configurations. By extending the length of the AAMV the aerodynamic force is greatly increased and the take off speed is much easier to achieve. However, the extra length must be at the cost of payload, or better use of structural design and materials.

7. CONCLUSIONS

The concept of aerodynamic alleviation of marine vehicles has been studied and it has been found that the standard model of a wing in ground effect is not necessarily valid for a multihull vehicle. In such a situation it was found that a ducted flow was more appropriate and that the side-hull shape must therefore be an integral part of the design as well as the cross deck.

It was found that significant levels of lift can be produced by careful design of a ducted hull, with aerodynamic lift coefficients over 1.4 at only moderate angles of attack and L/D ratios of nearly 50 for a full aero-hydro model of the AAMV concept.

Preliminary stability and performance analysis showed that the AAMV concept can provide a significant improvement over a conventional planing hull, with a total drag reduction of 45% at top speed.

The AAMV proved to be unstable beyond 80 knots in this configuration and it was shown that control surfaces would be needed to maintain greater cruise speeds. It was also noted that better performance could be achieved with control surfaces.

The AAMV concept was compared to the optimised INCAT vessels with aerostatic support and it was found that aerodynamic support can be made to fit the optimum levels required. However, either the level of lift produced must be further increased, the weight of the vehicle reduced, or the size increased. Most likely a combination of the three would be required.

The AAMV concept shows promise for reducing the drag of high-speed multihull. With an increasing demand on ships to achieve higher speeds, and the knowledge that the present design is an early concept which it may be hoped will be much improved, it seems likely that the AAMV may provide a realistic avenue of development for high-speed sea travel.

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