A STUDY OF THE LOSSES AND INTERACTIONS BETWEEN ONE OR MORE BOW THRUSTERS AND A CATAMARAN HULL

L Boddy and **T Clarke**, Austal Ships, Australia

SUMMARY

CFD analysis has been conducted on a 100m catamaran hull shape with various bow thruster positions in order to develop an understanding of the effects and losses that are generated from situating thrusters near the hull as well as the effect of having a hull downstream of the thruster. Various thruster angles, hull separations, and vertical heights were investigated to determine their influence on thruster losses.

NOMENCLATURE

T	Effective thrust
T_0	Maximum thrust
X	Distance between thrusters
D	Thruster diameter

1. INTRODUCTION

Bow thrusters have been used for a number of years in high speed craft, and even longer in conventional hull forms, but understanding the effects of having bow thrusters in catamarans and the associated losses that result from hull-thruster interactions has not been widely researched. These losses are due to the interaction effects of the flow from the upstream thruster impacting on the downstream hull and also affecting the flow of the downstream thruster. The thruster also produces forces on the hull in which it is situated due to the Coanda effect.

A 100m high speed catamaran, similar to those Austal Ships have produced, was used as a basis to better understand how various parameters and designs effect the resultant forces from bow thrusters. This hull form was fitted with retractable thrusters in each hull and their fixed rotation angle, height offset, and number was varied.

This study has allowed the identification of trends which can be used to optimise the position and orientation of the thrusters to maximize the available power.

2. CFD MODEL

STAR-CCM+, a general purpose multi-physics computational fluid dynamics (CFD) package from CD-adapco, was used in this study. It is particularly suited to this application since the air-water interface must be modelled as a free surface and its volume of fluid method is very computationally efficient and widely used in marine applications.

The bow thruster studied in this report is a simplified 50Hp retractable non-azimuthing thruster designed by HRP. This type of thruster was chosen as it is typical of those used at Austal in both catamaran and trimaran high speed craft.

2.1 CREATING THE MODEL

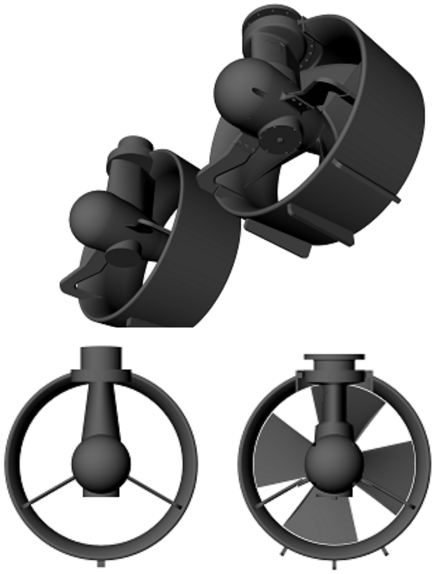


Figure 1: *Showing comparison of Actual Bow thruster (right) to the simplified model (left) used in the CFD analysis*

The bow thruster used in the analysis was simplified from the actual design, as seen in Figure 1, to reduce the computational complexity and solve time of the simulations. The overall shape, dimensions and aerofoil sections of the nozzle was kept as per the real design, but areas such as bolting arrangement, the shape of the vertical shaft and struts were simplified.

Figure 2 illustrates the bow thruster in position in the hull with the associated cut out and closing cap. The shape of the cut out section was taken as a generic shape from the various hulls that have been built at Austal and not one ship in particular. Where multiple thrusters have been fitted into the hulls a similar shape cut-out has been used.

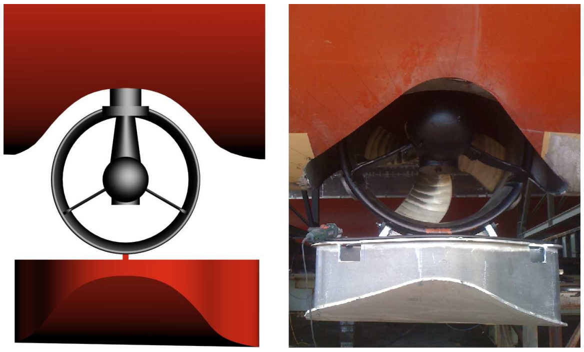


Figure 2: *The bow thruster fitted to the vessel, showing the cut out in the hull and the associated closing plate underneath the bow thruster. Note that the vessel (right) does not have the thruster fully deployed.*

2.2 MESHING

One key benefit of STAR-CCM+ is the integrated automatic meshing features and this allowed for quick and easily meshed structures to be generated and for the same mesh settings to be replicated for multiple designs.

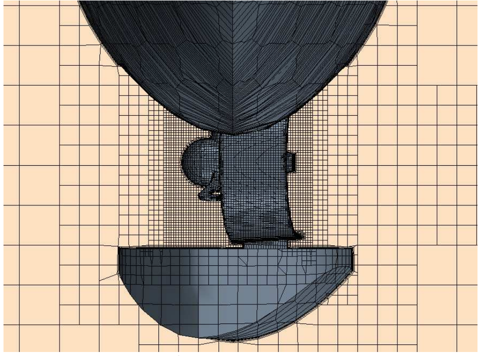


Figure 3: *Example of the mesh around the bow thruster area, note that the bow thruster is in a rotated position.*

The number of cells in the solution was typically 1.5 million hexahedral cells increasing to 2.5 million cells with an additional thruster. The mesh was refined downstream of each thruster in the expected flow direction to capture its flow stream more accurately. Additionally the model domain was extended well beyond the hull region to reduce the effects of recirculation and allow increased simulation time for the solution to stabilise.

2.3 PHYSICS

In addition to establishing a constant meshing structure for all run cases, the model physics was also constrained. To reduce simulation time and complexity, the hull was held in a fixed position with respect to both translation and rotation. The environment surrounding the hull was modelled as a volume of fluid (VOF) flat wave, allowing for the distortion of the free surface due to thruster flow patterns. Additionally the initial flow in both the air and water phases was zero, ensuring that all forces calculated are a result of thruster flow interactions.

2.4 FLOW RATES

There are several ways to model the accelerated flow that results from the bow thruster propellers, and the most accurate method in CFD is to rotate the propellers as they do in real life, since this method produces the forces on the hull from the blades as well as generating the correct flow patterns. The problem with this method is that the solution time and mesh required was outside the scope of this study, and accurate CAD models of the blades where not available. Another method is to model the blades in the nozzle and not rotate them but instead the solver adds the required forces to the fluid (the frozen rotor method). This reduces the solve time significantly but still has many of the benefits of the rotating blades, but requires blade geometry and the associated increased mesh count.
A third and chosen method to simulate the propellers for this research was to add a momentum source based on the specified thruster flow rate in the same location as the blades, accelerating the flow through the thrusters.

To confirm that the model was created accurately and that the flow rates modelled were as per the manufactured system, the flow rates from HRP were obtained. The volume of flow is 7.94m^3/sec which results in an average flow across the thruster nozzle of 9.17m^2/sec. The momentum source added to the CFD model had a measured average flow rate of just over 9 m^2/sec.

3. RESULTS

In catamaran hull forms there are two primary causes for the reduction in thruster performance from the published values supplied by the manufacturers. The first is the effect of the flow from the upstream thruster entering the intake stream of the downstream thrusters, reducing the velocity differential across the thrusters and hence the amount of thrust generated. The second cause of reduction is the generated water flow impacting on the hulls and reducing the net force on the vessel when the thrusters are in use.

This report focuses on the thrust reductions that result from thruster generated flow interacting with the vessel hull and other thrusters. All force results were extracted once the simulation had stabilised such that results could be extracted with reasonable accuracy.

3.1 THRUSTER-THRUSTER LOSSES

No attempt was made in this report to investigate the effect of thrust losses, due to modelling of the thruster blades as momentum sources. Additionally **Wartsila [1]** have published the following formula for the associated losses dependant on relative thruster angle and the separation distance of the thrusters.

The first situation is for the case when the thrusters are installed on separate pontoons, such as a catamaran.

$$T/T_0 = 1 - 0.8^{(x/D)^{\frac{2}{3}}}$$ [1]

***Equation 1:** Thrust Ratio for thrusters operating in tandem in free water*

When the thrusters are below a fixed structure such as on the bottom of a barge the equation below should be used.

$$T/T_0 = 1 - 0.75^{(x/D)^{\frac{2}{3}}}$$ [1]

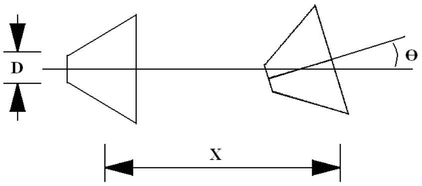
***Equation 2:** Thrust Ratio for thrusters operating in tandem under a flat body*

The other factor that has an effect on the thruster losses is the inflow angle between the two thrusters. By offsetting the inflow angles the amount of thrust that is lost can be reduced.

$$t_\theta = t + (1-t)\frac{\theta^3}{130/t^3 + \theta^3}$$ [1]

***Equation 3:** Thrust Ratio for thrusters operating at different angles*

It must be noted that the best reduction by this equation is to have the thruster having the maximum angle, however it must be remembered that rotating the thruster results in vectoring of the thrust in the desired direction.



[1]

***Figure 4:** Explanation of terms for the bow thruster interaction losses*

3.2 HULL-THRUSTER LOSSES

To understand the effects of the losses arising from the thruster flow impacting on the hulls, both upstream and downstream, four different scenarios have been investigated.

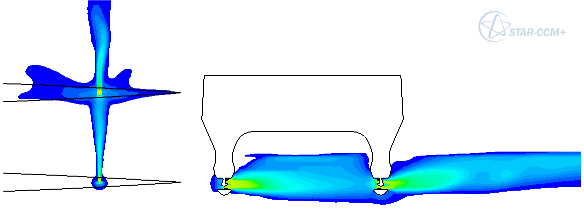


***Figure 5:** Flow patterns for the standard arrangement of thrusters*

The normal installation situation is illustrated in Figure 5 with the flow from the upstream thruster clearly interacting with the downstream hull and thruster. The plan view shows that the flow patterns resulting from the impact with the downstream hull is asymmetric due to the realistic hull form not being a constant symmetrical shape.

3.2 (a) Coanda Effect

To better understand what components are causing the forces on the hull the individual thrusters, downstream and upstream, were run independently in the normal position to determine what forces are present on each hull.

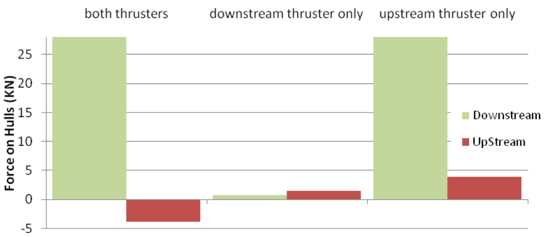


***Figure 6:** Force on hulls from individual thrusters*

When the downstream thruster is run in isolation the resulting force on the downstream hull is minimal compared to the amount of force that is produced, on the downstream hull, by the upstream thruster. This indicates that the force that is attributed to the Coanda Effect is not a major contributor to the losses of thrusters on a catamaran.

One interesting result observed was the direction of the force on the upstream hull changed depending on whether one or both of the thrusters were running. When both thrusters where running the force was generally always negative, but if either the upstream or downstream thruster was running alone the force was positive. This unexpected result is due to the fact that each thruster affects the flow patterns of the other thruster as well as the net flow pattern around the hull.

3.2 (b) Total Hull Separation

The next area that was investigated looked at the effect of changing the vessel beam, and thus the thruster separation, on the amount of force the thruster flow generated on the hulls.

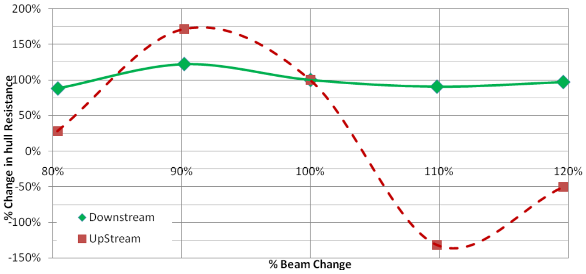


***Figure 7:** % change in forces on the hull for varying vessel beam. Note: forces measured on the upstream hull are small, hence minor variation in force causes drastic percentage change.*

As indicated in Figure 7 Varying the hull beam between 80-120%, the forces on both the upstream and downstream hulls resemble sine waves. This variation both increasing and decreasing with increasing hull separation is a result of changing both the amount and velocity of upstream flow hitting the downstream hull.

As hull separation increases further the hull interference will tend to zero, resulting in a significant reduction in hull-thruster losses.

3.2 (c) Thruster Deployment Distance

Another method to reduce the losses resulting from hull-thruster interactions is to lower the thrusters further away from the hull and thus let more flow escape under the opposite hull.

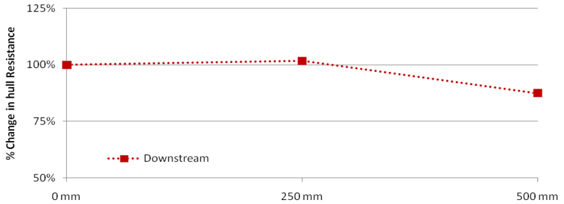


Figure 8: *% change in hull resistance for downstream hull, varying vertical thruster deployment distance.*

Results indicate that variations in thruster deployment distance has little effect on the upstream hull forces, as such these results are not reported here. The downstream hull however experienced a reduction in interaction force of 12% at 500mm additional deployment depth. As the deployment distance increases, the interaction force will continue to decrease as the flow from the upstream thruster passes beneath the downstream hull.

In reality, the magnitude of deployment distance will be limited by both available space in the hull, and bottom clearance beneath the hull in shallow water.

3.2 (d) Changing the Horizontal Angle

The next area of investigation looked at the effect of rotating the thrusters horizontally between ±10°. Positive rotation angle relates to rotating the upstream thruster in a clockwise direction, while the port thruster is rotated anticlockwise.

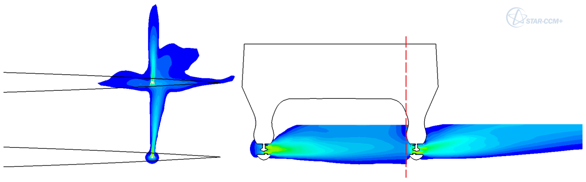


Figure 9: *Flow patterns when then thruster is rotated +10°. The flow patterns have been taken through the thruster flow direction, not the hull perpendicular.*

Based on the thruster-thruster losses outlined in 3.1, rotating the thrusters is known to reduce the thruster-thruster interactions by directing the outflow of the upstream thruster away from the inflow of the downstream thruster, the effects on the hull forces are however more complex.

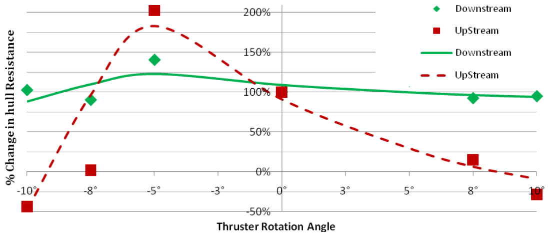


Figure 10: *% change in forces on the hull for varying thruster rotation angles. Trend curve is based on the average of the normalised data for both upstream and downstream thrusters.*

The results from this study indicate a general improvement in hull interaction losses of up to 10% with horizontal angles away from 0°, with the exception of -5° which results in an increase in hull resistance as a result of the hull shape in the vicinity of the thruster. It is important to note, that whilst increasing the angle of the thruster reduces the effects of hull interactions, the vectoring of the developed thrust reduces the effectiveness of the thruster. This vectoring is further complicated because the upstream flow impacts on the direction of the downstream flow. For example if the upstream thruster is angled at 5°, the downstream thruster should be angled at -5° but in reality it is more like -2°, creating a small moment and lateral force on the vessel at all times when operational.

3.2 (e) Effect of Multiple Thrusters in each Hull

In many situations it is common to install two thrusters in one hull to increase the available thrust beyond the ability of a single thruster. In the event that two thrusters are installed in each hull the effects and associated losses of changing the longitudinal spacing between thrusters has been investigated.

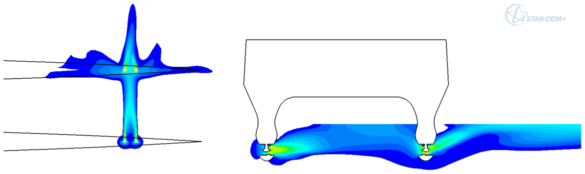


Figure 11: *Flow pattern for thrusters with a separation of 2m.*

This case involves the additional interaction of both the inflow and outflow pattern of the two thrusters on each hull. The effect of this interaction varies with separation, as the two flows from a single hull transition from acting as one flow to acting as two separate flows. Up to two meters separation the outflow streams merge together, while at three meters separation the flows remain distinct. This transition can be seen in Figure 11**,** with the resultant force on the downstream hull around 150% of the force that would be acting on the hull if there was only one thruster, when the flow between the thrusters separates the amount of loss drops to 140% because of the resultant lower velocities in the separate flow streams.

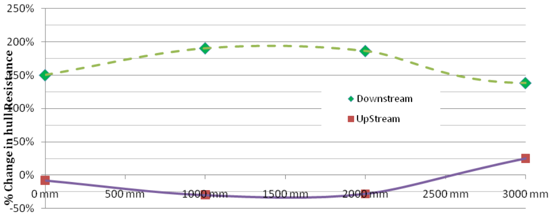


Figure 12: *% change in forces on the hull for varying thruster separation when there are multiple thrusters, relative to the single thruster case.*

As the separation increases theory suggests that the values on both hulls should tend towards 200% of the force of a single thruster per hull because there is twice the flow. But at small separations there are interference effects between each flow stream resulting in the value being lower. It can be seen that the upstream hull is trending towards 200%, and this should occur sooner than the downstream hull as the flows are much more localized upstream compared to downstream. The localised flow means that flow interactions will become negligible for much smaller separations in the upstream hull. The curves in Figure 12 have been faired with the assumption that the values are trending to 200%

4. VALIDATION OF RESULTS

Without the available resources to conduct model or full scale testing and measurements of forces and flows on a vessel, it is impossible to validate the particular results. In Reference **[1]** there is reference to a barge and various hull-thruster reductions for different applied thrust angles. In the perpendicular flow case when the flow is going directly into the other hull it suggests that the reductions are approximately 21% of the total thruster power. From the CFD analysis shown in this paper the reductions are in the range of 27%. This different can easily be accounted for because of the difference hull forms as well as hull/thruster layout.

5. EFFECT ON STATION KEEPING

The thruster losses outlined above reduce the effectiveness of a thruster, and as such have a negative effect on the ability to manoeuvre a vessel as well as maintain position in wind.

With respect to station keeping, a reduction in effective thrust from a thruster results in a reduced ability to produce sway forces and turning moments. The effects of these reductions will differ from vessel to vessel, depending on hull type, size and propulsion layouts. An arbitrary 100m catamaran, powered by four steerable waterjets was investigated with one bow thruster installed in each hull.

For a vessel to hold position the motion both transversely and longitudinally must be zero, and the vessel must not be rotating. The waterjets provide the necessary force to hold the vessel from moving forwards and backwards as well as provide some turning moment, but the largest turning moments are often generated by the thrusters. In most situations, and particularly if the vessel is propeller driven, the need for moment control is the limiting factor in the analysis.

For this 100m vessel every 10% loss in efficiency from the thrusters resulted in a reduction of approximately 1 knot maximum wind ability.

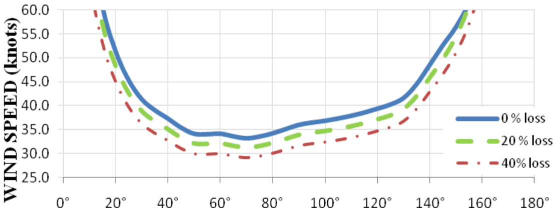


Figure 13*: maximum wind speed capability for a100m catamaran with varying thruster losses.*

6. CONCLUSIONS

All cases investigated in this report indicate that the thrust losses experienced as a result of operating multiple thrusters, either alongside or inline with each other, and their interactions with the hull is significant. These results indicate a loss of effective thrust in the order of 30%, and highlights the fact that these losses must be considered when selecting and sizing thrusters.

Several hull-thruster system parameters were varied to determine there effects on reducing losses. The most effective method was to increase the vertical distance between the thruster and the hull, achieving reduction in losses in the order of 15%, with some benefit observed from changes in horizontal angle (10%) and separation (10%). Additional reductions in loss may be achievable through some combination of the methods outlined.

Whilst several methods for reducing the thrust losses have been identified, the results indicate there will always be a significant unavoidable loss in thruster potential. Figure 13 shows the effects of thruster losses in a real world application, and indicates the importance of understanding the resultant force generated from a specified thruster under defined conditions.

7. ACKNOWLEDGEMENTS

Thank you to Austal Ships for allowing the time and resources to undertake this research. Thanks goes to Peter Ewing at CD-adapco for his guidance and assistance in supplying additional computing resources and guidance. Also a thank you to HRP for supplying data and confirming the results from the CFD analysis is as they expect. Further thanks go to our wives and families for allowing us to undertake this work.

8. REFERENCES

1. DANG, J & Laheij, H, 'Hydrodynamic Aspects of Steerable Thrusters', *Dynamic Positioning Conference*, 2004.

9. AUTHORS BIOGRAPHY

Lee Boddy works in the Research and Development department at Austal Ships. He is responsible for the development of manoeuvring simulators as well as conducting model and full scale trials to determine the required coefficients. Since the introduction of CFD capabilities into Austal he has been one of the main users of the software.

Tobias Clarke works in the Research and Development department at Austal Ships. He is responsible for the development and testing of new hull forms as well as the trialling of vessels once constructed. He also works on developing and testing the ride control systems and hardware installed on the vessels built. Since the introduction of CFD capabilities into Austal he has been one of the main users of the software.