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EVALUATION OF TRIMARAN SIDE HULL ANGLES ON FORWARD REZISTANCE

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ABSTRACT

This project reflects the authors’ view on the influence of the side hulls rotation with respect to X and Z axis on trimaran’s total forward resistance. Even though the first modern trimaran was built decades ago, this domain is still new and full of unbeaten paths. One of the most important aspects in the design of this type of vessel is the hulls layout. This decision can influence the propulsive, seakeeping and manoeuvring capabilities of the vessel as well as the main deck layout. While there are plenty of studies which analyses the effect of the side hulls translation, with respect to X and Y axis, there is no information regarding the influence of the side hulls rotation on the vessel’s performance. Therefore, the main goal of this project is to get a first insight into the importance of this aspect.

Keywords: trimaran, side hull angles, vessel’s performance

1. INTRODUCTION

Almost four millennia ago, the Pacific islanders discovered that a vessel consisting of three bodies behaves better than one which is made of only one body, laying, in this way, the foundation of the today’s trimaran. Despite the fact that the concept dates back in time, the modern trimaran history is only a few decades long.

In a few words, this type of ship is defined by a central hull having the L/B ratio up to 18 and two side hulls situated at a certain distance from the main hull with L/B ratios up to 40. The most challenging aspect of the designing process is to determine the side hull position with respect to the main hull, both longitudinally and transversally, Fig. 1.1, which can account for the vessel maximum seakeeping, manoeuvring and propulsive capabilities.

Fig.1.1. Clearance and stagger definition

Considerably work has been done in order to determine the most suitable configuration. For constant clearance, the heave and pitch motions of a trimaran ship decrease with the stagger reduction. Regarding the powering performances, the most suitable location of the side hulls is towards the aft end of the main hull.

Having mentioned this, it is natural, at this point, to raise one question: are the trimaran performances affected only by the side hulls position or by their angle of inclination as well. The aim of this project is to determine the effects of the side hulls inclination, with respect to X and Z axis, on the trimaran performances, undergoing model towing tests.

Ideally, the present study would include analyses regarding both, forward resistance and ship motions, but due to the limited time frame, only the part, related to resistance, has been developed.

Generally speaking, the project is not necessarily focused on finding a certain arrangement which can lead to a reduction in forward resistance, but on determining possible arrangements which make no significant difference in resistance but can make a huge difference in seakeeping or manoeuvring.

The present study can be divided into three major sections:

- the first one is focused on the side hull angles in the YZ plane;
- the second one is focused on the side hull angles in the XY plane;
- the third one analysis potential combinations of both angles.

In addition to this, the report contains a brief analysis of the wave interactions between hulls and presents the variation of this phenomenon with speed and angle. It is well known that for Fn numbers higher than 0.3, the vessel tends to change its trim, so that the aft end lowers and the fore end rises. A perfectly rigid arm counteracts this pitching moment and can affect the results to some extent.

Despite knowing this and due to the fact that designing and building a proper arm is a time consuming action, the model was attached to its centre of gravity and connected to the load cell through a rigid arm.

A solution for this source of errors would be to put a certain weight on the aft end of the model and record the load cell's output. Afterwards, if the error is significant, the results can be corrected using this value.

2. EXPERIMENTAL PROCEDURE

2.1 General Aspects

Due to the fact that it is formed of three separate hulls, the total wetted surface of a trimaran is considerably greater that the wetted surface of an equivalent mono-hull. Therefore, at low speeds, a trimaran returns a higher frictional resistance and subsequently a higher total resistance than a mono-hull. But trimarans are designed to be high speed vessels and under these conditions, due to its slender shape, the wave making resistance is reduced considerably. More than this, if the hulls are tuned such that the wave interference is favourable, then the wave making resistance can be further reduced giving trimarans a significant advantage over both mono-hulls and catamarans. Regarding the side hulls location, previous studies proved that at high speeds the total resistance decreases with the decrease of the longitudinal distance between the main hull and side hull transoms. Talking about the position along the Y axis, this aspect influences the total resistance only by reducing or amplifying the interferences. Thus, in order to reduce the wave interferences between hulls, the side hulls should be situated as far away from the main hull as possible. But this solution brings both important advantages and disadvantages as well. Such an arrangement will provide the vessel with very good stability but in the same time it will bring about important issues regarding the docking facilities and procedures. Fig. 2.2 presents the trimaran model towed in the towing tank.

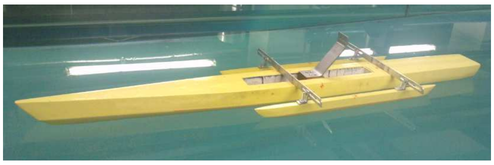

Fig.2.2. Trimaran model

The total length of the towing tank is 19 meters but the towing tests make use of only 11 meters. Taking into account that the model needs a certain distance to accelerate and a certain distance to decelerate, the actual distance where the measurements can be carried out and where the speed of the model is constant and the flow is stationary is reduced significantly.

Table 2.1. Model Side and Main Hull data

	Main Hull [5]	Side Hull
L_{WL} [m]	1.5	0.6
B_{WL} [m]	0.1	0.0142
T [m]	0.055	0.032
D [m]	0.107	0.06
C_P	0.603	0.809
C_M	0.827	0.713
C_W	0.755	0.87
Side Hull span [m]	0.0132	
VCG [m]	0.0815	
Overall Beam [m]	0.28	

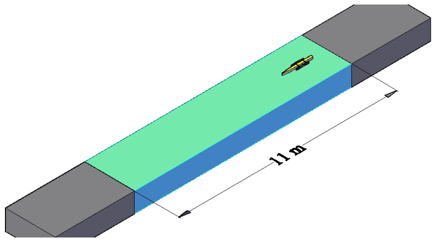

Fig. 2.3. Scaled image of the towing tank and model

Model Speed

As mentioned above, the speed of the model corresponding to the maximum speed of the real ship is 1.54 m/s. However, in order to be able to generate power-speed curves, the model was tested at other speeds, under and above this limit as well. These values centralized in Table 2.2, together with the corresponding speeds of the real vessel.

Table 2.2. Model and ship speed

Model [m/s]	0.5	1.0	1.54	2.0
Ship [m/s]	5	10	15.4	20
Ship [kts]	9.75	19.5	30.0	38.9

2.2 Side hull angles of interest

The project aims towards determining the influence of the side hull rotation with respect to X and Z axes, on the total forward resistance.

Broadly speaking, the experiment comprises two major parts:
- tests involving angles in the YZ plane;
- tests involving angles in the XY plane.

2.2.1 Case of angles in the YZ plane

Taking into account that in order to reduce the Radar Cross Section, the warship hull flare is 7^0, it was decided to test angles which are multiples of this value. Thus, the angles of interest with respect to X axis are: -7^0, 0^0, 7°, 14^0 and are presented in Fig. 2.5.

It is of great importance to mention that the side hulls have been rotated with respect to the line generated as the intersection between the main deck plane and the middle line plane, Fig. 2.4.

The reason behind this choice is keeping the box structure dimensions and thus the main deck area to constant value.

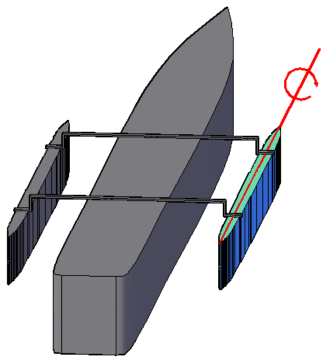

Fig. 2.4. Side hull axis of rotation

Fig. 2.5. -7^0,0^0,7^0,14^0

2.2.2 Case of angles in the XY plane

Previous studies suggested that due to interferences, not only will the water plane be horizontal any longer, but also the pressure field around the hull is no longer uniform.

In this case, the axis of rotation is generated as the intersection between the mid ship section plane and the middle line plane and is illustrated in Fig. 2.6.

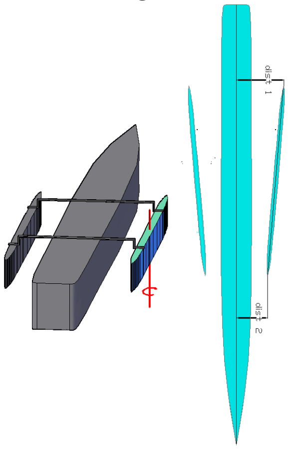

Fig. 2.6. Side hulls axis of rotation and angle measurement

The accuracy of the measurements is ensured by measuring the departures of the side hull extremities from the main hull middle line plane for each angle analyzed. This operation is sketched out in Fig. 2.6.

Having no other starting point, angles of 50 and 100 were considered and four possible arrangements were analyzed and presented below in Fig. 2.7.

Fig. 2.7. Side hulls rotated at 5^0

3. RESULTS

The experiment comprises of the following sections:

- towing tests using the entire trimaran model:
  - angles in the YZ plane;
  - angles in the XY plane;
  - combination of angles in the YZ plane and XY plane;
- towing tests using the main hull only;
- towing tests using the side hulls only:
  - angles in the YZ plane.

The main and side hulls were tested separately in order to be able to illustrate the wave interference between hulls.

3.1 Towing tests using the entire trimaran model

3.1.1 Case of angles in the YZ plane

The trimaran model has been towed at four different speeds having four possible side hull angles in the YZ plane:

-7°, 0°, 7° and 14°. The total resistance coefficients for the ship are presented below, in Table 3.1.

Figure 3.1 illustrates the total resistance coefficient variation with speed for constant side hulls rotation angle and Fig. 3.2 presents the variation of the same parameter with side hulls angle for constant speed.

Table 3.1. Real ship c_T for different side hulls transverse angles

Speed	[kts]	9.75	19.5	30	38.9
	[m/s]	5	10	15.4	20
Angle [°]		$c_T \cdot 10^3$			
0		1.91	2.52	2.72	2.98
-7		2.01	2.52	2.65	2.91
7		2.3	2.44	2.76	3.14
14		1.89	2.22	2.58	2.98

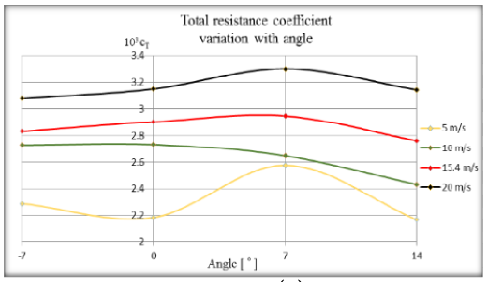

Fig. 3.1. $c_T = f(v)$ curves for transverse angles

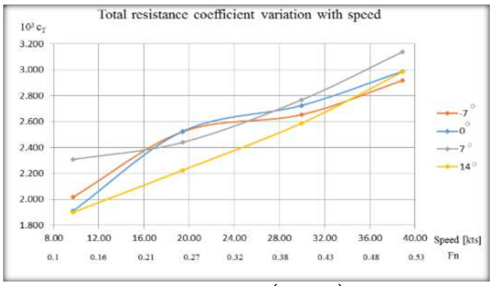

Figure 3.2. $c_T = f(angle)$ curves for transverse angles

3.1.2 Case of angles in the XY plane

Similar to previous case, four possible arrangements at four different speeds have been analysed and the results are presented below in Table 3.2 and Fig. 3.3, which illustrates the total resistance coefficient variation with speed.

Table 3.2. Real ship c_T for different longitudinal angle for side hulls

Speed	[kts]	9.75	19.5	30	38.9
	[m/s]	5	10	15.4	20
Angle [°]		$c_T \cdot 10^3$			
5 in		2.82	2.69	2.79	3.04
5 out		2.46	2.78	2.95	3.66
10 in		3.7	3.47	3.34	4.49
10 out		3.44	3.75	3.6	4.75

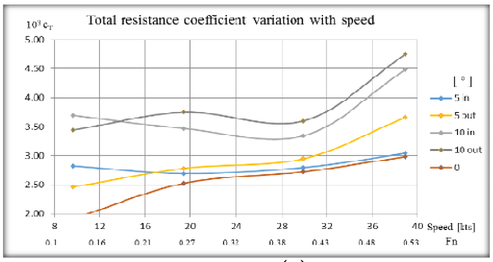

Fig. 3.3. $c_T = f(v)$ curves for longitudinal angles

3.1.3 Case of combined angles

Trying to anticipate the results, it was noticed that combinations of 5° in with +7° and 5° in with -7° might return favourable results.

Therefore, the trimaran model having these two side hulls arrangements was towed at the same four speeds and the results presented below in Table 3.3 and Fig. 3.4.

Table 3.3. Real ship c_T for the above combinations

Speed	[kts]	9.75	19.5	30	38.9
	[m/s]	5	10	15.4	20
Angle [°]		$c_T \cdot 10^3$			
5 in_-7		2.56	2.77	2.67	2.9
5 in_+7		2.63	2.65	2.93	3.05

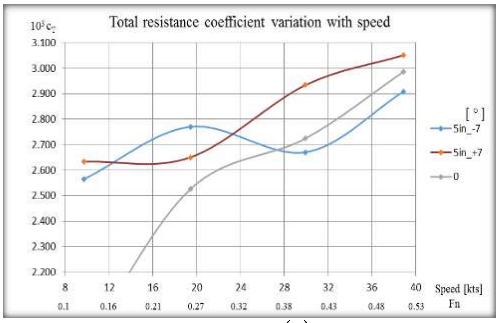

Fig. 3.4. $c_T = f(v)$ curves for combined angles

3.2 Towing tests using the main hull only

The main hull was tested alone in order to determine its contribution to total resistance.

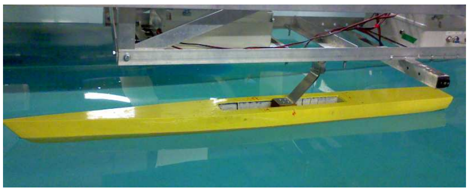

Fig. 3.5. Main hull towing test

The results are presented below:

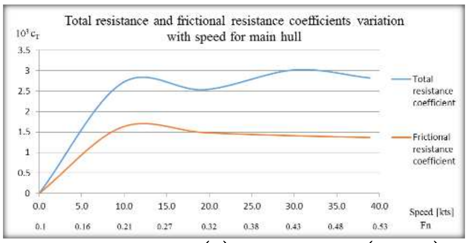

Fig. 3.6. $c_T = f(v)$ and $c_T = f(angle)$ curves for main hull

3.3 Towing tests using the side hulls only

Due to the fact that in the absence of the main hull, there are no wave interferences between the two side hulls, they were towed together and the results were treated as being twice the total forward resistance of a side hull. The set-up is presented in Fig. 3.7.

Using the arrangement presented above, the side hulls were tested at the same four speeds but only for the angles in the transverse plane: -7°, 0°, 7° and 14°. The results are presented below in Table 3.5 and Fig. 3.8

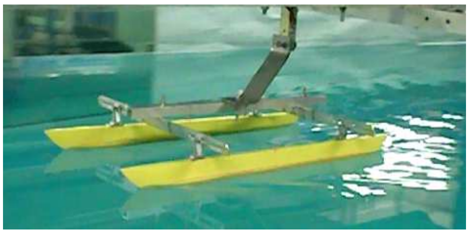

Fig. 3.7. Side hulls towing test

Table 3.5. Real ship c_T (side hulls only)

Speed	[kts]	9.75	19.5	30	38.9
	[m/s]	5	10	15.4	20
Angle [°]		$c_T \cdot 10^3$			
0		3.06	2.59	2.63	2.4
-7		2.25	2.6	2.69	2.38
7		2.66	2.77	2.97	2.43
14		2.07	2.69	2.66	2.36

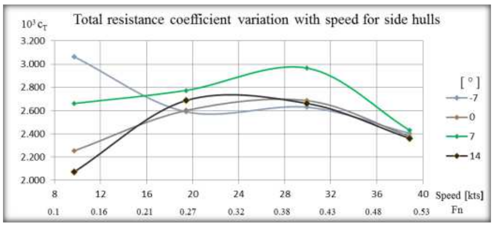

Fig. 3.8. $c_T = f(v)$ curves for side hulls

3.4 Wave interactions between hulls

The residual resistance of a trimaran vessel is highly influenced by the wave interactions between hulls. This phenomenon can increase or decrease the residual resistance if the hulls arrangement is judiciously chosen. The wave interference was analysed only for the case of side hulls rotation angles in the YZ plane.

Considering that at low speeds, the wave interaction between hulls is insignificant, the focus is on the range of speeds between 20 to 40 knots respectively 10 to 20 m/s. The results are given in Table 3.6 as dimensionless coefficients and their evolution with speed and angle is presented in Fig. 3.9.

Table 3.6. Interference dimensionless coefficients

Speed	[kts]	19.5	30	38.9
	[m/s]	10	15.4	20
Angle [°]		Interference dimensionless coefficients [$x10^3$]		
0		0.026	0.203	-0.204
-7		0.026	0.208	-0.279
7		0.155	0.235	-0.42
14		0.348	0.34	-0.281

Notes. Positive values of the dimensionless coefficients assume positive interference and, therefore, a reduction in total resistance whereas negative values suggest negative interference and an increase of the same parameter.

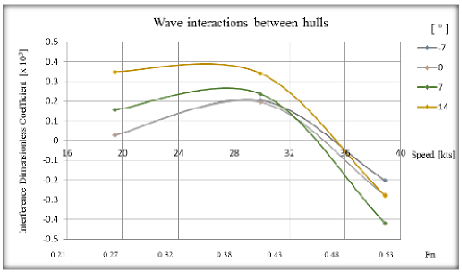

Fig. 3.9 Wave interference variation with speed

4. DISCUSSIONS

Broadly speaking, this chapter will be divided into three main sections covering the results analysis, the error generators and further work.

4.1 Results analysis

4.1.1 Case of angles in the YZ plane

The total resistance coefficient variation with speed for all angles is illustrated again in Fig. 4.1.

Broadly speaking, Fig. 4.1 suggests that the best results are obtained for the largest side hull angle of rotation. Drawing a parallel between these results and the one corresponding to 0^0 inclinations, which is the traditional arrangement for trimarans, one can conclude that at low and high speeds there are no significant differences.

However, within this range, for the trimaran with 14^0 angle of inclination of side hulls, the total resistance can record improvements up to 10%, Table 4.1.

This fact is not surprising since the chosen axis of rotation allows a slight translation of the side hulls as well. For this case, since 14^0 is the largest analysed angle, the translation of the side hulls is the most significant and the wave interaction between hulls is, this way, decreased (the magnitude of the wave interference is strongly influenced by the distance between hulls).

On the same token, the fact that at high speeds, the side hull angle of -7^0 behaves better than 14^0 can be explained also by interference.

Table 4.1

Speed [kts]	9.75	19.5	30	38.9
Speed [m/s]	5	10	15.4	20
% c_T improvement	0.7	11.9	5	0.1

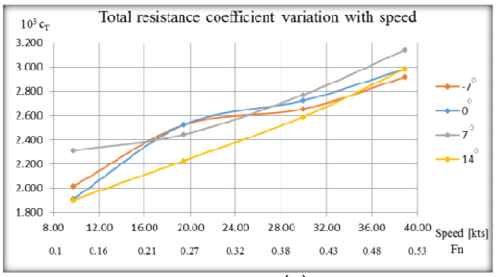

Fig. 4.1. $c_T = f(v)$ curves for transverse angles

4.1.2 Case of angles in the XY plane

Due to the fact that the centre of gravity and the centre of buoyancy are situated very closely, it would not make a big difference if the side hulls would have been rotated with respect to vertical axes through these two points. Therefore, considering that the mid ship section is representative for any hull, it was decided to rotate the side hulls with respect to a vertical line contained in the mid ship section.

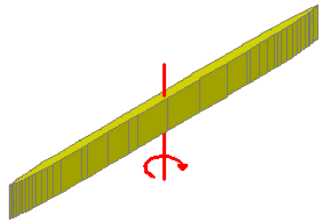

Fig. 4.2. Chosen axis of rotation

The variation of total resistance coefficient with speed for the analysed arrangements is presented in Fig. 4.3.

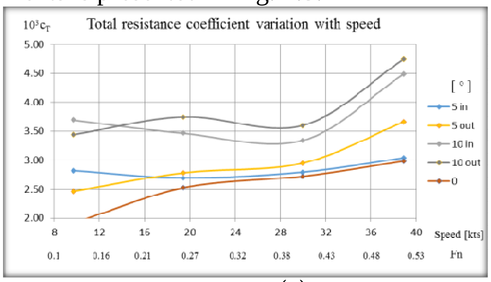

Fig. 4.3. $c_T = f(v)$ curves for longitudinal angles

Analysing Fig. 4.3, one can gather the following:

- overall, side hull angles of 10^0 induce considerably greater resistance than angles of 5^0 and 0^0;
- for both 5^0 and 10^0, the "out" arrangement generates lower resistance at low speeds and higher resistance at medium and high speeds, whilst the "in" arrangement shows a mirrored behaviour. An explanation of this fact can be that at low speeds, the interactions between hulls are insignificant, but as speed increases, the interferences increase and the total resistance builds up.
- judging by these results, the theory which triggered this study seems unfounded. However, the 5^0-in arrangement seems to return results good enough to be the premises of further research. It might be the case that the theory is not totally wrong but incomplete.

4.1.3 Case of combined angles

Before carrying out any towing test, and realising that actually the best combination might be 5^0 in in the XY plane and 14^0 in the YZ plane, it was expected to obtain the best results from the following two arrangements:

- 5^0 in in the XY plane and -7^0 in the YZ plane;
- 5^0 in in the XY plane and 7^0 in the YZ plane.

Therefore, these two solutions were analysed and the total resistance coefficient variation with speed is plotted below.

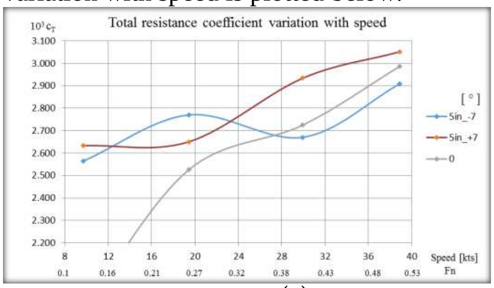

Fig. 4.4. $c_T = f(v)$ curves for combined angles

From the graph in Figure 4.4, it can be concluded that:

- due to wave interactions, the $c_T = f(v)$ curve records local points of minimum and maximum. This feature can be used for trimaran ferries, in order to design for a particular speed;
- although it doesn't seem to be the most successful combination, the 5^0 in -7^0 arrangement returns a lower resistance than the traditional 0^0 layout, at medium and high speeds;
- at low and medium speeds, the 5^0 in -7^0 combination records a local maximum, whilst the 5^0 in $+7^0$ records a local minimum, therefore within this range of speeds, the latter returns better results.
- the fact that for the same range of speeds, the two plots are out of phase, suggests a significant variation of the interferences between hulls. A more refined analysis of the total resistance within the domain, 5^0 in -7^0 to 5^0 in $+7^0$, by considering intermediate steps (such as 1^0 in -7^0, 2^0 in -7^0, 3^0 in -7^0,...,5^0 in -1^0, 5^0 in -2^0,... etc) might lead to a better understanding of the governing factors of the interactions between hulls.

4.2 Sources of error

As any other experimental project, the results of the present study are, to some extent, influenced by the environment, the equipment used to perform the experiment and, more than this, by the items which make the object of the experiment. All these aspects are referred to as errors and in order for an experiment to be validated their magnitude shouldn't exceed certain values.

For the current project, the errors can be induced by:

- *model size*: in order to reduce the scale effects as much as possible, for resistance towing tests, the overall length of the model should be between 4 and 10 m and the scale of the model in the range $15 < \lambda < 45$. For the present case, the corresponding values of the above parameters are:

$$L_{OAm} = 1.5m;\ \lambda = 100.$$

Therefore, the scale effects can be more pronounced in this case.

- *tank length: t*he length of the towing tank should be as large as possible in order to achieve a longer steady state (in this case constant speed for the model and stationary flow) as possible. The total tank length for the present towing tests is only 11 m with only 5 to 7 m available for actual measurements. For speeds up to 2 m/s the time frame available is only 2 to 3 seconds which proved to be insufficient to achieve perfect constancy.
- *accuracy of angles: e*ven though a lot of effort was put into measuring the angles involved in the experiment, there is, without no doubt, a degree of inaccuracy in the measurements which can be avoided by using specialised equipment.
- *load cell accuracy:* The present project was developed using a load cell designed to measure loads up to 3 kg. During towing tests, the maximum load applied on the load cell was only 0.4 kg, therefore some errors in measurements are expected.

- *connection arm;* During towing tests, the model was connected to the carriage using a rigid arm, setup which blocked the model on all six degrees of freedom. This arrangement did not allow the model to change its trim once the speed increases and therefore, the results may have been affected to some extent. This error can be corrected by recording the load cell's output when a certain weight is added on the aft end of the model. The results can be then altered by this correction factor.
- *connections;* A lot of effort was put into ensuring that the trimaran model is rigid enough. However, it is possible that the large number of connections between the main hull and side hulls allowed for local deformations, making the connections to act as dampers and affect the results.

3. CONCLUSIONS

The present research shows that at low and high speeds there are no significant differences in forward resistance, regardless of the side hulls inclination angle (14deg, 7deg, 0deg, -7deg). However, within this range, for the trimaran with 140 angle of inclination, it was found that the total resistance can record improvements of up to 10%, for speeds between 16 and 26 knots.

Further research is required to establish if the present findings are valid, and more than this, to identify if an optimum speed range exists, which can be considered in trimaran designs.

Additionally to a second experimental study, a numerical analysis must be employed. This can allow for smaller steps in inclination angles (circa 2 deg) in order to refine and validate/invalidate the present study.

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