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Drop Down in Speed of Fast Attack Craft

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Abstract— Sri Lanka Naval fleet consists of 55 Fast Attack Craft (FACs) belonging to the Sri Lanka Navy (SLN) and Coast Guard which are propelled by water jets, conventional V-drive propulsion systems, and Articulated Surface Drive (ASD) powered by twin diesel engines. Recently, the drop in speed of FAC's has been a challenging problem to SLN. The objective of this research is to find out the reasons for the speed drop of FACs, and the effect of hull cleaning/routine underwater maintenance as a solution. The research mainly focused on gathering information related to speed with RPMs and observing changes to the hull, and finally modelling of a similar shaped hull and analysing effects on speed due to the changes in the hull form.

Keywords: ***hull cleaning, fast attack craft, underwater maintenance, Sri Lanka Navy***

I. INTRODUCTION

The fast attack craft is a mono hull planing craft which is also known as "Dvora". These craft are designed for an average of 24m length, 5.5m breadth and 50 Tons of light load displacement. The engines and propulsion system of these craft are as follow;

Table 1. Propulsion systems of FAC series

Craft Series	Engines Used	Propulsion System
P 40, Coast Guard Craft (P 44 Series)	Engines	Conventional V-drive propulsion system
P 41, P 42, P 43, P 47	Engines	LIPS Water Jets
P 45, P 48, P 49	Engines	KAMEWA Water Jets
P 46, P 444	Engines	Articulated Surface Drives (ASDs)

Craft with conventional propulsion systems are designed for a top speed of 36 knots and other craft with ASDs and water jets are designed to achieve 45 knots in full load condition.

A. Planing craft

Planing hulls are designed with more aft sections. A typical 'deep V' bottom hull has the same angle to the 'V' (the same deadrise angle) from amidships to the transom. They are designed to rise completely out of the water at high speed and "hydroplane" on top of the water. At planing stage water is breaking clearly from the transom and the hull is riding on its straight aft sections.

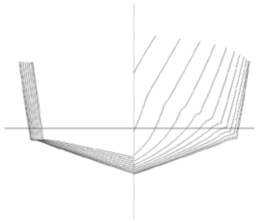


Figure 8. Lines plan of a Mono hull planing craft

A craft can be determined whether it is a planing craft by its Froude number which is defined by the following equation;

$$Fn = \frac{V}{\sqrt{(g.lw)}} \qquad (1)$$

Where; F_n - Froude number
g - Gravitational acceleration
l_w - wetted length

Baird (1998) Defines a high speed vessel as a craft with a maximum operating speed higher than 30 knots, whereas hydrodynamicists tend to use Froude number greater than 0.4 to categorize a fast vessel supported by the submerged hull, such as mono hulls and catamaran hulls.

The pressure carrying the vessel can be divided into hydrostatic and hydrodynamic pressure. The hydrostatic pressure gives the buoyant force which is proportional to the submerged volume (displacement) of the ship. The hydrodynamic pressure depends on the flow around the hull and is approximately proportional to the square of the ship speed. When Froude number > 1.0-1.2 the hydrodynamic force mainly carries the weight and this can be called as a planing craft. [1]

B. Resistance of a ship

Resistance of a ship at a given speed is the force required to tow the ship in the calm water, assuming no interference from the towing ship. If the hull has no appendages, it is called bear-hull or towing resistance. This is not exactly same as the propulsion resistance due to hull/propeller interaction. A ships resistance is particularly influenced by its speed, displacement and hull form.

The total resistance when not planing can be divided into three main categories as follows;

Viscous resistance/ Frictional resistance (R_f)
Residual resistance (R_r)
Air resistance(R_a)

Viscous resistance (R_f) is also called frictional resistance and is due to the motion of the hull through a viscous fluid which depends on the wetted surface area of the ship(S) and the specific frictional resistance coefficient (C_f). The empirical formula for frictional resistance is as follows;

$$R_f = 0.5\rho C_f S U^2 \qquad (2)$$

Where ;
$C_f = \frac{0.075}{(\log_{10} R_n - 2)^2}$; Towing tank conference (ITTC) 1957

$$R_n = \frac{UL}{\nu} \qquad (3)$$

$\nu - Kinematic\ viscosity$
$L - Overall\ submerged\ ship\ length$

$$\nu = \frac{\mu}{\rho} \qquad (4)$$

$\mu - Dynamic\ viscosity, p$
$- Mass\ density\ of\ fluid$

Residual resistance (R_r) comprises wave resistance (Rw) and eddy resistance (Re). Wave resistance refers to the energy loss caused by waves created by the vessel during its propulsion through the water, while eddy resistance refers to the loss caused by flow separation which creates eddies, particularly at the aft end of the ship.

Air resistance (R_a) in calm weather can be expressed by the following equation;

$$R_a = 0.5\rho_a C_D A U^2 \qquad (5)$$

$\rho_a - Mass\ density\ of\ air$
$A - Cross\ sectional\ area\ of\ the\ hull\ form$
$C_D - Wing\ tunnel\ tests\ are\ used\ to\ obtain$
$this\ and\ value\ between\ 0.5\ and\ 0.7$

Total resistance can be calculated using the following formula;

$$R_T = R_f + R_r + R_a \qquad (6)$$

The drop in speed of FACs is one of the main problems which the Sri Lanka Navy confronts which directly affects the craft's operational capability. This research, is intended to elaborate on identified root causes for the drop in speed of FACs.

II. OBJECTIVE

As a solution to the speed drop of the FACs Sri Lanka Navy adopts hull cleaning of the craft in the periods of six months. Once a year a craft will undergo Routine underwater maintenance and a hull cleaning in the periods of six months. The objective of this research is to identify the reasons for the speed drop of the FACs and provide solutions to minimize the preventable causes of the drop in speed of FACs

III. LITERATURE REVIEW

Researches elaborate on the performance drop of FACs such as drop in designed speed, acceleration delay and poor turn manoeuvring performance of water jet propelled FACs (Pathirana, 2014).

Following root causes were identified in above mentioned research to drop in speed of FACs.

i. Increased skin friction resistance owing to the rough bottom surface due to thick and irregular paint coating, left with protruded weld seams.
ii. Dented shipside and superstructure causing higher wind resistance.
iii. Moderate growth after 4-5 months of routine underwater maintenance that leave a doubt on self-polishing paint scheme (SPC) performance.
iv. Mechanical defects such as higher water jet impeller tip clearance; as per jet manufacturer doubling of tip clearance causes 1 percent speed drop.
v. Overloading of vessels.

Research by Avci and Barlas on the use of trim interceptors shows the gaining of speed by few knots than the bare hull form of the vessel. It is clearly said that the interceptor blade depth has to be adjusted related to the operation speed of the vessel. The study clearly states that the interceptor systems decreases the unwanted trim angles in high speeds and increase the forward speed up to 4 to 5 knots in full scale, and gain approximately 25% fuel savings. The system also decrease the wetted surface area and supplies a clear angle of sight for the boat operators.

A study on the planing behaviour of a fast monohull was investigated with reference to the change in

LCG positions and its effect on the resistance, dynamic trim and sinkage were explored based on dedicated model tests by Danisma. Based on findings in this study a slight aft trim may increase the resistance below the planing speed, but provided with sufficient power it can help the vessel to reach her planing regime as well as reducing the resistance at speeds beyond the planing speed.

A study on increasing frictional resistance of a hull due to surface fouling has to be carried out by Demirel, Uzun, Zhang &Turan. They considered two types (M type and S type) of barnacles and found the change of the percentage of the C_f due to the presence of barnacles. Results are as follows;

Table 2. Effect of resistance due to Barnacles

Sr. No.	Type of Barnacle	Surface Coverage (%)	Change in C_f (%)
a.	M	10	44
		20	71
		40	107
		50	115
b.	S	10	23
		20	43
		40	68
		50	77

IV. METHODOLOGY

i. Collection of data related to the speed of the FACs before and after hull cleaning, tabulate them and analysis of data gathered.
ii. Collection of data related to maximum speed, monthly running hours pattern and the number of patrols carried out by few FACs belongs to SLN over a year and analysis of data gathered.
iii. Gathering data related to the deformation of hull shapes, mechanical defects which can directly affect on reduction of speed of FACs.
iv. Designing a hull form equivalent to a hull shape of FACs and analysis of the hull shape.
v. Calculating planing LCG of the designed hull shape, and planing speed of the designed hull by the software developed by Dingo Tweedie (2004).
vi. CFD representation of flow around the hull form due to movement of the vessel before planing and after planing.
vii. CFD representation of flow pattern around the hull form when the hull is deformed.
viii. Validating of the methods carried out to prevent speed drop of FACs by SLN with the gathered data.

V. DATA REPRESENTATION AND DATA ANALYSIS

Data of the speeds of the FACs before and after hull cleaning has been gathered from the ship's logs/ trial sheets. Speeds of the FACs before and after hull cleaning are as follows;

Table 3. Speeds of FACs before and after hull cleaning

Craft	Speed before slipping	Speed after slipping
P 402	19	23
P 410	40	43
P 423	43.4	36
P 433	32	35
P 435	31.4	40.6
P 439	39	40
CG 403	30.6	34
P 450	23	42
P 451	32	38
P 471	19.9	21.7
P 472	32	40
P 473	16.5	42
P 475	22	42
P 485	36	40
P 497	38.5	42.8
P 4443	44	48.5
P 4444	44	48.5
P 4445	47.5	48
P 4446	44.3	47

The above graph clearly shows that the speed of the craft has been increased in a considerable amount after the hull cleaning. In some craft, the speed gained only a little after the hull cleaning and it was observed that due to the rough sea conditions the speed has not been gained by the craft.

Data of the running hours pattern, patrols carried out during the month and the maximum speed gained by the ship has been collected by using the ship's logs for few FACs and the data tabulated as follows for the convenience of the analysis of the data. The black dot shows the speed after RUWM. (only one FAC is considered here for easy reference)

Table 4. Details of P451 Craft

Month	Number Of Patrols	Running Hrs During Month	Average Speed	
			RPM	KNOTS
Post slipping trials were carried out on 08 March 17 after Hull cleaning and achieved 40 knots when both engines were in maximum RPM (2100 x 2)				
March		9.00	2070 x 2	40.00
April	5	127.00	1850 x 2	30.50
May	7	176.00	1900 x 2	32.00
June	14	295.15	2000 x 2	36.00
July	14	268.10	1800 x 2	30.00
August	10	203.20	1900 x 2	31.00
September	10	99.50	2000 x 2	32.00
Post slipping trials were carried out on 03 October 17 after RUWM and achieved 42 knots				
October		4.30	2070 x 2	38.00
November	4	47.20	1900 x 2	35.00
December	7	72.00	1900 x 2	35.00
January	5	76.00	2000 x 2	36.50

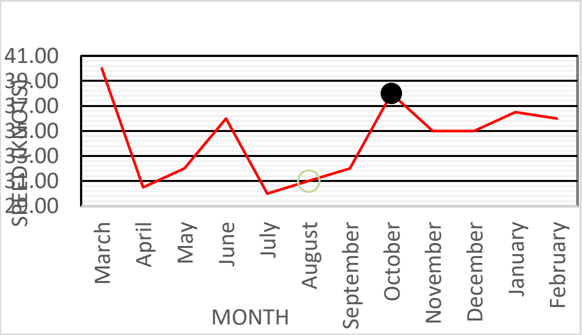


Figure 2. Data tabulation of P451 Craft

A routine under water maintenance (RUWM) is being carried out in each craft per year. In the RUWM a new paint coating is being applied on the hull after cleaning the hull and propellers or in the case of a water jet propelled craft the water jet tunnel, impeller, the nozzle is being cleaned.

A hull cleaning is being carried out every six months for each craft and during this period cleaning of hull fouling, cleaning of propellers/ impellers, water jet tunnel etc. is being carried out. Covering of removed patches of the paint coating is being carried out in this period.

Analysis of the above data validates that hull cleaning or RUWM is an effective method of preventing speed drop of the FACs. By this method it prevents the followings;

i. Added resistance force due to barnacles.
ii. Extra added weight and shifting of LCG of the craft.
iii. Eddy resistance due to fouling of the ship's hull.

Further analysis shows that the running hours pattern of the FACs affects the speed drop of the craft. Months which there is a low running hours during the month has a slight considerable drop of the speed during the month. The reason for this is the rate of fouling of the ship's hull is considerably high when the ship is at rest.

Also, the speed drop occurs when the engines of the craft are not achieving their maximum RPMs due to various reasons. Most of the sea trials show that the same throttle position does not give the same RPM of both engines. Further, calibration errors lead to mismatch of RPMs of both engines installed onboard and it can be directly affects the speed of the craft.

Most of the trim tabs available are locked due to operational defects and locked trim tabs is another reason for craft failing to gain maximum speeds at maximum RPMs. As described previously the interceptor blade/trim tab depth have to be adjusted related to the operation speed of the vessel.

To design an equivalent hull form of a FAC, Delft Ship (Version 10.20) free software is used. The hull form is as follows. The Lines plan is attached herewith as Annex A to this document.

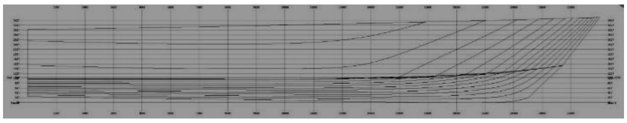


Figure 3. Profile of Hull

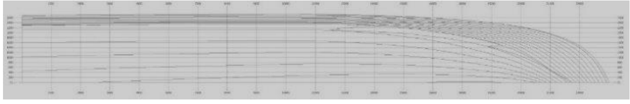


Figure 4. Half Breadth Plan

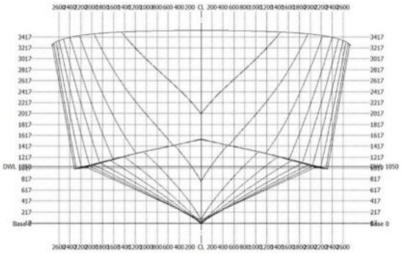


Figure 5. Body Plan FWD

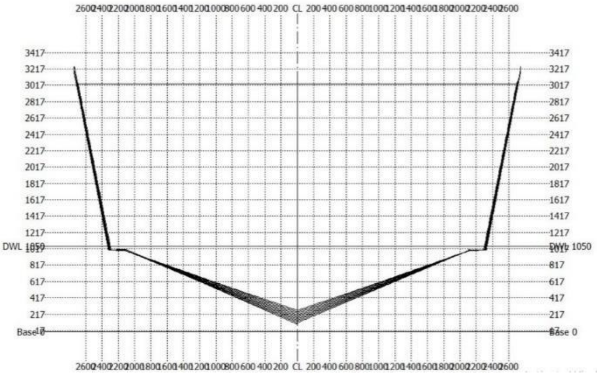
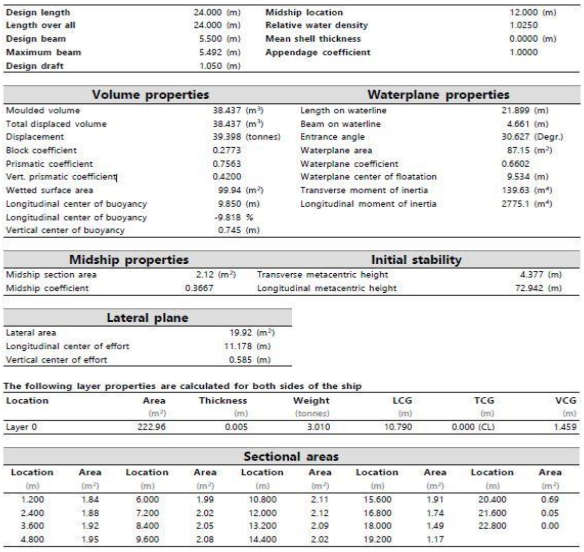


Figure 6. Body Plan AFT

The design hydrostatics of the hull form are as follows



Design length	24.000 (m)	**Midship location**	12.000 (m)
Length over all	24.000 (m)	**Relative water density**	1.0250
Design beam	5.500 (m)	**Mean shell thickness**	0.0000 (m)
Maximum beam	5.492 (m)	**Appendage coefficient**	1.0000
Design draft	1.050 (m)		

Volume properties		**Waterplane properties**	
Moulded volume	38.437 (m³)	Length on waterline	21.899 (m)
Total displaced volume	38.437 (m³)	Beam on waterline	4.661 (m)
Displacement	39.398 (tonnes)	Entrance angle	30.627 (Degr.)
Block coefficient	0.2773	Waterplane area	87.15 (m²)
Prismatic coefficient	0.7563	Waterplane coefficient	0.6602
Vert. prismatic coefficient	0.4200	Waterplane center of floatation	9.534 (m)
Wetted surface area	99.94 (m²)	Transverse moment of inertia	139.63 (m⁴)
Longitudinal center of buoyancy	9.850 (m)	Longitudinal moment of inertia	2775.1 (m⁴)
Longitudinal center of buoyancy	-9.818 %		
Vertical center of buoyancy	0.745 (m)		

Midship properties		**Initial stability**	
Midship section area	2.12 (m²)	Transverse metacentric height	4.377 (m)
Midship coefficient	0.3667	Longitudinal metacentric height	72.942 (m)

Lateral plane	
Lateral area	19.92 (m²)
Longitudinal center of effort	11.178 (m)
Vertical center of effort	0.585 (m)

The following layer properties are calculated for both sides of the ship

Location	Area (m²)	Thickness (m)	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)
Layer 0	222.96	0.005	3.010	10.790	0.000 (CL)	1.459

Sectional areas

Location (m)	Area (m²)	Location (m)	Area (m²)	Location (m)	Area (m²)	Location (m)	Area (m²)	Location (m)	Area (m²)
1.200	1.84	6.000	1.99	10.800	2.11	15.600	1.91	20.400	0.69
2.400	1.88	7.200	2.02	12.000	2.12	16.800	1.74	21.600	0.05
3.600	1.92	8.400	2.05	13.200	2.09	18.000	1.49	22.800	0.00
4.800	1.95	9.600	2.08	14.400	2.02	19.200	1.17		

Figure 7. Design Hydrostatics

Designed hull particulars have been entered into the software developed by Dingo Tweedie (2004) and the planing speeds at different LCG positions were obtained. The gathered data are as follow for the different LCG positions; (only the data most relevant is mentioned here such as speed where planing of the hull begins)

Table 5. LCG at 10.79m from the transom

V	LCG		$P_{effective}$		Planing/ Not Planing
[kn]	[ft]	[metres]	[ehp]	[ekW]	
10	35.4	10.790	96	71	NP
11	35.4	10.790	140	105	NP
13	35.4	10.790	230	171	NP
15	35.4	10.790	319	238	NP
17	35.4	10.790	409	306	NP
19	35.4	10.790	503	376	NP
21	35.4	10.790	603	450	NP
23	35.4	10.790	710	530	NP
25	35.4	10.790	827	617	NP
27	35.4	10.790	955	713	NP
29	35.4	10.790	1,095	817	NP
31	35.4	10.790	1,249	932	NP
33	35.4	10.790	1,417	1,057	NP
35	35.4	10.790	1,600	1,194	NP
37	35.4	10.790	1,801	1,344	NP

Table 6. LCG at 8.5m from transom

V	**LCG**		**$P_{effective}$**		Planing/ Not Planing
[kn]	[ft]	[metres]	[ehp]	[ekW]	
10	27.89	8.501	96	72	NP
11	27.89	8.501	143	107	NP
13	27.89	8.501	235	175	NP
15	27.89	8.501	325	242	NP
17	27.89	8.501	415	310	NP
19	27.89	8.501	507	378	NP
21	27.89	8.501	603	450	NP
23	27.89	8.501	703	525	NP
25	27.89	8.501	807	603	NP
27	27.89	8.501	917	684	NP
29	27.89	8.501	1,032	771	P
31	27.89	8.501	1,156	863	P
33	27.89	8.501	1,288	961	P
35	27.89	8.501	1,432	1,069	P
37	27.89	8.501	1,589	1,186	P

Table 7. LCG at 7.49m from transom

V	LCG		$P_{effective}$		Planing/ Not Planing
[kn]	[ft]	[metres]	[ehp]	[ekW]	
10	24.6	7.498	107	80	NP
11	24.6	7.498	158	118	NP
13	24.6	7.498	259	193	NP
15	24.6	7.498	358	267	NP
17	24.6	7.498	457	341	NP
19	24.6	7.498	557	416	P
21	24.6	7.498	656	490	P
23	24.6	7.498	755	564	P
25	24.6	7.498	853	637	P
27	24.6	7.498	952	710	P
29	24.6	7.498	1,053	786	P
31	24.6	7.498	1,161	866	P
33	24.6	7.498	1,276	952	P
35	24.6	7.498	1,402	1,046	P
37	24.6	7.498	1,539	1,149	P

Table 8. LCG at 6.5m from transom

V	**LCG**		$\mathbf{P_{effective}}$		Comments
[kn]	[ft]	[metres]	[ehp]	[ekW]	
10	21.33	6.501	129	96	NP
11	21.33	6.501	191	142	P
13	21.33	6.501	312	233	P
15	21.33	6.501	432	322	P
17	21.33	6.501	549	409	P
19	21.33	6.501	659	492	P
21	21.33	6.501	760	567	P
23	21.33	6.501	850	635	P
25	21.33	6.501	934	697	P
27	21.33	6.501	1,016	758	P
29	21.33	6.501	1,100	821	P
31	21.33	6.501	1,190	888	P
33	21.33	6.501	1,287	960	P
35	21.33	6.501	1,394	1,040	P
37	21.33	6.501	1,512	1,129	P

The above tables show the effect of the LCG position on the planing speed. When the craft's LCG shifts towards transom the speed where craft planes decrease. Also it is obvious that the power required to achieve the planing speed reduces drastically when the LCG shift towards the transom.

Yet there is a limit for the LCG to be shifted in order to maintain the stability, manoeuvrability and habitability of the craft. Furthermore, moving LCG of the craft improves the ability of the craft to plane and further increasing causes power required to maintain the momentum at some point.

CFD analysis has been carried out for a model hull form of a FAC. The hull shape is smooth and fine. The pressure profile, velocity profile and streamlines around the hull are as follows;

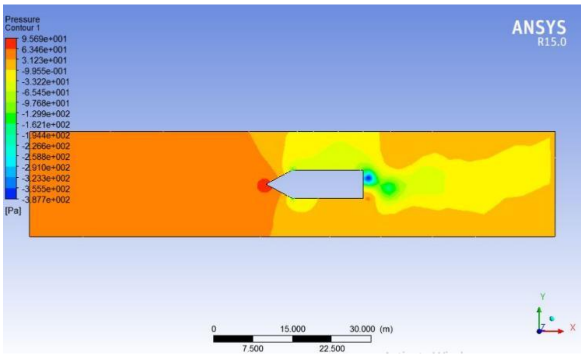


Figure 8. Pressure profile around the model hull

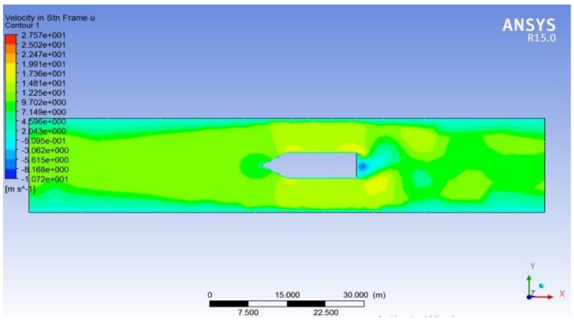


Figure 9. Velocity profile around the model hull

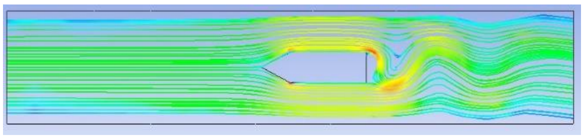


Figure 10. Streamlines around model hull

It is obvious that the pressure profile, streamlines and velocity profile around the hull are fine and smooth due to the smoothness of the hull. In this case, there won't be increased resistance to the hull or eddy resistance generated by the hull. Also, resistance due to wave making might not be added in this situation.

In order to obtain the pressure profile, streamlines and velocity profile around a deformed hull in which fouling is existing a hull form was designed and the CFD analysis was carried out and results are as follows;

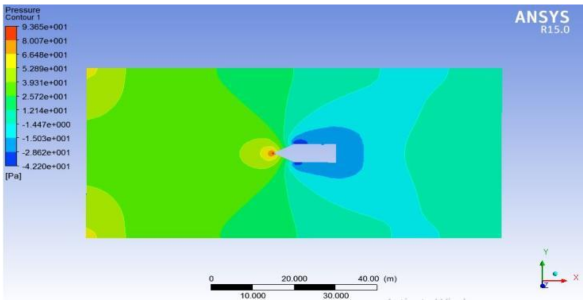


Figure 11. Pressure profile around the deformed hull

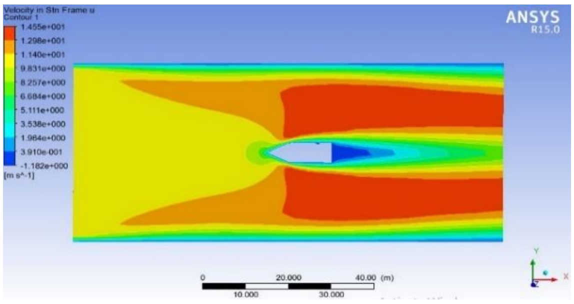


Figure 12. Velocity profile around the deformed hull

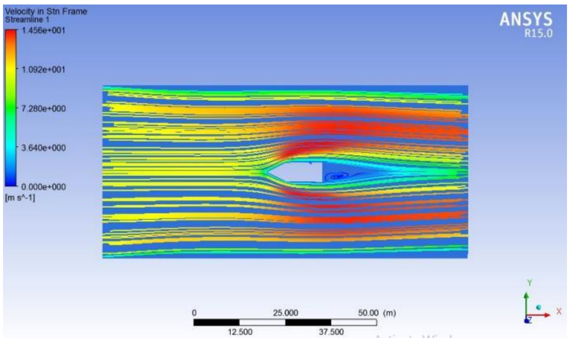


Figure 13. Streamlines around the deformed hull

It can be clearly identified that the maximum velocity of the hull shape has been reduced to 14.5 m/s from 27.5 m/s due to the deformation of the hull. The same effect occurs when fouling occurs in the hull form.

Further, the streamlines create eddies due to the hull shape deformations. This is called as eddy resistance of the hull. It can be clearly identified when the RPM of the engines increases the speed of the craft reduces drastically due to fouling of the hull.

VI. CONCLUSION

As per data gathered it is obvious that the speed of the craft has been drastically increased after a hull cleaning/RUWM. This is mainly due to removing of the fouling/ underwater growth. Furthermore, the following reasons causes the speed drop of the FAC's;

i. Mechanical errors such as defects in trim tabs.
ii. Electrical errors such as RPM differences.
iii. Restrictions in RPMs.
iv. Shifting of LCG of the craft due to heavy loading.

It is true that the main reason for the speed drop due to underwater growth which is named fouling of the hull. Considering all the above facts the RUWM and hull cleaning after six months of RUWM is an effective method to prevent fouling of the hull.

Further, in order to prevent speed drops the FAC's the facts which are mentioned in the above para are to be addressed and rectified.

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