PRELIMINARY STUDY OF MEDIUM-SPEED MONOHULL PASSENGER FERRIES

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ABSTRACT

The recent development of medium-speed monohull passenger ferries has shown their importance for certain routes. The aim of the intensive studies performed in the recent years is to fulfil the pending technical and environmental issues concerning the HSC crafts. They operate at the Froude number range of 0.55 to 0.80 which is beyond the last hump of the wave resistance curve. In fact, they need a high power to maintain their operation speeds. The present project is to find the best design based on the layout of the passenger arrangement and the hull form configurations. The layout includes the seat arrangement and the distribution of passengers at the main and upper decks. Due to the lack of design data base of those kinds of semi-planning ships, a parent ship of 250 passengers is considered in this study. During the design process, the rules and mandatory issues are taken into account. The results of the design parameters and general layout of a series of parent ships are presented in this paper. The results will be applied in a future parametric study, particularly to find the best layout and hull form with the minimum engine power.

Keywords: Ship design, general arrangement, engine power, passenger vessel

1. INTRODUCTION

Nowadays, there are a lot of medium-speed passenger ferries operating in all regions of the world. Those ships operate up to a top speed of 23 knots. The existence of those ships is to fulfil a transition speed region between the conventional ferries (speeds < 15 knots) and HSC (speed ranges 25 to 40 knots). Also their existence is to fulfil some pending issues about HSC ferries such as cost, comfort, safety and environmental issues. Since emerging-time of those ships, they had been developed to be operated in many regions. Most of the ships are multi-hulls but due to their simplicity, the monohulls have also been developed and have a promising future markets. Most of those ships constructed recently use Aluminu as hull material. The application of this material to those ships gives the benefits of increasing the payload or reducing the engine power. In addition, in some Asia and Pacific regions, there are a lot of monohull medium-speed passenger ferries in composite material (Fibreglass Reinforced Plastic).

In fact, those medium-speed ships operate at the range of Froude number Fn from 0.55 to 0.80. This range is beyond the last hump of the wave resistance curve (Fn > 0.50). Therefore, they need a great amount of energy to maintain their service speed. An effort should be done in order to find the solution of minimizing the engine power for those ships. Since there was no the database available for these kind of ships then a parent ship was designed in this preliminary study. In addition, a modified ship was developed also. The design parameters of the modified ship were compared to those of the parent ship. The comparisson was made particularly for the two important design parameters, i.e., ship propulsion and stability.

2. DESIGN OF PARENT SHIP

2.1 INPUT DESIGN

Several important key factors were summarized from Knox (2003), Levander (2003), Calhoun (2003), Gale (2003) and Olson (1990) concerning the arrangement of the passenger ferries. They are:

- Spaces, volumes, service rooms, access and services are provided for the passengers.
- Accomodations are provided on board to ensure the comfort for the passenger during the travel.
- The arrangement of ship is fixed to fulfill the safety standart regulations.
- The facilities are provided to support the operation of the ship.
- The design parameters that should be considered during the operation such as safety, stability, seakeeping and manuevering capability.

Input design parameters include:

- Type of ship : Pasenger Ferry/Class B
- Number of passenger : 250 pax
- Passenger Distribution: 70 % at main deck
  30 % at upper deck
- Number of crew : 5
- Service speed : 22 knots
- Navigation range : 200 n.m
- Type of pax accomodation : seat
- Number of seat in row : 10
- Type of pax room : passenger saloon
- Type of seat : West Mekan

The input design parameters were computed and analyzed during the design process. The process is finished when the ouputs meet the ship requirements. The layout of the ship was determined to fit the rules of International Code of Safety for High-Speed Craft (2000), 2008 Edition. The structure components of the ship were determined based on the Rules for the Classification of High Speed Craft, Bureau Veritas, February 2002. The hull material of the ship is Aluminium Alloy. The type of alloys used for the ship are 5083 H111 for plating and 6082 T6 for profile.

2.2 SHIP DIMENSIONS

The dimensions of the ship (parent ship), obtained from the design process are presented in Table 1. The hydrostatic parameters of the ship were computed by using Maxsurf Version 13.01. The results of hydrostatic paremeters are presented in Table 1. The lines plan of the parent ship are showed in Figure 1.

Table 1: Main Dimensions and Hydrostatic Parameters of Parent Ship

No	Parameters	Value	Unit
1	Length Overall, L_{OA}	32.00	m
2	Length of Waterline, L_{WL}	28.625	m
3	Beam, B	7.00	m
4	Beam of Waterline, B_{WL}	6.686	m
5	Draft, T	1.375	m
6	Deck Height, D	2.60	m
7	Volume	94.655	m^3
8	Displacement	97.02	tonne
9	Wetted Surface Area, WSA	187.74	m^2
10	Max cross sect area	4.993	m^2
11	Waterplane area, WPA	161.688	m^2
12	Prismatic Coefficient, Cp	0.662	
13	Block Coefficient, Cb	0.36	
14	Midship Coefficient, Cm	0.543	
15	Waterplane Area Coefficient, Cwp	0.845	
16	LCB from amidship	-0.139	m
		-0.484	% L_{WL}
17	LCF from amidship	-2.022	m
		-7.065	% L_{WL}
18	Vertical C. Buoyancy KB	0.956	m
19	Vertical C. Gravity, KG	0	m
20	Transverse Radius of Metacentric, BMt	5.667	m
21	Height of Metacentric, GMt	6.623	m
22	Immersion (TPc)	1.657	tonne/cm
23	Ship Lightweight, LWT	60.55	tonne
24	Deadweight, DWT	36.12	tonne
25	Total Weight	96.67	tonne
26	Longintudinal C. Gravity	-0.609	m

2.3 SHIP LAYOUT

The layout of the ship is defined considering the requirements linked to the passengers and their comfort during the travel. The place of the passengers is in the passenger saloon. In addition, access and services were provided for the passengers. Other service rooms such as toilets and small kiosk are provided also in this layout. The equipments and ship systems of the ship are also provided and placed to their proper locations. The layout of the ship is presented in Figure 2.

2.4 MODIFICATION OF PARENT SHIP

The modification of the parent ship was performed in order to assess the effect of changing the dimensions of few design parameters. For instance, this was done by increasing the number of seats in row from 10 to 11 seats. The results of such modification are presented in Table 2.

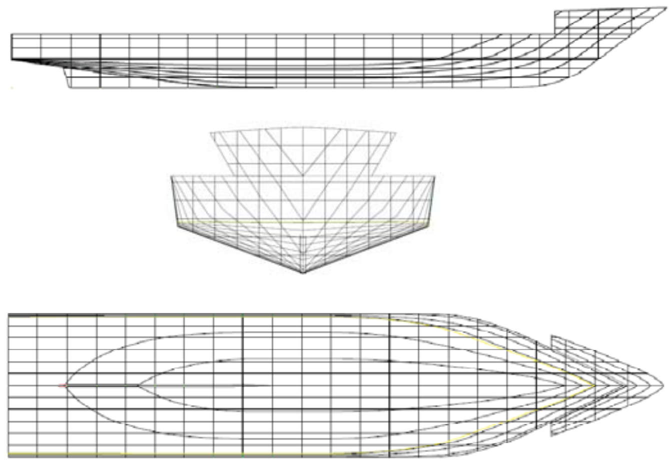

Figure 1: Lines Plan of the Parent Ship

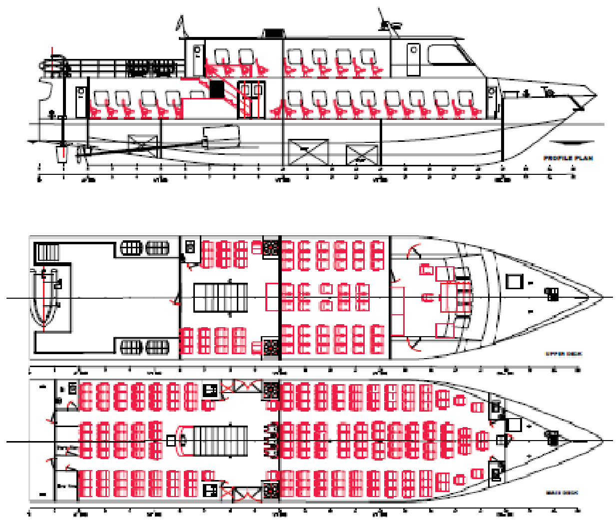

Figure 2: Layout of the Parent Ship

During the process of modification, some parameters changed such as:

- Increasing of ship beam, dB = 7.48 – 7.00 = + 0.48 m or 6.42 %
- Decreasing of ship length, dL_{OA} = 32.00 – 31.03 = -0.97 m or 3.03 %
- Increasing of stuctural weight, dW = 33.76 – 33.06 = + 0.7 tonne = + 2,07 %
- Decreasing of draft, dT = 1.375 – 1.365 = - 0.01 m = - 0.73 %

The design parameters of parent and modified ships were investigated. However, in this preliminary study, two important design parameters are concerned i.e. the power and stability of the ship. In the next sections, these two ships are named P250S10 (the configuration with 250 passengers and 10 seats in row) and P250S11 (the configuration with 250 passengers and 11 seats in row).

Table 2: Main Dimensions and Hydrostatics Parameters of the Modified Ship

No	Parameters	Value	Unit
1	Length Overall, L_{OA}	31.03	m
2	Length of Waterline, L_{WL}	27.64	m
3	Beam, B	7.48	m
4	Beam of Waterline, B_{WL}	7.163	m
5	Draft, T	1.365	m
6	Deck Height, D	2.60	m
7	Volume	95.37	m^3
8	Displacement	97.75	tonne
9	Wetted Surface Area, WSA	188.84	m^2
10	Max cross sect area	5.281	m^2
11	Waterplane area, WPA	164.13	m^2
12	Prismatic Coefficient, Cp	0.653	
13	Block Coefficient, Cb	0.353	
14	Midship Coefficient, Cm	0.54	
15	Waterplane Area Coefficient, Cwp	0.829	
16	LCB from amidship	-0.302	m
		-1.094	% L_{WL}
17	LCF from amidship	-2.074	m
		-7.503	% L_{WL}
18	Vertical C. Buoyancy KB	0.948	m
29	Vertical C. Gravity, KG	0	m
20	Transverse Radius of Metacentric, BMt	6.476	m
21	Height of Metacentric, GMt	7.424	m
22	Immersion (TPc)	1.682	tonne/cm
23	Ship Lightweight, LWT	61.25	tonne
24	Deadweight, DWT	36.12	tonne
25	Total Weight	97.37	tonne
26	Longintudinal Center of Gravity	-0.588	m

3. ASSESSMENT OF SHIP STABILITY

In this preliminary study, the computation of ship stability was done for the full load condition. The load case of those two ships are presented in Table 3. The stability of the ship is computed by using Maxsurf version 13.01. The criteria that have been used are based on the IMO Code: A.749(18) Ch3 - Design criteria applicable to all ships. The results of stability computaions for those two ships are presented in Table 4.

Table 3: Load Cases for Ship P250S10 and P250S11

No	Item Weight	Weight (tonne)	LCG from AP (m)	TCG From CL (m)	VCG from BL (m)
A	**Ship P250S10**				
1	Passengers, Crews and Lugages	27.030	13.670	0.0	6.390
2	Lightship	60.553	12.929	0.0	2.893
3	Tank 1 (F.O.T)	3.217	15.400	- 0.677	0.744
4	Tank 2 (F.O.T)	3.217	15.400	0.677	0.744
5	Tank 3 (F.W.T)	1.247	18.532	- 0.590	0.503
6	Tank 4 (F.W.T)	1.247	18.532	0.590	0.503
7	Tank 5 (B.W.T), 15 %	0.153	6.288	0.0	0.590
8	Total	96.664	13.435	0.0	3.663
	Fluid Correction				0.004
	VCG Fluid				3.667
B	**Ship P250S11**				
1	Passengers, Crews and Lugages	27.030	13.210	0.0	6.390
2	Lightship	61.253	12.491	0.0	2.893
3	Tank 1 (F.O.T)	3.233	14.445	- 0.683	0.731
4	Tank 2 (F.O.T)	3.233	14.445	0.683	0.731
5	Tank 3 (F.W.T)	1.268	17.566	- 0.603	0.490
6	Tank 4 (F.W.T)	1.268	17.566	0.603	0.490
7	Tank 5 (B.W.T), 15 %	0.179	6.603	0.0	0.533
8	Total	97.458	12.941	0.0	3.654
	Fluid Correction				0.027
	VCG Fluid				3.681

Table 4: Evaluation of Stability Values for Ship P250S10 and P250S11

No	Criteria	Unit	Value	P250S10		P250S11	
				Actual	Status	Actual	Status
1	Area 0 to 30 (>=)	m.deg	3.151	8.714	Pass	11.508	Pass
2	Area 0 to 40 (>=)	m.deg	5.157	10.057	Pass	14.043	Pass
3	Area 30 to 40 (>=)	m.deg	1.719	1.343	Fail	2.535	Pass
4	Max GZ at 30 or greater (>=)	m	0.200	0.263	Pass	0.391	Pass
5	Angle of max GZ (>=)	deg	25.00	16.400	Fail	18.200	Fail
6	Initial GMt	m	0.150	2.909	pass	3.728	Pass
6	Passenger crowding: angle of equilibrium (<=)	deg	10.00	8.4	Pass	6.4	Pass
7	Turning: angle of equilibrium (<=)	deg	10.00	7.5	Pass	6.1	Pass
8	Severe wind and rolling: Area1/Area2	%	100	1.654	Fail	16.68	Fail

Analyse of the stability values:

- The stability values of ship P250S10 is worse compared to ship P250S11.
- The stability of both ships should be improved more in order to meet some criteria of stability especially for the large angle on inclination.

4. ASSESSMENT OF THE ENGINE POWER

4.1 SHIP RESISTANCE

The ship resistance was computed by using the statistical resistance prediction method derived by Mercier and Savitsky (Lewis, 1988); Larsson (2010). This method is suitable for the semi-planning ships. The general form of the resistance equation adopted by Mercier and Savitsky is as follows:

$$R_T/W = A_1 + A_2X + A_4U + A_5W + A_6XZ + A_7XU + A_8XW + A_9ZU + A_{10}ZW + A_{15}W^2 + A_{18}XW^2 + A_{19}ZX^2 + A_{24}UW^2 + A_{27}WU^2 \quad (1)$$

where: $X = \nabla^{1/3}/L$; $Z = \nabla/B^3$; $U = \sqrt{2 i_E}$,;
$W = A_T/A_X$.

The values of the coefficients A_1 to A_{27} and correction factors are presented in Lewis (1988). In addition, an aproach to compute the wetted surface area is:

$$S/\nabla^{2/3} = 2.262 \sqrt{(L/\nabla^{1/3})} \, [\, 1 + 0.046 \, B/T + 0.00287 \, (B/T)^2 \,] \quad (2)$$

The effective power of the ship is computed as:

$$P_E = R_T \times V \quad (3)$$

where:
R_T = total resistance and V = speed of the ship

Futhermore, the resistance of the ship was computed by using the sofware of Maxsurf version 13.01 and the results are presented in the Table 5 and Figure 3 and 4.

Table 5: Comparisson of Total Resistance and Effective Power for P250S10 and P250S11

No	Ship Parameter	Unit	Values				
1	Speed of Ship	Knot	19,0	20,0	21,0	22,0	23,0
2	Resistance of Ship P250S11	kN	86,423	89,46	92,04	95,097	97,437
3	Resistance of Ship P250S10	kN	83,353	85,887	88,580	91,847	94,350
4	Half Effective Power P250S11	hp	563,118	613,580	662,835	717,465	768,532
5	Half Effective Power P250S10	hp	537,034	589,072	637,918	692,946	744,187

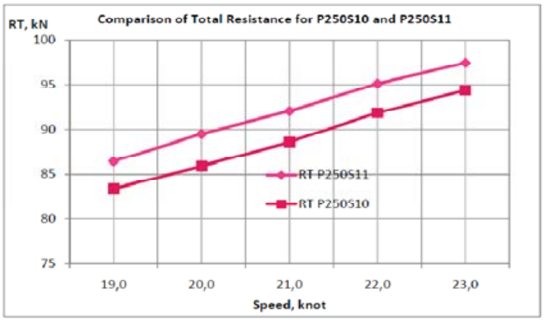

Figure 3: Comparison of Total Resistance for P250S10 and P250S11

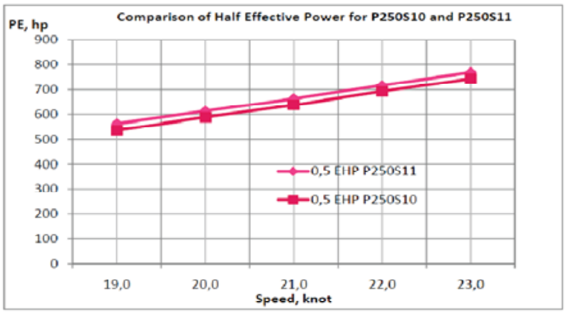

Figure 4: Comparison of Effective Power for P250S10 and P250S11

4.2 ENGINE POWER

The engine power (brake power P_B) is computed in relation with the effective power P_E (Parsons, 2004).

$$P_B = P_E \,/\, (\eta_h \, \eta_o \, \eta_r \, \eta_s \, \eta_b \, \eta_t) \quad (4)$$

where: η_h = hull efficiency;
η_o = propeller efficiency;
η_r = relative rotative efficiensy = 1.0
η_s = seal efficiency;
η_b = line shaft bearing efficiency;
η_t = transmission efficiency;
$\eta_s \, \eta_b$ = 0.97 for machinery amidship
η_t = 0.975 for medium speed diesel plant

Hull efficiency is computed as:

$$\eta_h = (1 - t)/(1 - w) \quad (5)$$

where :

w = Taylor wake fraction

$$= 0.5 \, C_B - 0.05 \quad (6)$$

C_B = block coefficient
t = thrust deduction factor

$$= 0.6 \, w \quad (7)$$

The maximum continuous rating (MCR) of the main engine is determined by adding a power service margin as 20% to the brake power.

$$MCR \geq (1 + MS) \, P_B \quad (8)$$

where: MS = power service margin

Two units for the main engines are selected for the propulsion system of the ship. It would be better to select the existing types of main engine to be used for the ship. However, as assumption for this preliminary study, the main engine and following characteristics were selected.

Type of main engine : MAN V12-1360
Maximum output (MCR) : 1360 hp
Rated speed : 2300 rpm
Brake Power at NCR (20% MS) : 1088 hp
RPM at normal Brake Power : 2100 rpm
Reduction ratio : 2.0 : 1
Fuel Consumption at rated power : 264 l/h
Fuel : DIN EN 590
Exhaust gas status : IMO/MARPOL 73/78, EPA Tier 2, Recreational Craft Directive 95/24/EC, SAV

4.3 PROPELLER DATA

Two screw propeller units are used for the ship. The screw propellers were evaluated based on the propeller data from the Wageningen B-Screw Series (Lewis 1988). The propeller types of B 4-40, B 4-55, B 4-70, B 4-85 and B 4-100 were evaluated for a range of ship speed from 19 to 23 knots. In addition, an evaluation for the cavitation of the propeller was executed based on Burril Diagram of cavitation. The trend line of suggested upper limit for merchant ship propeller is used in this evaluation. In fact, this trend line is still subjected to 2.5 % to 5% of back cavitation of propeller blade. The results of computation of the propeller parameters are presented in Table 6.

4.4 ANALYSE OF ENGINE POWER AND PROPELLER DATA

- The values of resistance or effective power for ship P250S10 is less than those for P250S11. The difference of values for a range of speed is about 3.5 %.
- The trend lines of the total resistance R_T and effective power P_E are almost linear for the speed range of 19 to 22 knots.
- With the similar engine power and configurations applied for those two ships, the maximum speed achieved by two ships are different.
- The maximum speed for the ship P250S10 is 21.09 knot and for the ship P250S11 is 20.36 knot. The difference value is 3.6 %.
- The decreasing of speed for ship P250S11 is caused by the increasing of resistance.

Table 6: Propeller Parameters for Ships P250S11 and P250S10

	Type of screw propellers	Max ship speed	Ratio P/D	Propeller Efficiency	Propeller diameter	(AE/AO) required
		(knot)		η_O	(m)	
A	Ship P250S10					
	B 4-40	21,785	0,817	0,609	1,008	0,767
	B 4-55	21,752	0,800	0,607	1,026	0,704
	B 4-70	21,470	0,816	0,594	1,013	0,704
	B 4-85	21,093	0,856	0,575	0,989	0,767
	B 4-100	20,633	0,909	0,554	0,951	0,858
	Selected Propellers: B 4-85	21,093	0,856	0,575	0,989	0,767
B	Ship P250S11					
	B 4-40	21,214	0,812	0,605	1,005	0,789
	B 4-55	21,125	0,789	0,601	1,025	0,711
	B 4-70	20,871	0,808	0,588	1,011	0,735
	B 4-85	20,357	0,842	0,566	0,982	0,793
	B 4-100	19,921	0,894	0,549	0,947	0,884
	Selected Propeller: B 4-85	20,357	0,842	0,566	0,982	0,7925
	Difference P250S11 to P250S10 (%)	-3,615	-1,709	-1,627	-0,676	3,229

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

1. Since there is no available database for such medium-speed passenger ferry, the results achieved in this preliminary study provide some relevant initial data for our the future works.

2. In addition, several modifications of the parent ship should be executed in order to find the formulations for the future optimization process.

3. The difference in the results between the two ships P250S10 and P250S11 may give an example of how the design parameters (stability and power) are changing due to the changing of ship beam.

4. In fact, the engine power required for those ships are still high and some modifications should be executed to improve the stability of and evaluated for the next design process.

5. Our future works will be to minimize the engine power of this medium-speed passenger ferry. The modification of ship layout and hull forms will play a key roles in this work. However, other factors should be taken into account as recommended there after.

5.2 RECOMMENDATION

The future works should be executed for:

- Optimizing the ship structure in order to reduce the structural weight of ship
- Optimizing the hull forms in order to reduce the ship resistance
- Rearranging the ship layout in order to increase the stability level of the ship
- Executing the model tests in order to achieve a the better results of the ship resistance
- Selecting the proper screw propeller to reduce the engine power
- Selecting the proper main engine in order to improve the perfomance of propulsion system.

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PREFACE

In many arenas there is growing concern about the environment and climate change. In 2007, international shipping contributed approximately 3% of global anthropogenic CO_2 emissions. For this reason, the sector needs to address these important issues, particularly as it is expected that its global share of CO_2 emissions will continue to increase. The industry (including users of shipping's services, operators of ships, manufacturers of ships and equipment) has been exploring a number of ways in which it could increase shipping's energy efficiency and reduce its CO_2 emissions. In addition, there have been a number of national, international and joint industry/academic activities to research the subject. Therefore, the main aim of the LCS 2011 conference is to:

- Facilitate the exchange of knowledge
- Develop new ideas
- Enhance collaboration between industry and academia.

The Low Carbon Shippping (LCS) consortium is a Research Council (UK) and industry funded collaborative project between 5 UK Universities and 15 industry and government partners (including ship operators, designers, builders, technologists, brokers, classification society, NGOs, shipping industry clubs). The LCS consortiums main objectives are to contribute to reducing the CO_2 emissions of the shipping industry and its high level aims are to investigate:

- The relationship between transport logistics and future ship designs
- The future demand for shipping (in relation to other transport modes)
- The impacts of technical and policy emission reduction schemes on shipping
- Implementation barriers to technical and policy emission reduction
- The allocation and enforcement of emission allowances in policy scenarios

The International Conference, 'TECHNOLOGIES, OPERATIONS, LOGISTICS AND MODELLING FOR LOW CARBON SHIPPING' (LCS 2011) is hosted by the University of Strathclyde in Glasgow, UK, and the Organising Committee is grateful to Lloyd's Register, Shell UK and IMarEST for their support for the conference.

LCS 2011 brings the world's leading experts from a mixture of both commercial and academic sectors to discuss and share the results of their work, to identify issues and find solutions to these issues with a focus on Low Carbon Shipping.

With 36 papers being presented at the conference, it is anticipated that LCS 2011 will create a world-wide network on Low Carbon Shipping. This network will focus their efforts in a concerted way, to address the Challenge of reducing CO_2 within the shipping industry, which is multi-disciplinary, complex and resource intensive.

Finally, we would like to thank all the members of the Organising Committee for their hard work and commitment. In addition, thanks to the participants and presenters for their contribution in making this conference a success.

We wish you a productive and enjoyable stay in Glasgow.

Osman Turan and **Atilla Incecik**

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