

Overview of the Korean Marine Industry and VPP Analysis of a 28ft Sailing Yacht

Yeongmin Park* · Hoyun Jang*** · Minsu Kang***

* Researcher, Enterprise Collaboration Division/SMEs Business Support Center, Research Institute of Medium and Small Shipbuilding, 46757, Busan, Korea

** Rrincipal Researcher, Green-ship Research Center, Research Institute of Medium and Small Shipbuilding, 46757, Busan, Korea

*** Principal Researcher, Enterprise Collaboration Division/SMEs Business Support Center, Research Institute of Medium and Small Shipbuilding, 46757, Busan, Korea

대한민국의 해양 레저 시장 및 28ft급 세일요트의 VPP 성능해석 연구

박영민* · 장호윤*** · 강민수***

* 중소조선연구원 기업협력본부 연구원, ** 중소조선연구원 친환경선박센터 책임연구원,

*** 중소조선연구원 기업협력본부 책임연구원

Abstract : *The South Korean marine industry is emerging as a significant market, driven by the growing popularity of various water leisure activities, including sailing. This trend suggests a rising demand for sailing yachts. Consequently, since 2022, the design and development of a 28ft sailing yacht have been ongoing, supported by the government and the Ministry of Oceans and Fisheries, to promote yachting culture in South Korea. The Velocity Prediction Program (VPP) analysis was conducted using WinDesign during the preliminary design stage to evaluate performance and determine design parameters. The hydrodynamic model used for this vessel is based on regression methods developed from years of experience in naval architecture and yacht research at the Wolfson Unit, providing reliable estimates for most modern yachts. However, owing to the lack of specific hydrodynamic data from towing tank tests or CFD numerical analysis, verification of the hydrodynamic model has faced some challenges. Additionally, an incomplete weight estimate resulted in variable VCG values, potentially affecting stability and overall performance. The optimal boat speed for this vessel was determined at true wind speeds (TWS) of 4, 8, 12, 16, and 20 knots, using both the jib (up to 120° TWA) and the spinnaker (from 80° TWA). The optimized speed of the yacht was found to be comparable to that of international similar-class yachts.*

Key Words : *Sailing yacht, Sailing yacht design, Velocity Prediction Program (VPP), Korean marine industry, Marine leisure equipment*

요 약 : 대한민국의 해양레저산업은 세일링을 비롯한 다양한 형태의 수상레저 활동이 증가하는 추세에 따라 세계적으로 신흥시장으로 주목받고 있어 세일링 요트에 대한 수요가 높아질 것으로 추정된다. 이에 따라 2022년 현재 우리나라 요트 문화의 부흥과 보급을 위해 해양수산부의 지원을 받아 28피트 세일 요트의 설계 및 개발이 착수되었다. 개발 초기 단계에서의 성능을 확인하고 이를 통해 설계 인자를 결정하기 위하여 속도 예측 프로그램 VPP(Velocity Prediction Program) 분석이 수행되었다. 본 연구에서 사용된 소프트웨어는 University of Southampton의 Wolfson Unit社의 WinDesign으로, 속도 예측에 적용된 유체역학적 데이터 모델은 Wolfson Unit社 자체적인 조선공학 및 요트 연구 분야에서 수십 년간의 예인 수조 시험 데이터를 회귀 분석한 방법으로 대부분의 현대식 요트에 대해 신뢰할 수 있는 추정치를 제공하는 것으로 여겨진다. 하지만 예인 수조 시험이나 CFD 수치해석 등을 통한 실험 결과적인 유체역학적 정보가 없기 때문에 소프트웨어에서 제공하는 유체역학적 데이터 회귀 모델의 저항 값은 다소 차이가 있을 것으로 예상된다. 또한, 아직 미완료된 무게 중심 추정에 의한 VCG 값은 속도 예측의 입력 변수 중 하나로, 성능 결과에 어느 정도 영향을 미칠 수 있을 것으로 예상된다. 개발 세일 요트에 대한 최적화된 보트 속도는 풍속 4, 8, 12, 16 및 20노트의 집세일 조합(최대 120° TWA) 및 스피네커 세일 조합(80° TWA부터) 모두에서 확인되었으며, VPP를 활용하여 얻어진 최적화된 속도는 국제적으로 유사한 등급의 요트와 견줄수 있는 수준으로 확인되었다.

핵심용어 : 세일요트, 세일요트 설계, 속도 예측 프로그램(VPP), 한국해양레저장비산업, 해양레저장비

* First Author : ympark@rims.re.kr, 051-974-5545

† Corresponding Author : hyjang@rims.re.kr, 051-974-5581

1. Introduction

1.1 Project Outline

Thanks to the advent in latest national income of \$ 30,000 in South Korea and recent new labour law legislation, it is positively predicted that people now have more free time and become substantially interested in marine leisure activities such as sailing, these facts supported are based upon from Korea Coast Guard statistic, showing on increase trend both leisure craft registration status and new boat licence issued. In addition, Korea benefit from geographical advantage which is surrounded by the water on three sides, it is evaluated to be perfect for water leisure activity. However, it is still severely low level of recognition about yachting culture in addition to low supplies of domestic yachts (Tim Coventry, 2014).

With the aid of the South Korean government, Ministry of Ocean and Fisheries, This project has been inspired by potential needs from consumptive demand and potential possibilities opened in the pleasure craft market in South Korea. The second national marina development master plan led by the South Korean government covers 70 developments to be completed by 2029. The project, itself, therefore holds immense importance as the first South Korean sailing yacht design created. The vessel will be dedicated to designing to be competitive with other foreign company designs, and enables sailing culture in South Korea to grow by being affordable to anyone, and also to improve local economy and a level of technology by transferring the whole entailed development process of the vessel to local manufacturers.

The developing sailing yacht is a racing yacht designed to be with the final goal of nationally recognized registration in Korea, and formulate a production plan of 20 vessels for taking place a racing event in Pohang, South Korea.

VPP evaluation makes it possible to provide a better insight into aspects of the sail performance in early design stage, and hence plays a crucial role in modern yacht design. It is suitable for a broad range of designs and by its flexible structure, the user can easily adjust several aspects to its own requirements.

This paper will review a glance of South Korea market at first and VPP analysis of the developed sailing yacht including hydrodynamic model and aerodynamic sail force model concepts. With these theoretical reviews the necessary background is established to make the decisions regarding the backbone of the VPP analysis.

1.2 Description of developing sailing yacht

The primary purpose of developing the vessel is to popularize yachting culture in South Korea at the action of increased demand of various form of water leisure activities including sailing. Production cost comes first and foremost, which is proportional to size. Therefore, the size of the vessel, 28ft, has been justified with following reasons:

This has been designed considering stability, light weight, and easy maneuverability. The optimized sail area to weight ratio of the developed vessel was designed to demonstrate excellent sailing performance in any wind conditions. In particular, in order to revive Korea's poor sailing culture, major equipment characteristics and design factors such as wide beam, twin rudder, swing kill, and simple steering system and etc. were reflected for most novice standard to learn and entertain easily. This enables navigation with a minimum number of people, guarantees stable maneuvering even in strong winds, and has the characteristics of being easily propelled in light wind condition. Lastly, considering the ease of accessibility, the main dimensions of the vessel were determined so that it can be trailable on the road (Fig. 1, 2) and Table 1 represents its specific design parameters.

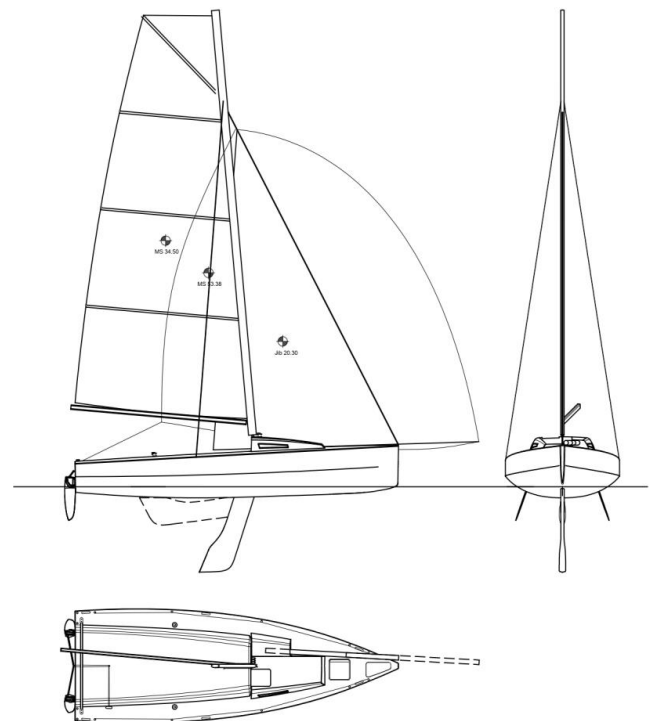


Fig. 1. Sails plan.

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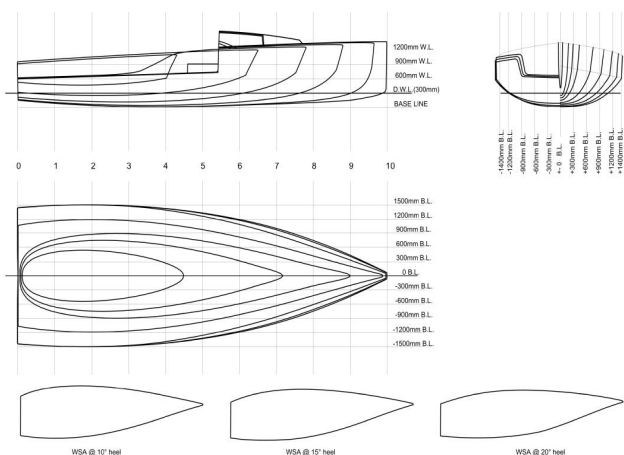


Fig. 2. Lines plan.

Table 1. Hydrostatics of sailing yacht

Hydrostatics	
Length overall (m)	8.5
Wateline length (m)	8.3
Beam overall (m)	3
Waterline beam (m)	2.28
Canoe body draft (m)	0.3
Total draft (m)	2.2
Total displacement (kg)	1605
Wetted surface area (m ²)	15.29
waterplane area (m ²)	13.31
LCB from FPP (m)	5.37
LCF from FPP (m)	5.36
Prismatic coefficient	0.59
Midship coefficient	0.73

2. Korean Marine Leisure Industry Analysis

2.1 Market Trend

Marine leisure related tourism has become a daily routine due to changes in global tourism trends after COVID-19. The demand for marine leisure activities is expected to continue to increase substantially in Korea as the demand for direct experiences rather than indirect experiences is expanding. As such direct experiences are rapidly evolving from conventional marine leisure experiences and tourism to in the form of long-term use such as fishing, boating, and sailing in Korea. Besides, with the recent revision of the Marina Port Act, ‘Marina Business One-Man Entrepreneurship’ opens, and the number of businesses using motorboats and sailboats

Table 2. Boat licence registration and boat registration trend

Year	Leisure Craft Registration	Boat License Registration		
		Total	Motor Yacht	Sailing Yacht
2023	24,988	294,043	19,770	313,813
2022	29,934	284,086	18,882	303,818
2021	28,271	269,132	17,525	287,507
2020	27,516	249,460	15,884	266,194
2019	26,086	230,423	14,515	245,788
2018	24,202	214,553	13,413	227,966

is growing simultaneously. Given that trend, as can be seen in the Korean Coast Guard statics (Table 2) below, vessel registrations and license holders gradually increasing since 2018 and touched 24,988 vessel registration mark and 313,813 boat license (motor boat and sailing yacht) mark respectively.

2.2 Industrial Policy

In 2020, the Ministry of Oceans and Fisheries launched the second implementation of the eight (8) year 2nd Marina Port Development Plan (MPDP) with the objective of paving the way to achieve the vision of “Leading the future of marine leisure in marina ports” The plan is mainly dealing with the creation of facilities for marine leisure sports and boosting industrial growth through the marina ports development. In particular, in order to expand public leisure facility and popularize marine leisure culture, detailed tasks including: establishing a marina vessel use information system, supporting the development of marine vessel tourism products, holding a marine leisure festival, developing human resource for boat management, maritime services, various foam of marine leisure activities instructors and etc. have been planned. Furthermore, to encourage startups insurance and funding support plans also have been established (Marina Port Basic Plan, 2020).

Provision of distribution and linkage services for domestic leisure vessels, construction of leisure vessels and development of related materials, and creation of a marina business center for R&D of marine leisure equipment.

As for marina development, it is planning to expand a total of current 2,403 berths of 37 marinas to 70 marina following gradual increase in leisure vessels (Fig. 3).

The establishment of MPDP the government envisions to accelerate and expand public marine leisure services and marine industry that shall render the country’s economic environment more

Table 3. MPDP six major programs

2nd Marina Port Development Plan Summaries	
Component 1	Expansion of national leisure space and popularization of marine leisure
	<ul style="list-style-type: none"> - Expansion of marine leisure experience classes at each marina port - Yacht competition/marine leisure festival held - Marina ship tourism product development support - Establishment of marina vessel usage information system
Component 2	Growth of marine leisure tourism by region through marina ports
	<ul style="list-style-type: none"> - Maintenance/expansion of regional marina ports - Marina vessel mooring space maintenance - Marina port facility improvement/environmental management program development
Component 3	Marina port-based marine leisure and service industry development
	<ul style="list-style-type: none"> - Construction of Marina Biz Center - Training of professionals in the marina service industry - Marina business start-up support
Component 4	Marina use service improving conditions
	<ul style="list-style-type: none"> - Support for improving marina service environment - Strengthening the function of marina water-friendly recreation space - Expansion of marina usage information service
Component 5	Establishment of marina business start-up environment
	<ul style="list-style-type: none"> - Distribution of marina business start-up support programs - Improvement of marina industry professional manpower training system - Establishment of marina business support system
Component 6	Establishment of foundation for manufacturing marine leisure equipment and ships
	<ul style="list-style-type: none"> - Construction of Marina Business Center - Enhancement of domestic boat shows and support for participation in overseas boat shows

conductive for flourishing of business, influx of investments and facilitation of trade within the country; promote and develop the human resource for maritime services.

In its abridged edition, the MPDP features six (6) priority programs to be implemented until 2028, herewith Table 3.

3. Main Features of the Velocity Prediction

VPPs have been employed for a considerable period in order to predict sailing yacht performance. Initially, these tools were devised for the designer to determine main design parameters at the preliminary stages of designing. Additionally, they were utilized in handicapping purpose in the IMS. However, the majority of VPPs



Fig. 3. Marina development plan according to the MPDP.

usually depend on empirical data, which renders them inaccurate to some extent for the modern sailing yachts, and therefore the combination of numerical method including CFD or towing tank testing can lead to increase the accuracy of results. Nevertheless, it is certain that a conventional method of VPP still plays an important indicator.

3.1 Principle

The Velocity Prediction Program used for this project, WinDesign, is a repetitive program which evaluates the performance of a sailing yacht in a variety of wind condition by balancing hull and sail forces. It is based on the principle 4 degrees of freedom, neglecting heave and pitch momentum, which are both regarded as minor and having minimum impact on the performance of the vessel.

The principal impetus for the development of VPP lies in the assessment of vessel performance, aimed at discerning areas necessitating refinement during the preliminary design phase. This endeavor necessitates the comprehensive consideration of various components constituting the aggregate resistance and lift of a sailing vessel. Total resistance comprises upright resistance,

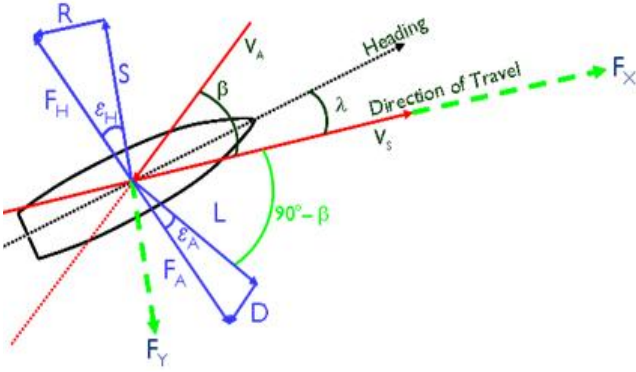


Fig. 4. Force and moment equilibrium of the VPP.

resistance due to heel, induced resistance, parasitic drag, and additional resistance due to wave action (Jang et al., 2010; Soupez, 2014).

3.1.1 Equilibrium

When the boat is in equilibrium, the total aerodynamic force and the total hydrodynamic force must be equal and in opposite

$$F_H = F_A \quad (1)$$

$$M_{Righting} = \nabla \cdot \rho \cdot g \cdot \overline{GZ} \quad (2)$$

$$M_{Heeling} = F_A \cdot (CE + CLR) \quad (3)$$

$$F_X = F_A \cos(90^\circ - \beta + \epsilon_A) = \sin(\beta - \epsilon_A) \quad (4)$$

$$F_Y = F_A \sin(90^\circ - \beta + \epsilon_A) = \cos(\beta - \epsilon_A) \quad (5)$$

$$F_A = F_X + F_Y = F_A \cos \epsilon_A \quad (6)$$

$$F_H = S + R \quad (7)$$

directions (Equation 1, 2, 3). Resolving the horizontal component of sail lift to the direction of travel can determine the magnitude of the drive force in relation to sail lift. The VPP is based on solving force and moment equilibrium in x direction and performance then can be determined (Equation 4, 5). Figure 4 above outlines this equilibrium and the formulation that the VPP based on.

Components in Equation 2, ∇ , ρ , g , and \overline{GZ} represent underwater volume, density, gravitational force and righting arm and CE for Center of effort and CLR for Center of Lateral Resistance in Equation 3. ϵ_A and ϵ_H are measures of rig and hull efficiency in Equation 4, 5.

3.2 Hydrodynamic Model

The hydrodynamic model is essentially based on its internal formulations: Standard WinDesign. The internal hydrodynamic force model provides credible estimates for most modern sailing yachts, specially for the majority of a keel-fin type monohull sailing yacht. The dataset of hydrodynamic model was derived through empirical regression analyses, drawing upon findings obtained from towing tank experiments spanning multiple decades of yacht research conducted by naval architects (Fossati and Drayton 2015).

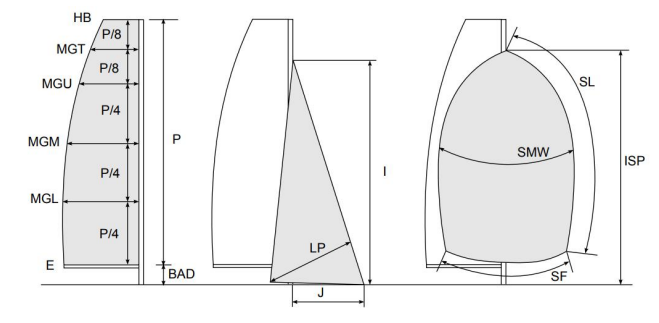
3.3 Aerodynamic Model

The determination of aerodynamic lift and drag relies fundamentally on Hazen's coefficient (Hazen, 1980), a parameter widely employed in both Velocity Prediction Programs (VPPs) and aerodynamic models. Specifications pertaining to sail and rig dimensions are delineated in accordance with the Offshore Racing Congress (ORC) class rule, thereby establishing windage and sail forces (Offshore Racing Congress, 2013). The following table gives rig measurements used for the analysis of the boat according to the ORC.

Table 4 below lists the characteristics of the sails used in the sail force model. The symbols used are illustrated in the diagram below (International Sailing Federation, 2013).

Table 4. Rig measurements

	Main	Jib	Spin	Main Mast
P	10.5m	IG 8.95m	ISP 9.12m	MDT1 0.09m
E	4.2m	J 3.73m	SPL 5.61m	MDL1 0.20m
			SMW 8.34m	MDT2 0.09m
		LP 4.35m	SLU 7.94m	
BAD	1.62m	0.91	SLE 10.4m	MDL2 0.20m
Area	19.8m ²	Area 31.6m ²	Area 63.4m ²	TL 2.29m



3.4 Assumption and Uncertainty

The uncertainties related to the wind tunnel testing and towing tank testing of “Wolfson Standard Model” for both hydrodynamic model and aerodynamic model have not been quantified in any of publications or software company (Wolfson Unit, 2014), and therefore insufficient data for a quantitative analysis. As a result, a qualitative analysis of potential uncertainties will be discussed. The uncertainty analysis of hydrodynamic model is divided in two sections: Hull form and additional factors (Jang et al., 2017).

3.4.1 Hull Form

In order to validate the Wolfson Standard Model for hydrodynamic method, the resistance prediction should be compared to actual towing tank data for a known vessel from the Wolfson database. For the validation to be more relevant, a suitable hull must be selected among the database, and it must cover an appropriate range of Froude numbers, a similar hull shape, a hull in terms of design parameters. However, since the Wolfson Unit regard the Wolfson Standard Model as appropriate for most modern hulls, its application to the designated hull has been justified (Barkley, 2012).

3.4.2 Additional Factors

The following additional resistance constituents to consider, as referred to propeller drag, roughness, and added resistance due to wave have not been accounted for in this study. These components can be obtained from CFD numerical analysis or towing tank testing (Böhm, 2014)

3.5 Sail Plan

In addition, since sailing culture is not a highly developed sport in South Korea, most Korean people are considered novice sailors. Hence it is preferable to have easier handling by having minimal deck fittings, however, at the same time keeps it enjoyable to an extent. Moreover, provisions for different wind conditions have been also made by having multiple reefs.

3.6 Righting Arm

Righting arm plays a key role in terms of sailing yacht performance as heeling degree is a function of righting moment. When the yacht heels, the appendages become closer to the free surface, which leads to an increase in residuary resistance due to pressure field around the appendages are changed, and thus affecting to the total resistance.

Table 5. Weight estimate of the vessel

Item	Total Mass (tonne)	Long. Arm (m)	Trans. Arm (m)	Vert. Arm (m)
Unknown Weight	0.302	3.228	0	0.3
Hull	0.223	3.905	0	0.458
Deck	0.148	3.2	0	0.997
Structure	0.129	3.682	0	0.447
Deck Fittings	0.113	3.712	0.038	1.153
Appendage	0.444	3.427	0	-1.673
Riggings	0.104	4.067	0	5.124
Sail Sets	0.039	4.098	0	5.431
Nav and Electronics	0.009	4.471	0	1.4
Internals	0.539	2.7	0	0.8
Total Loadcase	2.055	3.22	0.01	0.256
FS correction				0
VCG fluid				0.256

Righting arm at different degrees of heel has been calculated with reference to Vertical Center of Gravity (VCG) obtained from the weight estimate as shown in the Table 5. However, unknown weight of about 302kg has been remained to develop further and therefore, it is assumed that the VCG value of 0.256m from the Lwl could be changed. Despite the fact that the VCG value is reasonable.

4. Results

4.1 Results

The best boat speed for the vessel has been obtained at true wind speeds of 4, 6, 8, 10, 12, 14, 16 and 20knots and for both upwind opset of the jib and main (up to 135° TWA) and downwind opset of the additive spinnaker (from 110° TWA). The analysis considers 4 degrees of freedom; results for the boat speed are presented in the Figure 5, where the upwind opset is shown in blue and the downwind opset in red; the intersection of the two lines can be observed.

Another information of the velocity polar is how fast the boat is sailing into the wind. This is described as the Velocity Made Good (VMG) of the boat, which depicted by circles. When looking towards maximum VMG, these differences are of minor importance for upwind conditions. However, they might be important for downwind conditions.

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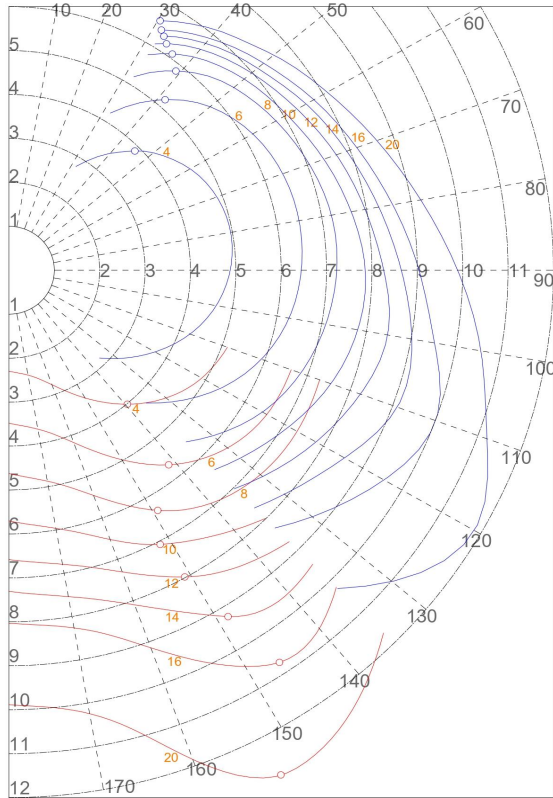


Fig. 5. VPP polar plot of the boat.

Table 6. Best Boat speeds (knots)

V_T [knots]	V_T = 4	V_T = 8	V_T = 10	V_T = 12
VMG _{UP} [knots]	2.71	4.54	4.93	5.16
β _T [°]	44.7	37.6	34.8	33.4
VMG _{DN} [knots]	4.01	5.47	6.24	7.91
β _T [°]	139.5	148.9	152.2	152.0
V_T [knots]	V_T = 14	V_T = 16	V_T = 20	V_T = 25
VMG _{UP} [knots]	5.33	5.47	5.68	5.95
β _T [°]	32.4	31.6	30.4	-
VMG _{DN} [knots]	9.34	10.77	12.94	-
β _T [°]	147.5	145.5	152.8	-

Table 7. Best Heel Angle (deg.)

V_T [knots]	V_T = 4	V_T = 6	V_T = 8	V_T = 10
Heel _{UP} [deg.]	4.94	11.26	15.81	17.53
V_T [knots]	V_T = 12	V_T = 14	V_T = 16	V_T = 20
Heel _{UP} [deg.]	18.17	17.99	17.84	17.59
VT [knots]	VT = 4	VT = 6	VT = 8	VT = 10
Heel _{DOWN} [deg.]	1.80	3.08	3.04	3.27
V_T [knots]	V_T = 12	V_T = 14	V_T = 16	V_T = 20
Heel _{DOWN} [deg.]	4.55	8.91	16.26	13.03

Table 8. Best Leeway Angle (deg.)

V_T [knots]	V_T = 4	V_T = 6	V_T = 8	V_T = 10
Leeway _{UP} [deg.]	1.87	2.01	2.03	1.92
V_T [knots]	V_T = 12	V_T = 14	V_T = 16	V_T = 20
Leeway _{UP} [deg.]	1.87	1.89	1.91	1.95
VT [knots]	VT = 4	VT = 6	VT = 8	VT = 10
Leeway _{DOWN} [deg.]	0.58	0.49	0.36	0.3
V_T [knots]	V_T = 12	V_T = 14	V_T = 16	V_T = 20
Leeway _{DOWN} [deg.]	0.32	0.39	0.38	0.18

Table 9. Best Flat

V_T [knots]	V_T = 4	V_T = 6	V_T = 8	V_T = 10
Flat _{UP}	1	1	0.805	0.617
V_T [knots]	V_T = 12	V_T = 14	V_T = 16	V_T = 20
Flat _{UP}	0.527	0.527	0.526	0.524
VT [knots]	VT = 4	VT = 6	VT = 8	VT = 10
Flat _{DOWN}	1	1	1	1
V_T [knots]	V_T = 12	V_T = 14	V_T = 16	V_T = 20
Flat _{DOWN}	1	1	1	1

The following Tables 6, 7, 8, 9 give an overview of the optimum upwind and downwind VMG, optimum heeling angle, leeway angle and best mode of flat with its accompanying true wind angle for all wind speeds.

5. Conclusion

In conclusion, the evolution of marine leisure tourism in Korea presents a dynamic landscape shaped by shifting global tourism trends, particularly in the wake of the COVID-19 pandemic. With a growing preference for direct experiences over indirect ones, the demand for marine leisure activities has surged, leading to a significant increase in vessel registrations and boat licenses. The proactive measures undertaken by the Ministry of Oceans and Fisheries, such as the Marina Port Development Plan (MPDP), reflect a strategic vision to foster the growth of the marine leisure industry. By expanding marina facilities, promoting marine leisure culture, and supporting startups, the government aims to not only stimulate economic growth but also enhance public access to marine leisure services. Through these concerted efforts, Korea is poised to emerge as a leading destination for marine leisure, offering diverse opportunities for business development, investment, and trade while nurturing a skilled workforce in maritime services.

The MPDP represents a pivotal step towards realizing this vision, ensuring a vibrant and sustainable future for the marine leisure sector in Korea.

The preliminary design of 28ft korean style sailing yacht has been conducted and also its VPP analysis to correspond to consumptive customers and promote domestic yachting culture. The vessel has been designed to contain primary design parameters as appropriate for both modern sailing yacht features and novice level of crews.

The vessel appears to be optimum particularly at 8 knots of wind speed at 40° and 12 knots at 52°, sailing to close-hauled at around 5.95knots and 7.05 knots respectively.

However, for velocity prediction of a sailing yacht, the use of CFD today is very common. The aero and hydrodynamic input can be introduced, based on experimental data or numerical analysis (CFD) for accuracy improvement. Since the design is still at preliminary stage, the traditional velocity prediction program tool, WinDesign has been only used for this project that rely on empirical relations, and therefore uncertainties were still remained to develop further for effectiveness of the results.

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