The North African Journal of Scientific Publishing (NAJSP)
مجلة شمال إفريقيا للنشر العلمي (NAJSP)
E-ISSN: 2959-4820
Volume 2, Issue 3, July – September 2024, Page No: 160-167
Website: https://najsp.com/index.php/home/index
SJIFactor 2023: 3.733 | معامل التأثير العربي (AIF) 2023: 0.63 | ISI 2023: 0.383

Comparative Performance Evaluation of B-Series and Kappel Propeller Design Methods for an Oil Tanker Vessel

Abdallah Abdalhafeez [1], Mohammed Rabha [2], Muad Hadeedan [3], Nuri M. Eshoul [4*]
[1,2,3,4] Marine and offshore Engineering, Faculty of Engineering, University of Tripoli, City, Tripoli, Libya

مقارنة وتقييم الأداء لطرق تصميم الرفاسات *B-Series* و*Kappel* لناقلة نفط

م. عبدالله عبد الحفيظ[1]، م. محمد بن رابحة[2]، م. معاذ حديدان[3]، أ.د. نوري محمد الشول [4*]
[1،2،3،4] قسم الهندسة البحرية والمنصات العائمة، كلية الهندسة، جامعة طرابلس، طرابلس، ليبيا

Corresponding author: nurieshoul@yahoo.com and nurieshoul@uot.edu.ly

Received: June 26, 2024	Accepted: August 16, 2024	Published: August 22, 2024

Abstract:
The maritime sector's reliance on efficient and dependable propulsion systems is crucial for the secure and cost-effective movement of goods and passengers worldwide. Ship propellers, as the primary mechanism for converting engine power into thrust, play a pivotal role in optimizing vessel performance. This study presents a comparative analysis of two prominent ship propeller design methodologies: the B-Series and Kappel methods. The study focuses on an oil tanker powered by a 13,000 KW engine, sailing at a speed of 15.2 knots. By calculating the required propeller diameter and evaluating the performance in terms of thrust power and efficiency, the research aims to elucidate the strengths and limitations of each design approach. Results indicate that the Kappel method significantly outperforms the B-Series method in both thrust power and efficiency, achieving a thrust of 1678.8 KN and an efficiency of 62.3%, compared to 1047.7 KN and 59% for the B-Series propeller. However, the Kappel method's higher computational complexity and cost are notable considerations. These findings provide valuable insights for ship designers, naval architects, and marine engineers, highlighting the importance of selecting the appropriate design methodology based on specific vessel requirements and operational conditions.

Keywords: Propeller Design, B-Series Propeller, Kappel Propeller.

الملخص
يعتمد القطاع البحري بشكل كبير على كفاءة وموثوقية أنظمة الدفع، لضمان حركة امنة وفعالة من حيث التكلفة للبضائع والركاب في جميع أنحاء العالم. تعتبر رفاسات السفن، بصفتها الآلية الرئيسية لتحويل قوة المحرك إلى قوة دفع، ذات أهمية محورية في تحسين أداء السفينة. هذه الدراسة تقدم تحليلًا مقارنًا لطريقتين بارزتين لتصميم الرفاسات البحرية للسفن: طريقة *B-Series* وطريقة *Kappel*. يركز البحث على ناقلة نفط تعمل بمحرك قوته 13,000 كيلوواط، وتسير بسرعة 15.2 عقدة. من خلال حساب قطر الرفاس المطلوب وتقييم الأداء من حيث قوة الدفع والكفاءة، يهدف البحث إلى إبراز نقاط القوة والحدود لكل أسلوب تصميم. تشير النتائج إلى أن طريقة *Kappel* تتفوق بشكل كبير على طريقة *B-Series* من حيث قوة الدفع والكفاءة، حيث تحقق قوة دفع 1678.8 كيلو نيوتن وكفاءة 62.3٪، مقارنة بـ 1047.7 كيلو نيوتن و 59٪ ل *B-Series*. ومع ذلك، تُعَد التعقيدات الحسابية والتكلفة الأعلى لطريقة *Kappel* عوامل ملحوظة. توفر هذه النتائج رؤى قيمة لمصممي السفن والمهندسين المعماريين البحريين والمهندسين البحريين، مع التأكيد على أهمية اختيار طريقة التصميم المناسبة بناءً على متطلبات السفينة المحددة والظروف التشغيلية.

الكلمات المفتاحية: تصميم الرفاس، رفاس *B-Series*، رفاس *Kappel*.

Introduction
The maritime sector heavily depends on efficient and dependable propulsion systems to ensure the secure and cost-efficient movement of goods and passengers worldwide. Ship propellers, serving as the primary mechanism for converting engine power into thrust, hold a pivotal role in achieving optimal performance of vessels. Their design significantly affects fuel consumption, speed, maneuverability,

and overall efficiency, thereby emerging as a critical element influencing the economic feasibility and environmental friendliness of maritime activities. [1]

Over time, numerous methodologies for propeller design have surfaced, each presenting its unique set of principles and considerations. Among these, the B-Series and Kappel methods have stood out due to their widespread adoption and distinctive design philosophies. The B-Series approach, originating in the 1960s, relies on empirical data and standardized propeller geometries to strike a balance between performance and cost efficiency [2]. In contrast, the Kappel method, introduced in the 1980s, adopts a more analytical stance by employing advanced computational techniques and optimization algorithms to customize propeller designs according to specific operational conditions and hull configurations [3], Figure 1 and 2 Shows B-Series and Kappel propeller.

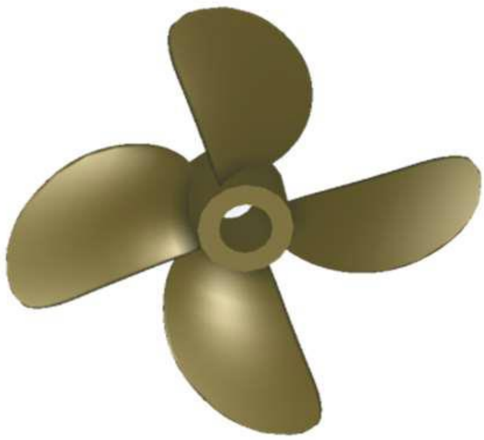

Figure 1 Four-blade B-series propeller.

Figure 2 Four-blade Kappel propeller.

Initial designs of Kappel propellers were based on theoretical frameworks, specifically lifting-line and lifting-surface theories, which were subjected to thorough validation through open-water performance evaluations and cavitation tunnel tests [4, 5].

The Kappel propeller has shown promising results in full-scale operation tests, demonstrating a 4% increase in propulsion efficiency compared to conventional propellers [6].

The utilization of Kappel propellers in the commercial sector was accelerated when MAN Diesel & Turbo Corporation incorporated MAN Alpha Kappel series propellers with MAN B&W low-speed diesel engines. This combination led to notable energy efficiency improvements and a decrease in carbon dioxide emissions [7]. As of 2014, these propellers had been fitted on various large commercial ships, such as three 8500CEU pure car and truck carriers built by the Xiamen Shipping Industry.

The analysis of Kappel propellers has greatly benefitted from theoretical and computational studies. Kehr and Wu [8] introduced a three-dimensional coordinate conversion formula to address the tip rake, while Cai [9] enhanced the lifting-line theory by considering the influence of induced speed in three dimensions. Furthermore, Computational Fluid Dynamics (CFD) has been employed to assess how geometric parameters affect cavitation performance [10] and to verify the suitability of simulation techniques in evaluating Kappel propellers [11].

Cavitation plays a pivotal role in influencing both the efficiency and durability of propellers. Numerous research works have delved into the phenomenon of cavitation in Kappel propellers, examining aspects such as the correlation between tip rake and cavitation noise as well as efficiency [12], and the influence of blade tip inclination on both cavitation delay and propulsion efficiency [13].

Chen et al. conducted a comprehensive study on the effects of tip rake distribution on the hydrodynamic performance of Kappel propellers. Their research utilized a fourth-order B-spline curve to design various tip rakes and analyzed their performance using the RANS method coupled with the γ transition model. The findings indicated that an appropriate tip rake could improve propulsion efficiency by approximately 2.5% at the designed advance speed, highlighting the importance of tip rake optimization in propeller design [14].

Despite the increasing research on Kappel propellers, there is a lack of comprehensive comparisons between different design methods, including the B-Series and Kappel propellers previous studies have primarily focused on the performance analysis of individual propeller designs, with limited attention given to direct comparisons between different methods.

This study aims to address the research gap by comparing the design methods of the B-Series and Kappel propellers for an oil tanker ship powered by a 13,000 KW engine with a speed of 15.2 knots this encompasses the following.

1. To determine the necessary propeller diameter for the designated oil tanker utilizing both the B-Series and Kappel methodologies.
2. To assess and contrast the thrust power propulsive efficiency and fuel consumption of the propellers designed using each method.

By conducting this comparative study, this research seeks to contribute to the ongoing discourse on propeller design optimization, providing valuable insights for ship designers, naval architects, and marine engineers. The findings will illuminate the advantages and constraints of each methodology, potentially guiding future design decisions and promoting the advancement of more efficient and sustainable propulsion mechanisms for the maritime sector.

Methodology

A case study approach will be used in this study to evaluate the performance of the B-series Kappel propeller design methods for a specific oil tanker application The selected vessel is a very large crude carrier (VLCC) oil tanker and will serve as a platform to demonstrate the practicality of both approaches and emphasize their relative performance characteristics, table 1 illustrates ship specifications.

A. Ship Specifications:

Table1: Vessel Specifications.

Specification	Value
Overall Length	250 meters
Breadth	44 meters
Total Deadweight	115,518 tons
Main Engine	MAN B&W 60 ME-C (13,000 KW)
Speed	15.2 Knots

This specification provides the input parameters required to calculate the required propeller diameter and to analyze the performance characteristics using both methods.

B. Propeller Diameter Calculations:

The B-Series method utilizes a standardized series of propeller geometries, categorized by their blade number, pitch, and diameter the propeller diameter is calculated using the selected B-series 4.55 chart "Figure 3" and propeller pitch to ensure that the propeller operates at its optimal performance [15]

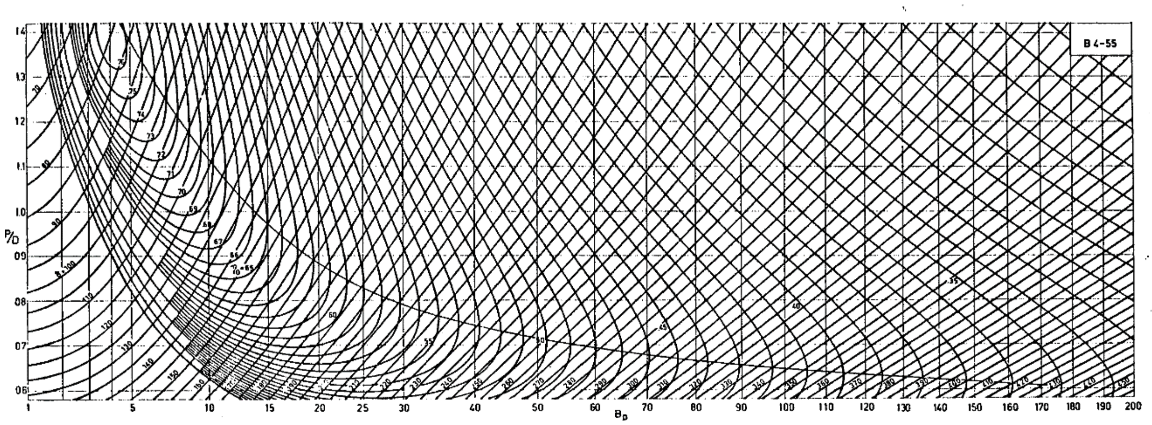

Figure 3 Wageningen B-Series chart [15].

C. Kappel method:

This study will adapt Kappel's method by relying on existing empirical data and analytical formulas. Since computational fluid dynamics (CFD) is not used, the International Towing Tank Conference (ITTC) Study Results of the Kappel propeller" Figure 4" will be used to obtain performance data for propellers of the same size as the B-Series propellers. These results will provide informative findings on thrust, efficiency, and torque for Kappel propeller design. [16].

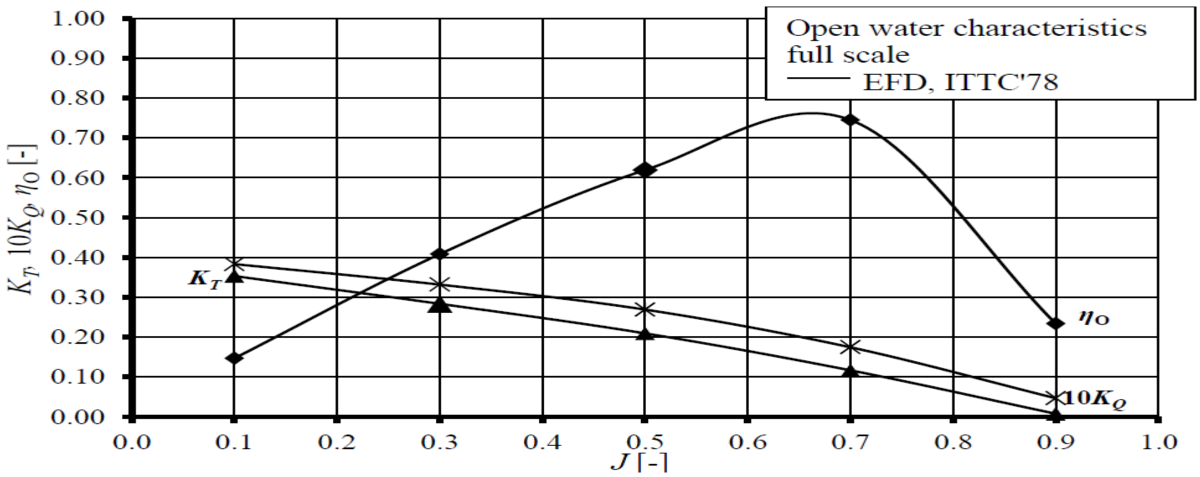

Figure 4 Open water characteristics of Kappel propeller full scale [16].

D. Governing Equations:

The initial design variable requirements of the propeller are given below [2]:
Delivered power (PD, KW): the power delivered to the propeller shaft.
Propeller rate of rotation (n, rpm): This is the rotational speed of the propeller.
Speed of ship (Vs, m/s): This is the forward speed of the ship.
Number of blades (Z): This is the number of blades on the propeller.
Taylor's wake friction (w): This represents the reduction in speed of the water flowing past the propeller due to the ship's hull.
The speed of advance (VA) is obtained from the ship's speed (Vs) using the following formula:

$$Va = Vs * (1 - w) \quad (1)$$

Where w is the Wake friction.?In this case, w = 0.20.

For B-Series Method:

The power coefficient (Bp): can be calculated using the following formula:

$$Bp = \frac{PD^{0.5} * n}{Va^{2.5}} \quad (2)$$

Propeller Diameter (D): The optimum diameter is given by:

$$D = \frac{\delta * Va}{n} \quad (3)$$

where δ is a coefficient obtained from the B-Series chart corresponding to the calculated Bp value.
Propeller Thrust (T): The propeller thrust can be calculated as:

$$T = \frac{Pt * 325.86}{Va} \quad (4)$$

Where Pt is the thrust power.
For the Kappel Method:
Advance Coefficient (J): The advance coefficient is calculated as:

$$J = \frac{Va}{n * D} \quad (5)$$

Thrust Coefficient (KT): The thrust coefficient is calculated as:

$$KT = \frac{T}{\rho * n^2 * D^4} \quad (6)$$

Torque Coefficient (KQ): The torque coefficient is calculated as:

$$KQ = \frac{Q}{\rho * n^2 * D^5} \quad (7)$$

Where n refers to rotational speed in RPS (revolution per second) Va is the speed of advance in m/sec, D is propeller diameter, T is thrust power, Q is Torque, and ρ denotes the density of water.

Results and discussion

Based on the mathematical model and equations presented the required calculations and comparisons were carried out, and, table 2 shows the results obtained:

Table 2: Calculations Result.

Parameter	Value
speed of advance Va	12.16 Knots
Brake Power PB	15254 HP
Delivered power PD	14650 HP
power coefficient Bp	24
Propeller Diameter D	23.61ft =7.20 m
Advance Coefficient J	0.5
Thrust Coefficient KT	0.209
Torque Coefficient KQ	0.267

As can be seen in Figure 5 when using Kappel method, the thrust performance was higher, amounting to 1678.8KN, while when using the B-Series method, the result was 1047.7KN.

The reason for the increased thrust performance when using the Kappel method is Drag Reduction, the design of the Kappel propeller is optimized to minimize drag. Reduced drag means that more of the engine power is converted into thrust rather than being lost to resistance and the Kappel propeller's non-planar blade surfaces create more lift, translating to greater thrust

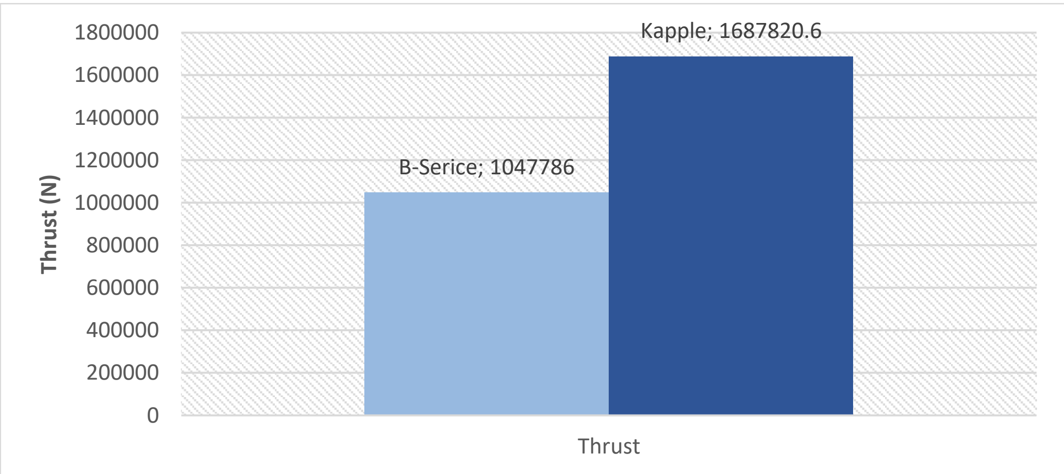

Figure 5 Thrust for B-Series and Kappel.

With Kappel propeller generating greater thrust, the engine can operate at a lower load to maintain the same vessel speed which has significant implications for fuel consumption, figure.6 illustrates the Specific fuel consumption (SFOC) and Exhaust Gas Data at different Engine Loads. It shows that the highest specific fuel consumption occurs at maximum engine load and minimum load, where the specific fuel consumption is 161g/KWh. However, at medium loads, the specific fuel consumption is lower, which means that running the engine at a medium load will achieve fuel savings [17].

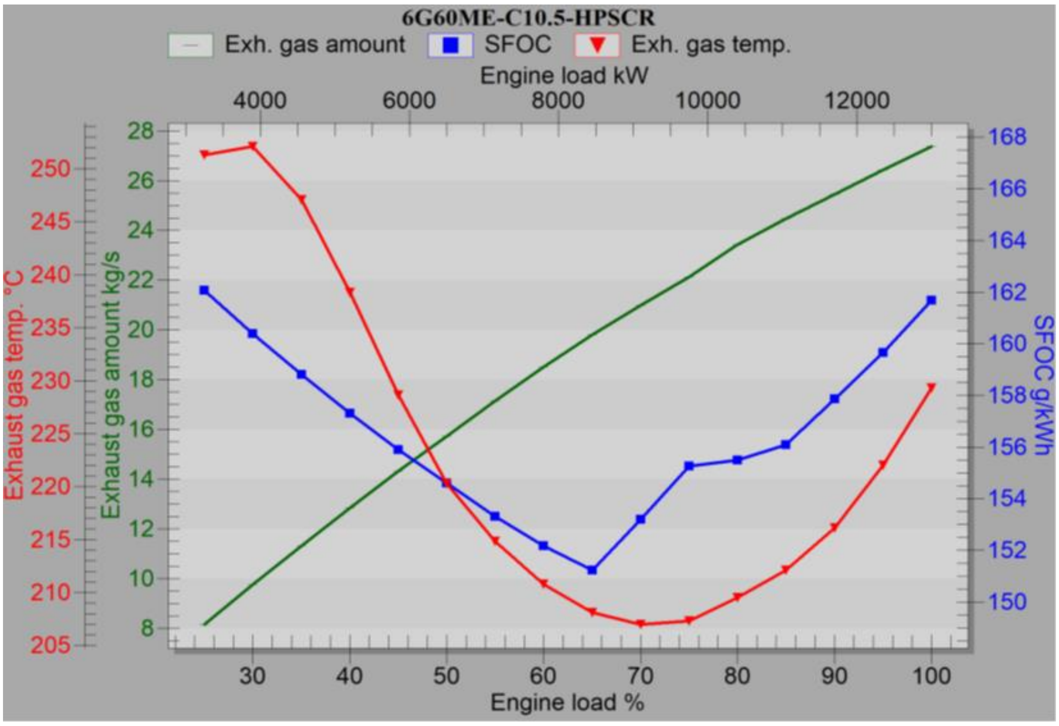

Figure 6 MAN B&W 6G60ME-C10.5 SFOC and Exhaust Gas Data [17].

Additionally, using Kappel propeller achieves a reduction in engine load by 31%, which means that the engine can be operated at 70% load and achieve the same speed as when using the B-Series Propeller and operating the engine at 100% load, this reduction in engine load by approximately 31%, can translate into substantial fuel savings, figure 7 shows that when using Kappel propeller, the daily fuel consumption is approximately 16 tons less than when using the B-Series Propeller.

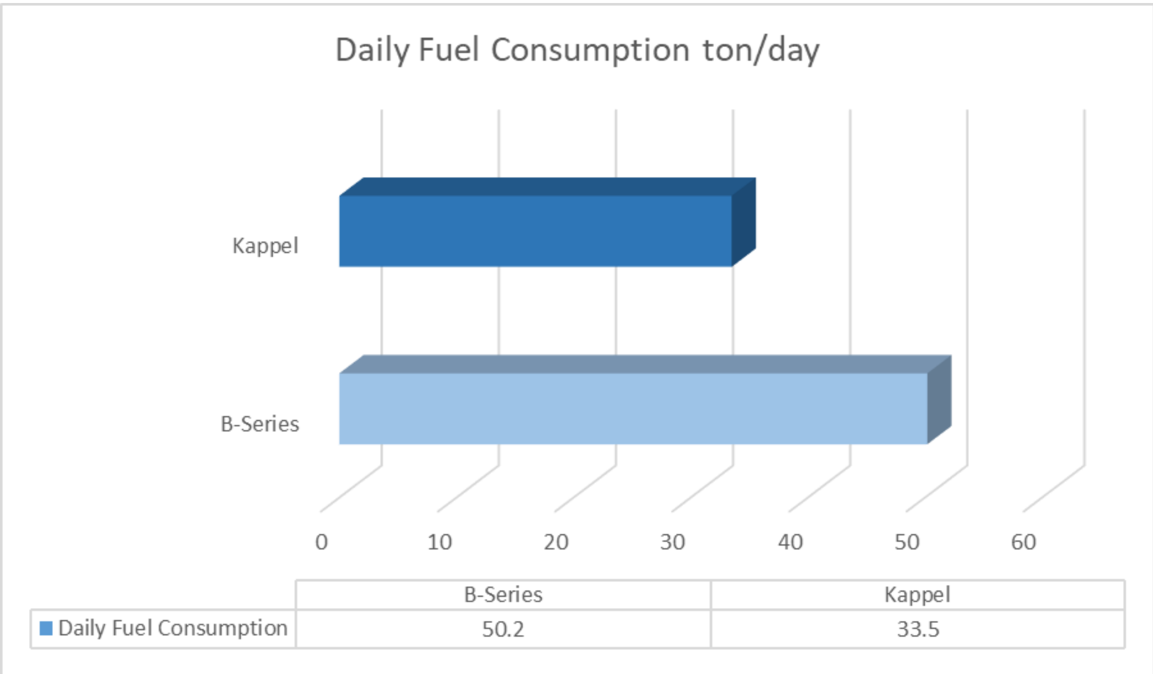

Figure: Daily Fuel Consumption.

In terms of efficiency also, when using Kappel method, the efficiency was higher at 62.3%, while when using the B-Series method, the efficiency was 59% as shown in figure 8, Kappel propeller achieves higher efficiency compared to the B-Series propeller due to several key factors related to its advanced design and optimization:

Drag Reduction: The advanced design of Kappel propeller provides better drag reduction than the B-Series propeller.
Non-Planar Lifting Surfaces: These surfaces provide a higher lift-to-drag ratio, converting more power into thrust.
Tip Rake Effect: The enhanced tip rake system reduces energy losses due to tip vortex and ensures better load distribution.

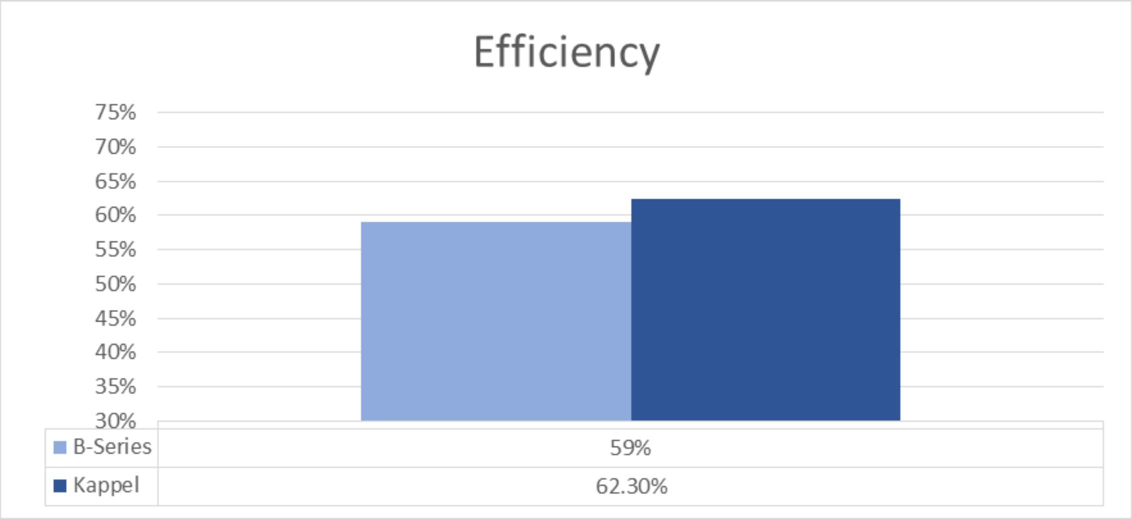

Figure 8 B-Series and Kappel propeller Efficiency.

By leveraging advanced design techniques that address drag, draft, non-planar lifting surfaces, and the effects of tip rake the Kappel propeller achieves higher thrust compared to the B-Series propeller and reduction in fuel consumption. These hydrodynamic optimizations result in more effective propulsion, making Kappel method a superior choice for maximizing thrust and efficiency in maritime applications

Conclusion

Based on the comparative analysis of the B-Series and Kappel propeller design methods for the selected oil tanker vessel, the following key conclusions can be drawn:

1. Thrust Performance: The Kappel propeller design demonstrated superior thrust performance, generating 1,687.8 KN of thrust, compared to 1,047.7 KN for the B-Series propeller. This can be attributed to the Kappel method's advanced hydrodynamic optimization, including drag reduction and enhanced non-planar lifting surfaces.

2. Propulsive Efficiency: The Kappel propeller achieved a higher propulsive efficiency of 62.3%, surpassing the 59% efficiency obtained with the B-Series propeller. The Kappel method's incorporation of design features such as the tip rake effect and better load distribution contributed to this improvement in efficiency.

3. Fuel Consumption: Increased thrust performance and higher efficiency with the Kappel propeller allow the engine to operate at a lower load to maintain the same vessel speed, resulting in significant fuel savings. This is particularly beneficial for long-term operational costs and environmental impact.

4. Customization and Adaptability: While the B-Series method relies on standardized propeller geometries, the Kappel approach offers greater flexibility in customizing propeller designs to specific vessel characteristics and operational conditions. This enhanced customization can lead to more optimized performance in complex or demanding maritime environments.

References

[1] J.S. Carlton, Marine Propellers and Propulsion, Butterworth Heinemann, 2013.
[2] M. P. Smith, Preliminary Propeller Selection Using the Wageningen B-Screw Series and a General Purpose Non-Linear Optimizer. Monterey, CA: Naval Postgraduate School, 1983.

[3] P. Anderson. On Optimum Lifting Line Propeller Calculation. Report No. 325; The Danish Center for Applied Mathematics and Mechanics, The Technical University Of Denmark: Lyngby, Denmark, 1986.
[4] P. Andersen.; Friesch, J.; Kappel, J.J.; Lundegaard, L.; Patience, G. Development of a Marine Propeller with Non-planar Lifting Surfaces. Mar. Technol. SNAME News 2005.
[5] P. Andersen.; Friesch, J.; Kappel, J.J. Development and Full-scale Evaluation of a New Marine Propeller Type. In Proceedings of the 97th Hauptversammlugder Chiffbautechnischen Gesellschaft, Hamburg, German, 20–22 November 2002.
[6] B. Anderson, E. Greitzer, and C. Tan, Potential Flow Theory and Lifting Line Theory for Kappel Propellers. Journal of Marine Science and Engineering, vol. 11, no. 4, pp. 748-760, 2005
[7] MAN Diesel & Turbo Corporation, MAN Alpha Kappel Series Propellers, 2012
[8] H. Kehr and J. Wu, Geometric Characteristics and Computational Methods for Kappel Propellers. Marine Engineering Review, vol. 23, no. 2, pp. 145-158, 2012.
[9] Z. Cai, Optimization of Lifting-Line Theory for Kappel Propellers. Ocean Engineering Journal, vol. 47, no. 1, pp. 34-45, 2014
[10] Y. Huang, On the Study of Efficiency and Cavitation Characteristics of Non-planar Propeller. Master's Thesis, National Taiwan Ocean University, Jilong, Taiwan, 2008.
[11] Bertetta, D.; Brizzolara, S.; Canepa, E.; Gaggero, S.; Viviani, M. EFD and CFD Characterization of a CLT Propeller. Int. J. Rotating Mach. 2012
[12] X. Huang, Cavitation Performance of Kappel Propellers: Effects of Geometric Parameters. Marine Propulsion Journal, vol. 29, no. 3, pp. 223-237, 2016.
[13] J. Gao, D. Kang, et al., Impact of Tip Inclination on Cavitation and Propulsion Efficiency. Journal of Ship Research, vol. 63, no. 4, pp. 307-320, 2019.
[14] C.-W. Chen, H.-M. Li, X.-P. Chen, Z.-Y. Zhou, L.-W. Chen, C. Zhang, and T.-J. Zheng, Effect of Tip Rake Distribution on the Hydrodynamic Performance of Non-Planar Kappel Propeller. Journal of Marine Science and Engineering, vol. 11, p. 748, 2023.
[15] A. Ishiodu, E. Williams, O. Ezenwa, and K. Ejabefio, Design Procedure of 4-Bladed Propeller. West African Journal of Industrial and Academic Research, vol. 8, no. 1, September 2013.
[16] ITTC Propeller Benchmark, Tip Rake Propeller P1727, Report 4487, Potsdam, April 2016
[17] MAN B&W 6G60ME-C10.5,MAN Energy Solutions.