

GEOMETRIC ANALYSIS OF AIRFOIL THICKNESS RATIO DISTRIBUTION IN FIXED-PITCH PROPELLER BLADES

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Abstract: This study investigates the geometric characteristics of airfoil sections in three fixed-pitch propellers used in general aviation training aircraft. The analysis focuses on the distribution of chord length, maximum thickness, and thickness ratio along the blade span. Measurements were conducted at ten radial stations, from 10% of the blade length to the blade tip, using precision measuring tools. Statistical analysis, including normality, homogeneity, and comparative tests, revealed no significant differences among the three propeller types in terms of these geometric parameters, allowing the use of averaged values for further interpretation. The results show consistent geometric trends across all propellers, with chord length and maximum thickness decreasing from root to tip, while the thickness ratio follows a similar pattern. The region around 70% of the blade span was identified as the most aerodynamically efficient, with an average thickness ratio of approximately 0.11. Additionally, differences between aluminum and wooden propellers were observed, with wooden propellers generally exhibiting higher thickness ratios due to material constraints, although these differences were not statistically significant. The study also highlights the aerodynamic implications of thickness ratio variation. Higher thickness ratios tend to increase lift and drag while reducing lift-to-drag ratio and stall performance, whereas thinner airfoils provide better aerodynamic efficiency and contribute more effectively to thrust generation. Overall, the findings emphasize the importance of balancing structural and aerodynamic considerations in propeller blade design and provide a useful reference for future research on airfoil geometry, including the role of maximum thickness location.

Keywords: Aerodynamic Performance, Airfoil Geometry, Chord Length, Maximum Thickness, Propeller Blade, Thickness Ratio

Introduction

Aircraft propulsion systems generate thrust primarily through two mechanisms: aerodynamic action and jet reaction (El-Sayed, 2016; Rolls-Royce, 2015; Sforza, 2017). In propeller-driven aircraft, thrust is produced through aerodynamic action when an engine rotates a propeller, which functions as a rotating airfoil that generates lift in the direction of the aircraft's longitudinal axis. Propellers may be driven by piston engines or turboprop engines. Piston-propeller aircraft are commonly used in general aviation and consist of an internal combustion engine coupled with a propeller system (Altuntas et al., 2015; Geça et al., 2017). In contrast, turboprop propulsion systems are generally employed in unmanned aerial vehicle and commuter (Aygün et al., 2022), or in regional transport aircraft (Yuksel & Aygün, 2025).

Propeller blades are typically designed as twisted airfoils with non-uniform or irregular planform geometry in order to optimize aerodynamic performance along the blade span (Federal

Aviation Administration, 2023). Because the rotational velocity of a propeller increases with radial distance from the hub, each blade section experiences different aerodynamic conditions. Consequently, propeller blades incorporate variations in geometric parameters such as chord length, thickness, and pitch angle along the span to maintain efficient aerodynamic performance.

Each section of a propeller blade contains a specific airfoil configuration that determines its aerodynamic characteristics. In classical airfoil design, the geometry of the airfoil is defined by several key parameters. For example, the NACA four-digit airfoil series characterizes airfoil geometry using three primary parameters: maximum camber, the position of maximum camber relative to the leading edge, and maximum airfoil thickness (Anderson, 2017). Another important parameter is the thickness ratio, defined as the ratio between the maximum airfoil thickness and its chord length (Jan Roskam, 1997). The thickness ratio significantly influences both the aerodynamic performance and structural strength of the airfoil.

Despite the importance of airfoil geometry in propeller performance, detailed geometric data of propeller blade sections used in general aviation training aircraft are relatively limited in publicly available literature. Understanding the geometric distribution of airfoil parameters along the blade span is valuable for both educational purposes and engineering analysis.

Therefore, this study aims to analyze and compare the geometric characteristics of airfoil sections used in several fixed-pitch propeller blades, with particular emphasis on chord length, maximum thickness, and thickness ratio. The analysis focuses on propellers installed on general aviation aircraft located in Hangar 01 of the Aircraft Maintenance Engineering Study Program (Program Studi Teknik Pesawat Udara) at Politeknik Penerbangan Indonesia Curug.

Method

Propeller Specimens

This study examined three fixed-pitch propeller models installed on general aviation aircraft used for aircraft maintenance engineering education at Hangar 01 of the Aircraft Maintenance Engineering Study Program, Politeknik Penerbangan Indonesia Curug. All propellers analyzed in this research are two-blade propellers commonly used in piston-powered training aircraft.

The propeller models included in this study consist of two aluminum propellers manufactured by Sensenich and one wooden propeller manufactured by Pacesetter. The general specifications of the propellers are presented in **Table 1**.

Table 1 Propeller spesification

No	Manufacture	Model	Specification
1.	Sensenich	76EM8S5-0-60	Fixed-pitch, aluminum, two blades, 76-inch diameter
2.	Sensenich	74DM6-058	Fixed-pitch, aluminum, two blades, 74-inch diameter
3.	Pacesetter	Pacesetter 200	Fixed-pitch, wood, two blades, 60.375-inch diameter

Data Collection and Measuring Procedure

Direct observation and dimensional measurements were conducted to determine the geometric characteristics of the airfoil sections along each propeller blade. Each blade was divided into ten radial sections, corresponding to the blade tip and radial stations located at 90%, 80%, 70%, and continuing sequentially down to 10% of the total blade length measured from the propeller center.

At each radial station, the geometric parameters of the airfoil profile were measured, including: chord length, maximum airfoil thickness, and thickness ratio. The measurements were performed using a vernier caliper with an accuracy of 0.001 inches and an outside caliper to ensure

precise dimensional measurements of the airfoil geometry. Each section was carefully measured to obtain reliable geometric data for subsequent analysis. The thickness ratio for each airfoil section was calculated using the following relationship (Jan Roskam, 1997):

$$\text{Thickness ratio} = \frac{\text{Maximum thickness}}{\text{Chord length}}$$

Statistic Analysis

Statistical comparison methods were employed to evaluate differences in the geometric parameters among the three propeller models. The collected quantitative data were analyzed using Statistical Package for the Social Sciences (SPSS) Version 25. Prior to comparative testing, normality and homogeneity tests were performed to assess the distribution characteristics of the datasets. Depending on the results of these tests, either parametric or non-parametric statistical methods were applied: one-way ANOVA was used for normally distributed data (Chatzi & Doody, 2023) and the Kruskal–Wallis test was applied for non-normally distributed datasets (Okoye & Hosseini, 2024). A significance level of $p \leq 0.01$ was adopted to determine statistical significance. The statistical analysis aimed to identify whether the geometric parameters of the airfoil sections differed significantly among the three propeller models.

Result

The results of the geometric measurements of the airfoil profiles are presented in **Table 2**, which compares the chord lengths of the three propeller types. The blade section is expressed as a percentage of the total blade length, measured radially from the propeller center to the respective station location, with chord length measured in inches.

Table 2 Comparison of chord lengths of three propeller types

No	Blade section	Sensenich 76EM8S5-0-60	Sensenich 74DM6-0-58	Pacesetter 200
1.	10%	5.450	5.500	4.968
2.	20%	5.421	5.120	5.510
3.	30%	5.700	5.406	5.648
4.	40%	5.760	5.562	5.845
5.	50%	5.809	5.555	5.985
6.	60%	5.650	5.109	5.810
7.	70%	5.335	5.045	5.350
8.	80%	4.790	4.532	4.713
9.	90%	3.963	3.125	3.610
10.	Blade tip	2.134	2.698	2.924

A graphical comparison of the three propellers is presented in **Figure 1** for chord length distribution. The chord length measurements of the Sensenich 76EM8S5-0-60 propeller showed a mean value of 5.001 (SE = 0.365), and the data were normally distributed. The chord length measurements of the Sensenich 74DM6-0-58 propeller yielded a mean value of 4.765 (SE = 0.326), with the data demonstrating a normal distribution. The results of the chord length measurements for the Pacesetter 200 propeller indicated a mean value of 5.036 (SE = 0.324), and the measurements followed a non-normal distribution. The homogeneity test confirmed that the data were homogeneous. A non-parametric Kruskal–Wallis comparative analysis further demonstrated that there was no statistically significant difference in chord length among the three

propellers ($p = 0.466$). Therefore, the chord length values of the three propellers were averaged, as shown in **Table 5**.

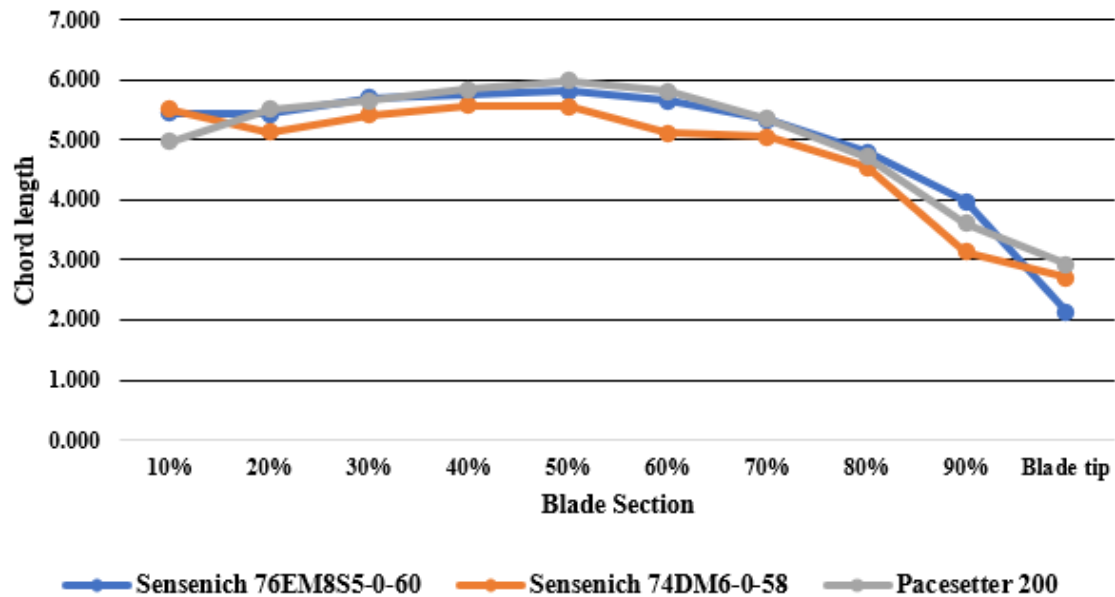


Figure 1 Chord length comparison

Table 3 presents the results of the geometric measurements of the airfoil profiles, including a comparison of the maximum thickness among the three propeller types. Similar with chord length, the blade section is given as a percentage of the total blade length, measured radially from the propeller center to each station location, while the maximum thickness is reported in inches.

Table 3 Comparison of maximum thickness of three propeller types

No	Blade section	Sensenich 76EM8S5-0-60	Sensenich 74DM6-0-58	Pacesetter 200
1.	10%	4.112	3.342	4.745
2.	20%	1.657	1.595	2.469
3.	30%	1.170	1.140	1.895
4.	40%	0.932	0.903	1.490
5.	50%	0.744	0.715	1.167
6.	60%	0.570	0.600	0.965
7.	70%	0.504	0.479	0.825
8.	80%	0.370	0.392	0.625
9.	90%	0.265	0.304	0.458
10.	Blade tip	0.205	0.210	0.325

A graphical comparison of the maximum thickness distribution of the three propellers is presented in **Figure 2**. The airfoil maximum thickness measurements for the Sensenich 76EM8S5-0-60 propeller showed a mean value of 1.053 ($SE = 0.368$) and followed a normal distribution. Similarly, measurements for the Sensenich 74DM6-0-58 propeller produced a mean value of 0.968 ($SE = 0.295$) with normally distributed data. In contrast, the Pacesetter 200 propeller exhibited a mean maximum thickness of 1.496 ($SE = 0.418$), with the data showing a non-normal distribution. Homogeneity testing indicated that the datasets were homogeneous. Furthermore, a non-parametric Kruskal–Wallis test revealed no statistically significant difference

in maximum thickness among the three propellers ($p = 0.348$). Therefore, the maximum thickness values of the three propellers were averaged, as presented in **Table 5**.

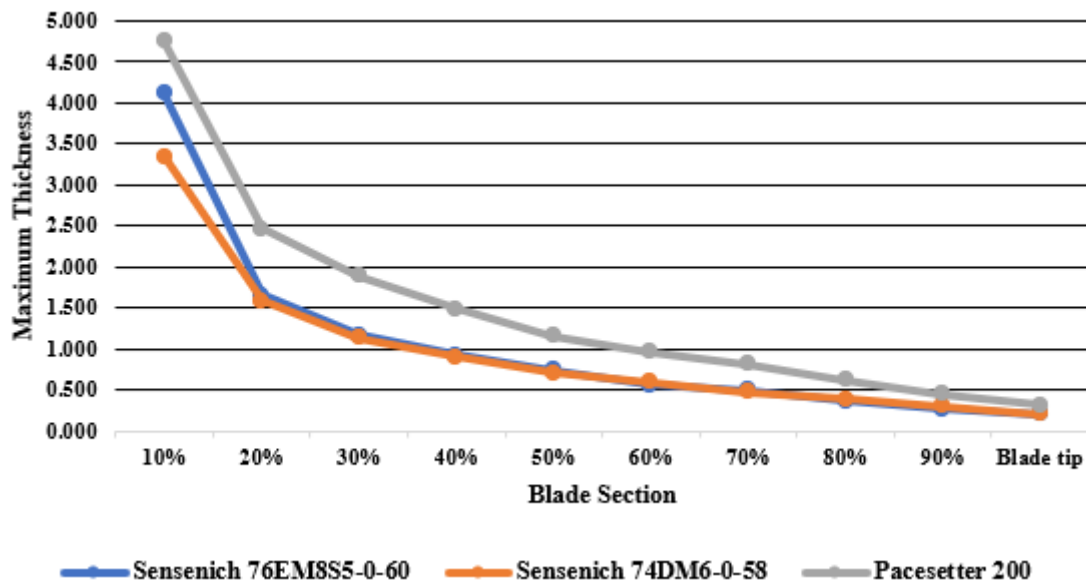


Figure 2 Maximum thickness comparison

The geometric measurement results of the airfoil profiles are presented in **Table 4**, where the thickness ratio of the three propeller types is compared. As with the chord length and maximum thickness, blade sections are defined as a percentage of the total blade length measured radially from the propeller center to the corresponding station, whereas the thickness ratio is a dimensionless parameter.

Table 4 Comparison of thickness ratio of three propeller types

No	Blade section	Sensenich 76EM8S5-0-60	Sensenich 74DM6-0-58	Pacesetter 200
1.	10%	0.7545	0.6076	0.9551
2.	20%	0.3057	0.3115	0.4481
3.	30%	0.2053	0.2109	0.3355
4.	40%	0.1618	0.1624	0.2549
5.	50%	0.1281	0.1287	0.1950
6.	60%	0.1009	0.1174	0.1661
7.	70%	0.0945	0.0949	0.1542
8.	80%	0.0772	0.0865	0.1326
9.	90%	0.0669	0.0973	0.1269
10.	Blade tip	0.0961	0.0778	0.1111

A graphical comparison of the thickness ratio distribution of the three propellers is shown in **Figure 3**. The airfoil thickness ratio measurements for the Sensenich 76EM8S5-0-60 propeller yielded a mean value of 0.1991 ($SE = 0.066$) and were normally distributed. Similarly, the Sensenich 74DM6-0-58 propeller demonstrated a mean thickness ratio of 0.1895 ($SE = 0.052$), with the data also following a normal distribution. The Pacesetter 200 propeller exhibited a mean thickness ratio of 0.2879 ($SE = 0.081$), and the measurements likewise showed a normal distribution. Homogeneity testing confirmed that the datasets were homogeneous. Subsequently, a parametric one-way ANOVA indicated that there was no statistically significant difference in

thickness ratio among the three propellers ($p = 0.531$). Therefore, the thickness ratio values of the three propellers were averaged, as summarized in **Table 5**.

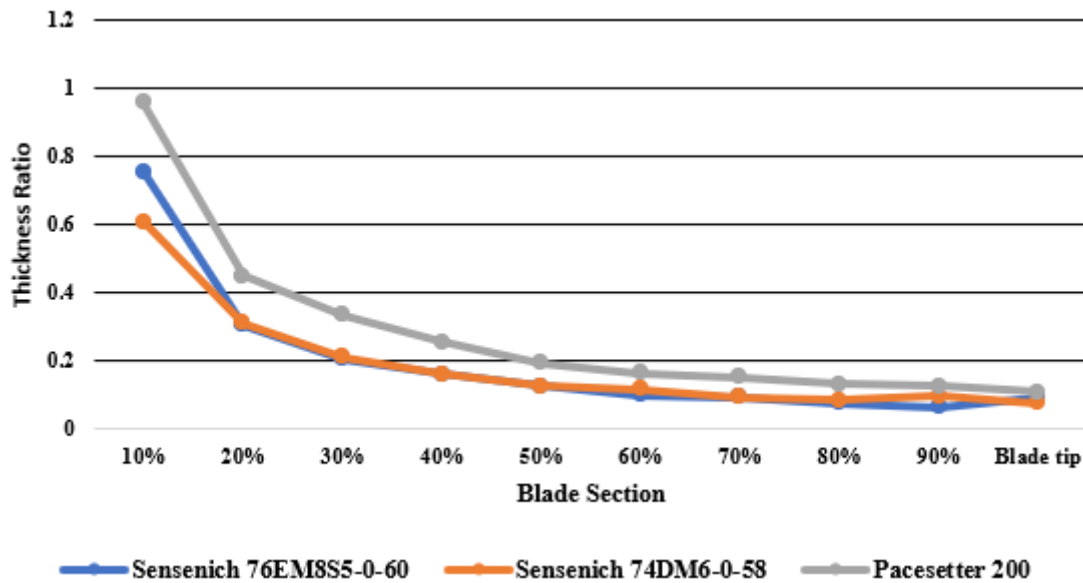


Figure 3 Thickness ratio comparison

Table 5 presents the average geometric measurement results of the airfoil profiles for the three propeller types. As previously described, the blade sections are defined as a percentage of the total blade length, measured radially from the propeller center to each corresponding station. Meanwhile, the chord length and maximum thickness are expressed in inches, whereas the thickness ratio is a dimensionless parameter. The averages were calculated after confirming that there were no statistically significant differences in chord length, maximum thickness, and thickness ratio among the three propeller types.

Table 5 Mean values of chord length, maximum thickness, and thickness ratio

No	Blade section	Chord length	Max. Thickness	Thickness ratio
1.	10%	5.306	4.066	0.772
2.	20%	5.350	1.907	0.355
3.	30%	5.585	1.402	0.251
4.	40%	5.722	1.108	0.193
5.	50%	5.783	0.875	0.151
6.	60%	5.523	0.712	0.128
7.	70%	5.243	0.603	0.115
8.	80%	4.678	0.462	0.099
9.	90%	3.566	0.342	0.097
10.	Blade tip	2.585	0.247	0.095

Discussion

The present study analyzed the geometric characteristics of airfoil sections used in three fixed-pitch propellers: the Sensenich 76EM8S5-0-60, Sensenich 74DM6-0-58, and Pacesetter 200 propellers. The analysis focused on the distribution of chord length, maximum thickness, and thickness ratio along the blade span in order to understand the geometric trends commonly applied in general aviation aircraft propellers.

The results show that the chord length distribution among the three propellers follows a similar pattern along the blade span. In general, the chord length gradually decreases from the root toward the blade tip. This geometric characteristic is consistent with typical propeller blade design principles, where larger chord lengths near the root provide structural strength and allow the blade to withstand higher loads generated by forces acting on a rotating propeller. In addition, larger chord lengths near the root facilitate geometric conformity with the propeller hub. Toward the tip region, the reduction in chord length contributes to more effective airfoil and tip design, as it can help reduce vibration induced by aerodynamic effects (Delp, 1979). An interesting observation is that, upon closer examination, the maximum chord length occurs near the mid-span of the blade, or approximately at the 50% blade section. This design allows for a wider chord in that region, thereby increasing the cross-sectional area of the propeller airfoil. Increasing cross-sectional area of the airfoil will increase lift atau pada propeller di sebut thrust. Increasing the cross-sectional area of the airfoil will enhance lift (Anderson, 2017), which in the context of a propeller is referred to as thrust.

A similar trend was observed in the maximum thickness distribution along the blade span. The largest airfoil thickness values occur near the root section of the blade, while progressively smaller thickness values are found toward the blade tip. Structurally, thicker airfoils near the root are necessary to accommodate the higher mechanical stresses and provide sufficient structural rigidity. The increasing thickness toward the near propeller hub (below approximately 40% span) reflects the structural requirement to withstand higher loads, as well as the need to conform to the geometry of the propeller hub. This represents a design trade-off, since thicker airfoils tend to be less aerodynamically efficient. To achieve a higher maximum lift-to-drag ratio, a thinner airfoil is generally preferred, provided that acceptable stall characteristics are maintained (Ma et al., 2015). Thinner sections toward the tip also help reduce profile drag and improve propeller efficiency. Wooden propellers generally have greater thickness across all blade sections compared to aluminum propellers. Aluminum propellers are therefore more desirable, as they allow the use of thinner, more aerodynamically efficient airfoils without compromising structural strength (Delp, 1979).

The pattern observed in the thickness ratio graph is similar to that of the maximum thickness; therefore, its discussion is adequately represented by the previous analysis of maximum thickness. However, it is important to note that there were no statistically significant differences in chord length, maximum thickness, or thickness ratio among the three propeller types, particularly with respect to the thickness ratio. Therefore, the mean values can be considered representative of all three propellers. If the propeller blade is divided into three regions—namely the tip region (70% blade section to the blade tip), the mid-span region (40% to 70% blade section), and the root region (10% to 40% blade section)—the corresponding thickness ratio ranges are 0.11–0.10, 0.19–0.11, and 0.77–0.19, respectively. When considered based on material type, there are observable differences between aluminum and wooden propellers, although statistical analysis indicates that these differences are not significant. This variation arises because aluminum propellers are typically manufactured thinner than wooden propellers (Delp, 1979). On average, the thickness ratio of aluminum propellers ranges from 0.09–0.08 in the tip region, 0.16–0.09 in the mid-span region, and 0.68–0.16 in the root region. In contrast, wooden propellers exhibit higher values, with corresponding ranges of 0.15–0.11, 0.25–0.15, and 0.96–0.25, respectively. In particular, the most aerodynamically efficient region of a fixed-pitch propeller is located at approximately 70% of the blade span (Federal Aviation Administration [FAA], 2023), where the average thickness ratio is about 0.11. In comparison, the average thickness ratio at this section is approximately 0.09 for aluminum propellers and 0.15 for wooden propellers.

Although plunging airfoil phenomena are more commonly associated with aircraft wings, the findings of Yu et al. (2012) remain relevant. For thick airfoils (thickness ratio > 0.09), pressure forces dominate thrust generation while viscous forces are negligible and mainly contribute to drag. In contrast, for thin airfoils (thickness ratio < 0.08), viscous forces contribute significantly to thrust and act as thrust-producing rather than drag-producing forces. The study by Kumar & Narayanan (2022) shows that the mean lift and viscous drag coefficients decrease linearly with increasing thickness ratio, whereas the total drag coefficient increases linearly, across a range of angles of attack and airflow velocities represented by the Reynolds numbers considered. An alternative term for the thickness ratio of an airfoil is relative thickness, as described by Ma et al. (2015). A larger thickness ratio tends to generate higher lift and drag forces, which ultimately lead to a lower lift-to-drag ratio and poorer stall characteristics pada lower angle of attack (Ma et al., 2015) and stall occurs earlier (Wang et al., 2023). Therefore, to achieve a higher maximum lift-to-drag ratio, a thinner airfoil is generally preferred, provided that acceptable stall characteristics are maintained. In addition to thickness ratio as a factor influencing the aerodynamic characteristics of an airfoil, Ma et al. (2015) demonstrated that the location of maximum thickness also plays a significant role. Therefore, in subsequent studies, the comparison of geometric characteristics of propeller airfoils should include the profile of the maximum thickness location. The explanations above can describe the conditions of thrust generation along the propeller blade sections, which exhibit varying thickness ratios along the span.

Conclusion

This study examined the geometric characteristics of airfoil sections in three fixed-pitch propellers, focusing on chord length, maximum thickness, and thickness ratio distributions along the blade span. The results demonstrate that all three propellers exhibit similar geometric trends, with chord length and maximum thickness decreasing from the root toward the tip, while the thickness ratio follows a comparable pattern. Statistical analysis confirmed that there are no significant differences among the three propeller types for these parameters, indicating that the averaged values can reliably represent their airfoil geometric characteristics. From a design perspective, larger chord lengths and greater thickness near the root are primarily driven by structural requirements and the need to conform to the propeller hub. In contrast, thinner and narrower airfoil sections toward the tip contribute to improved aerodynamic efficiency by reducing drag and vibration. The most aerodynamically efficient region of the blade is located around 70% of the span, where the thickness ratio is approximately 0.11, aligning with established propeller design principles. The findings also highlight the aerodynamic implications of thickness ratio variation. Thicker airfoils tend to generate higher lift and drag but result in lower lift-to-drag ratios and less favorable stall characteristics. Conversely, thinner airfoils offer improved aerodynamic efficiency and can enhance thrust generation, particularly due to the increasing role of viscous forces at lower thickness ratios. These observations are consistent with previous studies, confirming that thickness ratio is a key parameter influencing both aerodynamic performance and thrust production. Overall, the variation of geometric parameters along the blade span reflects a balance between structural strength and aerodynamic efficiency. Future studies should further investigate additional geometric parameters, particularly the location of maximum thickness, to provide a more comprehensive understanding of propeller airfoil performance.

Reference

- Altuntas, O., Karakoc, T. H., & Hepbasli, A. (2015). A parametric study of a piston-prop aircraft engine using exergy and exergoeconomic analysis methods. *International Journal of Green Energy*, 12(1), 2–14. <https://doi.org/10.1080/15435075.2014.889003>
- Anderson, J. D. (2017). *Fundamentals of Aerodynamics* (6th ed.). McGraw-Hill Education.
- Aygun, H., Kirmizi, M., & Turan, O. (2022). Propeller effects on energy, exergy and sustainability parameters of a small turboprop engine. *Energy*, 249, 123759. <https://doi.org/10.1016/j.energy.2022.123759>
- Chatzi, A., & Doody, O. (2023). The one-way ANOVA test explained. *Nurse Researcher*, 31(3). <https://doi.org/10.7748/nr.2023.e1885>
- Delp, F. (1979). *Aircraft Propellers and Controls*. Jeppesen Sanderson, Inc.
- El-Sayed, A. F. (2016). Performance Parameters of Jet Engines. In *Fundamentals of Aircraft and Rocket Propulsion* (pp. 161–218). Springer. <https://doi.org/10.1007/978-1-4471-6796-9>
- Federal Aviation Administration. (2023). *Aviation Maintenance Technician Handbook – Powerplant (FAA-H-8083-32B)*. Federal Aviation Administration. <https://www.faa.gov/regulationspolicies/handbooksmanuals/aviation/faa-h-8083-32b-aviation-maintenance-technician>
- Gęca, M., Czyz, Z., & Sulek, M. (2017). Diesel engine for aircraft propulsion system. *Combustion Engines*, 169(2), 7–13. <https://doi.org/10.19206/ce-2017-202>
- Jan Roskam. (1997). *Airplane Design Part II: Preliminary Configuration Design and Integration of the Propulsion System*. DAR Corporation.
- Kumar, S., & Narayanan, S. (2022). Airfoil thickness effects on flow and acoustic characteristics. *Alexandria Engineering Journal*, 61(6), 4679–4699. <https://doi.org/10.1016/j.aej.2021.10.022>
- Ma, D., Zhao, Y., Qiao, Y., & Li, G. (2015). Effects of relative thickness on aerodynamic characteristics of airfoil at a low Reynolds number. *Chinese Journal of Aeronautics*, 28(4), 1003–1015. <https://doi.org/10.1016/j.cja.2015.05.012>
- Okoye, K., & Hosseini, S. (2024). Mann–Whitney U Test and Kruskal–Wallis H Test Statistics in R. In *R Programming* (pp. 225–246). Springer. https://doi.org/10.1007/978-981-97-3385-9_11
- Rolls-Royce. (2015). *The Jet Engines* (2nd ed.). Wiley and Sons.
- Sforza, P. M. (2017). *Theory of Aerospace Propulsion* (2nd ed.). Todd Green, Elsevier. Inc.
- Wang, P., Wang, L., Kong, X., Wu, D., & Huang, B. (2023). Influence of relative thickness on static and dynamic stall characteristics and prediction of airfoils. *Ocean Engineering*, 271, 113690. <https://doi.org/10.1016/j.oceaneng.2023.113690>
- Yu, M., Wang, Z. J., & Hu, H. (2012). Airfoil thickness effects on the thrust generation of plunging airfoils. *Journal of Aircraft*, 49(5), 1434–1439. <https://doi.org/10.2514/1.C031720>
- Yuksel, O., & Aygün, H. (2025). Comparative performance analysis of a turboprop engine used in regional aircraft by considering design and flight conditions. *Aircraft Engineering and Aerospace Technology: An International Journal*, 97(3), 345–355. <https://doi.org/10.1108/AEAT-07-2024-0194>