Research on the Relationship between the Glide and Aspect Ratio

Yanchen Jin [1, *], Yiqi Yao [2]

[1] Shanghai World Foreign Language Academy, Shanghai, 200233, China

[2] Suzhou Foreign Language School, Suzhou, 215011, China

* Corresponding Author Email: peiyuwen@ldy.edu.rs

Abstract. Global warming along with other environmental issues like El Niño has radically reconfigured the biosphere mainly because of the increasing carbon footprint human beings have made up. The whole aviation industry shares the responsibility as manufacturers compete on the innovation of better aerodynamic shape of airplanes, application of a new type of sustainable fuel for decarbonization, and development of highly fuel-efficient turbofan engines. The objective of this study is to analyse glider airfoils with the now worldwide application, identify parameters affecting the glide ratio as well as coefficients, and initiate a discussion about the experiment that had been carried out with limited conditions of the circumstances. The glider model analytical data calculation is offered in this research, following the comparison of measurements of aspect ratio and glide ratio with other parameters provided. Theoretical evaluation utilising the results of measurements validates the statistical and analytical trends in gliding data, which clearly indicate a relationship between glide ratio increase and aspect ratio increase at a constant taper ratio. An aspect ratio increase was suggested as a viable way to increase aircraft gliding ability based on the results of the performed analysis, although it would come with a higher drag coefficient.

Keywords: Aspect ratio, glide ratio, experiment, self-designed.

1. Introduction

Human society is now progressing to a higher technological state as well as an increasingly deteriorated global environment, which results in the ascendance in the demand for cleaner power plants and energy sources [1]. In recent decades, the civilian aviation industry has dedicated most of its effort to the research of more advanced designs for airplanes, mainly airfoils [2], to achieve the goal of covering larger distances with less fuel consumption, and for engines to have higher fuel efficiency along with cleaner emissions [3, 4]. To delve into the field of figuring out better airfoils that can ensure the plane with a high gliding ability, gliders with their amateurs eventually become another trendy section of flying besides the commercial and military sectors [5, 6]. In the Aeronautical Journal, Welch, A. C considered the light aviation industry, also known as the ‘amateur’ flying sector, as a great starter cradle for new ideas and conceptual trials [5].

Gliders, having become a platform for studying the basics of aerodynamics and attitude control systems, testing different aircraft designs, and other design-related principles [7], have grown to a state of huge significance in modern aviation. Up to now, the most authorised and common method to raise the glide ratio is to increase the aspect ratio, which can be seen in many cases like DG-808, Rolladen-Schneider LS4, and ASH25M. These aircraft with immense wing spans always have an exaggerated glide ratio like 70:1 (Nimeta X). The current research situation has every few passages discussing how the aspect ratio alone affects the glide ratio of the aircraft, specifically glider, though there is some existences of research on the different aspect ratios found on animals [8], on underwater gliders and hang gliders [9, 10]. Real metal-made gliders are seldom used in this kind of basic research, which may mainly be due to the fundamentality of this kind of simple theoretical experiment which has already been authenticated at the very beginning of aviation history and at that time the span and slenderness of the wings are considered instead of calling it aspect ratio according to Wright Brothers [11]. However, except for the conventional commercial aviation market and military fighters, airplanes do not need a too high standard on the aspect ratio, especially for those light and ultralight aircraft with their credits given to the computers. Except for the specialized commercial and military aircraft, the theoretical data calculated from the software cannot predict the real construction modification afterward and it's time-consuming and rather complicated to rederive the parameters after discovering unreasonable problems during the construction of the prototype of a developing model.

Besides, since aspect ratio would not be the ultimate design target for certain functions of an aircraft, glide ratio control could be fulfilled by variable incidence angle or rigging angle, the application of drogue and kinetics model without configuring the additional pneumatic components of the aircraft [12-16]. While these means are used to take charge of the precise guidance of the parachute-based aerial delivery systems (PADS) [17], gliders usually make use of its spoilers and the pneumatic panels and thermals to reach an incredible gliding distance (3008km in 2003 by Klaus Ohlmann) [18]. The improvement in mechanical glide ratio, not the distance that can achieved in a real flight, is usually by increasing the aspect ratio and lift drag ratio [19]. However, these aircraft including gliders do not need mass production like the commercial ones, as tailoring for the specific aerodynamic shape appears to be much more important [20].

To tackle these economically and efficiently, the most direct way is still carrying out modelized experiments which is what this essay is about to do. The experiment provides a low-cost and highly flexible solution for testing the modeled aircraft as the subject with the only variable, aspect ratio, in a natural windless condition with a measurable initial speed or from static release. The most substantial point of this research is to delve into the simulation of real gliders by utilising a moderate-size lightweight model with different pairs of wings designed to have distinct aspect ratios to figure out the specific relationship between aspect ratio and glide ratio.

2. Background

In this paper, the model glider is used for the flight test on aspect ratios. Gliders have specially designed wings and fuselage to maximize the glide ratio. The glider makes the ultimate use of the aerodynamic forces of generated by the flowing fluid on each point of the wings and its fuselage either in normal or propagation direction. Fundamentally, the aerodynamic forces come from pressure and shear forces. The unit span force components operating on the elemental area of the breadth of the upper and lower surfaces may be used to determine both of them. Additionally, unit-span forces can be obtained by integrating them from the leading edge to the trailing edge [21]. The details are as follow.

$$c_p = \frac{p_s - p_\infty}{\frac{1}{2} \cdot p_\infty \cdot {v_\infty}^2} \tag{1}$$

$$c_l = \sum (c_{p,l} - c_{p,u}) \cdot d(\frac{x}{C}) \tag{2}$$

$$\mathrm{L}' = \frac{1}{2} \cdot \rho_\infty \cdot {v_\infty}^2 \cdot c_l \cdot C \tag{3}$$

$$\mathrm{L} = \sum L' \cdot dy \tag{4}$$

In this paper, the model glider is supposed to have a Schrenk distribution from the analytical method presented by Oster Schrenk [22], as the CFD method is not available. The mathematical model of the distribution is shown as follows.

$$L'_{elliptical} = \frac{4L}{\pi b} \sqrt{1 - (\frac{2y}{b})^2} \tag{5}$$

$$L'_{planform} = \frac{2L}{(1+\lambda)b} \cdot (1 + (\frac{2y}{b}) \cdot (\lambda - 1)) \tag{6}$$

$$L'_{Schrenk} = \frac{L'_{elliptical} + L'_{planform}}{2} \tag{7}$$

Where v is air's velocity, L is lift, L' is lift distribution, *D is* drag, *P is* static pressure, *C is* chord, *c is* coefficient, ρ is density, *x*, *y is* coordinates, *b is* span, μ is the fluid's viscosity, A is winging area.

The relative principle: The principle of how the gliders can take off mainly relies on aerodynamic principles, especially the generation of lift. On the one hand, it is related to Newton's Third Law. On the other hand, it is related to the difference in air flow rate. When a glider runs at a certain speed on the ground, air flows over the upper and lower surfaces of the wings, forming an airflow. Due to the shape and inclination angle of the wing, the airflow velocity on the upper surface is faster than that on the lower surface, resulting in a lower pressure of the airflow on the upper surface of the wing than on the lower surface. This pressure difference creates lift for the glider, causing it to detach from the ground.

3. Method and Results

3.1. Experiment Setups and Overview of the System Plan

As shown in Fig. 1, this research is done by following the workflow scheme.

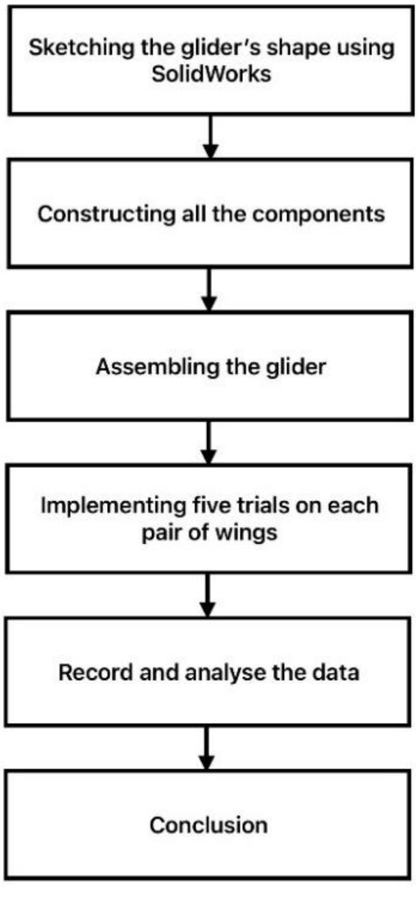


Fig 1. Workflow scheme. (Photo/Picture credit: Original).

Following the workflow, sketches, and modelling was carried out for the first step of the experiment. As shown in Fig. 2, the 3D printed components were also first modelled on CAD software. All the materials are shown in Table 1.

Table 1. The materials and dimensions of this model's aircraft components.

Material	Dimension type and quantity
Polypropylene board	
Coarse carbon rod	0.4m×2 and 0.28m×1
Thin carbon rod	0.334m×1 and 1m×10
Hard foam board	0.027m×0.44m×4
The nose of the aircraft	×3
Plastic board	0.5m×0.9m×0.04m×3
Battery	×6
viscose	×1

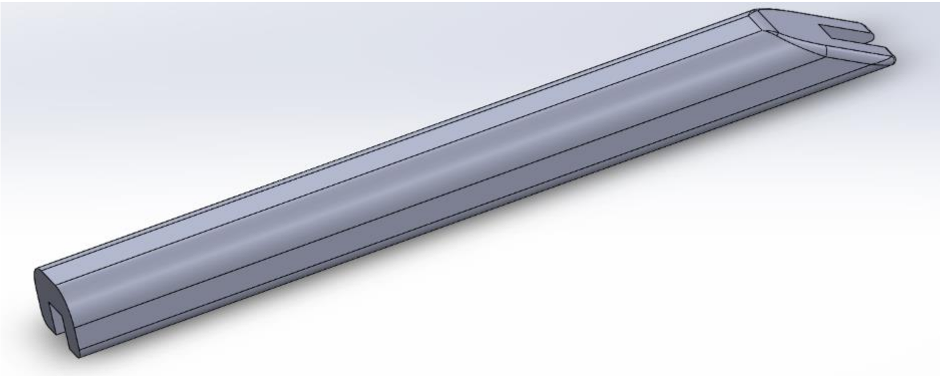


Fig 2. Design of the carbon rod connector. (Photo/Picture credit: Original).

As the model glider was an imitation of the DG-808C glider, the dimensions of the wings and fuselage are comparatively strictly controlled. The five pairs of wings only differ in the span, without changing anything else including the wingtip fold-up area. Some of the details are shown in Tables 2 and 3: (the illustrations of some components are in the appendix)

Table 2. The areas of five different pairs of wings.

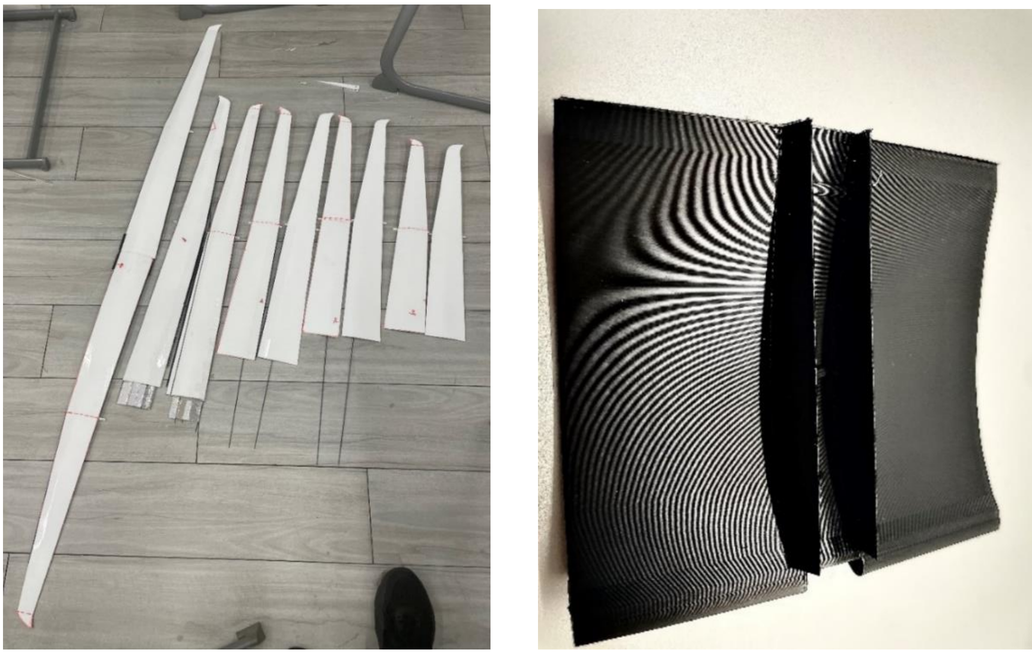
Wingspan after assembly / (m)	The total projection area of two wings / (cm^2)
1.20	389.4754
1.40	455.8504
1.60	515.2234
1.80	575.1184
2.00	630.1984

Table 3. Other dimensions of the wings have in common.

The part of the wing	The lengths and dimensions
The width of each length	0.102 m
The width of the wing at the midpoint	0.791 m
Horizontal length of the curved section of the wing head	0.0222 m
Width at the end of the wing (chord length)	0.0346 m
The distance between the intersection of two arcs and the endpoint perpendicular line	0.0071 m
Taper ratio (exclude irregular wingtip)	0.3388

At the same time, all the wings have a maximum width of about 0.102 meters, which was mainly due to the perimeter of the chamber curve of the wing-root joint as shown in Fig. 3 (b). The wing-root joint was one of the 3D printed components of the glider using the Bamboo Lab A1 printer with Polymaker’s black PLA filament along with the T-tail. At the same time, making a wing root by using the modelling and 3D printing technology, can fix the wings of the aircraft when they are raised by 3 degrees compared to the horizontal plane. Simply clip the wings into the grooves on both sides to easily secure them in place. When using longer wings, it is generally necessary to use tape for further fixation. In either case, it can be easily disassembled and replaced with new wings after the experiment is completed. The different angles at which the wings of the aircraft are raised can improve the stability of the aircraft to varying degrees. In this way, the aircraft can fly longer distances stably and the measured data is more reliable.

The taper ratio of the wings was strictly controlled at about 0.3388 as the only variable is the aspect ratio. To make the construction convenient, the wingspan was decided to have a consecutive progression of lengths to simplify the post-term calculation with the general idea of the shape of the wings illustrated in Fig. 3 (a).



(a) (b).

Fig 3. Wing structure diagram. (a) The five pairs of wings; (b) The wing-root joint. (Photo/Picture credit: Original).

For the implementation, the releasing site was altered once after changing the 80cm wings onto the model, which was mainly due to the unstable environmental conditions of the first and second outdoor ones. The main site was chosen to be an indoor one with a spatial lobby containing an approximately 8-meter-high ceiling. Flying tracks of all trials are recorded and analyse to find out the actual length of the gliding distance. The information on all the sites is shown in Table 4.

The height of the airplane releasing site needs to be controlled in this experiment, so the total mechanical energy of the glider will be under control as the approach to ensure the initial speed of the glider is constant. The practice of changing the initial height in the experiment is to correct the errors that occurred when selecting the experimental location at the beginning, and it will not affect the approximate experimental results.

3.2. Results and Analysis

The results of all the trials for the flying test are illustrated in Tables 4 - 8. In the form of primitive recordings with both linear gliding and circular gliding.

Table 4. Data was collected by using the 0.94 meters longwing.

Angle of roll	Radian	Centering angle	Chord length/m
-13	120	$2/3\pi$	16.18
-14	135	$1/4\pi$	15.05
-13	180	π	16.18

Table 5. Data was collected by using the 0.90meters longwing.

The angle of roll (in degree)	Radian (in degree)	Centering angle (in radian)	Chord length/m
-15	150	5/6π	19.05
-11	180	π	29.97
-13	150	5/6π	21.93

Table 6. Data collected by using the 0.60eters longwing.

The angle of roll (in degree)	Radian (in degree)	Centering angle (in radian)	Chord length/m
-18	150	1/3π	12.34
-19	180	1/2π	12.42
-16	150	1/6π	13.36

Table 7. Data was collected by using the 0.70eters longwing.

The angle of roll (in degree)	Radian (in degree)	Centering angle (in radian)	Arc length/m
-14	45	1/4π	18.45
-12	45	1/4π	21.474
-14	60	1/3π	18.83

Table 8. Data was collected by using the 0.80eters longwing.

The angle of roll (in degree)	Radian (in degree)	Centering angle (in radian)	Arc length/m
-17	150	1/3π	24.01
-23	180	1/3π	34.53
-16	150	1/3π	44.31

The first experiment was conducted during the process of making the aircraft model and did not consider the issue of variable control too much, so it was not included in the final data statistics table. At an altitude of about two meters, the glider was released and the plane turned 360 degrees backward in the air before falling vertically to the ground. After analysis, it was found that the center of gravity of the plane was too far back, and the decision to add weight to the nose of the plane was quickly adopted. Therefore, four batteries were tied to the nose of the plane. This problem is almost solved in this way. At the same time, the problem of the long wing sometimes shaking violently has also been easily solved.

As a matter of fact, the gliding distance of the model should be comparable with every trial, while the track was always circular instead of linear, the real distance was a little complicated as it needed post-processing.

Table 9. The aspect ratio and the glide ratio of every pair of wings.

Wingspan after assembly / (m)	The aspect ratio	The ratio of the distance the aircraft travelled and the height
1.88	31.72	5.88
1.80	28.17	6.50
1.60	24.84	6.35
1.40	21.50	4.50
1.20	18.49	3.49

As shown in Tables 9 and 10, after computing the glide ratio with all the aspect ratios of the wings presented, the trend can be clearly as the aspect ratio rises from 18.49 to 31.72, the glide ratio increases from 3.49 to 5.88. As shown in Figs. 4 and 5, the glide ratio of the 2 meters wingspan version of the model has a much lower glide ability than the second and third largest versions, which was mainly due to the additional weight imbalance compared to the others as it was not realized at the first place at all. However, the data was still used here to illustrate the general increasing trend.

The initial results recorded are not straightforward for the measurement of the relationship between aspect ratio and glide ratio without calculations of certain physical quantities. So, to inspect the status of the model glider metrically, with all aspects like lift and drag included, additional measurements must be taken to ensure the relationship can be clearly illustrated. As Table 9 shows, the dimensions of all three trial sites are listed.

Table 10. The coefficient of lift and the coefficient of drag in different lengths of wings.

Wingspan after assembly / (m)	Coefficient of lift	Coefficient of drag
1.88	0.799	0.202
1.80	0.663	0.181
1.60	0.353	0.090
1.40	0.470	0.311
1.20	0.313	0.080

To see the performance of the model glider specifically, coefficients are chosen to compare the difference between larger and smaller AR. As the wing surface mainly created the lift and the drag, including induced ones, the following measurements are used

$$c_l = \frac{2L}{A_2 \cdot \rho_{air} \cdot v^2} \tag{8}$$

$$c_d = \frac{2D}{A_1 \cdot \rho_{air} \cdot v^2} \tag{9}$$

Where A_2 is the projection wing area on the horizontal plane while A_1 here is the frontal area of the glider, ρ is the air density, v is the relative speed of the glider to the stationary air. This is due to the principles.

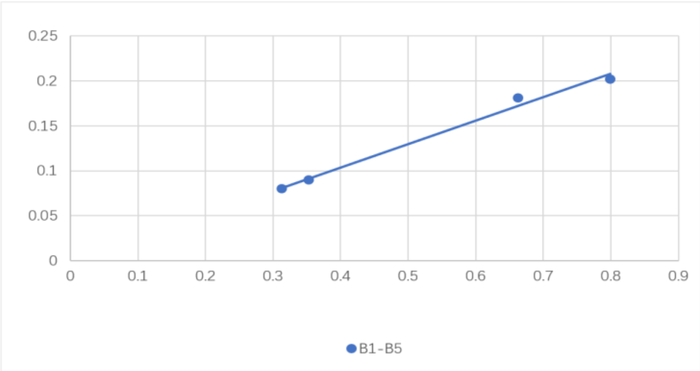


Fig 4. The change of the coefficient of lift with that of the coefficient of drag. (Photo/Picture credit: Original)

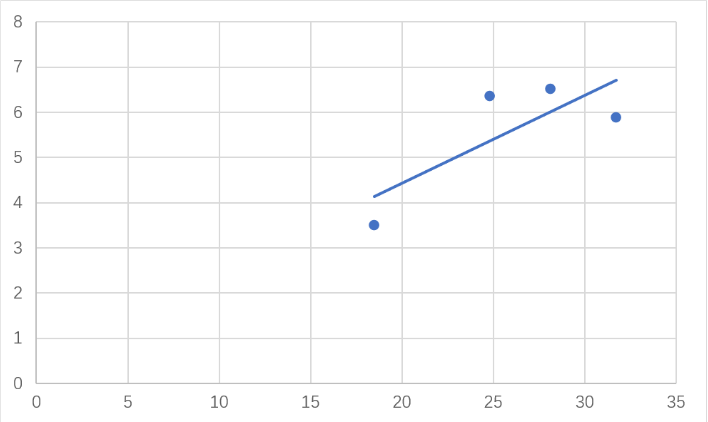


Fig 5. The change of aspect ratio and that of the ratio of the distance the aircraft travelled and the height. (Photo/Picture credit: Original)

Subsequently, it has a base that can securely hold it on the thick carbon rod on the central axis Due to time constraints and the fact that a glider was being produced this time, the aircraft controller and motor were not used in this experiment. In theory, the construction of the plane is about to end at this point.

4. Conclusion

The research delved into the specific relationship between the aspect ratio (AR) and glide ratio (GR), and by utilising an imitation model of the DG-808C glider, experiments of powerless gliding tests were carried out to get the specific data.

A preliminary design of a light model for an experimental glider, suitable for use in research, has been completed. The design process started with choosing the proper real matrix glider, the part that needs to be reconstructed, and the baseline, the upper limit of the chosen aspect ratios. After the computed sketch of the model for better engineering illustration, the model is constructed using fiber materials and polymerised foam materials to maintain strength while reducing weight. Then trials were carried out in three different sites to find the best releasing spot and altitude for the model to glide pleasantly. Finally, the second highest place in a spatial inner venue was chosen due to the windless condition and measurable height. By calculating the length of the actual track of the glider instead of only taking the linear distance into consideration, the glide ratio will be more accurate and thus the relationship of direct proportionality is more convincible and clarified. The research will lead to a significant reduction in the cost of research and development of new non-mass-produced aircraft, which fits the rise of several new model aircraft makers.

As a further step of the development, there are several issues that could be improved in the whole process from construction to results analysis. In the rough engineering session, the carbon fiber used for strengthening is a bit too thin to support the wing against the effect of lift on the winglet. The ideal diameter of the carbon beam should be above the current one for the wingspan far over the usual dimensions. The releasing sites were also not as perfect as expected as the height of the place is too small relative to the ground. One feasible solution is to release it stationarily at a height over the maximum height the water can reach with a pressure difference of an atmospheric pressure as the gliding pattern seems to be comparatively perfect in terms of theoretical calculations. For future works, the model could be regulated to an electrically controlled one that is capable of adjusting flying altitude in the air by a remote controller to achieve the best mode of glide for further research taking into consideration the influence of wind and free airflow.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Nowak, Mateusz, et al. “Adaptation of the LTO Test to the Local Airports Infrastructure.” Transportation Research Procedia, Elsevier BV, 2020, 51, pp. 349–56.

[2] “Application of Computational Methods to the Design of Large Turbofan Engine Nacelles.” General Electric Company, Cincinnati, Ohio. Accessed 6 Apr. 2024.

[3] Wie, Yong-Sun, et al. “Design of a Hybrid Laminar Flow Control Nacelle.” 30th Aerospace Sciences Meeting and Exhibit, American Institute of Aeronautics and Astronautics, Jan. 1992. Crossruff, https://doi.org/10.2514/6.1992-400.

[4] “Application of Computational Methods to the Design of Large Turbofan Engine Nacelles.” Numerical Methods for Engine-Airframe Integration, American Institute of Aeronautics and Astronautics, Jan. 1986, pp. 305–34. Crossruff, https://doi.org/10.2514/5.9781600865763.0305.0334.

[5] Welch, A. C. “Light aviation - past, present and future.” The Aeronautical Journal, vol. 107, no. 1072, June 2003, pp. 389–402. https://doi.org/10.1017/s0001924000097268.

[6] Davidson, Lee, and Robert A. Stebbins. “Air.” Palgrave Macmillan UK eBooks, 2011, pp. 26–56. https://doi.org/10.1057/9780230299375_2.

[7] WHAT IS A GLIDER? Aircraft Nerds, www.aircraftnerds.com/2018/09/what-are-gliders.html#:~:text=1%29%20Gliders%20are%20one%20type%20of%20aircraft%20which,different%20aircraft%20designs%20and%20other%20design%20related%20principles.

[8] Fu, Jun-Jiang, et al. “Effects of aspect ratio on flapping wing aerodynamics in animal flight.” Acta Mechanica Sinica, vol. 30, no. 6, Dec. 2014, pp. 776–86. https://doi.org/10.1007/s10409-014-0120-z.

[9] Jenkins, Scott A., et al. "Underwater glider system study." (2003).

[10] Coiro, D. P., et al. “Improving Hang-Glider Manoeuvrability Using Multiple Winglets: A Numerical and Experimental Investigation.” Journal of Aircraft, vol. 45, no. 3, May 2008, pp. 981–89. https://doi.org/10.2514/1.33265.

[11] Gliders and Sailplanes. Pressbooks, Last accessed 2024/09/22, https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/gliders-sailplanes.

[12] Sun, Hao, et al. “Accurate Homing of Parafoil Delivery Systems Based Glide-Ratio Control.” IEEE Transactions on Aerospace and Electronic Systems, vol. 56, no. 3, June 2020, pp. 2374–89. https://doi.org/10.1109/taes.2019.2946488.

[13] Patel S, Hackett N, Jorgensen D, et al, Qualification of the guided parafoil air delivery system-light (GPADS-Light), 14th Aerodynamic Decelerator Systems Technology Conference, and 1997: 1493.

[14] Ward M, Gavrilovski A, Costello M, Flight test results for glide slope control of parafoil canopies of various aspect ratios, 21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar, 2011: 2620

[15] Slegers N, Beyer E, Costello M, Use of variable incidence angle for glide slope control of autonomous parafoils, Journal of Guidance, Control, and Dynamics, 2008, 31(3): 585-596.

[16] Stein J, Madsen C, Strahan A, an overview of the guided parafoil system derived from X-38 experience, 18th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar, 2005: 1652.

[17] Cleminson, John. “Precision Aerial Delivery Systems: Modelling, Dynamics, and Control Edited by O. A. Yakimenko American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, USA. 2015. Distributed by Transatlantic Publishers Group, 97 Greenham Road, London, N10 1LN. 941pp. Illustrated £115. (20% discount available to RAeS members on request; email: mark.chaloner@tpgltd.co.uk Tel: 020–8815 5994). ISBN 978-1-62410-195-3.” The Aeronautical Journal, vol. 121, no. 1244, Oct. 2017, pp. 1579–83. https://doi.org/10.1017/aer.2017.73.

[18] “What is the furthest a glider has flown and how.” Black Mountains Gliding Club, 20 Jan. 2019, www.blackmountainsgliding.co.uk/gliding-faq/what-is-the-furthest-a-glider-has-flown.

[19] Katz, Joseph, and Bernhard Roglin. Tailoring lift/drag ratio for a lifting-body airplane configuration. Journal of aircraft, 2000, 37(4): 725-727.

[20] Welch, Ann. “Evolution of the High-Performance Glider.” The Aeronautical Journal 99.986 (1995): 243–259.

[21] Putra, C., et al. "Comparative study between Schrenk and CFD analysis for predicting lift distribution along wing span of glider aircraft." Aerospace Science and ‘Technology in Indonesia (2016).

[22] Schrenk, O. “A Simple Approximation Method for Obtaining the Spanwise Lift Distribution.” Journal of the Royal Aeronautical Society, vol. 45, no. 370, Oct. 1941, pp. 331–36. https://doi.org/10.1017/s0368393100101075.