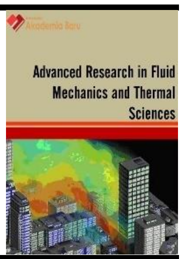
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Circulation Control Aircraft Design: Assessment on The Channel-Wing Lift-Thrust Performance Characteristics

Open Access

Muhammad Alimin Md Shafie[1], Mohd Faisal Abdul Hamid[1,*], Azmin Shakrine Mohd Rafie[1]

[1] Department of Aerospace Engineering, University Putra Malaysia, 43400 Serdang, Malaysia

ARTICLE INFO

Article history:
Received 15 October 2019
Received in revised form 12 November 2019
Accepted 20 November 2019
Available online 15 December 2019

ABSTRACT

Channel-wing has the ability to exceed the performance of conventional aircraft wing design; allowing for short take-off, overcome the needs for expensive conventional long runway setup and potential to decrease the aircraft running cost (e.g. flight duration, fuel usage). Assessment on the aerodynamic lift and propulsive thrust of three different sizes of the channel-wing design is carried out. The aim of the study is to provide an understanding of the channel-wing lift-thrust performance characteristics with the changes of the wing sizing (i.e. wing chord length). Fabrication of the channel-wing models was executed via 3D printer machine and the measured forces were analyzed using multiple load-cells and a microcomputer setup. All of the measurements are done in a controlled environment, and the channel-wings were tested at zero forward speed and at zero angles of attack. Indeed, the high speed rotating propeller mounted at the trailing edge of the wing generates a suction effect, reducing the pressure on the upper surface of the channel wing, producing lift. The results have shown that with a larger channel-wing size, the lift to thrust ratio can reach over 30%, however, when evaluating on the lift coefficient, the small channel-wing size is by far the most efficient. The amount of lift force generated and the reductions in the net thrust are found both dependents on the sizing of the channel-wing; longer wing chord promotes higher generations of lift, however, at the expense of some fraction of thrust.

Keywords:
Channel-wing; circulation control; aerodynamic force; flow control

1.Introduction

A need to overcome issues associated with the inefficient design of an aircraft for thin-haul air transportation in urban areas has become a hot topic in recent years [1–3]. The used of conventional (fixed- or rotary-wing) aircraft would requires a regular runway setup, inevitably expensive to build and run. An effective solution by adapting the active circulation control methods to boost the aerodynamic performance of the wing is the best option to alleviate this shortcoming. The pusher-type rotating propeller mounted at the trailing-edge of the wing entrained a high-velocity of airflow; creating a low-pressure region on the wing-upper-surface. In contrary, for the wing-lower-surface,

* *Corresponding author.*
E-mail address: mohd_faisal@upm.edu.my (Mohd Faisal Abdul Hamid)

the air is stationary, thus, the pressure is higher (ambient). As a result, there is a net pressure difference between the lower and upper part of the wing (Figure 1), therefore, some amount of lift can be generated.

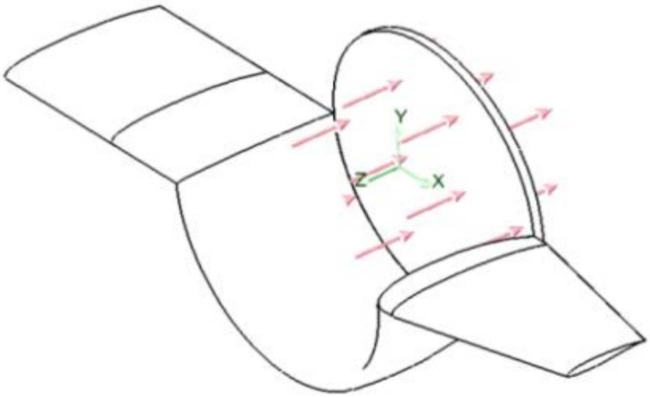


Fig. 1. Suction propeller on the channel-wing surface [4]

A lot of developments and patents utilizing the active circulation control design have been presented through several research programs [5], evolved from earlier STOL/VTOL concept aircraft [6]. On the earlier design, there are issues related to the controls and aerodynamics of the design [7]. One of the earliest examples (Figure 2) is flown and experimentally tested in 1950s, known as Custer Channel-wing Aircraft [8].

Fig. 2. Custer Channel-wing aircraft [8]

In the late 1980s, a group of researchers has conducted a study to identify and to improve the aerodynamic and control of the design by focusing on the aerodynamic interaction between propellers and wings [9]. This study was then further refined, in particular to look specifically on the aerodynamic installation effects reflecting to the over-the-wing propeller mounting configurations [10, 11].

Crucially, channel-wing design has the ability to go beyond conventional fixed-wing aircraft. The channel-wing can produce lift even at zero forward velocity (stand-still) and the wing have broader range of the angle of attack before stall ($-40°$ to $+40°$). Furthermore, the lift generated could reach twice higher than conventional wing. Also, perhaps under certain conditions it could also take-off even at zero ground roll [12, 13].

Although there are a lot of researches have been carried out to look on various aspects of channel-wing design performance, however, the lift-force performance characteristic for different sizing of channel-wing is still yet to be physically examined. The present paper will focus on the correlations between the aerodynamic lift and the propulsive thrust forces; i.e. for three wing sizes, each with different chord length. Aim is to provide an understanding on the channel-wing lift-thrust performance characteristics with the sizing of the wing. The test setup is similar to the one presented by Blick and Homer [14]; i.e. at zero forward speed and at zero angle of attack.

2. Methodology

For measurement of thrust and lift forces, two load cells and a microcontroller are used, which both are connected in parallel to a computer. The positioning of the engine/motor is revised, positioned behind the channel-wing, instead of inside the wing channel; allowing for undisturbed and smoother oncoming airflow.

2.1 Test Bench Setup

The channel-wing test bench setup consists of a channel-wing and a set of propeller-motor setup. The assembly and mounting positions of the main components of the channel-wing test bench setup are illustrates in Figure 3.

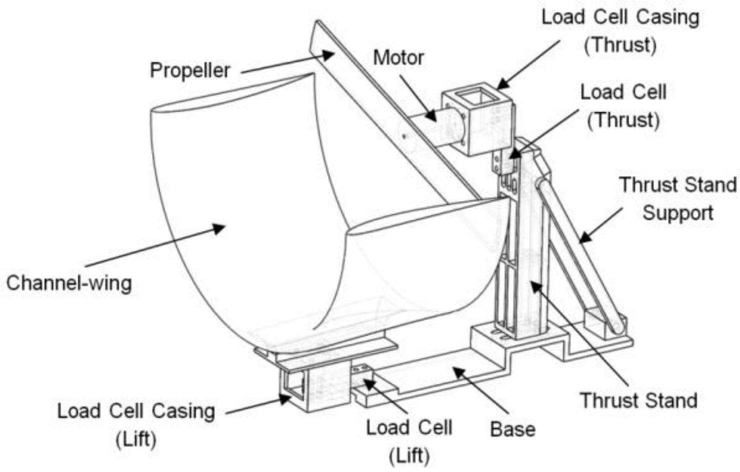


Fig. 3. Channel-wing test bench setup

The channel-wing profile is based on the NACA4412 airfoil [14]. The diameter for all of the three channel-wings is the same. An extra of $2\ mm$ clearance on each side of the propeller-blade tip is made to prevent the propeller-blades from colliding with the channel-wing. For the wing chord length, it is measured as the ratio of the wing chord length (C_{wing}) to the propeller diameter (D_{prop}); measuring at 20%, 35%, and 55%, for the small, medium and large wing size, respectively.

The Fused Deposition Modelling (DFM) 3D printing method is used to construct the channel-wing. The process starts with 3D modelling [15], then followed by slicer software to generate the g-code for the 3D printer. The printing process is executed using CR10 Plus printer; with maximum printing volume of $400\ mm^3$. Materials used for all 3D printing parts are Polylactic acid or polylactide (PLA). The printed channel-wing is stiff and strong, able to withstand pressure changes without any sign of deformation during the experiment.

For the propeller-motor setup, a 2-bladed propeller, $D_{prop} = 280mm(4.5\ pitch)$ is used; aligned perpendicular to the end part of the channel-wing trailing-edge. The mounting position of the motor is located behind the channel-wing. It is design and configured to allow high speed airflow (thrust), uninterrupted the low pressure region on the inner part of the channel-wing.

The electrical components of the propeller-motor setup consist of an electric motor $820K_v$(motor velocity constant, measured in RPM per volt), $30\ Amp$Electronic Speed Controller (ESC), Direct Current watt meter/digital multimeter, and $4-cells$Lithium-Polymer battery ($14.8V$); the combination is to complement with the rated power of the motor and the size of the propeller.

For the entire test, the input power supplied from the battery is increased from 5 to $45\ watts$watts, with increments of $5\ watts$. Below $5\ watts$, the motor unable to run smoothly, while over $40\ watts$the ratio of the lift-thrust produce is showed to reduce (detailed in the next section). The schematic of this electrical setup is given in Figure 4.

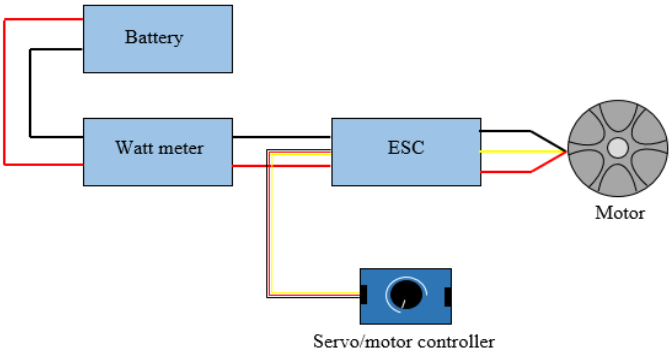


Fig. 4. The schematic of the propeller-motor setup

2.2 Measurement Process

For the force sensors measurement setup, as shown in Figure 5, two load-cells are used (each is rated at maximum load of $5\ kg$. Both of the load cells are connected in-parallel to an amplifier (HX711), and to the microcontroller that link to a computer.

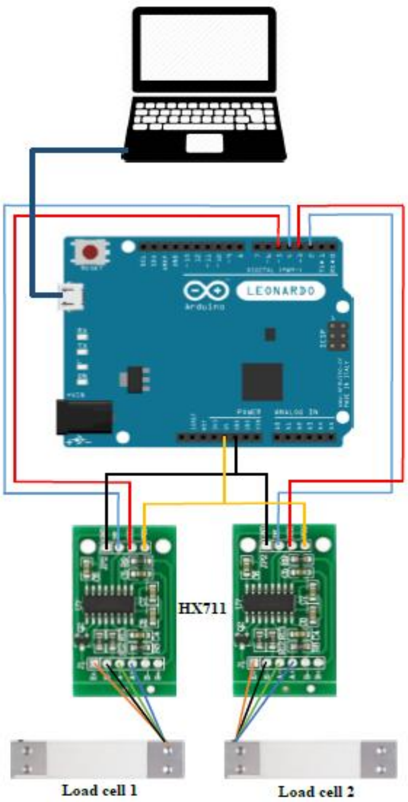


Fig. 5. The schematic of the force sensors measurement setup

The mounting of the load cells are positioned with respect to the direction of measured forces; one mounted vertically to the motor housing to measure the thrust and the other is mounted horizontally underneath the channel-wing to measure the lift produce. The microcontroller used is the Arduino Leonardo, capable of processing data at the rate of $1000/s$. It received the input from the load cells and transmits the output data to the computer via micro USB cable.

2.3 Calibration & Error Analysis

Calibration for each of the load cell is done prior to each of the test with a set of dead weight (calibration up to $600\ g$or $\sim 6\ N$, with $50\ g$ increments). The indicated error for each of the load cell is measured$\pm 0.5\ g$. The measured data from the microcontroller is displayed and stored on the computer (data logger), and each data point is taken by taking the average of 50 readings.

Both of the measured thrust and lift forces as well as the indicated power supplied to the motor are recorded during the measurement process. The test is carried out in a control environment; the ambient temperature at $20°$ Celsius, air density of $1.225\ kg/m^3$and humidity of 50%. Figure 6 shows uncertainty analysis for the experiment. Noted that average error is below 5%, thus, the data taken are consider precise and accurate.

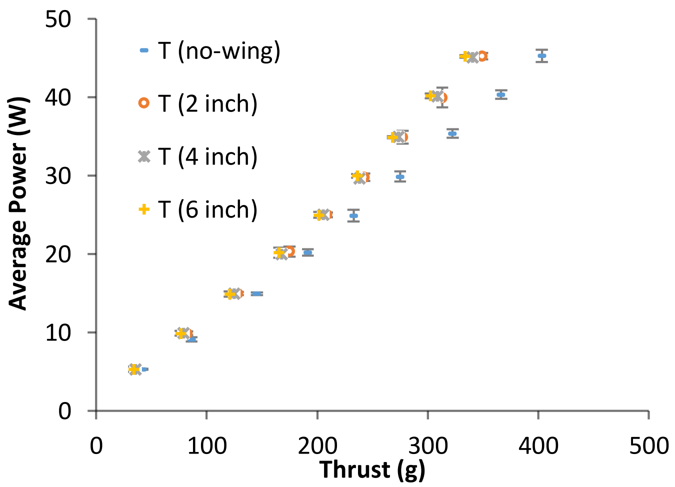


Fig. 6. Uncertainty analyses for collected data

3. Results and Discussions

There are three different sizes of wing are used for the test; small, medium and large. All of the tests are done at zero forward speed and at zero angle of attack. With channel-wing installed (as shown in Figure 7), the amount of thrust is shown to reduce. On average, the reductions in thrust are measured 11%, 13% and 15% for small, medium and large wing sizes, respectively; these percentages are calculated as compared to the isolated propeller (or without wing).

For the resultant force, with channel-wing installed the resultant forces are reduced; measuring 9%, 10% and 11% for small, medium and large wing sizes, respectively. The amount of thrust as well as the resultant force reductions is dependent on the length of the wing chord. A shorter wing chord length could give a fraction lesser impact than the longer one. With longer wing chord, the air would travel much longer distances and catches extra viscous forces; hence, decrease the momentum of the airflow, which leads to reduce the generated forces.

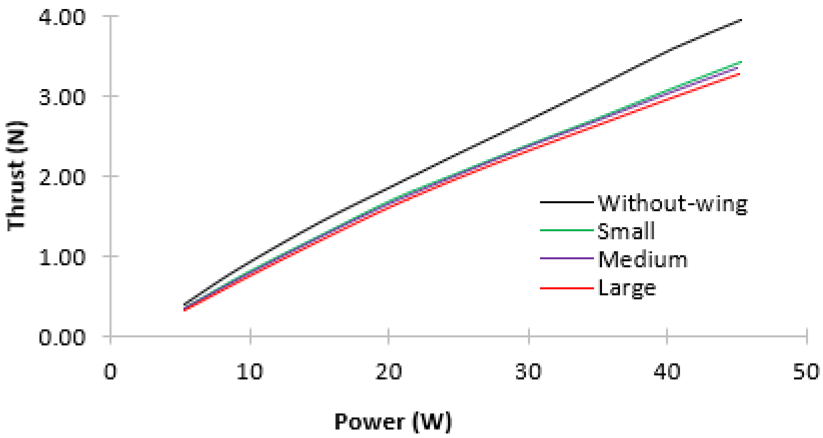


Fig. 7. Thrust characteristics with and without channel-wing installed

The changes in the lift subjected to the increases in the thrust for all wing sizes are presented in Figure 8. Increasing the thrust gives a positive impact on the generation of lift. Comparing between these three channel-wing sizes, longer wing chord length would give a better lift performance. This linear increment, however, will eventually plateau after reaching certain limits (i.e. when the value of thrust gets higher than 3.0 N).

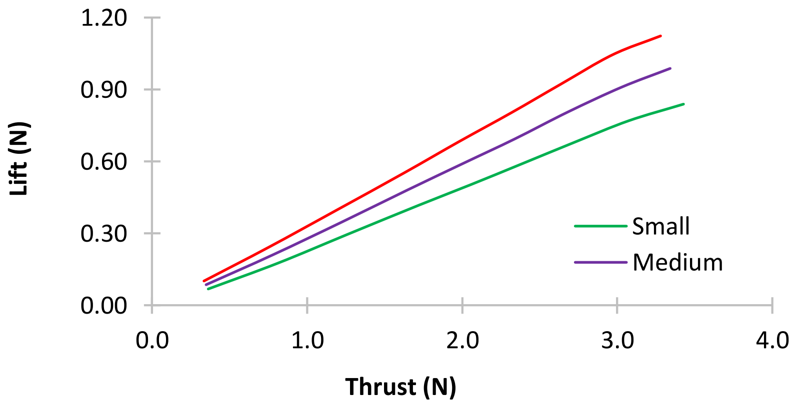


Fig. 8. Changes in the lift subjected to the increases in the thrust

For the lift to thrust ratio (L/T) versus power, as shown in Figure 9, the plotted lines can be characterized into three stages; steep increase in the beginning, gradually flattens, and diminishes towards the end. The correlations and trends of changes for all sizes of the channel-wing are shown to be consistent. The peak value of L/Tincrease from $\sim 25\%$, $\sim 30\%$and up to $\sim 35\%$for small, medium and large wing size, respectively.

Figure 10 shows the relationship between the lift-thrust performance characteristics and the sizing of the channel-wing. This finding is agree well with the results presented by Blick & Homer [14], which has shown that the percentage of L/Tcould go beyond 40%; i.e. here a relatively larger proportion of wing chord length to propeller diameter ratio $\left(C_{wing}/D_{prop}\right)\sim 1$is used. Note that, there is a slight difference on the positioning of the propeller-motor; the motor is positioned on the inside of the wing channel, while for the present study the motor is positioned on the outside to gains aerodynamic benefit.

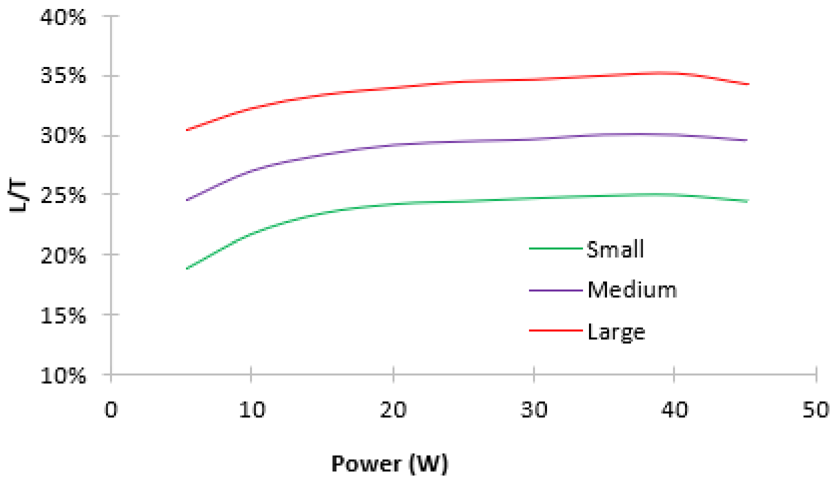


Fig. 9. The lift to thrust ratio (L/T) for three different wing chord length

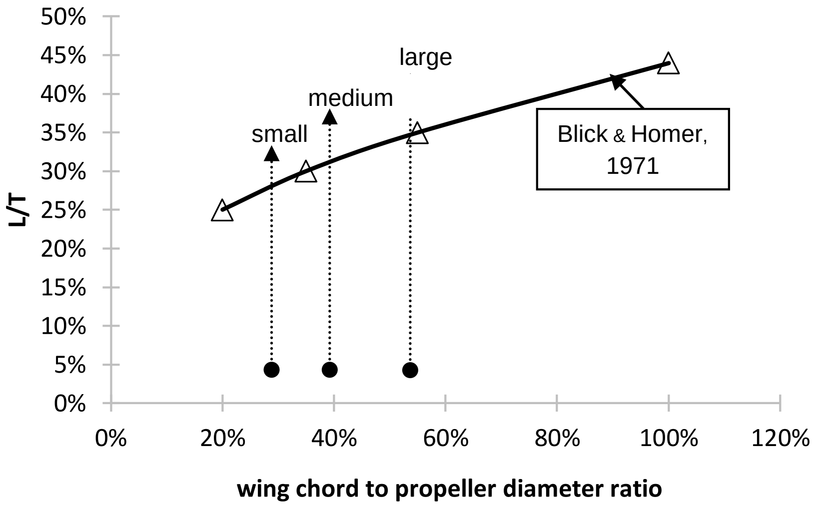


Fig. 10. The relationship between the lift-thrust performance characteristics and the sizing of the channel-wing

In contrast to the results as shown in Figure 9, which has shown that the smallest channel-wing having the lowest value of (L/T), here from Figure 11, lift coefficient value that could be achieved by the smallest channel-wing is the highest. This is due to the fact that the small channel-wing having the smallest surface area, which is approximately one-third than the large wing. The airflow would travel on a much shorter distance, lesser momentum losses due to skin friction and viscous effect.

Nonetheless, the results clearly have shown that with longer wing chord much greater amount of lift could possibly be extracted. With higher lift, the aircraft could take-off at a much lower speed and at a much shorter distance. Hence, a great benefit to the cost for a new runway setup. Also, with short take-off ability, the aircraft will save some fuel and perhaps prolong engine life (moving parts are working at low revolutions/flight cycle); this is due to the shortening of the duration of high engine speed/blast at take-off.

From the flight performance point of view, on cruising flight $(lift = weight)$, the required lift can be achieved at much lower flight speed. This is due to the high lift generated by the channel-wing. For an aircraft which adapting the channel-wing design, a smaller engine size can be used. Thus, the performance of the aircraft can be improved; this includes increase payload capacity, reduce engine size, less fuel consumption, improved stability, lighter structure, and optimizing other subsystems on the aircraft.

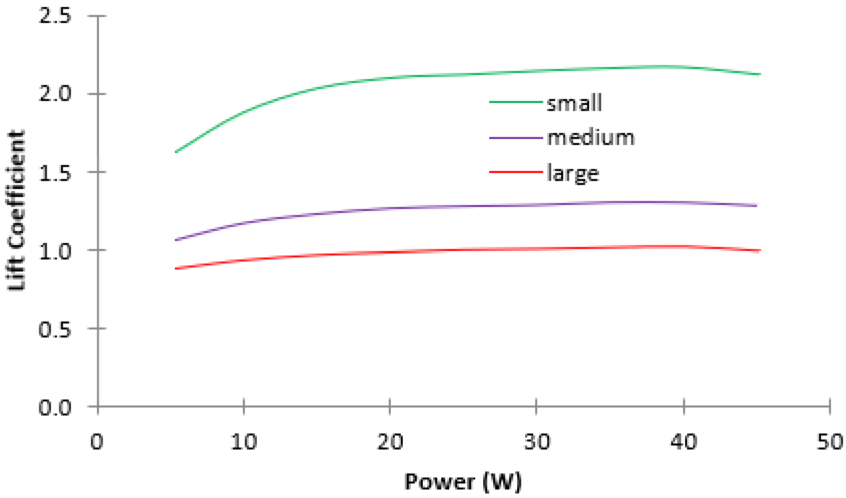


Fig. 11. The lift coefficient (C_L) for three different wing chord length

4. Conclusions

The aerodynamic lift force and the propulsive thrust of the channel-wing design at zero forward speed and zero angle of attack are assessed. The channel-wing lift-thrust correlations/relationship and the performance characteristics derived from aerodynamic lift and propulsive thrust forces for three different sizes of wing chord length are presented.

Indeed, the high speed rotating propeller mounted at the trailing-edge of the wing generates a high velocity slipstream, in which the slipstream energizing the boundary layer; taking advantage of the nature of the boundary layer. The flow adjacent to the upper surface creates pressure difference with the lower surface, generating lift.

Overall, the amount of thrust in generating the lift force and the reduction in the net thrust are both dependent on the sizing of the channel-wing (i.e. chord length). Longer wing chord length promotes the generations of lift, however, may slightly depreciates some fraction of thrust.

Further look into the refinement of the design is necessary, for instance the type of channel-wing airfoil and the paired propeller used. Optimizing the combination of these two elements could reduce airflow momentum loses, hence, optimizing the channel-wing lift-thrust performance.

On a bigger picture, this study could provide a useful solution to overcome problems associated with the runway setup for conventional aircraft that are expensive to build and run. Accordingly, zooming to the aircraft operational issue, this will eventually leads to a much broader dimension (e.g. less fuel consumption, cheaper to operate, etc.).

Acknowledgement

The authors would like to thank to the Universiti Putra Malaysia for providing the financial support through the Geran Putra IPM, Grant Agreements GP-IPM/2017/9537900. Also, thanks to Muhammad Nazrul Adam and Mohd Alimin, who have involved during the setup of the experiment.

References

[1] Savoni, Luciana, and Ralf Rudnik. "Pylon design for a short range transport aircraft with over-the-wing mounted UHBR engines." In *2018 AIAA Aerospace Sciences Meeting*, p. 0011. 2018.
[2] Radespiel, Rolf, Wolfgang Heinze, and Lothar Bertsch. "High-lift research for future transport aircraft." (2017).
[3] Diekmann, Jobst H. "Flight mechanical challenges of STOL aircraft using active high lift." *Journal of Aircraft* 56, no. 5 (2019): 1753-1764.
[4] Stanciu, Virgil, and Valeriu Dragan. "An analitical and numerical study of the Custer channel wing configuration." *International Journal of Advanced Scientific and Technical Research* 4, no. 2 (2012): 1-8.
[5] Ali, Jaffar Syed Mohamed, and M. Mubin Saleh. "Experimental and Numerical Study on the Aerodynamics and Stability Characteristics of a Canard Aircraft." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 53, no. 2 (2019): 165-174.
[6] Djojodihardjo, Harijono, and Naveeyindren Thangarajah. "Research, development and recent patents on aerodynamic surface circulation control-A critical review." *Recent Patents on Mechanical Engineering* 7, no. 1 (2014): 1-37.
[7] Pasamanick, Jerome. "Langley Full-Scale-Tunnel Tests of the Custer Channel Wing Airplane." (1953).
[8] Donald Liska. "Channelwing aircraft." *The Wisconsin Eng*., 57, no. 6 (1957): 16-19.
[9] Witkowski, Dave P., Alex KH Lee, and John P. Sullivan. "Aerodynamic interaction between propellers and wings." *Journal of Aircraft* 26, no. 9 (1989): 829-836.
[10] Müller, Lars, Wolfgang Heinze, Dragan Kožulović, Martin Hepperle, and Rolf Radespiel. "Aerodynamic installation effects of an over-the-wing propeller on a high-lift configuration." *Journal of Aircraft* 51, no. 1 (2014): 249-258.
[11] Gahraz, Seyed Reza Jafari, Tholudin Mat Lazim, and Masoud Darbandi. "Wind Tunnel Study of the Effect Zigzag Tape on Aerodynamics Performance of A Wind Turbine Airfoil." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 41, no. 1 (2018): 1-9.
[12] Englar, Robert, and Bryan Campbell. "Pneumatic Channel Wing Powered-Lift Advanced SuperSTOL Aircraft." In *1st Flow Control Conference*, p. 3275. 2002.
[13] R. J. Englar. "Development of Pneumatic Channel Wing Powered-Lift Advanced Super-Stol Aircraft." In *Proc., AIAA 2002-2929, 20th AIAA Appl. Aerodyn. Conf., AIAA, Reston, VA*, June (2002): 1–10.
[14] Blick, Edward F., and Vincent Homer. "Power-on channel wing aerodynamics." *Journal of Aircraft* 8, no. 4 (1971): 234-238.
[15] Ibrahim, Musa Alhaji, Auwalu Yusuf Gidado, Abdulrahman Shuaibu Ahmad, Saidu Bello, and Huang Kai Abubakar. "Modelling and Virtual Manufacturing of a Flange Tube Using CAD/CAM Tools." *Journal of Advanced Research in Applied Mechanics* 43, no. 1 (2018): 1-7.