REVIEW OF THE STOL CHANNEL-WING AIRCRAFT DESIGN AND DEVELOPMENT

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Abstract: Custer channel wings, sometimes referred to as channel wings, have become a viable solution to control aerodynamic flow and enhance air vehicle performance. This design breakthrough, which dates back to the 1920s, involves redefining the traditional wing shapes into semi-circular or U-shaped configurations to promote suction effect that improves lift generation. Although channel wings present an exciting opportunity to transform the aircraft design, there are still unanswered questions, especially on the best way to integrate them into the contemporary aircraft. In order to fill these gaps, this study examines the viability of channel wing technology and evaluates its possible effects on the operation and design of the commercial aircraft. Through the new developments in materials science and engine technology, previous limitations related to the channel wing designs including weight penalties and drag inefficiencies can be overcome.

Keywords: short-haul flights; channel-wing; aerodynamic design; U-shaped wing; STOL

1. Introduction

The increasing expansion of global economy has increased demands for air transport, necessitating faster long-distance delivery and more efficient people movement [1]. Flight operations are scheduled to restart when the globe recovers from the epidemic in 2020 (as illustrated in Figure 1) and the forecasts suggest an increase in air travel demands, accompanied by increase in the number of passengers [2]. In accordance with the United Nations, more than half of the global population currently resides in cities, the number projected to reach 60% by 2030 [3]. Despite the presence of numerous conventional aircraft in daily operation, the aviation industry needs a paradigm shift [4]-[5]. Conventional aircraft contribute significantly to air traffic congestion, necessitating substantial improvements in this domain. The focus should be on advancing Vertical Takeoff and Landing (VTOL) and Short Takeoff and Landing (STOL) capabilities to address this challenge effectively [6]-[8].

In line with this, revolutionizing the conventional wing is critical in influencing the future of aircraft design, providing a plethora of options for addressing current issues particularly those experienced in short-haul flights. The existing wing design's restrictions limit the ability to maximize its lift generation. Integrating active flow control technology stands out as a viable alternative for improving the wing's aerodynamic performance [9]. Implementing such innovations unlocks the possibility for enhanced lift generation and efficiency, opening the path for substantial advancements in aviation. Furthermore, it can be noted that efficiency, affordability and compact size are key considerations that are highly valued in the aviation community. To achieve this objective requires an aircraft with exceptional aerodynamic performance. Previous studies have shown that channel-wing aircraft have great potential in effectively addressing these challenges. The channel wing configuration has proven to be an excellent choice for short-haul flights, with the ability to perform VTOL and STOL maneuvers [10]-[11].

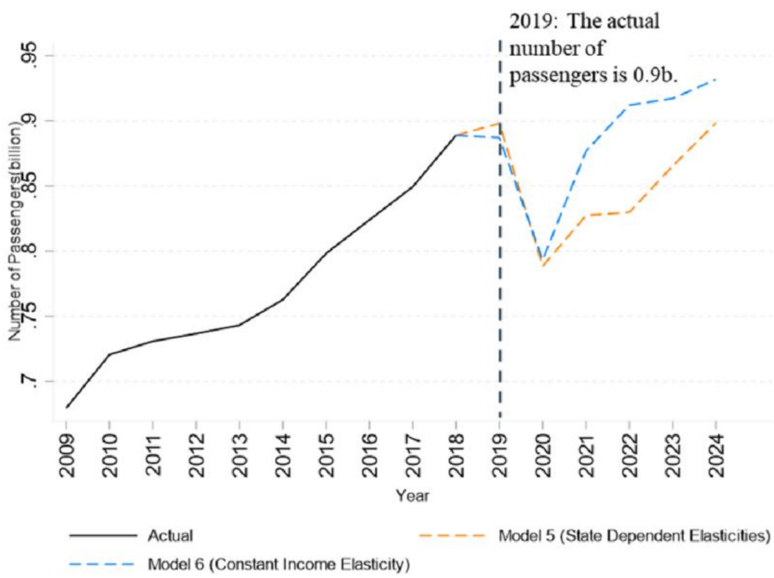


Figure 1: Air travel recovery in the next 5 years (2019–2025) [2]

2. Concept of Channel-Wing

The first concept of channel-wing configuration, which is depicted in Figure 2, came out in 1920s and pioneered by Willard Custer. In 1940s, the concept started receiving serious attention and as shown in Figure 3, further design improvements were made in 1950s where the wing was constructed in the shape of a hemisphere or a U-shaped channel [12]. By combining a fixed wing component with the U-shaped channel, the channel-wing is formed. The propulsion system is positioned near the trailing edge of the channel, allowing the air to flow over the wing's surface. The channel wing works by using the slipstream induced increased dynamic pressure to create lift, which is then directed through the channel to provide additional lift and thrust [13]. At the lower speeds or when stationary, the high-speed rotating propeller blades create a low-pressure region inside the channel, generating differential pressure on the upper and lower surfaces of the wing. This results in a significant amount of lift that surpasses what the conventional wings can achieve [14]. On contrary, at higher speeds, the advantage of the channel-wing becomes very limited. Nevertheless, the combined projected areas of the channel-wing and fixed-wing components can provide sufficient lift to keep the aircraft airborne [12].

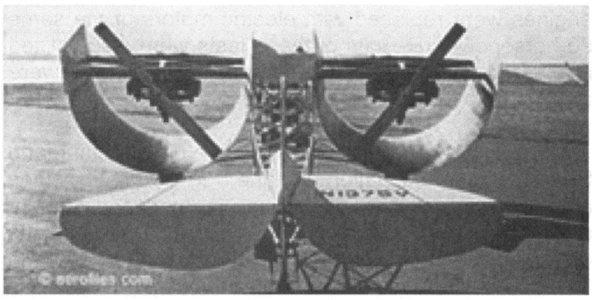


Figure 2: The CCW-2 series channel-wing aircraft [13]

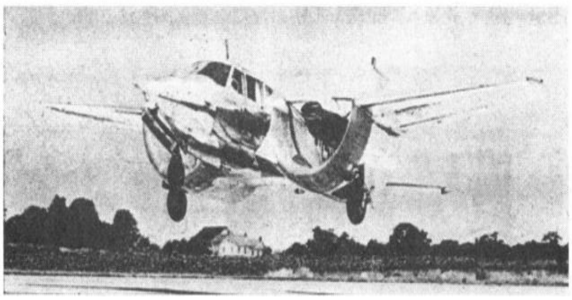


Figure 3: The CCW-5 series channel-wing aircraft [13]

In general, the channel-wing is a form of aircraft's wing that generates lift by utilizing Coanda effect and having a U-shaped wing that increases the surface area of the wing. A jet of air is forced across the curved surface of the wing to provide lift in the channel-wing [13]. The Coanda effect is also utilized in various aircraft designs such as the Coanda-1910 plane, which utilize it to generate lift and propulsion [15]. Many improvements have been tested on the channel-wing design to fully utilize both the U-shape and the aileron design, one of which is the pneumatic (blown) technology as shown in Figure 4. It can be noted that this technology has been shown to be capable to undertake various functions including high lift, drag reduction and better control, along with fitting blown components incorporated into the design to perform a range of functions that most of the time omit the use of moving parts on the outer surfaces of the aircraft [15]. At the moment, it has low blowing mass fluxes but recent research aims to lower this further. These efforts are important to produce much better effects. On the other hand, ideas such as giving pulsing blow on the pneumatic systems will help to deplete the blowing mass flow and subsequently lead to significant improvement in usable lift. In addition, it has been shown that takeoff or landing speeds and distances will significantly drop. This pneumatic solution can assist in addressing the issues of extreme STOL technology by providing an efficient and effective way of attaining high lift and control without the need of complicated and heavy mechanical systems [15].

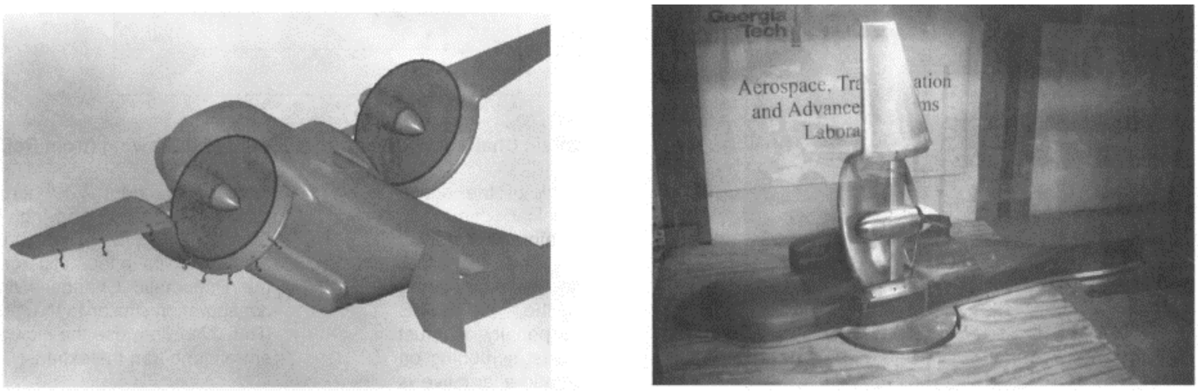


Figure 4: Conceptual pneumatic channel wing and semi-span model in GTRI [15]

In a conducted study on the channel-wing aircraft design, it has been found that despite successful demonstration of its advantages for take-off and landing performance, this aircraft design faces several challenges in meeting the certification requirements for general aviation use [13]. Furthermore, in terms of climbing and high-speed capabilities, it is also evident that the channel-wing aircraft design has lower performance in comparison to the available certified twin-engine aircraft designs in the current market. From the business perspective, the channel-wing aircraft design's modest improvement in field length performance is overshadowed by its numerous flight-related drawbacks and associated expenses. On a different note, it has been demonstrated that by angling the wing at approximately 40 degrees, it could potentially achieve vertical take-off and landing (VTOL) capabilities [15]. This has the potential to create more options for individuals or airlines dealing with limited runway lengths. It is crucial to consider the potential of channel-wing aircraft in modern context, particularly in addressing commercial and military needs like the V-22. The channel-wing aircraft might be able to offer intriguing lifting capabilities with higher cruise speeds at a lower weight/cost compared to the V-22 [16]-[17].

While the traditionally designed straight-wing aircraft have excelled in numerous aspects since their introduction, they do also come with certain trade-offs, particularly in terms of lift-to-drag ratios and stall characteristics. It is worth noting that the aircraft design and certification have a long history dating back to the early 1900s and the straight-wing concept has been the prevailing choice for the fixed-wing aircraft [18]. Considering this, there is a compelling need for more research and development efforts in the branch of channel-wing design [19]-[21]. Such endeavors have a potential to significantly contribute to the advancement of aviation technology, potentially leading to practical applications and influencing the design of future aircraft [22]-[23]. This exploration aligns with ongoing advancements in materials, propulsion and aerodynamics, offering the prospect of mitigating some of the existing limitations in aircraft design while maintaining the popularity of fixed-wing aircraft for various aviation applications.

3. Early Development of Channel-Wing

In 1925, Willard Custer was inspired to innovate the new channel-wing design after witnessing the natural phenomenon where a strong wind lifted the roof of a barn. He then realized that the high speed of the wind flow could create minimal pressure above the roof while the inner pressure stayed constant, resulting in the roof being blown off. This same theory could be applied to aircraft wings to generate lift, even when the aircraft is stationary. After conducting some research, Custer built his first U-shaped aircraft wing model in 1928, which he patented in 1929 [24]. In 1942, Custer further refined the design and created the Custer Channel-Wing 1 (CCW-1), which he flew for the first time. The CCW-2 model followed with even greater features such as the ability to perform almost vertical take-offs and leave the ground like a helicopter. Custer received positive feedback about his new wing design, particularly from military departments. In 1954, he began producing another remarkable series, known as CCW-5, which unfortunately turned out to be the last in the CCW series.

Custer's initial patent featured an aircraft with a conventional fuselage and tail, to which a channel-wing powered by the same engine and featured a variable pitch layout for forward flight performance. By placing the propellers close to the channel boundaries, the tip losses were minimized. This deliberate positioning of the propeller at the back of the wing, close to the trailing edge, was a key component of Custer's innovation, as shown in Figure 5. This unusual positioning created the suction effect over the channel, increasing lift. It was also recommended that the leading-edge propeller's blades feathered to reduce landing speed and Custer had an idea to regulate the feathering by working the engine and other controls. By exploiting the channel-wing's greater lift capability, the upwardly extending semi-cylindrical channel improved the jet aircraft's take-off and landing stability. One of the design aims was to reduce take-off and landing distance [25]. On the whole, the development of the idea of super circulation led to the successful testing of the Custer's channel-wing design [26].

Figure 5: The propeller location for CCW-5 aircraft [24]

In 1953, the work by Jerome Pasamanick became the crucial stepping stone in the evolution of the channel-wing aircraft [27]. This study provided empirical evidence on possibilities of the configuration by subjecting the Custer's channel-wing aircraft to few extensive tests in full-scale tunnels. The channel-wing design has actively changed since the 1950s and numerous significant improvements have already been achieved in the design's aerodynamics and control features over time.

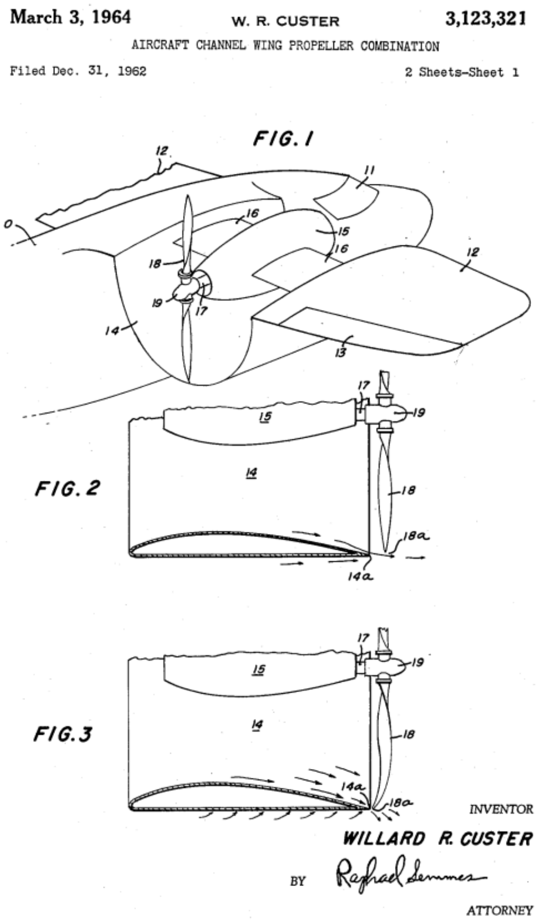
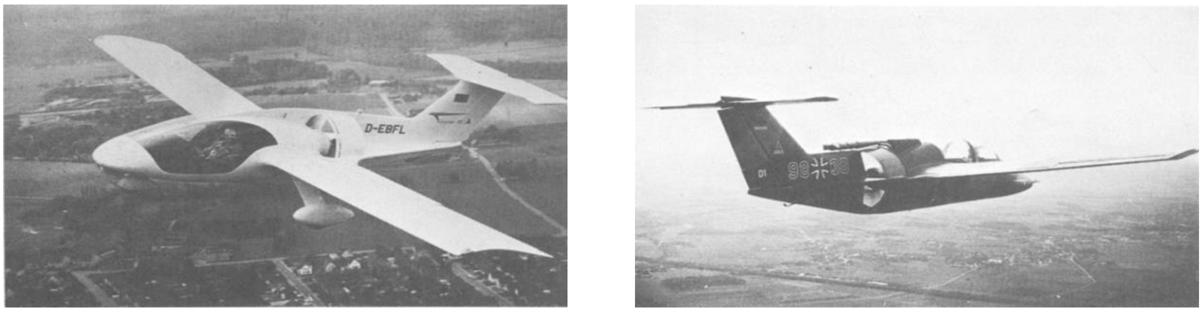


Figure 6: Willard Custer's patent (US3123321 A) that was published in 1964 [12]

Willard Custer came up with the original idea for the channel wing, which has its roots in the artistic milieu of the 1940s. The pusher system with the propeller placed at the trailing edge of the wing served as the basis for this configuration. The wing itself had peculiar half-cylindrical shape that was specifically designed to put the propeller tip near to the trailing edge. This structure became the foundation for the preliminary tests and studies that facilitated the channel-wing design to be further developed [28]-[29]. Without question, the channel wing is special experiment that pushed the limits of aviation innovation. It ventured to break from the tradition and contest the then accepted standards of aircraft design. The channel wing became a representation of bold exploration in aviation, thanks to the creative thoughts, thorough testing, and a dedication to pushing the boundaries of technology [30].

Figure 7: Original CCW-5 aircraft [31]

By utilizing the accelerated air near the propulsive device, which is often a propeller, lift force can be created even when the aircraft's forward velocity is minimal or zero. The main premise of the Custer channel wing is that lift is generated by the relative air velocity, not by the speed of the aircraft. Based on the preliminary assessment, propeller-based systems demand that the propeller be positioned near the back of the channel and have little space between the tips of the propeller and the duct. The airflow through the duct/propeller can generate lift force if the cross section of the duct has an airfoil shape with chord near to radius [31]-[32]. It is worth to note the improvements of the channel wing design made by Rhein Flugzeugbau. In less than ten years, he produced two successful powered gliders, the Sirius 1 and Sirius 2, as well as a twin-seat light aircraft, Fanliner, which made its first flight at the end of 1973 [33]. The Fanliner's success prompted the construction of its sister plane, Fantrainer, using the same concept while also testing the rotary engine's evolution, which is characterized by shifting standards brought on by the energy conservation and also the raw material considerations on 1977. The rotary engine's high power density, made possible by its kinematics and unrestricted ports, offers the advantages in size and speed. A 4-rotor, 1500 HP engine with the potential military and commercial applications is the recent development. The versatility of the rotary engine onto Fantrainer suggests further investigation in other areas [33]. Figure 8 shows both the Fanliner and Fantrainer aircraft.



(a) Fanliner aircraft design (b) Fantrainer aircraft design

Figure 8: Channel wing aircraft by Rhein Flugzeugbau [34]

Meanwhile, AN-181 was an experimental channel wing aircraft built by Antonov in the 1980s [9] [35]. However, very little is known about its handling qualities. An Open Day sponsored by Antonov OKB attracted notice in 1990 when a research aircraft with the designation "181" made an unexpected appearance, which is depicted in Figure 9. The two channel wings on the aircraft were derived based on a design by W R Custer from the mid-1950s. According to Custer's design, a 180° half-barrel aerofoil profile provided powered lift [35]. In short, the '181' was powered by a 210 hp Czech M-337A piston engine, which turned the tractor propellers above the leading edge. Its unusual tail design was intended to maintain effectiveness at low airspeeds. The aircraft's claims were deemed to be implausible in spite of its attractive design and polish. In fact, the Antonov authorities acknowledged it possibly should not have been presented [35].

Figure 9: The AN-181 aircraft [35]

All in all, the historical timeline overview for the channel wing is tabulated in Table 1.

Table 1: Timeline of channel wing development

Year	Major Development
1921	French engineer Félix du Temple patents a "compound aircraft" design, which features a central channel between two wings. While not exactly the Channel-wing, it lays the groundwork for the concept.
1930's	Aircraft designers and engineers begin exploring unconventional wing designs to improve lift, stability, and efficiency.
1940's	Willard Ray Custer conceptualizes the channel wing idea, inspired by research into the effects of wind gusts on corrugated metal surfaces.
1950's	Custer develops the pusher system with a propeller placed at the trailing edge of the wing, forming the foundation for the channel wing concept.
1952	Patent and Innovative Configuration: Custer receives his first patent for a Channel-wing with jet propulsion. Describe the aircraft's design featuring a conventional fuselage, a channel-wing, and jet propulsion. Highlight the placement of the propellers close to the channel boundaries and the concept of variable pitch for improved flight performance.
1953	Empirical Testing and Evolution: Jerome Pasamanick conducts extensive tests on the Custer Channel Wing aircraft in full-scale tunnels. Describe the purpose of the tests and how they provided empirical evidence of the configuration's possibilities.
1970's	Rhein Flugzeugbau made great progress in less than ten years, producing popular aircraft as the Sirius 1, Sirius 2 gliders (1971), and the twin-seat light aircraft Fanliner (late 1973). This achievement inspired the development of the Fantrainer (1977) as researchers explored the evolution of the Rotary Engine in response to changing energy and material standards. Rhein Flugzeugbau increased the size and speed of its engines by utilizing the Rotary Engine's power density.
1980's	The '181' research aircraft's introduction in 1990 exhibited an unconventional design founded in Custer's mid-1950s concept, although it was met with skepticism due to its unrealistic claims. Antonov's experimental AN-181 channel wing aircraft from the 1980s also aroused issues.

In a recent paper published in 2020, the channel wing aircraft is mentioned as an illustration of a cutting-edge design that was a little ahead of its time. According to the report, the channel wing concept offers a classic illustration of an idea worth exploring with modern tools and technology to determine the degree to which its STOL performance might resemble VTOL [9].

4. Performance of Channel-Wing

Over the years, several research studies have been done to analyze aerodynamic wing performance of the channel-wing aircraft in various aspects, including the coefficient of lift, coefficient of drag, lift-to-drag ratio, and also takeoff and landing efficiency [36]-[39]. These investigations are aimed to identify parameters affecting the aerodynamic performance of the channel-wing aircraft to meet current aviation demands. However, as air transportation increased over the years, the demand for commercial aircraft also increased, leading to flight delay issues [40]-[42]. Furthermore, to accommodate more capacity for conventional aircraft in terminals, airports worldwide require longer runways, creating challenges for the civil aviation industry [41]-[44]. This limitation has led aviation experts to dream of introducing a highly efficient, multipurpose, small-size aircraft that qualifies for Short Takeoff and Landing (STOL) to address these issues [32]. The STOL capability is a challenge for current conventional aircraft as they must meet specific criteria such as the duration of a runway, land and water. The performance of the channel wing is significantly influenced by where the propellers and channel wing are mounted on the airplane. The aerodynamic installation effects of the over-the-wing propeller mounting arrangements, which enhance the performance of a channel-wing aircraft, have played a significant part in the study of channel-wing design [22]. This results in a higher lift coefficient of around 5 in comparison to the traditional airplane's lift coefficient of around 2. The Custer CCW-5 is the most efficient aircraft built by Willard Custer, and it can take off and land in a very small distance at a speed of 20 mph, or even vertically if the engines are powerful enough [8]. This aircraft's outstanding STOL qualities make it well-suited for transferring payloads in tough settings lacking extensive runways, making it extremely ideal for humanitarian missions across the world [9]. The lift coefficient increases as angle of attack increases, allowing the aircraft to ascend to greater heights while maintaining a high angle of attack of more than 20° without stalling. This unique feature makes it an excellent alternative for aircraft requiring a quick takeoff or rapid ascension to obtain altitude [31][36].

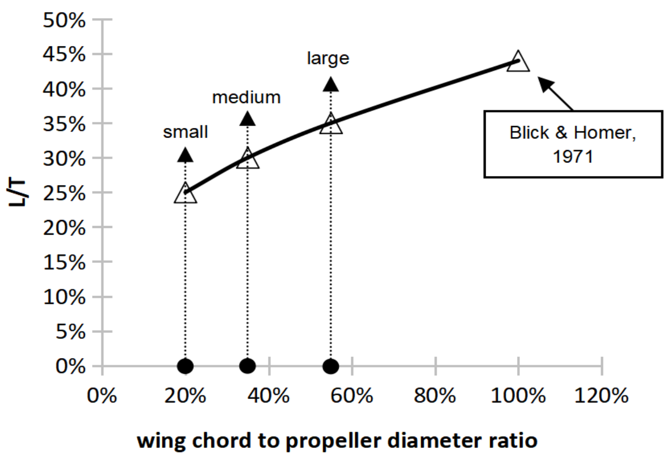


Figure 10: Relationship between lift-thrust performance and sizing of the channel-wing [22]

Previous research has explored the potential of channel-wing design to enable STOL capabilities [22], which would allow commercial or industrial complexes to have their own on-site aviation services while minimizing speed and range limitations. A study at Georgia Tech Research Institute (GTRI), the channel-wing has the potential to generate lift force even at a standstill and has a wider range of angle of attack before stalling (approximately -40˚ to +40˚). The lift generated by the channel-wing could be twice that of a conventional wing and could even allow for zero ground roll take-off [8]. Furthermore, following another study at the University of Southampton on a small-unmanned fixed-wing aircraft to evaluate the superior slow-flight performance of the channel-wing design compared to a conventional wing-propeller configuration [45]. The study revealed that STOL capabilities could reduce cruise speed by up to 9%. Additionally, the coupling effects of a distributed multi-propeller channel wing at low-speed conditions have also been studied as illustrated in Figure 11 [10]. To integrate the propellers with the wing, the computational technique used RANS equations and the Momentum Source Method. The study's findings demonstrated that the airfoil shape has a considerable impact on the lift of the channel wing during the Short/Vertical Takeoff and Landing (S/VTOL) stage. Furthermore, the study of the multi-propeller channel wing revealed the critical function of rotational direction in the interaction of outer propellers, with outboard-up rotation increasing lift in the outer channel. Different distortion and dissipation behaviors were identified in the wake of the propellers, which were significantly impacted by the presence of nearby propellers. On the other hand, a study at Beijing University of Aeronautics and Astronautics investigated the use of a fuel-saving double channel-wing (FADCW) arrangement in a propeller-driven aircraft to reduce the fuel consumption, as shown in Figure 12 [46]. The study proved that the design improves the wing's aerodynamic performance by leveraging the suction effect upstream of the propeller and the slipstream acceleration downstream of the propeller. It achieved a stunning over 10% increase in lift-to-drag ratio and a significant more than 20% reduction in fuel consumption when compared to the typical TPC design by integrating the propeller. The findings further validate the feasibility of the proposed design idea, emphasizing its capacity to minimize the fuel consumption in propeller-driven aircraft, which has the potential to achieve more range or longer loiter time.

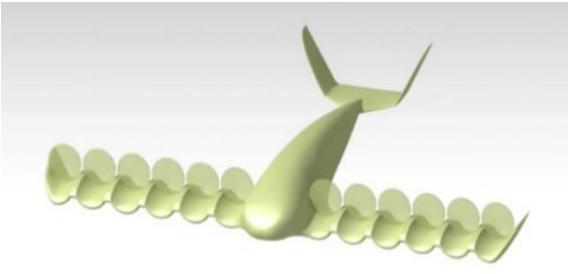


Figure 11: A model of the multi-propeller channel wing UAV [10]

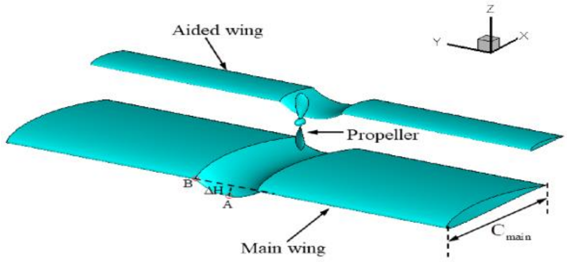
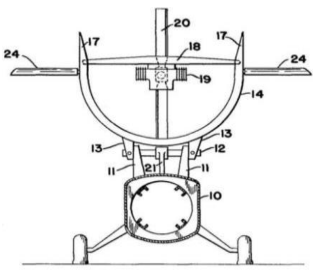


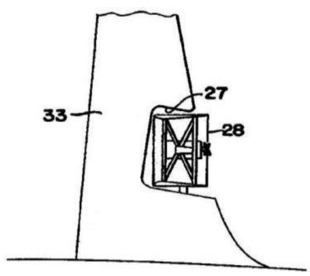
Figure 12: Fuel saving double channel wing configuration [46]

5. Available Patents of Channel-Wing Design

The filed patent of Taylor in 1954, displayed in Figures 13, was the first to feature a channel-wing design from someone other than Willard Custer. This patent combines the channel-wing idea with a movable mechanism that can alter the lift/thrust vectors and the aircraft's orientation. In short, the design consists of an aircraft with the semi-conventional fuselage situated and a channel on top and ailerons on either side. The propeller mount can be moved up, down, left, and right, allowing it to rotate in two dimensions. The aircraft primarily relies on the channel for lift, except for minor contributions from the fuselage's front area and the ailerons. To maintain stability, precise positioning of the aircraft's center of gravity is necessary. Meanwhile, Figures 14 shows the Fletcher's 1954 patent, which is a typical fuselage together with two wings that have four tilting channels placed at the ends of each wing. This patent successfully combines ideas from Custer and Taylor. A turboprop engine is housed within these channels. While hovering, climbing vertically or descending, the channels are modified to balance the lateral components of the lift and thrust vectors, producing an upward push. The channels tilt forward gradually as the airplane moves into forward flight and the aircraft's angle of attack is nearly zero. During these maneuvers, drag must also be considered.

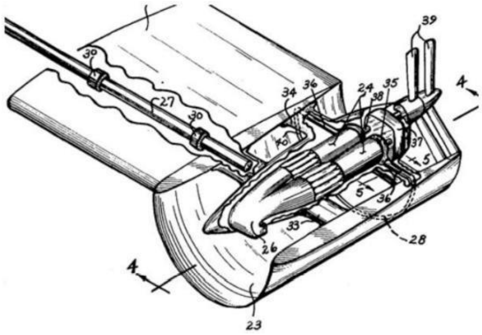


(a) Top mounted channel layout

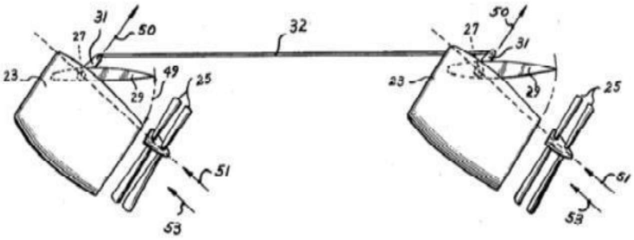


(b) Notched-channel design

Figure 13: Taylor's channel wing aircraft design patent [11]



(a) BLR layout



(b) Tilting channel configuration

Figure 14: Fletcher's channel wing aircraft design patent [11]

Moreover, Shew's invention as shown in Figure 15, was created in 1960. It includes two channels with a flying wing-like surface. The side plates that run through the entire length of the airplane and are fastened on both sides of the fuselage support the channels, which are located near to the front of the fuselage. The flaps and air brakes are two of the control surfaces included in this design. In addition, the bottom of the wing has additional vents that route the air in a way that promotes high lift. The high-speed airflow across the wing is controlled by these plates.

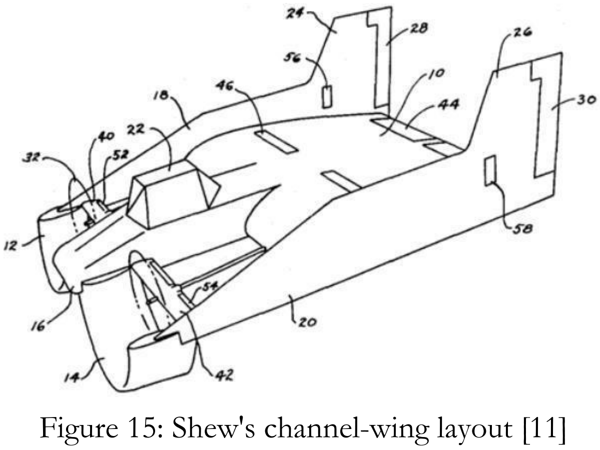


Figure 15: Shew's channel-wing layout [11]

In the meantime, the main goal of the current invention in Figure 16 is to create improved STOL aircraft that is able to land with or without power at relatively low speeds on unimproved, small airstrips while traveling at high speeds. This invention attempts to show that the wing arrangement in this design is suitable for a re-entry vehicle by folding the wings into an extended staggered stance and removing 90% of the drag. With less power, this idea also intends to increase speed variance from a very slow to a supersonic speed. Another objective of this construction is to make it as a vertical takeoff aircraft due to the design of its fuselage and wings. By using a double set of wings to create extremely large fuselage for increased load carrying capacity while maintaining the original design's gliding performance, this invention also aims to show that this wing layout is adaptable to a transport or cargo type aircraft [47].

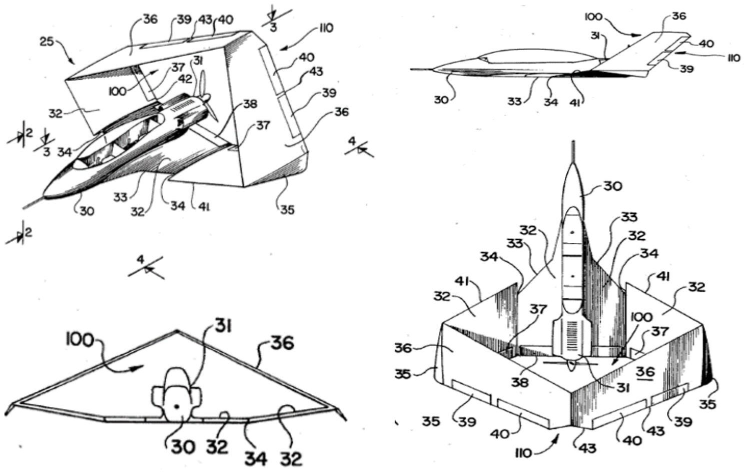


Figure 16: Patents on staggered channel wing-type aircraft [47]

Another current invention is illustrated in Figure 17, which is a pneumatic (blown) powered-lift aircraft is provided with significant increase in propulsive and aerodynamic forces. This permits flight control at these very low speeds, which is typically a considerable difficulty for Super STOL or VTOL aircraft, as well as the possibility for very low flight speeds and very short takeoff and landing distances. The significant improvement in flying safety is also the outcome of this better controllability and short response times. Furthermore, without using any moving parts, it is feasible to switch between thrust (needed for takeoff and ascent) and drag (needed for STOL approach). Because of its super STOL or VTOL characteristics, this aircraft can use short runways or landing pads. The propeller's position in this aircraft, located ahead of the channel's trailing edge and behind its leading edge, not only virtually eliminates ground-based noise perception but provides passengers with virtually complete protection against propeller contact. Unlike the typical Channel Wing aircraft with a sharp trailing edge, the blown channel CCW incorporates a channel characterized by rounded or nearly rounded trailing edge. This channel is equipped with a trailing-edge slot positioned adjacent to its rounded trailing edge. This slot is designed to allow the tangential discharge of the pressurized air over the rounded trailing edge and is connected to an intake linked to a source of pressurized air. The resultant jet effectively entrains the surrounding flow field and maintains the attachment to the rounded trailing edge, all thanks to the well-established Coanda effect [48].

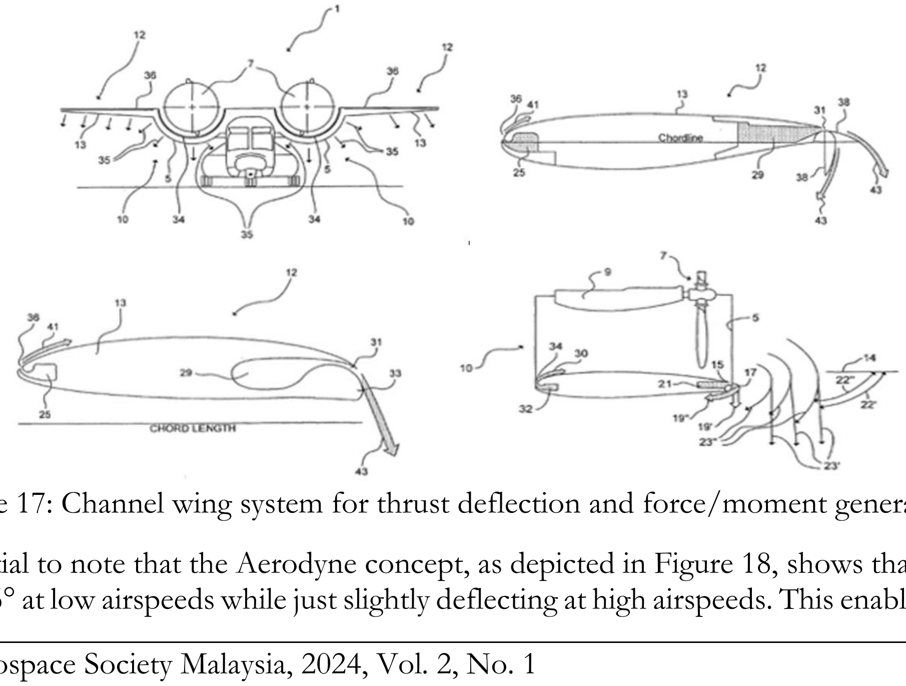


Figure 17: Channel wing system for thrust deflection and force/moment generation [48]

It is essential to note that the Aerodyne concept, as depicted in Figure 18, shows that the flow can deflect up to 26° at low airspeeds while just slightly deflecting at high airspeeds. This enables the channel wing to attain dependence on airspeed natural thrust vectoring capability. The propeller's location inside the wing channel and the fact that the effective exhaust blowing coefficient is larger at lower freestream velocities are the causes of this. A single channel has been used to successfully overcome the weaknesses relating to asymmetric lift during low-speed operations, an area where most channel wing flying tests ran into problems. It's important to note that Custer frequently used many channels while implementing the channel wing. Additionally, a single duct architecture adheres to the restrictions imposed by span limitations while offering the least amount of disc stress and the most ducted propeller area [49].

Figure 18: Lippisch Aerodyne concept in 1960s [49]

Figure 19 shows a patent that focuses on power that matches during takeoff and cruising between 125-150 mph on the same time maintaining the engine capacity not more than 100 hp. Leaning on the chances of blowing and trimming, this design of propulsion and aerodynamic combined make way of the possibility of utilizing maximum takeoff distance of 250 ft without supporting lift system actuating parts with maximum lift coefficient ranging from 6 up until 10. What prompted this ducted propeller idea was the effect it would make on propulsion system, which projected to cut down on its disc-loading and thus putting pressure on increasing the low-speed thrust, favorable for its safety appeals. A specific requirement on takeoff and landing field lengths, this patent should be able to manage the gust control reaching down to 30 mph on its rolling motion control during low-speed resulting to active blowing or oversizing the control surfaces. Though as promising as it might seem, this patents still have a lot of improvements that when implied to, may produce a better overall maneuverability. To move forward with the design, implementation of movable outer wing panel seems the most straightforward solution in managing the roll control of this aircraft and control surfaces in the propeller flow to cater its yaw and pitch control [49]-[50].

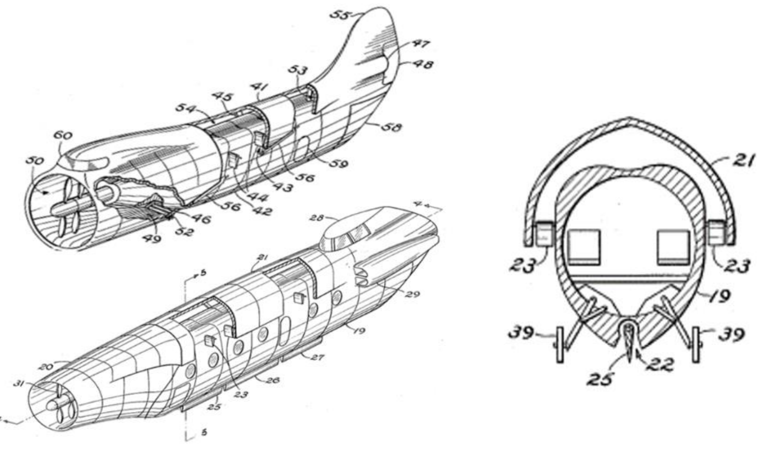


Figure 19 Patents on Aerodyne with External flow [50]

6. Conclusion

This paper provides an overview of the channel-wing design possibilities for STOL aircraft. This includes discussion of channel-wing design concept, a brief review of its early development, highlighting current research, assessing performance, patents, discussing limitations and bringing the prospect of the channel-wing for VTOL/STOL application. The concepts that surround the channel wing aircraft are the Coanda effect and U-shaped design of it, which were developed from avant-garde ideas in the middle of the 20th century, offering novel method of lift creation. Despite having difficulties compared to conventional aircraft designs, recent developments in pneumatic technology and modern equipment provide renewed promise. A convincing solution for STOL applications and potential solutions for the operational niches could result from reassessing its capabilities using contemporary methodologies. The channel-wing design has potential as aviation develops because of its distinct lift-enhancing principles and versatility in a range of flight scenarios. The development of channel wing demonstrates creative approaches to problems in aviation. Though there are several advantages, capabilities of the design do pose some challenges. This comprises an increase in drag owing to the profile shape and wetted surface area of the wing, as well as slight decrease in thrust due to pressure changes downstream of the propeller blade, which deflect the thrust force vector downward. Also, if one engine fails during flight, it causes an unbalanced lift force on the wing, making it more challenging to maintain stable flight. Despite that, it is still undeniable that its aerodynamic properties have been well-suited for the possibility of STOL applications. Its adaptability and efficiency improvements are also highlighted by notable studies like the multi-propeller channel wing and fuel-saving double channel wing configurations. With their ability to accommodate limited locations, humanitarian missions and better fuel efficiency, its developments' potential to reinvent aviation conventions has been positive once its design deficiencies are successfully addressed.

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References

[1] D. Y. Suh and M. S. Ryerson, 'Forecast to Grow: Aviation Demand Forecasting in an Era of Demand Uncertainty and Optimism Bias', Transportation Research Part E: Logistics and Transportation Review, vol. 128, pp. 400-416, 2019.

[2] D. Hanson, T. T. Delibasi, M. Gatti and S. Cohen, 'How Do Changes in Economic Activity Affect Air Passenger Traffic? The Use of State-Dependent Income Elasticities to Improve Aviation Forecasts', Journal of Air Transport Management, vol. 98, 102147, 2022.

[3] A. Menichino, V. Di Vito, B. Dziugiel, A. Liberacki, H. Hesselink and M. Giannuzzi, 'Urban Air Mobility Perspectives Over Mid-Term Time Horizon: Main Enabling Technologies Readiness Review', Presented at the Integrated Communication, Navigation and Surveillance Conference, Dulles, USA, April 2022.

[4] A. Abdelghany and V. S. Guzhva, 'Exploratory Analysis of Air Travel Demand Stimulation in First-Time Served Markets', Journal of Air Transport Management, vol. 98, 102162, 2022.

[5] Y. Y. Tee and Z. W. Zhong, 'Modelling and Simulation Studies of the Runway Capacity of Changi Airport', The Aeronautical Journal, vol. 122, no. 1253, pp. 1022-1037, 2018.

[6] J. H. Diekmann, 'Flight Mechanical Challenges of STOL Aircraft using Active High Lift', Journal of Aircraft, vol. 56, no. 5, pp. 1753-1764, 2019.

[7] G. R. Seyfang, 'Recent Developments of the Fan-Wing Aircraft', Presented at the International Conference of the European Aerospace Societies, Venice, Italy, October 2011.

[8] R. Englar and B. Campbell, 'Development of Pneumatic Channel Wing Powered-Lift Advanced SuperSTOL Aircraft', Presented at AIAA Applied Aerodynamics Conference, St. Louis, USA, June 2002.
[9] D. M. Bushnell and I. Wygnanski, 'Flow Control Applications', Technical Report (L-21092), National Aeronautics and Space Administration, Washington DC, USA, 2020.
[10] J. Zhao, Z. Fan, M. Chang and G. Wang, 'Coupling Effects on Distributed Multi-Propeller Channel Wing at Low Speed Condition', Energies, vol. 15, no. 15, 5352, 2022.
[11] Z. O. Gokce and C. Camci, 'Channel Wing as a Potential VTOL/STOL Aero-Vehicle Concept', Recent Patents on Mechanical Engineering, vol. 3, no. 1, pp. 18-31, 2010.
[12] W. R Custer, Aircraft Channel Wing Propeller Combination, US Patent (US3123321A), 1964.
[13] H. R. Clements, 'The Channel Wing Revisited', Journal of Aerospace, vol. 115, pp. 550-562, 2006.
[14] C. Gunther, J. Marchman and R. VanBlarcom, 'Comparison of Channel Wing Theoretical and Experimental Performance', Presented at the Aerospace Sciences Meeting and Exhibit, Reno, USA, January 2000.
[15] R. J. Englar and B. A. Campbell, 'Experimental Development and Evaluation of Pneumatic Powered-Lift Super-STOL Aircraft', Presented at NASA/ONR Circulation Control Workshop, Hampton, USA, March 2004.
[16] D. M. Bushnell, Fluid Mechanics, Drag Reduction and Advanced Configuration Aeronautics, National Aeronautics and Space Administration, 2000.
[17] D. Bushnell, 'Frontiers of the 'Responsible Imaginable' in (Civilian) Aeronautics', Presented at the Aerospace Sciences Meeting and Exhibit, Reno, USA, January 1998.
[18] M. H. Sadraey, Aircraft Design: A Systems Engineering Approach, John Wiley & Sons, 2012.
[19] C. Y. Justin and D. N. Mavris, 'Environment Impact on Feasibility of Sub-Urban Air Mobility using STOL Vehicles', Presented at the AIAA Scitech Forum, San Diego, USA, January 2019.
[20] C. Courtin, M. J. Burton, A. Yu, P. Butler, P. D. Vascik and R. J. Hansman, 'Feasibility Study of Short Takeoff and Landing Urban Air Mobility Vehicles using Geometric Programming', Presented at the Aviation Technology, Integration and Operations Conference, Atlanta, USA, June 2018.
[21] W. Sellers, B. Singer and L. Leavitt, 'Aerodynamics for Revolutionary Air Vehicles', Presented at the AIAA Applied Aerodynamics Conference, Orlando, USA, June 2003.
[22] M. A. M. Shafie, M. F. Abdul Hamid and A. S. Mohd Rafie, 'Circulation Control Aircraft Design: Assessment on the Channel-Wing Lift-Thrust Performance Characteristics', Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 64, no. 1, pp. 143-151, 2019.
[23] J. Sivapalan, A. S. Mohd Rafie, A. R. A. Talib, E. Gires, A. A. Basri, F. I. Romli, A. S. M. Harithuddin, S. A. Sobri and M. F. A. Hamid, 'The Aerodynamic Lift Performance Analysis of Channel-Wing Design for STOL Aircraft', Journal of Aeronautics Astronautics and Aviation, vol. 55, pp. 415-423, 2023.
[24] W. R. Custer, Aeroplane, US Patent (1,708), 1929.
[25] M. Zilberman, 'Custer Channel Wing (CCW) Phase III', Presented at the AIAA Scitech Forum, Online, January 2021.
[26] V. Stanciu and V. Dragan, 'An Analytical and Numerical Study of the Custer Channel Wing Configuration', International Journal of Advanced Scientific and Technical Research, vol. 4, pp. 1-8, 2012.
[27] J. Pasamanick, Langley Full-Scale-Tunnel Tests of the Custer Channel Wing Airplane, National Advisory Committee for Aeronautics, 1953.
[28] N. Intaratep, 'The Investigation of an Inboard-Winglet Application to a Roadable Aircraft', PhD Thesis, Virginia Tech, USA, 2002.
[29] R. Gimbert, A. Clos and S. Baty-Ferry, 'Channel Wing Airplane', Presented at TMAL02 Expert Conference, Linköping, Sweden, October 2017.

[30] R. H. Lange, 'Review of Unconventional Aircraft Design Concepts', Journal of Aircraft, vol. 25, no. 5, pp. 385-392, 1988.
[31] P. M. Keane and A. J. Keane, 'Use of Custer Channel Wings – Wing Ducts on Small UAVs', Journal of Aerospace Engineering, vol. 29, no. 3, 04015059, 2016.
[32] M. Chang, Z. Zheng, X. Meng, J. Bai and B. Wang, 'Aerodynamic Analysis of a Low-Speed Tandem-Channel Wing for eVTOL Aircraft Considering Propeller-Wing Interaction', Energies, vol. 15, no. 22, 2022.
[33] E. A. Willis, 'General Aviation Energy-Conservation Research Programs', Presented at Rotary Combustion Engine – Candidate for General Aviation Symposium, Cleveland, USA, February 1978.
[34] R. Staufenbiel, A. Kellner and G. Neuwerth, Dependence of Noise Generation by Rotors on Defined Disturbances in the Inflow, Springer-Verlag, 1979.
[35] E. Gordon and B. Gunston, Soviet X-Planes, Midland Pub, 2000.
[36] E. F. Blick and V. Homer, 'Power-on Channel Wing Aerodynamics', Journal of Aircraft, vol. 8, no. 4, pp. 234-238, 1971.
[37] L. Müller, D. Kozulovic, M. Hepperle and R. Radespiel, 'The Influence of the Propeller Position on the Aerodynamics of a Channel Wing', AIAA Journal, vol. 38, no. 5, pp. 784-792, 2012.
[38] M. Xiaoxuan, X. Ziyi, M. Chang and B. Junqiang, 'Performance Analysis and Flow Mechanism of Channel Wing Considering Propeller Slipstream', Chinese Journal of Aeronautics, vol. 36, no. 11, pp. 165-184, 2023.
[39] R. Nangia and M. Palmer, 'Channel and Arc Wing Aerodynamics with Propeller Effects for STOL Application', Presented at the 39th Aerospace Sciences Meeting and Exhibit, Reno, UA, January 2001.
[40] E. B. Peterson, K. Neels, N. Barczi and T. Graham, 'The Economic Cost of Airline Flight Delay', Journal of Transport Economics and Policy, vol. 47, no. 1, pp. 107-121, 2013.
[41] B. F. Santos, M. M. Wormer, T. A. Achola and R. Curran, 'Airline Delay Management Problem with Airport Capacity Constraints and Priority Decisions', Journal of Air Transport Management, vol. 63, pp. 34-44, 2017.
[42] S. S. Cavusoglu and R. Macário, 'Minimum Delay or Maximum Efficiency? Rising Productivity of Available Capacity at Airports: Review of Current Practice and Future Needs', Journal of Air Transport Management, vol. 90, 101947, 2021.
[43] J. F. O'Connell, 'The Global Airline Industry', in The Routledge Companion to Air Transport Management, Routledge, 2018.
[44] P. Belobaba, A. Odoni and C. Barnhart, The Global Airline Industry, John Wiley & Sons, 2015.
[45] J. Mihalik and A. J. Keane, 'Custer Channel Wings for Short Takeoff and Landing of Unmanned Aircraft', Journal of Aircraft, vol. 59, no. 1, pp. 196-205, 2022.
[46] H. Wang, W. Gan and D. Li, 'An Investigation of the Aerodynamic Performance for a Fuel Saving Double Channel Wing Configuration', Energies, vol. 12, no. 20, 3911, 2019.
[47] A. Ratony, Staggered Channel Wing-Type Aircraft, US Patent (US4053125A), 1976.
[48] R. Engler and D. Bushnell, Channel-Wing System for Thrust Deflection and Force/Moment Generation, US Patent (US20050029396A1), 2006.
[49] M. Moore, '21st Century Personal Air Vehicle Research', Presented at AIAA International Air and Space Symposium and Exposition: The Next 100 Years, Dayton, USA, July 2003.
[50] A. M. Lippisch, Aerodyne with External Flow, US Patent (US2918233A), 1959.