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Aerodynamic Analysis of Conventional and Non-Traditional Paper Aircraft: Wind Tunnel and Flight Analysis

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AUTHOR BIOGRAPHY

Yifan Wang is a Grade 11 student at St. Robert Catholic High School in Toronto, Canada. Their interests include aerodynamics, aerospace engineering, and the application of machine learning in aerospace. Yifan has built a functional RC aircraft from scratch and founded a non-profit organization focused on using aircraft modification to teach aerodynamic principles, which inspired this work.

ABSTRACT

This paper examines the impact of non-traditional paper aircraft geometries on aerodynamic performance through wind tunnel testing and controlled flight trials. Three models were tested - the Dart, the F-117 Nighthawk-inspired jet, and the Maple Seed-inspired biomimetic flyer. Five metrics were evaluated for wind tunnel testing: Laminar Flow Quality, Flow Symmetry, Separation Control, Vortex Stability and Wake Coherence. For flight trials, four metrics were evaluated: Straightness of Flight, Stability, Autorotation, and Glide Smoothness. The key findings of this paper included the dart, as the control, being the most efficient due to low drag and pronounced laminar flow, while the unmodified F-117 faced severe flow separation and vortex instability. On the other hand, the Modified F-117 had the tailfin repositioned aft, which in turn improved stability and control. Finally, the Maple Seed had extremely stable autorotation, but low speed and efficiency, in turn causing no linear movement. The aerodynamic geometry of these non-conventional flyers governs airflow, stability and efficiency, while small modifications can yield major improvements, balancing the basics of engineering efficiency with inspiration from nature.

***Keywords**: Paper aircraft, aerodynamics, flight stability, glide performance, autorotation, wind tunnel testing, biomimetic design, aircraft geometry, lift and drag, experimental aviation, paper airplane engineering, aerodynamic optimization*

INTRODUCTION

Paper aircraft experiments only focus on traditional and simple shapes, such as basic darts and gliders. While these designs are well-studied, few studies explore complex aerodynamic inspirations such as advanced experimental aircraft and biomimetic flyers. Previous work (Su, 2024) has primarily evaluated basic flight distance and stability, with little attention given to nontraditional geometries or to studies that combine engineered and natural flight inspirations in a single analysis. There is a gap in understanding how non-traditional wing shapes and body structures affect aerodynamic behaviour. Filling this gap is important due to the influential nature of unconventional flight structures, such as those found in military jets and flyers like bats, which can inform the next generation of high-performance and low-energy aircraft. The economy has a growing demand for efficient and maneuverable air systems; understanding the aerodynamic strengths of non-traditional designs is highly relevant. By comparing Skunk Works aircraft with biomimetic structures evolved over centuries for their stability, lift efficiency, and low-speed control, this project generates insights with potential implications for the development of future aviation technology.

Unlike prior studies, this research integrates radical engineered geometries with evolved natural forms, utilizing both flight trials and wind tunnel testing to comprehensively analyze aerodynamic behaviour. Applications of said technology include unmanned aerial vehicles and drone optimization, stability, and energy efficiency, as well as advanced aerospace prototypes such as forward-swept wings and hybrid bodies. Bioinspired engineering is especially crucial for the future of autonomous flight with regard to dirty air, jetstreams, and turbulence. This paper contributes to a better understanding of how nonstandard geometries behave under airflow through model testing and physical experimentation. It also offers data that could influence future design strategies in aeronautics, robotics, and national defence.

This study focuses on three specific paper aircraft models: an F-117 Nighthawk-inspired Skunk Works jet, a classic dart as a control, and a maple seed-inspired biomimetic flyer. Each model was designed to highlight unique aerodynamic principles, such as airflow interaction, lift, drag, and autorotation tendencies, which will be qualitatively analyzed through both flight trials and wind tunnel tests. The project was conducted under the mentorship of Dr. Rijan Maharjan, who provided access to a home-made wind tunnel, facilitated flow visualization, and contributed valuable guidance and resources throughout the experimental process. His support was pivotal in enabling the detailed aerodynamic observations and studies presented in this paper. The primary research goal is to investigate how these different structural designs affect glide distance, airtime, and flight stability, providing insight into which design features contribute most effectively to aerodynamic performance.

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LITERATURE REVIEW

Prior research on paper aircraft has primarily examined straightforward, conventional designs, such as darts and basic gliders, focusing on variables like glide distance and stability (Su, 2024; Ismail et al., 2021). Wing geometry work, such as aspect ratio, camber, and sweep, has demonstrated a substantial impact on lift, drag, and glide efficiency, laying the groundwork for aircraft performance modifications (Jin, 2024; Liang, 2024; Li, 2023) According to research on biomimetic flyers, such as maple seeds and wings modeled after ants, autorotation, flexible structures, and passive aerodynamic control are beneficial for maneuverability and stability (Ortega-Jimenez et al., 2019; Wang et al., 2024; Withers, 1981). Design decisions for unconventional geometries are influenced by research on experimental jets and forward-swept wings, which highlights the trade-offs between low-speed stability and high-speed efficiency (Frei & Moore, 1985; Xue & Khawaja, 2014). These results collectively highlight the lack of research that integrates natural and engineered inspirations in a single comparative analysis, which inspired the current study to investigate the aerodynamic behaviour of both conventional and non-traditional paper aircraft.

METHODOLOGY

Materials

Three models were folded for this study:

1. Dart (Control) - Standard A4 printer paper (210 x 297 mm) folded into a classic dart design. This model served as the baseline for comparison. q.v. ref.
2. F-117 Nighthawk-Inspired Model - Standard A4 printer paper folded to mimic the angular, faceted design of the F-117 stealth aircraft. Folding instructions were adapted from Amazing Paper Airplanes. q.v. ref.
3. Maple Seed-Inspired Model - Standard A4 printer paper folded to emulate the autorotating flight of a maple seed. Folding instructions were based on YouTube tutorials ([Maple Seed Helicopter Tutorial], 2023). q.v. ref.

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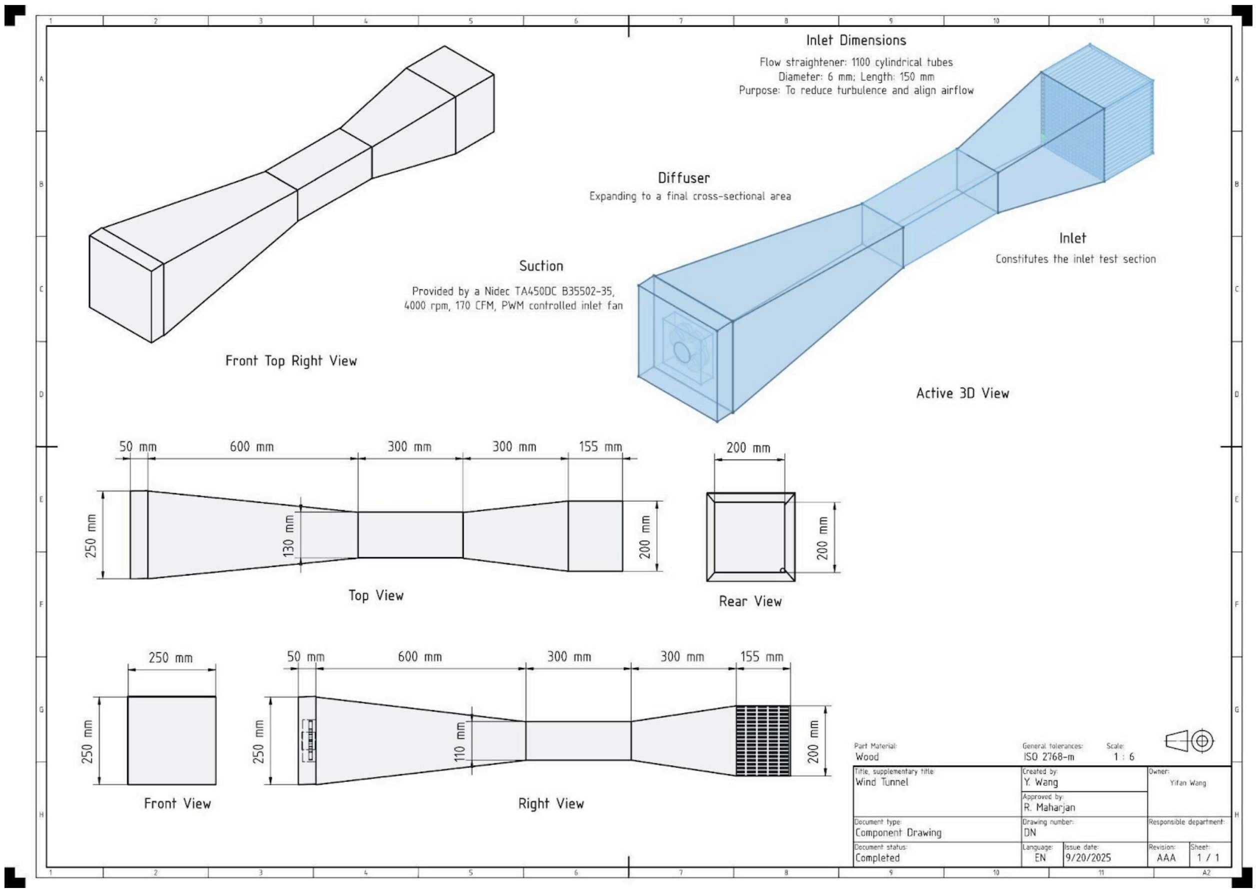

Detailed Blueprint of Wind Tunnel, 1:6 Scale

Wind Tunnel

- Custom-Built Wind Tunnel:
    - Inlet: 200 mm × 200 mm with 1100 cylindrical tubes (6 mm diameter, 150 mm length) to straighten airflow
    - Test Section: 110 mm × 130 mm, 300 mm long
    - Diffuser: 600 mm long, final area 250 mm × 250 mm
    - Suction: Nidec TA450DC B35502-35 fan, 4000 rpm, 170 CFM, PWM controlled
- Measurement Tools:
    - Tape measure for horizontal glide distance
    - Stopwatch for airtime measurement
    - Smoke generator for visualizing airflow in the wind tunnel

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- Camera for documentation of airflow patterns and flight paths

Experimental Approach

This study employed a two-pronged experimental approach to analyze the aerodynamic behaviour of paper aircraft: qualitative wind tunnel observation and flight trials. Three paper aircraft models were tested: an F-117 Nighthawk-inspired Skunk Works jet, a classic dart (control), and a maple-seed-inspired biomimetic flyer. To guarantee uniformity across trials, each model was built using standard A4 paper with the same measurements and folding techniques. To reduce the impact of outside variables like wind and temperature, all experiments were carried out indoors.

Predicted Results

Based on the geometry and aerodynamic principles, this chart of predicted results has been created.

Table 1
Predicted Results of Each Paper Airplane

	Wind Tunnel Experiment	Flight Test
Basic Dart	• Very smooth laminar flow along the pointed nose • Very streamlined, minimal lift • Minimal drag due to narrow profile	• Longest horizontal distance • High directional stability, flies straight • Sharp, straight glide • Descends at a constant rate, no nose-diving
F117 Nighthawk	• Mostly smooth laminar flow over flat surfaces, but some small vortices at the sharp edges • Minimal lift, mostly gliding stability • Moderate drag due to flat, wide surface	• Relatively far distance, should glide straight if thrown properly • Nose-heavy design may cause a sharp descent • Fairly stable in pitch, but may roll slightly • Sharp drop at the end
Maple Seed	• Lots of asymmetric drag, due to its rotational nature • Spiral airflow pattern behind the	• Very short horizontal travel, mainly vertical descent • Very little lift

	figure ● Creates a stable vortex	● Very efficient at cutting through air, with minimal drag ● High directional stability

Materials and Equipment

The paper aircraft were folded from standard A4 printed paper. A small, enclosed lab wind tunnel provided by Dr. Rijan Maharjan was used for airflow observation. The airflow was set to a steady speed of 1.5m/s, which was selected because it provided a clear and observable flow visualization while keeping the Reynolds number in a low-to-moderate range suitable for small-scale paper models. Flight trials were conducted indoors, using a cased measuring tape for glide distance and a stopwatch for airtime. Observations were documented through typed notes and sketches to capture qualitative airflow and flight characteristics.

Wind Tunnel Testing

All aircraft models were clipped in a fixed orientation using a screw at the base of the wind tunnel. Observations focused on characterizing aerodynamic phenomena, including laminar and turbulent flow regions, boundary layer behaviour, flow separation, vortex formation and shedding, recirculation zones, and wake development behind the said models. The interaction between model geometry and airflow was carefully examined. Each trial was conducted for 4-5 minutes to allow the airflow to stabilize around the model and to provide sufficient time for smoke visualization, ensuring consistent and repeatable observations. Streamline visualization and pressure gradient effects were also noted to assess the coherence and symmetry of the airflow around each model.

Flight Trials

Flight trials were conducted under controlled conditions. Each aircraft was released from the same height by hand, at a 45-degree angle. Key measurements included glide distance, airtime, and rotational behaviour. Each plane was flown three times, and the results were averaged to allow comparison between models. Qualitative observations of flight path, tilting, and wobbling were also recorded.

Quantitative Data

To add quantitative data, a scoring system was employed to evaluate qualitative aspects of flight and aerodynamics, as seen in the tables below.

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Table 2
How to Quantify Data for Wind Tunnel Testing

Criterion	Score Range	Notes
Laminar Flow (LFQ)	1-10	Indicates the smoothness of airflow along the aircraft's surfaces. A score of 1 corresponds to highly turbulent, disrupted flow, while 10 represents fully smooth, attached laminar flow.
Flow Symmetry (SYM)	1-10	Evaluates whether airflow behaves similarly on both sides of the aircraft. A score of 1 indicates highly asymmetric flow, and 10 indicates nearly identical, symmetrical flow patterns.
Vortex Stability (VXS)	1-10	Measures the consistency and control of vortices generated behind the aircraft. A score of 1 corresponds to chaotic, unstable vortices, while 10 indicates minimal or highly stable vortex formation.
Separation Control (SEP)	1-10	Reflects the aircraft's ability to maintain attached airflow. A score of 1 denotes extensive flow separation, while 10 represents minimal separation and a stable boundary layer.
Wake Coherence (WKC)	1-10	Describes the structure and predictability of the airflow downstream of the aircraft. A score of 1 indicates a turbulent, disorganized wake, while 10 indicates a narrow, structured, and coherent wake.

Table 3
How to Quantify Data for Flight Testing

Criterion	Score Range	Notes
Straightness of flight (SOF)	1-10	Assesses the linearity of the flight path. A score of 1 indicates a highly curved or erratic trajectory, while 10 represents a perfectly straight glide.

Stability (STA)	1-10	Evaluates how steady the aircraft remains during flight. A score of 1 corresponds to wobbly or uncontrolled motion, while 10 indicates a smooth, stable flight.
Autorotation (ATR)	1-10	Measures the aircraft's ability to spin or rotate consistently during descent. A score of 1 indicates no rotation, while 10 reflects consistent, controlled autorotation.
Glide Smoothness (GS)	1-10	Reflects the evenness of the aircraft's movement through the air. A score of 1 indicates jerky, uneven motion, while 10 represents a smooth, fluid glide.

Controlled Variables

Paper type and dimensions, folding procedure and construction consistency, Wind tunnel airflow speed (1.5m/s), aircraft mounting orientation in the tunnel, release height and method for flight trials, and number of trials per model were all controlled.

Data Recording and Analysis

Quantitative data were recorded using a cased measuring tape for distance and a stopwatch for airtime. Averages were calculated for each aircraft type. Qualitative observations were documented through typed notes to capture airflow interactions, flight path shapes, and stability characteristics.

Justification of Method

This approach offers a thorough evaluation of non-traditional paper aircraft's aerodynamic performance. While flight trials offer useful insight into how geometry affects glide and autorotation, wind tunnel observations enable direct analysis of airflow interactions. When combined, these techniques capture both the theoretical and practical aspects of aerodynamics, producing insights that are pertinent to the design of bioinspired and engineered aircraft.

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RESULTS

Wind Tunnel Testing Results

Wind tunnel observations revealed distinct aerodynamic behaviours across the three tested paper aircraft models, demonstrating how geometry strongly influences airflow interaction. Flow visualization was achieved through smoke tracing at a constant freestream velocity of 1.5m/s, enabling the identification of laminar flow regions, separation zones, vortex formation, and wake development.

To summarize the aerodynamic performance across metrics, a Composite Wind-Tunnel Score (CWT) was computed for each model.

These anchors were selected because together they capture the two defining aspects of aerodynamic performance: efficiency and stability. Laminar Flow Quality and Separation Control evaluate how effectively a design manages drag and lift through smooth airflow retention, while Flow Symmetry and Vortex Stability indicate balance and steadiness in flight. Wake Coherence provides the final measure of overall energy efficiency by assessing the stability of the aircraft's trailing flow. Collectively, these anchors offer a comprehensive framework for comparing aerodynamic behaviours across models.

Table 4
Results of Wind Tunnel Testing

Model	LFQ	SYM	SEP	VXS	WKC	**CWT Score**
Dart	9	9	9.5	8	8	8.88
F-117	6	5	5	5	5	5.45
F-117MOD	8	6	7	6	6	6.85
Maple Seed	3	2	5	9	4	4.30

The Composite Wind-Tunnel Score (CWT) was calculated using the weighted formula:

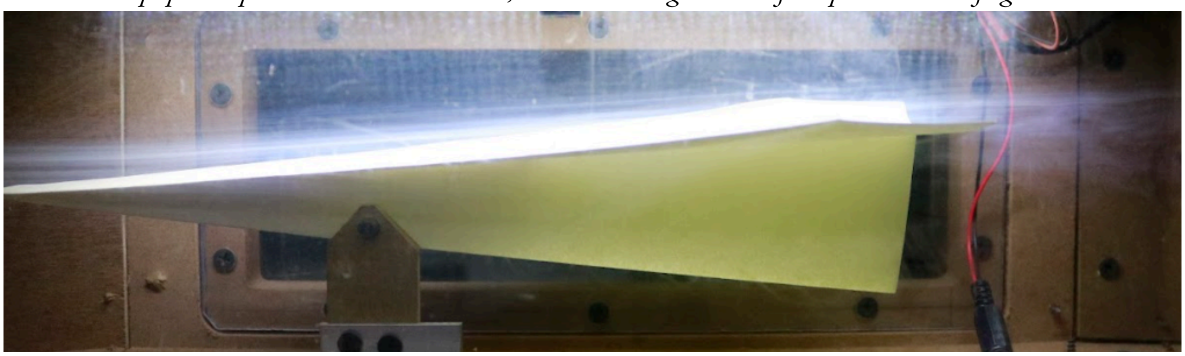
$$CWT = (0.30 \times LFQ) + (0.20 \times SYM) + (0.25\ X\ SEP) + (0.15 \times VXS) + (0.10 \times WKC)$$

Weights for each variable were chosen to emphasize smooth, attached flow (LFQ) and effective separation control (SEP) for low-speed efficiency, while still accounting for flow symmetry, vortex stability, and wake coherence.

Dart (Control)

Figure 1

Classic Dart paper airplane in the wind tunnel, demonstrating basic airflow patterns and flight behaviour.



The dart model exhibited the most stable and coherent airflow pattern. Streamlines travelled smoothly across its narrow fuselage, maintaining laminar flow with minimal disturbance. No significant flow separation was observed, and the wake behind the aircraft was thin and symmetric. These results align with the dart's slender, pointed nose and low-drag geometry, which promoted efficient airflow attachment. The dart's superior performance in flight trials, where it achieved the longest glide distance and highest stability, was consistent with the laminar profile's indication of low-pressure drag. The Dart was the most aerodynamically efficient model of all, outperforming the F-117 designs, which had separation zones and turbulent wakes, and the Maple Seed, which depended on rotational flow.

F-117 Nighthawk-Inspired Jet, Unmodified

Figure 2

Unmodified F-117 paper airplane in the wind tunnel, showing baseline airflow and stability before modifications.

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The unmodified F-117-inspired model demonstrated pronounced turbulent interactions and unsteady wake development. Smoke visualization revealed early flow separation near the leading edges, particularly where sharp angular folds disrupted streamline attachment. Strong vortex shedding occurred downstream, generating a wide and unstable wake. These characteristics highlighted the model's high drag profile, which likely contributed to reduced stability during flight. Despite the F-117's stealth-inspired geometry in real applications, its faceted design proved aerodynamically inefficient at low speeds, relative to paper airplane size. In contrast to the Dart's thin, symmetric wake and efficient glide, the unmodified F-117 showed how poor streamline attachment and angular geometry can amplify instability, placing it at the opposite end of the aerodynamic spectrum.

<u>F-117MOD Nighthawk-Inspired Jet, Modified</u>

Figure 3
Modified F-117 paper airplane in the wind tunnel, showing baseline airflow and stability before modifications.

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The F-117 paper airplane was altered in an effort to address this problem by moving the tailfins farther aft, which produced a more streamlined profile. During testing, this modification improved airflow over the airframe, which decreased drag and might have improved flight stability. Significant improvements were seen in the airflow surrounding the F-117-inspired model. In comparison to the unaltered version, streamline attachment was marginally more coherent along the mid-body, even though vortices and recirculation zones were still present. The wake narrows and becomes more structured, indicating a reduction in turbulent drag. However, because of persisting flow instabilities close to the trailing edges, the revised design was still unable to match the dart's aerodynamic efficiency. As a result, the F-117MOD fell somewhere in the middle; it was less chaotic than the original jet but still couldn't compete with the Dart's superior wake structure and clean laminar flow.

Maple Seed-Inspired Biomimetic Flyer

Figure 4

Maple Seed paper airplane in the wind tunnel, showing autorotation and lift-enhancing airflow effects.

The maple seed-inspired flyer displayed the most unconventional flow interactions. Smoke visualization revealed immediate asymmetry in the flow field, with strong swirling patterns indicative of autorotation tendencies. Instead of streamlined laminar flow, the model induced a pronounced vortex trail, with alternating shedding resembling a Von Kármán vortex street. While inefficient for long, stable glides, this phenomenon illustrated the design's ability to exploit rotational aerodynamics, closely mimicking the natural dispersal mechanics of samaras in nature. Unlike the engineered designs, which sought stability and efficiency, the Maple Seed's design revolves around instability, turning chaotic vortex formation into a functional autorotational mechanism. This is an aerodynamic strategy entirely distinct from the Dart's clean glide or the F-117's drag-dominated flight.

Flight Trials Results

Flight trials revealed clear differences in performance across the four paper aircraft models, demonstrating how geometry and modifications influence glide behaviour, stability, autorotation, and overall flight smoothness. Each aircraft was launched under controlled indoor conditions to minimize external disturbances, with trajectory and descent carefully observed.

To summarize aerodynamic performance across metrics, a Composite Flight Score (CFS) was computed for each model.

The chosen evaluation metrics, such as Straightness of Flight (SOF), Stability (STA), Autorotation (ATR), and Glide Smoothness (GS) capture the most critical aspects of paper aircraft performance. SOF was included as a measure of how well the aircraft maintains a consistent trajectory, reflecting control and predictability. STA evaluates the aircraft's resistance to wobbling or rolling, ensuring stable and repeatable flights. ATR highlights designs capable of sustained rotational descent, extending flight duration in a controlled manner. Finally, GS accounts for the aerodynamic efficiency of the glide, emphasizing smooth, stall-free motion during descent. Together, these four metrics balance controllability, stability, sustained performance, and aerodynamic refinement, forming a comprehensive framework for comparing aircraft designs.

Table 5
Results of Flight Trial Testing

Model	SOF	STA	ATR	GS	CFS Score
Dart	9	9	1	9.5	7.1
F-117	6	6	3	5	5.1
F-117MOD	8	7	2	6	6.0
Maple Seed	1	1	10	1	3.3

The Composite Flight Score (CFS) was calculated using the weighted formula:

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$$CFS = (0.35 \times SOF) + (0.25 \times STA) + (0.25 \times ATR) + (0.15 \times GS)$$

Weights were chosen to emphasize trajectory straightness (SOF) and stability (STA) as primary indicators of controllable, efficient flight, while still accounting for autorotation (ATR) and glide smoothness (GS) to capture descent behaviour and aerodynamic efficiency.

Dart

The Dart achieved the highest overall performance, demonstrating near-straight trajectories and strong stability. Its glide smoothness made its flight path predictable and efficient, though its autorotation score shows little capacity for controlled spin or lift generation outside linear gliding. Qualitatively, the Dart behaved much like a traditional airplane: it excelled in delivering consistent distance and accuracy but stood out because it lacked the instability and turbulence of the F-117 and the chaotic autorotation of the maple seed. The aerodynamic balance of low drag and consistent lift highlighted how simplicity in geometry often outperforms more complex folding strategies.

F-117 Nighthawk-Inspired Jet, Unmodified

The baseline F-117 scored the lowest among the fixed-wing designs. Its moderate straightness and stability reflected a tendency to wobble mid-flight, often leading to curved or shortened paths. Glide smoothness was also limited, with abrupt corrections visible in airflow interaction. However, its angled geometry occasionally induced unintended spins. Qualitatively, the unmodified F-117 displayed the weaknesses of its design: it prioritized visual resemblance to the stealth aircraft but suffered in aerodynamic efficiency, making it the direct opposite of the Dart’s clean, efficient glide.

F-117MOD Nighthawk-Inspired Jet, Modified

After modification, the F-117 showed noticeable improvement. Its straightness increased, suggesting that pushing the tailfins back reduced turbulent drag and allowed for a cleaner trajectory. Stability also improved, though autorotation remained poor, indicating that while the redesign streamlined airflow, it did not address rotational dynamics. The F-117MOD had a steadier descent than its predecessor thanks to a slight increase in glide smoothness. Qualitatively, the altered design closed the gap between the efficiency of the Dart and the instability of the unaltered F-117 by striking a balance between improved performance and aesthetics.

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Maple Seed

The Maple Seed stood out for its unique flight behaviour, with strong autorotation but extremely low straightness and stability. Its glide smoothness was minimal, resulting in a jerky, spiralling descent. It was the lowest-performing aircraft overall in terms of distance and control. Qualitatively, however, the Maple Seed demonstrated a fundamentally different aerodynamic principle: controlled autorotation for vertical descent rather than horizontal glide. Unlike the Dart, which maximized distance, or the F-117 designs, which struggled with stability, the Maple Seed prioritized rotational descent, highlighting a contrasting aerodynamic strategy inspired by nature.

DISCUSSION

Wind tunnel testing provides a controlled and isolated system for analyzing complex interactions between aerodynamic geometry and fluid behaviour. A wind tunnel functions by driving a controlled stream of air over a stationary object. In this way, researchers can analyze and reproduce aerodynamics and other related threats using a wind tunnel in a controlled laboratory. The nozzle accelerates air capture and later gains velocity as it is passed through air straighteners and the honeycomb screen. Further, the airspeed undergoes further increase as it passes through the contraction cone and enters the test area. In this area, models, as well as paper airplanes, are readily visible. Lift, drag, flow separation, and also turbulence are all viable within this no longer sanitized aerodynamic environment. This greatly increases the tolerable amount of error during data collection and ensures that results are more reliable than those which are obtained via less sophisticated means.

Fluid Dynamics and Flow Behaviour

The Reynolds number is a dimensionless parameter that characterizes the relative influence of inertial versus viscous forces in a fluid, and it is key to the observed results, which dictate whether flow remains laminar, transitions, or becomes turbulent. The paper aircraft tested falls in the low to moderate Reynolds regime, where viscosity plays a dominant role and flow separation can occur more easily. For instance, the unmodified F-117 design, with its sharp edges and flat surfaces, induces separated flow that forms large vortices, explaining its relatively unstable wake pattern and lower overall stability scores. In contrast, the Dart maintains smoother, more attached flow due to its streamlined geometry, which increases lift-to-drag efficiency.

The von Kármán vortex street is a well-known fluid dynamics phenomenon that occurs when fluid flows past a bluff body, causing alternating vortices to shed from either side. This generates a repeating pattern of swirling vortices downstream, which induces oscillatory forces perpendicular to the flow direction. In wind tunnel testing, this effect was particularly evident at the trailing edges of the paper aircraft models. The Maple

Seed, in particular, produced a repeating pattern of alternating vortices in its wake, closely resembling a von Kármán vortex street. This vortex formation contributed directly to its autorotation, increased angular rotations, and reduced forward stability, providing a natural demonstration of vortex-induced motion. These alternating vortices also contribute to energy redistribution in the wake, affecting not only stability but also the efficiency of momentum transfer and the induced drag experienced by the aircraft.

These results show that even small geometrical changes can have a significant effect on aerodynamic behaviour, affecting lift, drag, and overall flight performance. The Maple Seed's autorotation also shows a natural exploitation of vortex-induced torque by employing rotational energy to stabilize vertical descent despite reduced forward glide, directly linking its design to von Kármán vortex dynamics. The Dart reduces unsteady vortex shedding to produce smoother forward trajectories and increased glide efficiency. All of these results show how Reynolds number, flow separation, vortex formation, and geometric design work together to determine aerodynamic behaviour. This information is useful for both engineered and bio-inspired flight strategies.

Modified vs. Unmodified F-117

The F-117MOD presents a change of view on how slight geometric changes such as shifting the tailfins can increase wake coherence and diminish flow separation, displaying how highly sensitive aerodynamic performance can be to the tiniest design variations. It is very much possible that the flow on the mid-body on this modified F-117 version may be more coherent, and also it exhibits a wake that is slender and well-structured, granting it more stability when it flies, as compared to the unmodified F-117. The unmodified F-117 generates big vortices that disrupt laminar flows and create a broad, unstable wake, while the F-117MOD lessens those vortex intensities, even though there is still some unsteady flow near the trailing edges. By reducing unsteady vortex shedding and partial flow separation, the F-117MOD descends into much smoother glide paths, demonstrating the extent to which tiny geometric tweaks can be used to manipulate wake dynamics and flight stability.

Pressure Distribution and Thermodynamic Considerations

Aerodynamic lift is fundamentally governed by Bernoulli's principle and pressure differentials. Streamlined models maintained more favourable pressure gradients across their chord lines, delaying separation. Conversely, the faceted geometry of the F-117 generated abrupt changes in flow velocity and pressure, resulting in localized adverse pressure gradients that accelerated boundary-layer detachment.

Although paper airplanes operate at low speeds and do not experience significant compressibility effects, the thermodynamics of airflow remain relevant. In higher-speed cases, compressibility can lead to shock formation and strong pressure-temperature coupling. Even in subsonic flow, small isentropic compressions and expansions affect micro-pressure fields, subtly influencing stability. Understanding this energy exchange underscores why full-scale aircraft must account for both aerodynamic forces and thermodynamic state variables.

Vortex Dynamics and Stability

The modifications applied to the F-117 highlight how vortex control can enhance performance. By repositioning the tailfins further back, the F-117MOD effectively altered its center of pressure and wake coherence, leading to reduced asymmetric vortex shedding. This increased longitudinal stability without significantly improving glide distance, indicating a trade-off between directional control and forward efficiency. The Dart, however, demonstrated both stable vortical flow and sustained glide, reinforcing how streamlined geometries naturally minimize energy loss in the wake.

The Maple Seed model represents an entirely different aerodynamic section: autorotation and induced drag exploitation. Its high autorotation score reflects the aerodynamic principle of passive vortex stabilization, similar to how real maple seeds descend. Although inefficient for forward glide, this behaviour demonstrates the diversity of aerodynamic strategies found in nature and leveraged in bio-inspired engineering.

Limitations and Future Work

While wind tunnel visualization and flight testing provided strong qualitative insights, the results are limited by the simplified nature of paper aircraft. Scaling effects mean that turbulence characteristics, energy dissipation, and stability modes may differ at larger Reynolds numbers. Future experiments should incorporate force balance measurements, smoke-wire visualization, and pressure-sensitive films to quantitatively map flow behaviour. Additionally, integrating computational fluid dynamics (CFD) could complement physical testing, allowing detailed analysis of pressure fields, vortex structures, and thermal effects across geometries.

CONCLUSION

This study examined how non-traditional paper aircraft geometries influence aerodynamic performance through combined wind tunnel testing and controlled flight trials. The Dart, the F-117 Nighthawk-inspired jet (unmodified and modified), and the Maple Seed-inspired biomimetic flyer all distinctly demonstrated different airflow interactions, stability, and glide characteristics. The Dart excelled in laminar flow, flow symmetry, and glide smoothness, confirming the efficiency of streamlined, low-drag geometries. The unmodified F-117 exhibited significant flow separation, vortex formation, and wake instability, resulting in reduced flight stability, while repositioning the tailfins in the modified F-117 improved airflow coherence and increased stability without sacrificing aerodynamic efficiency. The Maple Seed, on the other hand, was a biomimetic design that uses passive autorotation for stability. It is extremely stable, but less efficient and slower than traditional geometries and cannot move in the horizontal direction. These findings highlight the interactions between natural inspiration and engineering optimization, providing insights into potential educational aspects and experimentation. Limitations of this paper include the simplified nature of paper models and qualitative metrics, which may not apply to real-world scaling effects. In its entirety, this paper shows how small geometric changes can cause major aerodynamic differences. Future work should include quantitative measurements, computational simulations, and larger-scale models to extend these results and refine our understanding of basic aerodynamics while showing the values of unconventional designs.

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