SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

Make It Fly: Experimental Aerodynamic Optimization of Existing Paper Aeroplanes through Flight Analysis

By Gayatri Papagari

AUTHOR BIOGRAPHY

Gayatri Papagari is a Grade 12 student in Indus International School, Hyderabad, India. She is a student interested in aerodynamics and aviation, specifically experimental optimization and analysis, which led to the creation of this project.

ABSTRACT

The aim of this paper is to analyse existing paper aeroplane designs and improve their performance which are evaluated through a fixed set of quantitative and qualitative criteria while being launched similarly. To do this, three different existing models were tested: the Basic Dart, the V-wing and the Hunting Flight. The chosen criteria for success was whether the design could fly for 4.67m consistently across 15 trials with a total success rate higher than 50%. First, the planes were flown with no modifications to establish the baseline and then, based on visual and wind tunnel observations, would be improved upon by making changes to control surfaces and other launch characteristics (launch velocity and angle of attack). Post-modifications, the Hunting Flight had the most significant success rate increase from 6.7% to 93.3% after the addition of a dihedral angle to the wing and removal of any angle of attack. The key finding of these experiments was that most paper aeroplanes fly best when launched with a negligible angle of attack, showing how minimal modifications can significantly improve flight.

Key words: *Paper aircraft, aeroplane, control surfaces, airflow, lift and drag, experimental optimization, wind tunnel analysis, flight behaviour, boundary layer*

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

INTRODUCTION

There are a few basic aerodynamic concepts required to understand why certain modifications influence paper aeroplane behaviour. These concepts include ideas like forces acting upon the plane (lift and drag), different types of flow, boundary layer behaviour and the structure of a paper aeroplane. These concepts not only give context to the data but also help explain why certain decisions were made throughout the course of this experiment.

Lift and Drag Forces

When understanding the behaviour of structures through a fluid, lift and drag are two very essential forces to understand. Lift is the component of net force perpendicular to the flow direction that opposes the weight of the aeroplane and holds it in the air, while drag is the component of net force along the direction of the flow that opposes the aircraft's motion through the air (Houghton & Carpenter, 2003, p. 26). Lift is created when there is a resultant upward force on an airfoil (streamlined body) created by a pressure difference. This happens when the flow over the top of the wing is faster than that over the bottom, leading to the pressure on the top being higher than that on the bottom (Houghton & Carpenter, 2003, p. 30). Lift and drag for certain structures are understood through their lift and drag coefficients, which are dimensionless quantities that relate lift and drag respectively to fluid density, fluid velocity and reference area (Houghton & Carpenter, 2003, p. 28). Lift and drag are important concepts that will be used to understand flow, which will help optimize structural designs of paper airplanes.

Flow and Boundary Layer Behaviour

There are two types of flow: laminar and turbulent flow. Laminar flow is when fluid flows smoothly in layers without significant mixing. It moves in straight lines and the velocity increases as it moves towards the centre of the flow. It has lower velocity and a lower pressure drop across the flow path. It is predictable and steady as fluid resistance or skin friction drag is low. However, this makes it less stable (Houghton & Carpenter, 2003, p. 377). Turbulent flow has irregular and seemingly chaotic movement of fluid particles as they mix, swirl and form eddies or vortices. This happens due to higher fluid resistance. Due to these fluctuations and movement of mass across layers, velocity varies with time. However, the mean velocity is generally higher than velocity in laminar flow. It also has an increased pressure drop (Houghton & Carpenter, 2003, p. 377).

Figure 1

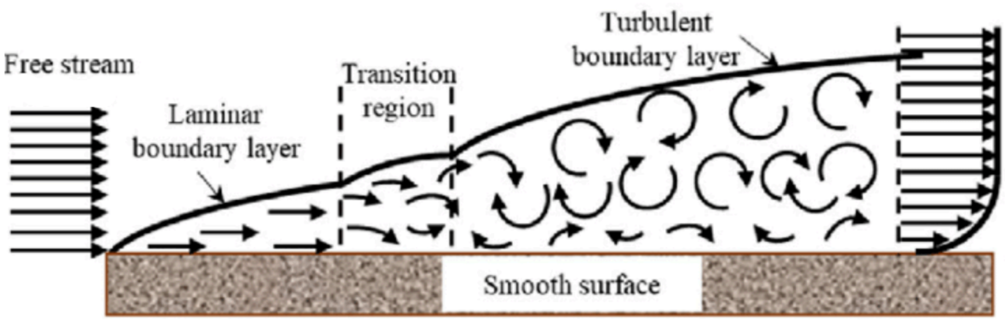
SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

Free stream over a smooth surface



Note *The behaviour of free stream over a smoother surface as it begins as laminar flow before transitioning to turbulent flow. The arrows depict direction of flow. Adapted from Fig 1 from "A review on turbulent flow over rough surfaces: Fundamentals and theories," Kadivar et al., 2021, International Journal of Thermofluids, 10(151):100077 (https://doi.org/10.1016/j.ijft.2021.100077).*

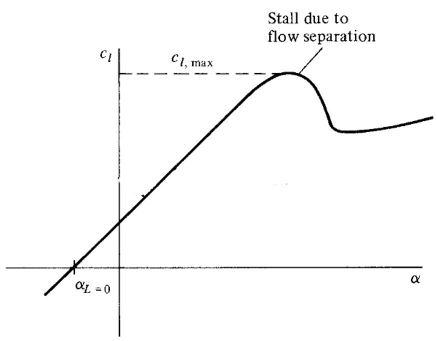
As a fluid flows over a solid surface, at the interface of the fluid and the solid body, the velocity of the fluid layer is zero due to intermolecular attraction forces. This phenomenon is called the no-slip condition. The velocity of the fluid increases as it moves away from the solid surface until it reaches the free stream velocity (Anderson Jr, 2011, p. 69). This layer of fluid where the velocity is increasing from zero to free stream is called the boundary layer. The boundary layer flow over a wing surface begins as a smooth and slow laminar flow. As the flow moves from the leading edge - or point of first contact - to the back, the laminar boundary layer thickens (Houghton & Carpenter, 2003, p. 379), as seen in *Figure 1.* As the fluid moves across the surface, the pressure increases in flow direction on the top, leading to a reduction in lift as the pressure difference between the top and bottom decreases. This also happens because this adverse pressure gradient acts against the boundary layer, leading to deceleration (Houghton & Carpenter, 2003, p. 380). Eventually, this adverse pressure increases enough on the surface that there is an eventual separation of the flow from the surface. This flow separation - or boundary layer separation - occurs unpredictably and rapidly, leading to a dramatic loss of lift and increase in drag caused by pressure drag (Anderson Jr, 2011, p. 385).

It should be noted that laminar flow separates much easier than turbulent flow would. So, to maximise drag reduction, the transition should be as far away from the leading edge as possible (Anderson Jr, 2011, p. 376). This means during design, a larger amount of the wing surface should be attempted to be kept within the laminar portion of the boundary layer as Reynold's number controls transition point. The other alternative would be to trip the boundary layer into turbulence as the turbulent boundary layer sustains the pressure change without separating so even though skin friction increases, overall drag decreases (Anderson Jr, 2011, p. 498).

When flow separation occurs, stalling occurs due to the dramatic loss of lift and reversal of flow. This happens especially when the angle of attack (AoA), or the angle of launch, is large (Anderson Jr, 2011, p. 321). This relationship is visualised in *Figure 2*

Figure 2

Relationship between Angle of Attack (L) and Lift Coefficient (cL)



Note *The relationship between Angle of Attack (α_L) and Lift Coefficient (c_L) that explains how increased angle of attack leads to a higher likeliness of flow separation, leading to stalling. Adapted from "Fundamentals of Aerodynamics," J.D Anderson Jr., 2011, Mc-Graw-Hill, p. 321, (https://ia800808.us.archive.org/22/items/FundamentalsOfAerodynamics5thEdition/Fundamentals_of_Aerodynamics_5th_edition.pdf).*

Paper Aeroplane's Structure

SCHOLARLY REVIEW

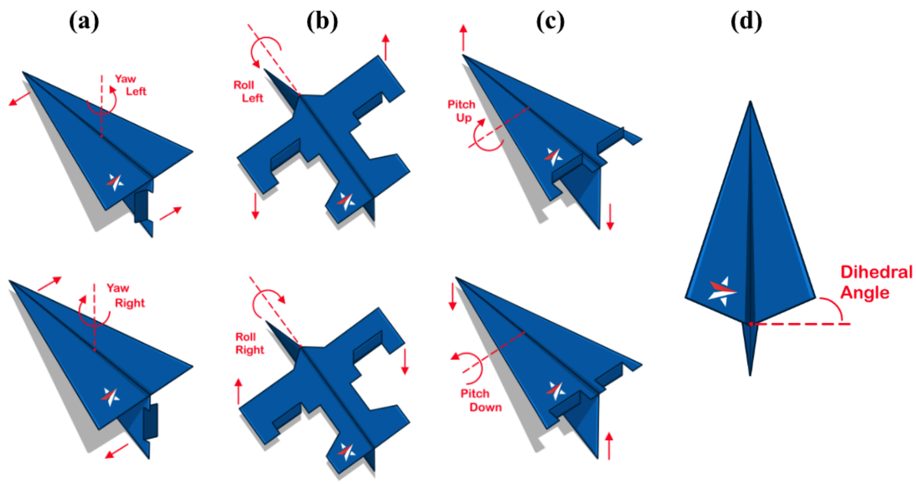
SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

Figure 3

Possible control surfaces for paper aeroplanes



Note *Control surfaces used to control yaw, roll, pitch and stability. a) Controlling yaw through the addition of rudders; b) the addition of ailerons to control roll; c) the addition of elevons to control pitch; d) the addition of a dihedral angle to improve stability. Adapted from "How to Steer a Paper Airplane", FoldNFly, n.d, Accessed on June 24th 2026, (https://www.foldnfly.com/lounge/steer-aim.php).*

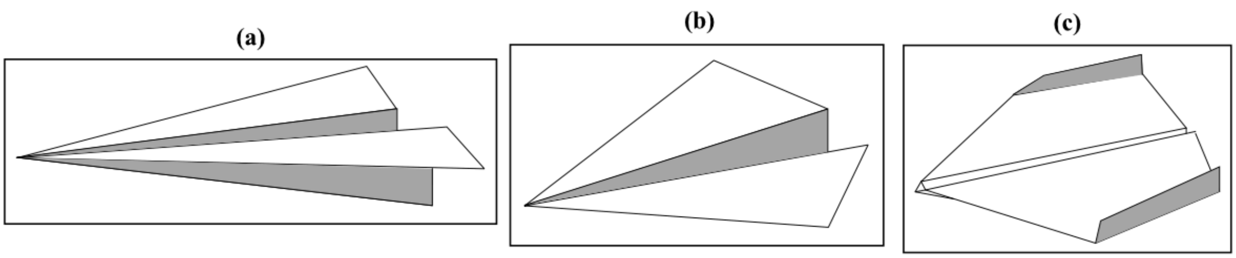
There are three different axes of control on an aeroplane: roll (the longitudinal axis), pitch (the lateral axis), yaw (the vertical axis) (Glenn Research Center, Airplane Parts and Functions). Diagrams for all these modifications can be seen in *Figure 3*. Yaw is controlled by the addition of rudders which deflect the air and push the plane in the direction of the rudder (Glenn Research Center, Rudder Interactive). For example, a rudder folded to the left will cause the plane to turn left. Roll is controlled by adding ailerons. This is only a viable option when the paper aeroplane model has a distinct tail and wing. Ailerons correct roll by redirecting airflow between upper and lower wing surfaces, influencing the lift difference between the bottom and the top of the wing, leading to roll control as lift proportions below and above the wing influences roll (FoldnFly, How to Steer a Paper Airplane). Pitch is controlled by the use of upward or downward-facing elevators which redirect airflow by creating a force on the back of the plane that causes it to be pushed either upwards or downwards based on the direction of the elevators (FoldnFly, How to Steer a Paper Airplane). Upward facing elevators cause the plane to pitch upwards and downward facing elevators do the opposite.

Apart from axis based control, the wing angle can influence the stability of the plane (Glenn Research Center, Wing Geometry Definitions Interactive). A dihedral angle, or a positive wing angle, increases stability and prevents the plane from spinning by being self-righting. The addition of a dihedral wing leads to a different angle of attack for the air approaching the wing when the plane has a tendency to roll in one direction. This leads to higher pressure on the bottom of the wing and lower pressure on the top. This pressure difference leads to the creation of lift, which leads to a rolling moment along the longitudinal axis that opposes the original disturbance, allowing for self-righting (Leishman, 2026, Chap. 59). On the other hand, a plane with an anhedral angle, or a negative wing angle, causes instability and is likely to cause the plane to spin over as it flies. It is particularly useful if one wishes to create an acrobatic or more maneuverable plane (Glenn Research Center, Wing Geometry Definitions Interactive).

METHODOLOGY

Materials and Apparatus

Figure 4
Unmodified sketches of designs



Note *Sketches depict side-views of three different designs that were flown for the pre-modified data, which were the unmodified basic dart (a), the unmodified v-wing (b), and the unmodified hunting flight (c).*

Standard A4 paper of the 75 GSM variant was used to fold three planes: the Basic Dart (BD), the V-Wing (VW) and the Hunting Flight (HF). The designs of these planes were constructed as described in the FoldAndFly catalog included in the appendix of this paper. We chose three specific designs of the planes based on ease of fold and the difference in aerodynamic properties. The basic dart ("Basic Dart," FoldNFly, n.d., Retrieved June 9th 2026) is chosen as it is one of the most common, easiest to fold, and built for distance. Typically characterised by a sharp nose, long body and short wingspan, it is built for distance. Choosing the common BD gives us the opportunity to collect control data points to compare the other designs - with varied aerodynamic properties - against. The second plane we choose is the V-Wing ("V-Wing," FoldNFly, n.d., Retrieved June 9th 2026), characterized typically by its larger wing span and wide body. Finally, the third model of the plane we choose is the Hunting Flight (HF) ("Hunting Flight," FoldNFly, n.d., June 9th 2026), which is typically characterised by the raised wings, sharp nose but very wide body, creating a rectangular body. Sketches of these three designs that were flown for the pre-modified data collection can be seen in *Figure 4*.

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

These three designs were tested within a closed badminton court with no obstructions. A closed but open space was chosen to prevent any uncontrollable draft/wind that would influence these very light and impressionable designs. This can be seen in *Figure 5*. Each throw was as uniform as possible, which meant keeping angle of attack and force of the throw as consistent as possible across all trials. This also meant standing at the same location for every throw, which was at the launch line, according to *Figure 5*.

Figure 5

Experimental Venue

Note *The experimental venue was an indoor badminton court, with the figure signifying relevant distance and apparatus markers for experimental set-up (including launch line position, designated 4.67m line, and camera position).*

The decided conditions for a successful flight was that the plane must make it over the 4.67m mark in the venue, as shown in *Figure 5*. Along with the success of the flight, the total distance travelled by the plane, the time taken for the plane to cross the 4.67m mark, and the observed qualitative characteristics of the flight were recorded. The time taken was recorded using a stopwatch on an Apple iPhone 17 Pro, the distance was recorded using a measuring tape, and there was one camera recording the experiment, which was a GoPro (HERO13) set up at the 4.67m mark on a tri-pod.

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

The previously mentioned qualitative observations included the path of the flight and the behaviour of the flight. The type of flight can be smooth or unsteady, and fast or slow. The path of the flight can be straight, slanted, and curved. Additional notes about the behaviour, such as deviations, were also observed and noted. Using these guidelines, at least 15 trials for each type of aeroplane were taken. In some cases, more trials were taken if uncertainties regarding the behaviour of the design still persisted. However, the success rate – or the percentage of successful trials – will be recorded using the data from only the initial 15 trials.

After the changes in behaviour were observed, the designs would be put inside a wind tunnel with a cross sectional area of 110mm x 130 mm running at 12 km/h - which was measured using an anemometer - to more clearly understand changes in flow that can be attributed to the change in behaviour. Due to its limited size and functionalities, a lack of clear viewing of airflow can be expected, leading to possible uneven understanding of airflow behaviour across all designs.

Modifications

Using this set-up, these materials, and this procedure, the baseline performance level was established for each design without any modifications. All designs were thrown similarly, which was at a significant angle of attack of around 45° with some force - or significant initial velocity, as dictated by the launcher - from the launch line *(Figure 5)*. Then, each plane was modified depending on the baseline performance and observations and then re-thrown in as similar conditions as possible. The performance of the modified designs were then compared with the baseline to understand the way different features of the design contributed to success or failure of flight.

Basic Dart

These modifications were different for each design. For the initial design of the basic dart (BD1), there were no major failures in performance. The BD1 flew very smoothly, with high uniformity in flight across numerous trials. It frequently rolled in air but those deviations did not disrupt flight path. To categorise this design on flight behaviour and path of flight, it flew mostly smooth, fast and straight, with curving on occasions. When thrown with more force and an angle of attack, it rolled very quickly and flew directly into the ground instead of gliding, leading to fast but unsteady flight. The rolling behaviour was likely due to geometrical asymmetry caused by repeated throws (weakened folds, bent edges) and human error, further aggravated by initial velocity and angle of attack. It had 6/15 successful flights, which translates to a success rate of 40%.

Figure 6

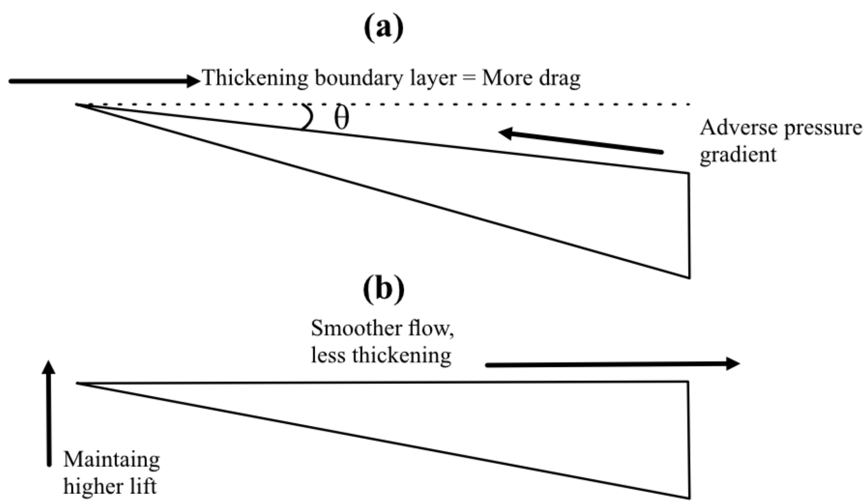
Modification of Basic Dart

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026



Note *Modification for BD 2.1 (modified design) of removing angle of attack to optimise stability in comparison to BD1 (unmodified design) to reduce likeliness of any stalling. Side-view of unmodified basic dart with existing angle of attack seen in (a) and side-view of modified basic dart (BD 2.1) with no angle of attack seen in (b).*

As there were no structural issues identified specifically, two modifications were made to this design in an attempt to optimize despite the unclear short-coming. The first modification was to add yaw control with a rudder to offset the geometrical asymmetry that led to the curve and tilt. The second modification was to reduce angle of attack during throws. This resulted in two modified designs: one with the rudder to be flown with no angle of attack (BD 2.1), and one to be flown with no angle of attack (BD 2.2). The modification for BD 2.1 and BD 2.2 can be seen in *Figure 6* and *Figure 7* respectively.

Figure 7

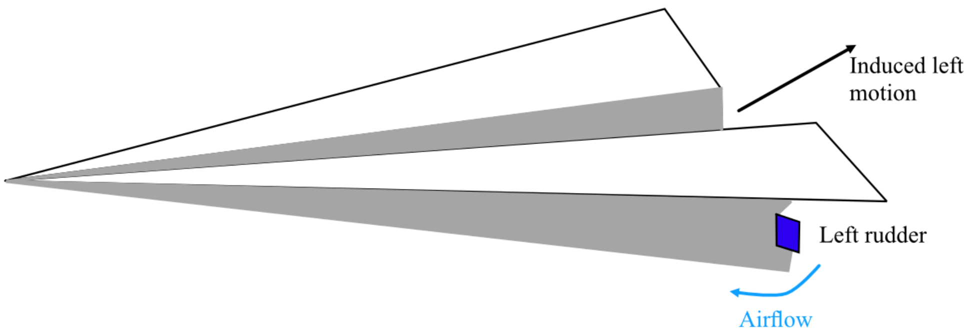
Side view of BD 2.2 (Modified Design)

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026



Note *Modified design has a left rudder to correct the tilting motion that occurs as there is a redirection of airflow, leading to the creation of a turning moment.*

V-Wing

The initial design of the V-Wing (VW1) frequently had jerky flight as it did not have a smooth flight path but instead stalled and then dipped and flew in levels of height. It had an erratic flight path, which included looping, turning 180° turns, curving and tilting while maintaining height. There were a few trends that were observed regarding angle of attack and force. It was observed that when thrown at a higher angle, it was often seen to stall in the air, dip to a lower level and either fly smoothly or curve/turn. When thrown at a higher angle with more force, it would stall and turn around and fly in the direction of the thrower. This led to the conclusion that when thrown at a significant angle of attack, flow separation occurred, which led to stalling. To categorise based on flight path and type of flight, it had either unsteady, fast and straight flight or straight, fast but curved flight. It had 5/15 successful flights, which translates to a success rate of 33.3%.

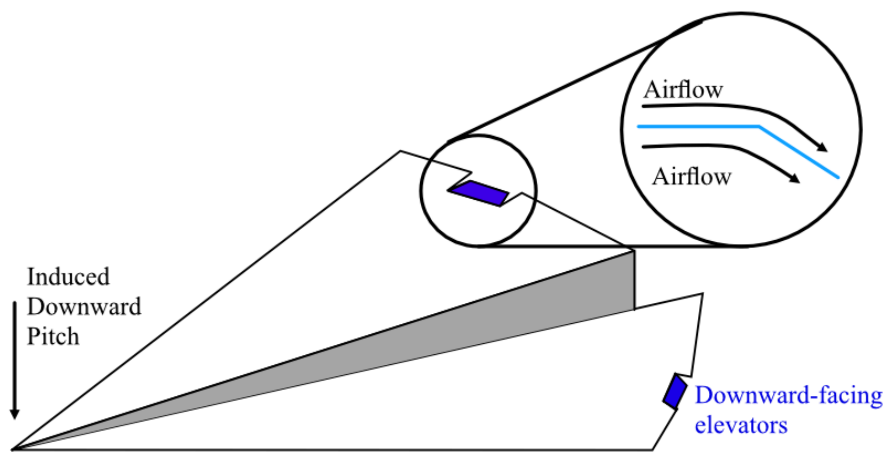
SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

Figure 8
Modified V-wing (VW2)



Note *Modified design has the addition of downward-facing elevators to correct the intuitive upward pitching by redirecting airflow.*

To mitigate the flight behaviour of the VW1, which included erratic flight that stalled quickly and turned rapidly, modifications were made to fix these issues. These modifications included downward facing elevators to force the plane to pitch downwards to prevent a higher angle of flight that leads to flow separation. Another modification was to throw the plane with less force to prevent it from flying too high, too early. This was because it was observed that when thrown with a higher force, it led to a faster stall as the design was inclined to pitch upwards faster. The modified version of the design, VW2, can be seen in *Figure 8.*

Hunting Flight

The HF1 had a very unpredictable flight pattern. It flew upwards and then stalled almost every flight and then went on to behave one of three ways: dipping and then continuing to fly smoothly in levels; completing a 180° loop/turn while continuing to either fly shakily or drop quickly; turning downwards and nosediving into the floor. During the successful flights, it completed short loops, but these didn't disrupt the flight path. This design didn't fly well with an angle of attack because when it was flown horizontally with a push, it flew the best, which meant it had a smooth, long flight with dips and stalls that didn't interrupt the flight. To categorise the flight type and path, it flew slowly and unsteadily at a slant due to the stalling and dipping, or – rarely, and with a low angle of attack – smoothly, lowly and straight. It had 1/15 successful flights which translates to a success rate of 6.7%.

SCHOLARLY REVIEW

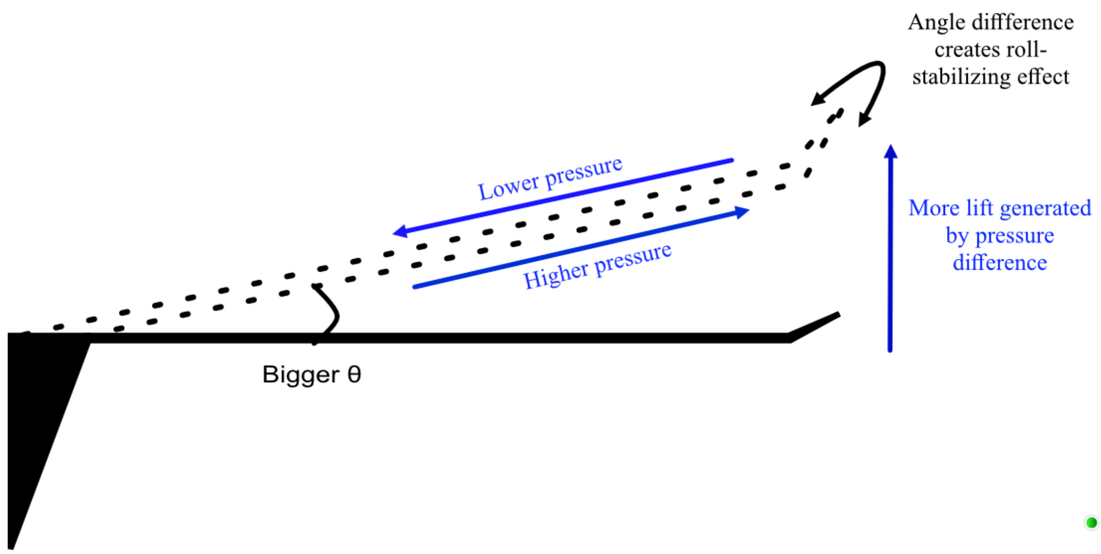
SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

The flight behaviour of HF1, which was very unstable and unpredictable, was mitigated by making the angle of the wing more dihedral as stability was a central issue, especially roll stability. Another modification was to throw it gently with a nonexistent angle of attack as it was found that when a significant angle of attack existed, the design ended up stalling quicker, likely due to flow separation. The modified design, HF2, can be seen in *Figure 9*.

Figure 9
Front-view of modified Hunting Flight



Note *Modified design has an added dihedral wing to stabilize roll to correct the tendency to roll during flight by creating roll-stabilising effect through the additional lift generated.*

RESULTS AND DISCUSSION

Post-Modifications Observations
Basic Dart

Across the two sets of modifications for the basic dart, two very different observations were made. Firstly, for the BD 2.1, which had a new rudder and was flown with no angle of attack, it performed very poorly, with a success rate of only 20%. It was extremely unsteady in the air, losing lift quickly and crashing. This was likely due to the fact that BD1 varied in the directions it veered towards, so having a fixed direction for the rudder ended up being counterproductive as it pushed the plane towards one direction no matter which direction it was veering towards, leading to unsteadiness.

In comparison, BD 2.2, which was flown with only no angle of attack, performed quite well with a success rate of 60%. It had consistently steady and smooth flight, but similar to the initial BD design, curved frequently. However, this did not heavily reduce the success rate as curving would often happen past the 4.67m mark. According to the wind tunnel tests, when removing angle of attack for the BD, there is a reduction in the thickening of the boundary layer, which stops lift reduction from happening which was previously what was occurring for BD1. So, this proves that out of the two modifications, the reduction of angle of attack was much more effective than the addition of a rudder due to the initial unpredictability of the basic dart in terms of direction as it achieved the decided upon success criteria, which was relatively stable flight with a success rate higher than 50%.

V-Wing

Post-modifications, the VW2 had a mostly smooth flight. The most common flight path was a smooth climb in height before descending in a controlled curve. The extent to which the design curved varied, which means the final deviation from the center varied from approximately 70° to around 20°. This was in sharp contrast to the behaviour of the VW1, which was jerky while making sharp turns. The failed flights were those that did not climb in height as much before descending. So, it can be assumed that this failure was not attributed to a flaw in design but rather a variation in launch as force with which the design was launched has been seen to influence the behaviour of the design to a great extent. To categorise based on flight path and type of flight, it was smooth, relatively fast, and the path of the flight was slightly curved. It had 8/15 successful flights, which translates to a success rate of 53.3%, a significant increase from the baseline throws which had a success rate of 33.3%.

This improvement in behaviour can be verified by the wind tunnel images which show that with a reduction in angle of attack and the addition of downward facing elevators, there was a smoother flow along with avoidance of any flow separation as seen in *Figure 10* which shows the airflow after the modifications in comparison to *Figure 11*, which shows the airflow prior to the modifications.

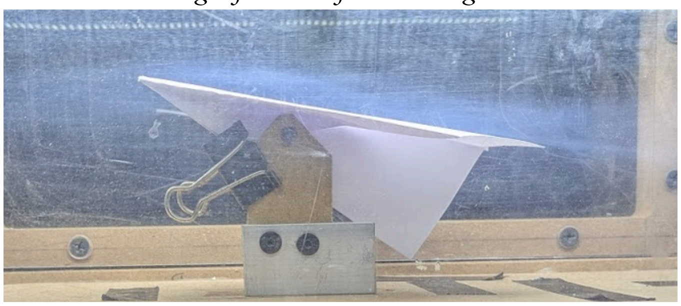
SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

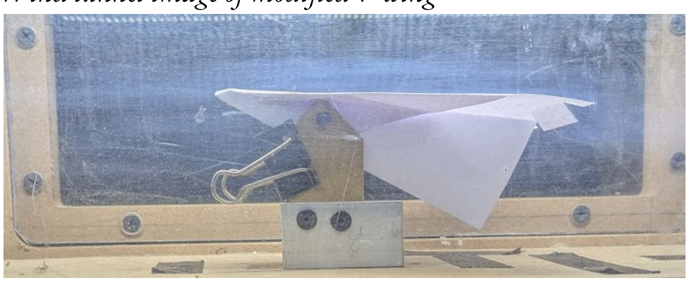
FALL 2026

Figure 10
Wind tunnel image of unmodified V-Wing



Note *Airflow over VW1 with a significant angle of attack that led to flow separation as seen in the slight bump towards the head of the plane followed by messier wake/airflow.*

Figure 11
Wind tunnel image of modified V-wing



Note *Airflow over VW2 after the addition of downward facing elevators that redirects flow downwards to pitch the plane downwards, as seen towards the tail of the plane. The more streamlined airflow also suggests less drag and more lift in general.*

Hunting Flight

The HF2 had a very consistent and predictable overall flight behaviour. After launch, it would descend slowly while swinging from left to right slightly in the air. It deviated very slightly from a completely straight path from trial-to-trial, flying in a mostly straight line. The plane also flew a longer distance than all other designs, and had a gliding landing where it slid across the ground for a few inches before stopping. This behaviour stayed consistent across almost all throws. This varied in the singular failed flight that occurred, where the plane rapidly climbed height before crashing. This mimics the flight behaviour of the baseline experiment. This means that the failed flights were probably due to an accidental angle of attack, which would have led to flow separation that led to the crash landing. This varies from the baseline behaviour to a great extent as it has a

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

consistent flight behaviour without major deviations or failed flights. To categorise the flight type and path, it flew smoothly and slowly in a straight line. It had 14/15 successful flights, which translated to a success rate of 93.3%.

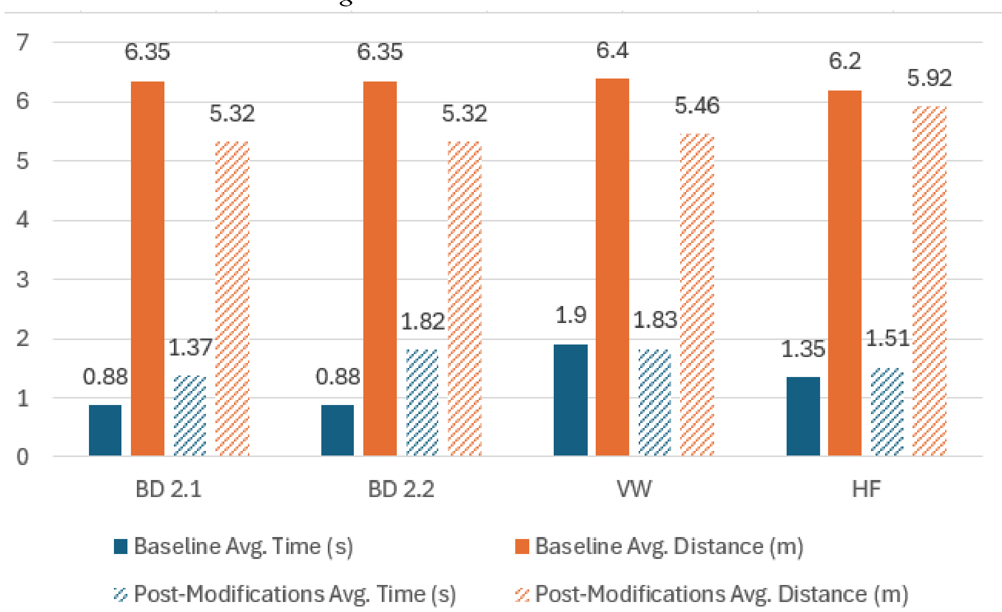
After placing the design in the wind tunnel, it became easier to understand why the addition of a dihedral angle and the removal of an angle of attack led to a higher success rate. Before the modifications were completed, the design had a more turbulent wake. Turbulent wakes lead to the general of opposite-rotating vortices, which create a rolling moment. The dihedral angle stabilizes this rolling moment, which is why this was the optimal modification to improve this design.

ANALYSIS OF RESULTS

As previously mentioned, the average time and distance of each of the successful flights for each plane was recorded and calculated along with the success rate. A graph depicting the average time of flight and average distance of flight across both initial and final designs can be seen in *Figure 12* below.

Figure 12

Cumulative data across all designs



Note *Average time of flight and average distance of flight across all designs (baseline and post modification), showing how minor variations were seen for average time before and after modifications in all designs but there was*

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

a decrease in average distance after modifications across all designs in comparison to the average distance before modifications.

Regarding changes in average distance and time, it is clear that even though all the designs achieved higher success rates, they did travel shorter distances in a longer duration according to the graph. This tells us that with a higher success rate post-modifications, the planes flew at a lower speed.

Figure 13

Raw and Processed Data for All Designs

Design	Raw Data	Success Rate	Avg Time (s)	STDEV Time (s)	Avg Distance (m)	STDEV Distance (m)
BD1	6/15	40.0%	0.89	0.12	8.47	0.64
VW1	5/15	33.3%	1.87	0.33	6.40	0.81
HF1	1/15	6.7%	0.88	0.11	6.13	1.56
BD 2.1	3/15	20.0%	1.82	0.41	5.32	0.77
BD 2.2	9/15	60.0%	1.36	0.20	5.33	0.62
VW2	8/15	53.3%	1.37	0.28	5.48	0.68
HF2	14/15	93.3%	1.51	0.21	5.92	0.85

Note *Cumulative Data of different designs including the success rate, average time and standard deviation for time of flight, average distance and standard deviation for distance flown, and the raw data for success rate.*

According to the results, primarily the success rates, the design whose performance improved the most was the Hunting Flight, going from a success rate of 6.7% to 93.3%. This demonstrates that the dihedral angle was a needed component to the plane. Across all planes, it is clear that having a lower angle of attack and lower initial velocity also contributed to the increase in success rate, demonstrating that these specific throwing habits can be held fairly consistent across different designs.

The standard deviation values also give us insight into the behaviour of flight itself. The time of flight remained generally consistent across all designs as the standard deviation remained relatively low in comparison to the standard deviation for distance, which was much higher in comparison. This tells us that even though the time of flight stays relatively the same, the distance flown by the plane still varies due to a range of factors, highlighting the unavoidable unpredictability of paper aeroplane flight.

ANALYSIS OF EXPERIMENT

Despite the measures taken to control the conditions of the experiment, there were a few variations that might have contributed to the results found. The first of which is human error. Human error was seen in thrower variability, where despite the efforts, there were variations in angle of attack for each trial and the initial velocity the planes were thrown with. Human error could also be expected when recording the time taken for the flight of 4.67m as this relies on human reactivity only. While human error in time-keeping could be significant, as average time is a secondary data in comparison to the directly observable, qualitative data, this doesn't influence the validity of the experiment to a great extent. However, thrower variability is a random error that must be acknowledged as it explains changes in behaviour, like distance flown successfully or location of flow separation due to change in initial velocity. While this error was attempted to be off-set by the higher number of trials completed, its effect is still significant.

The second factor which was considered to impact validity is shifting environmental factors. Even though the experiment was conducted indoors, the initial and final experiments were taken at different times of the year, and so there was a variation in humidity and temperature, with temperature varying by around 2-3 °C. This variation influences the viscosity of the fluid the planes fly through, influencing the Reynolds number. However, when compared against other errors like human error and thrower variability, the impact of these changes in environmental conditions becomes negligible.

The third and final factor for error is wear-and-tear of the materials. As the same paper aeroplane was used for all 15 trials of each design, due to repeated harsh landings, there were slight variations in the design. This includes changes angles for dihedrals, rudders and elevators with each throw as well as changes in rigidity of the paper due to humidity and continued movement. While the impact of the error is minimal, such irregularities could lead to tilts and curves due the structural asymmetry that is created.

The standard deviation values for average time of flight and average distance flown revealed in *Figure 13* reveal that out of all the designs, BD 2.1 had the most inconsistent flight data according to the standard deviation, with it having the highest deviation for time and one of the highest for distance. Other notable instances of higher standard deviation values which signal towards inconsistent flight behaviour is VW1 which varied in distance and time, and HF2 which varied with just distance. These values are particularly significant regarding the design of the experiment as they indicate that a possible extension would be to decrease the standard deviation by aiming to fly the plane to a certain distance, discussing the accuracy of aim of a plane rather than its general flight behaviour.

Regarding the use of the wind tunnel, due to its limited functionalities, a clear understanding of airflow could not be acquired and so a useful improvement could be to place the designs in a larger, more advanced wind tunnel to gain a more sure understanding of airflow to develop the current understanding of the way structural changes influence airflow.

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

CONCLUSION

This paper aimed to optimize existing paper aeroplane designs and make extrapolatable observations to the general behaviour of paper aeroplanes. This was achieved by optimising three paper aeroplane designs: the Basic Dart, the V-wing, and the Hunting Flight, all chosen due to their varying structural characteristics and flight behaviour. These planes were flown without any modifications and observations were made regarding their flight behaviour by categorising them based on flight type (smooth or unsteady, and fast or slow) and path of flight (straight, slanted, or curved). After these observations were made, modifications were made and then the designs were flown again, all of them achieving a success rate higher than 50%, the central pre-decided success criteria. The most significant change was seen in the Hunting Flight, which increased from a success rate of 6.7% to 93.3% as taken from the 15 trials conducted each round. Another significant finding was that almost all planes perform better when thrown with a lower launching velocity and with a negligible angle of attack as paper aeroplanes are particularly susceptible to flow behaviour, which changes quite radically when thrown at an angle of attack due to the way this influences boundary layer behaviour. There are many possible extensions to this experiment which include aiming to optimise aiming accuracy rather than a specific distance and minimising straight-line deviation. These extensions, when combined with the findings from this experiment, could provide a greater understanding into the behaviour of paper aeroplanes. Eventually, they could help understand the way airflow influences particularly pliable materials, helping improve the development of machines such as small drones, deployable sensor systems in agriculture and security, and many more.

SCHOLARLY REVIEW

SCHOLARLY REVIEW JOURNAL

E-ISSN: 2996-8380
Published by Leadership & Innovation Lab

FALL 2026

REFERENCES

Anderson Jr, J. D. (2011). *Fundamentals of Aerodynamics* (Fifth Edition ed.). McGraw-Hill. https://ia800808.us.archive.org/22/items/FundamentalsOfAerodynamics5thEdition/Fundamentals_of_Aerodynamics_5th_edition.pdf

FoldNFly. (n.d.). *Basic Dart*. FoldNFly. Retrieved June 9, 2026, from https://www.foldnfly.com/1.html#Basic-Dart

FoldnFly. (n.d.). *How to Steer a Paper Airplane*. FoldNFly. Retrieved June 24, 2026, from https://www.foldnfly.com/lounge/steer-aim.php

FoldNFly. (n.d.). *Hunting Flight*. FoldNFly. Retrieved June 9th, 2026, from https://www.foldnfly.com/6.html#Hunting-Flight

FoldNFly. (n.d.). *V-Wing*. FoldNFly. Retrieved June 9th, 2026, from https://www.foldnfly.com/39.html#V-Wing

Glenn Research Center. (n.d.). *Airplane Parts and Functions*. Guide to Aerodynamics. Retrieved August 24, 2026, from https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/airplane-parts-function/

Glenn Research Center. (n.d.). *Rudder Interactive*. Guide to Aerodynamics. Retrieved August 24, 2026, from https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/rudder-interactive/

Glenn Research Center. (n.d.). *Wing Geometry Definitions Interactive*. Guide to Aerodynamics. Retrieved August 24, 2026, from https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/wing-geometry-interactive/

Houghton, E. L., & Carpenter, P. W. (2003). *Aerodynamics for Engineering Students* (Fifth Edition ed.). Butterworth-Heinemann. https://soaneemrana.org/onewebmedia/Aerodynamics---Houghton&Carpenter.pdf

Kadivar, M., Tormey, D., & Mcgranaghan, G. (2023, 3). A review on turbulent flow over rough surfaces: Fundamentals and theories. *International Journal of Thermofluids*, *10*, 100077. 10.1016/j.ijft.2021.100077

Leishman, G. J. (2022). *Introduction to Aerospace Flight Vehicles* (January 2026 ed.). ERAU Pressbooks. https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/aircraft-stability-control/