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Accident Investigation on In-Flight Loss of Control Due to Configuration Change on Piper Arrow

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by

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Abstract

Title: Accident Investigation on In-Flight Loss of Control Due to Configuration Change on Piper Arrow

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Between 2012 and 2021, NTSB has identified over 2200 accidents due to loss of control. The majority of which happened while flying in the pattern. The most challenging phase of a flight is the take-off and landing. During these phases, the pilot initiates a change of configuration of the airplane by lowering or retracting the flaps. Lowering the flaps slows down the plane and increases the lift of the wing but also changes the longitudinal free response of the aircraft. The pitch changes of the plane require the pilot to promptly compensate to keep straight and level flight and avoid a stall. Past research at FIT, involving the flight test of different General Aviation aircraft, suggests that this free response longitudinal change is a factor that can lead to the aircraft's loss of control. Proper use of the trimming wheel helps the pilot to relieve some of the constant pressure from the yoke, necessary to compensate for the pitch change. It is paramount that pilots from different backgrounds are properly trained to deal with each phase of the flight and each configuration change of the aircraft. This research emphasizes the importance of identifying the underlying factors that lead to spins and stalls in aircraft, rather than solely focusing on reacting to these situations once they have already occurred. By shifting attention to the root causes of these events, such as the aerodynamic interaction between the wing and the tail, it will be possible to identify and mitigate factors contributing to setting a pilot up to lose control of an airplane, resulting in a stall or spin. This thesis focuses on analyzing the NTSB accident reports of the Piper Arrow series that occurred from

1983 onward. This model was produced in two configurations: the Arrow III with a traditional tail and the Arrow IV with a T-tail. The research found that there was a statistically significant difference in the loss of control accident rates between these two models. Through an analysis of these accident reports, this study gathered evidence that longitudinal trim change caused by the extension or retraction of flaps can be considered a key factor contributing to the loss of control of the aircraft.

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Acknowledgement

First of all, I would like to thank the great professor Ralph Kimberlin who suggested the title and topic of this thesis, the result of the intuition of a life spent more in the air than on the ground. Professor Kimberlin is for me a great example of versatile and multifaceted ingenuity, to be taken as a model also in aspects of everyday life.

My colleague and great friend Trupti Mahendrakar was close to me in the most important phases of my life as a graduate student at the Florida Institute of Technology. She spent lots of time listening to my doubts and my discouragements supporting me, helping me, giving me suggestions for my thesis, advising me through professional career, and always helping me to find the way out of the mazes of international bureaucracy and procedures.

The COES Director of operations and Projects, Peter Zappalà gave me the opportunity to work and teach at school every semester, thus helping me to bear the huge costs of the master's degree. I felt very close to him, perhaps also due to his common Sicilian origins.

And, last but not least, I thank my parents, Santi and Laura Caruso, who have supported me in this great undertaking of mine both economically, with great sacrifices, and psychologically. When at the age of six I showed everyone my desire to become a pilot, I was looked at with indulgence and irony. Only they have always believed in me. Furthermore, they also pretended not to suffer the absence from my native places.

Dedication

Of Life immense in passion, pulse, and power,
Cheerful, for freest action form'd under the laws divine,
The Modern Man I sing.
(Leaves of Grass – Walt Whitman)

It seems like yesterday when, still a minor, I crossed the world to start a great adventure. A new country, new friends, new methods of study, a sweet climate in a land a few kilometers from Palo Alto, in Petaluma, the town of the American Graffiti film set. And behind the campus, a few meters away, a sign of destiny, a small airport where I learned to fly, colliding every day with the difficulty of the force of gravity, and above all of, a new language to speak with the control tower. Then, always in flight crossing all the States, to reach Melbourne, and again, a few kilometers from Cape Canaveral, the myth. This is my life, a very long journey from my native Sicily. I was born in the land of ancient myth, the land of Ulysses' journey, the land where you can hear the roar of the largest volcano in Europe, Etna. And I arrived in the United States, the land of the modern myth, of the new frontier, of the journey of Armstrong, Aldrin and Collins, where the roar of the Rocketdyne F-1, the most powerful single combustion chamber liquid-propellant rocket engine, still resonates.

From the past to the future.

This new land, the United States of America, welcomed me like a son, it raised me, it made me mature, strong, and protected, it revealed the secrets of the forces of nature to me, it made me walk on my own legs and fly with my wings, it revealed to me the marvels of its nature and the strength of its climate, it gave me everything it possesses, asking only love and passion in return. And it is to this wonderful land that I dedicate this work of mine, the culmination of a long cycle of study, a symbol of the transition to adulthood. Thank you very much, beloved country, for giving me the most precious thing a man can aspire to: the future.

Chapter 1
Introduction

Motivation

According to the National Transportation Safety Board (NTSB) General Aviation Accident Dashboard, in the years between 2012 and 2021, there were 1671 fatalities caused by loss of control during flight which comprise 44% of the total fatalities in general aviation flights [1]. Most of the accidents due to in-flight loss of control happen in the critical phases of flight during take-off, landing, climb, descent, go around a transition in the pattern. Once the aircraft is subject to a loss of control while flying in one of these critical phases, it is very hard for the pilot to recover control due to the lower heigh above the ground. Pilots need to be able to properly and promptly react to any change that might lead the aircraft to a loss of control in any of the critical phases of flight. Numerous studies conducted on in-flight loss of control conclude that the most effective strategy to prevent this kind of accident is through proper flight training [2]. Most general aviation aircraft are not equipped with any sort of flight data recorder (FDR) or black box that can be retrieved and analyzed after an accident. It is therefore challenging for the NTSB investigators to determine with accuracy what led to an in-flight Loss of Control (LOC) event. However, the NTSB accident reports might suggest that loss of control is more likely to happen during specific phases of flight in the pattern, when the aircraft changes configuration by lowering the landing gear or extending / retracting the flaps. Several research studies conducted at FIT investigated how flaps deployment affects longitudinal stability. A particular test campaign looked into some of the most common general aviation aircraft among which the Piper PA-28-180, PA-28-181, PA-32, Cirrus SR20, Diamond DA40, Cessna C172N and Mooney M20C. From the test data it was found that at least 4 planes were pitching up more than 30°in 5 seconds after flap extension which caused airspeed to drop below stall speed [3]. Changes in longitudinal control force and the free pitch response of the aircraft, when flaps are extended, can lead to loss of control. This abrupt change in pitch attitude requires the pilot to promptly compensate by pitching down with the elevator. This increase in workload can become a factor which leads to the loss of control of the aircraft. The study presented in this thesis aims to validate this hypothesis through accidents investigation on the PA-28R Arrow series aircraft.

Consideration on Spin/Stall prevention

In-flight loss of control has been a significant issue in general aviation for many decades, with a large number of accidents resulting from this problem. Historically, there was a belief among engineers and designers that the primary factor contributing to in-flight loss of control was the ability of the airplane to resist and recover from a spin. This led to a focus on designing aircraft with features to prevent or mitigate spins, such as spin-resistant wing designs, which were intended to reduce the risk of a spin occurring in the first place. A spin is an out of control maneuver at an angle of attack beyond the stall, during which the aircraft rotates around its C.G. and an axis perpendicular to the earth while descending at high rate. If a spin occurs at traffic patterns altitude, a safe recovery is unlikely [4]. Non-aerobatic light aircraft have typically been designed to allow for spin recovery. Prior to 1991, both the FAA and European codes limited the number of turns or the duration of time allowed to recover from a spin. Additionally, these regulations required that even if an improper recovery procedure was executed, the aircraft could still return to straight and level flight. Research conducted in the United States during the 1980s and 1990s indicated that the majority of accidents attributed to spinning occurred at altitudes too low for effective recovery. As a result, the FAA determined that it would be preferable to focus on preventing spins rather than solely on ensuring recovery from this condition. It was found that the implementation of spin resistant design element also hinders spin recovery, thereby causing the aircraft to potentially fall short of meeting the original requirements of spin recovery. It appears that spin resistance and spin recovery are mutually exclusive, as positive characteristics in one area tend to have a negative impact on the other. In 2008 the European Aviation Safety Agency (EASA) conducted a study that examined 57 incidents of aircraft stalls and spins and identified where they occurred. Among these incidents, 10 took place between 1999 and 2008 involving Cirrus SR-20 and SR-22 planes, which were designed to resist spinning. The study discovered that 79% of these incidents took place at heights below 1000 feet, and 84% of those low-altitude accidents happened within the traffic pattern [5]. This thesis emphasizes the importance of identifying the underlying factors that lead to spins and stalls in aircraft, rather than solely focusing on reacting to these situations once they have already occurred. By shifting attention to the root causes of these events, such as the aerodynamic interaction between the wing and the tail, it will be possible to identify and mitigate factors contributing to setting a pilot up to lose control of an airplane, resulting in a stall or spin.

FAA Guidelines

Title 14 of the Code of Federal Regulation (CFR) lists a series of requirements that regulate aircraft design, issued by the Department of Transportation (DoT) and the Federal Aviation Administration (FAA). Section 23 includes airworthiness standards: normal, utility, acrobatic, and commuter category airplanes.

Part 23.143 applies to the controllability and maneuverability of the airplanes which is of particular interest for the scope of this investigation and is listed below [6]:

§ 23.143 General.

(a) The airplane must be safely controllable and maneuverable during all flight phases including—

(1) Takeoff;

(2) Climb;

(3) Level flight;

(4) Descent;

(5) Go-around;

(6) Landing (power on and power off) with the wing flaps extended and retracted.

(b) It must be possible to make a smooth transition from one flight condition to another (including turns and slips) without danger of exceeding the limit load factor, under any probable operating condition (including, for multiengine airplanes, those conditions normally encountered in the sudden failure of any engine).

(c) If marginal conditions exist with regard to required pilot strength, the control forces necessary must be determined by quantitative tests. In no case may the control forces under the conditions specified in paragraphs (a) and (b) of this section exceed those prescribed in the following table:

Table 1. Control Forces Limitations

Values in pounds force applied to the relevant control	Pitch	Roll	Yaw
(a) For temporary application:			
Stick	60	30	
Wheel (Two hands on rim)	75	50	
Wheel (One hand on rim)	50	25	
Rudder Pedal			150
(b) For prolonged applications	10	5	20

14 CFR 23.145 is a set of regulations concerning longitudinal stability that covers a variety of scenarios [7]:

"§ 23.145 Longitudinal Control.

(a) With the airplane as nearly as possible in trim at 1.3 V_{S1}, it must be possible, at speeds below the trim speed, to pitch the nose downward so that the rate of increase in airspeed allows prompt acceleration to the trim speed with—

 (1) Maximum continuous power on each engine;

 (2) Power off; and

 (3) Wing flap and landing gear—

  i. retracted, and

  ii. extended.

(b) Unless otherwise required, it must be possible to carry out the following maneuvers without requiring the application of single-handed control forces exceeding those specified in § 23.143(c). The trimming controls must not be adjusted during the maneuvers:

 (1) With the landing gear extended, the flaps retracted, and the airplanes as nearly as possible in trim at 1.4 V_{S1}, extend the flaps as rapidly as possible and allow the airspeed to transition from 1.4V_{S1} to 1.4 V_{SO}:

  i. With power off; and

  ii. With the power necessary to maintain level flight in the initial condition.

 (2) With landing gear and flaps extended, power off, and the airplane as nearly as possible in trim at 1.3 V_{SO}: quickly apply takeoff power and retract the flaps as rapidly as possible to the recommended go around setting and allow the airspeed to transition from 1.3 V_{SO} to 1.3 V_{S1}. Retract the gear when a positive rate of climb is established.

 (3) With landing gear and flaps extended, in level flight, power necessary to attain level flight at 1.1 V_{SO}, and the airplane as nearly as possible in trim, it must be possible to maintain approximately level flight while retracting

the flaps as rapidly as possible with simultaneous application of not more than maximum continuous power. If gated flat positions are provided, the flap retraction may be demonstrated in stages with power and trim reset for level flight at 1.1 V_{S1}, in the initial configuration for each stage—

i. From the fully extended position to the most extended gated position;

ii. Between intermediate gated positions, if applicable; and

iii. From the least extended gated position to the fully retracted position.

(4) With power off, flaps and landing gear retracted and the airplane as nearly as possible in trim at 1.4 V_{S1}, apply takeoff power rapidly while maintaining the same airspeed.

(5) With power off, landing gear and flaps extended, and the airplane as nearly as possible in trim at V_{REF}, obtain and maintain airspeeds between 1.1 V_{SO}, and either 1.7 V_{SO} or V_{FE}, whichever is lower without requiring the application of two-handed control forces exceeding those specified in § 23.143(c).

(6) With maximum takeoff power, landing gear retracted, flaps in the takeoff position, and the airplane as nearly as possible in trim at V_{FE} appropriate to the takeoff flap position, retract the flaps as rapidly as possible while maintaining constant speed.

(c) At speeds above V_{MO}/M_{MO}, and up to the maximum speed shown under § 23.251, a maneuvering capability of 1.5 g must be demonstrated to provide a margin to recover from upset or inadvertent speed increase.

(d) It must be possible, with a pilot control force of not more than 10 pounds, to maintain a speed of not more than V_{REF} during a power-off glide with landing gear and wing flaps extended, for any weight of the airplane, up to and including the maximum weight.

(e) By using normal flight and power controls, except as otherwise noted in paragraphs (e)(1) and (e)(2) of this section, it must be possible to establish a zero rate of descent at an attitude suitable for a controlled landing without exceeding the operational and structural limitations of the airplane, as follows:

(1) For single-engine and multiengine airplanes, without the use of the primary longitudinal control system.

(2) For multiengine airplanes—

i. Without the use of the primary directional control; and

ii. If a single failure of any one connecting or transmitting link would affect both the longitudinal and directional primary control system, without the primary longitudinal and directional control system."

Furthermore, the FAA defines *Accident* as an "occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage..." while it defines *Incident* as "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations." These two definitions can be found in the *49 CFR § 830.2* [8].

Flaps

Flaps are high-lift devices, which comprise part of the secondary flight controls. When deployed, flaps increase the lift produced by the wing at any given angle of attack (AoA). The flaps are hinged to the trailing edge of the wing. Flaps allow the aircraft to compromise high cruising speeds when retracted and low landing speeds when extended. There are several types of flaps, but each serves the same purpose. When deployed, flaps change the shape of the wing, increasing the camber of the airfoil and sometimes its area. As the chamber increases, the coefficient of lift is increased too, thus producing more lift at any given AoA (Equation 1). Furthermore, with an increase in lift there will also be an increase in induced drag, which is helpful to slow down the aircraft during the landing phase of flight without incurring in a stall. One concept that is of particular interest in this investigation is that when flaps are lowered, the change in chamber shifts the center of pressure C_p of the wing aft, causing a pitch down moment of the airplane (Figure 1) [9].

$$L = C_l * \frac{1}{2} * \rho * V^2 * A \quad (1)$$

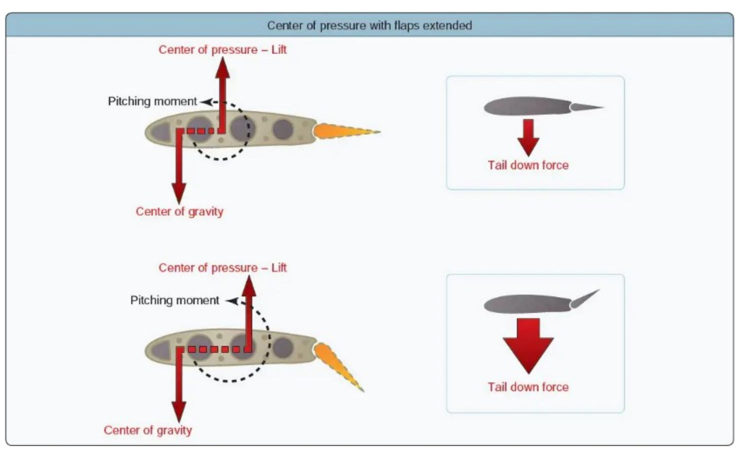

Figure 1: Center of Pressure with Flaps Extended.

For a novice pilot this is a counter intuitive concept as most general aviation aircraft have a pitch up tendency when flaps are deployed. To mention a few examples, the Piper PA-32-260 Cherokee six or the Cessna 172M are commonly known to show these tendencies. Student pilots who learn to fly in one of the aforementioned airplanes are trained to push the control wheel down, when the flaps are being extended, to maintain a straight and level attitude. The horizontal tails are designed to meet the longitudinal stability around common trimming points. The wing aerodynamics cannot explain the substantial nose-up moment tendency typical of many GA airplanes, therefore, the only other significant factor that contributes to the nose up tendency can be attributed to the aerodynamic interaction between the wing and the stabilator.

The cause of this pith up tendency is to be found in two aerodynamic factors: one is the downwash of the wing over the horizontal tail, and the other is the vortex generated by the tip of the flaps that impact the horizonal tail, increasing the downwash. Most aircraft are designed so that the Center of Pressure is behind the Center of Gravity making the aircraft slightly nose heavy. The downwash from the wing helps the horizontal tail to generate a downward force which balances the airplane. Airspeed affects the downwash and consequently the magnitude of the horizontal stabilizer downward load (Figure 2).

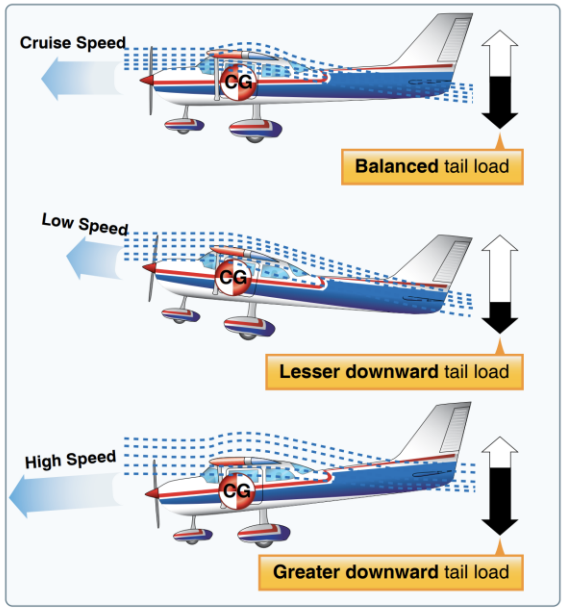

Figure 2: Effect of Speed on Downwash

Another aerodynamic factor that contributes to the change of airflow over the tail is the production of vortices generated by the flaps. Flap-Tip vortices are generated with remarkably similar dynamics of wing-tip vortices. When an airfoil has a positive AOA, there is a pressure differential between the top and bottom of the wing. The air pressure above the wing is lower than air pressure below the airfoil. Because air tends to move from high pressure to low pressure, and it is easier to go around the tips of the wing, there is a sideways movement of air from under the airfoil outwards from the fuselage around the tips. This creates a spinning mass of air called a vortex. The air bends upward around the tip and joins with the downwash to make a fast-rotating trailing vortex (**Error! Reference source not found.**). These vortices cause drag because they use up energy in making the turbulence. Just like wingtip vortices, when extended and exposed to the freestream airflow, the flaps tips generate vortex which impact the tail. The location and degree extension of the flap determines the magnitude of vortex that affects the horizontal tail (Figure 4). On aircraft having the inboard flap tip flushed with the fuselage, it is assumed that any vortex generate will be rapidly dissipated by the wall of the fuselage.

Figure 3: Flap-tip vortex

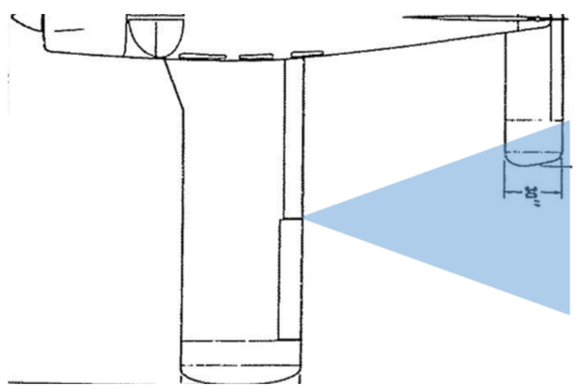

Figure 4. Flap-tip Vortex Area of Interaction

The same but opposite effect can be observed when flaps are retracted. When the pilot suddenly raises the flaps, the same aerodynamic interaction mentioned above comes into play, and the aircraft will experience an abrupt nose down pitch tendency.

On a T-Tail configuration, because the horizontal tail is situated above the wing, it is not as subject to its down wash (Figure 5) and not severely affected by the vortex generated from the flap-tips when extended. A T-tail solely relies on the free stream to generate a balancing tail force.

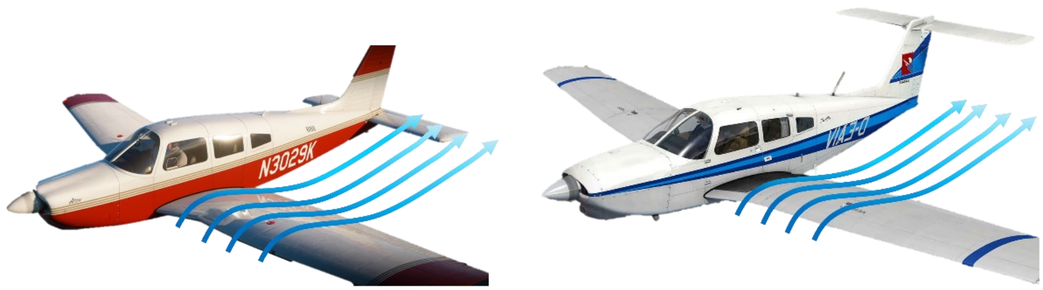

Figure 5. Wing Downwash on Horizontal Stabilator

Trim

The trim is one of the secondary control surfaces with the purpose to adjust all aerodynamic forces exerted by the control surfaces. When properly trimmed, an aircraft can maintain a set attitude without any control's input. The trim system is design to reduce the pilot workload by reliving the need to apply constant pressure on the yoke during a climb, a descent, or straight and level flight. The most common trim system on GA aircraft is a single trim tab hinged to the trailing edge of the elevator. The pilot can operate the amount of trim through a trim wheel and a trim tab position indicator. If an aircraft exhibits substantial longitudinal trim change when subject to a configuration change, the pilot can use the wheel trim to retrim the aircraft for the desired attitude and airspeed. However, this additional task to retrim the aircraft adds up to the pilot workload. If the airplane is designed to remain in balance with a 0 pitch rate after deploying or retracting the flaps, the pilot can shift his or her focus over to other important tasks of flight [9].

T-tail

A T-tail is a type of empennage with the horizonal stabilizer or stabilator mounted in the upper part of the fin. Looked from front or back it, in fact, resembles the shape of the letter T. The main advantage of a T-tail, over the traditional configuration, is that the elevator is above most of the downwash of the propeller and the wing. The smoother airflow over the elevator reduces drag and requires a smaller planform area of the elevator. A T-tail solely relies on the free stream to generate a balancing tail force. The only downside of a T-tail configuration is the high risk of entering a deep stall but only when used in an aircraft with swept wings. As the swept wing aircraft approaches the critical angle of attack, the wing tips tend to stall first. From there, the upper surface airflow produces a wake of turbulent and slower airflow behind the wingtips. The reduced lift due to stalled state of the wing tips causes the center of pressure to shift forward and toward the wing roots (Figure 6).

Figure 6. Wing Tips Stall and Cp Shift

Forward C_p creates an unstable pitch up moment, reduced lift and more drag causes the airplane to sink. At high AoA, a deep stall results in a substantial reduction of elevator effectiveness which can lead to an unrecoverable control of the aircraft. As shown in Figure 7, the airplane which exceeded the critical AoA entered a stall and the wake of a stalled wing now covers the horizontal stabilator, drastically reducing its effectiveness [10].

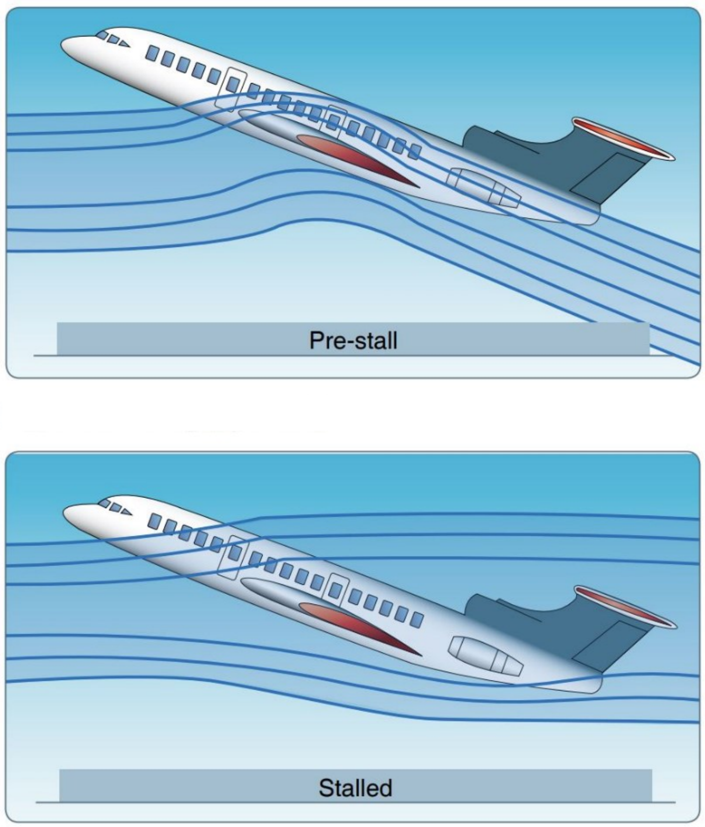

Figure 7. Deep Stall in a T-tail Configuration

However, the deep stall does not raise any concerns in a straight wing airplane since the C_p does not shift forward and nose down pitch still occurs when loweing the flaps. In general aviation, T-tails are therefore not more susceptible to stalls than conventional tail configuration [11].

Chapter 2
Piper Arrow

History of the Piper Arrow

In order to find evidence showing that extra workload caused by the pitch-up attitude change could play a role in aircraft loss of control, the Piper Arrow series aircraft was taken into study. Different versions of the piper Arrow were designed in the '70s, the last of which led to the integration of a T-tail.

Cherokee Arrow

By the middle of the 1960s, Piper was evaluating the PA-28 as a potential entry point into the market for light four-seaters retractable. Mooney controlled that market segment at the time. The Beechcraft Debonair, a retractable that was less priced than a Mooney by a third, was the only comparable aircraft. In 1967 Piper announced the PA-28R-180 Cherokee Arrow. The step up for a GA pilot transitioning to a higher performance airplane. The Arrow came from the same bloodline of the Cherokee but with the addition of a retractable landing gear and a constant pitch propeller. The peculiar safety feature of the Cherokee Arrow to bridge the experience gap was the implementation of automatic gear lowering system. That following year Piper developed the PA-28R-200 Cherokee Arrow [12].

Cherokee Arrow II

In 1970 Piper developed the PA-28R-200 Cherokee Arrow II, a stretched-out version of the Cherokee which increased the fuselage length of 5 inches at the forward wing attach points, providing a more spacious rear cabin. The Arrow II was equipped with a 2ft larger stabilator taken from the PA-32, a new dorsal fin and an increase in wingspan of 24 inches [12].

Cherokee Arrow III

The first prototype of Arrow III had the same fuselage as the Arrow II but with a semi-tapered wing and a T-tail. The new wing increased performance especially in terms of glide. In 1976, Dr. Ralph Kimberlin test flew the PA-28RT-201 Cherokee Arrow III with tail number N1169X. However, the Aircraft was written off following a spin test where it was not able to recover from the spin, forcing Dr. Kimberlin to parachute to safety. In order to determine the causes of the N1169X spin, a new plane was built with a rectangular wing and an 18 inches fuselage extension. This version had a T-tail with a 10° trailing edge down elevator and was tested in this configuration at Piper Lakeland. Later tapered wings were added and tests repeated before being sold to NASA in 1978 for further research on spin. For the Cherokee Arrow III, Piper decided to build it using the conventional low tail and the tapered wing. The PA-28R-201 was announced in 1977. This version had an increased fuel capacity and was 100lb heavier in gross weight. A turbo version of the Arrow III, the PA-28R-201T, was developed in 1976 using a turbo-charged 200hp Continental TSIO 360-F engine [11].

Cherokee Arrow IV

Following the incident of N1169X, Piper tried to move the T-tail aft, on a PA-28R, and solved the spin problem. In 1978 the PA-28RT-201 Arrow IV and PA-28RT-201T Turbo Arrow IV were developed with a new T-tail. A new tail cone was added which stretched the fuselage of 12 inches [11]. In the following years, with slowing aircraft sales, Piper discontinued the production of the T-tail turbo Arrow IV in the summer of 1988. Although a prototype of the Arrow V was built and tested in 1985, the project was terminated for lack of money [12].

For the purpose of this research, we compared the Piper PA-28R-201 Arrow III and the PA-28RT-201 Arrow IV. These two models have the same wing type and dimensions. The main difference is in the T-tail of the Arrow IV, with the horizonal stabilator from the original Cherokee 140, while the Arrow III kept the low tail configuration with the stabilator from the PA-32. 1293 models of the Arrow III were built, while 1404 models of the Arrow IV were built, all including prototypes [13]. Table 2 shows some of the relevant airplane characteristics of these two models [14] [15].

Table 2. Airplane Specifications: Arrow III and Arrow IV

Model	Max. Takeoff Weight (lb.)	Length (ft)	Wing Span (ft)	Wing Area (ft^2)	Tail Span (ft)	Aspect Ratio	Wing Loading ($\frac{lb^2}{ft}$)
Arrow III	2750	24.8	35.5	170	12.8	7.41	16.2
Arrow IV	2750	27	35.5	170	10.8	7.41	16.2

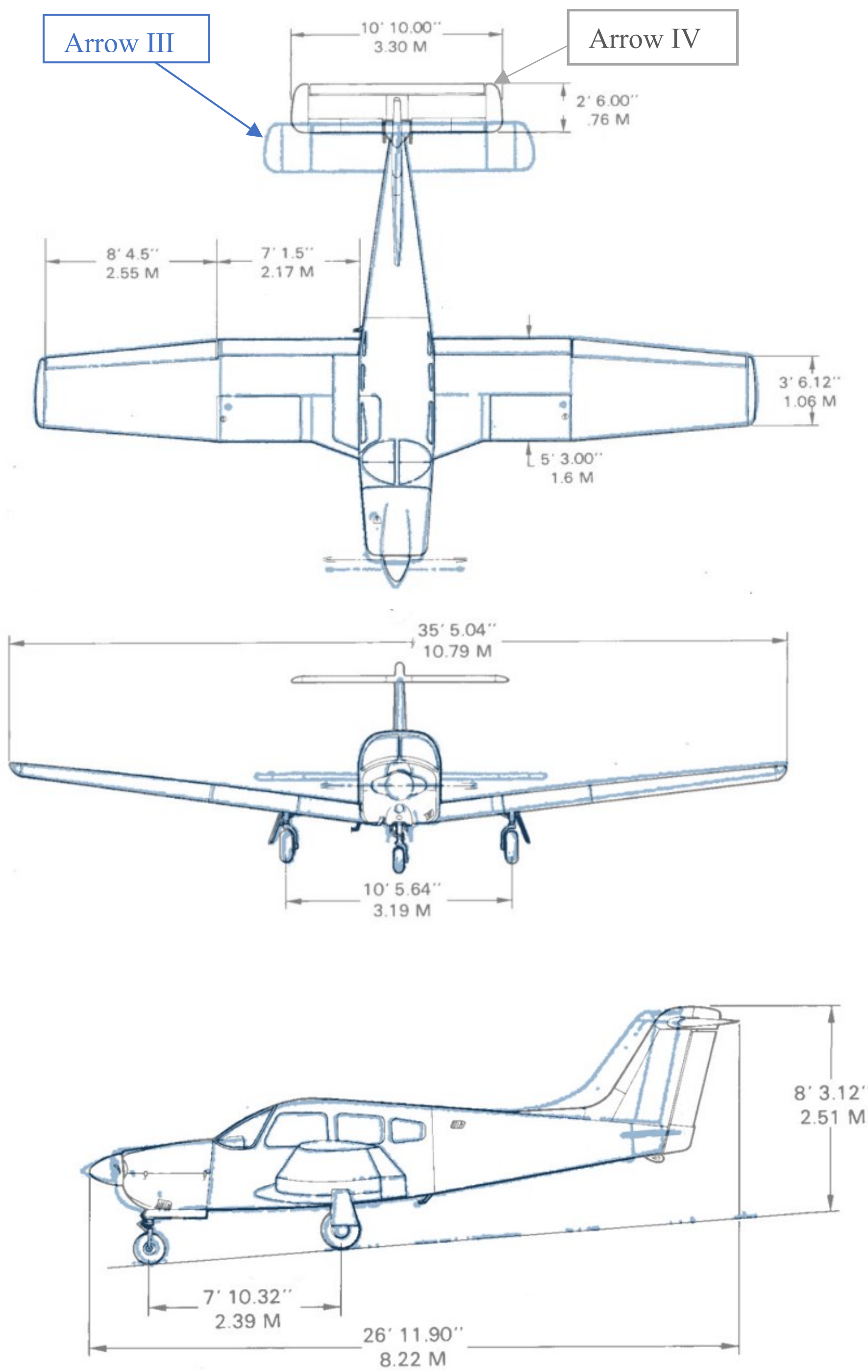

Figure 8 - Arrow III and Arrow IV Comparison

Chapter 3
Data Collection Method

NTSB Aviation Accident Database

The NTSB maintains the officials census of aviation accidents for the United States. The database is accessible to the public and is updated monthly. The Case Analysis and Reporting Online (CAROL) tool allowed us to search NTSB investigation and reports starting from 1983. The Advance Search feature of CAROL allows the user to find report using custom search criteria [16]. The criteria used to find accident related to the Piper Arrow III are shown in Figure 9. The search yielded 76 results.

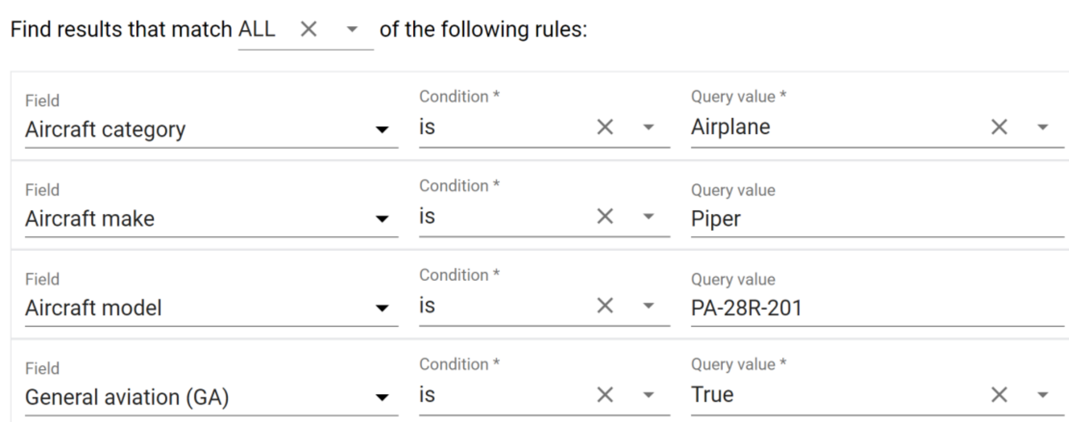

Figure 9: CAROL Search Criteria for Piper Arrow III

The criteria used to find accident related to the Piper Arrow IV are shown in Figure 10. The search yielded 60 results [16].

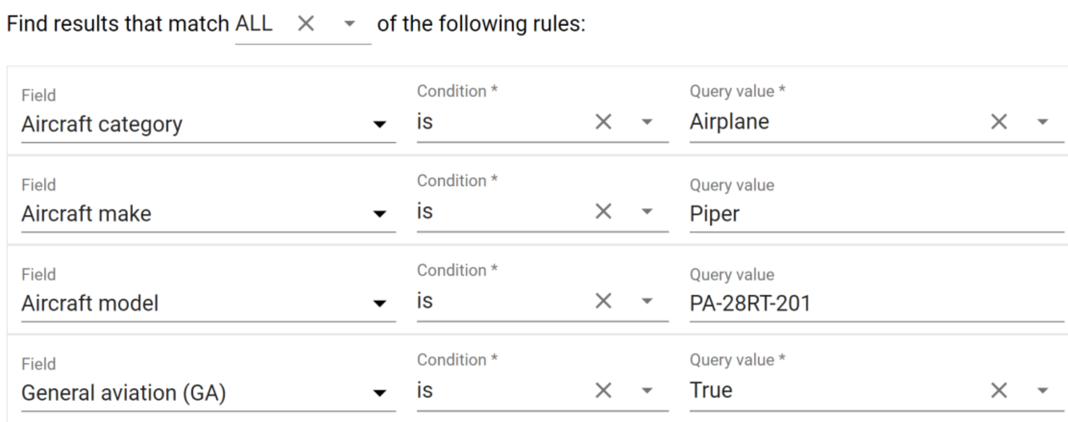

Figure 10: CAROL Search Criteria for Piper Arrow IV

After each search, a .CSV dataset was downloaded. The dataset contained the case NTSB's number, the aircraft tail number, the event date and location, the fatal injuries and a summary of the probable cause.

Chapter 4
Results

After a meticulous review of each accident's probable cause, it was found that at least 12 out of the 76 accidents were caused by loss of control for the Arrow III (Appendix A). On the other side, only 4 out of 60 accidents could be blamed on loss of control for the Arrow IV (Appendix B). For each model, the ratio of LOC accidents to total number of airplanes manufactured was computed. This calculation gives us a comparable metric that takes into account the difference in the sample of total number of planes for each model. The percentage of LOC accidents of the total number of accidents reported was also computed. It was found that the Arrow III models had more accidents due to loss of control in flight than the Arrow IV.

Table 3: Table of Results

Model	Total Number of Airplanes Produced	Total Number of Accidents	Accidents due to Loss of Control	LOC ccident %	LOC Accidents / Total number of airplanes Produced
Arrow III	1293	77	12	15.6	0.0093
Arrow IV	1404	60	4	6.7	0.0028

To determine whether the difference in accident rates between the two aircraft is statistically significant, a hypothesis test was performed using a significance level of 0.05. The null and alternative hypotheses were setup as follows:

- Null hypothesis (H0): The accident rates in both aircraft are equal.
- Alternative hypothesis (H1): The accident rates in the two aircraft are different.

We used a two-sample proportion test to test the hypotheses.

$$Z = \frac{(p_1 - p_2)}{\sqrt{\hat{p} * (1 - \hat{p}) * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad (2)$$

where:

- p_1 is the proportion of LOC accidents for the Arrow III.
- p_2 is the proportion of LOC accidents for the Arrow IV.
- $\hat{p}$ is the pooled proportion.
- n_1 is the sample size of Arrow III aircraft.
- n_2 is the sample size of Arrow IV aircraft.

First, the proportion of LOC accidents for each aircraft was calculated:

- $p_1 = \frac{12}{1293} = 0.0093$
- $p_2 = \frac{4}{1404} = 0.0028$

Next, the pooled proportion was calculated:

- $\hat{p} = \frac{p_1 * n_1 + p_2 * n_2}{n_1 + n_2} = \frac{12+4}{1293+1404} = 0.0056$

We then calculate the test statistic plugging in each value in the equation 2:

$$Z = \frac{(0.0093 - 0.0028)}{\sqrt{0.0056 * (1 - 0.0056) * \left(\frac{1}{1293} + \frac{1}{1404}\right)}} = 5.16$$

The calculated z-value is greater than the critical value of 1.96 (for a two-tailed test with a significance level of 0.05), indicating that the difference in accident rates between the two airplane models is statistically significant. Therefore, we reject the null hypothesis (H0) and conclude that the accident rates in the two aircraft are different [17].

Analysis

The reports found in the NTSB database on LOC accidents for the Arrow III and Arrow IV model show that the T-tail model was subject to less LOC accidents compared to the traditional tail model. The hypothesis that the wing downwash, as well as the interaction of flap-tip vortices and the horizontal tail can cause unexpected, abrupt changes in airplane flight characteristics is strongly supported by the findings of this study. This interaction is assumed to be a significant contributor to in-flight LOC accidents, especially during the deployment and retraction of flaps at low altitude in the traffic pattern. There are two possible scenarios where such accidents are likely to occur: one involves a distracted pilot who abruptly extends flaps while looking outside the airplane and fails to notice rapid changes in airspeed and pitch attitude, and the other involves a less experienced pilot in high-workload, instrument meteorological conditions (IMC) approach who executes configuration changes at critical points during the approach, such as selecting approach flaps upon intercepting the glideslope. It is important that the airplane's response to flap extension does not add to the pilot's workload. Ideally, when the pilot extends the flaps, the airplane should remain balanced with no change in pitch rate. To address the problem of abrupt pitching motion after flap extension, it is important to train pilots to properly respond to attitude changes before critical limits are reached. It is important to point out that when a pilot is looking out the side window, he/she cannot tell the pitch attitude change of the aircraft and therefore changes by airplane manufacturers are required. For new aircraft designs, the interaction of flap-tip vortices and the horizontal tail must be accounted for. Changes such as tail with a shorter span, T-tail and/or interconnecting the flaps with the horizontal elevator can improve the longitudinal trim change tendency when lowering or retracting flaps. Additionally, if the flap span is increased, the flap-tip vortex will be generated further away from the wing root, resulting in a decreased impact of the vortex over the tip of the horizontal stabilizer (Figure 11).

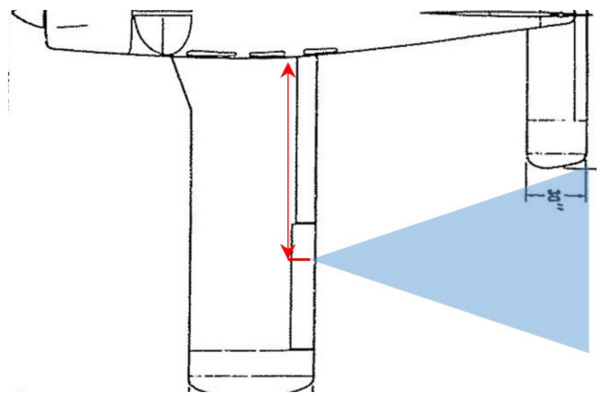

Figure 11: Flap-tip Vortex Area of Interaction with Long Span

Chapter 5
Conclusion

According to NTSB records, GA retains the highest number of fatal airplane crashes, the majority of which can be attributed to loss of control in flight. Most of these accidents occur in the traffic pattern, when the airplane is low to the ground and approaching airspeed limitations. This occurs in a critical phase of flight where the pilot has to divide his or her attention between configuration management, flying the airplane, and communicating with ATC or other aircraft in the pattern. Previous research conducted at FIT over seven of the most popular GA aircraft has shown that the control forces needed to adjust the aircraft pithing attitude, following a rapid extension of the flaps, exceeds the strength capabilities of most pilots [3]. When the pilot is not able to counteract those forces, the aircraft pitch angle will increase and the airspeed will decrease, leading to stall conditions within seconds. The cause of this pith up tendency is to be found in two aerodynamic factors: one is the downwash of the wing over the horizontal tail, the other is the vortex generated by the tip of the flaps that impact the horizontal tail. The study presented in this thesis gathered data from NTSB accident reports of the Piper Arrow III and Arrow IV. The Arrow III has a traditional tail configuration while the Arrow IV T-tail configuration. The reports found show that the T-tail model was subject to less LOC accidents compared to the traditional tail model. The hypothesis that the interaction of flap-tip vortices and the horizontal tail can cause unexpected, abrupt changes in airplane flight characteristics is strongly supported by the findings of this study. To avoid that change of configuration addition to pilot workload, and therefore setting the pilot up for failure, we encourage the aviation authorities to revise the airworthiness certification requirements by decreasing the maximum allowable longitudinal control force. On the commercial side, we also advise the manufacturers to account for aerodynamic interaction between the wing and the stabilator when designing the empennage. Additionally, we recommend aircraft manufacturers incorporate flight data recorders in the aircraft assembly process to gain a better understanding of the wing to horizontal tail interaction and the factors leading to in-flight loss of control.

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Appendices

Appendix A: Piper Arrow I-LOC NTSB Reports

Table 4: Piper Arrow III LOC NTSB Reports.

NTSB No	Event Type	Mkey	Event Date	City	State	Country	N#	Highest Injury Level
CHI99FA140	ACC	46204	1999-05-02 T10:45:00Z	CURRAN	Michigan	United States	N5274A	Fatal
SEA97LA121	ACC	42614	1997-05-26 T13:15:00Z	POCATELLO	Idaho	United States	N30563	None
MIA93FA038	ACC	33173	1992-12-27 T22:19:00Z	JACKSONVILLE	Florida	United States	N3620M	Fatal
ATL93FA039	ACC	8681	1992-12-21 T14:10:00Z	PHENIX CITY	Alabama	United States	N9319C	Fatal
CHI00FA234	ACC	49926	2000-08-02 T09:32:00Z	BELOIT	Kansas	United States	N2732Q	Fatal
NYC99LA014	ACC	45274	1998-10-21 T14:20:00Z	MATTITUCK	New York	United States	N31869	None
LAX97LA222	ACC	29819	1997-06-22 T16:00:00Z	SAN DIEGO	California	United States	N6471C	Minor
CHI96LA356	ACC	10405	1996-09-30 T11:30:00Z	CHESTERFIELD	Missouri	United States	N6008H	None
CHI95LA273	ACC	9990	1995-08-12 T00:30:00Z	WHEELING	Illinois	United States	N43847	Serious
CHI94LA173	ACC	9541	1994-05-24 T11:50:00Z	GRAND FORKS	North Dakota	United States	N804ND	None
CHI91LA156	ACC	15065	1991-05-14 T12:54:00Z	GRAND FORKS	North Dakota	United States	N804ND	None
CHI89LA050	ACC	14324	1989-02-12 T15:00:00Z	STEVENS POINT	Wisconsin	United States	N16TP	None

Table 5. Piper Arrow IV LOC NTSB Reports

NTSB No	Event Type	Mkey	Event Date	City	State	Country	N#	Highest Injury Level
NYC98FA111	ACC	39470	1998-05-23 T15:38:00Z	LINCOLN	Massachusetts	United States	N82824	Fatal
IAD05FA146	ACC	62435	2005-08-26 T21:15:00Z	Dunkirk	New York	United States	N8164H	Fatal
FTW98FA031	ACC	20386	1997-10-24 T19:12:00Z	HAZEN	Arkansas	United States	N8146R	Fatal
NYC90LA087	ACC	36627	1990-04-19 T20:30:00Z	MARSHFIELD	Massachusetts	United States	N2184N	None

Appendix B: PA-28R Specification and Performance

Table 6. Arrow Specification and Performance

PA-28R Arrow SPECIFICATION & PERFORMANCE								
	28R-180 28R-180 B	28R-200 28R-200 B	28R-200 II	28R-201 III	28R-201T III	28RT-201 IV	28RT-201T IV	28R-201 (1988 onwards)
Engine	180hp Lycoming IO-360-B1E	200hp Lycoming IO-360-C1C	200hp Lycoming IO-360-C1C	200hp Lycoming IO-360-C1C6	200hp Continental TSIO-360-F	200hp Lycoming IO-360-C1C6	200hp Continental TSIO-360-FB	200hp Lycoming IO-360-C1C6
Engine TBO (hrs)	2000	1200	1600	1600	1400	1600	1800	1600, later 2000
No of seats	4	4	4	4	4	4	4	4
Wing Span (ft/ins)	30/0	30/0	32/0	35/5	35/5	35/5	35/5	35/5
Length (ft/ins)	24/2.5	24/2.5	24/7	24/8	25/0	27/0	27/3.5	24/8
Height (ft/ins)	8/0	8/0	8/0	7/10	7/10	8/3	8/3	7/10
Usable fuel (US gal)	48	48	48	72	72	72	72	72
Max takeoff weight (lbs)	2500	2600	2650	2750	2900	2750	2900	2750
Max Ramp Weight (lbs)	2500	2600	2650	2750	2900	2750	2912	2758
Standard Equipped Weight (lbs)	1380-1431	1459-1470	1508-1531	1601	1663	1593-1641	1638-1704	1798
Useful load (lbs)	1069-1120	1130-1141	1119-1142	1149	1237	1109-1157	1208-1262	960
Propeller	Hartzell 2 blade	Hartzell 2 blade	Hartzell 2 blade	Hartzell 2 blade	Hartzell CS	McCauley 2 blade	Hartzell 2 or 3 blade	McCauley 2-blade
Max speed (kts)				152	178	152	178	152
Cruise speed (kts)	141 @ 75%	146 @ 75%	148 @ 75%	143 @ 75% 122 @ 55%	172 @ 75% 154 @ 55%	143 @ 75%	172 @ 75%	137-143 @ 75%
Fuel flow (gph)	9.4 @ 75%	10.2 @ 75%	10.2 @ 75%		14 @ 75%	10 @ 75%	12 @ 75%	12.7 @ 75%
Stall speed (kts)	53	56	56	55	58	55	56	55
Climb @ s/l (fpm)	875	910	900	831	940	831	940	831
Range with reserves (nm)	743 @ 75% 864 @ 55%	710 @ 75% 833 @ 55%	740 @ 75% 850 @ 55%	810 @ 75% 980 @ 55%	675 @ 75% 860 @ 55%	720-810 @ 75%	695-790 @ 75%	880 @ 55%
Service Ceiling (ft)	15,000	16,000	15,000	16,200	20,000	17,000	20,000	16,200
Take Off (G/R) (ft)	820	770	1025	1025	1110	1025	1110	1000
Take Off (over/50ft) (ft)	1665		1800	1600	1620	1600	1620	1600
Landing (G/R) (ft)	776	780	780	615	645	615	645	620
Landing (over 50ft) (ft)	1340		1380	1525	1555	1525	1555	1520