5-2023

A Study to Determine Performance Characteristics of the Mississippi Cowling - Piper Archer vs. Piper Warrior

Zilvinas Visockas

A Study to Determine Performance Characteristics of the Mississippi Cowling - Piper Archer vs. Piper Warrior

by

Zilvinas Visockas

A thesis submitted to the College of Engineering and Science of
Florida Institute of Technology
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Flight Test Engineering

Melbourne, Florida
May, 2023

We the undersigned committee hereby approve the attached thesis,
"A Study to Determine Performance Characteristics of the Mississippi Cowling - Piper Archer vs. Piper Warrior."
by
Zilvinas Visockas

Ralph D. Kimberlin, Dr.-Ing.
Professor
Aerospace, Physics, and Space Sciences
Major Advisor

Mary Ann Gaal, Ph.D.
Assistant Professor
Mechanical and Civil Engineering

Brian A. Kish, Ph.D.
Graduate Faculty
Aerospace, Physics, and Space Sciences

David C. Fleming, PhD.
Assistant Professor and Department Head
Aerospace, Physics, and Space Sciences

Abstract

Title: A Study to Determine Performance Characteristics of the Mississippi Cowling - Piper Archer vs. Piper Warrior

Author: Zilvinas Visockas

Advisor: Ralph Kimberlin, Ph.D.

Today, aviation is one of the most technologically advanced and innovative sectors in the world. With fast-depleting natural resources, increasing environmental pollution, and continuous growth in fuel cost, efficiency has become industry's top priority. Engineers are making gradual improvements that offer overall increase in aircraft's performance.

Drag is critical factor in aviation as it directly impacts aircraft's fuel efficiency, range, and speed. During the design phase, engineers invest significant effort and expense in attempting to minimize the drag profile by implementing aerodynamic shapes and constantly reducing component weights.

One of the real-life examples of such engineering attempts is Piper Archer, what many pilots consider to be the best compromise of power, performance, useful load, and economy in the PA28 line. Debuted in 1974, Archer is horizontally opposed, air cooled, normally aspirated, directly driven, and equipped with a Lycoming engine O-360, gaining 20-hp over its predecessor Piper Warrior. Increase in horsepower was certainly not the only improvement that resulted in Archer's dominance over the Warrior. In 1995, Piper stepped up the Archer III by incorporating a new cowling utilizing NASA inspired, University of Mississippi-developed, axisymmetric engine inlets. The idea behind the new cowling was to

gain an extra knot or two of speed, modernize the airplane's looks, and increase cooling efficiency.

The objective of this thesis is to determine the Mississippi cowling performance on the Archer and examine its drag characteristics in comparison to the Piper Warrior. Steady level flight performance test flights at different altitude configurations were conducted with each of the aircraft. Flying at 2500, 5000, and 7500 feet, the aircraft was accelerated at full throttle and maximum cruise RPM till the maximum level flight speed was reached. Once stabilized, data was collected at different time intervals with the reduction in RPM until the level flight can no longer be maintained. RPM readings were then taken using the electronic tachometer as well as O.A.T. gauge, and airspeed. This procedure was repeated until the aircraft reached the back side of the power required curve where RPM must be increased to maintain altitude and achieve a lower airspeed.

Testing revealed the evidence that the Mississippi cowling increased drag efficiency of the Piper Archer. Plotted flight performance graphs of the Archer vs. Warrior show success in Mississippi cowling design and is a valuable information for future modifications to improve aircraft performance.

Table of Contents

List of Figures

List of Tables

List of Equations

Acknowledgement

I would like to express my deepest gratitude to Dr. Ralph Kimberlin for his knowledgeable counsel towards the completion of my thesis research. His extensive experience in the aviation industry was the answer to my questions and his kind way of helping students allowed me to gain deeper insight into flight test engineering as well as get to know him as a person.

Thank you, Dr. Brian Kish, for coaching me throughout my studies at Florida Tech. Starting with his support during my undergraduate years and transitioning into graduate program, Dr. Kish taught me a great deal about Aerospace and Flight Test Engineering. The personal touch in teaching is what makes his name echo in student's memory. Thank you for always willing to help me and believing in the fundamental one-on-one connections between professor and student.

Dr. Mary Ann Gall, thank you for introducing me to the world of project management. Your taught knowledge and skills are key factors of success running business or working corporate job. Continue on demonstrating professionalism and elegance. Thank you.

A very special thank you to my fellow flight test engineering graduate student Soufiane Ait Yahia for all his help and support while working on my thesis research. Soufiane's experience as a pilot and knowledge about the aircraft and general aviation in general helped me along the way.

Dedication

I dedicate this thesis to myself. It is a reminder of a great work ethic, busy lifestyle, and the proof that nothing worth having was ever achieved without effort. I know sour, which allowes me to appreciate the sweet. Thesis research project is the fruit of long three years studies of Flight Test Engineering. I appreciate this moment.

Chapter 1
Introduction

Piper Cherokee

Piper is one of the most widely used aircraft in general aviation sector. The history of Piper Aircraft has been the subject of numerous books and research projects with over 80 years of aviation industry leadership. For aviation fanatics, the Cherokee is synonymous with Piper Aircraft Corporation. The Piper PA-28 Cherokee is a family of two-seat or four-seat light aircraft built for air taxi, flight training, and personal use. The original Piper Cherokees PA-28-150 and PA-28-160 received its type certificate from the Federal Aviation Administration back in 1960 and the series remains in production to this day. Multiple models are currently in use in general aviation including the well-known Piper Warrior and Archer.

Piper Archer vs. Piper Warrior

Debuted in 1974, the Piper Archer is what many pilots consider the best compromise of power, performance, useful load, and economy in the PA28 line. The PA28-181 Archer is horizontally opposed, air cooled, normally aspirated, directly driven and is equipped with a Lycoming engine O-360, certainly, one of the industry’s legends for reliability, durability, and economy. Archer made its entry into the aviation industry gaining 20-hp difference from the previous Cherokee models and this was not the only improvement that resulted in Archer’s dominance over the Warrior. In 1995, Piper implemented big changes on Archer’s outside design by introducing a new cowling utilizing NASA inspired, University of Mississippi-developed, axisymmetric engine intakes along with a new windshield line, upgraded panel, and a modernized interior. Reaching to glean an extra knot or two of speed, modernize the airplane’s looks, and increasing cooling efficiency was the whole purpose of the new cowling. Although the old Warrior had almost the same cruise and handling performance, Archer’s five-inch fuselage stretch allows Archer to carry four people but remain certified under the same FAR Part 23 certification as Warrior.

In order to prove the efficiency of a new cowling design, flight testing had to be performed on each of the aircraft. The analysis and comparison of data from both aircraft will help determine if the drag advantages from the upgraded cowling design did in fact improve the performance and handling qualities of the aircraft.

Chapter 2
Test Methods and Materials

Test Aircraft

The Piper Archer, after being in production over the fifty years, remains one of the longest-lived aircraft. Equipped with an advanced Garmin G1000 Avionics Suite and a four-cylinder, normally aspirated, direct drive, air-cooled, horizontally opposed, carburetor equipped Lycoming Model O-360-A4A engine charging through its pistons 180 horsepower at 2700RPM, Archer is what many pilots consider the greatest compromise of power, performance, and economy. Just like the Warrior, Archer has a four-place cabin, low wing, and a fixed tricycle landing gear. It is a modern and reliable aircraft suitable for both teaching and cross-country flying. Piper Archer is owned by Florida Institute of Technology with FAA registration N648FT (Figure 1).

Figure 1 Piper Archer

The test aircraft used to conduct the second part of this thesis was Piper Warrior with FAA registration N625FT (Figure 2Figure 2). This aircraft is also owned and operated by Florida Institute of Technology. Manufactured in 1985, the Piper Warrior is a four-place, fixed landing gear, low wing, single-engine aircraft equipped with a four-cylinder, normally aspirated, air-cooled, horizontally opposed Lycoming O-320 engine producing a maximum of 160 horsepower at 2700 RPM. The aircraft has a fixed pitch propeller and conventional flight controls with full flaps setting corresponding to 40 degrees of flap deflection. The maximum gross takeoff weight of the aircraft is 2440 pounds.

Figure 2 Piper Warrior

Instrumentation

The Piper Warrior instrument panel is designed to accommodate for VFR and IFR flights. Equipped with standard instruments that include a compass, an airspeed indicator, a tachometer, and an altimeter, the system supplies both ram and static pressure. The aircraft is also equipped with two Garmin 5 (Figure 3**Error! Reference source not found.**) attitude indicators offering reversionary display capability and added redundancy of dual ADAHRS and dual back up batteries. Although the altimeter error is less than 50 feet, the accuracy of both altimeter and the airspeed indicator is not enough for the purpose of this thesis. Therefore, the airspeed and altitude data was collected from the G5 replacing the traditional electromechanical instruments. Despite Warrior's OEM traditional 3 1/8' marked recording tachometer, with 50-2700 green, 2700 red, an electric propeller tachometer was used to read the blade passage (Figure 4Figure 4).

Figure 3 Garmin G5 Electronic Flight Instrument

Alike the Warrior, Archer’s electrical system is capable of supplying sufficient current to all the required equipment for day/night IFR and day/night VFR operations. The Piper Archer uses a modern glass cockpit, with no need to use vacuum pump driven spinning gyros to determine altitude. The instrument panel is designed to accommodate the Garmin G1000 system that has an Attitude and Heading Reference Systems (AHRS) used to determine the aircraft pitch, roll, and yaw and have AiR Data Computers (ADC) to give altitude and airspeeds. Just like the Piper Warrior, the airspeed readings are not accurate enough, since it is limited by the certification range that Garmin has forth. Since the production RPM gauge or the GARMIN G1000 is not accurate enough, optical tachometer was used to read the RPM precisely.

Figure 4 Optical Tachometer

Flight Test Plan

The level flight performance of an aircraft is the measurement of power required for the aircraft to remain in steady, level flight. In flight testing, the determination of engine power serves two purposes, to determine the engine power as installed in the airframe and to measure the drag of the airplane with the propulsive system operating. Having in mind aircraft's induction, exhaust, cooling system, and engine accessories interaction effects on engine's power of the propeller-driven airplanes, tests performed on the manufacturer's test stand will cause data errors. In order to take care of some of these interaction effects, the PIW-VIW method was used in this research. Test flights were conducted taking off from the FIT Aviation facility at Melbourne International Airport (KLMB) in Melbourne, Florida. Testing was performed in areas to the east and southwest of the airport over the Atlantic Ocean under Visual Flight Rules (VFR), early morning in calm winds and temperatures close to standard day within the limits of the Piper operator's manual (Figure 5Figure 5). Considering the fact that both airplanes do not have manifold pressure gauges, the power output for comparison was determined flying at three altitudes in order to obtain a good data sample: 2500, 5000, and 7500 feet at a constant altitude in steady level flight, the aircraft was accelerated at full throttle and maximum cruise RPM till the maximum level flight speed was reached. Once stabilized, data was collected at different time intervals with the reduction in power setting (RPM) until the level flight could no longer be maintained. RPM readings were taken using the electronic tachometer as well as O.A.T. gauge, and airspeed. This procedure was repeated until the aircraft reached the back side of the power required curve where RPM had to be increased to maintain altitude and achieve lower airspeed. The same flight test procedure was followed for both, Warrior and Archer aircraft taking average one hour and twenty minutes each.

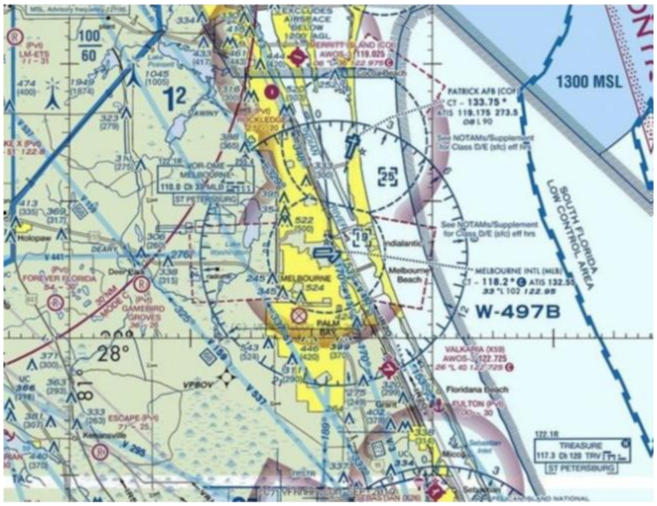


Figure 5 Test Location

Flight Log

Table 1 Flight Log

Date	Aircraft	Crew	HOBBS (h)
03/02/2023	Piper Archer N648FT	Soufiane Ait Yahia Zilvinas Visockas	1.3
03/04/2023	Piper Warrior N625FT	Soufiane Ait Yahia Zilvinas Visockas	1.1

The flight testing crew consisted of the pilot Soufiane Ait Yahia and a crew member Zilvinas Visockas who collected the data. Using the benefits of working as a Flight Instructor over at FIT Aviation, Soufiane was able to rent both aircraft which was a huge help in the process of thesis research. Piper Archer was flown on March 2nd and the Warrior, two days later, on March 4th. Aircraft took off from runways 5 and 23.

Figure 6 Flight Test Crew

Chapter 3
Data

Data Reduction

Collected data was reduced using the Microcoft Office Excel. The very first step in the data reduction process was calibrating the airspeed using charts from the Piper POH. Indicated altitude was also corrected using the graph. In flight test, the importance of reducing data to sea level standard day values is vital, since flight testing was not performed in standard conditions. Further on in the data reduction process, the instrument corrected altitude was corrected to sea level standard pressure ratio δ (Equation 2**Error! Reference source not found.**) and the outside air temperature was corrected to sea level standard temperature ratio θ (Equation 1**Error! Reference source not found.**). Test aircraft's weight at each data point was determined leading in to the weight ratio (Equation 4**Error! Reference source not found.**) and density ratio (Equation 3) calculations. The amount of fuel burned was then subtracted from the weight before the take off.

$\sigma - density\ ratio$

$\delta - ambient\ density$

$\theta - sea\ level\ density$

Equation 1 Temperature Ratio

$$\theta = \frac{273.15 + OAT(C°)}{288.15}$$

Equation 2 Pressure Ratio

$$\delta = (1 - (6.87535 * 10^{-6}) * Instrument\ Corrected\ Altitude)^{5.2561}$$

Equation 3 Test Density Ratio

$$\sigma = \frac{\delta}{\theta}$$

Equation 4 Weight Ratio

$$Weight\ Ratio = \frac{W_T}{W_S}$$

$W_T - Test\ Aircraft\ Weight$

$W_S - max\ gross\ weight$

$W_T = W_{TOTAL} - ((Total\ Fuel - Fuel\ Burned) * 6$

$W_{TOTAL} = W_{RAMP\ WEIGHT}$

Then the RPM was corrected for density and weight in a manner similar to that used for the PIW and VIW terms and call it NIW.

Equation 5 RPM Correction to Sea Level Sandard Day

$$NIW = \frac{RPM - \sqrt{\sigma}}{\sqrt{\frac{W_T}{W_S}}}$$

Finally, after reducing the RPM to a Sea Level standard day value, power can be determined at each data point by multiplying the propeller load curve constant by the RPM cubed.

K - Constant units of (HP/RPM3)

Equation 6 Power

$$HP = K * NIW^3$$

We can now proceed to instrument/weight corrected power (PIW) and instrument/weight corrected velocity (VIW) calculations for each test point. The power term, PIW, was determined. For fixed-pitch propellers, propeller efficiency cannot be assumed, since the the change in RPM is so great with change in power. The plot of PIW vs NIW provides the method of relating the engine power to the RPM.

Equation 7 Corrected Horsepower for Weight and Density

$$PIW = \frac{HP\sqrt{\sigma}}{\frac{W_T}{W_S}^{1.5}}$$

Equation 8 Corrected Airspeed for Weight and Density

$$VIW = \frac{V_C}{\sqrt{\frac{W_T}{W_S}}}$$

Sample Calculations

Sample calculations for Piper Archer at 2500ft altitude test point number 3:

$OAT = 20(C°)$

$\theta = \frac{273.15 + 20(C°)}{288.15} = 1.01735$

$Instrument\ Corrected\ Altitude = 2599$

$\delta = (1 - (6.87535 * 10^{-6}) * 2599)^{5.2561} = 0.90958$

$$\sigma = \frac{0.909581}{1.017352} = 0.89407$$

$$Piper\ Archer\ Max\ Gross\ Weight = 2558lb$$

$$W_{RAMP\ WEIGHT} = 2411lb$$

$$Piper\ Archer\ Standard\ Weight = 2558lb$$

$$Take\ off\ fuel = 48\ gallons$$

$$Weight\ Ratio = \frac{2411 - ((48 - 45) * 6)}{2558} = 0.935496$$

$$NIW = \frac{2403 - \sqrt{0.89407}}{\sqrt{0.935496}} = 2349.19$$

$$HP = 8.317 * 10^{-9} * 2349.19^3 = 107.8251996$$

$$PIW = \frac{107.8251996 * \sqrt{0.89407}}{0.935496^{1.5}} = 112.679$$

$$VIW = \frac{106}{\sqrt{0.935496}} = 109.593$$

Data Analysis

Figure 7 represents Piper Archer propeller load curves for three different altitudes: 2500, 5000, and 7500 feet. X-axis represents revolutions per minute (RPM) of the propeller while y-axis represents the power necessary to propel the propeller at a given velocity. Analyzing the graph one can see, that as the RPM increases, the power required to push the propeller also increases. This is to be expected as more energy is required to move the propeller faster through the air. Going up in altitude, the power required to spin the propeller at a given RPM setting increases. Overall thrust available decreases but the the amount of horsepower required to sustain the same RPM at higher altitudes increases. (Figure 7) shows that at the lower altitude less power is required for a given RPM setting For instance, Archer flying at 2500 feet, the propeller requires 62hp at 2000 RPM setting while flying at 7500 feet – 66HP. The airplane is unable to maintain level flight at a higher RPM as the altitude increases. This can also be expected since there is a decrease in performance as the air is less dense. Air density decreases as the altitude goes up, reducing the amount of thrust generated by the propeller which shows altitude’s impact on naturally aspirated combustion engines’s performance. In comparison to the Piper Archer, Piper Warrior (Figure 8) has a higher power required to sustain level flight.

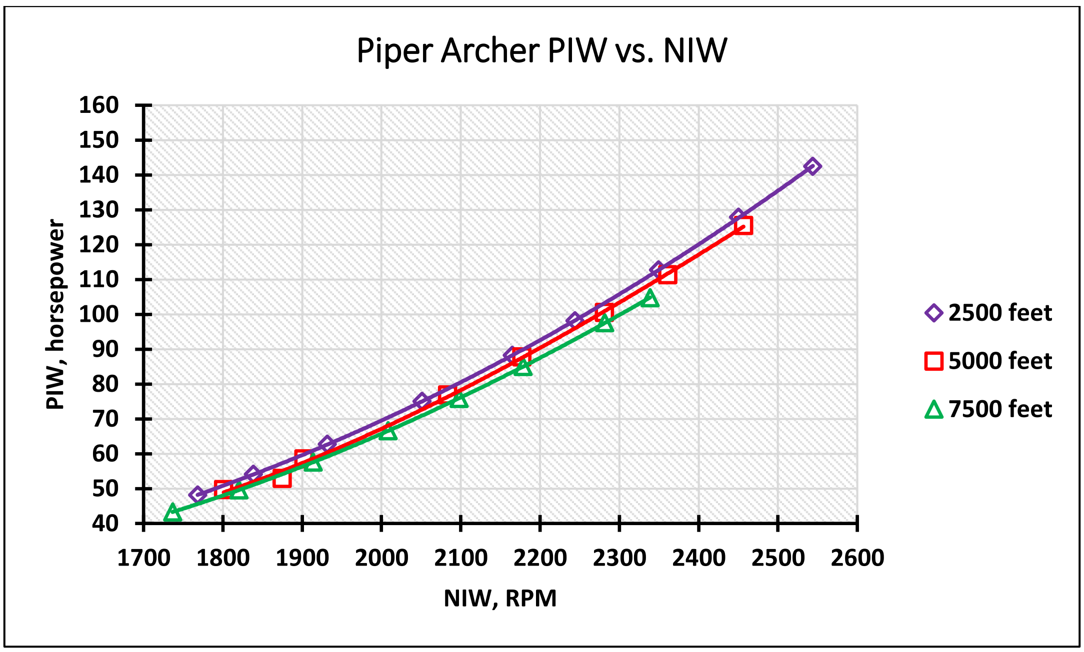


Figure 7 Piper Archer Propeller Load Curves at 2500ft, 5000ft; 7500ft

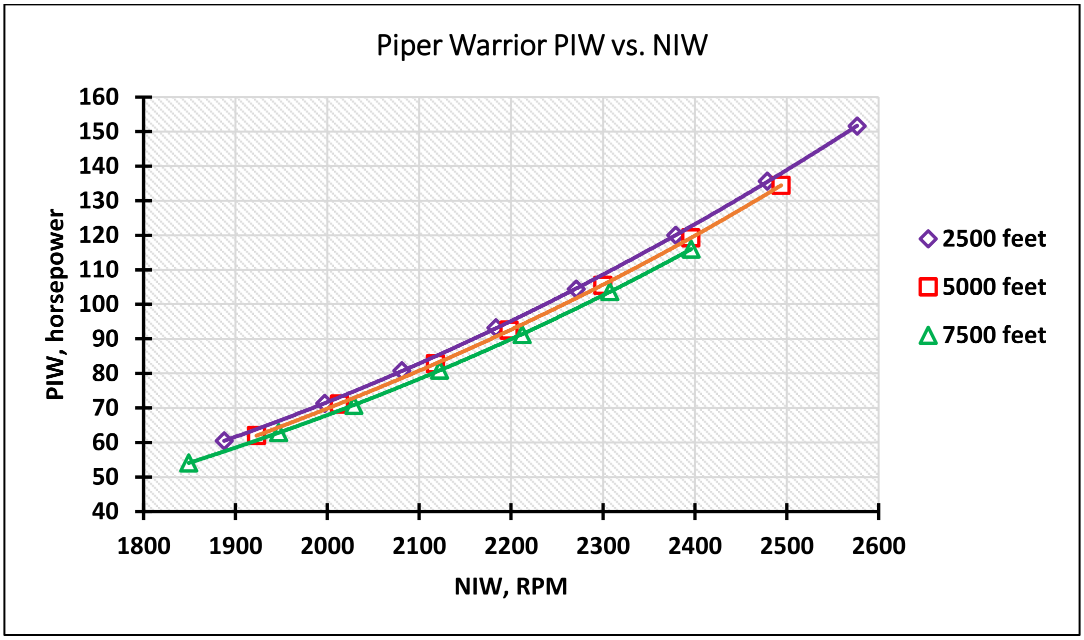


Figure 8 Piper Warrior Propeller Load Curves at 2500ft, 5000ft; 7500ft

Figures 7 and 8 provide valuable information about the performance characteristics of a fixed-pitched propeller at different altitudes. However, the main objective is to prove the decrease in drag on the Archer vs. Warrior. Drag curves were obtained for both aircraft allowing us to determine the drag measurement for the airplane. The VIW vs. PIW graph has all altitudes accounted for a single trendline. The minimum of this curve is the minimum drag.(Figure 9) represents the drag curve for Piper Archer. PIW in the y-axis is the horsepower corrected for weight and density and VIW is the airspeed corrected for weight and density on the x axis. The equation obtained is a second order function representing the drag of the aircraft. As it was expected, obtained drag curves indicate Mississippi cowling’s positive impact on Archer’s drag reduction.

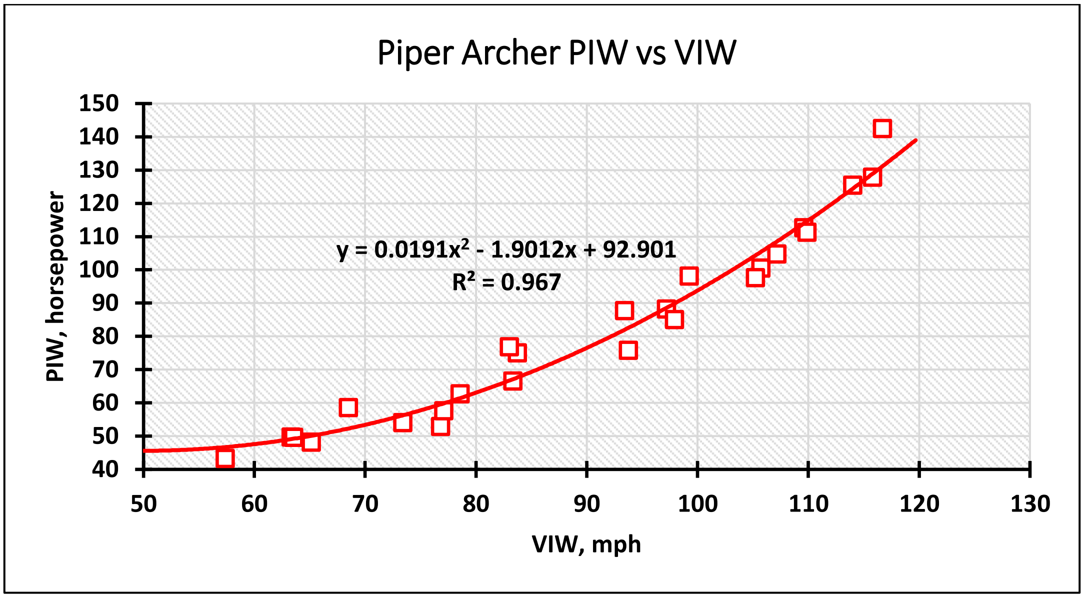


Figure 9 Piper Archer Drag Curve

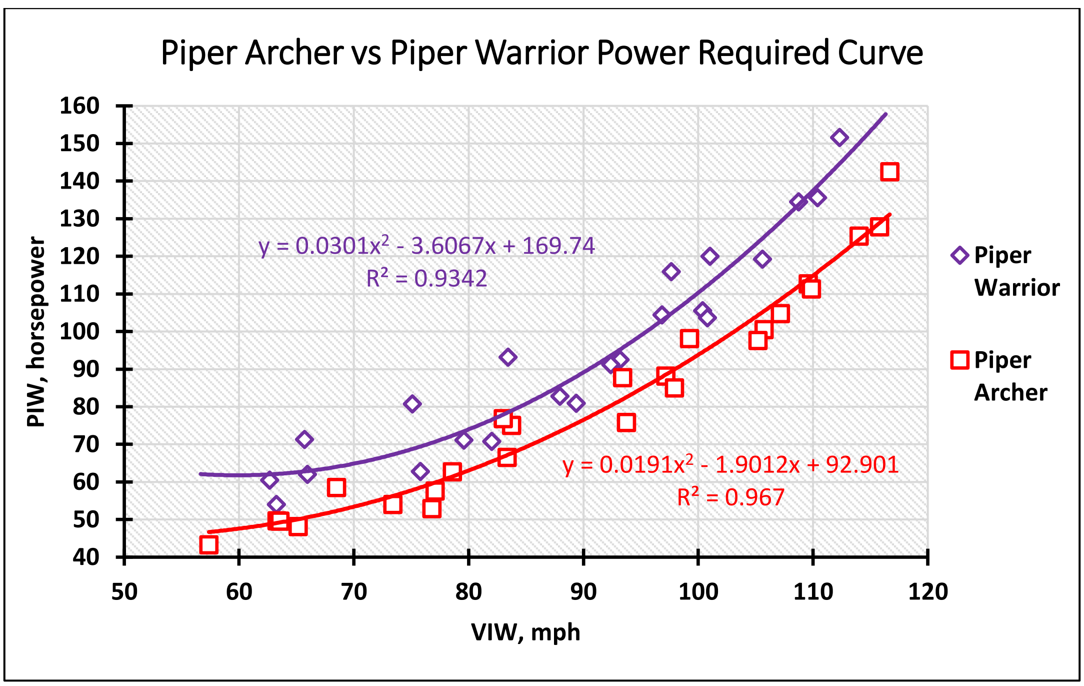


Figure 10 Piper Archer vs. Piper Warrior Drag Curves

Chapter 4
Conclusion and Future Work

Conclusion

The research explored Mississippi cowling modification on Piper Archer and its effects on drag performance in comparison to the Piper Warrior. Two test flights were successfully performed and the data collected was presented in the form of graphs. Obtained propeller load curves as well as drag curves proved Mississippi cowling's significant advantages in reducing drag. Compared to the standard Piper Warrior cowling, the Mississippi cowling with the NACA duct inlet creates a more efficient flow of air to the engine resulting in less turbulent airflow and increased overall efficiency. Additionally, with the streamlined Mississippi cowling design, less surface area to airflow is exposed which further reduces drag. For the same RPM setting at any given altitude, Archer requires less horsepower which shows the Mississippi cowling's drag reduction benefits. However, while there is clear proof of the improvement in drag performance on the Piper Archer, it is important to keep in mind both aircraft age, powerplant, propellers, and airframe. Wear and tear over the years could have an impact on aircraft performance and accuracy of the data collected. Overall, the Mississippi cowling design is a valuable improvement on the Piper Archer boosting its aerodynamic performance, providing a more efficient airflow and reduced drag.

The execusion of this research project was a complex process. Due to lack of resources, the research was conducted with a help of my fellow graduate student Soufiane Ait Yahia. Soufian's professional situation, him working as a flight instructor at the Florida Institute of Trchnology Flight Line, had a profound effect on the progress of this thesis. Soufiane's ability to rent and fly both airplanes while I was collecting the data was a huge help. Cost of rented aircraft was our personal expense.

Future Work

This thesis research project on the Mississippi cowling modification to the Pieper Archer is a great proof of how important minor changes are in aviation industry. Small changes to the airplane's design can have a significant impact on its aerodynamic performance. Today, as the aviation industry continues to evolve, the importance of flight test developing new aircraft and improving existing ones is utmost. It remains an essential part of aircraft design and certification, as it gives valuable data that cannot be obtained using advanced technologies such as computational fluid dynamics.

The Mississippi cowling design is a good example of how flight testing can validate something that could possibly be only predicted by using advanced technologies. By conducting flight test engineering on the Piper Archer, equipped with the Mississippi cowling modification, other important parameters of the aircraft can be determined. Further testing could be done to evaluate how Mississippi cowling design affects range, fuel efficiency, and handling characteristics. Results could lead into greater design improvements.

References

R. D. Kimberlin, Flight Testing of Fixed-Wing Aircraft, Reston, VA: American Institute of Aeronautics and Astronautics, 2003.

NASA. (2013, August 8). An exploratory investigation of the cooling drag associated with general aviation propulsive systems - NASA technical reports server (NTRS). NASA. Retrieved April 12, 2023, from https://ntrs.nasa.gov/citations/19760003929

Piper Archer. AOPA. (2020, September 10). Retrieved April 9, 2023, from https://www.aopa.org/go-fly/aircraft-and-ownership/aircraft-guide/aircraft/piper-archer

Cox, B. (2019, October 21). *Archer*. Piper Owner Society. Retrieved April 9, 2023, from https://piperowner.org/archer/

Piper Cherokee. AOPA. (2009, September 23). Retrieved April 9, 2023, from https://www.aopa.org/go-fly/aircraft-and-ownership/aircraft-fact-sheets/piper-cherokee

Piper Aircraft. (1982). Warrior II. PA-28-161 Pilot's Operating Handbook. Vero Beach.

Appendix A

Flight Test Plan

Purpose

The purpose of this test is to determine if there is a reduction in drag after the installation of the new Mississippi cowling on the Piper Archer in comparison to the Piper Warrior.

Scope of Test

The evaluation will be conducted at Melbourne International Airport, Melbourne, Florida during daylight under Visual Flight Rules (VFR). The evaluation will be conducted in 2 flight tests.

Test Envelope

Testing will be conducted early morning in calm winds and temperatures closer to standard day with the limits of the Piper operator's manual. Tests will include a low altitude, medium altitude, and high-altitude points.

Test Loadings

The airplane will have one pilot and one flight test engineer collecting the data. Aircraft weight will vary only due to the amount of fuel used during the flights.

Method of Test

Tests will be conducted at three altitudes: 2500, 5000, and 7500 feet. At a constant altitude in steady level flight, the aircraft is accelerated at full throttle and maximum cruise RPM till the maximum level flight speed is reached. Once stabilized, data is collected at different time intervals with the reduction in RPM until the level flight can no longer be maintained.

RPM readings will be taken using the electronic tachometer as well as O.A.T. gauge, and airspeed. This procedure is repeated until the aircraft reaches the back side of the power required curve where RPM must be increased to maintain altitude and achieve a lower airspeed.

Instrumentation and Data Extraction/Processing

Propeller tachometer is the external equipment required to collect the desired test data. Data will be recorded manually.

The following will be taken at each data point:

1. Pressure altitude

2. RPM standard gauge

3. RPM tachometer reading

4. OAT

5. Airspeed

Safety Considerations

Prior to performing flight testing, test crew must be well familiarized with aircraft limitations. Flights shall be conducted within the limitations set forth by the Pilot Operating Handbook. Should any unusual handling characteristics or vibrations occur, testing will be terminated.

Risk Management

Flights will be conducted early in the morning in VFR conditions over the Melbourne's shoreline and at proximity of Valkaria and Melbourne Airport. In case of any weather or technical anomalies, the pilot will land at one of the closest airports. The pilot will use his decision making to terminate the fight at any time it is deemed unsafe.

Appendix B

Raw Data

ARCHER

		Airspeed		Altitude															
	Test Pt.	Indicated Airspeed (mph)	Calibrated Airspeed (mph)	Indicated Altitude (ft)	Instrument Corrected Altitude (ft)	OAT (C°)	RPM	Fuel Qty. (gal)	Ts (C°)	Weight Ratio	δ	θ	Density Ratio σ	NIW	VIW	PIW	HP		
2500	1	113	114	2600	2630	20	2607	46	9.74	0.937842	0.908544	1.017352	0.893048	2543.98	116.6846	142.4789	136.9328298	Ramp Weight [lbs.]	2411
	2	112	113	2560	2590	20	2506	45	9.82	0.935496	0.909883	1.017352	0.894364	2450.288	115.7969	127.8827	122.3539178	Archer Standard Weight [lbs.]	2558
	3	106	106	2569	2599	20	2403	45	9.802	0.935496	0.909581	1.017352	0.894068	2349.188	109.5935	112.6788	107.8251996	Full Fuel [gal]	48
	4	96	96	2610	2640	20	2297	45	9.72	0.935496	0.90821	1.017352	0.89272	2243.869	99.25449	98.11905	93.96346876		
	5	94	95	2580	2610	20	2215	45	9.78	0.935496	0.909213	1.017352	0.893706	2164.96	97.18669	88.17602	84.39495232		
	6	81	83	2540	2570	20	2097	45	9.86	0.935496	0.910552	1.017352	0.895022	2051.135	83.74597	75.04174	71.77105065		
	7	76	79	2540	2570	20	1975	45	9.86	0.935496	0.910552	1.017352	0.895022	1931.803	78.57647	62.69154	59.95912858		
	8	71	76	2500	2530	20	1878	45	9.94	0.935496	0.911893	1.017352	0.89634	1838.277	73.40697	54.05954	51.66533384		
	9	63	68	2460	2490	20	1805	45	10.02	0.935496	0.913235	1.017352	0.897659	1768.121	65.13576	48.13875	45.97294129		
5000	1	110	110	5060	5100	13	2594	43	4.8	0.930805	0.828938	0.993059	0.834732	2456.484	114.0153	125.4278	123.2845222		
	2	106	106	5060	5100	13	2493	43	4.8	0.930805	0.828938	0.993059	0.834732	2360.838	109.8693	111.3398	109.4373269		
	3	102	102	5020	5060	13	2407	43	4.88	0.930805	0.83018	0.993059	0.835983	2281.105	105.7233	100.5109	98.71943269		
	4	90	92	5010	5050	13	2294	42	4.9	0.92846	0.830491	0.993059	0.836296	2177.167	93.40303	87.73594	85.83060709		
	5	80	83	5010	5050	13	2195	42	4.9	0.92846	0.830491	0.993059	0.836296	2083.209	83.02492	76.86008	75.19094055		
	6	74	78	5040	8080	13	2092	42	-1.16	0.92846	0.740511	0.993059	0.745686	1874.814	76.79805	52.90235	54.80768681		
	7	66	71	5000	5040	13	2004	42	4.92	0.92846	0.830802	0.993059	0.836609	1902.293	68.49556	58.535	57.25309505		
	8	61	66	4950	5030	13	1897	42	4.94	0.92846	0.831113	0.993059	0.836922	1801.061	63.3065	49.68778	48.59053344		
7500	1	103	103	7480	7523	12	2571	40	-0.046	0.923769	0.75643	0.989589	0.764388	2338.716	107.1657	104.7637	106.3895302		
	2	101	101	7500	7543	12	2506	39	-0.086	0.921423	0.755853	0.989589	0.763806	2281.618	105.2184	97.61091	98.78602783		
	3	94	95	7500	7543	12	2393	39	-0.086	0.921423	0.755853	0.989589	0.763806	2178.736	97.92607	84.99302	86.01623292		
	4	90	92	7520	7563	12	2305	39	-0.126	0.921423	0.755277	0.989589	0.763223	2097.815	93.759	75.8413	76.78360404		
	5	80	83	7500	7543	12	2206	39	-0.086	0.921423	0.755853	0.989589	0.763806	2008.479	83.34134	66.58428	67.38587115		
	6	74	78	7520	7563	12	2103	39	-0.126	0.921423	0.755277	0.989589	0.763223	1913.972	77.09074	57.59845	58.31409257		
	7	61	66	7450	7483	12	1997	39	0.034	0.921423	0.757583	0.989589	0.765554	1820.273	63.54777	49.62211	50.16212691		
	8	55	60	7420	7463	12	1902	38	0.074	0.919077	0.758161	0.989589	0.766137	1736.552	57.37024	43.26684	43.5542006		

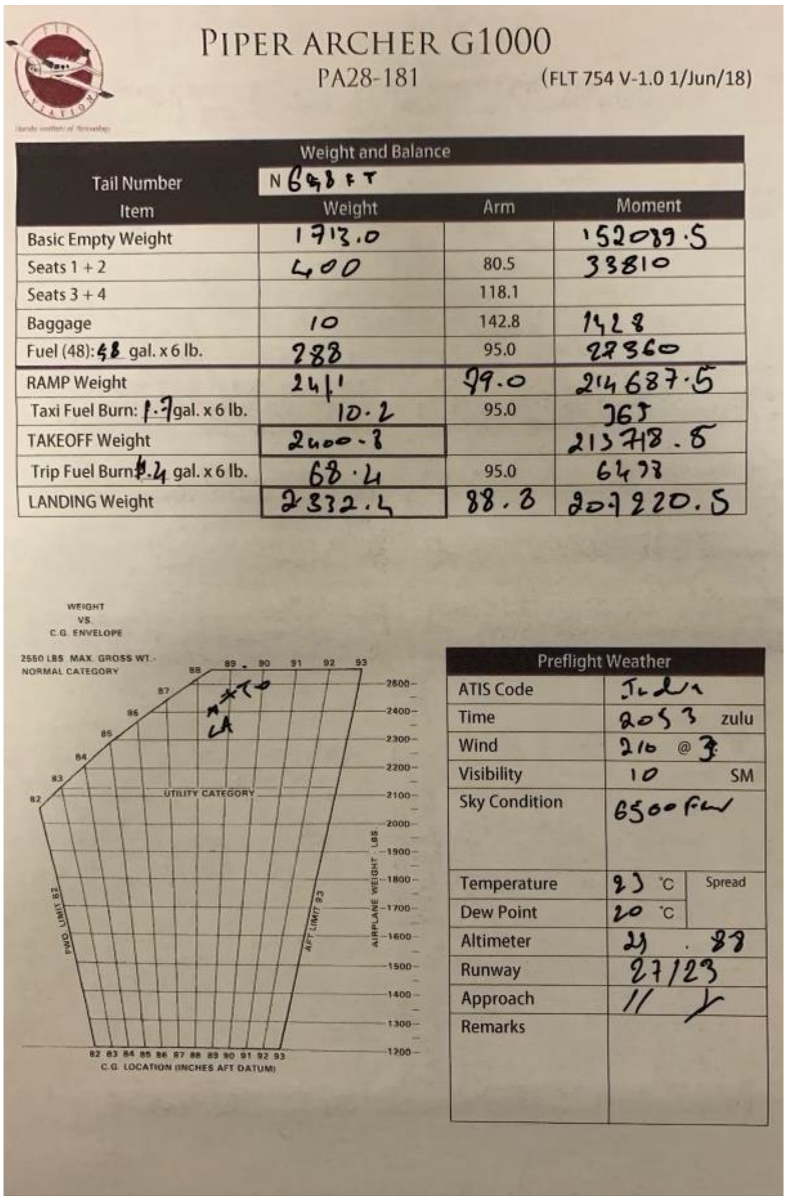
Figure 11 Data Reduction for Piper Archer

WARRIOR																			
		Airspeed		Altitude															
	Test Pt.	Indicated Airspeed (mph)	Calibrated Airspeed (mph)	Indicated Altitude (ft)	Instrument Corrected Altitude (ft)	OAT (C°)	RPM	Fuel Qty. (gal)	Ts (C°)	Weight Ratio	δ	θ	Density Ratio σ	NIW	VIW	PIW	HP		
2500	1	108	109	2560	2590	19	2615	46	9.82	0.924397	0.909883	1.013882	0.897425	2576.567	112.3297	151.636	142.262705	Ramp Weight [lbs.]	2274
	2	106	107	2530	2560	19	2511	45	9.88	0.921945	0.910887	1.013882	0.898416	2478.751	110.396	135.6271	126.6675447	Archer Standard Weight [lbs.]	2447
	3	97	98	2500	2530	19	2409	45	9.94	0.921945	0.911893	1.013882	0.899408	2379.373	101.0227	120.0259	112.0351853	Full fuel [gal]	48
	4	93	94	2470	2500	19	2298	45	10	0.921945	0.9129	1.013882	0.900401	2270.991	96.85686	104.4174	97.41207209		
	5	80	81	2460	2490	19	2206	44	10.02	0.919493	0.913235	1.013882	0.900732	2183.378	83.42875	93.18125	86.56725017		
	6	72	73	2440	2470	19	2102	44	10.06	0.919493	0.913907	1.013882	0.901394	2081.21	75.08587	80.73258	74.97461256		
	7	63	65	2460	2490	19	2018	44	10.02	0.919493	0.913235	1.013882	0.900732	1997.306	65.70014	71.33054	66.26749952		
	8	60	63	2440	2470	19	1904	43	10.06	0.917041	0.913907	1.013882	0.901394	1887.687	62.65516	60.48261	55.9443749		
5000	1	104	104	5080	5120	14	2616	42	4.76	0.914589	0.828317	0.99653	0.831202	2493.893	108.7478	134.4666	129.0031735		
	2	101	100	5060	5100	14	2512	42	4.8	0.914589	0.828938	0.99653	0.831825	2395.645	105.6108	119.2369	114.3494432		
	3	96	96	5030	5070	14	2410	42	4.86	0.914589	0.82987	0.99653	0.83276	2299.661	100.3825	105.5307	101.148188		
	4	89	89	5000	5040	14	2299	41	4.92	0.912137	0.830802	0.99653	0.833695	2197.923	93.18798	92.55881	88.30888579		
	5	84	85	5000	5040	14	2215	41	4.92	0.912137	0.830802	0.99653	0.833695	2117.617	87.9527	82.77936	78.97846398		
	6	76	78	4980	5020	14	2105	41	4.96	0.912137	0.831424	0.99653	0.83432	2013.206	79.57625	71.15533	67.86275519		
	7	63	66	4990	5030	14	2011	41	4.94	0.912137	0.831113	0.99653	0.834008	1922.945	65.96452	61.99579	59.13812621		
7500	1	93	93	7560	7603	10	2605	39	-0.206	0.907233	0.754126	0.982648	0.767443	2395.915	97.63903	115.9646	114.3880623		
	2	96	96	7540	7583	10	2508	39	-0.166	0.907233	0.754702	0.982648	0.768029	2307.58	100.7887	103.6447	102.1967018		
	3	88	88	7540	7583	10	2404	39	-0.166	0.907233	0.754702	0.982648	0.768029	2211.891	92.38962	91.27837	90.00314256		
	4	85	85	7530	7573	10	2303	38	-0.146	0.904781	0.754989	0.982648	0.768321	2122.236	89.36081	80.96615	79.49640492		
	5	78	80	7510	7553	10	2201	38	-0.106	0.904781	0.755565	0.982648	0.768907	2029.015	82.00169	70.78545	69.47402454		
	6	72	74	7480	7523	10	2108	37	-0.046	0.902329	0.75643	0.982648	0.769787	1947.033	75.79664	62.83831	61.38847127		
	7	60	65	7470	7513	10	1999	36	-0.026	0.899877	0.756718	0.982648	0.770081	1849.223	63.24986	54.06638	52.59376474		

Figure 12 Data Reduction for Piper Warrior

Appendix C

Weight and Balance



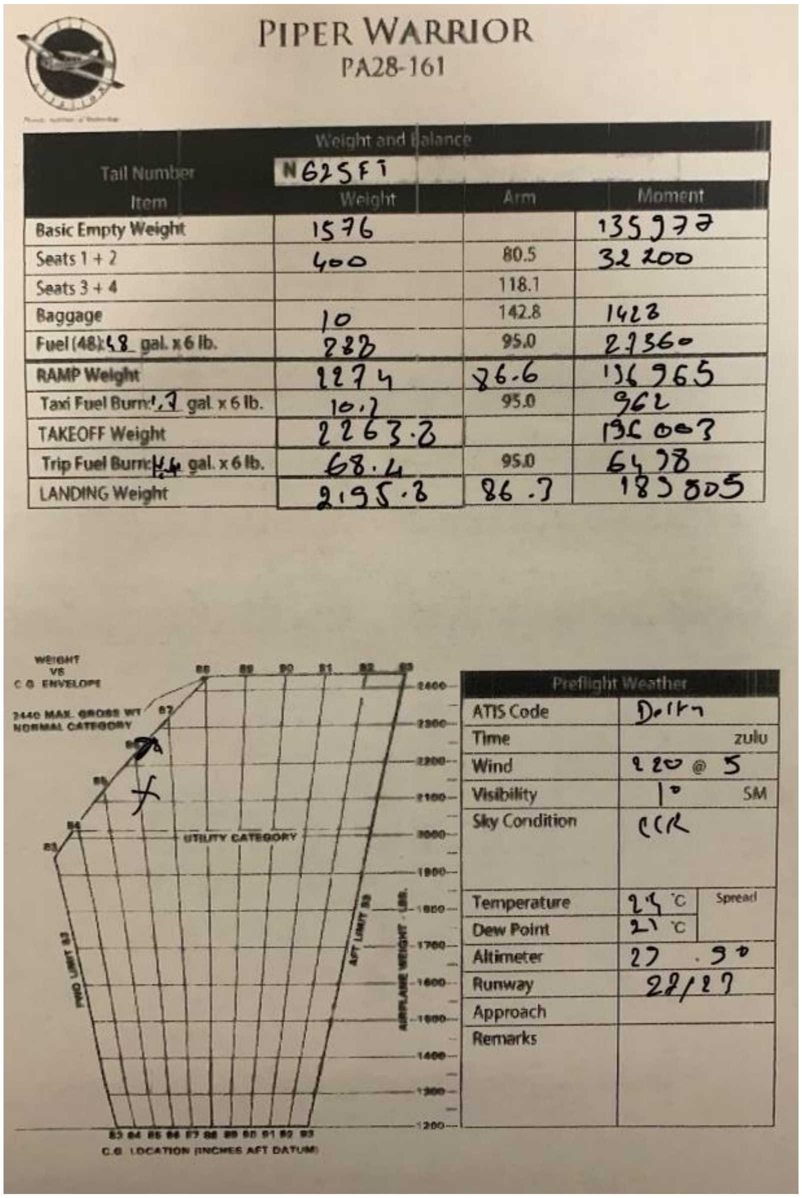
PIPER ARCHER G1000

PA28-181 (FLT 754 V-1.0 1/Jun/18)

Weight and Balance			
Tail Number	N 6?8 FT		
Item	Weight	Arm	Moment
Basic Empty Weight	1713.0		152089.5
Seats 1 + 2	400	80.5	33810
Seats 3 + 4		118.1	
Baggage	10	142.8	1428
Fuel (48): 48 gal. x 6 lb.	288	95.0	27360
RAMP Weight	2411	89.0	214687.5
Taxi Fuel Burn: 1.7 gal. x 6 lb.	10.2	95.0	969
TAKEOFF Weight	2400.8		213718.5
Trip Fuel Burn: 11.4 gal. x 6 lb.	68.4	95.0	6498
LANDING Weight	2332.4	88.8	207220.5

Preflight Weather		
ATIS Code	Julia	
Time	2053	zulu
Wind	210 @ 3	
Visibility	10	SM
Sky Condition	6500 FEW	
Temperature	23 °C	Spread
Dew Point	20 °C	
Altimeter	29 . 88	
Runway	27/23	
Approach	✓	
Remarks		

Figure 13 Piper Archer Weight and Balance



PIPER WARRIOR

PA28-161

Weight and Balance			
Tail Number	N625FT		
Item	Weight	Arm	Moment
Basic Empty Weight	1576		135972
Seats 1 + 2	400	80.5	32200
Seats 3 + 4		118.1	
Baggage	10	142.8	1428
Fuel (48): 48 gal. x 6 lb.	288	95.0	27360
RAMP Weight	2274	86.6	196965
Taxi Fuel Burn: 1.7 gal. x 6 lb.	10.2	95.0	962
TAKEOFF Weight	2263.8		196003
Trip Fuel Burn: 11.4 gal. x 6 lb.	68.4	95.0	6498
LANDING Weight	2195.3	86.7	189505

Preflight Weather		
ATIS Code	Delta	
Time		zulu
Wind	220 @ 5	
Visibility	10	SM
Sky Condition	CLR	
Temperature	25 °C	Spread
Dew Point	21 °C	
Altimeter	27 . 90	
Runway	28/27	
Approach		
Remarks		

Figure 14 13 Piper Warrior Weight and Balance