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Determining Performance Characteristics from the Mississippi Cowling - Piper Warrior vs. Piper Archer

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by

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Abstract

Title: Determining Performance Characteristics from the Mississippi Cowling - Piper Warrior vs. Piper Archer

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Today, Piper is one of the most used aircraft in the 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 their 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.

The Piper Archer debuted in 1974. This last, 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. The Archer is also equipped with improved avionics Garmin 1000.

Certainly, one of the industry's legends for reliability, durability, and economy. The Piper Archer also gained a 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 stepped up the Archer III by incorporating a new cowling utilizing NASA inspired, University of Mississippi-developed, axisymmetric engine inlets, a new windshield line, an improved panel, and a

revamped interior. The idea behind the new cowling was to glean an extra knot or two of speed, modernize the airplane’s looks, and increase cooling efficiency. Though the old Warrior had almost the same cruise and handling performance, Archer has the capability to carry four people but remains certified under the same FAR Part 23 certification as Warrior.

Following these changes, one can only wonder how efficient they are. These alterations obviously influenced the handling and performance qualities of the aircraft. To determine the changes, we have decided to make two sorties on the aircraft. The FIT Aviation uses the Piper Archer and Piper Warrior as part of their training fleet. The sorties will be conducted on one of the aircrafts from FITA.

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Acknowledgement

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Finally, I would like to thank my family for providing support and motivation.

Without their sacrifices and encouragements, even thousands of miles away, achieving a higher education would not be possible without them.

Chapter 1
Introduction

The performance of an aircraft is a critical factor in ensuring its safe and efficient operation. In this study, we aim to determine the effect of changes made to two aircraft models on their flight performance. Specifically, we will be analyzing data collected from two aircraft in the training fleet at FIT Aviation: the Piper Archer and Piper Warrior. We believe the NACA duct inlet on the Piper Archer facilitates a more efficient flow of air directly to the engine, reducing turbulent airflow that could contribute to drag. This, in turn, improves the aircraft's overall aerodynamic efficiency and results in lower drag. Secondly, the streamlined design of the Mississippi cowling means that it has less surface area exposed to airflow, resulting in less drag compared to the standard cowling on the Piper Warrior.

To determine the effect of the changes on the performance we decided to conduct two sorties on the Piper Archer and Piper Warrior aircraft. The analysis and comparison of the data from both aircrafts will help determine if the increased horsepower affects the aircraft's performance and if the drag advantages from the upgraded cowling design did in fact improve the performance qualities of the aircraft. Determining performance can also give a prediction of the handling qualities of the aircraft. A change in performance whether it is lift, drag, excess power or power required will change the handling qualities of the airplane. The handling qualities are dependent on the mission of the aircraft.

The certification of aircraft in the United States is overseen by the Federal Aviation Administration (FAA). To be considered safe and airworthy, an aircraft must comply with the certification regulations developed by the FAA. These regulations cover various aspects of an aircraft's design, such as flight qualities, structural design, performance, required equipment, and operating limitations. Different certification regulations exist, and the applicable one depends on factors like the aircraft's type, size, and mission. For example, Part 23 of Title 14 of the Code of Federal Regulations governs the certification of airplanes that weigh 12,500 pounds or less, hold no more than 9 passengers, and are used for recreational, training, personal travel, and limited commercial purposes. The same regulation also applies to commuter category airplanes weighing 19,000 pounds or less and holding no more than 19 passengers. The presented research focuses on these two aircrafts certified under Part 23, specifically under 14 CFR 23 Subpart B 23.2100- 23.2130.

Chapter 2
Test Methods and Materials

Test Aircraft

The PA-28-161 Piper Warrior with FAA registration N618FT, shown in Figure 1, is the test aircraft owned and operated by the College of Aeronautics at Florida Institute of Technology and FIT Aviation. It is a single-engine light trainer with a maximum gross takeoff weight of 2440 pounds. This low-wing, fixed landing gear, four-place aircraft is powered by a normally aspirated Lycoming O-320 engine that can produce a maximum of 160 hp. The aircraft has conventional flight controls and a fixed-pitch propeller. It also features full flaps setting corresponding to 40 degrees of flap deflection. Manufactured in 1985, the aircraft is equipped with the Garmin G5.

Figure 1: PA-28-161 Piper Warrior

Figure 1 showcases the PA-28-161. This single-engine light trainer has a horizontally opposed, air-cooled, normally aspirated engine that is directly driven and equipped with a carburetor. The Warrior is used for flight training private and instrument and CFI candidates at FIT Aviation.

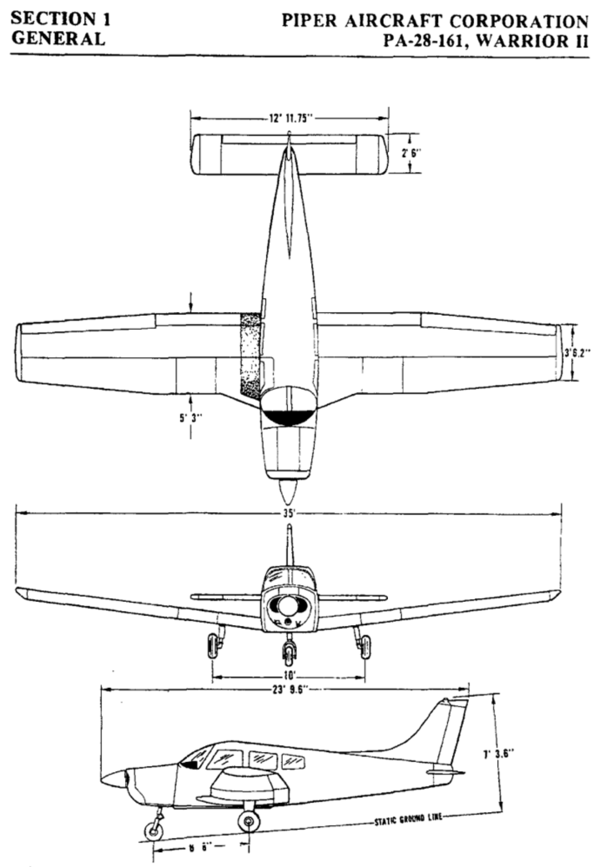


Figure 2: PA-28-161 Piper Warrior POH [3]

Table 1: PA-28-161 Piper Warrior POH [3]

1.9 OIL

(a) Oil Capacity (U.S. quarts)		8
(b) Oil Specification		Refer to latest issue of Lycoming Service Instruction 1014.
(c) Oil Viscosity per Average Ambient Temp. for Starting		
	Single	Multi
(1) Above 60°F	S.A.E. 50	S.A.E. 40 or 50
(2) 30°F to 90°F	S.A.E. 40	S.A.E. 40
(3) 0°F to 70°F	S.A.E. 30	S.A.E. 40 or 20W-30
(4) Below 10°F	S.A.E. 20	S.A.E. 20W-30

1.11 MAXIMUM WEIGHTS

	Normal	Utility
(a) Maximum Takeoff Weight (lbs)	2440	2020
(b) Maximum Ramp Weight (lbs)	2447	2027
(c) Maximum Landing Weight (lbs)	2440	2020
(d) Maximum Weight in Baggage Compartment (lbs)	200	0

1.13 STANDARD AIRPLANE WEIGHTS

Refer to Figure 6-5 for the Standard Empty Weight and the Useful Load.

1.15 BAGGAGE SPACE

(a) Compartment Volume (cubic feet	24
(b) Maximum Ramp Weight (lbs)	22
(c) Maximum Landing Weight (lbs)	20

1.17 SPECIFIC LOADINGS

(a) Wing Loading (lbs per sq ft)	14.4
(b) Power Loading (lbs per hp)	15.3

Table 2: PA-28-161 Piper Warrior POH [3]

PIPER AIRCRAFT CORPORATION PA-28-161, WARRIOR II	SECTION 1 GENERAL
1.3 ENGINES	
(a) Number of Engines	1
(b) Engine Manufacturer	Lycoming
(c) Engine Model Number	O-320-D2A or O-320-D3G
(d) Rated Horsepower	160
(e) Rated Speed (rpm)	2700
(f) Bore (inches)	5.125
(g) Stroke (inches)	3.875
(h) Displacement (cubic inches)	319.8
(i) Compression Ratio	8.5:1
(j) Engine Type	Four Cylinder, Direct Drive, Horizontally Opposed, Air Cooled
1.5 PROPELLERS	
(a) Number of Propellers	1
(b) Propeller Manufacturer	Sensenich
(c) Model	74DM6-0-60 or 74DM6-0-58
(d) Number of Blades	2
(e) Propeller Diameter (inches)	
(1) Maximum	74
(2) Minimum	72
(f) Propeller Type	Fixed Pitch
1.7 FUEL	
AVGAS ONLY	
(a) Fuel Capacity (U.S. gal) (total)	50
(b) Usable Fuel (U.S. gal) (total)	48
(c) Fuel	
(1) Minimum Octane	100 Green or 100LL Blue Aviation Grade
(2) Alternate Fuel	Refer to Fuel Requirements, Section 8 - Handling, Servicing and Maintenance.

Figure 2 and Tables 1 and 2: Warrior Pilot Information Handbook and has different information regarding the aircraft's general operation.

Figure 3: PA-28-181 Piper Archer

The Piper Archer N643FT (PA-28-181) in figure 3 is used by FIT Aviation for training commercial time building and student seeking a commercial certificate. The Piper Archer, which made its debut in 1974, is widely regarded by many pilots as the best compromise of power, performance, useful load, and economy in the PA28 line. Equipped with a Lycoming engine O-360, the horizontally opposed, air-cooled, normally aspirated Archer is also equipped with improved avionics Garmin 1000. The Archer gained a 20-hp difference from the previous Cherokee models, and this improvement led to its dominance over the Warrior. In 1995, Piper upgraded the Archer III by incorporating a new cowling that utilized NASA-inspired, University of Mississippi-developed, axisymmetric engine inlets, a new windshield line, an improved panel, and a revamped interior. The new cowling was designed to increase cooling efficiency, modernize the airplane's looks, and glean an extra knot or two of speed. Although the old Warrior had almost the same cruise and handling performance, the Archer can carry four people.

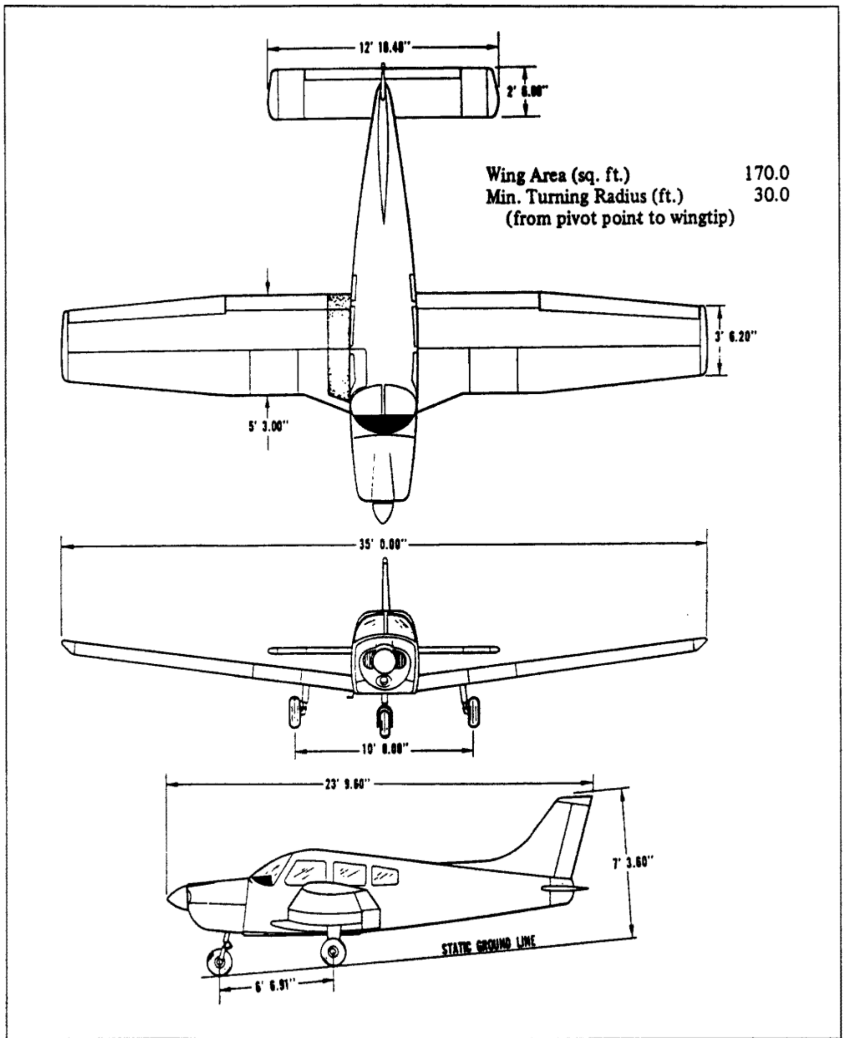


Figure 4: PA-28-181 Piper Archer POH [2]

Table 3: PA-28-181 Piper Archer POH [2]

1.3 ENGINES

(a) Number of Engines	1
(b) Engine Manufacturer	Lycoming
(c) Engine Model Number	O-360-A4M
(d) Rated Horsepower	180
(e) Rated Speed (rpm)	2700
(f) Bore (inches)	5.125
(g) Stroke (inches)	4.375
(h) Displacement (cubic inches)	361.0
(i) Compression Ratio	8.5:1
(j) Engine Type	Four Cylinder, Direct Drive Horizontally Opposed, Air Cooled

1.5 PROPELLERS

(a) Number of Propellers	1
(b) Propeller Manufacturer	Sensenich
(c) Model	76EM8S5-0-60
(d) Number of Blades	2
(e) Propeller Diameter (inches)	
(1) Maximum	76
(2) Minimum	76
(f) Propeller Type	Fixed Pitch

1.7 FUEL
AVGAS ONLY

(a) Fuel Capacity (U.S. gal.) (total)	50
(b) Usable Fuel. (U.S. gal.) (total)	48
(c) Fuel Grade, Aviation (min. octane)	100/130 Green

1.9 OIL

(a) Oil Capacity (U.S. Quarts)	8
(b) Oil Specification	Refer to latest issue of Lycoming Instruction No. 1014.

(c) Oil Viscosity per Average Ambient Temp. for Starting

	MIL-L-6082B Mineral SAE Grade	MIL-L-22851 Ashless Dispersant SAE Grades
(1) All Temperatures		15W-50 or 20W-50
(2) Above 80°F	60	60
(3) Above 60°F	50	40 or 50
(4) 30°F to 90°F	40	40
(5) 0°F to 70°F	30	30, 40 or 20W-40
(6) 0°F to 90°F	20W-50	20W-50 or 15W-50
(7) Below 10°F	20	30 or 20W-30

When operating temperatures overlap indicated ranges, use the lighter grade oil.

Figure 4 and Tables 3 and 4 are from the Piper Archer's Pilot Information Handbook and has different information regarding the aircraft's general operation.

Table 4: PA-28-181 Piper Archer [2]

1.11 MAXIMUM WEIGHTS

		NORMAL	UTILITY
(a)	Maximum Takeoff Weight (lbs)	2550	1950
(b)	Maximum Landing Weight (lbs)	2550	1950
(c)	Maximum Weights in Baggage Compartment	200	0

1.13 STANDARD AIRPLANE WEIGHTS*

(a)	Standard Empty Weight (lbs): Weight of a standard airplane including unusable fuel, full operating fluids and full oil	1390
(b)	Maximum Useful Load (lbs): The difference between the Maximum Takeoff Weight and the Standard Empty Weight	1160

1.15 BAGGAGE SPACE

(a)	Compartment Volume (cubic feet)	24
(b)	Entry Width (inches)	22
(c)	Entry Height (inches)	20

1.17 SPECIFIC LOADINGS

(a)	Wing Loading (lbs per sq ft)	15.0
(b)	Power Loading (lbs per hp)	14.2

Instrumentation

Figure 5: PA-28-161 and PA-28-181 Cockpit

Data was manually written by pen on the flight test card by my classmate Zilvinas, while I was flying the test plan. The data was gathered from the airspeed indicator and altimeter of the Piper Warrior, which has a pitot mast collecting Ram Air and Static Air. The airspeed indicator uses both Ram and Static Air while the altimeter only uses Static Air. In addition to the traditional instruments, the Piper Warrior is equipped with the Garmin G5 (Fig. 6), which can be configured in various positions, such as attitude, DG/HI/HSI, and turn coordinator (Fig. 5). The airplane also has dual G5 installation, which offers reversionary display capability and dual ADAHRS and backup batteries for added redundancy. To ensure accuracy, airspeed and altitude were collected from the G5 for the purpose of the research as the traditional instruments do not read as accurately. The Piper Warrior also has a traditional 3 1/8’ marked recording tachometer, but it was found to be inaccurate

due to its ability to only show RPM in increments of 100s. The mechanical tachometers are inaccurate and need to be checked every annually, 100 hours or any time the performance of the aircraft is checked.   As a result, an electronic propeller tachometer was used to read the RPM which was handheld by Zilvinas while collecting the data. The TruTach II Optical Digital Tachometer can accurately measure the speed of the aircraft's propeller from inside the airplane. By simply pointing the device at the propeller or rotor blades, the TruTach II displays the rotational speed with a high resolution of 1 RPM. This device does not require any connection to the aircraft's systems and can measure speeds ranging from 240 to 70000 RPM.
The TruTach II (Fig. 6) can display the speed of 2, 3, 4, and 5 blade propellers directly. Its Digital Signal Processing technology ensures that the display is stable and accurate, even in single and multi-engine aircraft and helicopters. To use it, we selected the number of propeller blades, and pointed at the propeller. The TruTach II operates on a standard 9-volt battery, so time of charge was not a factor for our thesis since it can provide up to 150 hours of operation.

For fuel calculations, preferably we would use a fuel flow meter, but our aircrafts are equipped with the basic piper fuel gauges which do not provide very accurate readings rather approximate. The total time spent in the air was less than 60 mins for each flight, therefore not much fuel was consumed and the effect this has on the data is minimal. The fuel was verified from the fuel tanks prior to taking off and measured again after landing. The POH provides us with an estimated burn rate, which was used to come up with our numbers.

The Piper Archer utilizes a modern glass cockpit, eliminating the need for vacuum pump driven spinning gyros to determine altitude. The G1000 in the Piper Archer employs an Attitude and Heading Reference Systems (AHRS) to determine pitch, roll, and yaw, and Air Data Computers (ADC) to provide altitude and airspeeds (Fig. 5). However, similar to the Piper Warrior, the airspeed readings are limited by the certification range set by Garmin. RPM was measured using an electronic propeller tachometer.

Figure 6: Electronic Tachometer and G5 Instruments

Flight Test Plan

The test flights were carried out at Melbourne International Airport, Florida, following the Visual Flight Rules (VFR) during early morning hours with calm winds and temperatures close to standard day as specified in the Piper operator's manual. The tests were performed at three different altitudes, namely 2500, 5000, and 7500 feet MSL.

There are no FAA requirements for level flight performance. However, some the acceptable methods for FAA climb performance require the use of parameters derived from the airplane drag polar which is obtained from level flight performance [1].

To determine the level flight performance of an aircraft, it is essential to measure the required power. Level flight performance refers to the aircraft's steady and balanced flight. This performance is necessary to calculate the drag in relation to velocity, where two main types of drag affect the aircraft's operation: induced drag and parasite drag. Induced drag is generated as a byproduct of lift, so it always exists when lift is present. When the airspeed decreases, particularly in the reverse command region, induced drag increases due to the downwash produced by lift surfaces, causing the lift vector to tilt backward. The difference between theoretical and actual lift is what defines induced drag. Parasite drag on the other hand, is unrelated to lift production and results from the airflow disruption caused by leakage, interference, skin, or friction of the aircraft. Friction drag increases with airspeed but decreases when airspeed decreases.

During our flight, the aircraft was maintained at a constant altitude in steady level flight, and then the throttle was fully opened to accelerate the aircraft to its maximum level flight speed at maximum cruise RPM. Data was collected at different time intervals with RPM reduction until the aircraft could no longer maintain level flight. RPM readings were recorded using an electronic tachometer, O.A.T. gauge, and airspeed. This process was repeated until the aircraft reached the backside of the power required curve, where RPM had to be increased to maintain altitude and achieve a lower airspeed.

Table 5: Flight Log

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

The tests were performed from the FIT Aviation facility at the Melbourne International Airport (KMLB) in Melbourne Florida. The tests were conducted to the Southeast of the Class Delta Melbourne International Airport over the Atlantic shoreline.

The flight tests were conducted by two crews. The aircrafts were rented by me from FIT Aviation. I was also the pilot for both these flights meanwhile my classmate Zilvinas was collecting the data by hand on the test plan.

Figure 7: Sectional Aeronautical Chart

Archer Aircraft and Cowling Design

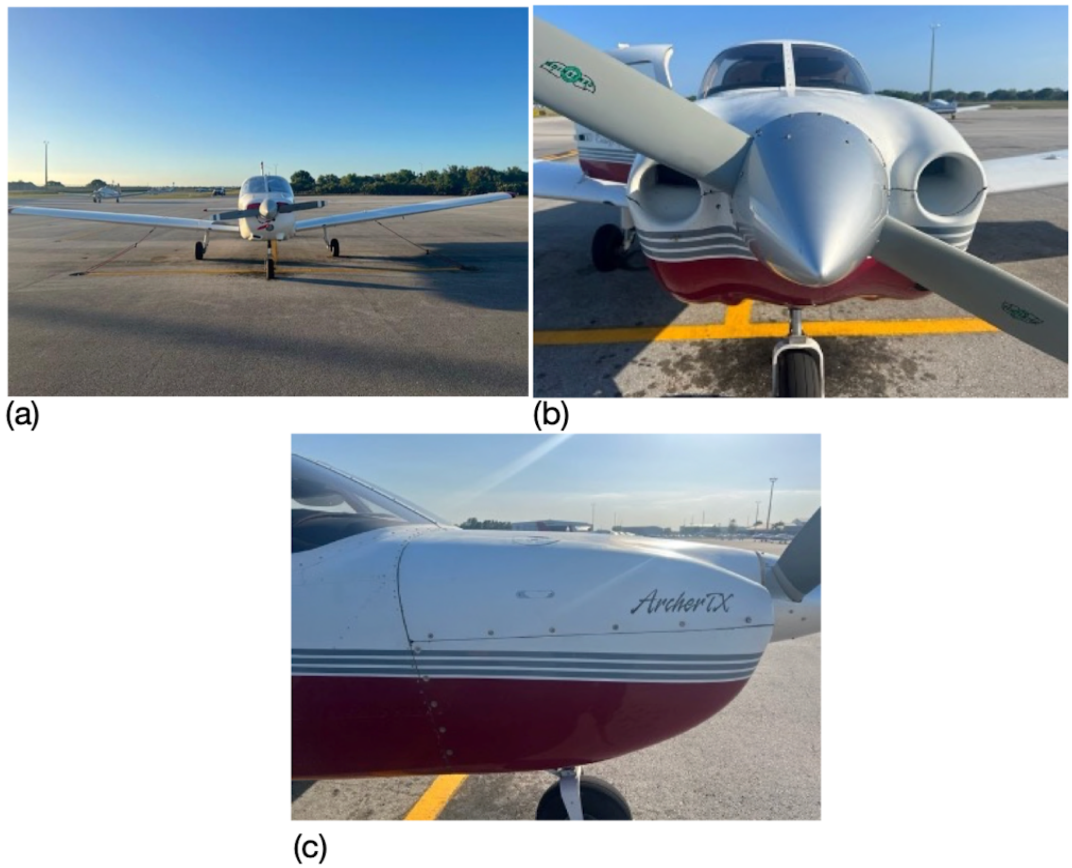
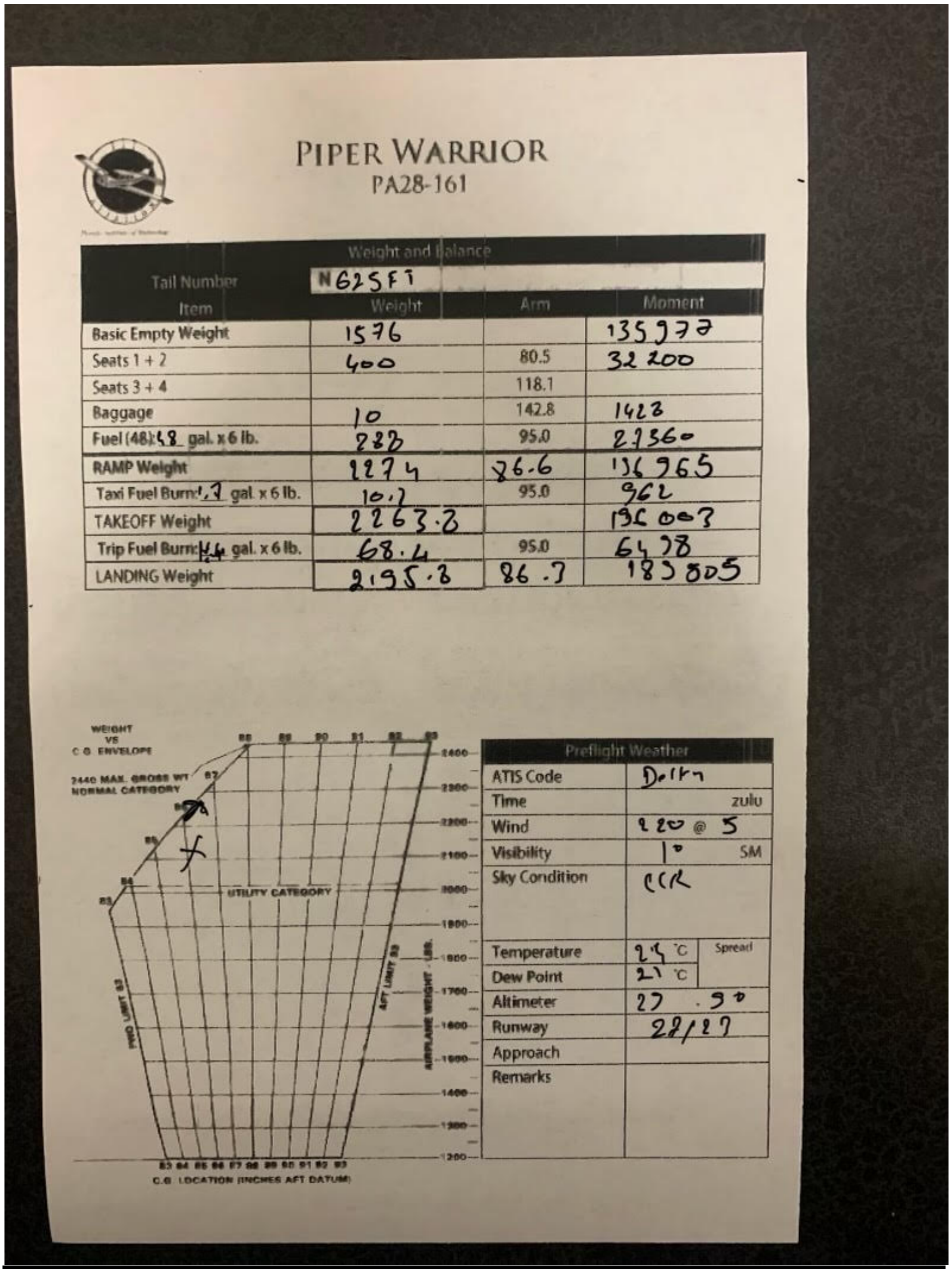


Figure 8: Archer Aircraft (a, b) and Cowling Design (c)

The Piper Archer cowling in figure 8, is equipped with the Mississippi cowling. Piper incorporated round inlets in place of outboard-facing, D-shaped inlets of old. Piper also moved the landing light out of the high vibration cowling onto the wingtip.

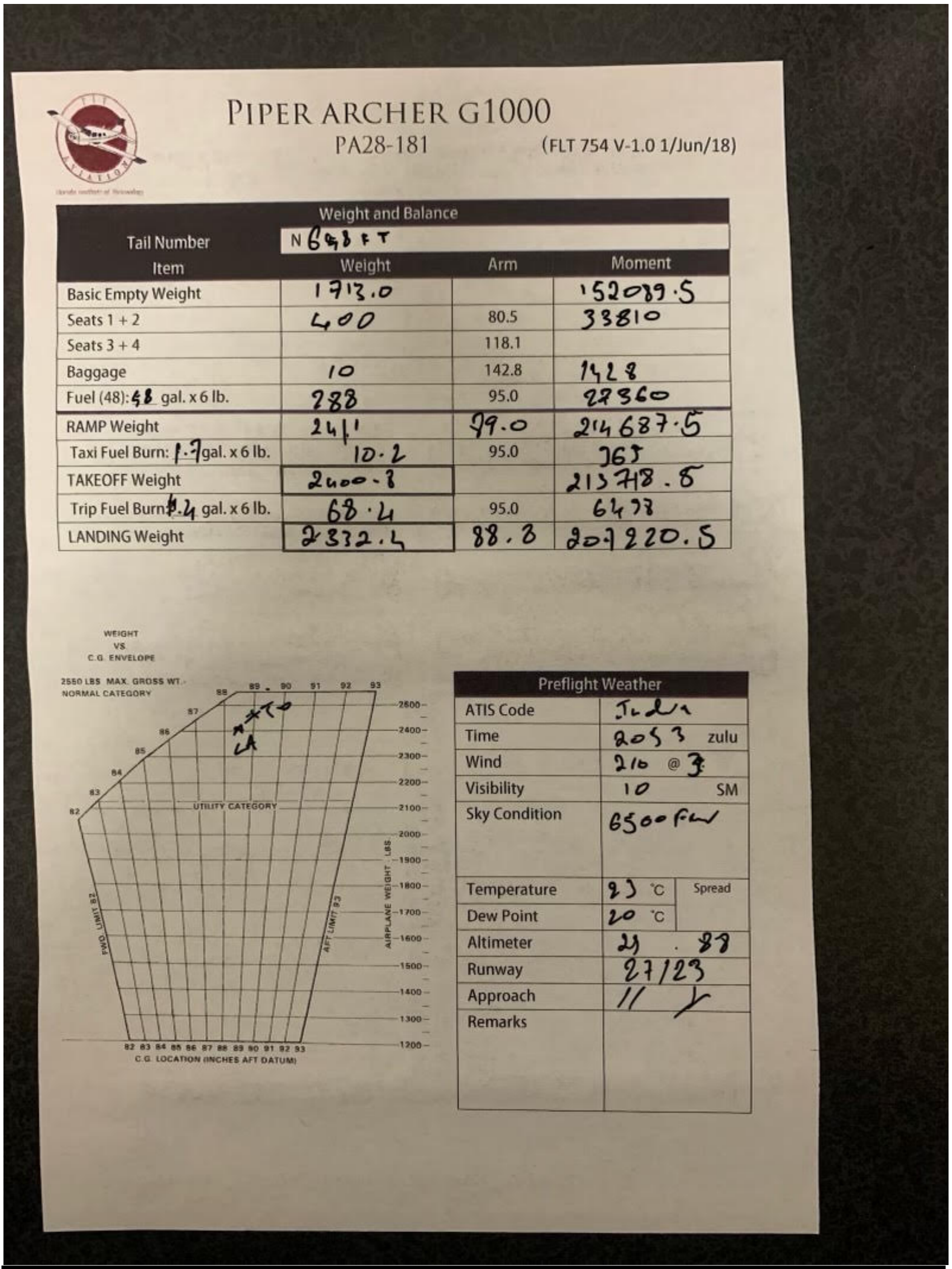


PIPER WARRIOR
PA28-161

Weight and Balance			
Tail Number	N625FT		
Item	Weight	Arm	Moment
Basic Empty Weight	1576		135977
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	2195.8	86.7	189505

Preflight Weather		
ATIS Code	Delta	
Time	zulu	
Wind	220 @ 5	
Visibility	10 SM	
Sky Condition	CLR	
Temperature	24 °C	Spread
Dew Point	21 °C	
Altimeter	29.90	
Runway	28/27	
Approach		
Remarks		

Figure 9: Weight and Balance for the Piper Warrior



PIPER ARCHER G1000

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

Weight and Balance			
Tail Number	N648FT		
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	99.0	214687.5
Taxi Fuel Burn: 1.7 gal. x 6 lb.	10.2	95.0	365
TAKEOFF Weight	2400.8		213718.5
Trip Fuel Burn: [illegible] gal. x 6 lb.	68.4	95.0	6498
LANDING Weight	2332.4	88.8	[illegible]220.5

Preflight Weather		
ATIS Code	Juliet	
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	ILS	
Remarks		

Figure 10: Weight and Balance for the Piper Archer

Warrior Aircraft and Cowling Design

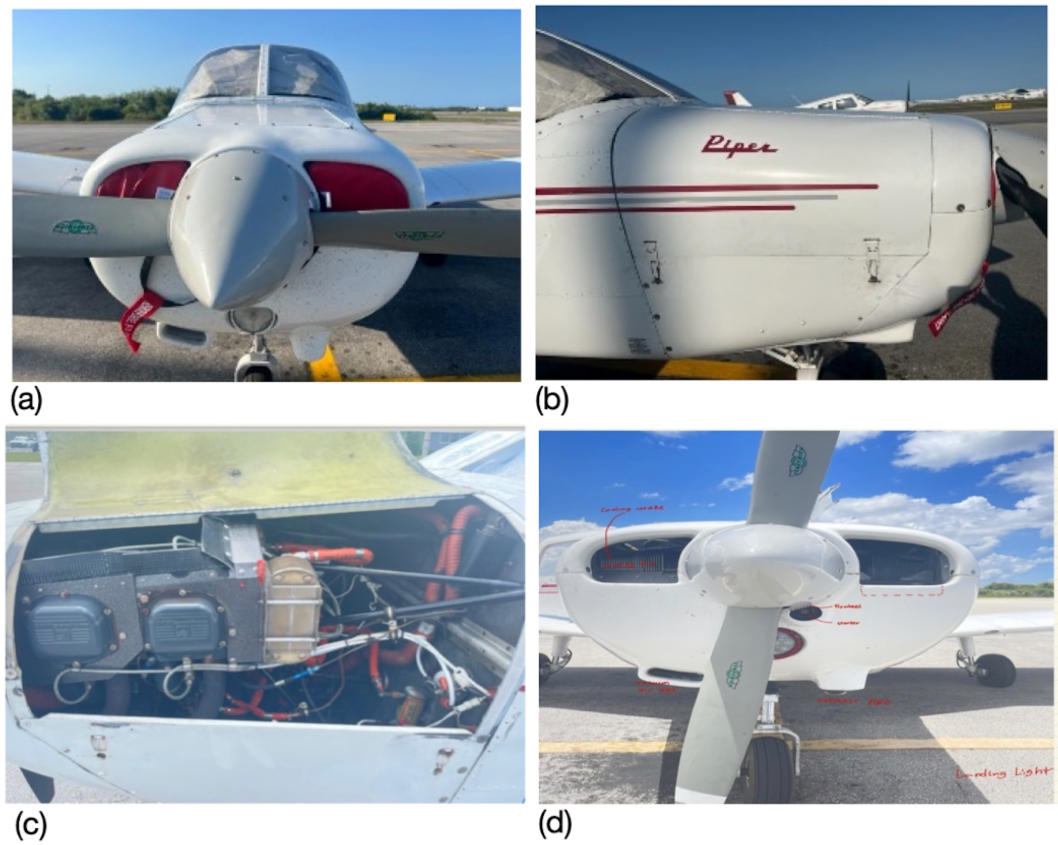


Figure 11: Warrior Aircraft (a) and Cowling Design (b) (c) (d)

The Piper Warrior cowling in Figure 12, is the original cowling. From the side of the airplane, we can access the engine compartment by twisting the two metal knobs on the side. The cowling and shape of the inlets of the airplane are more rectangular in comparison to the warrior which less advantageous aerodynamically. Air enters on either side of the propeller through opening in the nose cowling and is carried through the engine baffling around the engine and oil cooler [2].

Data Reduction

To conduct our tests, several parameters were necessary, including time, indicated airspeed, pressure altitude, RPM, outside air temperature, Manifold pressure, fuel quantity. In our case both airplanes are equipped with a constant speed propeller and do not have a manifold pressure gauge. Since the airplanes operated were already certified and used for training by FIT Aviation, we were not allowed to make any changes to the current aircraft, therefore unable to install a manifold pressure gauge. The data reduction method used is for fixed pitch propeller airplanes specified under the Flight Testing of Fixed Wing Aircraft [1].

The pilot did not require any extra flight-testing equipment or data acquisition systems since all the parameters were already at our disposal. The information was documented using manually written flight cards. In order to establish the density and weight ratios, the weight of the aircraft was computed for each data point, and the amount of fuel consumed during the flight was subtracted from the takeoff weight. Both the Warrior and Archer aircraft were tested using the same flight test procedure, with each test taking approximately one hour and twenty minutes.

The data collected was processed using Microsoft Excel. The initial step involved calibrating the airspeed using the chart provided in the POH. The indicated altitude was also adjusted using the corresponding graph. Since the flight testing was not conducted in standard conditions, it was necessary to adjust the data to sea level standard day values. Preferably, we would use a fuel flow meter, but our aircrafts are equipped with the basic piper fuel gauges which do not provide very accurate readings rather approximate. The total time spent in the air was less than 60 mins for each flight, therefore not much fuel was consumed and the effect this has on the data is minimal. The fuel was verified from the fuel tanks prior to taking off and measured again after landing. The POH provides us with an estimated burn rate, which was used to come up with our numbers.

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

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

$$W_S - aircraft's\ gross\ weight$$

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

The instrument corrected altitude was corrected to sea Level Standard Pressure Ratio which is δ.

The outside air temperature was corrected to Sea Level Standard Temperature Ratio θ.

We can now proceed to instrument/weight corrected power (PIW) and instrument/weight corrected velocity (VIW) calculations for each test points.

Equation 1. The generalized power [1]

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

Equation 2. The standard airspeed [1]

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

When it comes to airplanes that have propellers with a fixed pitch, the efficiency of the propeller cannot be assumed to remain constant due to the significant change in RPM (revolutions per minute) that occurs with changes in power. Since RPM is the primary power parameter that pilots can control, it is crucial to establish a way to connect the power produced by the engine with the RPM. To do this and account for changes in propeller efficiency, we must adjust the RPM for density and weight in a manner similar to the approach used for PIW and VIW terms, and this adjusted value is referred to as NIW.

Equation 3. Density and weight corrected propeller RPM [1]

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

Note: PIW, NIW, & VIW need to be corrected for nonstandard weight and density for the comparison purposes.

Equation 4. Horsepower [1]

$$HP = K * NIW^3$$

K - Constant units of (HP/RPM3)

Sample Calculations

δ =(1-(6.87535*10^(-6))*2630)^(5.2561) = 0.908544

θ=((273.15+20)/288.15) = 1.017352

σ= δ/ θ= 0.908544 / 1.017352 = 0.893048

$NIW = \frac{2607 * \sqrt{0.893048}}{0.8052706}$ =2745.412

$HP = K * 2745.412^3 = 147.363$

Data Analysis

The data that was reduced using Microsoft Excel was utilized to generate graphs for each aircraft at different altitudes. These graphs were then utilized to calculate NIW, which represents RPM adjusted for Density and weight The propeller load curve is a graphical representation of the correlation between a fixed-pitch propeller's RPM and the power needed to drive it at a specific speed. The power consumed by the propeller is directly proportional to the cube of its RPM. With a fixed-pitch propeller, airspeed is the only means of controlling engine torque, which is linked to engine power output. Consequently, if the power output changes (torque), the engine will attempt to accelerate or decelerate until an RPM is reached where the power supplied to the engine matches the power consumed by the propeller.

However, this equation cannot be used for flight test data because it is only accurate for standard sea level conditions. For non-sea level flight test data, the equation is adjusted to $HP = K * NIW^3$, where K is a constant.

The equation must include the density ratio to correct for non-standard atmospheric conditions, transforming test day data to standard day conditions. Including the density ratio shows that flight test data from various altitudes can be reduced to a single line, which are then overlayed onto one plot.

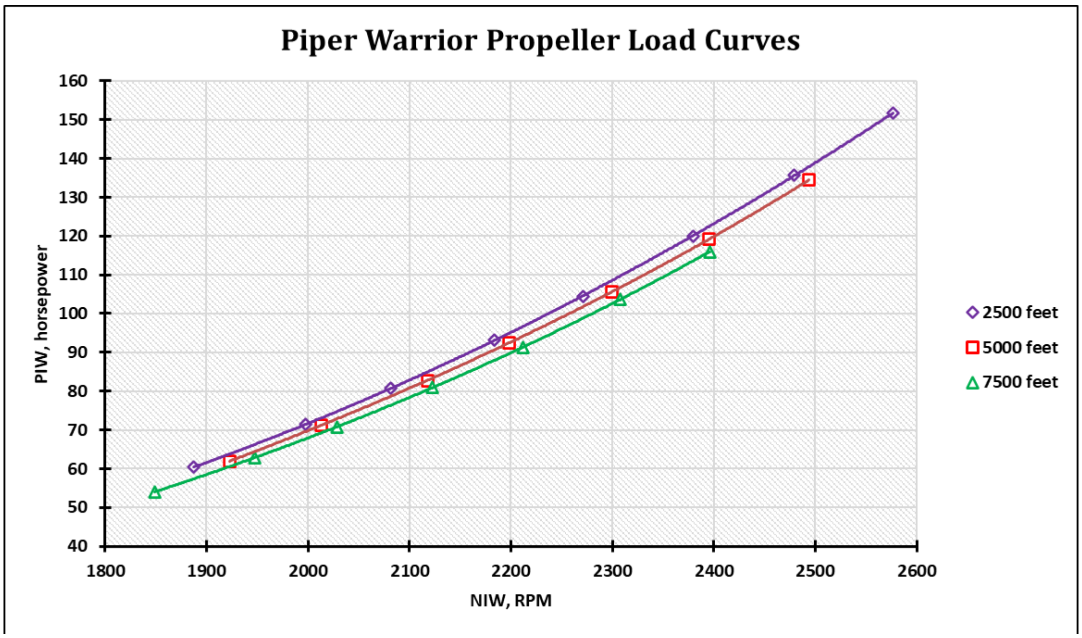


Figure 12: Warrior Propeller load at varying altitudes 2500ft (a), 5000ft (b) and 7500ft (c)

The RPM (revolutions per minute) of the propeller is represented on the x-axis, while the power required to propel the propeller at a given velocity is represented on the y-axis. By examining the data points, it becomes apparent that as the RPM increases, so does the power required to propel the propeller. This is unsurprising, as more energy is needed to move the propeller faster through the air. The graph for 5000 and 7500 also demonstrate this trend as it moves upward. For a given altitude and RPM less power was required.

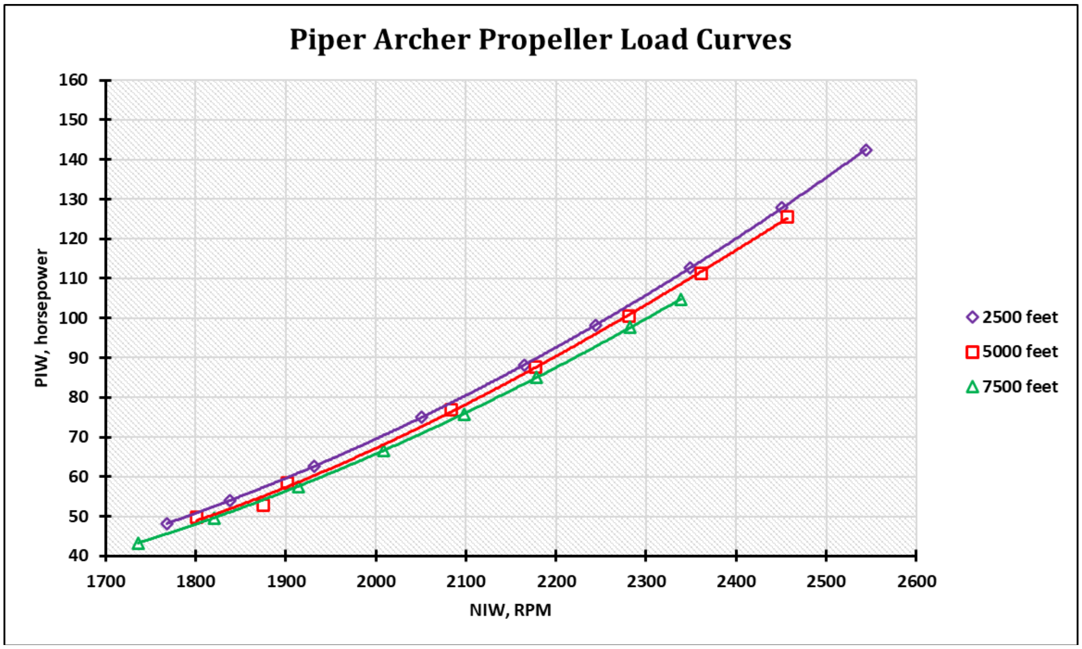


Figure 13: Archer Propeller load for at varying altitudes 2500ft (a), 5000ft (b) and 7500ft (c)

The graph displayed in this analysis represent propeller load curves for three distinct altitudes, namely 2500 feet, 5000 feet, and 7500 feet. By examining the values along the y-axis for each data set, we can observe that the power needed to drive the propeller at a specific RPM increases as altitude increases. This is due to the decrease in air density at higher altitudes.

By evaluating the bottom of the curve of the PIW vs NIW plots for the Archer and Warrior, we can notice that the power required is noticeably higher for Warrior than it is for the Archer to maintain level flight. The aircraft requires less HP for the same RPM setting and density altitude.

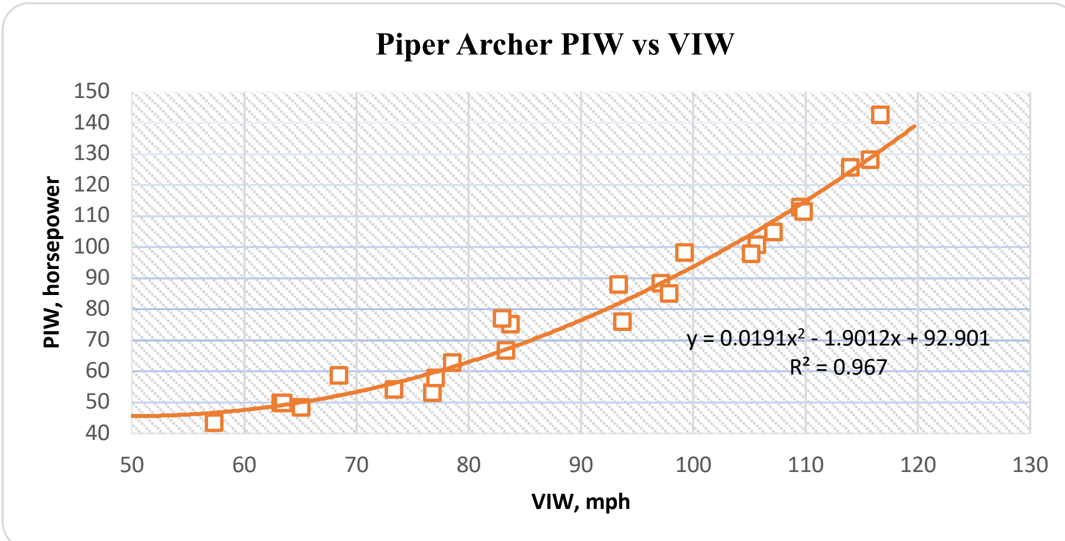


Figure 14: Drag Curve (Piper Archer) at 2500ft (a), 5000ft (b) and 7500ft (c)

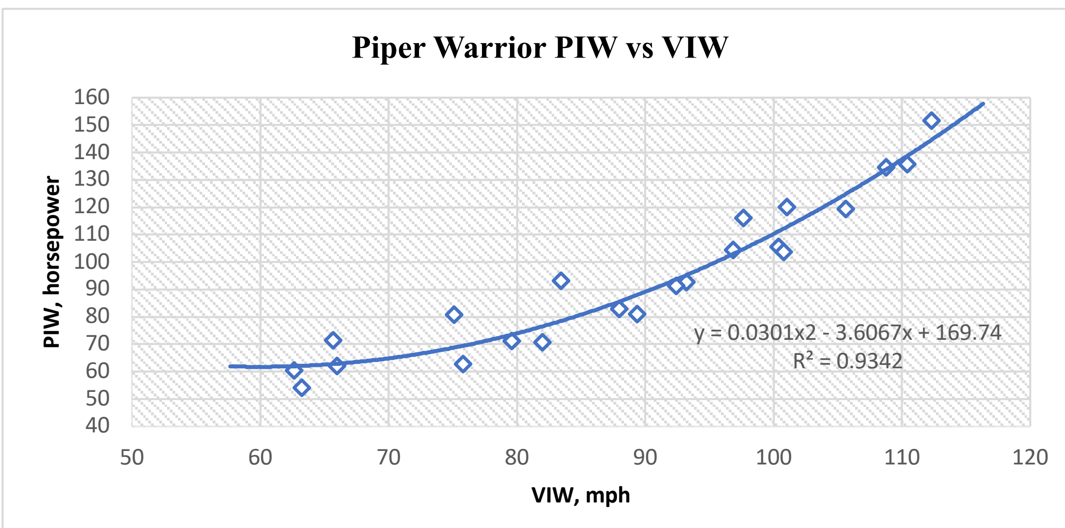


Figure 15: Drag Curve (Piper Warrior) at 2500ft (a), 5000ft (b) and 7500ft (c)

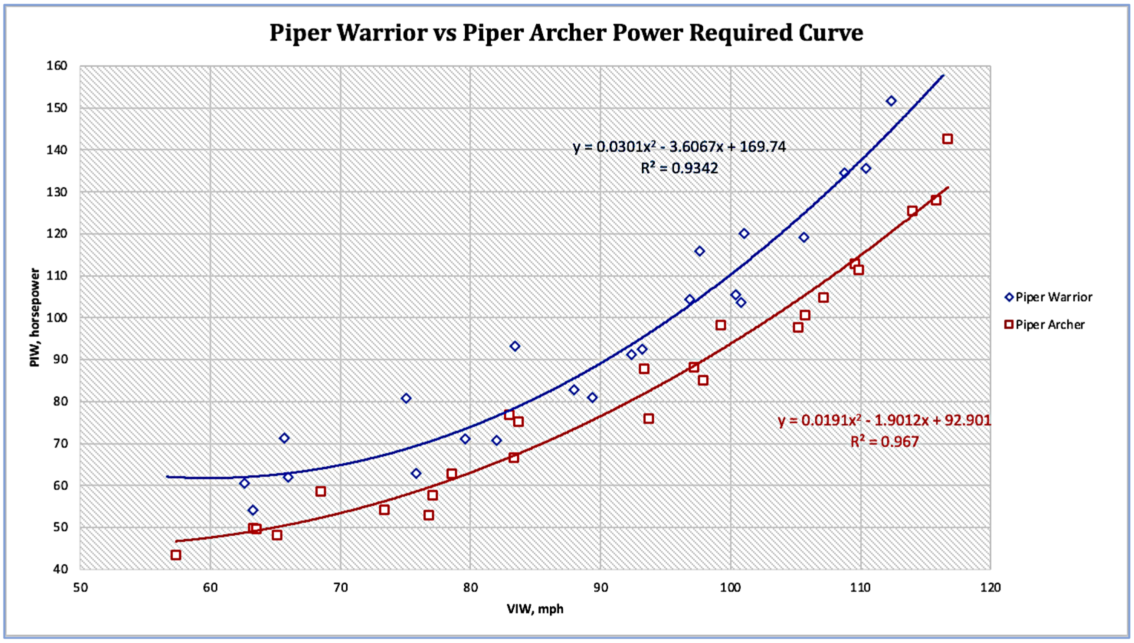


Figure 16: Piper Warrior vs Piper Archer Power Required Curve

The PIW vs VIW curve is a graphical representation that depicts the drag measurements for an aircraft. The curve is composed of three altitudes and a trendline that indicates the drag curve. When we examine the bottom of the curve for the PIW vs VIW plots of the Archer and Warrior, we can observe that the power required to maintain level flight for the Warrior is significantly greater than that of the Archer.

There could be several factors contributing to the decrease in horsepower required by the Archer, and one of these factors could be the decrease in drag as illustrated in the PIW/VIW plot. This suggests that the Archer requires less horsepower for the same RPM setting and density altitude. This reduction in drag could be due to various reasons such as a more streamlined design provided by the Mississippi Cowling and a reduction in weight.

Conclusion and Future Work

Conclusion

The modification of the Piper Archer entails installing a NACA duct inlet on the top of the cowling to improve engine cooling and optimize airflow around the cowling. In contrast to the standard cowling design of the Piper Warrior, the Mississippi cowling offers numerous drag reduction advantages.

In summary, we believe that the Mississippi cowling provides a substantial improvement over the standard cowling on the Piper Warrior, allowing the Piper Archer to achieve superior aerodynamic performance, a more efficient flow of air, and reduced drag. From a pilot perspective of handling qualities, the Archer is a smoother airplane to fly compared to the warrior. The Archer felt heavier at higher power settings compared to the Warrior. The controls were also heavier compared to the warrior. The warrior is very maneuverable, on the other hand making the perfect aircraft for its common use, flight training. The extra speed on the Archer makes it preferable for long distance flights.

The Piper Archer aircraft can benefit from the Mississippi cowling modification that aims to enhance its aerodynamic performance by minimizing drag. We can determine from the graphs that the Piper Archer is able to stall at a lower airspeed in comparison to the Piper Warrior. From both graphs at 7500 feet the Warrior stalled at 1946 RPM meanwhile the Archer stalled at 1881 RPM. For the same RPM setting, the Archer produces higher airspeeds, mostly noticeable at lower speeds. For the same RPM setting the Archer requires less HP than the Warrior at the same altitudes. The drag curve also showed us the decreased total drag from the Archer. These differences in performance can be due to the Mississippi cowling that helps in drag reduction. One of the major factors to take into consideration when analyzing the data is the age of the airplanes we are comparing. Both aircrafts are old and mainly used for flight training. The airplanes are most definitely not performing to their best performance due to wear and tear and the overall age of the aircrafts. These airplanes are equipped with old powerplant, propellers, and airframe. These factors may have an impact of the data's accuracy.

As our department provided little assistance, my classmate Zilvinas Visockas and I had to organize and coordinate this thesis on our own due to limited resources. We collaborated to choose an airplane and plan the sorties. Luckily, I was a flight instructor at the university, which enabled us to rent the necessary aircraft for both sorties. However, we paid for both flights out of our own pockets. During the flights, I flew the test plans for both the Warrior and the Archer, while Zilvinas collected the required data.

Future Work & Recommendations

Flight testing is an essential part of aircraft design and development, as demonstrated by the Mississippi cowling modification to the Piper Archer aircraft. Although advanced technologies like Computational Fluid Dynamics (CFD) can predict aerodynamic performance, physical flight testing provides valuable data that cannot be obtained through simulation alone. This data is particularly important for validating the design of new technologies or modifications, as engineers can collect data on actual aerodynamic performance in real-world conditions. Flight testing can also evaluate the overall impact of a modification on other aspects of aircraft performance, such as fuel efficiency, range, and handling characteristics, leading to further improvements and adjustments. As the aviation industry continues to evolve, flight testing will remain an essential tool for optimizing aircraft performance and safety.

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Appendix

Excel Data

Table 6: Archer 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	HP non SL	Sigma * HP^3
2500	1	113	114	2600	2630	20	2607	46	9.74	0.9378421	0.908544	1.017352	0.893048	2543.98	116.6846	142.4789	136.9328298	129.4032	2292966.18
	2	112	113	2560	2590	20	2506	45	9.82	0.9354965	0.909883	1.017352	0.894364	2450.288	115.7969	127.8827	122.3539178	115.7111	1638203.25
	3	106	106	2569	2599	20	2403	45	9.802	0.9354965	0.909581	1.017352	0.894068	2349.188	109.5935	112.6788	107.8251996	101.9543	1120807.79
	4	96	96	2610	2640	20	2297	45	9.72	0.9354965	0.90821	1.017352	0.89272	2243.869	99.25449	98.11905	93.96346876	88.78029	740614.454
	5	94	95	2580	2610	20	2215	45	9.78	0.9354965	0.909213	1.017352	0.893706	2164.96	97.18669	88.17602	84.39495232	79.78362	537209.842
	6	81	83	2540	2570	20	2097	45	9.86	0.9354965	0.910552	1.017352	0.895022	2051.135	83.74597	75.04174	71.77105065	67.89943	330888.452
	7	76	79	2540	2570	20	1975	45	9.86	0.9354965	0.910552	1.017352	0.895022	1931.803	78.57647	62.69154	59.95912858	56.72469	192929.943
	8	71	76	2500	2530	20	1878	45	9.94	0.9354965	0.911893	1.017352	0.89634	1838.277	73.40697	54.05954	51.66533384	48.91427	123614.778
	9	63	68	2460	2490	20	1805	45	10.02	0.9354965	0.913235	1.017352	0.897659	1768.121	65.13576	48.13875	45.97294129	43.55701	87220.454
5000	1	110	110	5060	5100	13	2594	43	4.8	0.9308053	0.828938	0.993059	0.834732	2456.484	114.0153	125.4278	123.2845222	112.6372	1564128.7
	2	106	106	5060	5100	13	2493	43	4.8	0.9308053	0.828938	0.993059	0.834732	2360.838	109.8693	111.3398	109.4373269	99.98593	1094065.3
	3	102	102	5020	5060	13	2407	43	4.88	0.9308053	0.83018	0.993059	0.835983	2281.105	105.7233	100.5109	98.71943269	90.26124	804276.28
	4	90	92	5010	5050	13	2294	42	4.9	0.9284597	0.830491	0.993059	0.836296	2177.167	93.40303	87.73594	85.83060709	78.49141	528793.922
	5	80	83	5010	5050	13	2195	42	4.9	0.9284597	0.830491	0.993059	0.836296	2083.209	83.02492	76.86008	75.19094055	68.76152	355513.792
	6	74	78	5040	8080	13	2092	42	-1.16	0.9284597	0.740511	0.993059	0.745686	1874.814	76.79805	52.90235	54.80768681	47.32816	122766.718
	7	66	71	5000	5040	13	2004	42	4.92	0.9284597	0.830802	0.993059	0.836609	1902.293	68.49556	58.535	57.25309505	52.3673	157007.136
	8	61	66	4950	5030	13	1897	42	4.94	0.9284597	0.831113	0.993059	0.836922	1801.061	63.3065	49.68778	48.59053344	44.4523	96015.2145
7500	1	103	103	7480	7523	12	2571	40	-0.046	0.9237686	0.75643	0.989589	0.764388	2338.716	107.1657	104.7637	106.3895302	93.0156	920471.815
	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	86.335	736324.682
	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	75.17472	486098.237
	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	67.0802	345507.27
	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	58.89253	233716.477
	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	50.94474	151346.463
	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	43.88982	96628.1284
	8	55	60	7420	7463	12	1902	38	0.074	0.9190774	0.758161	0.989589	0.766137	1736.552	57.37024	43.26684	43.5542006	38.12267	63298.9883

Table 7: Warrior Data

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	HP non SL	Sigma * HP^3
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	134.769	2583874.04
	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	120.0616	1825885.44
	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	106.2509	1264794.57
	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	92.43377	832288.975
	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	82.15828	584327.528
	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	71.18224	379889.685
	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	62.89242	262118.232
	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	53.11459	157828.013
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	117.6125	1784463.26
	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	104.2917	1243752.33
	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	92.30345	861775.123
	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	80.63213	574143.735
	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	72.11281	410708.285
	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	61.98659	260751.616
	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	54.00731	172493.472
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	100.2083	1148651.62
	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	89.56237	819762.473
	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	78.87627	559951.502
	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	69.68174	385998.333
	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	60.91994	257834.744
	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	53.86072	178086.536
	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	46.15325	112031.179

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 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 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.