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

Soufiane Ait Yahia
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by

Soufiane Ait Yahia

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Master of Science in Flight Test Engineering

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We the undersigned committee hereby approve the attached thesis, “Determining Performance Characteristics from the Mississippi Cowling - Piper Warrior vs. Piper Archer” by Soufiane Ait Yahia

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, Ph.D.
Associate Professor and Department Head
Aerospace, Physics, and Space Sciences
Abstract

Title: Determining Performance Characteristics from the Mississippi Cowling - Piper Warrior vs. Piper Archer
Author: Soufiane Ait Yahia
Advisor: Ralph D. Kimberlin, Dr.-Ing.

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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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](image)

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

<table>
<thead>
<tr>
<th></th>
<th>Single</th>
<th>Multi</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Above 60°F</td>
<td>S.A.E. 50</td>
<td>S.A.E. 40 or 50</td>
</tr>
<tr>
<td>(2) 30°F to 90°F</td>
<td>S.A.E. 40</td>
<td>S.A.E. 40</td>
</tr>
<tr>
<td>(3) 0°F to 70°F</td>
<td>S.A.E. 30</td>
<td>S.A.E. 40 or 20W-30</td>
</tr>
<tr>
<td>(4) Below 10°F</td>
<td>S.A.E. 20</td>
<td>S.A.E. 20W-30</td>
</tr>
</tbody>
</table>

1.11 MAXIMUM WEIGHTS

<table>
<thead>
<tr>
<th></th>
<th>Normal (lbs)</th>
<th>Utility (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Maximum Takeoff Weight</td>
<td>2440</td>
<td>2020</td>
</tr>
<tr>
<td>(b) Maximum Ramp Weight</td>
<td>2447</td>
<td>2027</td>
</tr>
<tr>
<td>(c) Maximum Landing Weight</td>
<td>2440</td>
<td>2020</td>
</tr>
<tr>
<td>(d) Maximum Weight in Baggage Compartment</td>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

1.13 STANDARD AIRPLANE WEIGHTS

Refer to Figure 6-5 for the Standard Empty Weight and the Usefull 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]

<table>
<thead>
<tr>
<th>PIPER AIRCRAFT CORPORATION</th>
<th>SECTION 1</th>
<th>GENERAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA-28-161, WARRIOR II</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.
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 76E885-0-60
(d) Number of Blades 2
(e) Propeller Diameter (inches) 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

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

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

<table>
<thead>
<tr>
<th>Description</th>
<th>NORMAL</th>
<th>UTILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Maximum Takeoff Weight (lbs)</td>
<td>2550</td>
<td>1950</td>
</tr>
<tr>
<td>(b) Maximum Landing Weight (lbs)</td>
<td>2550</td>
<td>1950</td>
</tr>
<tr>
<td>(c) Maximum Weights in Baggage Compartment</td>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

#### 1.13 STANDARD AIRPLANE WEIGHTS*  

<table>
<thead>
<tr>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Standard Empty Weight (lbs): Weight of a</td>
<td>1390</td>
</tr>
<tr>
<td>standard airplane including unusable fuel,</td>
<td></td>
</tr>
<tr>
<td>full operating fluids and full oil</td>
<td></td>
</tr>
<tr>
<td>(b) Maximum Useful Load (lbs): The difference</td>
<td>1160</td>
</tr>
<tr>
<td>between the Maximum Takeoff Weight and</td>
<td></td>
</tr>
<tr>
<td>the Standard Empty Weight</td>
<td></td>
</tr>
</tbody>
</table>

#### 1.15 BAGGAGE SPACE

<table>
<thead>
<tr>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Compartment Volume (cubic feet)</td>
<td>24</td>
</tr>
<tr>
<td>(b) Entry Width (inches)</td>
<td>22</td>
</tr>
<tr>
<td>(c) Entry Height (inches)</td>
<td>20</td>
</tr>
</tbody>
</table>

#### 1.17 SPECIFIC LOADINGS

<table>
<thead>
<tr>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Wing Loading (lbs per sq ft)</td>
<td>15.0</td>
</tr>
<tr>
<td>(b) Power Loading (lbs per hp)</td>
<td>14.2</td>
</tr>
</tbody>
</table>
Instrumentation

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**

<table>
<thead>
<tr>
<th>Date</th>
<th>Aircraft</th>
<th>Crew</th>
<th>HOBBS (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/04/2023</td>
<td>Piper Archer N648FT</td>
<td>Soufiane Ait Yahia Zilvinas Visockas</td>
<td>1.3</td>
</tr>
<tr>
<td>03/02/2023</td>
<td>Piper Warrior N625FT</td>
<td>Soufiane Ait Yahia Zilvinas Visockas</td>
<td>1.1</td>
</tr>
</tbody>
</table>
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.
Figure 9: Weight and Balance for the Piper Warrior

<table>
<thead>
<tr>
<th>Tail Number</th>
<th>Weight and Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Item</td>
</tr>
<tr>
<td></td>
<td>Basic Empty Weight</td>
</tr>
<tr>
<td></td>
<td>Seats 1 + 2</td>
</tr>
<tr>
<td></td>
<td>Seats 3 + 4</td>
</tr>
<tr>
<td></td>
<td>Luggage</td>
</tr>
<tr>
<td></td>
<td>Fuel (465 gal x 6 lb)</td>
</tr>
<tr>
<td></td>
<td>RAMP Weight</td>
</tr>
<tr>
<td></td>
<td>Taxi Fuel Burnt (2 gal x 6 lb)</td>
</tr>
<tr>
<td></td>
<td>TAKEOFF Weight</td>
</tr>
<tr>
<td></td>
<td>Trip Fuel Burnt (4 gal x 6 lb)</td>
</tr>
<tr>
<td></td>
<td>LANDING Weight</td>
</tr>
</tbody>
</table>
Figure 10: Weight and Balance for the Piper Archer
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.

\[ \sigma = \frac{\delta}{\theta} \]

\[ \text{Weight Ratio} = \frac{W_T}{W_S} \]

\( W_S \) – aircraft’s gross weight

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

The instrument corrected altitude was corrected to sea Level Standard Pressure Ratio which is \( \delta \).

The outside air temperature was corrected to Sea Level Standard Temperature Ratio \( \theta \).

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]**

\[ PIW = \frac{BHPt\sqrt{\sigma}}{W_T^{1.5}} \]
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]

\[ NIW = \frac{RPM \times \sqrt{\sigma}}{W_T \sqrt{W_S}} \]

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

Equation 4. Horsepower [1]

\[ HP = K \times NIW^3 \]

K - Constant units of (HP/RPM^3)
### Sample Calculations

\[
\delta = (1 - (6.87535 \times 10^{-6}) \times 2630) \times (5.2561) = 0.908544
\]

\[
\theta = (273.15 + 20) / 288.15 = 1.017352
\]

\[
\sigma = \delta / \theta = 0.908544 / 1.017352 = 0.893048
\]

\[
NIW = \frac{2607 + \sqrt{0.893048}}{0.8052706} = 2745.412
\]

\[
HP = K \times 2745.412^3 = 147.363
\]

### 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 \( HP = K \times NIW^3 \), 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.
The graph displayed in this analysis represents 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.
References


### Appendix

**Excel Data**

#### Table 6: Archer Data

| Airspeed Tt Pl. | Indicated Airspeed (mph) | Calibrated Airspeed (mph) | Altitude (ft) | OAT (°F) | KPH | Fsp Offs. (mph) | Vs (mph) | Weight Ratio | a | Density Ratio | N/W | V/W | P/W | HP | HP min SL | Signa * HP
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**Notes:**
- HP = Horsepower
- HP min SL = Horsepower minimum specific load
- Signa = Signature
- *HP = Horsepower

---

**Source:** Data provided by Archer Airspeed.

---

**Further Reading:**
- Archer Airspeed Manual
- Advanced Aviation Performance Calculations
- Aerodynamics for the Pilot
Table 7: Warrior Data

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**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**

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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.