CReSIS

Flight Tests Report

for

Cessna C – 182 Flight Test with Piccolo Communication System

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Abstract

Three flight tests on a C-182 (total flight time: 12 hours) were completed with the 2.4 GHz antenna system provided by the Piccolo autopilot system for the purpose of determining its communication performance.

Based on the flight test data, it shows that the Piccolo communication link provides a stable performance within two nautical miles, where RSSI signal is equal to or above \(-93 \text{ dBm}\) (max: \(-71 \text{ dBm}\); min: \(-115 \text{ dBm}\)). However, there are exceptions in some circumstances such as flying overhead, take off, taxi and heading problems, which will be discussed in detail in this report.

Recommendations are given here to improve the problems found during testing. An amplifier or high power radio could be used to amplify the transmission signal in order to increase the range. A technique of splitting one antenna signal into two is also feasible so that an omni directional and directional antenna could be used simultaneously at the ground station. Another possible solution is to use a tracking antenna system to have the ground station antenna track the UAV all the times. The antenna position on the aircraft is also a crucial factor that can affect the system’s performance. More flight tests will be needed to find the ideal location. The advantages and disadvantages of each solution will be discussed in more detail in this report.
C-182 Flight Test Report

Revisions

Rev.--..........................................................Date : 08/30/2007

Rev.A..........................................................Date : 09/04/2007
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1 Test Overviews

The objective of this report is to provide a concise summary of the C-182 flight tests. The purpose of this flight test effort is to measure the performance of the communication link provided by the Piccolo autopilot system. The test data will be used to determine the effective range where it is safe to operate in the pilot or manual control mode.

All the flight test results are plotted in this report. As the aim of this report is to give a brief summary of the test results and recommendations to resolve the problems as found in these tests. The details of each set of flight test data are not discussed in this report.

1.1 Flight Test Dates

According to the original proposal, the flight tests were to be completed in two days. The actual flight tests were finished in three flight test days as listed below.

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Test Location</th>
<th>Test Description</th>
<th>Test Card Index[^1]</th>
</tr>
</thead>
</table>
| Aug 7, 2007 | Lawrence Municipal Airport | ▪ Long Approach Test  
▪ Short Pattern Test              | Run 1A, 2A  
Run 1B, 2B, 3B, 4B               |
| Aug 10, 2007| Clinton Lake R/C field | ▪ 1st Clover Leaf test  
▪ 2nd Clover Leaf test           | Run 1C  
Run 1D (half)                    |
| Aug 15, 2007| Clinton Lake R/C field | ▪ Clover Leaf Test (gear up)  
▪ Race Track Pattern Test  
▪ Figure Eight Test  
▪ Clover Leaf Test (gear down)   | Run 1C.1  
Run 1E, 2E, 3E, 4E  
Run 1F, 2F, 3F, 4F  
Run 1G, 2G, 3G, 4G,  
5G, 6G, 7G, 8G  
Run 1C, 1D               |

1.2 Flight Test Procedure

Please refer to Ref[1], Flight Test Safety Report, for the details of all flight test requirements, flight test patterns, and flight test procedures.

1.3 Test Setup

In the first flight test in August 2007, the ground station unit and antennas (UHF, GPS and iridium antennas) were set up on a mobile table. Based on the discussions in the debriefing after the first flight test, it was suggested to set up both antennas on a separate tripod to minimize the interference between the two antennas. Figure 1 shows the final setup of the ground station at the Clinton Lake RC aircraft flight field on the August 5 flight test.
Figure 1 Ground Station Setup
2 Test Result Summary

2.1 Discussions

Performance
Based on the flight test data, the overall performance of the UHF communication link could be summarized in a short statement: within two nautical miles distance, the communication link provides good performance, with the RSSI signal equal to or higher than –93 dBm (max: –71 dBm; min: -115 dBm) most of the time. The signal strength starts to decline after two nautical miles and was lost when the distance reached six nautical miles. In some cases, the communication link remained connected at up to eight nautical miles, but it didn’t exist consistently, and the RSSI signal remained at –108 dBm, which is very weak.

There are exceptions to the above statement in circumstances which will be discussed in the “Problems” section. In those cases, the signal strength will decrease below –93 dBm, and dropped out for a few seconds in the worst case.

Equipment Issue
The GPS antenna failed in the 3rd flight test. This GPS antenna is a combination antenna module (also an Iridium antenna). The flight test was aborted when the failure was discovered. The cause of the failure is unknown. The GPS antenna on the C-182 was used to continue the flight test. Since the Iridium antenna and the failed GPS antenna are built into the same module, the performance of the Iridium antenna becomes questionable. It seemed to work normally throughout the whole flight test.

A software issue was experienced as the ground station Operator Interference (OI) software froze during one of the flight tests. During that time, all the telemetry data was lost and the software had to be rebooted.

Problems
The problems could be categorized as listed below:

- Heading Problem
  From the test data the distance at which the signal is regained when the aircraft flies towards the ground station is shorter than the distance where the signal is lost when it flies away from the ground station. This could be seen in one of the range tests as illustrated in Figure 2.
This could be the result of the interference with the landing gear, engine, and/or propeller. The range test shows that the gear up configuration mitigates the problem but it is not totally resolved as the propeller and engine effect still exists.

- **Take off Problem**
  During the take-off process, when the aircraft starts to pitch up (while the main gear is still on the ground), the tail of fuselage pitches down so that it blocks the path of the signal between the onboard antenna and the ground station antenna. The situation improves when the aircraft starts to climb, so communications are regained. An example is shown in Figure 3 for one of the short pattern tests.

- **Overhead Problem**
  In the range test, a signal drop out issue was experienced every time the aircraft flew over the ground station antenna. The average drop out time is about 3 to 6 seconds. This is an anticipated problem resulting from the blind zone in the radiation pattern for both antennas based on the antenna design. A demonstration of this problem is shown in Figure 4.

- **Taxi (Ground Effect) Problem**
  When the aircraft is taxiing, the onboard antenna underneath the fuselage is very close to the ground and is at a lower altitude than the ground station antenna relative to the ground. The fuselage and the ground will reflect most of the signal before the ground station receives it. The angle of the path between the two antennas decreases when the aircraft taxies further away. Therefore, the signal drops out very fast during taxi. The first flight test at Lawrence airport shows that the communication range is only 0.6 Nm during taxi, as illustrated in Figure 5.
Communication Range - Flight Test Date: Wed Aug 15 2007

- Regained signal distance
- Focal point

Figure 2 Clover Leaf Pattern Test - Fly Towards and Away from GS

Communication Range - Flight Test Date: Tue Aug 07 2007

- Signal declines

Figure 3 Short Pattern Test - During Landing and Take Off
Communication Range - Flight Test Date: Fri Aug 10 2007

- Signals drop out for 6 seconds

Communication Range - Flight Test Date: Tue Aug 07 2007

- Signals drop out after 0.3 Nm

Figure 4 Clove Leave Test - During Over Flight

Figure 5 Short Pattern Test – During Taxi

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2.2 Recommendations

- The heading, taxi and take-off problems could be resolved by moving the onboard antenna position to optimize its performance. Since it will be difficult to find a location that will satisfy all circumstances, another solution for this would be to split the antenna signal into two to have two antennas in different locations. More tests will be needed to test the new location.

- The range problem could be improved by adding an amplifier or high power radio to increase the transmission power (illegal to do in the USA for the 900 MHz and the 2.4 GHz frequencies). However, when amplifying the signal, the noise will be amplified at the same time and the signal to noise ratio (SNR) will change. More hardware design work will be needed to mitigate the SNR issue for this solution.

- Another way to do is to improve the ground station antenna setup by splitting the antenna outputs into two so an omni directional and directional antenna can operate simultaneously. A directional high gain antenna can improve the link over a short range while the omni directional antenna will handle the communication over a long range. The disadvantage to this solution is that the transmitter power on each antenna will be cut in half after splitting the signal into two so the omni directional antenna would not have a 1 watt output like it currently does. Therefore, it will decrease the maximum range. However, it might be possible to add an amplifier to recreate the 1 watt output signal for both antennas. More studies are needed on this solution.

- Another more possible solution is to use an off-the-shelf tracking antenna system. The tracking antenna takes the telemetry data (GPS) from the UAV and will point the ground station antenna at the UAV all the times. With the tracking antenna system, a high gain directional antenna could be used to maximum the range in all directions. This could avoid the problems with low transmitting power caused by splitting the antenna signal, and the SNR issue due to the amplifying process. The only concern for this solution would be the cost for the tracking antenna system. One of the available products can be found from Advanced Ceramic Research at the link: [Advanced Ceramic Research](http://www.acrtucson.com/UAV/antenna/index.htm)

- The “overhead” problem is due to radiation pattern for both the onboard and the ground station antennas. One possible solution is to change the radiation pattern of antenna, physically changing the antenna design. The easiest solution is to limit the operation of the aircraft to ensure the aircraft never flies directly over the ground station antenna.

- A higher quality antenna will be required to replace the currently used antennas to ensure its reliability as this is an essential component for the autopilot system. Any failure of the GPS antenna will result in a malfunction of the autopilot and will cause a catastrophic failure.
3 1\textsuperscript{st} Flight Test Result

Test Date : August 07, 2007  
Test Location : Lawrence Municipal Airport  
Test Item : Long Approach test; Short pattern test  
Take off Time : 08:41  
Landing Time : 09:41  
Test Duration : 1 hrs

3.1 Test Conditions

\textit{Ground Station Location}

The test was performed at Lawrence Municipal Airport. The Piccolo ground station was set up between the main runway and taxiway, as illustrated below.

\begin{figure}[h]
  \centering
  \includegraphics[width=\textwidth]{ground_station_location.png}
  \caption{Ground Station Location for August 07 Flight Test}
\end{figure}

\textit{Test Sequence}

\textbf{Table 3-1 Test Sequence for August 07 Flight Test}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Sequence & Test Description & Test Card Index & Figure No. \\
\hline
1 & Long Approach & Run 1A & Figure 7 \\
2 & Long Approach & Run 2A & Figure 8 \\
3 & Short Pattern & Run 1B & Figure 9 \\
4 & Short Pattern & Run 2B & Figure 10 \\
5 & Short Pattern & Run 3B & Figure 11 \\
6 & Short Pattern & Run 4B & Figure 12 \\
\hline
\end{tabular}
\end{table}
Communication Range - Flight Test Date: Tue Aug 07 2007

Flight Trajectory - Ground Station located at Center Point

Figure 7 Long Approach Test (Run 1A)
Communication Range - Flight Test Date: Tue Aug 07 2007

 RSSI (dBm) vs. Time (min)

 Range (Nm) vs. Time (min)

 Heading Angle (deg) vs. Time (min)

 Flight Trajectory - Ground Station located at Center Point

Figure 8 Long Approach Test (Run 2A)
Communication Range - Flight Test Date: Tue Aug 07 2007

Flight Trajectory - Ground Station located at Center Point

Figure 9 Short Pattern Test (Run 1B)
Communication Range - Flight Test Date: Tue Aug 07 2007

Flight Trajectory - Ground Station located at Center Point

Figure 11 Short Pattern Test (Run 3B)
Communication Range - Flight Test Date: Tue Aug 07 2007

Figure 12 Short Pattern Test (Run 4B)
4 2\textsuperscript{nd} Flight Test Result

<table>
<thead>
<tr>
<th>Test Date</th>
<th>August 10, 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Location</td>
<td>Clinton Lake RC field</td>
</tr>
<tr>
<td>Test Item</td>
<td>Clover Leaf Test</td>
</tr>
<tr>
<td>Take off Time</td>
<td>08:54</td>
</tr>
<tr>
<td>Landing Time</td>
<td>13:00</td>
</tr>
<tr>
<td>Test Duration</td>
<td>4 hrs 6 mins</td>
</tr>
</tbody>
</table>

4.1 Test Conditions

**Ground Station Location**

The ground station antenna is set up at the west side of the shelter on the R/C field. It is about 3~5 feet away from the shelter.

![Ground Station Location](image)

Figure 13 Ground Station Location for Aug 10 Flight Test

**Test Sequence**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Test Description</th>
<th>Test Card Index</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clover Leaf – focal point at GS</td>
<td>Run 1C</td>
<td>Figure 14</td>
</tr>
<tr>
<td>2</td>
<td>Clover Leaf – focal point away from GS</td>
<td>Run 1D</td>
<td>Figure 15</td>
</tr>
</tbody>
</table>
Communication Range - Flight Test Date: Fri Aug 10 2007

Flight Trajectory - Ground Station located at Center Point

Figure 14 Clover Leaf Test – Focal Point at GS (Run 1C)
Communication Range - Flight Test Date: Fri Aug 10 2007

Flight Trajectory - Ground Station located at Center Point

Figure 15 Clover Leaf Test – Focal Point away from GS (Run 1D)
5 3rd Flight Test Result

Test Date : August 15, 2007
Test Location : Clinton Lake RC field
Test Item : Clover Leaf Test (gear up), Race Track Test, Figure Eight Test, Clover Leaf Test, Clover Leaf Test (focal point shift).
Take off Time : 06:08
Landing Time : 13:43
Test Duration : 7 hrs 35 mins

5.1 Test Conditions

Ground Station Location

Based on the last flight test experience, it was proved that the shelter blocked the signal. So the ground station was set up at about 500 ft west of the shelter this time to avoid these problems.
## Table 5-1 Test Sequence for August 15 Flight Test

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Test Description</th>
<th>Test Card Index</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clover Leaf (gear up)</td>
<td>Run 1C.1</td>
<td>Figure 17</td>
</tr>
<tr>
<td>2</td>
<td>Race Track Left turns – 10 Deg</td>
<td>Run 1E</td>
<td>Figure 18</td>
</tr>
<tr>
<td>3</td>
<td>Race Track Left turns – 20 Deg</td>
<td>Run 2E</td>
<td>Figure 19</td>
</tr>
<tr>
<td>4</td>
<td>Race Track Left turns – 30 Deg</td>
<td>Run 3E</td>
<td>Figure 20</td>
</tr>
<tr>
<td>5</td>
<td>Race Track Right turns – 10 Deg</td>
<td>Run 1F</td>
<td>Figure 21</td>
</tr>
<tr>
<td>6</td>
<td>Race Track Right turns – 20 Deg</td>
<td>Run 2F</td>
<td>Figure 22</td>
</tr>
<tr>
<td>7</td>
<td>Race Track Right turns – 30 Deg</td>
<td>Run 3F</td>
<td>Figure 23</td>
</tr>
<tr>
<td>8</td>
<td>Race Track Right turns – 40 Deg</td>
<td>Run 4F</td>
<td>Figure 24</td>
</tr>
<tr>
<td>9</td>
<td>Race Track Left turns – 40 Deg</td>
<td>Run 4E</td>
<td>Figure 25</td>
</tr>
<tr>
<td>10</td>
<td>Figure Eights – 1 Nm</td>
<td>Run 1G</td>
<td>Figure 26</td>
</tr>
<tr>
<td>11</td>
<td>Figure Eights – 2 Nm</td>
<td>Run 2G</td>
<td>Figure 27</td>
</tr>
<tr>
<td>12</td>
<td>Figure Eights – 3 Nm</td>
<td>Run 3G</td>
<td>Figure 28</td>
</tr>
<tr>
<td>13</td>
<td>Figure Eights – 4 Nm</td>
<td>Run 4G</td>
<td>Figure 29</td>
</tr>
<tr>
<td>14</td>
<td>Figure Eights – 5 Nm</td>
<td>Run 5G</td>
<td>Figure 30</td>
</tr>
<tr>
<td>15</td>
<td>Figure Eights – 6 Nm</td>
<td>Run 6G</td>
<td>Figure 31</td>
</tr>
<tr>
<td>16</td>
<td>Figure Eights – 7 Nm</td>
<td>Run 7G</td>
<td>Figure 32</td>
</tr>
<tr>
<td>18</td>
<td>Clover Leaf – focal point on GS</td>
<td>Run 1C</td>
<td>Figure 33</td>
</tr>
<tr>
<td>19</td>
<td>Clover Leaf – focal point away from GS</td>
<td>Run 1D</td>
<td>Figure 34</td>
</tr>
</tbody>
</table>
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 17 Clover Leaf Test (Run 1C.1)
Figure 18 Race Track Test – Left Turns 10 deg (Run 1E)
Communication Range - Flight Test Date: Wed Aug 15 2007

RSSI (dBm)

Time (min)

Range (Nm)

Time (min)

Heading Angle (deg)

Time (min)

Bank Angle (deg)

Time (min)

Flight Trajectory - Ground Station located at Center Point

Figure 19 Race Track Test - Left Turns 20 deg (Run 2E)
Figure 20 Race Track Test - Left Turn 30 deg (Run 3E)
Communication Range - Flight Test Date: Wed Aug 15 2007

RSSI (dBm)

Range (Nm)

Heading Angle (deg)

Bank Angle (deg)

Flight Trajectory - Ground Station located at Center Point

Figure 21 Race Track Test - Right Turns 10 deg (Run 1F)
Figure 22 Race Track Test - Right Turns 0 deg (Rune 2F)
Figure 23 Race Track Test - Right Turns 30 deg (Run 3F)
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 24 Race Track Test - Right Turns 40 deg (Run 4F)
Communication Range  - Flight Test Date : Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 25 Race Track Test – Repeat Left Turns 40 deg (Run 4E)
Communication Range - Flight Test Date: Wed Aug 15 2007

Time (min)

Range (Nm)

Heading Angle (deg)

Bank Angle (deg)

Flight Trajectory - Ground Station located at Center Point

Figure 26 Figure Eight Test - 1 Nm (Run 1G)
Communication Range - Flight Test Date: Wed Aug 15 2007

Range (Nm)

Head Angle (deg)

Bank Angle (deg)

Flight Trajectory - Ground Station located at Center Point

Figure 27 Figure Eight Test - 2 Nm (Run 2G)
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 28 Figure Eight Test - 3 Nm (Run 3G)
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 29 Figure Eight Test - 4 Nm (Run 4G)
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 30 Figure Eight Test - 5Nm (Run 5G)
Communication Range - Flight Test Date : Wed Aug 15 2007

Range (Nm)

Heading Angle (deg)

Bank Angle (deg)

Flight Trajectory - Ground Station located at Center Point

Figure 31 Figure Eight Test - 6 Nm (Run 6G)
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 32 Figure Eight Test - 7 Nm (Run 7G)
Communication Range - Flight Test Date: Wed Aug 15 2007

Flight Trajectory - Ground Station located at Center Point

Figure 33 Clover Leaf Test – Focal Point at GS (Run 1C)
Communication Range - Flight Test Date: Wed Aug 15 2007

RSSI (dBm)

Time (min)

Range (Nm)

Time (min)

Heading Angle (deg)

Time (min)

Flight Trajectory - Ground Station located at Center Point

RSSI > -93

RSSI < -93

Figure 34 Clover Leaf Test – Focal Point Away from GS (Run 1D)
Reference