Steps to Autonomous Flight

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1 Introduction

This document outlines the steps involved in configuring, installing and operating the Piccolo autopilot system. It also touches on the many operational considerations involved with flying small UAVs. While primarily intended for fist time users it also provides a good review for the experienced UAV integrators.

Flying autonomous vehicles can be a dangerous undertaking with potentially serious consequences. To ensure success and the safety of others, it is important to develop an understanding of all the issues involved, become proficient at operating the Piccolo system, and be aware of the consequences. Safety should be the primary consideration at every step in the process.

2 Overview

The steps to autonomous flight are listed in chronological order below. We feel these steps, in the order that they are presented, is crucial to ensure safety and success. The next section describes each step in detail. It is very important not to skip steps or move forward without first developing the proper working knowledge and understanding of each of these steps.

1. Read Piccolo Documentation.
2. Set-up Hardware-in-the-loop Simulation
3. Develop Simulation Model
4. Simulate and Develop Autopilot Gains
5. Integrate Piccolo avionics
6. Perform Control Surface Calibration
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2.1 Read the Piccolo Documentation

The CD included with the Piccolo Developer's kit contains the Piccolo system documentation. It is important to read through these documents to get familiar with the content. The *Piccolo User's Guide* provides an excellent overview of the system and its operation. Many of the required documents can also be found on the Downloads page at www.cloudcaptech.com.

2.2 Set-up Hardware-in-the-Loop Simulation (HiL)

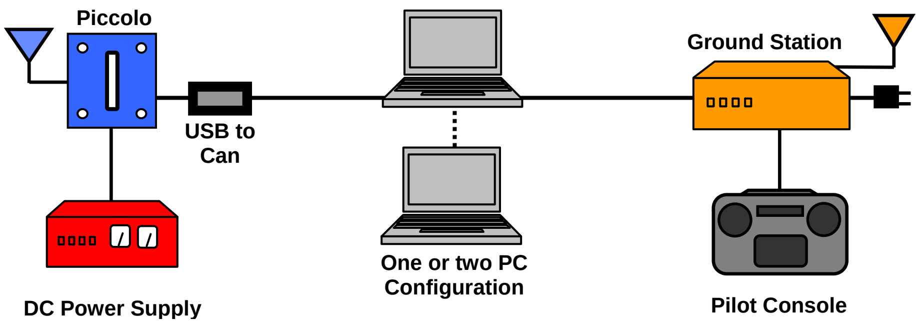

Figure 1 - HiL Simulation Environment

We strongly recommend reading the *Piccolo Setup Guide* for setting up the Hardware-in-the-Loop simulation in the lab. This step helps to understand the system components, the features available, and a working knowledge of how it operates. Simulating with a reference model is an excellent point for evaluating new vehicle integration for the basics such as stability, turn rate, and tracking performance.

To setup a proper HiL, you will need a ground station kit, one Piccolo autopilot, and a Developer's Kit. Contact Cloud Cap Technology for more information about obtaining these items.

Figure 2 - HiL Setup Items

2.3 Develop Simulation Model

The next step is to develop a simulation model of your aircraft.

Flight simulation is a key step in minimizing the time and cost required to get to a first flight. Most newcomers to the UAV field do not appreciate the usefulness of the Hardware-in-the-Loop Simulation.

Please review the **`T15_Honda_AVL.txt`** in the **`T15ModelAVL`** directory on the install CD. It provides a working example of a typical aircraft model file and will help in developing a text file for your aircraft. Also review the *Piccolo Simulator* document that outlines the various parameters and/or coefficients required to model aircraft dynamics in the Piccolo system.

The importance of this step cannot be emphasized enough! It is critical to develop a proper simulator model for your vehicle. A proper model allows you to do the following:

- Learn how to operate the system in the safety and comfort of a lab environment
- Tune the autopilot gains
- Fly proposed missions

If you have any questions regarding the modeling process, contact please contact us, we are here to help.

2.4 Simulate and Develop Autopilot Gains

Once a model file has been built, the next step is to fly it manually in the simulator to see if it responds as expected. If the model parameters are close, it should perform similar to an actual vehicle in flight.

The next step is to develop a set of autopilot gains for the aircraft using the simulator rather than in the field. The process for tuning gains is outlined in the *Piccolo Vehicle Integration Guide*. This is where the modeling work pays off. Initial tuning of the autopilot gains in simulation is simpler and safer than trying to do it on a first flight.

2.5 Integrate Piccolo Avionics

Read the *Piccolo Vehicle Integration Guide* included in the documentation CD. This will help to develop an integration plan for your particular vehicle. This process can be done in conjunction with the previous steps. It important to take the appropriate amount of time to thoroughly work through the integration details at this step. Poor workmanship and or inattention to details at this step can complicate further steps in the process of making a first flight.

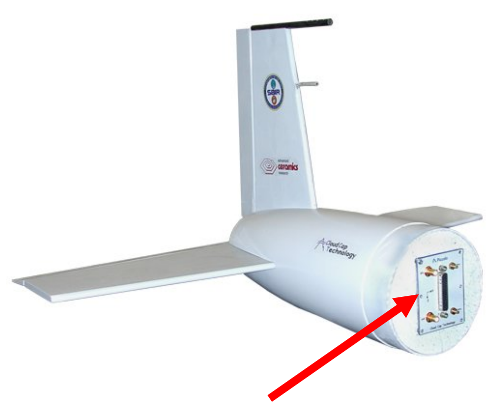

Figure 3 - Piccolo Integration Example

2.5.1 ARF Airframes

A common acronym used in the RC world is ARF (Almost Ready to Fly). Our experience with these airframes has shown that this is not always the case. While it may seem like a useful and logical first step to integrate a Piccolo autopilot into an existing RC trainer aircraft, care must be exercised when using any hobby grade components. If using one of the many existing hobby airframes, it is important to go over them carefully with an eye toward potential failures.

The following two items should be completed if using an ARF hobby airframe:

- Pin or redo all the control surface hinges. Every ARF airframe CCT has evaluated has had poor control surface hinging.
- Add the largest fuel tank possible before installing the Piccolo. Once flying autonomously, the flight time of a typical model with a stock fuel tank is only approximately 10 to 15 minutes.

2.6 Perform Control Surface Calibration

In the *Piccolo User's Guide*, see the *Surface Calibration* section. This section provides instructions on the control surface calibration procedure. An inclinometer (or other device) is needed for this procedure to measure the angular deflection of the control surface from the neutral position. This is done for each surface by commanding a pulse width then measuring the deflection. The values are then entered into the corresponding table and saved to the avionics EEPROM . This process takes out the nonlinear characteristics of the linkages. Once complete, the pilot should be able to run through a complete controls check. All surfaces should respond accordingly. If not check the table for sign errors or non-monotonic values.

2.7 Secure a Flying Site

It is very important to find a proper flying site. Flying autonomously requires a great deal of space. For flight test purposes, it is imperative to find a flying site that offers the following:

- A large uninhabited area for over flight. There should be limited buildings, houses, major roads or highways.
- A suitable runway surface with an unobstructed approach for landing and takeoffs.
- A limited amount of people to inhibit operations.
- Ready access to a phone – cell or line – in the event of an emergency.

RC hobby flying sites are a poor choice. The airspace is too small for autonomous flying and it can conflict with other RC users.

The current FAA policies on Unmanned Aircraft Systems can be found on the Unmanned Aircraft Systems (UAS) Regulations & Policies page of the FAA website.

2.8 Develop Flight Plan and Emergency Procedures

The next step is to develop a suitable vehicle flight plan for the initial testing. Use the Layers window in Piccolo Command Center (PCC) and find an appropriate image of the flying site so it can be displayed in the Map window of the PCC.

Local layers exist as files on the local computer. Many different formats of maps are supported, both raster (i.e. based on a picture) and vector maps.

Map layers coming from the internet are referred to as WMS (Web Mapping Service). WMS defines a protocol that allows applications to query a map server for its capabilities. For example, the *terraserver*, a popular internet map service, supports three different map types:

- Uurban area imagery - 0.5 meter resolution in color, but only available in some large US cities
- Digital Orthographic Quadrangles (DOQ) - 1 meter resolution in black and white
- Topographic maps

For maps outside the U.S., select the *wms.jpl.nasagov* server and then select *global_mosaic – WMS Global Mosaic, pan sharpened*. The global mosaic layer is worldwide Landsat data with a 15 meter resolution. There are commercial services that offer WMS mapping data, such as GlobeXPlorer (http://www.globexplorer.com/products/imageconnect-wms.shtml).

See the *Piccolo User's Guide* for more information about adding map layers.

The next step is to build a large rectangular flight plan (4 points, **Figure 4**) in the constraints of the test site. It is important to have one of the long legs over the runway as shown in this example diagram over the Webster Field map image.

Figure 4 - Webster Field St. Inigoes, Maryland

The initial flight plan should also overlay the runway and be in the direction of the takeoff roll. The initial waypoint should be set to the first waypoint at the end of the takeoff roll (upwind leg waypoint). It is also a good idea to add a second flight plan (a smaller one or an orbit waypoint) over the center of the field or other safe open area within close proximity. Use one of the waypoints in the second flight plan as the lost communications waypoint.

During this set-up it also is extremely important to address any potential emergency situations and how they should be handled.

2.9 Flying in Simulation

The next step is to fly an initial mission in simulation using the tests cards outlined in the *Initial Flight Test Cards* document. Working through the initial set of test cards in simulation allows a good place to practice skills and sort out any confusion in a relaxed and stress free environment.

It is important to become comfortable with setting up and testing each loop, making autopilot gain adjustments, and testing the limits. This also allows a safe place to become proficient at operating the aircraft and to address any unanswered questions.

The simulator also provides the opportunity to test both lost GPS and lost communication, which are two critical failure modes of the system. It's important to exercise both modes in simulation to understand what will happen, given the configuration and limit settings, in the event of a failure. To test lost GPS, disable the GPS in the simulator. To test Lost Communications, turn off the ground station. Leave it off longer than the lost communications timeout set in the limits page. The reaction to both failures depends on the user-supplied settings on the limits page.

During this step it is also important to verify any external flight termination designed in or connected to the deadman's output.

DO NOT attempt flying in the field until the system has been tested extensively in simulation.

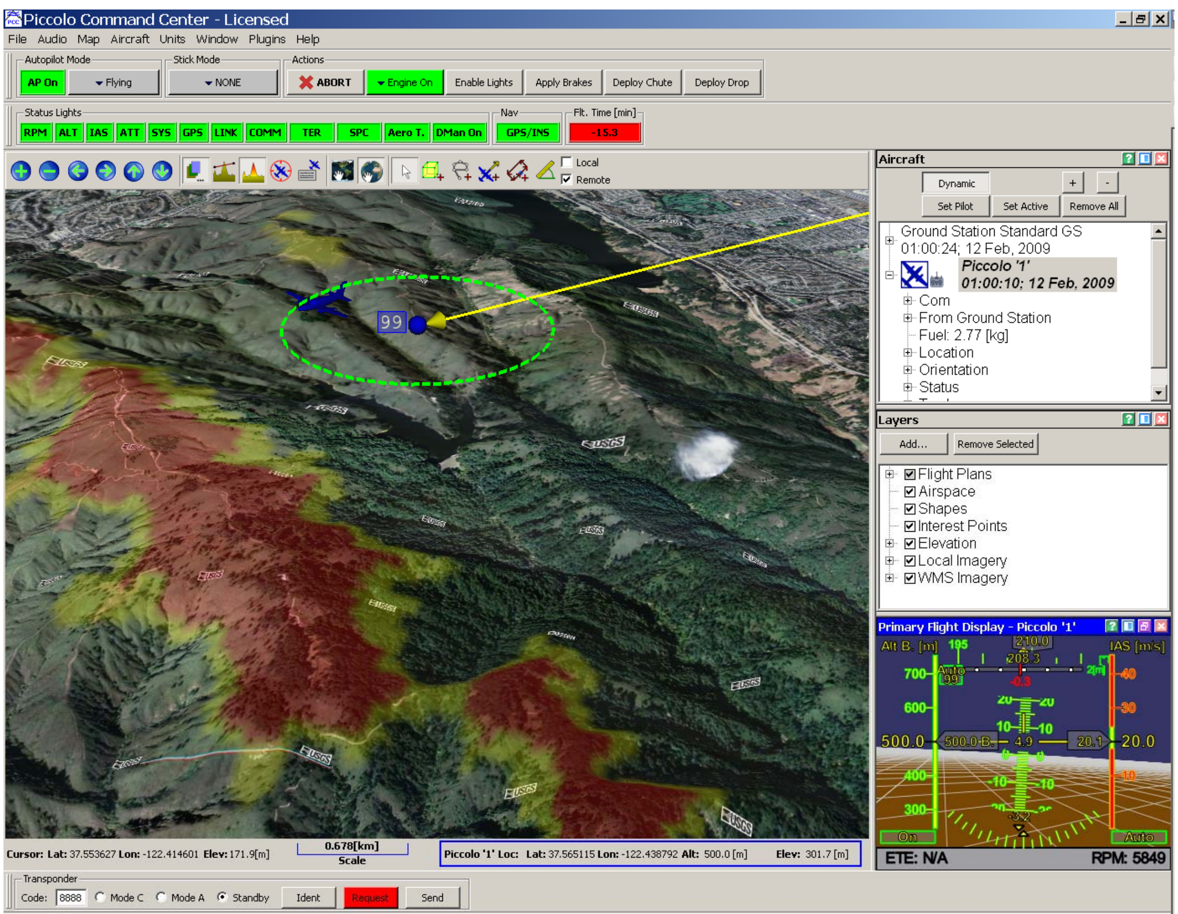

Figure 5 - Piccolo Command Center Simulation Environment

2.10 Send in Model Files

Email CCT the aircraft model file and lookup tables, the map of the flying site, and the exported XML configuration files that contain the AP gains and other settings. CCT can review them and provide useful feedback.

2.11 Communications and GPS Check

At the flying site, it is important verify communications and GPS performance. Refer to the *Piccolo Vehicle Integration Guide* for specifics on the required testing. Since the GPS is the primary flight sensor, never fly if there is any indication of poor performance. For additional guidelines and tests see the *Communications Troubleshooting Guide*.

The GPS should have no drop outs and have a 3D track 100% of the time in all flight attitudes and conditions.

2.12 Complete Preflight Checklist

The Piccolo Command Center user interface has a preflight checklist page (**Figure 6**). It is critical that this be preformed prior to every flight. The *Piccolo Vehicle Integration Guide* includes the same checklist with added details for many of the steps.

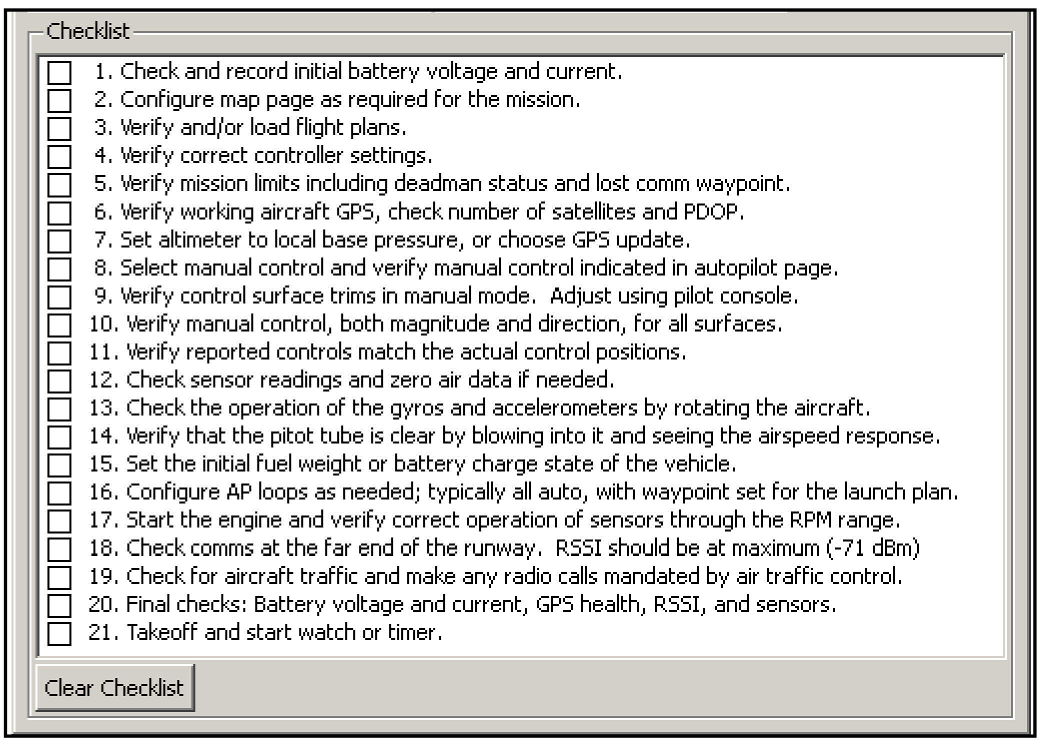

Figure 6 - Preflight Checklist

2.13 Autonomous Flight - Testing the Gains

Once the aircraft is airborne under manual control, test the gains that were developed in simulation. Follow the *Initial Flight Test Cards 2.x* document during your testing. Typically the control loops are tested individually. Usually the vehicle parameters derived from a good simulation model are adequate to get the vehicle flying successfully autonomously. If necessary doublet maneuvers can be performed to refine the vehicle parameters. And if further performance improvements are necessary that can be addressed with more loop tuning. Sometimes flight testing will turn up other issues like vibration which need to be addressed before the best performance can be achieved.

Figure 7 - Controller Configuration in PCC

The following are the main control loops for the 2.x controller. See *Tuning Piccolo Control Laws 2.x* for a more complete description.

- ☑ **Bank Control:** Bank control is accomplished by feedback of the bank angle error through a commanded roll rate. The most important number affecting this term is the aileron effectiveness vehicle parameter.
- ☑ **Total Energy Control:** Provides outputs to altitude rate command, throttle, and flaps.
- ☑ **Airspeed Control:** Maintains the airspeed of the vehicle. It uses the airspeed sensor and drives the vertical acceleration command.
- ☑ **Pitch Damper:** Damps out pitch oscillations. It uses the pitch gyro and drives the elevators.
- ☑ **Altitude Control:** Maintains the altitude of the vehicle. The altitude loop drives the vertical rate command.
- ☑ **Vertical Rate Control:** The vertical rate command is used to feed the Z acceleration loop
- ☑ **Z acceleration Loop:** This loop can take inputs from airspeed or altitude loops, and affects the elevator actuator.
- ☑ **Tracker Control:** Performs navigation. It uses the GPS and drives the turn rate command.
- ☑ **Yaw Damper Control:** Damps out yaw oscillations. It uses the yaw gyro and drives the rudder.

Review and print a copy of the *Initial Flight Test Cards* document and have it for reference during the first flight.

If there are any issues or problems with running this test, go back to the simulator and sort them out before flying again.

2.14 Post Flight Review

Once the first flights have been completed, it is important to become familiar with the data-logging feature and the replay mode of the Piccolo Command Center.

All telemetry data coming down from the aircraft is logged in both ASCII and binary formats identified by the ".log" and ".tel " extensions respectively. The binary file allows a replay of the flight telemetry. The replay mode can be run in from the communication setup dialog window during PCC start-up.

The ASCII file allows you to pull the data into Mat Lab or Excel for detailed post flight analysis. We also have additional Matlab analysis tools posted on our web site.

If there are any problems, send CCT the initial telemetry files and we will be happy to look them over and provide feedback. Contact us at:

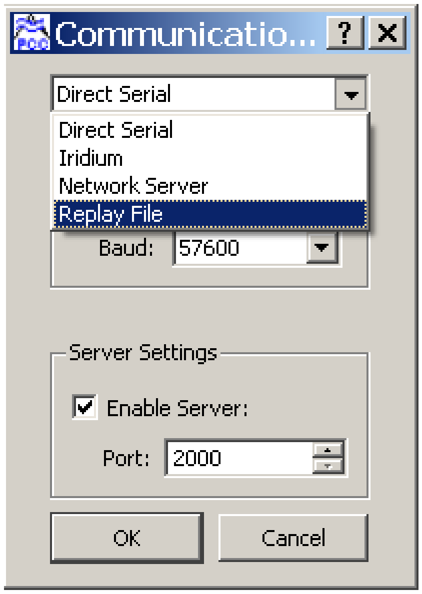

Figure 8 - Replay File

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