System Invoice and Description

RDF-UAV - a low-cost aerial radio tracking system for avian conservation in the Northern Marianas Islands.

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Introduction and project goals

In 2007 I was contacted by Paul Radley about the possibility of developing a UAV (Unmanned Aerial Vehicle) system equipped with a RDF (Radio Direction Finding) pod to be used for tracking radio tagged animals. The idea for the system was that an electric motor powered model aircraft could be fitted with an autopilot and a tracking pod to locate animals in remote areas where conventional tracking methods are difficult or impossible. The tracking pod is the key innovation of the system and combines a very sensitive radio receiver with a radio direction finding device to detect tracking tag pulses from the air, determine the direction of the pulse relative to the plane, and localize the tag using triangulation techniques. Paul Radley initially wanted to use the tracking system to monitor radio tagged bridled white-eyes released on the uninhabited northern Marianas island of Sarigan. The deployment date was to be late April 2008.

Since this would be a complex system, with many new and untested parts, and was the first of its kind, it was understood that this should be considered a high risk project. The potential benefits to CNMI FWS of having a working aerial tracking system were thought to outweigh the risks.

The system (two aircraft, RDF tracking pod, ground station and accessories, see "UAV-based radio tracking system bill of materials" below) was to be delivered and deployed in May 2008 to track tagged bridled white-eyes on Sarigan during the translocation project. Due to funding delays and hardware problems, it was not possible to deliver a functional system in time for the 2008 translocation. As a result, the system remained in Portland Oregon so that it could be refined and tested throughout 2008 and early 2009 for deployment in the May 2009 Sarigan bridled white-eye translocation. The system was successfully delivered and deployed at that time, and the complete package is now stored in a case at the CNMI FWS office on Saipan. A report on the 2009 deployment, and the results of the tracking system are included in this document.

2009 Sarigan deployment report

Introduction

In May 2009, biologists from the Commonwealth of the Northern Mariana Islands (CNMI) Division of Fish and Wildlife carried out a pilot project to introduce 50 Tinian-native Bridled White-eyes (Zosterops conspicillatus) to the uninhabited island of Sarigan. The purpose of the project was to test the feasibility of, and develop techniques for future introductions of threatened or endangered avian species to safe and undisturbed islands within the Mariana archipelago.

A key goal of the Sarigan translocation project was to develop and improve techniques for monitoring released birds attached with radio location tags. In a previous 2008 Sarigan translocation it was determined that conventional (i.e., manual) radio tracking techniques can be used, but that the dense vegetation on the island made it extremely difficult and time consuming. Manual tracking techniques are particularly problematic for the project goal of locating large numbers of tagged birds on a daily basis.

As part of the 2009 Sarigan translocation project, we tested a possible solution for the tracking dilemma: an autonomous aerial tracking system, developed by J. Burt, that could theoretically locate all tagged individuals daily (weather permitting) by flying over the habitat in a search pattern. Such a system could enhance or even eliminate ground tracking efforts and could potentially be used in many other difficult terrain radio tracking scenarios.

Methods and Aerial Tracking System Description

The aerial platform consists of an electric motor powered glider (Multiplex Cularis), under autopilot control (Paparazzi open source autopilot). The autopilot is capable of fully autonomous flight (for safety purposes, take-off and landing are under manual control), and can be programmed to fly any route desired by assigning a series of course waypoints for the plane to traverse. During a flight, the aircraft maintains continuous contact with a ground station laptop via a radio modem link. The ground station software allows pilots to adjust course waypoints in-flight and instruct the plane to return to a "home" position at the end of a mission. The entire system was designed to be inexpensive, light weight, rugged, and extremely portable.

A custom-built radio tracking pod mounts onto the top of the aircraft fuselage. The tracking pod contains a very sensitive radio receiver that can be programmed to tune into a repeating sequence of radio tag frequencies. The receiver output feeds into a custom radio direction finder (RDF) device (Picodopp RDF, Robert Simmons), that outputs the compass direction (relative to the plane's position) of every tracking transmitter pulse received. Each tag pulse compass angle is transmitted to the ground station (as well as stored on an on-board data logger). Tracking tag positions are determined by combining several tag pulse compass angle determinations taken while the plane flies.

Figure 1: Side view of aircraft and radio tracking pod. The four vertical antennas are used by the system to detect radio tag transmissions and generate an angle to the signal source relative to the nose of the plane. Multiple tag pulse detections at different aircraft locations allow the signal source to be triangulated.

A typical locator mission involves launching the plane under manual control, switching on the autopilot and monitoring the plane as it flies a fixed course that circumnavigates the island over habitat containing tagged birds, then regaining manual control and landing the plane. After the flight, it take a few minutes to analyze the tracking data collected and estimate the position of any tags that were detected. A portable solar panel is used to recharge motor and laptop batteries for the next flight.

May 2009 Deployment on Sarigan & Testing Methods

The aerial system was originally scheduled to be deployed to Sarigan with pilot/operator J. Burt from May 4-10. Our goal was to conduct multiple flight tests and to locate birds mounted with transmitters. Delays due to bad weather reduced the deployment dates to May 7-10, and high winds on some days reduced flight testing to several flights without the locator pod on board, and one test flight with the locator pod on the plane. Furthermore, our radio tag mounting procedure was faulty, causing tags to fall off the birds after release. Therefore, instead of tracking tagged birds as planned, we tested the system by placing two tracking transmitters in trees at known locations. Results of the single radio tracking test flight in the late afternoon of May 9, 2009 are reported here.

Ground station setup and location: After scouting about the upper plateau near the camp site we located a suitable place to install the ground station and launch the aircraft. A ground station modem antenna pole was mounted on a small hill near a ridge that offered an unobstructed view and an ideal launch/landing zone (See Figures 1-3, Sarigan map).

Radio tracking test flight methods: Two transmitters (Holohil BD-2N 0.43g, 148.558 and 148.758 MHz) were placed in trees at approximately 2m height. The placement was intended to simulate a bird perched in the upper canopy of the habitat. Transmitter locations were determined to within 5m accuracy using a standard GPS receiver. The tracking pod receiver scanner was programmed to alternate listening at each of the transmitter frequencies every six seconds.

After the transmitters were placed in trees and turned on, J. Burt launched the aircraft with the tracking pod attached. The airplane was manually flown to the transmitter test area and climbed to about 90m above ground level. At this point the autopilot was switched on, allowing the plane to fly several pre-selected route patterns over the upper plateau of the island. The flight patterns were designed to repeatedly traverse a range of distances from the two test transmitters. After about 10 minutes, J. Burt switched the autopilot back to manual control and landed the plane in a patch of sawgrass near the launch site.

Figure 2. Ground station, radio modem antenna mast and laptop shade box were located on a small hill at the NE corner of the plateau, about 70m from the campsite.

Figure 3: Launching the aircraft near ground station (at right). After launch, pilot flies plane to safe altitude and then switches control to autopilot. The ground station software displays current airplane location on a map and allows in-flight switching of autopilot to different route patterns, as well as command plane to return home.

Results

Custom Matlab software was written to analyze the tracking flight log data stream (GPS position, altitude, speed, heading), and the direction angles and frequencies of detected transmitter pulses. The post flight analysis combined the pulse detection angles for each tag to generate multiple triangulation-based location estimations, and then averaged these to create a single estimation of each transmitter tag location (Figure 4).

During the flight, the tracking pod detected 93 transmitter pulses (49 from tag #1, 44 from tag #2). The farthest pulse detected was 239m for tag #1, and 240m for tag #2. The uniform range distance for both transmitters indicates that this is close to the absolute range for detection of this transmitter type in these conditions. Given that range, an effective tracking flight path would traverse the habitat in 200m transects.

Location estimate error was 33m for tag #1 and 37m for tag #2, based on averaged triangulation estimates from the detected tag pulses.

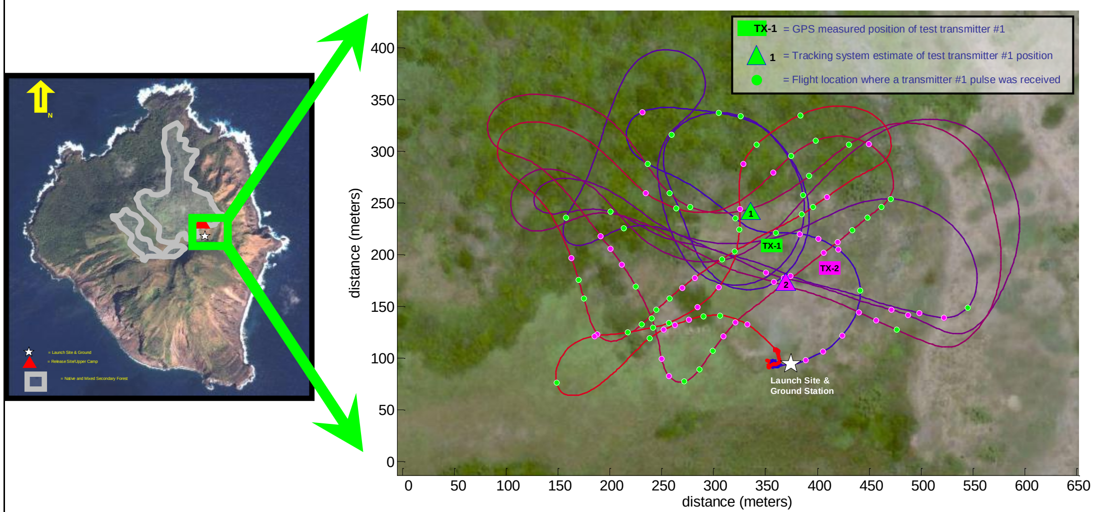


Figure 4: Radio tracking flight results. Blue-red line is the flight path (color shifts from blue at launch to red at landing). Colored circles along the flight path indicate places where a transmitter tag pulse was received (color coded to tag#). The tracking pod receiver was programmed to alternate between the two tag frequencies, hence alternation between green (tag #1) and pink (tag #2) pulse detections. By combining these pulse detections, the tracking system was able to locate each transmitter to within approximately 35m.

Conclusions

The results of this single test flight on Sarigan show that an aerial radio tracking platform is a feasible alternative, or enhancement to manual radio tracking on the ground. This technology is especially helpful in difficult or impassible terrain, as found on Sarigan. The system's main drawbacks are the need for at least occasional mild weather conditions, an area for takeoff/landing, and a radio control airplane pilot.

This autonomous aerial tracking system was a first-version prototype and cost approximately $12,000 to design, test, and deploy. Subsequent versions will be less expensive. Cost-wise, this tracking method can be thought to lie between manual tracking (cheap) and other much more expensive tracking methods, such as manned full-size aircraft, and fixed position autonomous tracking stations like those used by STRI on Barro Colorado Island in Panama.

The relatively short 240m range of the tracking system for these tags is disappointing but not surprising: the tags used for very small birds like Bridled White-Eyes necessarily sacrifice transmit power for reduced size and weight. Larger tags have much higher output power and should be detectable at greater range (this remains to be tested).

The position estimate error results for the tags were 33m and 37m. These estimates may not reflect error under real conditions given that they were based on many more pulses/tag than would likely be detected in an actual tracking flight. We are currently working on reducing this location error with a combination of analysis refinements, and electronics upgrades.

Source Links

For more information about this project, email John Burt at quill@uw.edu

A PDF file version of this poster can be downloaded at:
www.burtsoft.com/uav/sarigan09aou.pdf

Holohil systems BD-2N transmitter tag: http://www.holohil.com/bd2.htm

Doppler DF Instruments PicoDopp Direction Finder:
http://www.silcom.com/~pelican2/PicoDopp/PICODOPP.htm

Paparazzi Open Source Autopilot: http://paparazzi.enac.fr

Multiplex Cularis electric glider: http://www.multiplexusa.com/models/kits/cularis_.php

System design, methods and description

The powered sailplane (Cularis model, Multiplex Modelsports USA, Poway, California) that serves as the tracking platform was fitted with an efficient and powerful electric motor and high capacity batteries. This high performance model is capable of staying aloft for more than ½ hour, and is operable in winds up to 20mph. It is also very rugged, inexpensive, and all parts of the plane are pre-made and replaceable. Two complete flight-ready Cularis aircraft with autopilots were provided in case of damage to or loss of one of them.

The aircraft's autopilot system (Paparazzi open source autopilot, board purchased from PPZUAV.com), with IR attitude sensors and high rate GPS, can be programmed on the ground or during flight to fly missions with multiple waypoints, communicates with the ground station via a radio modem (model 9Xtend; Maxstream, Inc., Lindon, Utah), and can be commanded to abort the mission and return the launch point. The RDF (radio direction finding) pod is a separate unit that attaches to the top of the aircraft over the wings. The RDF pod includes a scanning VHF FM radio receiver (model R302-2; Hamtronics, Inc., Hilton, Ney York), four custom built antennas, a modified Doppler direction finder (Picodopp; Santa Barbara Automation, Santa Barbara, California).

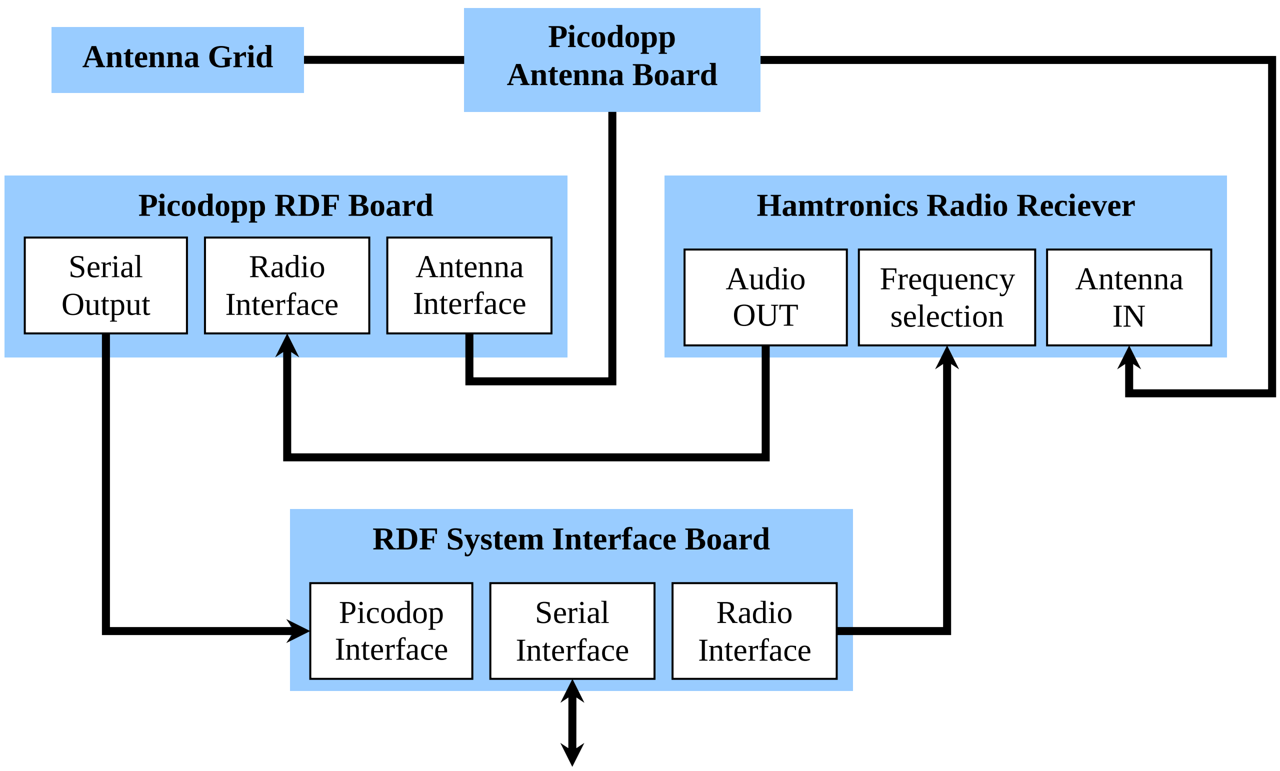
While aloft, the scanning frequency of the radio receiver can be programmed via the ground station. This function enables the operator to manually set an individual transmitter frequency, sample enough bearings to locate it, then switch to and locate another active transmitter frequency. The plane was programmed to fly several transits of the island to locate as many of the transmitters as possible before returning to the base station for a freshly charged battery.

The base station used an omnidirectional antenna attached to a telescoping boom, a radio modem to receive the aerial RDF data and transmit commands to the tracking platform, and a PC laptop running Paparazzi software to control the aircraft and map it's location on the screen.

A typical aerial locator mission would involve launching the sailplane via manual radio-control, switching it to autopilot, and then monitoring the aircraft as it flies a fixed course that circumnavigates the island to locate the radio-tagged Bridled White-eyes. At the end of each mission (which would either occur when all transmitters are located or the motor batteries have run down) the sailplane would be commanded to return to the launch point, the autopilot switched off upon arrival, and landed manually with a radio-control transmitter.

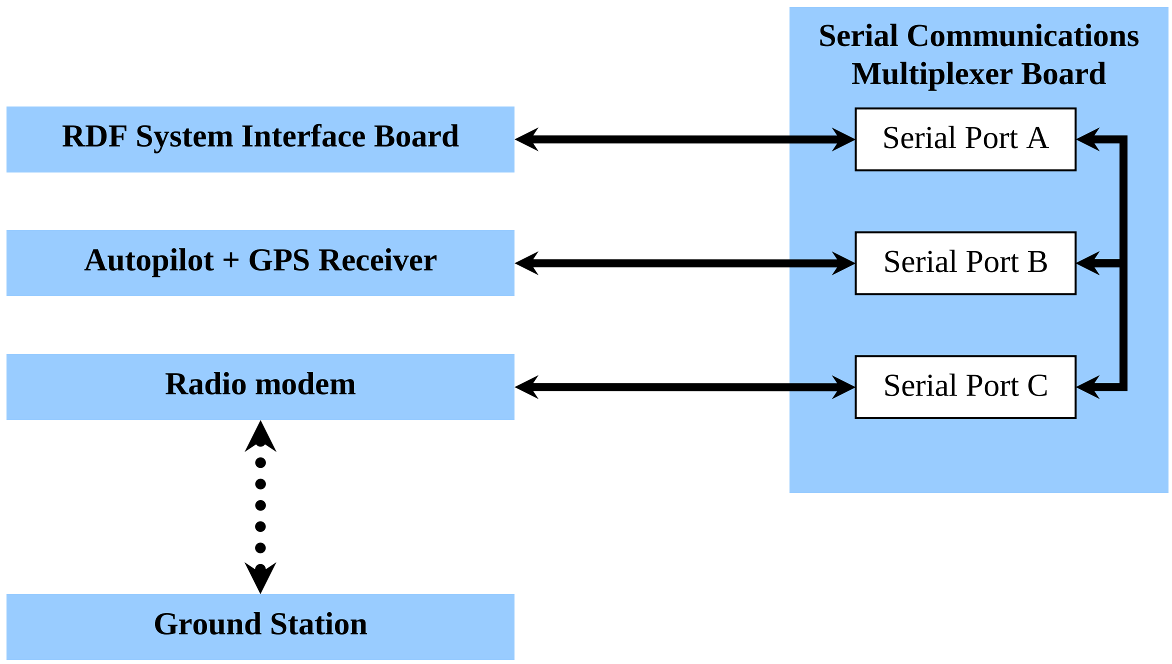
The RDF based telemetry location system (Figure 5) depends on the interaction of three basic components or modules: 1) The RDF circuit, which includes the antenna grid, a Hamtronics programmable radio, a Picodopp RDF device, and a System Interface Board that provides a single interface to these two components (Figure 1), 2) the autopilot system, and 3) a communication system that provides a real-time radio-modem interface to parts 1) and 2) (Figure 2).

Figure 5: Radio Direction Finding System connections



The UAV flight system (Figure 6) relies on several devices to allow autonomous control of aircraft, course correction and commands from the ground station, and ground control and functioning of the RDF pod. The Serial Communications Multiplexer Board (or Serial MUX) filters and distributes messages from the RDF board on the pod, the Paparazzi autopilot, and the ground station (via the radio modem). All parts of the system except the radio modem were custom built for this project.

Figure 6: UAV Flight system Major System Devices



Project milestones and timeline

2007-2008 Hardware system design period

July 5 2007: Receipt of $1000 check from the AZA. This was enough money to start testing the feasibility of the radio direction finder (RDF) unmanned aerial vehicle idea, but not enough to buy a plane and autopilot and start testing those parts of the system.

July 2007: When I received the AZA check, I contacted Bob Simmons, designer of the RDF circuit board that we would use. He agreed to test out his RDF board with a radio transmitter tag I sent him. After testing his RDF board, called "PicoDopp", with one of the Sarigan project transmitter tags, Bob discovered that he would need to make extensive modifications to the hardware and software of his RDF device to allow detection of the very brief transmitter pulses. He agreed to do this and worked for the next three months on the project. Because I couldn't purchase an airplane or autopilot, my involvement was reduced to supporting Bob as he worked out the details of the RDF device. This was unfortunate because the summer and fall were the best time for flight testing, and I had more time available to work on the project.

July - December 2007: Purchases at this time were for electronics and parts to build a prototype RDF testing rig. This hardware eventually consisted of a PicoDopp board, a Hamtronics radio receiver (to receive the transmitter tag pulses), and a custom-built four-element antenna. By December, I had been able to test the RDF system and it looked like it might work, given the accuracy I was measuring.

February 2 2008: Received and deposited DFW check for $12500. On this day, I mailed a $1000 payment to Bob Simmons for the work he had done to develop the customized RDF device (which we dubbed "ChirpDopp") for the project.

February - March 2008: I began purchasing parts and assembling the UAV and RDF systems as fast as available time allowed. During this time, I began assembling the plane and also designing two key microcontroller based devices that the UAV system would depend on: the communications node board, and the radio receiver controller board (descriptions below).

February - March 2008: Designed the communications node circuit and firmware, a crucial custom made component of the UAV system. The communications node is a device that combines the data streams from all the various devices on the plane (GPS, RDF, autopilot, etc) and transmits them to the ground station (or sends it to an onboard logging device). It also acts as a filter in the other direction: receiving commands from the ground station and distributing them to appropriate devices (e.g., "autopilot: return home", or "radio: change to channel 2"). This device was a challenging problem and took many weeks for me to design and build.

February - March 2008: Designed the radio receiver controller board, which provides a remote interface to the Hamtronics R302 radio receiver that senses the transmitter tag pulses and is a key component in the RDF system. With the controller board, we can select the desired tag frequency to scan from the ground, while the plane is in flight, and the board also has a "scan mode", allowing us to program a set of radio tag frequencies into the controller board so that it can sequentially scan through them and thus detect multiple tag locations.

2008 System construction

April 20-28 2008: By April 20, I had finally assembled the first flight-ready RDF pod, assembled the first UAV plane, completed the communications node and the receiver controller, and had purchased all of the components for the ground station as well as the parts needed to assemble another UAV and RDF pod. However, although I had the components, I struggled for the next week to complete final assembly, and conduct the crucial test flights that would allow me to verify that the RDF system would work in the air. In the last week, I was plagued with several system glitches that prevented me from collecting the critical data proving that the system would work on Sarigan.

April 29 2008: By the date of the 2008 Sarigan translocation, I had not been able to properly test or verify the UAV RDF system. What testing I had been able to conduct suggested that there were still several serious unresolved problems with the autopilot and the RDF tracking system. The chances of the system not working, and of losing the equipment in a crash was extremely high. Rather than risk deploying a malfunctioning system, and/or losing the aircraft and RDF pod, I decided to not deploy the system in the incomplete state that it was at. My reasoning was that the UAV RDF system still had a very good chance of succeeding and would be useful for future projects, but that I needed the equipment with me on the mainland to complete development and testing.

2009 System improvement and reconfiguration

December 2008 - January 2009: Refined the autopilot system, debugged interference problem that caused extremely reduced range on failsafe radio control system. Prepared for extensive early spring testing of the autopilot to ensure proper functioning during RDF tests. Made modifications to the autopilot firmware to optimize it for the Sarigan deployment.

2009 Pre-deployment flight testing

February 2009: First test flights on a smaller aircraft (Multiplex Easystar) using updated autopilot system. Now flying in a large cornfield in Vancouver WA. Used smaller airplane because it is cheap and stable and I expected lots of crashes while tuning the autopilot. Indeed, there were many crashes, some extreme and requiring extensive repairs.

March 2009: Continued test flights, prepared Cularis aircraft for autopilot. Purchased additional ground station components, such as solar panels to charge batteries.

April 1-15 2009: Started autopilot testing with the Sarigan project airframe: Multiplex Cularis. Designed flight plans for Sarigan, and researched launch and landing sites on Sarigan. Developed RDF data analysis software. Assembled solar charging system.

April 16-30 2009: Tested complete system: Cularis + autopilot (w/ ground station link) + RDF pod. Testing of RDF pod with a Holohil BD2N radio transmitter tag attached to 2m pole. Late April test flights confirmed that the RDF pod system could detect and log transmitter pulses. Test flights also demonstrated full functionality of autopilot system, including radio link to ground station, and real-time mapping and control of aircraft navigation by ground station software.

2009 Sarigan deployment (May 1-12)

May 1 2009: Arrival in Saipan (from Portland Oregon) at 1AM. I spent the afternoon repairing a broken antenna wire on the tracking pod, unpacking and testing the equipment.

May 2-5: A tropical depression delayed all flights to Sarigan. I spent these days programming significant updates to tracking data analysis software, developing flight plans for tracking flights, testing and preparing the various pieces of system hardware for the flight to Sarigan.

May 6: Weather permitted flight to the island. In the morning we attached transmitters to birds using thick superglue. Paul flew out to release the birds, and discovered that all of the transmitters had fallen off. This meant that the bird tracking component of the project was now not possible. I therefore re-programmed the tracking pod receiver to scan only the frequencies of two test transmitters which I would bring to the island. This would allow us to test the aerial tracking system by placing transmitters in known locations and flying the aircraft over them at various distances and altitudes.

May 7: I flew to Sarigan in the morning. That afternoon, we scouted the plateau and located a site to install the base station and launch the aircraft. Installed the base station antenna pole and prepped the site for plane launches. Assembled solar charging station at camp: two flexible solar panels stretched onto a PVC pipe framework, with a cable to a box containing battery chargers and power plugs.

May 8: First test flight occurred at 10AM. Plane was flown without the tracking pod, with a flight plan route that circled over the plateau in a triangular pattern. Flight duration about 10 minutes, with a rough landing due to a downdraft in front of the landing zone. After the flight, I re-calibrated the flight plan and repaired minor damage to the airframe.

In the afternoon, I assembled and tested the tracking pod. The radio receiver in the pod initially gave false direction angles, which I debugged. Solution seemed to be that the pod components need to be turned on in a specific sequence.

For the second test flight (without tracking pod), we mounted a digital camera in video recording mode onto the wing to record an in-flight video. Flight was similar to first, but at slightly lower altitude, and with slightly modified route waypoints. Landed in sawgrass with no damage to plane, though it was deep into the grass and took a while to recover.

May 9: In morning I prepared for a test flight with tracking pod attached to aircraft. Obtained GPS coordinates of chosen sites where the two test transmitters to be "tracked" would be located. Test transmitters were placed in branches of bushes as high as possible. The morning and early afternoon were too windy for a flight test so we waited until late afternoon for the test flight, when the wind had died down. The test flight was successful - the aircraft detected the two test transmitters and flew the flight route as planned. The plane was landed in sawgrass near to the base station for easy retrieval.

May 10: We had intended to try a second tracking pod flight, but high winds made this unsafe (the pod increases drag and causes a risk of stalling). I should note here that flight conditions were ideal in the early morning, but that we were not ready at those times. Flights should be possible on most days by flying shortly after dawn. In the afternoon, despite the 20 mph winds, I decided to try a flight without the pod, but with the video recording camera again. This flight successfully demonstrated the ability of the aircraft to fly in extremely marginal conditions (albeit without the pod). The plane was landed in a low patch of sawgrass near the base station.

May 11: Scrubbed another tracking pod flight attempt due to windy conditions. Packed the system up for transport. At 10AM helicopter arrived and flew me back to Saipan. In Saipan, I packed the entire tracking system (two aircraft, RC transmitter, tracking pod, base station, batteries, solar power system, etc) into the golf case that I had brought everything in. The case was transported to the FWS building for storage.

May 12: Returned to Portland OR.

UAV-based radio tracking system bill of materials

List of equipment delivered to Saipan (currently stored in black golf bag transport case at CNMI FWS building):

Two complete (partially disassembled) Cularis (www.multiplexusa.com) model gliders. Each includes: Paparazzi Tiny 2.11 autopilot (ppzuav.com), infra-red horizon sensors for attitude control, brushless motor and speed controller, control servos, 9Xtend radio modem (www.digi.com) and antenna, Berg 4L radio control receiver (www.castlecreations.com).

A Futaba 7CAP radio control transmitter.

A radio tracking pod. Pod includes: custom made collapsible four-antenna rig and pod shell, R302 tag pulse receiver (www.hamtronics.com), Picodopp direction finder device (www.silcom.com/~pelican2), custom made board that manages receiver channel control and Picodopp direction finding output.

Two roll-up solar panels (Powerfilm R15-1200) and custom PVC frame and mounting hardware.

An Asus EEE-PC 701 netbook loaded with Paparazzi autopilot ground station software, along with storage case, extra backup battery, AC charger, DC charger.

A ground station radio modem box and antenna cable, telescoping antenna pole, fiberglass mounting rod, plastic hammer, guy wire kit.

A ground station netbook shade box (custom) and mounting tripod, weight sack (to hang below tripod for stability), and folding stool.

A battery charging station (tackle box), containing: switch harness, cables, lithium polymer battery chargers, an assortment of lithium polymer batteries for battery backup, aircraft motor power, and aircraft equipment power.