A LOW COST FLIGHT TEST INSTRUMENTATION PACKAGE FOR LIGHT AIRCRAFT

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Keywords: *DGPS, flight test, instrumentation, laser rangefinder, performance.*

Abstract

The advent of relatively inexpensive DGPS and portable computer equipment enables small aircraft manufacturers to achieve greatly improved flight test efficiency and accuracy when measuring aircraft performance. Furthermore such equipment enables the takeoff performance of floatplanes to be measured which is an important part of the business at Found Aircraft of Canada.

Found has developed a low-cost flight test instrumentation package based on DGPS measurements for deriving distance, height and ground speeds. To verify the accuracy of DGPS height measurements made during airfield performance testing, a laser rangefinder system was incorporated suitably corrected for aircraft climb attitude. It was found the laser height measurements generally correlated well with the DGPS derived heights and now DGPS is used as the source of height data, unless problems are flagged.

This paper describes the development and features of the instrumentation package. Some flight test results are provided for a landplane version of the Bush Hawk. It is shown that aircraft takeoff accelerations can be derived from DGPS data, thereby reducing the need for accelerometers.

1 Introduction

The test methods first used when Found Aircraft Canada recently measured the Bush Hawk's airfield performance for certification purposes, were based on recommendations from the FAA for small airplane manufacturers, as contained in [1] and [2]. Such methods are very simple to implement using video cameras along with hand recording of instruments but they are manpower intensive. Also they do not permit rapid turnaround and evaluation of results, or provide performance engineers with enough detail for developing improved methods of analysis and estimation. Furthermore, these procedures cannot be adapted for measuring floatplane performance which is a very important part of the business at Found.

To address such deficiencies Found has developed a new, portable, low cost flight test instrumentation package based on differential GPS (DGPS) for distance and height, a laser altimeter for verifying height, an engine monitor, and a portable PC for recording data from the flight test instruments. The DGPS is also useful in performance work done at altitude such as calibration of the ASI system, for measuring the stall speeds and for providing backup rate of climb information.

The Ag132 DGPS system that is used can employ signals from a Coastguard station or satellite data for the differential correction. Most of the work has been done in Ontario, Canada, and Florida in the US and the Coastguard signals have proven reliable at both locations.

The accurate measurement of height above the runway is an essential part of airfield performance testing. At the outset the height accuracy of DGPS was uncertain as long term drift of more than a metre may be encountered based on published data. However the airborne part of a takeoff only takes about six seconds duration, so short term behaviour is the issue actually of concern. Accordingly, to measure height more accurately a laser rangefinder was mounted vertical to the fuselage floor and the distance obtained was corrected for aircraft attitude to obtain height above the runway.

This paper will describe the features of the instrumentation package, highlight some experiences during its development and provide some comparisons of the DGPS and laser test data. It will also be shown that the outputs from the DGPS can be used to derive acceleration data that are useable for calibrating performance prediction methods.

The tests reported here took place after May 2000 when the discontinuance of selective availability improved the accuracy of GPS signals.

Figure 1: Flight test takeoff from water

2 Key Components

The main elements of the instrumentation package are shown in the schematic in Figure 2. The key hardware comprises:

- A DGPS for distance, speed and altitude measurement
- A laser rangefinder for measuring the height above the runway
- Pressure sensors for monitoring airspeed and altitude
- An analogue to digital interface for various sensors
- An engine monitor to record exhaust gas and cylinder head temperatures and related performance parameters
- A flight test boom with a swiveling head for measuring pitot-static pressures and also equipped with an incidence vane
- A portable laptop PC for recording the data.
- A portable ground station for weather.

The following sub headings give further information on the individual items and also provide some background on the choices that were made.

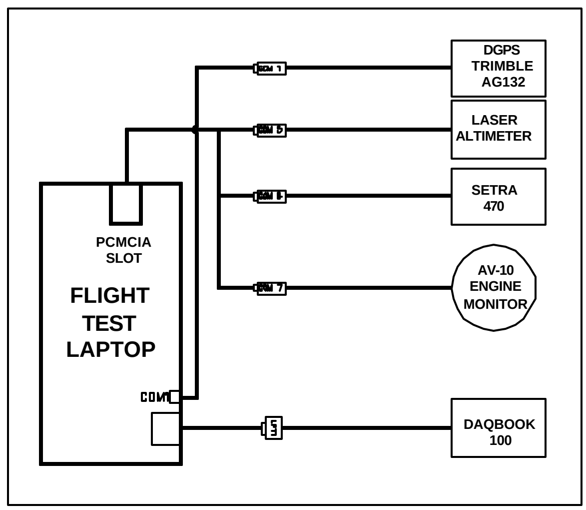

Figure 2: Schematic of the Flight Test Package.

DGPS

The equipment selected is a Trimble Ag132 which is commonly used for crop spraying aircraft to record their track. It has a maximum update rate of 10 hertz which was deemed essential for this kind of work. The unit is rugged, reasonably priced and, most importantly, local support was available. A low profile, external antenna is used mounted on top of the fuselage. The DGPS unit and a standard antenna are both shown in Figure 3, while their locations on the aircraft are shown in Figure 4.

Figure 3: Ag132 DGPS and an antenna

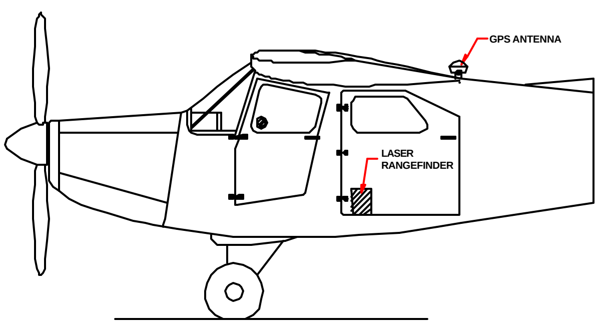

Figure 4: DGPS antenna and laser rangefinder installation.

In tests the DGPS unit is mounted on top of the flight test package facing the flight test engineer so that the entry keypad controls and the display are readily accessible, Figure 5.

Figure 5: Found flight test package

Laser Rangefinder

The rangefinder used is a Laser Atlanta Advantage unit. This instrument, shown in Figure 6, has a calibrated accuracy of 0.5ft out to distances of 5000ft. It also includes a liquid type of inclinometer that can be used in steady flight conditions to correct the measured range

Figure 6: Laser rangefinder

and find the actual height above the runway. This unit was also selected based on reasonable price and for its rugged packaging desirable for use in a harsh test environment. The unit is mounted normal to the fuselage floor to fire through an aperture cut in the lower skin of the fuselage shell. Attempts to find a suitable transparency to cover the aperture were not successful as the unit is quite sensitive to reflections due to the confined space available.

Initially there were problems with reliability and the unit dropped off line frequently due to reflections of side lobes from the fuselage interior structure. The fuselage interior is now coated locally with a mat black finish to reduce spurious reflections. The reliability is still not 100% and the installation needs further work on reflections.

Pressure Sensors

The absolute pressure used for determining the aircraft altitude is measured using a Setra 270 electronic pressure cell. This unit has an accuracy of 0.05% FS and this choice was made based on best value for the desired performance. The ASI system uses a

Setra 239 differential pressure cell also with an accuracy of 0.07% FS. Engine manifold pressure is measured by a Setra 470 which has an accuracy of 0.02% FS.

AV-10 Engine Monitor

The engine data recorded includes the six cylinder head temperatures (CHTs), six exhaust gas temperatures (EGTs), engine rpm, oil temperature and outside air temperature. The data are sampled at one second intervals using analogue sensors and their outputs are converted to digital data by an AV-10 engine monitor and then recorded on the laptop. The analogue to digital uses a ten bit conversion. The AV-10 is locally made and it is a cockpit instrument suitable for use in GA and homebuilt aircraft. It also enables audible warnings to be set on key engine parameters.

Other Components

Several other channels of data are recorded including a pitch incidence vane, landing gear contact switches, position sensors on the elevator and the tailplane trim setting, and a manually operated event marker button.

The test package is now contained in an enclosure, Figure 5, which anchors to the seat rails and is readily transportable between aircraft. The enclosure also contains the voltage regulators and inverters needed for the electrical supply. The unit is also equipped with a status indicator so that the test engineer can determine a “go” condition before initiating a test sequence.

3 Preliminary Checks

The distance measured by the laser rangefinder over 50 and 100 feet was checked using a steel measuring tape to set the distances. The results were within the manufacturer's specified accuracy of +/- 0.5 foot. Next, the laser rangefinder was used to lay out the north-south runway at the local airport between the runway thresholds, along with intermediate way points every 1000 feet. With the DGPS on, the aircraft was motored slowly along the runway between the thresholds with the test engineer also marking the way points.

A comparison of the DGPS data for distance and height with the airport survey data showed agreement within two feet of error at all locations. This test also provided the first inkling that DGPS height changes might be sufficiently stable for use over short periods of recording.

In order to calibrate the landing gear contact switches the airplane was suspended horizontally from a cable and lowered slowly onto its mainwheels. The aircraft attitude, the aircraft floor height (datum) above the ground as measured by the laser rangefinder, and the condition of the wheel contact switch were recorded until the tailwheel touched the ground. These data were used later to estimate the liftoff point and the point at which the mainwheels passed through fifty feet height during takeoffs.

4 Airfield Performance Measurements

4.1 Takeoff Trajectories

A comparison of typical height versus distance records for a takeoff obtained from the laser and DGPS sources is shown in Figure 7. The agreement is generally good and typically within about one foot. After numerous takeoffs showing similar good agreement it is considered that DGPS is usable as a reliable source for height data as well as distance.

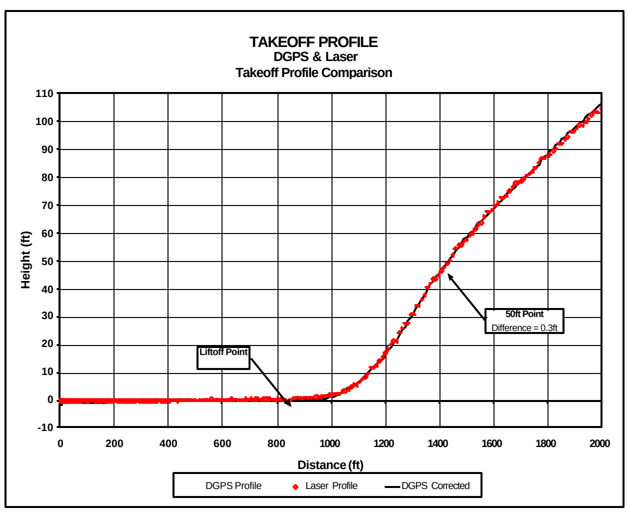

Figure 7: A typical takeoff profile.

Sometimes there are significant steps in the DGPS outputs due to losing or switching satellite data during runs. Such events are flagged in the output from the unit and they are identified during post processing by visual scanning of the data and the flight trajectories.

It proved difficult to estimate the actual lift off point of the aircraft. As it is a "tail-dragger", the aircraft spends much of the takeoff running along the ground with the tail up. As lift off is approached the main wheel loads lighten and the landing gear response to runway bumps and pilot actions leads to the landing gear switches being highly excited. Often there was no pronounced break in voltage at liftoff, then other sources including the DGPS and laser rangefinder would be used to estimate the liftoff point. This area is being further developed.

Landings are essentially a takeoff in reverse sequence. The same procedures work for locating the touchdown point, then the airborne portion is worked backwards from this position.

4.2 Takeoff Accelerations

In lieu of an accelerometer, the DGPS ground speed and height data can be differentiated to extract the longitudinal and normal "g" components obtained during airfield operations. Similar results for deriving horizontal accelerations were also noted in [3].

A typical plot of DGPS based ground speed and vertical speed, and the derived horizontal and vertical accelerations, is shown in Figure 8. The horizontal accelerations were derived from the DGPS's ground speed data which has some filtering from the algorithms used by the manufacturer. The accelerations derived appear sufficiently accurate for use in future work on improving airfield performance methods.

The vertical velocities and accelerations shown were derived from the raw DGPS heights and they were smoothed using the MATLAB Loess method. The ground speed and vertical speed were then used to find the flight path angle of the aircraft. The results from the same flight are shown in Figure 9.

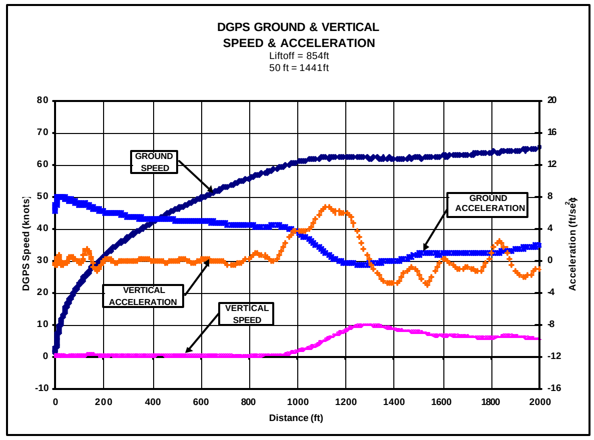

Figure 8: DGPS ground speed and derived accelerations

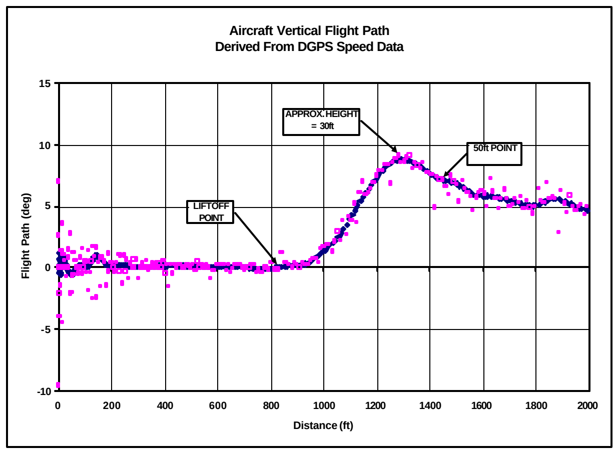

Figure 9: Flight path climb angle from DGPS data

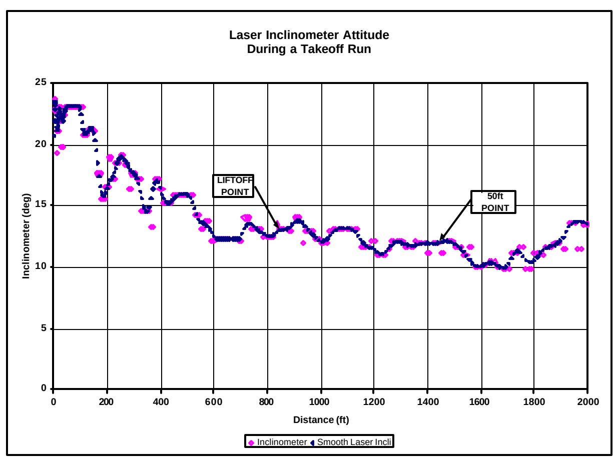

Figure 10: Inclinometer based aircraft attitude data

During takeoffs the inclinometer data from the laser rangefinder are unreliable during periods with significant acceleration present. Typical results are shown in Figure 10. Useful results are obtained above about thirty feet of height when the airborne transition to climb is usually complete. The inclinometer values were used in correcting the laser rangefinder data for fuselage attitude to determine the aircraft wheel height above the runway as given in Figure 7.

5 ASI Calibration

Another application of DGPS of benefit to small aircraft manufacturers is the calibration of the airspeed indicating system. In the past this was done by flying reciprocals over an airport runway at low altitude, manually recording the times taken between a prescribed set of distance markers [2] and averaging to find the mean ground speed. These tests must be done in low wind conditions and usually take considerable time and pilot effort to accomplish.

Now, using DGPS this can be done relatively quickly at altitude provided the winds aloft are modest and turbulence is light. The test procedure used is from [4]. In the test the aircraft is flown along three consecutive legs at 90 degrees of heading to each other, recording the DGPS ground speed and direction, and also the airspeeds from the ship's instruments or flight test boom. The analysis then solves for the aircraft's average true airspeed and also obtains the speed and direction of the winds aloft. The ASI corrections can then be established from the true airspeed and the ASI values. As a DGPS provides speeds to one tenth of a knot accuracy the results are of higher quality than given by simpler GPS units.

The use of DGPS also enables the ASI corrections to be readily determined in flight near the stall with idle power. Also as this can be done without requiring a test boom to be installed on the aircraft, it simplifies making ASI checks on production aircraft.

6 Performance Measurement at Altitude

The use of electronic recording of flight test parameters has improved the reliability and quality of data relative to the hand recording procedures used previously [1]. The problem now is coping with the large volume of data produced and reducing the amount of testing to the absolute minimum required.

At present the method used for extracting aircraft drag polars from the flight test data requires reasonably steady state climb or level flight cruise conditions to be achieved. The results of height versus time for a typical climb case are shown in Figure 11 based on heights derived from the pressure cell taken at one second intervals. Although not very obvious, there is scatter in these data due to pilot actions, plus the effects of atmospheric turbulence and the accuracy of the pressure cell used for determining heights.

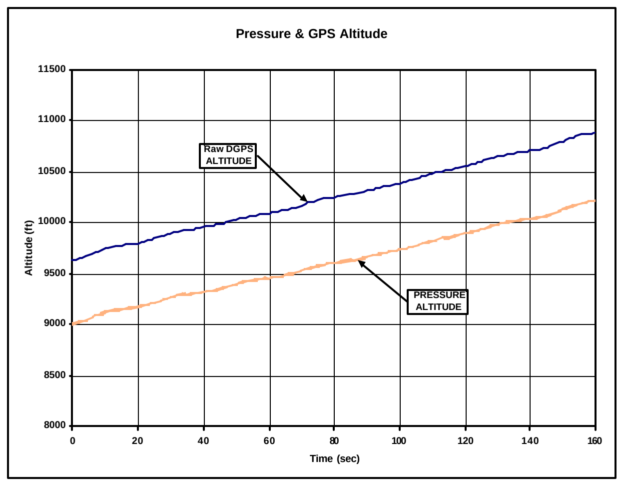

Figure 11: A sample climb profile

The raw height data from DGPS measurements are also included in Figure 11. These show very similar results to the pressure altitudes when the offset is removed, which indicates they can be used as a backup for rates of climb.

Typical rates of climb derived are shown in Figure 12 based on data smoothing using either nine or twenty one points for averaging. The phugoid motion becomes evident in the results when using nine point averaging, with a period of about 20 seconds. Longer averaging of over 40 seconds of data is needed to obtain steady climb data. In the future in order to reduce overall test time, there is need for work on dynamic test methods that can extract the drag polars from the shorter time slices where the data includes the phugoid motion.

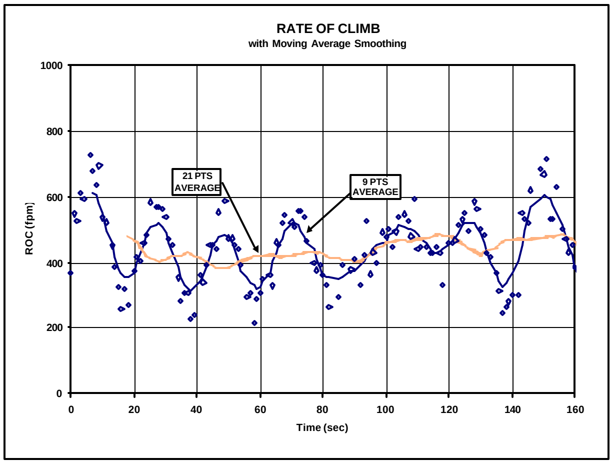

Figure 12: Rates of climb

7 Conclusions

The availability of relatively inexpensive DGPS equipment and laptop computers enables small aircraft manufacturers to accomplish significant improvements in their flight test capabilities. The flight test instrument package being developed at Found Aircraft of Canada has such features and testing has shown the following :

1) Significantly shortened test durations, reduced manpower requirements and much earlier availability of processed results for review and test redirection.

2) The DGPS data was found to be sufficiently accurate and reliable for measuring both distance and height during airfield performance testing. By extension it is usable for measuring floatplane performance. However as DGPS may lose sight of satellites the output flags must be monitored to ensure data remains reliable.

3) The laser rangefinder used for measuring height over the runway in airfield testing, enabled the DGPS height results to be verified. However, the laser system still needs development as it occasionally drops off line and internal reflections can be a problem.

4) Further improvements in test productivity should come from using dynamic test methods for analyzing climb and cruise data from the aircraft.

5) The DGPS data enabled horizontal and vertical accelerations to be estimated with enough precision for use in refining airfield performance methods. Thus accelerometers are not essential for these axes, leading to simpler instrumentation.

Acknowledgements

The authors wish to acknowledge their appreciation of the valuable assistance given by the following entities : Aventech Research Inc. in developing the software used for collecting and storing the flight test data; the Picodas Group Inc. in supporting the application of the Trimble Ag132 DGPS equipment; Audio Flight Avionics in the application of the AV-10 engine monitor; Laser Atlanta Inc. in the application of the Advantage rangefinder, and by Mr. S. Kereliuk the DAR test pilot during most of the development.

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