# A PORTABLE DATA ACQUISITION SYSTEM FOR FLIGHT TESTING LIGHT AIRCRAFT

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## ABSTRACT

With the resurgence of the general aviation market, there is a growing need to acquire flight test data on light aircraft and to educate engineers on the methods used to test such aircraft. Data acquisition for such operations has often been performed by manually recording instrument readings from the aircraft's instrument panel. Until recently, electronic data acquisition was not realistic for flight testing light aircraft, because the instruments' weight and bulk could significantly alter the performance and handling characteristics of the aircraft.

This paper describes the development and testing of portable, computer-aided electronic instrumentation. This instrumentation can be used to acquire flight test data on a variety of light aircraft in a cost effective manner with simple installation procedures. Multidisciplinary coordination was necessary between system engineers, mechanics and pilots to ensure that the system was legal for installation and useful during flight. An instrumented light aircraft can be used to educate engineering students and professionals in flight testing procedures without altering the aircraft used. Airspeed calibration and long-period mode (phugoid) experiments were performed to demonstrate the usefulness of such instrumentation.



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## INTRODUCTION

In recent years there has been an increase in the number of aircraft designs for the general aviation market. This includes production light aircraft that are designed for FAA certification, as well as experimental amateur-built kit aircraft. In the past, flight test data has been acquired from such aircraft by manually recording data from instrument panel dials onto lapboards. Such methods are not suited for aircraft performing dynamic maneuvers, since the data acquisition rate is insufficient. Lags and inaccuracies in the cockpit instruments can affect the phase and quality of the data.

The inherent problems with using cockpit-mounted instruments can be mitigated by employing a relatively inexpensive Global Positioning System (GPS) receiver, inertial rate gyros and automatic data logging. Advances in computer technology and miniaturization of electronics have enhanced the capabilities of the instruments involved in testing aerospace vehicles, as well as the method of logging and processing the data. These factors were involved in the decision to develop a more automated flight test data acquisition system.

Such capability can enhance the ability of universities and private firms to teach flight testing procedures at an economical cost. An instrumented aircraft that is registered in the Federal Aviation Administration's (FAA) "normal category" can be very useful in teaching and promoting the proper procedures to be followed in testing aircraft. The benefit was recognized and became the goal of this project: to build an instrument system for aircraft that can be utilized for flight test education in a university or corporate training environment, without altering the FAA certification of the aircraft.

If the aircraft is registered in the normal category the data acquisition system must not affect the category certification, either when it is installed, operated or removed. For this reason, control force, control displacement and air data instruments could not be temporarily installed on the aircraft. Such would require modification and temporary or permanent re-certification of the aircraft. The mounting of these instruments was not a possibility for this project due to the additional operating restrictions on the Purdue aircraft. These requirements are not applicable if the instruments are mounted on aircraft with experimental certification.

## DESIGN CONSIDERATIONS

The design requirements were quite different than permanently mounted flight test instrumentation systems. Three considerations were paramount in the design of this system.

First, the instrumentation and data logging system must be small, lightweight and portable. This negates the case of a testbed aircraft being burdened with instruments that are bulky, expensive and permanently attached to the aircraft.

Secondly, the instruments must be simple to be mounted and removed. Non-destructive attachment of the instruments will ensure that the aircraft is not permanently altered from its certified form.

Thirdly, the equipment must not necessitate re-certification into the FAA's Experimental Category. This will prevent the following scenarios:

- An aircraft being permanently designated for flight test training.
- Repeated re-certification of an aircraft for short-term purposes.

The method that was decided upon was to interface an array of instruments to acquire inertial data at a rate of 10Hz via a portable computer. Physical phenomena occurring at up to 5 Hz can be resolved (due to the Nyquist sampling criterion). Such a capability yields more comprehensive data with less time delay and errors compared to data logged by hand. In addition, it offers the ability for data to be recorded digitally for more efficient processing.

Given the aforementioned problems and goals, there are several factors that influence the design and use of such a system. The power consumption, weight and volume are factors that must be addressed at every step in the development process. Data transmission capability should allow accurate synchronization of measurements with a time series (correlation between the measurements and the measurement times). The configuration and placement of the instruments and computer system must allow convenient installation into the aircraft.

Regulatory requirements permit "minor alterations" to be performed when engine, structure, aerodynamics, control and handling qualities are not significantly altered[7]. The definition of minor vs. major alteration is, however, at the discretion of individual FAA Inspectors. Under the Federal Air Regulation (FAR) of the United States, any alteration to a normal category aircraft must be documented and approved. Also, no change to an aircraft specification as set forth in the aircraft's original Type Certificate can be made unless a Supplemental Type Certificate is developed, applied for and approved. If alterations are intended, an FAA Form 337 must be filed for minor alterations. If major alterations are to be made, the aircraft are often temporarily recertified as research & development aircraft under the "experimental" airworthiness category for the purpose of testing these alterations. For these reasons the instrumentation was expressly designed to keep the aircraft in the normal category. The data acquisition system is fully independent of the aircraft's electrical power, structural, and flight control systems and does not intrude into the freestream atmosphere.

Originally, air data measurements (static and dynamic pressures, angles of attack and sideslip) and pilot control measurements (control displacement and yoke force feedback) were to be acquired. However, issues arose regarding FAA certification, maintenance, and flight training needs arose. Since the Purdue aircraft are to be operated in the normal category, the flight test system cannot alter the aforementioned characteristics of the aircraft. The decision was made to keep the instrumentation system completely transparent to the category certification. While this restricts the acquired data to inertial measurements only, it is anticipated that instruments for air data acquisition and control surface measurements will be installed as follow-on projects. When properly engineered, the modifications can be performed with a one-time alteration. The aircraft can then be approved for routine operations in the normal category.

The data acquisition system was flown on a Cessna 182 "Skylane" to demonstrate the system capabilities. The Cessna 182 has been used in recent years as a student lab in a flight testing course at Purdue University.

## EXPERIMENTAL APPARATUS

The instrument array includes a small Inertial Navigation System (known by its trade name as the μ-INS) and a power system that is independent of the aircraft's electrical system. The computer data logging system consists of a Dell Inspiron 8000 laptop computer and a smaller Sony Vaio handheld computer acting as a lap-mounted user interface and Microsoft Windows based software.

The system layout and main components of the system are shown in Figures 1 and 2. The components on the mounting pallet are placed in the baggage compartment of the aircraft, while the Sony Vaio computer is placed on an occupant's lapboard. The Dell is used to acquire and store the flight test data from the u-INS. The Dell is strapped down to a box of Signal Conditioning Equipment (SCE) that can give filtered output to the computer by means of a data cable and PCMCIA card inside the computer.

The SCE was not employed for the demonstration flight experiments listed in this paper. A future phase of this project will investigate the possibility of placing control surface position sensors inside the aircraft, with air data measuring equipment on the starboard wingtip. When such instruments become practical, anti-aliasing filters inside the SCE can be used to condition the output signals from the added instrumentation and sensors.

The system geometry allocates most of the equipment in the cargo compartment with the handheld computer as the user interface. The weight and moment arm contribution of the instrument pallet can be easily accounted for. The geometric relation between the cargo floor and the defined reference axes for the aircraft must be determined in order to construct a linear transformation between the μ-INS axes and the aircraft body centered axes for later analysis.

LabVIEW is the data acquisition software used for the project. It is a software package developed by National Instruments Inc. and is designed primarily for data acquisition and control. The key features of LabVIEW are its graphical user interface and ease of modification of the data acquisition source code. The software runs on a Microsoft Windows operating system. The data recording, retrieval and software modifications are more user-friendly than if DOS-based data acquisition code on a small microprocessor is used.

The μ-INS and RS-422 to RS-232 protocol converter hardware were developed by Microbotics Inc. of Langley, Virginia[8]. This RS-232 data is output in hexadecimal form and is then fed through a 9-pin serial cable to the Dell, where it is decoded into a base ten text file by the LabVIEW software. The data acquisition functions of the Dell are controlled from the cockpit via a Sony Vaio handheld computer and an ethernet cable via Transmission Control Protocol/Internet Protocol (TCP/IP). Effectively, an intranet is being connected inside of the aircraft. This configuration was chosen because another flight research program at Purdue will be using multiple computers connected through TCP/IP. Use of this protocol negates the need to rewrite software drivers in order to interface the computer components. This speeds up development time and makes the software architecture more flexible.

The Microbotics μ-INS forms the core of the data acquisition instrumentation. It is an integrated system comprised of three solid state accelerometers, three angular rate gyros, pressure transducers, a magnetometer, GPS receiver and proprietary software filters. The μ-INS integrates inertial sensor data with internal GPS and magnetometer readings and can provide full state vector information.

The GPS receiver manufactured by μ-Blox Corporation of Switzerland is housed inside the μ-INS chassis, but has an external antenna. The receiver itself was not intended to be used in experimental flight test work. However, our purpose of the μ-INS is for academic use and the test aircraft never relies on the μ-INS for life-critical navigation. Therefore, the installation and use of this instrumentation is legal by FAA regulations. Although the μ-INS is out of production, the follow-on unit is available from Microbotics Inc.

The black chassis box contains two 12 VDC sealed lead acid batteries which are connected in series. In this configuration the power system acts as a 24 VDC source. The RS protocol conversion box contains hardware to convert RS-422 serial output from the μ-INS to the RS-232 serial input that the Dell requires.

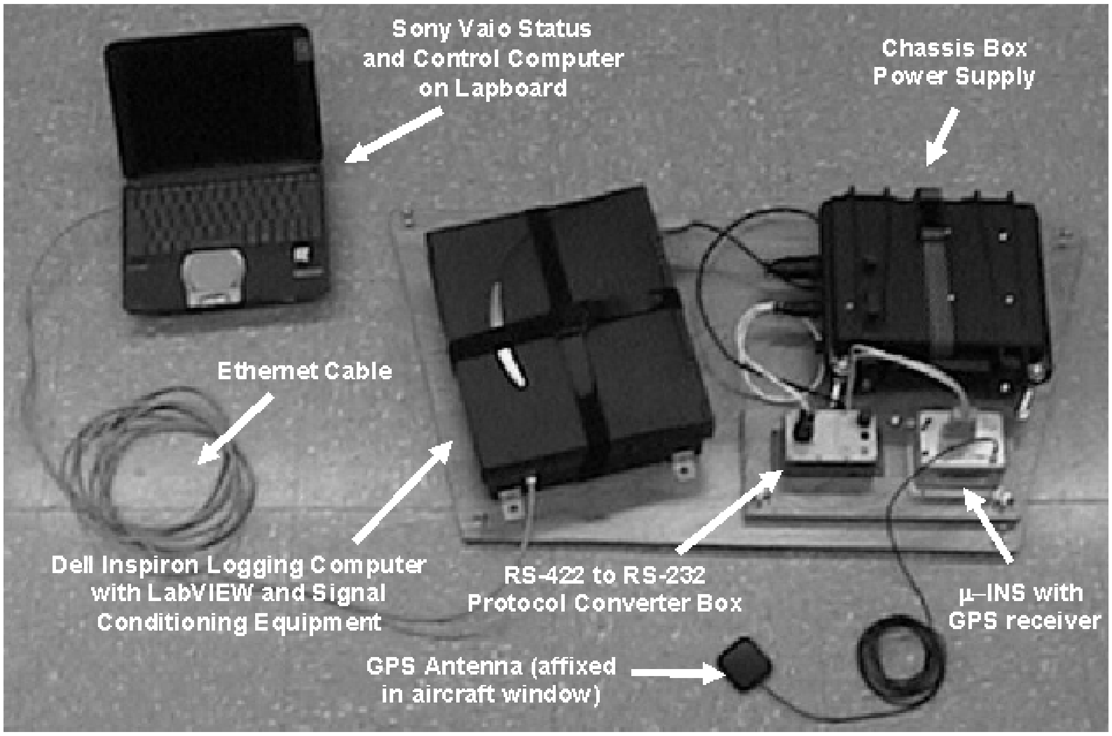


**Figure 1. Photograph of Data Acquisition System**

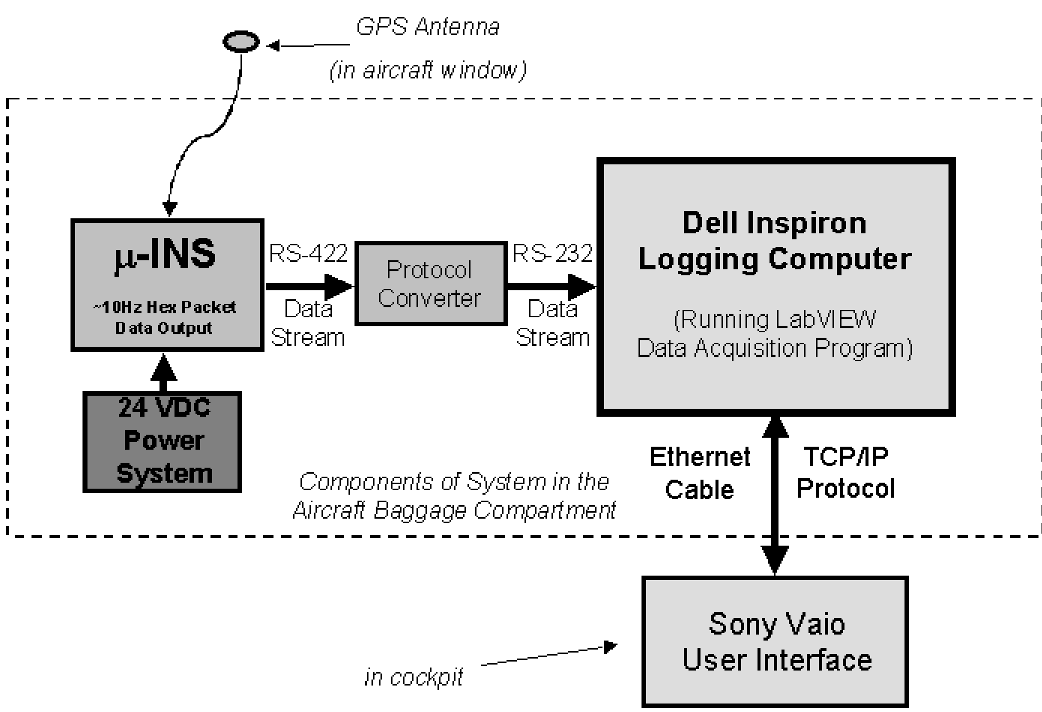


**Figure 2. System Schematic**

| µINS Specifications[1] | |
|---|---|
| **Power Requirements** | |
| Input Voltage | 9 VDC - 32 VDC |
| Power | 4W |
| **Performance** | |
| Angular rate | |
| Range | ±300°/sec |
| Noise | 0.10°/sec 1σ |
| Acceleration | |
| Range | ±10g |
| Noise | 14mg 1σ |
| Attitude solution | |
| Pitch/Roll accuracy | ±1.5° |
| Heading accuracy | ±2.5° |
| Velocity accuracy | 0.4 m/s |
| Position accuracy | 8m |
| Alignment time | 60 sec [3] |

**[1]Typical values**
**[3]Performance specs are given based on a 5-minute warm-up time**

**Table 1. µ-INS Specifications**

| |
|---|
| Latitude |
| Longitude |
| Altitude |
| Yaw (magnetic) |
| Yaw (true) |
| Pitch Angle |
| Roll Angle |
| GPS Time |
| Velocity East |
| Velocity North |
| Velocity Up |
| X Axis Rate |
| Y Axis Rate |
| Z Axis Rate |
| X acceleration |
| Y acceleration |
| Z acceleration |
| Static baro |
| Dynamic baro |
| Status |

**Table 2. µ-INS Data Output**

**Equation (1): Wind Direction**

$$\Psi = \tan^{-1}\left[\frac{-V_{G1}^{2} + 2V_{G2}^{2} - V_{G3}^{2}}{V_{G3}^{2} - V_{G1}^{2}}\right]$$

**Equation (2): Wind Velocity**

$$V_W = \frac{1}{2}\left[V_{G3}^{2} + V_{G1}^{2} \pm \sqrt{(V_{G3}^{2} + V_{G1}^{2}) - \left(\frac{-V_{G1}^{2} + 2V_{G2}^{2} - V_{G3}^{2}}{\sin\Psi}\right)^{2}}\right]^{\frac{1}{2}}$$

**Equation (3): True Airspeed**

$$V_T = \sqrt{\frac{V_{G3}^{2} + V_{G3}^{2}}{2} - V_W^{2}}$$

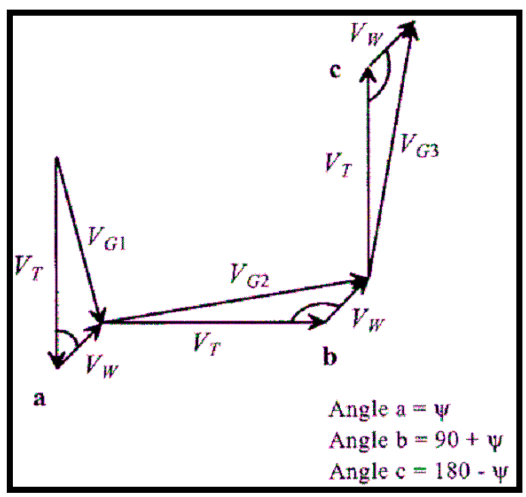


**Figure 3. Flight Path for GPS Airspeed Calibration Test**

Differentiation between horizontal and vertical position accuracy is not provided by the μ-INS manufacturer. However, vertical position in GPS systems is typically the least accurate due to geometric dilution of precision (GDOP) caused by satellite geometry[2,5]. Blended μ-INS and GPS measurements are given in Latitude, Longitude, and Altitude (above reference ellipsoid) at 10 Hz[8]. GPS-only data is supplied at 1 Hz and is in WGS-84 coordinates. The angular rate and acceleration specifications are in terms of system capability and noise (from all noise sources combined).

## DEMONSTRATION FLIGHT EXPERIMENTS

The Cessna 182 was flown with the u-INS in the baggage compartment and a GPS antenna temporarily affixed inside the rear window. Several "racetrack" patterns were flown to produce an airspeed calibration chart and calculate winds aloft. This test was done in accordance with GPS airspeed calibration methods described in papers by Gray[7] and Lewis[1]. At the time of this writing, these papers and accompanying data analysis spreadsheets were available as downloads from the National Test Pilot School website: www.ntps.com.

Among the several methods used to calibrate airspeed indicators, the use of GPS is relatively new. In general, GPS airspeed calibration involves flying the aircraft at a constant indicated airspeed at a constant pressure altitude and a noted temperature. GPS airspeed calibration methods have several advantages over conventional methods. No calibrated chase aircraft is needed, nor do the GPS procedures have to be flown at low altitude (as in tower fly-by procedures).

The demonstration flight involved four ground tracks to calculate true airspeed, which can then be corrected for air density and compressibility to obtain calibrated airspeed. This calibrated airspeed is then correlated with the indicated airspeed to obtain the position error correction for the aircraft. The direction and magnitude of the winds aloft can also be calculated from the acquired data.

A geometric diagram of the "racetrack" pattern and accompanying equations are included in Figure 3. A minimum of three tracks are necessary to determine the true airspeed, wind speed, and wind direction. In Figure 3, $V_{G1}$, $V_{G2}$ and $V_{G3}$ represent the measured groundspeed in knots for the first through third legs respectively. $V_W$ and $V_T$ are the calculated values of wind speed and true airspeed (both in knots).

For the demonstration flight, a fourth track was made starting at point **c** and headed towards the origin of leg #1. The data from the fourth leg ($V_W$, $V_T$, and $V_{G4}$) are defined in the same manner as the variables in the other three tracks. This calculation procedure uses these four tracks in sets of three, using equations 1-3. In other words, tracks 1, 2 and 3 are used to calculate true airspeed, wind speed and wind direction. Next, tracks 2, 3 and 4 are used. This process is continued until each leg has been used in three different calculations in combination with each other track leg, the results of which are then averaged together.

For the demonstration flight experiment, the Cessna 182 was equipped with the flight test data acquisition system and flown to pressure altitude of 6000' at a location east of Lafayette, Indiana. The airspeed was stabilized at 130 KIAS on a heading of 180 degrees and data was taken with the flight test system for approximately one minute. The aircraft was then turned left to a 90 degree heading, the airspeed was stabilized again at 130 Knots Indicated Airspeed (KIAS), and data was taken again for approximately one minute. Test runs on headings of 360 and 270 degrees then followed, all at 130 KIAS and within a tolerance of 100' pressure altitude of the 6000' pressure altitude indication. The temperature was measured by the Outside Air Temperature (OAT) gauge on the aircraft and was manually recorded. This procedure was repeated for other airspeeds in 10 KIAS increments down to an airspeed of 70 KIAS. The data from each test run (written to different files in the laptop) were converted from hexadecimal format into base ten text files by the LabVIEW software and later used in a MATLAB data analysis program (produced by the Mathworks Inc.). The groundspeed of the Cessna 182 was determined by the square root of the sum of squares of the 3-dimensional velocities output by the μ-INS.

In addition to the data taken by the flight test system, the aircraft's KLN 89 Instrument-Certified GPS was set to output groundspeed information. The KLN 89 unit is manufactured by Bendix King and is capable of Instrument

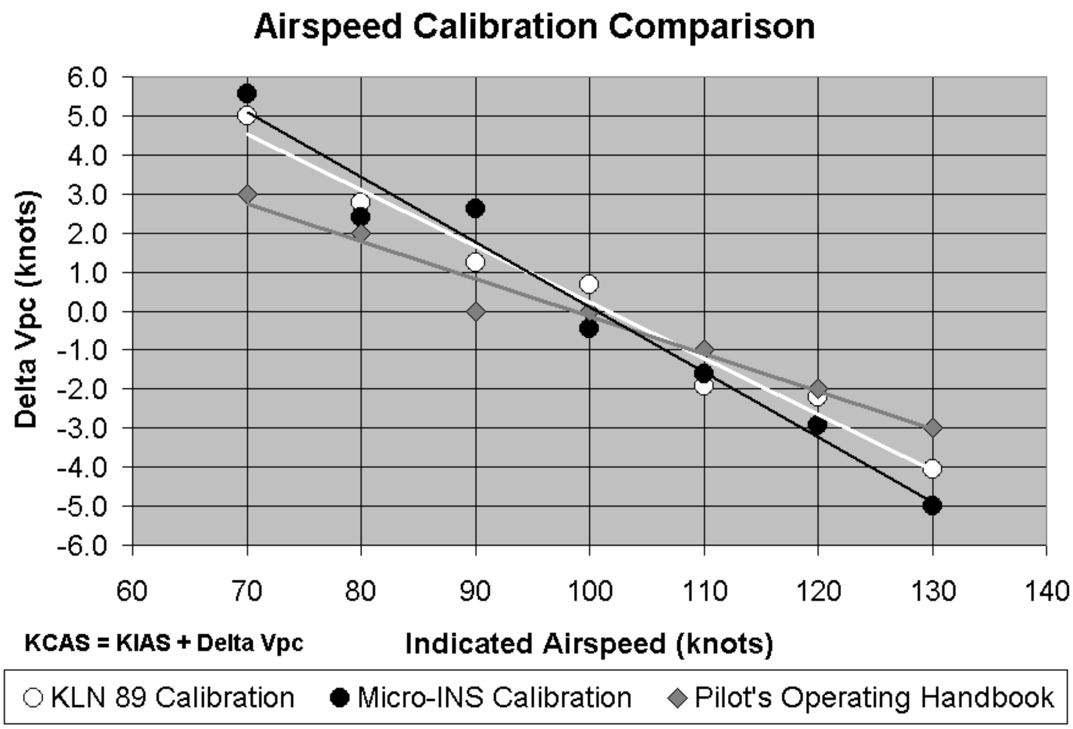


**Figure 4. GPS Airspeed Calibration Test Comparison**

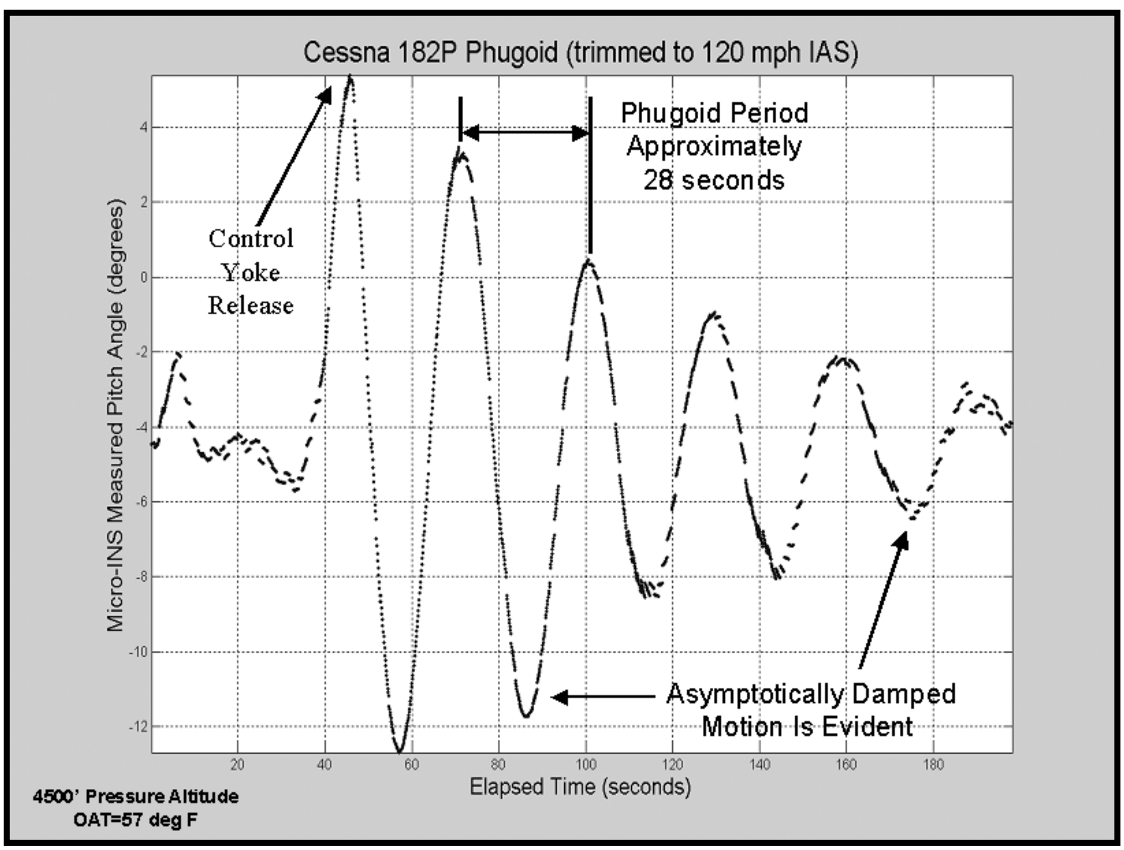


**Figure 5. Phugoid Mode Demonstration**

Flight Rules navigation and instrument approaches. The output of the KLN 89 is a whole-knot value and cannot be logged by the computer. Because of this, the average groundspeed for each 1-minute leg must be estimated and recorded on a lapboard. The groundspeed data from the KLN 89 and the μ-INS ground track tests serve as a comparison between a certified GPS-only unit and the flight test data acquisition system.

Spreadsheet computations were made with this information. This allowed the true airspeed spreadsheet calculations from the μ-INS obtained groundspeed and the KLN 89 GPS groundspeed can be compared directly. These values of Knots True Airspeed (KTAS) are then corrected for air density and compressibility[4,6]. The result of these corrections is the calibrated airspeed, which is compared to the indicated airspeed during each racetrack pattern.

The calculated values of calibrated airspeed were used for the generation of a position error correction chart for the Cessna 182 using both the μ-INS and KLN 89 to obtain groundspeed. The resulting calibration plots can then be compared to the airspeed calibration chart from the Cessna 182 Pilot's Operating Handbook (POH).

Figure 4 displays the airspeed calibrations with the μ-INS and KLN 89 along with the calibration from the published POH. The number of knots to be added to the indicated airspeed to obtain the calibrated airspeed is known as the "position error correction" (Delta $V_{pc}$ in Figure 4). The linear regression lines from the airspeed calibration plots show a general agreement with the Cessna 182 POH chart.

A phugoid mode test was also performed with the Cessna 182 to demonstrate the capabilities of the μ-INS. The phugoid is a second order longitudinal oscillation[4,6]. At an indicated airspeed of 120 knots the pitch was increased until the airspeed decreased by 10 knots. The control yoke was then released and the aircraft was allowed to pitch through multiple phugoid oscillations. The 120 knot oscillation demonstration is displayed in Figure 5. The data record was started just before the initial pitch-up to bleed off airspeed by 10 knots. With a data acquisition rate of 10 Hz, the system can be used to test the aircraft performance during dynamic maneuvers, which would not yield good results if all the data were hand-logged.

## SUMMARY AND CONCLUSIONS

An instrumentation package was produced and successfully interfaced to a light aircraft with a minimum of setup time. Common commercial computer equipment allowed Microsoft Windows compatible software and standard device drivers to be used. The National Instruments LabVIEW software greatly facilitated modifications to the data acquisition software, as well as allowing the use of a graphical user interface on the screen of the Sony Vaio computer. The flights were performed in a normal category aircraft used alternately for flight test education and for general-purpose flight training with no alterations to the aircraft.

Flight experiments were performed to validate the ability of the data acquisition system to acquire and log data on aircraft behavior. The GPS airspeed calibration flight comparisons between the data taken with the μ-INS and the onboard KLN 89 demonstrate the ability of the μ-INS to determine position error corrections of the airspeed indication system. Airspeed calibration charts derived from the data taken with the data acquisition system agreed well with the KLN 89 calibration and the Pilot's Operating Handbook. The phugoid mode determination displayed the ability to collect dynamic data with the system. Data acquisition at such a rate and precision is not possible by manually recording information on lapboards.

This system can be a valuable tool in teaching flight test techniques and data acquisition procedures to engineering students and industry personnel. The flight test data acquisition system provides a capability to acquire reasonably fast data in a compact system with minimal changes in the aircraft's weight and balance. The system features a minimum of specialized hardware and software. The post-processed data can be directly imported into software programs commonly used in industry and academia. The system is interchangeable between different aircraft types and can be used in aircraft of normal category certification.

ACKNOWLEDGEMENTS

A grant from Rockwell Collins of Cedar Rapids, Iowa made this work possible. Dr. Robert Santini, Dr. Mike Everly, Mark Carlsen, and Bob Fagan of Purdue's Jonathan Amy Facility for Chemical Instrumentation aided in designing and building the LabVIEW interface and hardware. Mr. Brian Stirm was the mechanic who aided in the integration into the aircraft. Finally, the authors would like to recognize Professor Larry Gross for making the aircraft available for demonstration flights.

DISCLAIMER

Mention of corporations in this paper does not necessarily constitute an endorsement of these corporations by Purdue University, its employees, or by anyone mentioned in this paper.

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