An Airborne Laboratory for Undergraduate and Postgraduate Education

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Abstract*: This paper provides an overview of the Flight Laboratory Program at the School of Aerospace, Civil and Mechanical Engineering at the Australian Defence Force Academy. This is an airborne laboratory in which undergraduate and postgraduate students investigate aircraft performance, instrumentation and stability* in-flight*. The success of this program has been such that the School now owns a specially instrumented aircraft and has been approached by a number of other tertiary institutions who are interested in setting up similar programs. The production of an accompanying video series is also be described.*

Introduction

In 1994, the School of Aeronautical and Mechanical Engineering (SAME) at the Australian Defence Force Academy (ADFA) began offering a complete four year Aeronautical Engineering degree. Until that time, the School had presented the first two years of the degree and students completed the final two years of their studies at RMIT or Sydney University. The new program was developed in cooperation with the School's major industry partner, the Australian Defence Force.

Like many other engineering Schools, the SAME recognised the importance of student laboratories to complement classroom theory. This is because laboratory work enables students to observe the relationship between theory and practice. Importantly, students begin to gain confidence in the application of theory by observing its practical limitations, (Eley, 1995). For this reason, it was decided to develop an airborne laboratory facility.

This laboratory was initially developed to support classes in aircraft performance and stability. It has also been used for a variety of research projects. Furthermore, in a bid to share the program outside ADFA, the airborne laboratory was used as the basis of the 'AirKraft' video series. This series targets students studying Flight Mechanics and includes theory, history and practical experiments.

This paper describes ADFA's airborne laboratory and is structured as follows: The design and description of the undergraduate experiments; Instrumentation; Student and Staff Response; The AirKraft video series; Conclusion.

Design and Description of Undergraduate Experiments

For the purposes of the laboratory, it was decided to use a light aircraft with two students accompanying the pilot on each flight. This decision ensured all students would have an uninterrupted view of the aircraft's instruments and controls. Larger groups would have required a specialised aircraft with duplicated instrumentation and additional laboratory demonstrators. This was not an economic option and would have added to the complexity of the laboratory's operation. A small number of universities worldwide including Texas A&M (Saric, 2006) and the US Air Force Academy operate airborne laboratories, and like SACME, have chosen light aircraft with limited student numbers aboard each flight.

Initially, experiments were designed around the instrumentation commonly fitted to all light aircraft. This was necessary because for the first few years of operation, the program made use of rented aircraft including the Cessna 172RG (Figure 1a), Mooney 201 and Cessna 210 and it was not practical to modify these aircraft's instrumentation. These instruments included the airspeed indicator, vertical speed indicator, altimeter, engine instruments and a stop watch. Using these instruments, students measured the aircraft's climb performance and cruise flight power-speed relationship. These experiments were designed so that students could estimate performance figures from first principles and compare their values with the aircraft manufacturer's data. Figure 1b shows a typical result from a cruise performance test. During this test, data was gathered as the aircraft was progressively slowed whilst maintaining straight and level flight. Using their data, students were able to predict the aircraft's maximum range and endurance. Through these experiments, students also learnt to correct airspeeds for pressure disturbances caused by the aircraft (position error), instrument errors and the effects of changes in air density with altitude.

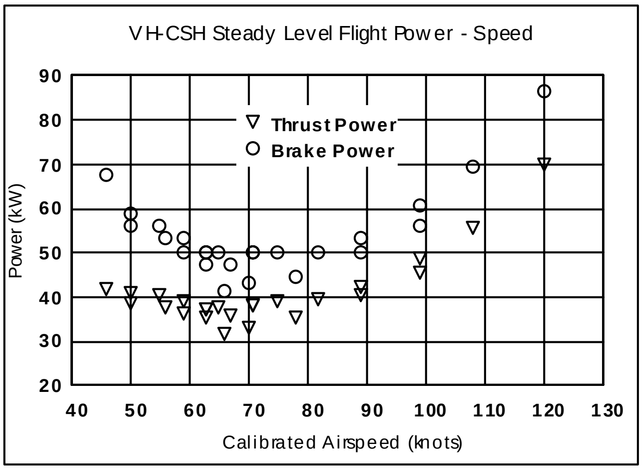


Figure 1a **Figure 1b**

Figure 1a - Students preparing Cessna 172RG VH-CSG for a flight laboratory.
Figure 1b – Typical steady-level-flight airspeed v's power results showing the effects of induced drag (dominant at low speeds) and parasite drag (dominant at high speeds).

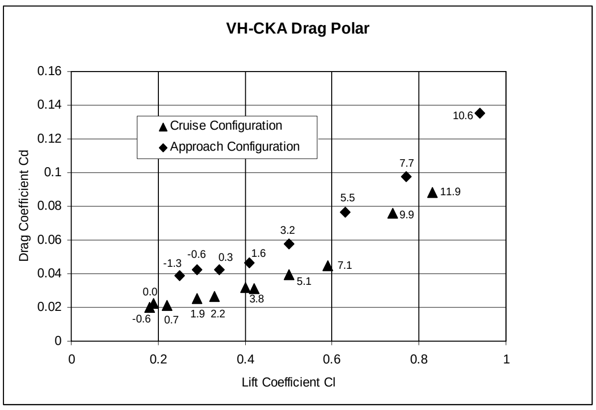
Initially an experiment exploring turn performance was included in the laboratory program. This made use of a simple 'g' meter to explore the relationship between rate and radius of turn and load factor. Using their measurements, students were able to predict the aircraft's minimum turn radius. In principle this proved to be a worthwhile experiment. However it was found that many students suffered from motion sickness because of the requirement to bank the aircraft in steady turns through progressively greater bank angles. For this reason it was discontinued.

In 1988, following a very positive student response to the airborne laboratory program, the School decided to purchase its own aircraft (Figure 2a). The primary benefit of this purchase was that it allowed the School to add the special instrumentation required to broaden the range of experiments that could be carried out. This instrumentation meant that the aircraft could be also used for undergraduate and postgraduate research. A second benefit was that this also freed the program from the uncertainties of using hired aircraft - both in terms of maintenance and availability.

Figure 2a **Figure 2b**

Figure 2a - Cessna 182RG VH-CKA purchased by SACME in 1998. Figure 2b - The air-data boom mounted on the starboard wing. The boom includes a pitot static system and angle of attack and sideslip vanes.

The specialised instrumentation fitted to the School's aircraft (described in the next section) has allowed new experiments investigating static and dynamic stability. Students are now able to compare the aircraft's static stability about all three aircraft axes (pitch roll and yaw) in the cruise and landing configurations. Furthermore, this instrumentation has allowed existing experiments to be flown much more efficiently. For example, traditionally the cruise performance experiment (see last section) required the aircraft to be flown in steady level flight over a range of airspeeds from the maximum speed to the stall speed. At each speed it was necessary to adjust the engine power and allow the aircraft's airspeed to stabilize whilst maintaining constant altitude. This is particularly challenging at lower airspeeds where the aircraft does not have positive speed stability - meaning that a speed disturbance will continue to grow unless the pilot intervenes. The new instrumentation allows for a more efficient procedure in which the pilot simply fixes the engine power and then varies the aircraft's rate of descent or climb to alter airspeed. At each airspeed, students record angle of attack, inclination and elevator deflection. This provides sufficient data to predict the aircraft's drag polar (Figure 3a) and longitudinal static stability (Figure 3b). This experiment is repeated in the cruise and landing approach configurations so students can compare the effects of wing flaps and undercarriage extension on the aircraft's cruise performance and stability. (The gradient of the curves in Figure 3b is a measure of static stability.)



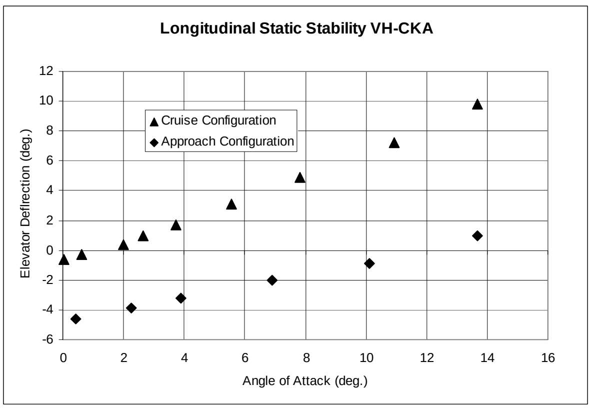


Figure 3a **Figure 3b**

Figure 3a. Drag polar for Cessna 182RG VH-CKA in the cruise and approach configurations. Figure 3b. Longitudinal static stability. Angle of attack v's elevator deflection for the cruise and approach configurations.

Instrumentation

All additional instrumentation installed in the School’s aircraft was designed so that it could be fitted with minimal modification to the basic airframe. Furthermore, because it was desired to maintain the aircraft in the ‘normal’ registration category, it was necessary to obtain air worthiness approval before modifying the aircraft. This was done in consultation with a designated engineer as permitted by Civil Aviation Regulation 35 (CAR35). Proposed modifications and designs were discussed with the CAR 35 engineer before formal submission for assessment and approval. Test flights were permitted under a ‘Permit to Fly’ issued for the proposed flight by the Civil Aviation Safety Authority (CASA). Once modifications were approved, an ‘Engineering Order’ was included in the aircraft’s flight manual. This specifies the nature of the modification, its installation and operation.

The most prominent instrument installed on the School’s aircraft is the air data boom (Figure 2b). This incorporates a pitot static system for airspeed and altitude measurement and vanes to measure angle of attack and sideslip. Although the aircraft has its own inbuilt pitot static system, a second system was installed in the boom so as to avoid compromising the integrity of the inbuilt system which is critically important to the safety of flight.

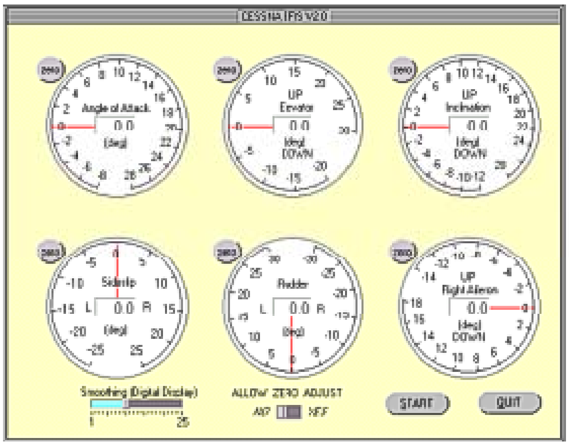
The most challenging aspect of the boom’s design was to control its’ lateral dynamic response to engine vibration and turbulence. Ideally, the boom must be sufficiently rigid so as to avoid significant errors in the angle of attack and sideslip measurements. However, it was found that to isolate the boom from engine vibration demanded a relatively flexible boom. The solution was to design a nonlinear vibration isolator which increased in stiffness with vibration amplitude. The boom isolator is relatively flexible at low vibration amplitudes so that it suppresses the boom’s resonant response to engine vibration. To counter the large dynamic inputs brought about by turbulence and rapid manoeuvering, the isolator stiffens so that the boom is held more rigidly to the airframe.

During the boom’s certification flight trials, the isolator’s performance was verified using an accelerometer mounted on the tip of the boom. Following certification, the boom’s pitot static system and vanes were calibrated by two final year BE students (Taylor, 2000) and (Pakai, 2000) respectively.

Another essential part of the aircraft’s instrumentation is the control surface deflection measurement system. This system was the outcome of a final year Aeronautical Engineering student project (Towell, 1999). The deflection of each of the primary control surfaces (elevator, rudder and aileron) is measured using a small, high quality potentiometer coupled to the control surface by a ‘string’ attached to a small tab. As the control surface moves, the string rotates the potentiometer against a return spring. A ‘weak link’ is incorporated in each string ensures this system cannot compromise the safety of the aircraft should a potentiometer jam.

Other instrumentation includes rate gyros to measure roll, pitch and yaw rates and an accelerometer to measure pitch angle.

A small Toshiba ‘Libretto’ computer is used to display and record all data during the airborne laboratories. A variety of interfaces are used depending on the nature of the flight. Figure 4a shows a typical display interface where steady state measurements are required. Students can also record dynamic signals at sample rates up to 100 Hz. This is particularly useful when investigating dynamic stability (Figure 4b).



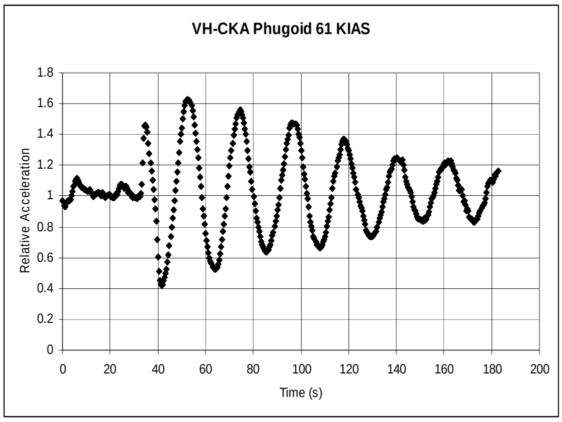


Figure 4a **Figure 4b**

Figure 4a - A typical data display using the Libretto computer. Figure 4b – Longitudinal dynamic stability. Phugoid response following a speed disturbance from trimmed level flight.

Currently work is underway to produce a pressure belt that will be used to measure the surface pressure on the aircraft's wings, tailplane and fuselage (McCarty, 2007). This system will allow students to explore wing and tailplane pressure distributions under steady and unsteady conditions.

Student and Staff Response

As mentioned above, student response to the airborne laboratory has been very positive. Students have been regularly surveyed using a post flight questionnaire and this helped shape the laboratory's evolution. A selection of typical student comments follows:

. . . the flight laboratory was very useful in relating theoretical concepts we have learnt in flight mechanics to actual flight. Further, it demonstrated that theoretical results can be very close to actual flight performance.
. . . I was very impressed with the flight laboratory. It was the relevant and worthwhile aspect of my degree conducted thus far. A lot of theory came into place.
. . I found it extremely valuable. I especially found the phugoid oscillation experience interesting as I was not sure of the phugoid concept before the lab so I certainly learnt something.

Given the nature of the laboratory, it is not surprising that student reaction is very positive. Students are clearly motivated by the laboratory. Students also value the opportunity to apply the classroom theory in practice. The comments that 'a lot of theory came into place' and the enlightenment regarding the 'phugoid concept' are particularly satisfying and consistent Magin's (2000) findings that 'one or two key experiments'can be instrumental in understanding.

Staff also view the learning outcomes of the laboratory program very positively. However, it must be recognised that this program is very demanding in terms of time and requires staff with skills in piloting and the ability to teach aircraft performance or flight mechanics. This is the most likely reason why airborne laboratory programs are uncommon, and provided the impetus for the AirKraft video series.

The AirKraft Video Series

Given the strength of the student's enthusiasm for the airborne laboratories, the School began to explore ways to make the laboratories more widely available. (At the time, it was identified that at least seven other undergraduate courses in Australia could benefit from flight laboratories.) A broader motivation was the desire to produce a quality teaching resource that would allow teaching staff to focus more broadly on *education* rather than the mechanics of course delivery.

Experience using an MIT video series (Hansman, 2005), had shown the potential of video media as a quality teaching aid. The MIT series was used in an instrumentation course at ADFA in an effort to provide a variety of teaching media and thereby improve learning (Andersen, 1990). This experience led to the decision to create a *video series* on aircraft performance based on the airborne laboratories.

From classroom observations using the MIT video series, it was found that:

1. Students were better engaged when videos were of very high quality,
2. Students maintained their concentration better when required to record information in workbooks as the videos were screened, and
3. 20 minutes was an appropriate target length for each episode as it allowed easy integration of the material into a typical 50 minute teaching period.

These observations helped shape the design of the AirKraft series. It was decided that each video would follow a common format and would begin by explaining the relevance of each topic and its historical perspective. This would be followed by a discussion of the appropriate background material and an *in-flight* experimental sequence using a Beechcraft 76 twin engine aircraft. It was also decided that AirKraft would be accompanied by detailed student workbooks. The workbooks would contain relevant background material and a series of questions designed to test the student's understanding of key concepts. The workbooks would also provide a framework in which students could **observe**, **record** and **analyse** their results from the in-flight experimental sequences shown on the videos.

The AirKraft video series was produced in conjunction with the Centre for Media Resources ADFA following funding from the Committee for the Advancement of University Teaching (CAUT). The production of three episodes and workbooks took three years and primarily involved three members of staff and trials using feedback from a student class. It was discovered that the students were very enthusiastic about being part of the development and evaluation process. For the purpose of the student trials, a detailed evaluation questionnaire was developed in conjunction with the UNSW's Educational Testing Centre. This included a section where students could include written comments. A selection of the comments follows:

. . *the interest in and motivation to do this lab leaves every other lab for dead.*
. . (main strength) *how the video and workbook interacted so well together*
. . *very relevant* **-** *instead of experimenting on specific things (such as momentum of pulleys etc. etc.) we were able to actually see how the theory relates to plane flight.*
. . *quality of presentation was extremely high.*
. . (main strength) *the logical order/progression in the explanations. It was relevant and helpful.*
. . *difficult concepts highlighted, very well paced.*
. . *it showed most things in real life. Showed how fundamental the measurements were. Showed the history* (and) *what happens when we neglect these things.*
. . (main strength) *the idea that the lab has RELEVANCE! ie. we can visually see why we are doing the lab.*
. . *clarity and conciseness of presentation and logical progression of workbook.*
. . *gave us a chance to see airspeed and altitude used in practical applications.*
. . *clear link between theory and practical.*
. . (main strength) *the excellent format of the workbook* (that) *was provided.*
. . *the link between the material in the workbook and that of the video gives us a better understanding of the topic in discussion, enabling us to view the subject from two perspectives.*
. . *it was interesting and relevant. You could see the immediate applications and implications.*

Student feedback was particularly useful in refining the pace of the experimental sequences and audio quality. The AirKraft series is now distributed through Insight Media in New York.

Conclusion

The airborne laboratory program at SACME is now in its seventeenth year of operation. Both the airborne laboratory program and the AirKraft video series provide teaching resources for students studying aircraft performance, stability and control. Student response to both has led to the conclusion that these programs successfully link classroom material to the outside world. The airborne laboratory program requires staff who are able to pilot aircraft *and* have a knowledge of flight mechanics. For this reason, laboratories like this are not common even though they provide valuable learning experiences. An economic solution for Universities unable to provide airborne laboratories is the AirKraft video series. Based on SACME's airborne laboratory, this series explores aircraft performance and has attracted positive student appraisal.

In addition to the airborne laboratory program, the School uses its aircraft for a variety of honours and postgraduate projects.

Future work at SACME will involve the installation of a system to measure wing pressure distributions under steady and dynamic conditions.

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