Teaching Flight Test Engineering with a PC-Based Simulator

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Abstract

This paper describes the process of establishing flight test laboratory experiments by use of a PC-based flight simulator, and the details of conducting such experiments. It was determined that it was feasible to perform airspeed calibration, and tests to determine stall speed, power required, rate of climb, cruise speed and range. While some of these tests yielded data that were a little on the optimistic side, the results were consistent, and provided theoretically predicted trends. Smooth curves could be fitted to the data. This approach to a flight test course proved to be quite effective. The reports were similar to those submitted when the same tests were performed in flight. While not quite as satisfying to students as when they got to fly all the experiments, they seemed happy to be able to learn real flight testing techniques. A number of graduates were able to secure flight test engineering positions in both industry and government activities.

I. Background

In 1963, the Aeronautical (now Aerospace) Engineering Department at Penn State University obtained a Piper PA-28-160 Cherokee from Piper Aircraft on a lease agreement for $1.00 a year. The next year, a flight test engineering course was launched. Students were divided into groups of three for the laboratory portion of the course, and each week they were scheduled for an in-flight lab session. Experiments were conducted in the following topics:

1. Airspeed calibration
2. Stall speed measurement
3. Power required and drag determination
4. Climb performance and ceiling prediction
5. Takeoff distance
6. Static longitudinal stability and neutral point
7. Dynamic longitudinal stability

The course was taught by a qualified pilot, who also acted as the test pilot/lab instructor for the flights. This arrangement worked well, because it carried over the lecture material into the cockpit environment. It also allowed for three students to be carried in the 4-place airplane, which seemed to be the ideal crew size. One student could read the instruments, one could do timing, if it was required in the experiment, and the third could record data. No special instrumentation was added to the aircraft.

The course was a senior elective, and proved to be quite popular. The original aircraft was replaced with a new 180-horsepower Cherokee in 1967, and that was followed by a 1974 Cherokee Arrow. The last two aircraft were actually purchased from Piper, when the company could no longer afford to continue the very generous lease agreement. The Arrow was a retractable gear aircraft, and allowed for demonstration of the additional drag of landing gear and its influence on performance. Drag measurements, and various items of performance, were made in both configurations. The Arrow was also equipped with a sensitive airspeed indicator, and a boom-mounted, swivel-head pitot-static probe during testing. The course continued for more than 30 years, with no incidents, or mishaps of any kind.

In 1995, however, the University administration became concerned about the liability associated with aircraft operation. They made a ruling that no department, or other Penn State entity, could operate an aircraft unless they carried $50 million liability insurance. Needless to say, this was tantamount to saying, “Get rid of the airplane.” Most companies would not even insure a single-engine aircraft for that amount, and the one that was willing wanted $25,000 annual premium. The Arrow, therefore, was sold, and the last flight test class with in-flight labs took place in Fall Semester 1999.

II. Formulation of Revised Course

Students of lower class standing began to inquire if there was any hope for replacing the flight test course. They were quite familiar with its existence, and were looking forward to scheduling it in their senior year. In the mid-1990’s, there also began to appear a number of computer-based flight simulator programs. Many of these were just games, but some were more sophisticated, and were being adopted by flight schools to assist in the training of students. The Federal Aviation Administration (FAA) even approved some of these software/hardware combinations to be used in the official training programs for certain pilot ratings. The FAA calls them PCATD’s (PC-based aviation training devices). Several of these software packages were investigated for their adaptability to a flight test course.

The major concern with using such software was that the flying qualities would not be sufficiently accurate to allow for fairly precise performance measurement. At the time that this study was initiated, there were four different packages approved by the FAA for flight training purposes. Several of these were found in demonstration booths at various airshows, and checked out briefly. Two of these were then ordered, and investigated more thoroughly. The Elite package was found to be most adaptable to this purpose. It had very realistic, and consistently reproducible, performance. The standard package also contained a simulation of the Piper Arrow, the last actual airplane that was operated by Penn State. A considerable amount of necessary data had been collected on this aircraft, such as drawings, engine charts, and propeller charts. A simulator program for the same aircraft was, therefore, quite convenient.

In order to make the flight simulation more realistic, control hardware, including control yoke, rudder pedals, and throttle quadrant, was also ordered. The FAA requires this for flight training purposes, and it was felt that this would make flying the tests much easier, and convey more real-world atmosphere to the students, rather than flying with a mouse.

There was some difficulty in mating the software to a computer in the first attempts. Much of this was due to the fact that the original software was DOS-based. The latest version of the software (Elite 6.0) is Windows-based. There are now packages of software and hardware combinations available at quite reasonable prices. The most complete of these consists of the software, combined yoke-throttle quadrant panel, rudder pedals, and avionics panel. The price on such a package ranges from about $3500 to $5000, although more professional models with hydraulically-damped controls can run to $11,000. Adding an adequate PC computer, the total price of the simulator is on the order of $5,500 to $7,000. The Penn State simulator package was somewhat pieced together, but, purchased complete, it now lists for $5195, and includes the following items:

Elite 6.0 software
Elite AP-3000 avionics panel
Elite Pro-panel flight console
PFC Cirrus rudder pedals.

III. Adapting Experiments to the Simulator

An attempt was made to fly all of the original experiments on the simulator. In some cases, they could be flown just as they were in the actual airplane. In others, modifications to the flight procedures were necessary. The simulator has inputs of atmospheric conditions, which realistically affect performance. Hence, non-standard day conditions were usually set so that the students experienced the process of reducing data to standard. In most cases, the actual conditions on the day of the experiment were used. Wind conditions could also be randomly set into the machine.

As is the case with most simulators, it is much more sensitive to control inputs than a real airplane, even with the sensitivity adjustment set very low. Hence, it was very difficult to hold exact values of airspeed, altitude, etc. To minimize error in the data, the autopilot was used for most of the experiments. This feature of the simulator worked quite well, and was almost necessary to obtain any useful data. Another useful feature was the ability to instantaneously place the aircraft at any altitude, without having to spend time climbing to it. This feature was helpful in saving lab time when high altitude measurements were required, such as in the climb performance experiment.

The following experiments were developed, and performed in the order listed.

Airspeed Calibration

Originally, the in-flight airspeed calibration was performed by timing flight in both directions over a measured course, calculating true airspeed by averaging groundspeed, and then converting to calibrated airspeed. The resulting values were then plotted against indicated airspeed for a calibration curve. In the last few years of testing in the air, a GPS (global positioning system) was used to directly record groundspeed. The software of the Elite 5.0 that was used did not contain GPS information. Hence, a new procedure had to be developed.

The simulator did have a DME (distance measuring equipment), and of course, VOR navigation receivers. These devices were utilized for the groundspeed measurement. The students were given a random wind direction. They then had to pick a radial of the nearby VOR that would take them to the station directly into the wind. The airplane was then flown on that course, and on the reciprocal heading. Students timed a specific distance in both directions, and then proceeded to calculate true airspeed by the same means as in the speed-course method. Groundspeed could have been read directly on the DME, but this approach gave them more of an engineering exercise. This method seemed to work quite well.

Stall Speed and Maximum Lift Coefficient

Once the airspeed was calibrated, it could be relied upon to yield accurate values in other performance. The stall speed was determined exactly as it was with the real airplane. It was flown to altitude, and gradually slowed until the stall break, when the speed was recorded. The test is repeated for all flap settings (four discrete settings on the Arrow), and maximum lift coefficient is calculated from the data. The simulator performed realistically in this area.

Power Required and Drag Coefficient

Power required is determined by flying at just enough power at various airspeeds to maintain level flight. Power available is then determined by reading RPM and manifold pressure at each speed, as well as atmospheric conditions, and referring to the appropriate engine and propeller charts. This experiment was also performed just as it was in flight, and seemed to yield acceptable results. Data are reduced to yield a standard weight, standard sea level power curve, or “universal power curve,” from which a drag coefficient and Oswald efficiency factor can be deduced. The procedure is repeated for gear and flaps extended.

Rate of Climb and Ceiling

Rate of climb is also determined as it was with the actual airplane. The airplane is flown in sawtooth patterns through a nominal altitude at various airspeeds, timed, and rate of climb calculated, and corrected to standard day and weight conditions. After repeating at several altitudes, the maximum climb rates are plotted against altitude, and extrapolated to yield absolute ceiling and sea level rate of climb. Best rate and best angle of climb speed can also be determined.

Cruise Speed and Range

Although not in the original list of in-flight experiments, over the years an additional one was added to the list to determine cruise speed and range at various power settings and altitudes. This experiment also lent itself well to simulator application. The airplane is flown to a certain pressure altitude, and temperature measured. The students then calculate the density altitude, and the power is set to specific settings (65%, 75%, etc.) according to the flight handbook. For the

Arrow, manifold pressure values are given for certain power settings at 2400 RPM. Hence, the simulator is flown at a constant RPM of 2400, and the students determine what manifold pressure should be set. The mixture is also leaned to peak EGT (exhaust gas temperature). The fuel flow and the airspeed for that particular power setting are then recorded. After repeating at several altitudes, and some data reduction, curves of cruise speed and range can be constructed for various density altitudes. This procedure worked out well on the simulator, also.

Other Experiments Considered

Takeoff and landing performance measurement was not deemed feasible on the simulator. Even with the real aircraft, this determination was somewhat difficult, and required definite distance markers on the runway. It was, therefore, not even attempted for this application.

Stability was also hard to determine. Although, the weight could be varied on the simulator, the CG could not be. The static longitudinal stability experiment that was previously done in-flight depended on shifting the CG, and measuring stick position versus trim speed. There also did not appear to be a direct correlation between the control yoke and the elevator positions on the simulator, which was also required for these experiments. For this same reason, it was impossible to perform dynamic stability tests. This was one area where the program did not represent the true airplane very well.

In order to give the students some experience with dynamic stability and its measurement, one actual flight was arranged by contracting with a local flight school to demonstrate a phugoid oscillation. The flight instructor was indoctrinated into the procedure by the course instructor so that he could serve as both pilot and lab instructor on these flights. A 4-place airplane was used, and the crews were set up as previously with the Department airplane. Measurements were taken of the time and speed history during the oscillation, from which plots of the motion can be made to determine the period and time-to-damp to half amplitude.

Part of the stall speed experiment used to be to tuft the wing, and have the students qualitatively evaluate the stall progression pattern. The flight school allowed us to do this on their airplane, and it was also performed on the same flight as the phugoid. The cost for flying a total of 18 students was about $600 at the local flight school at University Park Airport.

IV. Results

The course has been offered in this format for two semesters. Results between the two classes were pretty consistent. Data from all groups were collected and averaged to provide a baseline for comparing future results.

The airspeed calibration curve obtained seemed reasonable for typical light airplanes, with calibrated speeds being 1 or 2 knots higher than indicated in the low speed range, and 2 or 3 knots lower at the high speeds. The two values agreed at about 100 knots. Initially, there was some doubt as to whether the computer would display any error at all between indicated and calibrated values. Whether the difference was real or simply involved reading error was never clearly indicated. It did serve, though, to convey the real-world situation to the students.

Stall speeds varied considerably, depending on how the students interpreted the actual speed at the break. Maximum lift coefficients ran from about 1.5 in the clean configuration to about 2.3 with full 40 degrees of flap. While these results seem a bit on the high side, they are, nevertheless, in the ballpark area. Prior to offering the course, a student who was a licensed pilot, investigated all the experiments as a special project course. He found the C_{Lmax} to be 1.39 clean, and 1.74 with full flaps, more reasonable values. Because the stall speed is squared in the calculation, very slight error in reading it results in considerable difference in C_{Lmax}.

Power required measurements yielded fairly good curves in the higher speed range, but were difficult to measure accurately at the lower speeds. It was impossible to get on the back side of the power curve. Drag was determined by reducing all data to a universal power curve, and plotting $THP_{ew}V_{ew}$ versus V_{ew}^4. The slope of this curve yields the zero lift drag coefficient (C_{Do}), which turned out to be about 0.02 in clean configuration, and 0.027 gear and flaps down. These values seem a little low for the Arrow, but, again, in a reasonable range. Error could be introduced by the way in which thrust power is measured, using manufacturers' engine and propeller curves.

The rate of climb measurements yielded quite good results. After correcting to standard weight, the maximum rate of climb values were then plotted against altitude. Extrapolating this curve gave an absolute ceiling of 18, 600 feet, and a sea level rate of climb of 950 ft/min. These results compare quite well to those of the flight handbook for this aircraft, namely 18,000 feet ceiling, and 830 ft/min sea level climb. Cruising speed and range tests were made at various altitudes at both 65% and 75% power, and also gave good results. This chart showed about 1000 nm at 6000 feet and 75% power compared to 900 nm in the flight handbook, and 1050 nm at 65%, against the 925 handbook figure.

In general, the performance exhibited by the computer was a little better than the actual airplane in nearly all cases. The readings are taken on analog gauges, which are pretty small on the 17-inch screen, so that reading them involves some inherent error. Also, an interesting observation during the lab sessions was that many students seem to have trouble interpreting analog gauges. It was considered to be a consequence of the modern digital age.

V. Conclusions

1. PC-based flight simulators are quite adequate for laboratory experiments in airplane performance measurement. FAA-approved PCATD's yield best results in this area.
2. Suitable simulator packages can be purchased for well under $10,000, with economy versions under $5000 performing satisfactorily.
3. Simulators in this price range do not perform well in stability demonstrations.
4. Students are enthusiastic about this approach, and seem to gain better insight into both airplane performance, and aircraft operation in general.

5. Students are much more interested in such a course when actual flights are incorporated. Depending on facilities and budgets, anywhere from one to three experiments could be flown, with the rest conducted on the simulator.

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