

The Use of Flight Simulators for Experiments in Aerodynamics Courses

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Abstract

This paper summarizes the results of a novel approach to introduce flight simulators into an aerodynamics and flight mechanics course as a kind of virtual laboratory. Student response to this approach has been excellent, with many students willing to put in extra time above and beyond usual course requirements to participate in this part of the program. Four hardware and software packages are described, and are evaluated relative to the course objectives. The simulator selected is a personal computer aviation training device (PC-ATD), not a full motion simulator. Students calculate the performance of a typical four place lightplane and then fly the simulator through a series of flight profiles to compare theory with experiment. The simulator is treated as if the students were flight testing an actual aircraft. Performance measured includes stalling speed, maximum speed, and rate of climb versus velocity. The results obtained are good enough to justify the use of an inexpensive simulator to provide an effective flight test program. The project has turned out to be highly motivational for the students, as well as a good educational experience in aircraft performance calculation verification

I. Introduction

Laboratory experiments in aerodynamics courses have traditionally consisted of wind tunnel experiments of aircraft or wing models. Certain types of simulated “experiments” can be conducted in “virtual” laboratory type environments, as described by Henning and Higuchi¹. Computer programs² can also be used to simulate wind tunnel experiments in a virtual laboratory type environment. Schools with associated aircraft flight programs and high budgets occasionally use actual aircraft for flight test purposes.

This paper describes an evaluation of flight simulators to provide a virtual laboratory simulating a flight test program, and summarizes experiences and results with the introduction of a flight simulator into an aerodynamics course. The procedure is suitable for use in basic aerodynamics courses or in flight dynamics courses.

II. Course Structure

The course described here is titled “Aerodynamics and Flight Mechanics.” It is a three semester hour senior year technical elective offered as part of the Mechanical Engineering program at the University of Massachusetts Lowell. The course consists of 80% basic aerodynamics and 20%

flight mechanics (the so-called “static performance problem”). The course has been offered for over 20 years. The most recent offering of the course was patterned somewhat after the format of Mourtos³. The UMass Lowell aerodynamics course is currently structured as follows:

Two one hour examinations		10% each
Basic wind tunnel experiment	10%	
Basic airfoil computer project	10%	
Additional project no. 1		10%
Additional project no. 2		10%
Additional project no. 3		10%
Professional development component		5%
Final examination		25%

The professional development component requires each student to either: join AIAA as a student member and write a brief summary of an article from one of the journals, or attend a local monthly meeting of AIAA and write a brief summary of the meeting. This serves to expose the student to the engineering profession.

The additional project nos. 1 through 3 are chosen by the student from a list of several computer projects, experimental projects (mostly wind tunnel experiments), design projects, or analytical projects. Thus, the student can tailor 30% of the course emphasis in any direction that he/she wishes. One of the experimental projects is the Flight Test Engineering project, which consists of flying a prescribed aircraft on the simulator and measuring certain aspects of its performance. This project by far involves the most work, as it entails five extra lectures plus several extra hours of flight simulator practice by the student before conducting the flight test experiments. The interesting thing is that out of sixteen students taking the course, ten elected to do the flight simulator project at the beginning, and nine stayed with it until the end. This is a good example showing that many students are willing to do extra work on a project that is interesting.

III. Requirements for Simulator

The requirements for a simulator for aerodynamics course purposes are as follows: (1) Be a reasonably accurate representation of actual aircraft performance, static performance as a minimum, preferably dynamic performance for stability and control work, (2) Simulate an aircraft for which engine, propeller, and drag data are available from the manufacturer, or can be derived by simple means, (3) Have a realistic looking panel and controls to maintain student interest, and (4) Have sufficiently realistic terrain features also to maintain student interest.

The flight simulator does not need capability to provide aircraft motion cues. This type of simulator would be too expensive and not necessary for the course purposes. The final flight simulator selected for this program was actually a “personal computer based aviation training device,” PC-ATD, as it is referred to by the FAA. PC-ATD’s can simulate the flight training environment in many ways, but do not provide any aircraft motion cues. They typically consist of a computer and monitor hooked up to a yoke and rudder pedals, or in more elaborate cases, to a partially simulated control panel for an aircraft. The monitor displays the aircraft instruments, a portion of the control panel, some scenery, and some of the aircraft controls. Garrison⁴

presents a good summary of various types of flight simulators, including those providing motion cues.

Selection of a flight simulator for our purposes did not have to satisfy any FAA requirements, since it would not be used to log pilot time toward a rating. Instead, it only had to duplicate aircraft characteristics with sufficient fidelity so it could be treated as a flight test experiment for measuring aircraft performance. It also had to be simple enough so a student could learn to fly it without an excessive amount of training adding to the course demands. Finally, the simulator selected had to match an actual aircraft for which engine, propeller, and lift-drag characteristics were available.

IV. Simulators Evaluated

Four sets of hardware and four computer software packages were evaluated in this study. Two of the hardware sets were typical FBO flight school instrument flight training simulators, not PC based.

Hardware The hardware evaluated is summarized in Table 1.

Table 1. Simulator hardware evaluated

Simulator Type	Approximate Cost
Analog Training Computers ATC-610	\$2000 - \$3500 (used), or \$25/hr rental
Aviation Simulation Technologies AST-200	\$30,000 (used), or \$30/hr rental
Control Vision Corporation Simhawk Pro	\$1395 (without rudder pedals)
CH Products Flight Sim Yoke PC and CH Pro Pedals	\$290 (including rudder pedals)

The ATC-610 was evaluated by the author only and eliminated from further consideration for two reasons: (1) Lack of realistic horizon reference, which would make learning difficult on a short term basis -- it would require IFR flight training skills more than VFR training skills, and (2) The hardware simulated one generic aircraft only, with no alternate aircraft or performance options available.

The AST-200 was evaluated by both the author and by students doing a special topics course in aerodynamics. Although by far the most realistic, it was eliminated from consideration on a regular basis in the aerodynamics course primarily because of its high cost. This simulator had to be rented at a local college using it for flight training. This simulator was also generic to one family of complex lightplanes for which the manufacturer was unwilling to provide engineering data.

The Simhawk Pro flight simulator consists of a realistic looking aircraft yoke mounted on a control panel measuring 23” wide, 6” high, and 14” deep. The monitor sits on top of the panel, which has realistic throttle, mixture, and propeller controls, as well as carburetor heat, trim, and switches for landing gear, flaps, radio and navigation tuning knobs, etc. Rudder pedals are also available, but were not used due to their added cost (\$300). The simulator can be used without

rudder pedals simply by toggling on an “auto-coordination” switch in the software. Use of rudder pedals increases training time and is not required to illustrate the basic principles of the flight maneuvers, all of which are conducted in the longitudinal plane of motion.

The CH Products Flight Sim Yoke is a realistic looking aircraft yoke that simply clamps on a table top, with the monitor sitting behind it. There is no control panel as such, but a small throttle quadrant, pitch trim wheel and seven simplified buttons or toggle switches are mounted on the yoke support to control gear and flaps, etc. The switches can be assigned to various functions depending on the software used. Rudder pedals (CH Pro Pedals) were used with this simulator since the total cost was still very reasonable.

The Simhawk Pro and the CH products PC-ATDs were both used by students with appropriate software to be described. The Simhawk Pro was chosen to be the best overall compromise. It has realistic controls with suitable control feel at moderate cost. With appropriate software, it worked out very well. The CH product would certainly be suitable for departments with a limited budget, and worked fine for our purposes also, but the students avoided using it in the final flight tests, preferring the more realistic looking Simhawk control panel setup instead.

Software packages Software packages, of course, are only appropriate to the Simhawk Pro and CH Products PC-ATDs. The software packages evaluated are summarized in Table 2.

Table 2. Software packages evaluated

Software	Cost
ASA “On Top”	\$100
Jeppesen “Flight Pro” (standard version)	\$100
Microsoft “Flight Simulator 2000”	\$50
Sierra “Pro Pilot 99”	\$20

While all the software packages had numerous excellent features for course purposes, ASA On Top and Jeppesen Flight Pro were eliminated primarily because they lacked terrain features and might not maintain student interest. They are designed for serious IFR flight training where terrain features are generally immaterial, and the only features of importance are the immediate airport environment when one “breaks out” from an overcast. As such, it was felt they would not maintain student interest as well as the other two packages.

Microsoft Flight Simulator 2000 and Sierra Pro Pilot 99 both provided terrain features and could be used to simulate several aircraft, but Microsoft Flight Simulator was eliminated simply because it did not simulate the one airplane for which we were able to obtain the required data from the manufacturer (this is discussed in the next section). As a result, we used Sierra Pro Pilot 99 for the course purposes.

V. Theoretical Performance Calculations

Contacts were made with three aircraft manufacturers to obtain information required to make theoretical performance calculations. The items requested for the three aircraft were a lift-drag polar, a power available versus velocity curve, as well as general aircraft specifications. Only one of the three manufacturers responded favorably, thus the performance calculations were based on the aircraft we received data for, and that the simulator could model. We ended up studying a four place, high wing, single engine aircraft⁵ of 160 horsepower. During the course of the semester at appropriate points, all students calculated the theoretical performance of this aircraft as part of homework assignments. When wing theory was covered, calculations were made for stalling speed, and when power curves were covered, calculations were made for rate of climb, maximum speed, and power off glides. In addition to this being a homework assignment for all students, the students electing the flight simulator project would also use this data to compare with their experimental results.

VI. Simulator Training

An additional five hours of extra classes were required for those students pursuing the flight simulator project. Three of these hours consisted of classroom training on how to fly an airplane, similar to what would be given in a private pilot ground school course. This consisted of the function of flight controls and reading aircraft instruments, and performance of the “four fundamentals” (straight and level, turns, climbs, and glides). A series of slides were used similar to those used by flight schools. Only a small amount of coverage was given to radios and navigation instruments, since these were irrelevant to the course needs in this regard. This classroom time was followed by two hours of demonstration sitting at the flight simulator and computer screen. Each of the students was given some supervised practice at the flight controls. All this instruction was given during the first five weeks of the course, so students had plenty of time to practice with the simulator on their own during the remainder of the semester. In this manner, when the theoretical part of aircraft performance calculation was completed, each student would be ready to conduct the flight test portion of the project and still have time to write their final report before the end of the semester.

The students were then allowed to practice on the simulator during their own time and at their own pace. The experience level of the students coming into the course and doing this project ranged all the way from one student who had a commercial pilot’s license, to students who had never been in an airplane, and who had, at most, played a few aircraft video games. Most students had experience somewhere in between, presumably because they were interested in aeronautics to begin with. The students kept a log of their practice time for course assessment of the project, as well as their time performing the maneuvers required for the flight test. Examination of the logbooks showed that the student who spent the most time gave himself six hours of training prior to the flight tests, and then spent two hours on the flight tests themselves. The student who spent the least amount of time only logged 15 minutes, conducting his portion of the flight tests. His logbook noted that he had extensive experience using Microsoft Flight Simulator with a joystick prior to taking the course. The average time spent by the nine students self-training and conducting flight tests was 3.1 hours.

VII. Flight Tests Conducted

There were four types of flight tests required of the students: (1) Determination of rate of climb versus velocity, (2) Determination of maximum speed in level flight, (3) Determination of power on stalling speed, and (4) Determination of power off glide characteristics. The students could choose to do the project in groups of two or three. Three of the groups consisted of two students, and one group consisted of three students. The groups with two students did performance items nos. 1, 2, and 3. The group with three students did item nos. 1, 2, and 4, since this reflected more work for the larger group. In each case, one student acted as a pilot performing the maneuver, while another student acted as a flight test engineer standing behind the pilot and recording test data as the maneuvers were performed. The students then exchanged roles so that each student obtained experience as both pilot and flight test engineer.

VIII. Results

Abbreviated comparisons of the theory and flight test results obtained by each group are summarized in Table 3.

Table 3. Comparison of theory and experiment

Performance	Theoretical	Group 1 Exp.	Group 2 Exp.	Group 3 Exp.	Group 4 Exp.
Max rate of climb at Speed	940 fpm @ 79 kts	1090 fpm @ 78 kts	960 fpm @ 72 kts	1140 fpm @ 75 kts	1250 fpm @ 77 kts
Maximum speed	124 kts	108 kts	104 kts	112 kts	110 kts
Stalling speed with no flaps	56 kts	50 kts	NE*	48 kts	44 kts
Stalling speed with 30 deg flaps	42 kts	45 kts	NE*	37 kts	39 kts
Min glide angle at Speed	4.4 deg @ 76 kts	NE*	12.5 deg @ 76 kts	NE*	NE*
Min descent rate at Speed	540 fpm @ 63 kts	NE*	1370 fpm @ 46 kts	NE*	NE*

* NE = not evaluated

Except for the gliding performance, where the agreement between theory and experiment is poor, most of the other performance showed fair to good agreement with theory. Of course, with this type of project, it is not possible to assess what portion of the disagreement is related to the fidelity of the flight simulator, and how much is due to a typical comparison of theory with experiment where pilot technique is involved. Certainly, the variation of results from group to group indicates that better control needs to be exercised over the flying technique of the students in the future. Nevertheless, the project serves well to illustrate comparison of measured aircraft performance with predicted performance.

Evaluations conducted on student response to this project were generally positive, with one student expressing the opinion that the project should be required of all students in the aerodynamics course.

IX. Conclusions

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Flight simulators are an effective way to introduce students to aircraft flight testing and comparison with theory. The applications are limited only by the instructor's imagination and the time available in the course to introduce the simulator, without detracting from more important topics. Experience at the University of Massachusetts Lowell has shown that this type of instruction is enthusiastically received by the students and that they are willing to invest the extra time into the course to work on this interesting topic.

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