A&AE 490/AT490 Flight Testing

1. Instructors
   Professor Dominick Andrisani
   Office: Room 3203 Armstrong Hall
   Office phone: 494-5135
   login: andrisan@purdue.edu

   Professor Bernard Wulle
   Office: HGR6
   Office phone: 49-49973
   login: bernard.w.wulle.1@purdue.edu

   Teaching Assistant
   Rosemary Huang (TA for homework and project grading)
   login: rhuang@purdue.edu

   Student instructor pilots will be provided by Aviation Technology.

2. Textbook: *Flight Testing of Fixed Wing Aircraft,* Ralph D. Kimberlin, AIAA Education Series, 2003

3. Alternate Text: *Performance of Light Aircraft* by John T. Lowry, AIAA, 1999.

4. Seating: Starting next class, keep the same seat throughout the semester.

5. Eng. Grading
   6/8 of grade is based on homework and 6 flight experiments
   2/8 of grade is based on the final exam.

6. I reserve the right to raise or lower your grade by as much as one letter grade based on my judgment of your knowledge of the material in this course.

7. Course pre- or co-requisite for engineering students: A&AE 421 Flt. Dyn. and Control.

8. Class attendance is strongly recommended. You are responsible for obtaining notes and assignments on days you miss.

9. We will cover chapters 1-6, 8, 9, 11-13, 15-17, 19-23, 28-33 of the text.

A&AE 490A/AT490 Bibliography

Advisory Group for Aeronautical Research and Development of NATO (AGARD*), Flight Test Manual*, Volumes I, II, III, ~1954, General Editor, Cortland D. Perkins.

AGAR*D, Introduction to Flight Test Engineering*, AGARDograph No. 300, Volume 14 of AGARD Flight Test Techniques Series, 1995 (all the volumes in this series are useful).

AGAR*D, Pressure and Flow Measurement*, AGARDograph No. 160, Volume 11 of AGARD Flight Test Instrumentation Series, 1980 (all 17 volumes in this series are useful).

Aiken, William S., Jr., *Standard Nomenclature for Airspeeds with Tables and Charts for Use in Calculation of Airspeed*, NACA Technical Note No. 1120, September 1946, also NACA Technical Report 837, 1946.

Asselin, Mario, *An Introduction to Aircraft Performance*, American Institute of Aeronautics and Astronautics (AIAA) Education Series, 1997.

Biezad, Daniel J., *Integrated Navigation and Guidance Systems*, AIAA Education Series, 1999.

Hodgkinson, John, *Aircraft Handling Qualities*, AIAA Education Series. 1999.

Huston, Wilber B., *Accuracy of Airspeed Measurements and Flight Calibration Procedures*, NACA Report No. 919, 1948.

Kayton, Myron and Fried, Walter R., Avionics Navigation Systems, Second Edition, Wiley-Interscience, 1997.

Lan, Chan-Tau and Roskam, Jan, *Airplane Aerodynamics and Performance*, Roskam Aviation and Engineering Corporation, 1980.

Layton, Donald, *Aircraft Performance*, Matrix Publishers, Inc., 1988.

Miele, Angelo, *Flight Mechanics Volume 1 Theory of Flight Paths*, Addison-Wesley Publishing Company, Inc., 1962.

Ojha, S. K., *Flight Performance of Aircraft*, AIAA Education Series, 1995.

Pamadi, Bandu N., *Performance, Stability, Dynamics, and Control of Airplanes*, AIAA Education Series, 1998.

Perkins, Courtland D. and Hage, Robert E., *Airplane Performance Stability and Control*, John Wiley and Sons, Inc., 1949.

Roskam, Jan, *Airplane Flight Dynamics and Automatic Flight Controls, Part I*, Roskam Aviation and Engineering Corporation, 1979.

Smith, Hubert C., *Introduction to Aircraft Flight Test Engineering*, reprinted as JS312647C by Jeppesen Sanderson, Inc., 1988, available by special order at amazon.com or the bookstore. (This text is more understandable but less comprehensive then the textbooks mentioned above.)

Stinton, Darrol, *Flying Qualities and Flight Testing of the Airplane*, AIAA, 1996.

USAF Test Pilot School, *Flight Test Handbook. Performance: Theory and Flight Techniques*, AFFTC-TIH-79-1, 1979 (I don't yet have this).

USAF Test Pilot School, *Flight Test Handbook. Flying Qualities: Theory (Vol. 1) and Flight Test Techniques (Vol. 2)*, AFFTC-TIH-79-2, 1979 (I don't yet have this).

USAF Test Pilot School, *Stability and Control, Volume I of II, Stability and Control Flight Test Techniques*, AFFTC-TIH-74-2, July 1974.

Flight Test Teams:

We will attempt to develop some of the flight test culture in this course using well-integrated teams of AAE and AT students where possible. We will fly experiments in the Frasca 242 fixed base Simulator, the Cessna 182 aircraft and the Boeing 727 moving base simulator).

Every flight will be supervised by a certified instructor pilot from Aviation Technology. This AT instructor pilot will be the “Pilot-in-Command”. Only AT instructor pilots will take-off or land the Cessna 182.

There will be a maximum of 10 teams with 3 or 4 people per team.

Each team must have at least one person designated as the “Team Pilot.” This person will do most of the experiment flying during the course.

Ideally there will be 2 engineering students per team and one AT student to serve as the “Team Pilot” (not the instructor pilot).

Some engineering students have piloting experience and may serve as their “Team Pilot”. In this case there will be three engineers per team.

If a team has 3 engineering students with no piloting experience, an AT student will serve in a dual role as a team piloting advisor and instructor pilot. Flight experiments will be flown by the engineering student designated by the team as the “Team Pilot”.

The Frasca 242 Simulator is located in the Holleman-Niswonger Simulator Center, west of HGR 6 at the Purdue U. Airport. For Frasca experiments students will take the following roles (to be alternated among the three students on a team)

- Pilot (left seat)
- Co-pilot/Test engineer (right seat)
- Test Manager (at the Frasca Graphical Instructor Station (GISt desk))

Students are to organize themselves into teams and propose your teams to the faculty for their approval. Teams should determine which simulator session work for them. We will have to coordinate among ourselves in order to fill the available time slots.

AAE 490/AT490 Schedule

Week	Week Starting	Activity
1	1/11/10	Lectures: Andrisani
2	1/18/10	Lectures: Bernie Wulle (Flying an Aircraft)
3	1/25/10	Lectures: Andrisani
4	2/1/10	General Familiarization Flight (Frasca 242 Simulator)
5	2/8/10	Experiment #1: Stall Speed and CLmax (Frasca 242)
6	2/15/10	General Familiarization Flight (Cessna-182)
7	2/22/10	Experiment # 2: Performance (Frasca 242)
8	3/1/10	Experiment #3 Airspeed Calibration (Cessna-182)
9	3/8/10	Lectures: Andrisani
10	3/15/10	Spring Break
11	3/22/10	Experiment # 4: Performance (Cessna-182)
12	3/29/10	5 teams on 4/2?/09 do General Fam. Flt (Boeing 727 Moving Base Sim.)
13	4/5/10	Experiment # 5: Dynamic Perf. (Cessna-182)
13	Double up	Other 5 teams on 4/9?/09 do General Fam. Flt (Boeing 727 Moving Base Sim.)
14	4/12/10	5 teams on 4/16?/09 do Exp # 6: Lat. Direct. Flying Qual. (Boeing 727 Sim.)
15	4/19/10	5 other teams on 4/23?/09 do Exp # 6: Lat. Direct. Flying Qual. (B-727 Sim.)
16	4/26/10	Dead Week (Lectures: Andrisani)

Notes:

1 **There will be 9 flight experiences.**

2 **Six flight experiences involve experiments requiring team write-ups.**

3 **Individual homework and team write-ups and peer evaluation determine the course grade. There will be a final exam.**

4 **AT students are graded by Professor Wulle using appropriate grading criteria.**

Useful Web Sites Relating to Flight Testing

US Navy
http://flighttest.navair.navy.mil/

USAF Edwards Air Force Base
http://www.edwards.af.mil/
http://afftc.edwards.af.mil/

NASA
http://www.dfrc.nasa.gov
http://www.dfrc.nasa.gov/trc/ftintro/index.html

Society of Flight Test Engineers
http://www.sfte.org/

Society of Experimental Test Pilots
http://www.netport.com/setp/

Calspan
http://www.calspan.com/flight.html

National Test Pilot School
http://www.ntps.com/

International Test and Evaluation Association (ITEA)
http://www.itea.org/

Experimental Aircraft Association
http://www.eaa.org/

FEDERAL AVIATION ADMINISTRATION
http://www.faa.gov/

http://www.lockheedmartin.com/

http://www.boeing.com/

Federal Aviation Regulations
http://www.faa.gov/avr/AFS/FARS/far_idx.htm

Private Pilot Training
http://lights.chtm.unm.edu/~sarangan/aviation/training/training.html

Jeppesen
http://www.jeppesen.com

About Flight Testing

The objective of flight testing is to prove that a flying vehicle (most often a man/machine combination) can achieve the desired performance. By performance we include

- properties of the vehicle like range, speed maneuverability, and payload, strength,
    - the "ilities" like flying qualities, reliability, maintainability,
    - properties of the subsystems like auto-land and collision avoidance systems.

Flight testing is as old as man's attempts to fly.

Extended Flight Test Team:

Flight testing is conducted by extended flight test teams including

test pilots, flight test engineers, technical specialists of many kinds, instrumentation engineers and technicians, mechanical engineers and mechanics, data processing specialists, maintenance engineers, customers.

Flight Test Engineering:

Flight test engineering involves the testing in-flight of an aircraft or item(s) of aircraft equipment in order to investigate new concepts, provide empirical data to substantiate design assumptions, and to demonstrate that an aircraft or its equipment achieve specified levels or performance, etc.

Types of Flight Tests:

Prototype Testing

Prototype aircraft are the first aircraft of a given type to be flown. They are often unsuitable for operational flight but serve important purposes in the early stage of the evolution of an aircraft from idea to operational vehicle. The prototypes are used for many reasons including

to test new technology,
to improve the accuracy of aircraft mathematical modeling,
to help test and integrate subsystems,
to help develop flight simulators,
to give sufficient information in order to decide whether production of the vehicle is warranted,
to allow for competitive fly-offs in "fly-before-you-buy" procurements.

Developmental Test and Evaluation (DT&E)

…test and evaluation conducted to assist the engineering design and development process and verify attainment of technical performance specifications and objectives. Certification of civilian aircraft falls in this type of flight test activity, although the distinctions between different types of flight testing are often blurry.

Operational Test and Evaluation (OT&E)

… test and evaluation conducted to establish a systems operational effectiveness and *operational suitability*, identify needed modifications, and provide information on tactics, doctrine, organization, and personnel requirements.

Flight Testing Culture:
Involves closely integrated interdisciplinary teams containing pilots, technicians, engineers and managers.

Flight testing is inherently dangerous. Safety is paramount. People get killed when individuals loose sight of this.

Mr. Ken Szolai, former director of the NASA Dryden Flight Research Center says "We expect to make smoking holes in the desert."

"Since risk in flight testing can never be eliminated, we are in the business of managing risk."

"The desert at Edwards Air Force Base saves one life per year."

Murphy's law applies. Captain Edward Murphy, Jr. proclaimed the original version of the famous maxim: "If there are two or more ways to do something and one of those results in a catastrophe, then someone will do it that way."

Practical, real-world problems are addressed. The phenomena must be testable.

The approach is experimental.

- Ask a scientific question about an aircraft or system.
- Design an experiment including necessary instrumentation.
- Conduct flight tests in order to make scientific measurements so as to reveal the properties of the aircraft or system.
- Analyze the measurements and draw scientific conclusions about the tests.
- Document the process and results.

Arrogance is fatal. [arrogant. 1.overly convinced of one's own importance; overbearingly proud; haughty. 2.characterized by or arising from haughty self-importance.]

Cockiness is OK. [cocky, self-assertive or self-confident; conceited.]

Careful planning and execution are required.

The Role of Flight Research

Extracted from *Flights of Discovery, 50 YEARS AT THE NASA DRYDEN FLIGHT RESEARCH CENTER* by Lane E. Wallace, The NASA History Series, NASA SP-4309, National Aeronautics and Space Administration, NASA History Office. Washington, D.C. 1996

It was not only the lack of ground facilities that provided the justification for exploring ideas in flight, however. The importance of trying out new concepts and designs in flyable aircraft was understood even by Wilbur Wright, who in 1901 argued that "if you are looking for perfect safety you will do well to sit on a fence and watch the birds, but if you really wish to learn you must mount a machine and become acquainted with its tricks by actual trial."

The NACA shared Wright's belief, and flight research has always played a critical role in the work of both the NACA and its successor agency, NASA. By the mid-1960s, ground facilities were much more capable than they had been in the days of Wilbur Wright or the X- 1, but NASA administrator James E. Webb still considered flight research a critical activity. In 1967 he testified before Congress that

> Flight testing of new concepts, designs, and systems is fundamental to aeronautics. Laboratory data alone, and theories based on these data, cannot give all the important answers.... Each time a new aircraft flies, a "moment of truth" arrives for the designer as he discovers whether a group of individually satisfactory elements add together to make a satisfactory whole or whether their unexpected interactions result in a major deficiency. Flight research plays the essential role in assuring that all the elements of an aircraft can be integrated into a satisfactory system.

That argument still holds true today. No matter how sophisticated laboratory technology becomes, computers can only simulate what is known. The unknown is always, in a sense, unpredictable. A computer can extrapolate what *should* happen as a logical extension of what has happened up to that point, but the outcome cannot be assured until it is tested in realistic conditions, flight research is where that testing occurs. It is that unique point where the rubber meets the road, where the aircraft, human, and real-life flight conditions come together for the first time. And because flight research explores that ragged edge between the known and the unknown, it is a place where discovery happens.

Discovery is that moment of divergence where something other than what was expected occurs. Indeed, researchers say a discovery is marked less often by a shout of 'Eureka!" than by a perplexed murmur of "That's odd …" And for all the improvements in ground and laboratory facilities, there has yet to be a flight research project conducted at Dryden that did not have at least one such moment. Sometimes, the discovery shows only that the computational codes used to predict the performance of the aircraft need to be adjusted. Other times it turns the research in an entirely different direction, opening up a whole new set of questions from those envisioned at the start of the project.

In either case, it is these discoveries that slowly expand our understanding of the world of aeronautics. And it is the pursuit of these discoveries that differentiates flight research from the closely related discipline of flight test.

The Air Force Flight Test Center (AFFTC) is situated just a short hike down the flightline from the Dryden Right Research Center at what is now Edwards Air Force Base. The flightlines of both centers display an impressive array of high performance aircraft and, to a casual observer, there might seem little difference in the work the two facilities do. Both centers employ highly skilled pilots who fly new and experimental aircraft configurations to precise test points. In both cases, data from those maneuvers is collected by various types of instrumentation and recorded or sent back to the ground, where it is processed by engineers, technicians and analysts.

The difference between flight test and flight research lies not in the mechanics of each operation, but in the questions that drive the work and how unexpected discoveries are viewed. In flight test, the objective is to compare the airplane's performance against set specifications it is supposed to meet. The idea is not to explore new realms of aeronautical knowledge, but simply to make sure that a new aircraft design or configuration performs in an acceptable manner. Unless the anomaly is better-than-predicted performance, unexpected results in a flight test program indicate problems that need to be fixed. The information gained through flight test is also directed toward a specific customer with regard to a specific product.

Flight research, on the other hand, gathers information that can be used by a much wider audience for a wide variety of applications. In addition, flight research involves much broader questions. The objective is not simply to determine if an airplane performs in a certain way, but to understand why it does and to explore various factors that affect that performance. Discoveries are not problems to be fixed but doors opening into new realms of possibility. They give researchers a glimpse into the world beyond what we know, raise new questions and often lead to entirely new lines of research.

Discovery can and does happen in all types of research settings. But the potential for discovery is particularly great in flight research because it is an arena where so many variables and unknowns come together. For all of our technological advances, there is still much we do not understand.

Supersonic aircraft, for example, have been flying since the late 1940s. Yet although aeronautical engineers have learned how to design aircraft that can function in the supersonic realm, even researchers do not fully understand the dynamics of that environment. As Marta Bohn-Meyer, project manager of Dryden's supersonic laminar flow research program, says, "The more we get into this, the more I realize how little we really know about what happens in the transonic and supersonic regions."

The problems have also become more complex. In 1946, researchers were simply trying to see if it was possible for an aircraft to surpass the speed of sound. Today, the goals are broader. We want not just supersonic aircraft, but efficient, environment-sensitive supersonic aircraft, or highly maneuverable supersonic aircraft. So despite all the advances in aeronautics, flight research is still operating at the cutting edge of knowledge.

Even elements that are understood individually may interact in an unexpected manner when they are brought together in a realistic flight environment. This is especially true for any aircraft that requires a human pilot. Time after time, for example, computerized flight control systems for aircraft have been tested successfully in simulators, only to exhibit different tendencies in actual flight. One reason for this is that simulators rely on predicted data to model a new aircraft or system's performance. But another cause is the simple fact that pilots react differently in simulators, where even the worst mistake will cause them only embarrassment, than in an aircraft where the stakes are very real and very high. Yet if the end goal of aeronautical research is to improve the design of practical, flyable aircraft, it is essential to explore those reactions and discover potential problems with configurations or technology.

Indeed, another important function of flight research is that it forces researchers to focus on those particular problems that are truly critical to developing usable technology. Many interesting questions can arise in the course of laboratory and ground research. But putting a piece of technology on a flyable aircraft quickly differentiates those questions that are low-priority curiosities from those that suggest critical issues to address. Furthermore, a problem identified as critical cannot simply be put aside to be studied later. It has to be solved. In part because so many operational problems have to be addressed and solved before a concept can be tried on an aircraft, flight research can also play an important role in winning industry's acceptance for new technology. Technology that has been explored in flight is generally more mature than concepts investigated only in laboratory or simulator settings, leaving a smaller gap for industry to bridge in order to incorporate it into commercial products.

> Furthermore, there is a measure of credibility that can be achieved, almost instantaneously, from a successful demonstration of a technology on an actual aircraft in realistic flight conditions. As a former vice president of engineering at the Boeing Commercial Airplane Company argued, "laboratory development has great appeal and usually gets substantial government support. However... the attainment of credibility is [also] an important national issue. It is during this second phase that a technical concept achieves a state of readiness, validation and credibility such that private industry and financing can assume the attendant risks."

In some cases, laboratory research is sufficient for industry to see the benefits of a concept and invest in it. But especially as technology becomes more complex and expensive, making a commitment to a new technology is an increasingly difficult and risky gamble for industry to make. An idea that has been proven successful in realistic flight conditions is much more convincing, because while it might still be uneconomical or impractical, industry decision-makers at least know it can work.

Giving aerospace manufacturers the confidence to invest in new technology can, in turn, increase their global competitiveness. This has important implications, because aerospace is one of the few remaining fields in which the United States still has a trade surplus. If the country is to improve its balance of trade and overall economy, the aerospace industry must remain competitive.

Homework Policy

1. Homework is collected, graded, and returned.
2. NO LATE HOMEWORK IS ACCEPTED (unless your excuse makes me laugh or cry).
3. Cooperation on homework can be helpful in learning. Copying someone's homework will not be tolerated.
4. In reading assignments you are responsible for all material whether it is covered in class or not.
5. Homework Format:
   a. Staple multiple pages together.
   b. Every answer must contain physical units. (e.g. feet, seconds, slugs, etc.)
   c. All answers and physical units must be enclosed in a box.
   d. Answers should generally contain three significant digits (i.e. 2.15, 3.24×10^{-4}).
   e. Do not hand in a paper pulled from a spiral binder.
   f. Sketches defining coordinate directions, axis system, etc. are almost always required.

NOTES ON NOTE TAKING

1. Date all notes. This indicates the start and end of a lecture for comparison with other notes.
2. Copy everything written on board.
3. Learn to take notes verbally without waiting for the notes to be written by the professor.
4. Take notes on material not written on the board as well. At least jot down key ideas. Fill in the explanation at home.
5. Review, correct and *copy over* all notes shortly after class. Use the text to help. Any questions which result should be resolved. After this process the copied over notes should contain no errors and you should understand them thoroughly. Notes should be as thorough as a book.

Remarks

Step 5 is important if the class is being taught without a textbook.

My Responsibilities in this Course

1. Facilitate your learning the material of this course.

2. Help you develop into mature, confident, competent, ethical engineers and citizens. This involves material not found in the book or course description.

3. Evaluate your level of skill (assign a grade to your work).

Your responsibilities

1. Learn the material in this course.

2. Conduct yourself in an ethical manner regarding homework and tests and your relationships with colleagues and Purdue University.

3. Achieve the level of skill you are capable of.

4. Learn to speak and write effectively.

5. Survive till tomorrow.

Necessary Student Skills

1. Note taking from lectures.

2. Note taking from book.

3. Time management skills including regular reading, regular homework, and regular review of notes.

4. Learn to perform well in time restricted situations, e.g., quizzes and tests.