AC 2011-132: DEVELOPMENT OF AN ADVANCED EXPERIMENTAL AERODYNAMICS COURSE FOR UNDERGRADUATES

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Development of AE411: Advanced Experimental Aerodynamics

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Abstract

The development of an undergraduate advanced experimental aerodynamics course is discussed in this article. The aim of the course is to allow an easier transition to graduate level research through development of problem solving skills as well as exposure to the research process. The course comprises a mixture of applied theoretical and hands on project based learning. The theory component is modular, with coverage of topics supportive of the assigned projects. Use of numerical tools for airfoil and aircraft analysis is required, as is proficiency in LabView for data acquisition. Projects are performed in groups. Students generally conduct two projects. One is equipment based, where students become proficient in a particular technique or may develop equipment and software that may support their research, or be stand alone. Examples include design and manufacture of a water tunnel as well as a 3-component platform balance with associated LabView software. Research topics are typically assigned, but may be student initiated if of manageable scope. Projects have been broad in scope, ranging from transition control to morphable aircraft geometries. This article describes the approach, its successes as well as pitfalls.

1. Introduction

Most aerospace focused curricula contain at least one course devoted to experimental methods, typically with an aerodynamics focus. Subsequent experimental courses may entail introduction to instrumentation or structural analysis. However, common to these courses is the nature of the student exposure. Most experiments are "canned". The students perform a set experiment which has a well documented outcome. As such, the students are "passengers" in the educational experience, as the path and eventual outcome is pre-determined. This is not intended as a criticism; in many instances this is the first student exposure to experimental or "hands-on" learning. However, within the framework of experimental methods, the solution to open ended design style problems can yield significant benefits to undergraduate students, exposing them to many issues/complexities inherent in research, but still within the confines of a semi-structured course. An approach that incorporates research within the framework of an experimental aerodynamics curriculum is presented in Ref. [1]. An iterative formulation was used to develop the program as well as supporting classes.

Consequently, AE 411 was created as a technical elective to give undergraduate students the opportunity to experience the gamete of issues commonly seen in an open ended problem; clear identification of the problem, potential methods of solution, selection and implementation of a solution method and evaluation of results. The problem could range from the design of equipment to investigating an aerodynamic device, etc. Additionally, the use of numerical methods for experimental validation was also emphasized, where applicable. AE 411 was developed as a project based follow on to AE 314/315; the introductory experimental aerodynamics laboratory course offered at Embry Riddle Aeronautical University – Prescott campus. It is envisaged that the course design presented may be suitable for project orientated experimental courses with flexible learning outcomes.

II. Course description

The course consists of two 1 hour lecture periods per week and a 2½ hour laboratory. Formal lecture based instruction typically constituted one of the lecture periods per week. At the time of writing, this course has been offered twice. Typical enrollment is approximately 10 to 14 students. To provide students with sufficient skills to conduct their projects, core topics were covered in formalized lectures and assignments conducted towards the beginning of the semester. Topics covered included:

- Familiarity with NI LabView (implemented during the laboratory period)
    - Taught in four lectures with an application orientation.
    - Students learned LabView by writing an acquisition code for an ATI 6-component platform type balance.
    - Teaching approach was minimalistic such that students would need to explore the numerous menu options to find suitable VIs to perform a desired task. Note that a suggested approach to implementing the VI(s) was presented. Students worked individually.
- Familiarity with numerical aerodynamic prediction tools, exemplified by Xfoil [2] and AVL [3] (implemented during the laboratory period)
    - Two codes taught as a unit.
    - Students created an AVL “model” (Fig. 1) of an existing generic wind tunnel aircraft model, with airfoil sectional properties determined using Xfoil.
    - Students wind tunnel tested the model and contrasted the results with the predictions (conducted during the laboratory period).
    - Model also allowed breakdown analysis such that the aerodynamic impact of the components could be established.
    - A report was presented on their findings.

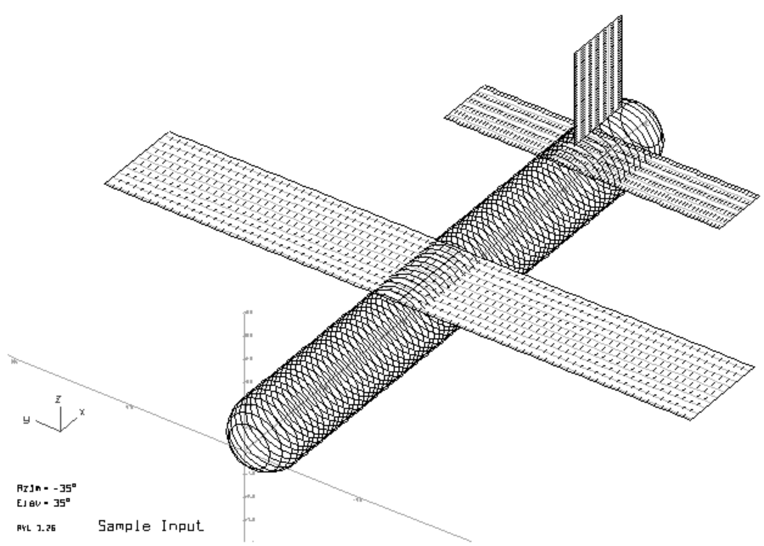

Fig. 1 AVL model representation

The following were covered during the formal lecture period:

- Application of wall corrections
- Drag extrapolation to higher Re numbers

- Incorporation of profile drag into finite wing drag estimates
- Wind tunnel test planning and procedures
- Application of trip strips
- Time series analysis
- Hot wire anemometry
- Non-intrusive lift and drag measurement

The second lecture period was commonly used for student recitation. This required the students to conduct literature surveys on their selected research topic culminating in class presentations on their findings. This confined students to a fixed time line and also exposed all students in the class to the breath of the research projects, often yielding cross-pollination of ideas as well as being an effective tool to motivate.

The laboratory component of the course consisted of two assignments/projects per group. The first project was essentially equipment based, where the group (typically 3 students) would implement or develop an item or implementation software. The second project could be coupled, and was research based. Most of the student effort was outside of the formal laboratory hours. The initiation of a project would entail discussion between the group and the instructor as to scope, focus, method of implementation and desired outcomes, with the instructor providing guidance to maximize the likelihood of success. However, the students were ultimately responsible for the method of implementation and the outcomes.

Equipment Laboratories

The following is a partial list of implemented projects.

1. Design and manufacture of a 5" by 12" water tunnel. (completed in 1 semester), see Fig. 2.
    - The students were asked to design a water tunnel facility and then manufacture it.
    - After initial surveys, the students opted for a design that was similar to those existent [4]. They felt that considering their time line, designing the tunnel from scratch would have greatly increased the likely hood of failure.
    - Cost analysis suggested that the tunnel could be made most economically from acrylic sheet.
    - They built a series of ribs and used them to stake out the tunnel profile.
    - The acrylic was formed using heat guns to allow small radius curvature.
    - The junction of the sides and floor was sealed with epoxy and then clear caulk.
    - Testing showed the tunnel leaked from the base/side joint. Attempts to fix this were unsuccessful.
    - The students then coated the tunnel with E glass. This rendered the tunnel waterproof.
    - All manufacture was performed by the students, as well as motor, pump and frequency drive specification. Their manufacturing skills were greatly augmented as was their realization of the impact of building items to a cost point.

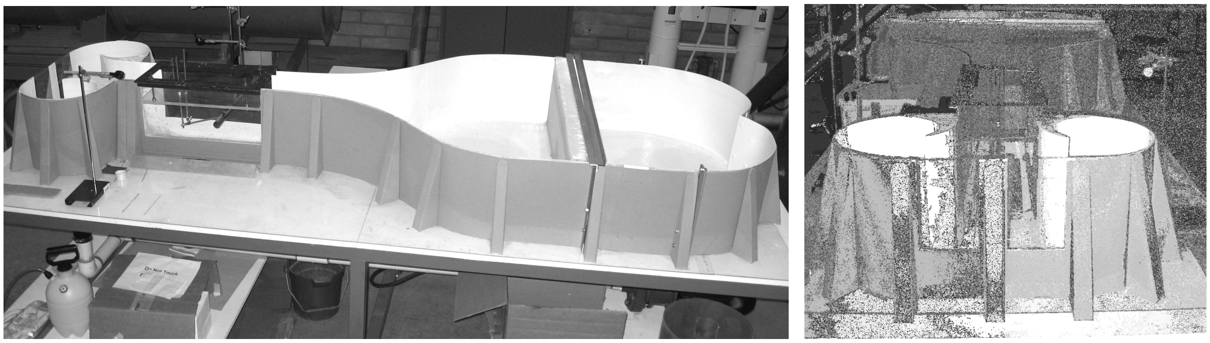

Fig. 2 5” by 12” water tunnel

2. Design of a low range platform balance. (completed in 1 semester), Fig. 3.
    - The students designed a three component low range balance from scratch.
    - They designed the flexures, as well as selected the load cells [5].
    - The pitch mechanism is stepper motor controlled, but was also designed such the stepper motor can be disengaged, leaving a free to pitch mount that still relays load data.
    - All manufacturing was performed by the students.
    - The final balance has demonstrated research capability with negligible hysterisis and repeatability of 0.01N (range is 45N).
    - Students gained valuable exposure in mechanical design.
    - Impact of imprecise machining was learned as well as poor design. Final balance required remanufacture of approximately one third of the components, while the load cell mounting brackets also required redesign.

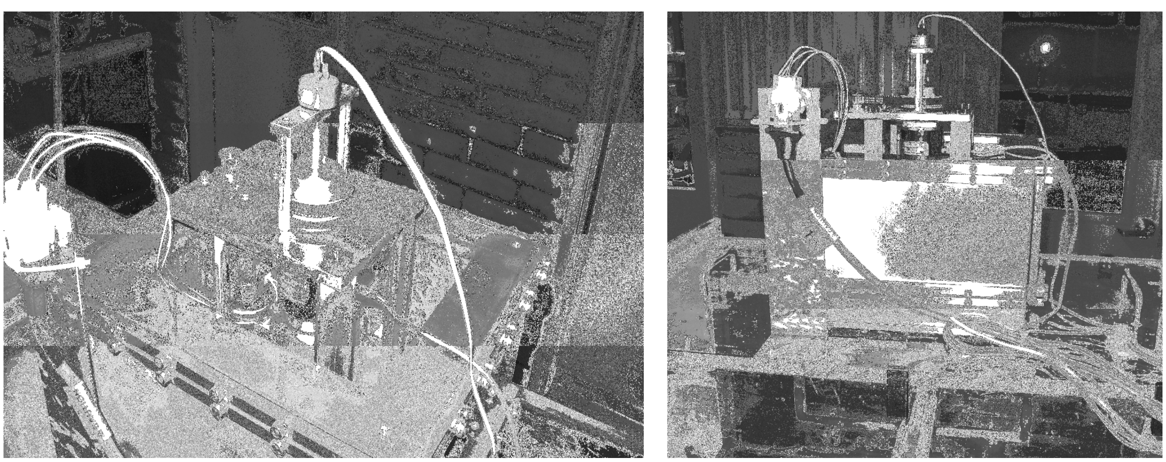

Fig. 3 Low range platform balance

3. LabView code generation to perform drag measurement through wake velocity deficit measurement
    - Students wrote a LabView VI to acquire data from a pressure scanner connected to a rake wake. This allowed real time determination of the instantaneous wake velocity profile as well as profile integration to yield drag estimates.
    - Implementation greatly improved the students LabView coding skills.

4. Dynamic stall test rig
   - Students designed and manufactured a sinusoidal pitch facility for airfoils.
   - Models would be pressure tapped and scanned to measure loads.
   - Two airfoils were manufactured; a S809 (wind turbine section) and a NACA0012.
   - Project was overly ambitious for the allotted time and was incomplete at the semester's end.
   - Most issues were traced to quality of manufacture. All components were manufactured by the students, however accuracy was lacking such that misalignment (and misfit) of parts, etc led to failure.
   - Facility was subsequently completed by a student as an independent research project.

Research Projects
The following is a partial list of projects

1. Development of a variable camber wing.
   - Students attempted to design a wing that could be systematically warped to provide twist or localized variable camber. This approach is currently pursued in the community [6,7].
   - Wing skin was made from carbon fiber with thin cable actuators.
   - Project ultimately did not succeed due to significant group discord and potentially ambitious scope for the allotted time.

2. Optimization of passive vortex generators
   - Students investigated vortex generator design methodology.
   - Subsequently they designed a wing with various generator geometries and layouts.
   - Wind tunnel testing indicated deleterious effects generally, and in certain instances no effect.
   - Surface visualization indicated that student selected airfoil was potentially ill-suited as a large laminar bubble was located over the primary regions where the vortex generators were applied, limiting their effectiveness.

3. Design of a variable transition location system
   - Student analysis using Xfoil indicated that significant improvements in aerodynamic performance could be realized at low Re numbers if the location of boundary layer transition could be controlled.
   - Students implemented a variable transition system using an Eppler airfoil section that was rapid prototyped.
   - Their approach used a multi chamber wing with spanwise rows of holes, see Fig. 4.

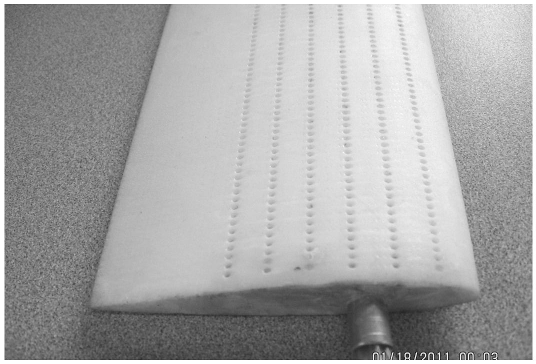

Fig. 4 Multi chamber wing without latex skin.

- Wing was covered with a thin “skin” of latex rubber. Localized spanwise dimples or indentions were created by applying suction or pressure to the desired plenum. Simulated an epoxy dot style trip strip.
- Difficulties were encountered in successfully adhering the latex to the rapid prototyped wing surface. This negated attempts to pressurize the plenums.
- While suction was successful, the indentions created were not effective at promoting transition.

4. Design of a reconfigurable monoplane/biplane and bounding flight demonstrator, see Fig. 5

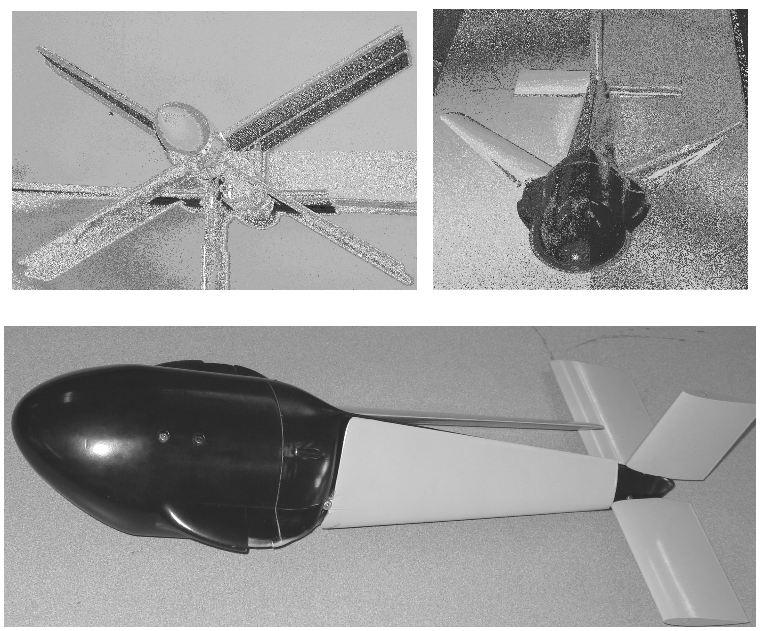

Fig. 5 X-wing and reconfigurable model

- Students developed a series of wind tunnel models to explore the aerodynamic effectiveness of a flight vehicle that could “morph” from a monoplane to X-wing geometry biplane.
- A second group designed a flight vehicle capable of sweeping the wings conformaly with the body such that the model could simulate “bounding flight” in birds.
- Students designed and constructed all models and successfully tested them [8].

- Project was successful with students continuing the research after the course completed.

III. Analysis

A review of the projects cited above reveals interesting trends. The equipment based projects were generally successful; while the research focused projects were not. This is in stark contrast to similar research based design projects in AE 315, the introductory experimental aerodynamics class. Contrasting the two indicates the most significant difference is the level of instructor involvement in the mechanical design process of the models and system, as well as their prior exposure to the model manufacturing technique. It would thus appear that many of the students in AE 411 have not yet gained sufficient skills for semi-autonomous investigation. However, when the research projects were derivative of student exposure in AE 315, they were successful. This is clearly indicative of a focused learning curve.

Following the completion of this class, many of the students continued on as research students. In contrast, the same students proved highly effective with a much higher success rate with their designated projects, despite a similar level of autonomy. It would thus appear that the lessons learned in AE 411 were valuable and ultimately led to the students becoming successful undergraduate researchers. The failures in AE 411 projects led to a significant increase in problem solving ability of these students, as well as perseverance.

IV. Conclusions

The development of a follow on course to the introductory experimental aerodynamics course offered at Embry Riddle Aeronautical University – Prescott campus is described. The course structure is detailed. Overall, the performance of students indicates that the course serves as a semester long learning curve, enabling the students to ultimately perform research semi-autonomously, although this ability was generally only realized after course completion.

V. References

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Author Biography

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