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## **AC 2011-2656: EXTROVERT: HELPING AES DEVELOP ADVANCED CONCEPTS**

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Dolores Krausche came to academe with an experiential background in research and development in the areas of military engineering and astrophysics. For more than fifteen years she worked with such organizations as the Naval Coastal Systems Center, David W. Taylor Naval Ship and Development Center, Eglin Air Force Base, Bell Aerospace Textron, and EDS, among others.

She served as the principal investigator and test director for infrared detectability assessments for the U. S. Navy's Amphibious Assault Landing Craft Program, as editor for operations manuals for the Navy's Special Warfare submarine delivery vehicles, and as associate program director for projects in electronic countermeasures and radar detection of submarine towed arrays. Her graduate studies in the area of high-resolution spectral analyses of Jovian decametric radiation, leading to a Ph.D. from the University of Florida, also included extensive field work in the installation and operation of observing stations in Florida and Chile.

Her collaborations with the faculty of the Department of Mechanical and Aerospace Engineering at the University of Florida led to an appointment as the Administrator for Undergraduate Programs in 1990. There she served on numerous department, college, and university-wide curriculum committees, including the University Senate, while also participating as co-principal investigator to develop and implement programs in process engineering for the National Science Foundation's SUCCEED Coalition.

In the last several years, she established the Florida Center for Engineering Education, a consulting group dedicated to support curricular development, program assessment for accreditation and university-industry collaboration. Through workshop sessions and mentoring, faculty are guided through the assessment process to meet program educational objectives and achieve best practices following ABET's Engineering Criteria 2000.

As a consultant, she has contributed to the University of Florida's MAE program by conducting numerous assessments and comparative gap analyses, based on the Department's database as well as ratings and data from the "US News & World Report," American Society for Engineering Education and the Aerospace Department Chair's Association. She has also conducted a faculty mentoring program with the objectives of supporting and validating an instructor's effort to enhance teaching methods.

She has participated in the ASEE activities since the early nineties, chairing numerous technical sessions - concerned with issues in accreditation and design - while advancing through the succession of offices from Program Chair to Chair of the Aerospace Engineering Division in 2000. In 2002, she received the Division's Distinguished Service Award. As a member of AIAA, she chaired technical sessions and served on the General Committee, which organized the jointly sponsored AIAA/SAE World Aviation Congress in 1999. She currently serves on AIAA's Aircraft Design Technical Committee, Student and Technical Activities Committees as liaison, the Academic Affairs Committee as the 2009-2011 Education Program Chair and as a Program Evaluator for ABET accreditation.

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# **Extrovert: Helping Aerospace Engineers Develop Advanced Concepts**

## **ABSTRACT**

The EXTROVERT project builds resources to enable engineers to solve problems cutting across disciplines. The approach is to enable learners to gain confidence with the process of solving problems, starting with their own preferred learning styles as far as possible. Ideas being implemented include a design-centered portal to aerospace engineering, vertical streams of technical content, learning assignments using case studies, a library of solved problems accessible from course content, and integrative concept modules. The project experiments with assessment strategies to measure learning in time to improve it. An introductory paper presented last year laid out the issues and built the concepts for dealing with them, summarizing the first year's progress. In this paper, we present second year experience, with formative and summative assessments from actual classroom and project use of the resources. A library of solved problems has been used in undergraduate courses at the sophomore and junior/senior levels, and will be again used in undergraduate courses, as well as expanded for application in graduate classes in the current semester, with assessment reported in the paper. Advanced concept development experience on several projects is included in the new experience base. Thus learning in both depth and breadth paradigms is being addressed.

## **INTRODUCTION**

This paper reports progress on building resources to help Aerospace engineers innovate solutions that draw on many disciplines. The need for such resources has been recognized at various levels [1-5]. The approach taken in the project is to enable learners to gain confidence with the process of solving problems, starting with their own preferred learning styles and areas of comfort as far as possible. Well-grounded in depth in their home disciplines, they can then venture into other fields, and apply similar learning strategies, finding and filtering appropriate knowledge to apply.

Reference [6] laid out the issues and the concepts for dealing with them, summarizing the overall structure of the project and the first year's progress. The ideas being implemented include a design-centered portal to aerospace engineering, vertical streams of technical content, learning assignments using case studies, a library of solved problems accessible from course content, and integrative concept modules. The project experiments with formative assessment strategies to measure learning in time to improve it, and summative assessment to refine perspectives of entire fields and their subsections. Ref. [7] presented the experience with the case study approach in junior level courses, and [8] with advanced concept development tying depth in one discipline through conceptual design, to demographic and public policy issues. The present paper goes on to briefly list second-year progress in aerospace problems. The paper then lays out initial data on how present-day aerospace engineering students learn, and how they are responding to formative and summative assessment. These reports serve both to establish a baseline, and to guide development over the next year.

## LEARNING RESOURCES

Figure 1 shows the project structure. The core content is distilled into vertical streams from course notes in specific disciplines. The aerodynamics vertical stream now goes from the introductory freshman (high-school) level all the way to the PhD qualifying examination level and the research leading edge. This is one spar of the aerospace knowledge structure, branching off into various disciplines such as Vehicle Performance and Propulsion, tied by their common use of fluid dynamics concepts through aerodynamics. The main spar is aerodynamics rather than fluid mechanics, because the emphasis is on engineering innovation rather than basic science knowledge. Another vertical stream goes from basic thermodynamics through undergraduate-level propulsion to combustion concepts, rocket propulsion, and on to advanced space propulsion science and engineering. The vertical track in structures and aeroelasticity includes an advanced knowledge base in composite structures, structural dynamics and aeroelasticity in addition to basic statics and dynamics. Three methods tie disciplines together:

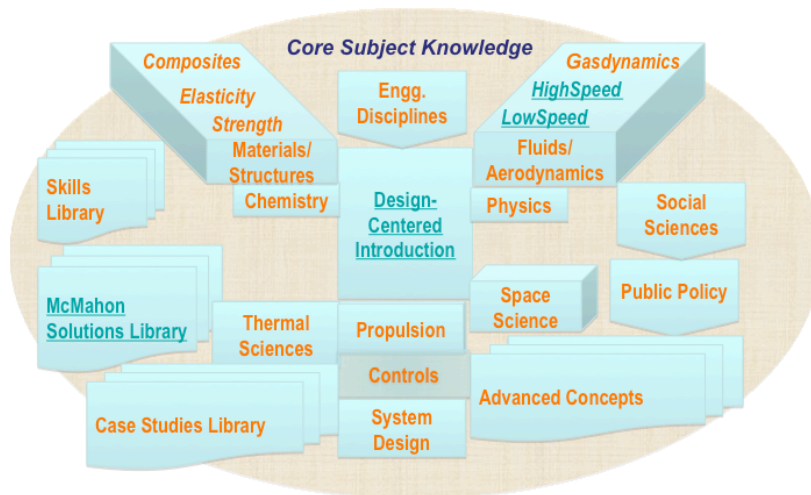


Figure 1: Organization of the EXTROVERT learning resources

1. Providing a portal, set in Conceptual Design of flight vehicles. This proceeds from defining requirements to closing the design by validating the flight envelope and range of a vehicle. It also shows the learner just enough flavor of each discipline to see how their role design.
2. The process of going through the design portal also shows the role of benchmarking by locating and

assessing knowledge from across the spectrum of disciplines. Thus learners are now able to find course materials not only from our websites, but from institutions all over the world. This in turn addresses a large part of the ‘learning styles’ mismatch between the particular approach of each instructor, and the differing needs of different students [9].

3. A growing set of Concept Essays (CEs) or Concept Modules (CMs) capture the essence of specific concepts in a concise yet practically useful manner, and bring together the applications of each concept from wherever it is used. The CE refers to a more descriptive and definitive essay whereas the CM delves more into engineering tools.

### How Learners Interact with the Resources

While our own training limits us to our discipline zones of “comfort”, we hope that new learners, will use these resources to solve problems in areas where they must start as novices yet move to leading edge application rapidly. Three types of interactions are implemented at present.

1. The condensed course material is placed on the web resources and presented in class.

2. Learners are guided by the instructor (in classes) or navigate the web portal (as independent learners) to the Solved Problems library as part of their formative assessment or preparation for tests.
3. Surveys provided through the web-based anonymous survey site, tied to individual modules of subjects, induce learners to think deeply about the material in each module. In the long term, we expect that professionals will do this on their own in an iterative manner. In the short term, the instructor might point out that while survey participation is entirely voluntary, there is no law prohibiting the use of questions on the survey in tests.

### **Course experience: introduction to aerospace engineering**

The design-centered introduction (DCI) course is offered at the level of the first-semester college freshman. It is therefore set at the graduating high school senior level, accessible to all who have taken some SMET courses in high school. Experience in developing this course and its success, have been documented in ASEE papers since 1998. We now have course presentations from several other instructors available with varying emphases and styles. The DCI form was last taught in Spring 2009, when students went through the exercise of concept design applied to a short-haul airliner, and then demonstrated their comfort with the iterative nature of design by rapidly changing the design to one fueled with liquid hydrogen. They brought in the carbon cost aspects of public policy issues to point to the source of development funds to advance liquid hydrogen as an aircraft fuel. Interestingly, the Senior Capstone Design in Fall 2009 also took up the challenge of a short-haul airliner. The point to note is that freshmen were more than able to complete a full cycle of conceptual design inside 6 weeks, then show the effects of the Learning Curve, in converting the entire design to a hydrogen-fueled craft (a huge change in all vehicle parameters except payload) within the last 2 weeks of the semester, and do some market calculations where societal issues were used to assess a market opportunity. Existing web-based course resources, now at the core of EXTROVERT, were extensively used.

### **Course experience: low speed aerodynamics**

The new resources were intensively used in the sophomore-level introduction to aerodynamics. This course reiterated the sections on atmospheric chemistry and physics, aerodynamics and vehicle performance used in the DCI, and went on to fluid mechanics, the conservation equation approach to tie engineering fluid mechanics analyses to the laws of physics, and to the potential and vortex methods used in low speed airfoil and wing aerodynamics, ending with a section on viscous flow and boundary layers applied to pipes, plates and airfoils. Most of the students responded extremely well to the new resources and technologies. The crowded classroom at 2-3pm seemed a recipe for a somnolent nightmare. However, the class was usually animated, with many questions, quite a bit of laughter and an intensive level of effort from many students. Formative assessment results are presented in this paper.

### **Course experience: high speed aerodynamics**

The new capabilities for vertical integration and concept exploration were brought back into the junior/senior level course in high speed aerodynamics in Fall 2010. This course is the last in the fluid mechanics/aerodynamics area for most aerospace undergraduates. It is a co-requisite for students taking fixed wing and rotary wing aerodynamic capstone design tracks, but not for those taking the space system design track. Many students take it after vehicle performance and jet propulsion courses. Thus one might expect them to be quite ready to move on to high speed

aerodynamics. However, optimism regarding student preparation persists only unless and until it is tested. The students were provided with extensive problem-solving and formative assessment preparation support through the institution's password-controlled, course-specific "T-Square" website, and through the EXTROVERT site and its McMahon Solutions Library. Student references to instructor-supplied sample tests in the assessment data that follow, indicate deep faith in such resources. The summative evaluations at the end of the semester were mixed. Several students were simply not prepared to respond, with predictable results in their grades. The point to note is what was happening at the other end of the performance spectrum: Several students were simply performing at what must be considered world-class levels. Throughout the course, tests were assigned with 20% more opportunity for credit than what could be reasonably expected for a score of 100. The best students had averages above 100, and were exempted from the final examination.

The key integrative assignment in this course took a technical paper published by an undergraduate student team in the summer of 2010 [10], and asked students to work in teams of two each, refining the calculations and improving the conceptual design in the paper if possible. The experience is discussed in a companion paper in this conference [11]. A surprising number of students across levels of performance showed the willingness to go and find technical papers, and use them to argue certain points in their reports. Thus one major assumption in developing cross disciplinary resources is seen to be well-founded: students do show a substantially increased willingness to explore outside the confines of their course, when given encouragement and exemplary precedent, in this case the experience of their contemporaries who co-authored the paper. Clearly, a key institutional objective in using instructional technology was achieved as well: the top performers did far better than prior generations were able to do.

### **Course experience: graduate high speed aerodynamics**

In Spring 2010, the graduate high speed aerodynamics class was given access to the McMahon Solutions library and the undergraduate vertical content stream. With these resources and a 2-week lecture summary of undergraduate aerodynamics, graduate students were expected to move on and use these methods and skills in solving problems. The course assignments included assessing hypersonic and transonic performance of some recent NASA/DARPA X-vehicles. Again, the availability of these resources correlated with a large spread in performance, both through the course and in the final assignment and final examination. Some students excelled. One innovation combined a MATLAB function with some concepts from finite difference computational fluid dynamics to develop a convenient method to analyze hypersonic aerodynamic loads on X-vehicle configurations. At the other end, some students simply did not try using the new resources, nor were they willing to use the traditionally rigorous books and papers for which the new resources might have provided convenient alternatives. In Spring 2011, the Surveys were used to good effect to induce deeper thinking at the start of the course, and to demand student attention to the assumed pre-requisites. After a couple of borderline-traumatic attention-getting quizzes, the level of student questions in that 8AM class has risen, at this writing, to keep the instructor wide awake and thinking hard.

### **Course experience: Aeroelasticity**

Undergraduate student lore cites senior-level aeroelasticity as one of the toughest courses in the curriculum. This course requires that students assimilate three different subdiscipline areas (fluid

mechanics, structural mechanics and controls), along with rigorous mathematical application. A common thread in student commentary is the need to recall information that was last studied two or three years ago. The CM approach has been utilized to provide concise introduction of specific technical material with links to applicable topics in the different discipline areas. This is augmented by worked problems that illustrate the mathematical principles necessary to resolve engineering problems of interest. Finally, structural dynamic and aeroelastic cases from current and historic applications (e.g., Tacoma Narrows Bridge, wind tunnel model failures) provide feedback on the importance of the topic. In prior semesters, data have been gathered to identify the weak points of student understanding of this material.

## ASSESSMENT

The following assessment results have been obtained:

1. Formative assessment and evaluation results from undergraduate courses at the freshman, sophomore, junior/senior levels in introduction to aerospace engineering, statics, dynamics, vehicle performance, aeroelasticity and high speed aerodynamics, with graduate course experience in the last two named areas.
2. An independent survey site (<http://www.surveymonkey.com>). This was part of the proposed assessment procedures, cleared through the Institutional Review Board.
3. The experience of student learning styles and preferences came through discussion fora set up in course management websites. Only general information can be provided from these.
4. An initial learning styles survey of students in different courses. The responses are analyzed below; no identifying information was sought.
5. Associated with each major course module in two courses, formative surveys were set up. Being technical in nature, students had somewhat strong motivation to answer these.

### Learning styles

The issue is “How do students in the year 2010 learn?” posed through several questions:

*Question 1: What types of resources are you most likely to FIRST TRY, when you are trying to learn a subject (for instance, as you prepare to do an assignment for an engineering class?)*

| Answer Options  | Response Percent |
|---|------------------|
| Read the notes  | 73.9%            |
| Work through the derivations  | 17.4%            |
| Solve the problems in the assignment before looking anywhere              | 17.4%            |
| Look for worked examples in the book or on the internet                   | 73.9%            |
| Talk to someone who might be able to help                                 | 30.4%            |
| Read a textbook   | 56.5%            |
| Look on the internet using a Search Engine                                | 26.1%            |
| Look for internet pages posted by other instructors or other universities | 26.1%            |
| Try to get some estimates of numbers on the magnitudes of quantities.     | 0.0%             |

*Question 2. What types of resources are you likely to eventually use, when you are trying to learn a subject?*

| Answer Options | Not likely | Some times | Often | Most probably |
|----------------|------------|------------|-------|---------------|
|                |            |            |       |               |

|  | %         | %         | %         | %         |
|--|-----------|-----------|-----------|-----------|
| 1. Read the notes  | 9         | 0         | 17        | <b>74</b> |
| 2. Work through the derivations  | <b>30</b> | <b>35</b> | 26        | <b>9</b>  |
| 3. First try to solve the problems in the assignment                     | 9         | 30        | 30        | 30        |
| 4. Look for worked examples in the book or internet                      | 0         | 22        | 30        | <b>48</b> |
| 5. Talk to someone who might be able to help                             | 4         | 39        | 39        | 17        |
| 6. Read a textbook   | 4         | 13        | 65        | 17        |
| 7. Look on the internet using a Search Engine                            | 0         | 35        | 9         | 6         |
| 8. Look for internet pages posted by instructors from other universities | 17        | 35        | <b>26</b> | <b>22</b> |
| 9. Try to get some estimates of numbers on the magnitudes of quantities. | <b>35</b> | <b>43</b> | 17        | <b>4</b>  |

#### *Other freeform responses*

1. "I work an easier problem, that I do know how to solve, to help me solve the more difficult ones assigned."
2. "Worked examples really are the best"

#### **Introduction to Fluid Mechanics**

1. *Please think how you learned this section. What did you find to be helpful? Please tick all that apply.*

|  |            |
|--|------------|
|  |            |
| <b>1. Read the course notes provided by the professor</b>            | <b>92%</b> |
| 2. Wrote down the notes on paper to see if you agreed with the logic | 84%        |
| 3. Read the textbook   | 42%        |
| 4. Tried the examples in the Solved Problems library                 | <b>0</b>   |
| 5. Solved old tests given by the instructor                          | 67%        |
| 6. Asked friends   | 50%        |

2. *Please list the top 5 concepts that you learned in this module. For example, your 4th choice may be: "vorticity is twice the rotation vector of a packet of fluid."*

|  |
|--|
| <b>1.</b> - The equation for a streamline                              |
| <b>2.</b> - dilatation is the divergence of velocity                   |
| <b>3.</b> - vorticity describes the rotation of flow                   |
| <b>4.</b> - circulation is the line integral of velocity about a curve |
| <b>5.</b> - Kutta-Joukowski Theorem                                    |

3. *What concepts pose(d) difficulties for you? Please discuss, and also how you solved the difficulty if you did.*

The physical interpretation of dilatation

4. Explain as to a 6th grader the 4 basic types of fluid motion

Translation is the air moving, dilatation is the expanding of a fluid like air in a balloon, rotation can be thought of stirring water so the water is rotating, and shearing can be thought of as rubbing something against jello and observing the jello shift in the direction of motion

5. Explain as to a 4th grader (or professor) two different types of fluid motion that lead to lift generation, and how the Kutta-Joukowski theorem allows you to calculate lift per unit span in low-speed flow.

Rotation leads to lift because if flow turns, it produces a force perpendicular to the turning due to it accelerating. This force can produce lift. Dilatation can also lead to lift because if the volume changes, the density changes and this can cause a pressure difference. The pressure difference also causes a force pointing in the direction of decreasing pressure. The Kutta-Joukowski theorem allows the calculation of lift by using the fact that rotating flow produces a force in a direction perpendicular to the rotation and also the velocity. So when the circulation is crossed with the velocity, it produces a vector perpendicular to both, lift.

6. Explain how fluids are different from solids

Fluids are different from solid by the fact that they take the shape of the container they're put in. They also have higher molecular velocities and have more freedom of movement

7. How many atoms of nitrogen are present in a cubic meter of air at 20,000 meters altitude in the International Standard Atmosphere? Repeat for 100,000m.

2.9E24, no data of density for 100,000 m

8. Why does shear cause rotation in a flow?

Because the flow will be moving slower the closer it gets to the surface causing the shearing. When there is a region of low velocity the region farther away with a higher velocity wants to move in towards the lower velocity, causing the flow to rotate

Detailed sample results for the “Introduction to Aerodynamics” module are listed in Appendix A since those are of less general interest to readers.

## DISCUSSION

**Table 1: Relation of Student Educational Outcomes to ABET**

| Outcome   | Mode of Address   |
|---|---|
| A. Fundamentals: Ability to apply knowledge of mathematics, science, and engineering.                 | Vertical streams of rigorous content in technical disciplines, with problem-solving.                                      |
| C. Design: an ability to design a system, component, or process to meet desired needs.                | Design-centered introduction, case studies and concept development exercises  |
| E. Problem-solving: an ability to identify, formulate, and solve engineering problems.                | Module-based surveys, solutions library, enabling deeper problem sets and tests.  |
| H. Broad education to understand the impact of engineering solutions in societal context.             | Advanced concept development exercises.   |
| I. Life-long learning: a recognition of the need for, and an ability to engage in life-long learning. | Experience of having to solve problems in areas outside formal lectures. College instructors help learn these techniques. |



### **Assessment: Iterative Refinement**

The survey results are interesting and encouraging because they show students introspecting and expressing thoughts well. We note that it was the sophomore classes that took by far the greater interest, whereas the junior/senior and graduate classes showed far less participation. The above responses provide guidance to refine modules. More detailed responses in Appendix A show examples where students pay too little attention to concepts explained in class. The reliance on notes, solved problems and textbooks is as expected and welcome. However it is interesting to note the near-absence of attention to order-of-magnitude estimates as a common-sense validation of work. This finding resonates with what was suspected from the formative and summative assessments, and it is definitely an area where more attention must be devoted. The fact that it was the sophomore class that provided the bulk of response to date, did correspond quite well to the idea that they had to be somewhat responsible in giving estimates. It was in the junior/senior and graduate classes, where engineers one to two semesters away from graduation showed a cavalier attitude towards magnitudes of numbers, forcing much more drastic remedial or at least exemplary anecdotal measures from the instructor. Similar assessments were conducted in the Aeroelasticity class in Spring 2011 where most students expect to be graduating seniors.

### **Role Of Other EXTROVERT Resources**

A companion paper in the Multidisciplinary Division [12], extending work from prior years[11,13], summarize our efforts to use advanced concept development as a way for students to learn how to proceed in the face of large uncertainties, and how to reduce the uncertainty through use of physical laws and “common sense”. This also addresses the above issue of inattention to orders of magnitude. While the survey responses above indicate minimal use of the solved problem library, anecdotal evidence from questions brought by students during courses and responses to other questions above, show that they are indeed using these problems, without identifying the resource with the word “library”. Use of this resource will expand as more of the examples and tests given out by course instructors are added here, after conversion to suitable formats. Clearly, web-based notes are as valuable as they are expected to be, and are the leading resource used by learners. This result may be biased by the fact that most respondents are taking these courses, an issue that remains to be studied as we get more data from alumni and other practicing professionals. Initial data from using Case Studies in a vehicle performance course [7] showed excellent impact in getting students to validate their work. Reference [11] shows comfortable use of CATIA and MatLab as problem solving and innovation tools. Sophomores in low speed aerodynamics showed an inclination to use Mathematica.

## **CONCLUSIONS**

This paper presents second-year results from formative and summative assessments of how learners respond to the new EXTROVERT resources for cross-disciplinary problem-solving. The emphasis here is on the vertical streams within aerospace engineering. Initial results on learning styles show the expected dependence on notes, a surprisingly good use of textbooks, some dependence on discussions with co-students, and extensive efforts with solved problems and old tests. A glaring message is that few students appear to appreciate the role of conducting order-of-magnitude estimates in order to bolster their problem-solving approaches. Work on advanced concept development, and stricter insistence on common sense in course formative evaluations,

is being used to address this issue which is often cited by industry employers and graduate advisors. Several lessons from here are transferable to other institutions and curricula. The first is that pushing the frontiers on what the best students can achieve, need not come at the cost of leaving anyone behind. The second is that a return to rigorous fundamentals is not at all inconsistent with experiential learning, teamwork or appreciation for global and societal contexts, when intelligently organized through experiences in advanced concept development. It is also apparent that it no longer matters where the resources are located if they can be reached through the Internet.

## ACKNOWLEDGMENTS

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## APPENDIX A

Sample raw Responses from Module Summative Assessment for Introduction to Aerodynamics. Respondents are Fall 2010 students in sophomore or junior aerodynamics courses.

*What concepts pose(d) difficulties for you? Please discuss, and also how you solved it.*

1.Proving that  $L/D$  max can be found on the drag polar by a line that goes through the origin. Solved it by taking a derivative of the equation  $C_d = C_{d0} + K C_l^2$  and knowing that  $L/D_{max} \rightarrow C_d = 2 K C_l^2$ . 2.Vortex-induced lift. Didn't understand it until the end of the semester when we discussed finite wing theory. 3.It was not intuitive for me that there is a set speed for minimum drag, after working through the derivation this became clear. 4.The equations were straight forward, making it easy to solve for things such as the coefficient of lift and drag. 5.Pressure coefficient. I wasn't sure how it was relevant. 6.The concept of how induced drag works exactly was a bit confusing. I looked through the book and the notes. 7.Understanding what the difference of lift slope curve of the wing and the lift slope curve of an airfoil. I eventually figured out that lift slope curve of the wing is  $dC_L/da$  of  $3D$ , and lift slope curve of the airfoil is the  $dC_l/da$  of  $2D$ . The equation differs since the  $3D$  uses the  $dC_l/da$  data from the  $2D$  lift curve slope. 8.Material derivative; look at examples, MIT courseware. 9.Deriving the speed for minimum drag. I solved it by doing it for the homework assignment.

*Explain as to a 6th grader (I presume that people learn about "acceleration" by then, at least as it applies to skateboards?) how aerodynamic lift is generated.*

1.Aerodynamic lift is generated by a rotation of flow.  $F=ma$  and every force has an equal and opposite force. So if a flow is accelerated downward (a downward force) there will be a equal but opposite upward for (lift). 2.lift is generated by the change in direction of flow. this changes the rate of momentum, which gives an acceleration. this acceleration produces a force perpendicular to the direction change. when the flow turns in a wing, the resultant force is lift. 3.Aerodynamic lift is generated by the pressure difference between the upper and lower wing surfaces. The pressure difference is caused by turning the flow, whether that is done using camber or angle of attack. This turning is caused by the accelerating or decelerating of the flow. 4.When air is flowing over a wing, the wing pushes the air apart, causing a separation. This separation of airflow causes the air to change directions. When things change direction, this causes an acceleration. The airplane "pushes" on the air to make it turn, thus causing the air to "push" back (Newtons 3rd law of motion). This "pushing back" of the air is what causes lift on an airplane.

5. Turning is a type of acceleration. When the flow is turned around an airfoil, it is because there is a force equal to the mass of the flow times the acceleration. Lift is a force generated by turning a moving fluid. 6. Aerodynamic lift is generated by turning the flow past a wing down. The reaction to this force is lift. 7. Lift is generated by the change of momentum or due to the acceleration of the object. This change in momentum generates force, which is the driving force of lift. Also, there is a rate of change in momentum along the direction perpendicular to the original direction. Using Newton's 3rd Law, there will be equal and opposite reaction of force, so whatever rate of change in momentum is exerted on the fluid, there will be a reaction exerted by fluid, which is lift. 8. The air around a wing is pushing on it, and the air below it is pushing more than on the top, so the wing goes up. This is called the generation of lift. 9. When there is a change in momentum and the net force required to cause this change causes an equal and opposite reaction that turns the flow.

*Explain as to a 4th grader (or professor) why airplanes have a "speed for minimum drag" other than zero.*

The amount of drag on an airplane is related to the amount of lift. If you take the derivative of the drag function in terms of velocity (or dynamic pressure) and set it equal to zero (for the minimum), you find it only exists when induced drag (due to lift i.e. velocity) equals  $C_{D0}$ . 2. Because a plane can't fly at zero velocity, so this is a trivial solution. 3. Drag consists of different types of drag. The Induced Drag coefficient is dependent on the lift coefficient, the lift coefficient has a minimum, namely the lifting surfaces still need to create enough lift to sustain flight. This induced drag is usually high at low speeds. The other part of drag is independent of lift it is dependent on form and increases as speed increases. Both these combine to the total drag and speed for minimum drag is something other than zero. 4. Speed for minimum drag occurs when the minimum total drag is equal to twice the zero lift drag. If you think about it, when an airplane is flying very slowly, a streamline is not neatly forming around the airfoil, rather it is just getting pushed out of the way, causing a lot of drag. When an airplane is traveling very fast, the air begins to separate from the airfoil, causing suction thus causing a lot of drag. So, there must be a happy medium between the two, a point where the speed you're flying creates a steady streamline reducing drag and at the same time having the air particles "stick" to the airframe so as not to separate. 5. Induced drag decreases with speed and profile drag increases with speed. 6. Airplanes have a speed for minimum drag because part of the drag comes from how fast the plane is going. The faster it goes, the lower that part of the drag is. 7. In aircraft, there needs to be a definite speed for minimum drag because there is a point where form drag and induced drag equals to each other. At that point, the aircraft is in a speed of min drag. 8. As the speed of an aircraft increases, the skin drag increases as the square of velocity. As you decrease the velocity, the Induced drag increases, because you need a higher  $C_L$  to fly at lower speeds, and  $C_{Di}$  is proportional to  $C_L^2$ , so adding together these two drags create a new total drag function that has a minimum. 9. Because the  $C_{Di}$  and  $C_{D0}$  are equal cause twice that zero-lift drag.

***What are the units for drag? Why do airplane industry engineers talk about drag in square feet?***

1. Newtons. Because everything produces drag, not just wings. So engineers represent drag with equivalent flat plate area. 2. N or lb, it's a force. because the square feet is a description of how big a flat plate the plane could be represented as with the same drag. 3. Drag is expressed in lbf or Newtons, it is the same as thrust since those are the two forces balancing each other.

When engineers talk about drag in terms of Square Feet, they are talking about the equivalent flat plate area which is just another way of expressing drag. 4.The units for drag are in Newtons (its a force). Engineers tend to talk about drag in square feet because they are referring to the equivalent drag on a square flat plate when introduced into the same velocity field. 5.Newtons 6.The units for drag are in Newtons. Drag in square feet usually refers to equivalent flat plate area, which is drag divided by dynamic pressure. 7.We talk drag in sq feet because we are still used to the english unit since the old time. 8.Newtons. that is the effective drag surface area. It's very easy to calculate. 9.Newtons or pounds - it is a unit for force; drag over a certain area because it can change

***Explain as to a 4th grader, why airfoils are shaped the way they are (including camber, rounded leading edge, thickness)***

1.Camber- Curve of the airfoil, curves the flow without requiring an AoA. Rounded LE - allows flow to easily and quickly rotate around the airfoil, causing circulation thus lift. Sharp TE-> Helps prevent separation and directs the flow. Thickness-> Airfoils are genuinely thin, to minimize drag and chance for separation. 2.airfoils are curved so that the air will stick to the airfoil and to make the air turn, if the air doesn't stick to the airfoil then the flow won't turn and there will be no lift. the leading edge is rounded to help start the turning of the flow. The airfoil thick because we don't want the air to turn the same way below the airfoil as above, so we don't want a curved plate, we need something with thickness. 3.Airfoils are designed to guide the flow around it and keep it attached as long as possible while at the same time inducing some sort of rotation in the flow, turning the flow. The rounded leading edge separates the flow smoothly, camber allows for more rotation of the flow, thickness of an airfoil should be enough to accommodate all internal necessary structures like fuel tanks but be as thin as possible to turn the flow. 4.When you stick your hand out of a car, you find that holding your hand vertically causes your hand to get pushed back a lot farther than if you held your hand horizontally. In fact, you are making your hand an airfoil. A cambered airfoil provides the maximum lift while delaying a stall (and therefore decreasing the amount of drag). The rounded leading edge allows you to have a much higher angle of attack while a sharp trailing edge (the back end of the wing) turns the flow, causing a delay in stall. The thickness in the wing causes the air flow to turn when it hits the front of thing, thus causing acceleration (lift) at low angles of attack. 5.Camber delays flow separation and stalling, rounded leading edge gives a larger range of angle of attack. 6.Airfoils are round at the front to keep the flow attached as the plane flies at different angles. Airfoils are not symmetric so that the flow stays on the wing longer, and they are thin at the back in order to turn the flow down to create lift. 7.The airfoil is created in that way because that shape has the best aerodynamic performance. Since drag forms from rough surface, and uneven wing structure, the engineer back then made many trials and error, and airfoil was the best answer that they have found. 8.camber helps create more lift, the rounded front part is so that when you change the angle of the airfoil, the flow doesn't freak out! and the thickness is small, so that you keep the flow from separating, because that creates huge drag..camber generates lift; the rounded leading edge delays stall; thickness generate flow and delay stall; all are used to turn the flow and delay stall

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