Khan Academy Style Videos For Sophomore To Senior Aerospace Engineering Courses (Work in Progress Paper)

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Abstract
Aerospace engineering students frequently encounter difficulty in their upper division courses because the course material is not only advanced but strongly specific to aerospace technical details, compared to the general engineering content of the lower division courses. Consequently students must learn many concepts and analysis techniques which are new to them. The objective of the work described in this paper is to improve student understanding and mastery and retention of specific technical theories, concepts, and methods as defined by specific ABET outcomes. The approach is to develop a series of Khan Academy style videos which are specific to aerospace engineering topics which students historically find challenging to understand and master.

Introduction
Aerospace engineering students frequently encounter difficulty in their upper division courses because the course material is not only advanced but strongly specific to aerospace technical details, compared to the general engineering content of the lower division courses. Consequently students must learn many concepts and analysis techniques which are new to them. Some of these, such as the vector derivative technique popularly known as the Kinematic Transport Theorem, directly build upon previously learned concepts and theories from calculus and vector analysis but are nevertheless difficult to master. Others, such as the numerical method for calculating the aerodynamic center location of a complete aircraft configuration known as the Multhopp Method, do not build directly upon any previously taught core concepts at all and must be both learned and mastered at the current time. The lectures which introduce and then develop these concepts are usually very detailed and technically dense by necessity. Students often audio record these lectures for repeated playback outside of class, but the associated derivations and diagrams cannot easily be captured unless taken cell phone video during lecture. This solution is not ideal since picture quality of written or projected imagery can be insufficient, and many professors do not wish to be videotaped during a lecture. This situation has led students to formally request high quality videos (technical content and production values) which can be repeatedly viewed outside of lecture as needed to assist with mastering the material.

The objective of the work described in this paper is to improve student understanding and mastery and retention of specific technical theories, concepts, and methods as defined by specific ABET outcomes. The approach is to develop a series of Khan Academy style videos which are specific to aerospace engineering topics which students historically find challenging to understand and master. This three year effort is part of the Thaman Professorship for Undergraduate Teaching Excellence which is supported and administered by the Center for Teaching Excellence at Texas A&M University. It is important to note that a hybrid course
structure is not being proposed or developed here. Thus the videos will not replace lecture content, but rather enhance it, and the videos will not be shown during lecture. They are only to be used by the students outside of the classroom for reinforcing the lectures. During the first year a set of six videos are being created for the junior level airplane stability and control course. During the second year a set of five videos will be created for the sophomore level dynamics course that is a prerequisite course for the junior course. In the third year a set of five videos will be created for the sophomore level introduction to aerospace engineering course. It is important to note that the three aforementioned courses are prerequisites for each other, in reverse order. The videos are being created in the order of higher level to lower level courses (i.e. working backward) to ensure that the higher level desired course outcomes are completely addressed by the videos used by the lower level courses.

Lindstrom reports on a pilot study of using a free online mathematics learning tool, Khan Academy (KA), to strengthen the relevant mathematics skills of pre-service science teachers in their introductory physics course at a large teacher education institution in Norway [1]. In this work the videos are being created, and in reverse curriculum order because the author has many years of experience with the junior level courses, but not as much experience with the sophomore level prerequisite courses. Starting with the terminal concepts videos will also ensure that essential nuances needed in the earlier videos will be included. This aspect is also being used in the present work for the same reason.

In his own experience and careful observation over a period of 22 years the author has identified the broad challenges and in many cases the specific technical stumbling blocks faced by students in these courses. The data and information comes from both student questionnaire evaluations and informal personal discussions, and five major topics to be addressed by a video have been identified. Each video will be discipline specific (in this case aerospace), focused on only one technical concept or idea, and have a maximum length of five minutes. The video content will be derivations, animations, case studies, and still photographs and short videos if necessary. Effectiveness of achieving the project objectives will be assessed by:

1. Post-course student outcomes assessed with written exams and quizzes that is compared to previously accumulated data for the same exams over a 22 year period. The final exam is the same exam that has been used in the course for the last 17 years and will provide the best statistical comparison. Homework will not be used for the assessment due to the potential teamwork factor which can obscure the assessment of individual students.

2. Student comments and feedback.

3. Faculty experiences based upon engagement and interaction during lectures and meetings during office hours.
Assessing Outcomes and Experiences

To evaluate and explore the effectiveness of the videos and also students’ perspectives of their experiences, data will be collected via pre and post-test questionnaires as well as through individual and focus group interviews following Krueger and Casey’s established and systematic focus group protocol approach [2]. This mixed-methods approach is advantageous as it supplements the quantitative data with qualitative perspectives that can help provide a richer insight into the effectiveness of the educational videos and student experiences as demonstrated by Creswell et al. [3].

Conclusions and recommendations from the three sources were to be presented in the final version of this paper. However, the course had not completed for the semester and permission to assess the students had not been obtained from the Institutional Review Board (IRB) before the final version of the paper was due. Therefore, the results, conclusions, and recommendations will be presented at the conference. Science the instructor is teaching the same course in the Fall 2017 semester a complete data record will be obtained since all videos will be completed and ready for student use and IRB permission obtained before the start of the semester. These results will be presented at the next ASEE Annual Conference.

Course Description and Learning Objectives Related to ABET Outcomes

The course addressed by the approach in the first year is AERO 321 Dynamics of Aerospace Vehicles. It is a second semester third year (junior) level course that all undergraduate students in the major are required to successfully complete with a minimum grade of C in order to be allowed to take fourth year (senior) level courses. It is a 3 credit hour course that consists of lecture plus two laboratory assignments that are completed during the semester. The course is offered each Fall and Spring semester, and the enrollment in the Spring 2017 semester was 99 students. The topics selected for enhanced explanation with video are related to the learning objectives for the course, which are taken directly from the course syllabus and produced in Table 1. Note that not every learning objective shown below will be represented with a video, but the entire list of learning objectives is shown for completeness and clarity.

The mapping from course objectives to ABET outcomes is shown below for reference on how the instructor defined objectives relative to the accreditation board defined outcomes.
Table 1. ABET Outcomes for AERO 321 Dynamics of Aerospace Vehicles

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Assessment Method</th>
<th>ABET Outcome</th>
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<tbody>
<tr>
<td>1. Understand and appreciate the relationships between airplane configuration design, flying qualities, and stability &amp; control, and the engineering tradeoffs and balances that result in terms of cost, performance, manufacturing, reliability, maintainability, and supportability.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(e), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
</tr>
<tr>
<td>2. Apply Newton’s laws to write the nonlinear equations of motion of an aerospace vehicle including aerodynamic, gravitational, and thrust forces and moments.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(e), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
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<tr>
<td>3. Linearize nonlinear equations about a steady-state equilibrium condition.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(e), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
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<tr>
<td>4. Develop parameterized relationships for aerodynamic and thrust forcing functions in terms of non-dimensional and dimensional stability and control derivatives.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(e), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
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<tr>
<td>5. Determine equilibrium (trim) conditions for steady-state straight and level flight, turning flight, and symmetric pull-up flight; takeoff rotation; and One Engine Inoperative (OEI) conditions.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(e), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
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<tr>
<td>6. Quantify static stability, dynamic stability, and dynamic response characteristics (frequencies, damping ratios, time constants) by developing and analyzing linear state-space models, eigenvalues, eigenvectors, and transfer functions.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(c), 3(d), 3(e), 3(g), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
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<tr>
<td>7. Know and identify the standard and non-standard airplane dynamic modes of motion (short period, Dutch roll, etc.), their reduced-order approximations, and the specific airplane characteristics which influence them.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(c), 3(d), 3(e), 3(g), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
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<tr>
<td>8. Understand the relationship between stability &amp; control and pilot workload/acceptance according to the Cooper-Harper scale, and determine the applicable flying qualities of flight vehicles according to Mil-F-8785C or Mil-Std-1797A.</td>
<td>Homework, quiz, mid-semester exam, and final exam.</td>
<td>3(a), 3(c), 3(d), 3(e), 3(g), 3(k), Dyn. &amp; Control AIAA Program Criteria</td>
</tr>
</tbody>
</table>
Videos which map to objectives 1, 2, 4, 5, 6, and 7 are selected and detailed below. *It is important to note that the video topics are selected from the concepts which the students traditionally have the most difficulty with, rather than the topics which the instructor feels are the most important.* For instance, Objective 3 is not represented since that topic does not usually pose a significant difficulty to the students. The textbook for the course is Schmidt [4] with a significant amount of supplementary material from the text by Roskam [5] and material by Valasek [6]. All of the topics which relate to objectives are contained in at least one and in some cases all three of the sources [4-6], but no one source contains all objective topics.

**Introduction and Summary of Topics Selected for Videos**

Considering the Course Learning Objectives and the ABET Relationship To Program Outcomes and previous experience teaching the course over a 22 year period, six topics were identified as those which pose the largest barriers to students satisfying the Learning Objectives and Program Outcomes. Section 2 listed the objectives as 1, 2, 4, 5, 6, and 7. The topic list below is chronological and all topics in fact build upon the previous ones, with item #6 representing a culmination of not only the other topics but also a main learning objective of the course. Each topic is briefly described.

1. **Kinematic Transport Theorem**
   
   Demonstrate how to properly take successive derivatives of vector quantities and relate them to relative motion between two defined reference frames. Start with the position vector \( \mathbf{r} \) and demonstrate how to take successive derivatives that produce the velocity vector \( \mathbf{v} \) and the four term acceleration vector \( \mathbf{a} \). 

   \[
   \mathbf{p} = \mathbf{r} \\
   \mathbf{v} = \frac{d\mathbf{r}}{dt} = \left. \frac{d\mathbf{r}}{dt} \right|_N + \omega_{A,N} \times \mathbf{r} \\
   \mathbf{a} = \frac{d^2\mathbf{r}}{dt^2} = 2\omega_{A,N} \times \left. \frac{d\mathbf{r}}{dt} \right|_A + \left. \frac{d\omega_{A,N}}{dt} \right|_A \times \mathbf{r} + \omega_{A,N} \times \left( \omega_{A,N} \times \mathbf{r} \right)
   \]
2. **Static Stability**

Explain how an airplane can be either statically stable, neutrally stable, or statically unstable by defining the static margin, which relates both the position and distance between the center of gravity (C.G.) and the aerodynamic center (A.C.).

3. **Stability Derivatives**

Define stability derivatives and derive them from the equations of motion for a generic aircraft configuration. Explain how to interpret them and their physical significance for evaluating the absolute stability of aircraft. For example,
letting \( \frac{\partial \text{force}}{\partial \text{control} \left( \frac{1}{m} \right)} = \text{force}_{\text{control}} \), dimensional derivatives are the linear or angular acceleration per change in the associated control variable. For instance, \( Y_{\delta_r} \) is the sideforce linear acceleration imparted to the airplane as the result of a unit change in rudder deflection. The total relations in the longitudinal axis are:

\[
\frac{1}{m} f_y = Y_{\beta} \dot{\beta} + Y_{\beta} \ddot{\beta} + Y_p p + Y_r r + Y_{\delta_r} \delta_r + Y_{\delta_\beta} \delta_\beta
\]

\[
\frac{1}{I_{xx}} l = L_{\beta} \dot{\beta} + L_{\beta} \ddot{\beta} + L_p p + L_r r + L_{\delta_r} \delta_r + L_{\delta_\beta} \delta_\beta
\]

\[
\frac{1}{I_{zz}} n = N_{\beta} \dot{\beta} + N_{\beta} \ddot{\beta} + N_p p + N_r r + N_{\delta_r} \delta_r + N_{\delta_\beta} \delta_\beta
\]

4. **Trim Diagrams**

Construct trim diagrams by drawing them, based upon given values of stability derivatives.

![Figure 4.10 Using a Trim Diagram to find Trimmed Lift Coefficients for Different Center of Gravity Locations](image-url)
5. **Representing Dynamical Systems in the State-Space Representation**

Conduct the derivations to show that in state-space modeling, equations of motion are expressed as first-order, linear, differential equations of the form:

\[
\begin{align*}
\dot{x} &= Ax + Bu \\
y &= Cx + Du
\end{align*}
\]

where \(x\) = state vector such that \(x \in \mathbb{R}^{n \times 1}\) (n = # of states)

\[u\] = control vector such that \(u \in \mathbb{R}^{m \times 1}\) (m = # of controls)

\[A \in \mathbb{R}^{n \times n}, \ B \in \mathbb{R}^{n \times m}\]

6. **Aircraft Standard and Non-Standard Dynamic Modes**

Using all of the topics contained in videos 1 - 6 described above, show the qualitative characteristics of the standard dynamical modes of motion. For instance, the short period mode is the primary and most useful standard longitudinal dynamic mode. It is:

- Second-order
- Stable, or unstable
- High frequency, well damped when stable
- Exhibited mostly in angle-of-attack and body-axis pitch rate
- Specified in military flying qualities regulations

Pitch maneuverability is based upon controlling and shaping this mode. A time history of this mode is shown immediately below.

![Typical Short Period Scale](image)

The non-standard longitudinal dynamical mode is Third Oscillatory Mode, which occurs when the Short Period and Phugoid modes combine to form one new second-order mode and two first-order modes. This situation is caused by the center-of-gravity of gravity lying far aft, and exists when either static stability or static instability exists since it is one of the first-order modes that becomes unstable, not the Third Oscillatory Mode.
Conclusions and Lessons Learned

This is a Work in Progress paper that was due before the end of the semester. The conference presentation will contain i) anecdotal results in the form of student comments, and ii) statistical results. The same comprehensive final exam has been used in this course for 17 years and it is taught at least twice per year, so there is a large statistical database on student performance on a standardized exam which did not use these videos. This will be compared to the first semester in which the videos were used. The limitation will be due to small sample size, since only one class using the videos (Spring 2017) will be compared to the performance of many classes that did not use them.

References

6. Valasek, J, AERO 321 Course Notes, Aerospace Engineering Department, Texas A&M University, College Station, TX, 2017.