AC 2011-283: HERDING CATS: WEAVING COHERENT APPLICATION THREADS THROUGH A MECHANICAL ENGINEERING CURRICULUM TO FACILITATE COURSE-TO-COURSE CONNECTIVITY AND IMPROVE MATERIAL RETENTION

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Herding CATs: Weaving Coherent Application Threads through a Mechanical Engineering Curriculum to Facilitate Course-to-Course Connectivity and Improve Material Retention

Introduction

Mechanical engineering (ME) is a broad and varied field, one reason why it is a popular choice for students pursuing engineering degrees. A downside of this breadth is that applications used as contextual examples in engineering-science core courses are also varied and diverse: e.g., bridges in introductory mechanics, I-beams in mechanics of materials, power plants in thermodynamics, pipe flows in fluid mechanics, etc. Though useful in focusing students on the topic at hand and exposing the broad nature of mechanical engineering, this compartmentalized approach can lead to a fractured understanding of the discipline. It also doesn’t map well onto real-world engineering problems that are best solved through an understanding of the integration and interaction of the various core concepts. In addition, material retention can suffer due to the lack of connectivity among various core topics.

Coherent Application Threads (CATs) are meant to address this issue. CATs are specific engineering application examples that are woven through the fabric of the ME curriculum, exposing students to the varied aspects of one application in the context of core ME principles covered in engineering science courses.

This paper will describe the concept of CATs and their initial implementation through a pilot testing of one coherent thread—wind turbines. Included are how the thread is mapped into the core curriculum, typical activities, and on-line supplemental learning modules.

CATs Concept and Motivation

Engineering is a problem-based learning discipline, with the core concepts of engineering science framed within the context of example and homework problems. In mechanical engineering, each engineering science sub-discipline features its own suite of applications from which problems are drawn, and these tend to be similar among the various textbooks. Problems are simplified to an extent that assures students can readily recognize the fundamental concept under study, isolated from the complicating factors of real-life applications.

This approach is vital for reinforcing basic principles (Newton’s Laws in Mechanics, First and Second Laws in Thermodynamics, etc.). But, by itself, it ignores the interconnectivity of these concepts and how they are interwoven in the fabric of real engineering problems—i.e., system-level engineering. This big-picture view is often covered in capstone design courses, but capstone design projects themselves cover a broad spectrum of applications, and don’t guarantee that all students leave with the same exposure to system-level integration and interactions.

In addition, the development of engineering science core concepts relies upon pre-requisite paths that allow advanced topics to be built upon more basic concepts introduced in earlier courses. However, a common complaint among faculty is a lack of retention of material from these earlier...
courses. Although there may be several reasons for low retention of material, one possible source is the lack of connectivity from course to course.

Coherent Application Threads, or CATs for short, are being developed to better connect concepts covered in undergraduate introductory courses, both along similar pre-requisite paths (e.g., thermal/fluids) and across disparate pre-requisite paths (thermal/fluids-structures). The concept of pre-requisite is backward looking, requiring students to search among the ocean of concepts learned in previous semesters to find those needed to move ahead. The idea of Coherent Application Threads is more forward looking, providing waypoints that not only remind students where they’ve been, but more importantly where they may be going.

CATs are engineering applications that meet several selection criteria: (1) they are system-level applications that encompass at least four different mechanical engineering core concepts; (2) their key elements are readily accessible through analysis of core concepts in introductory level courses; and (3) they are topics of current interest ideally connected to department research thrust areas and concentrations. CATs can be implemented through a variety of activities: lecture modules, projects, homework problems, example problems, and laboratory experiences. These are integrated through a Website that provides a framework for the coursework, as well as a portal for independent inquiry into related topics. When fully implemented, specific CATs will follow cohorts through their 4-year curriculum.

The concept of CATs draws inspiration from aeronautical engineering for which exists an inherent application thread—an aircraft—touched upon throughout the curriculum, and also the subject of a focused capstone design experience; the latter is a course taught by the author for the past 12 years. The result is a more unified, though admittedly narrower, view of fundamental engineering concepts, and an exposure to a critical systems engineering lesson—that various discipline-specific problems (aerodynamics, structures, etc) cannot be studied in isolation, but must be addressed in an integrated manner. The goal of CATs in the Mechanical Engineering curriculum is to emulate this, while still retaining the broader view of the discipline.

Though the main motivations for CATs are material retention and exposure to system-level applications, they can also address several other critical pedagogical issues, including: framing engineering topics in the larger societal context; exposing students to the importance of lifelong learning through supplemental learning material; and engaging students through topics of current interest.

Pilot Test: Wind Turbine Thread

An initial thread was developed around the topic of wind turbines. The manner in which the thread is woven through the ME curriculum can be seen in Figure 1, and a mapping of the various elements of wind turbine systems onto the core ME concepts is summarized in Table 1.

During fall semester, 2009, a few CAT wind-turbine activities were introduced into 3 courses: ME 301, Sophomore-level Mechanics, ME 303, Junior-level Fluid Mechanics and EK 127, Freshmen-level Engineering Computations (Matlab-based computations and problem-solving). For ME 301 and ME 303, problems were provided, with solutions that were useable for either example or homework problems (see example in Fig. 2). The relevant faculty were asked to use
these in their courses, and to point students to a BlackBoard site set up to coordinate CATs activities and content. Initially, the site included only a PDF document that served as an introduction to wind turbines. In the course EK 127, assistance was provided to the Graduate Teaching Fellows (GTFs) to develop a programming project (note that the course includes 3 projects each semester, one related to each of the 3 departments in the College of Engineering at BU). The CATs project involved using a Weibull distribution of wind speed and a wind turbine power curve (power vs wind speed) to estimate annual energy use.

At the end of the semester, students in all of these courses were asked to complete a short survey regarding the CATs activity in their course. The response rates were small, but the results overwhelmingly revealed a general lack of cognizance of the existence, much less the purpose, of the thread. In retrospect, this was not surprising given the relatively rushed effort (based on a late summer start date for the project funding) and the passive attempt to engage faculty. To address these issues, a sub-committee of the ME Department’s Undergraduate Committee was formed, consisting of the six undergraduate students on the committee and the CATs coordinator (author). The outcome of that meeting was several changes in implementations in the second semester, and in the overall direction of the project.

- The course coordinator went to each class that included CAT-related content or activities, and provided a 15-minute introductory talk, describing the concept of CATs.
- All problems, examples, etc., were “branded” with the CAT logo (see upper left corner of Fig. 2), so students could easily identify a thread-related activity.
- More hands on activities were planned, focusing on several mini-wind turbines that could be operated inside using room fans.
- A new website was planned for coordinating CATs, aimed at providing a more engaging on-line presence, though this was not developed until the summer of 2010, after the first year.
- Meetings would be held at the beginning of each semester with all faculty who teach courses with CAT-related content or activities, to discuss issues and to assure implementation.

The highlight of the second semester (Spring 2010), activity was the introduction of the mini-wind turbine project in freshmen EK 127 programming course. Prior to the project, a power curve for the wind turbine was generated using an instructional wind tunnel, with voltage measurements acquired using a Mobile Studio DAQ board (http://mobilestudio.rpi.edu/) accessed through MATLAB (Fig. 3). The project required students to run the wind turbine at 3 different fan speeds, and use the measured voltage and the supplied power curve to estimate the speed of the air from the fan. A similar project was implemented during the Summer 2010 offering of EK 127.

CATs Website

A Website devoted to Coherent Application Threads, developed in Summer 2010, now coordinates CATs-related activities for the wind-turbine thread (Figure 4). Students are taken on a brief tour of the site during the 15-minute introductory presentation in each CATs-relevant course. The site features include:

1 EK is a designation used for engineering core curriculum courses, taken by all engineering students at Boston University.
• Introductory video describing CATs and the rationale behind them.
• Multi-page introduction to various aspects of wind turbines, including wind resources, types of wind turbines, lift and drag concepts, wind turbine components and performance, and technical and social issues.
• Supplemental Learning Modules (SLM) for each course (accessed through the Students link in the main menu). These are PowerPoint presentations with accompanying video, created using the Camstasia screen capture program (Figure 5). Each SLM covers one aspect of wind turbines related to the core concepts associated with that course. Table 1 also lists the topics covered by SLM (to date).
• External links
• RSS (Real Simple Syndication) feed of wind turbine news.

Future Plans

Since CATs are intended to extend throughout all four years of the ME curriculum, their implementation and assessment is logically accomplished in stages. Based on an initial start of Fall 2010, the wind-turbine thread will follow the Class of 2014 cohort. Future plans include expanding course and topics to all those listed in Table 1. In addition, the following new experiential activities are also planned:

• Blade bending project in Mechanics of Materials (ME 305).
• Wind turbine laboratory in Instrumentation and Experimentation (ME 310), likely focusing on effect of blade design on turbine output.
• Laboratory in fluid mechanics (details TBA).

The most important element of the future plan is the introduction of a senior elective course that focuses on the systems-level aspects of that cohort’s thread. This will tie together concepts covered in CATs activities in previous courses, focusing on the integration of these concepts into a working system. The course will include an introduction to systems analysis and the use of simulation tools. By having students in the course formulate and develop new activities for introductory core courses, the process can be, to some degree, self-sustaining. This may be a long-term solution to the concerns raised on the survey regarding the small number of CATs activities in many courses.

Sustainability of effort beyond the two years of project funding is an important issue for the future robustness of CATs activities. A three-pronged approach is planned to address this issue.

1. Institutionalize CATS through the ME department undergraduate committee: To date, the topic of CATs was a standing agenda item at committee meetings, with reports and discussions on progress and implementation. As part of that, a sub-committee was formed, which included the 6 undergraduates on the committee. As described above, the sub-committee was formed primarily to brainstorm on how to address the issues raised by the student survey, but the plan is to continue it as a standing sub-committee. One critical activity for the committee will be actual development of activities for the courses.

2. Engage more faculty in the process: Thus far, two additional faculty have become highly engaged in the wind turbine thread, recognizing the benefit of the CATs approach for their courses. The intent is to recruit one or both of them for the UGRAD sub-committee,
and provide them with opportunities to shape the development of activities and the next thread. In addition, faculty will be recruited to help formulate activities for their courses, possibly with the promise of student support.

3. Focus on the freshmen year: By exposing freshmen to the benefits of the CATs concept and introducing hands-on experiences that engage them, an expectation is established that CATs are an organic part of the curriculum providing some “demand-pull” for faculty to participate. As part of this effort, an introduction to CATs is now part of the College-wide Freshmen advising course.

Summary

Coherent Application Threads, or CATs for short, are being developed and implemented as a means to improve connectivity among core Mechanical Engineering courses, to expose students to the system-level aspect of real engineering systems, and to better engage students through topics of current interest. Pilot testing of the concept is completed, and the initial implementation of a wind-turbine thread is underway. Though the CATs activities described here are relatively modest, future plans call for significant growth as well as new threads.
Table 1: Elements of wind turbine CAT covered in various courses.

<table>
<thead>
<tr>
<th>Yr</th>
<th>Course</th>
<th>Topics Covered</th>
<th>Special Activities</th>
<th>Supplemental Learning Modules (to date)</th>
</tr>
</thead>
</table>
| FR | EK 127 Computations               | - Turbine power curves  
- Annual wind energy estimation                                   | Mini wind-turbine project                   | - Mini-wind project introductory video          |
| SO | EK 301 Mechanics 1 (statics)     | - Vector forces on wind turbine & tower  
- Aligned bearings  
- Friction and braking  
- Tower reaction loads                           |                                             | - Vectors  
- Forces and equivalent systems  
- Friction and braking                           |
| JU | ME 303 Fluid Mechanics            | - Momentum method for calculating Betz limit  
- Tower drag  
- Lift and drag on blades *                                | Wind Turbine Lab*                           | - Control volume analysis and Betz limit  
- Atmospheric boundary layer effects  
- Introduction to lift and drag                   |
|    | ME 305 Mechanics of Materials    | - Fatigue loading of blades. *  
- Blade/tower stresses *  
- Blade bending                                      | Blade bending project *                     | - Blade bending and structural design            |
|    | ME 366 Probability and Statistics | - Weibull distributions for wind speed *                              |                                             | - Wind speed statistics and distributions       |
|    | ME 302 Mechanics 2 (Dynamics)     | - Rotor angular momentum*  
- Dynamic forces on rotor and tower *                                 |                                             |                                                 |
| SE | ME 310 Instrumentation & Experimentation | - Velocity transducers for wind speed measurements*  
- Power curves*  
- Measurement of power fluctuations *                       | Wind Turbine Lab*                           |                                                 |

NOTES: * Indicates topics and/or activities that have not yet been implemented
Figure 1: Illustration of wind turbine Coherent Application Thread woven through Boston University Mechanical Engineering curriculum
1. **3-D Equilibrium—aligned bearings**

The two-bladed wind turbine shown in the sketch is in the "locked" or "braked" condition, though there are still aerodynamic forces on the blades, as shown, due to the wind. The brake force that keeps the rotor locked is $F$ and acts on a brake disk with a radius of 3.5 m. Two aligned bearings at $A$ and $B$ support the rotor (15 kN weight), with the bearing at $A$ supporting an axial load. Find the braking force $F$ and the reaction forces of the two bearings.

**Solution**

\[ \sum F_x = 0 = -10 \text{ kN} - 10 \text{ kN} + A_y \]

\[ A_y = 20 \text{ kN} \quad (a) \]

\[ \sum F_y = 0 = A_y + B_y \]

\[ A_y = -B_y \quad (b) \]

Figure 2: CATs wind-turbine problem for Mechanics 1 (Statics). Note only first part of solution is shown to illustrate that problems supplied to faculty include solutions.
Figure 3: Mini wind turbine set-up, with Mobile Studio$^{SM}$ board.

Figure 4: Home page of CATs Website
Supplemental Learning Module
ME 303 Fluid Mechanics

Control Volume Analysis and the Betz Limit

Betz Limit Setup

Figure 5: Two frames from Supplemental Learning Module video for Fluid Mechanics Course