

A MATLAB-Based Upper-Division Systems Analysis Course for Engineering Technology

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Abstract

The Department of Engineering Technology at Old Dominion University offers TAC of ABET accredited baccalaureate programs in Civil Engineering Technology, Electrical Engineering Technology, and Mechanical Engineering Technology. All students are required to take traditional courses in algebra and trigonometry, as well as differential and integral calculus, at the freshman and sophomore levels. While these courses provided the necessary basic mathematical skills, it was difficult to justify the traditional upper-division mathematics courses such as differential equations, vector analysis, etc., as appropriate for the special needs of engineering technology students.

To address this issue, the Department has undertaken the development of a new "systems analysis" course that will cover the necessary upper-division engineering technology mathematical needs for ET students and it will be taught around a MATLAB based paradigm. While there are a number of fine computational software packages, MATLAB appears to be gaining broad acceptance in the engineering work place as one of the primary tools for advanced analysis. The course will consist of selected topics in linear algebra and matrices, differential equations, Laplace transforms, curve fitting, statistics, and optimization. Preliminary versions of the course have been offered several times to Electrical Engineering Technology Students and have received an excellent response. Beginning in the Spring of 2003, it will be offered to all Engineering Technology majors. Modifications to achieve that goal are currently underway.

All topics will be first introduced in their basic mathematical forms, but once the concepts are mastered with "simple" numbers and forms, students will begin utilizing MATLAB extensively to solve more practical and challenging problems. The paper presents a detailed breakdown of the topics selected for coverage in this new course along with examples of complex problems that are easily solved by students with MATLAB. A discussion of problems observed during the integration of students from all the discipline areas into the course will be made and proposed changes to improve the course will be discussed.

I. Introduction

Old Dominion University has been offering baccalaureate degrees in Civil Engineering Technology, Electrical Engineering Technology, and Mechanical Engineering Technology since the early 70s and has maintained continuous accreditation by TAC of ABET since 1976. Several options within each program are offered and there is a new

not-yet accredited program in General Engineering Technology which is being offered asynchronously to U. S. Navy personnel.^{1,2} Programs are available at nearly 50 sites through the distance learning program known as TELETECHNET. To support this distance learning program, the Department of Engineering Technology has developed a number of new initiatives for dealing with distance laboratories, samples of which are described in the bibliography.^{3,4,5}

II. Mathematics for Engineering Technology

The determination of appropriate mathematics courses for engineering technology students is an on-going challenge that never seems to be complete to everyone's satisfaction. For example, would engineering technology students be better served with special technical mathematics courses or should they take conventional mathematics courses that develop more rigor at the expense of applications? The answer to such a question will vary according to the backgrounds and individual experiences of faculty. In the final analysis, however, such answers also depend heavily on the particular educational environment, including enrollments and economic factors. At proprietary institutions where most of the students are technical, courses can be heavily tempered toward the technical disciplines, while in university settings, students are often guided toward conventional mathematics courses. However, there is no clear evidence that would suggest that either approach is superior to the other since much depends on the direction an individual follows in his or her career path.

For quite a few years, Old Dominion University engineering technology students have had some of both approaches. Since a significant portion of our students enter as transfer students at the junior level, the freshman enrollments do not justify special courses. Instead students take fairly conventional basic Precalculus courses and, in the past, have taken two three-credit Introductory Calculus courses. This was followed by a junior-level mathematics course developed by the Mathematics Department consisting of special topics suited for engineering technology students. This approach has worked well for more than two decades, but a new approach based on future evolutionary trends, will be pursued.

III. The Projected Mathematics Paradigm

The freshman sequence in Precalculus, consisting of standard algebra and trigonometry, will be retained since it provides a solid basis for the curriculum. However, instead of the two three-credit courses in Introductory Calculus, students take one four-credit course in Calculus and Analytical Geometry, which is the same as taken by engineering majors. This will ease the change of majors from engineering to engineering technology, or vice-versa, within the College of Engineering and Technology (COET). Our evaluation of student performance suggests that engineering technology students at this institution are just as well prepared for the four-credit course as their peers in engineering after completing the Precalculus sequence. This first semester calculus course provides most of the fundamentals of both differential and integral calculus with a reasonable degree of rigor.

The major change from the previous mathematics sequence for engineering technology students will be a new four-credit course taught by engineering technology faculty at the junior level. At the time the abstract was submitted, the term *Systems* was envisioned in the title, but more recently, the title has been changed to *Advanced Technical Analysis*. (For institutional political reasons, the word *mathematics* was not used in the course title.) The philosophy guiding the development of this new course is the *raison d'être* for this paper. Certain aspects of the course may seem radical, but we believe that it is focused in the right direction for guiding future engineering technologists and applied engineers.

The course will cover traditional topics appropriate to the junior level, but as a departure from tradition, the course will include a MATLAB-based emphasis throughout. While any one of several mathematical packages on the market could be employed, it appears that MATLAB is the prevalent program for advanced engineering applications. Moreover, it is sufficiently structured around C commands that it supports all the criteria for inclusion as a valid programming language.

In the past, when minimum credit numbers in various categories were required for accreditation, there was a statement in ABET guidelines that prohibited counting programming credits as mathematics. It is clear that the authors of that statement could not have envisioned the integrated, user friendly software of today and its power to support a range of educational goals. For example, it is impossible to properly utilize MATLAB without understanding the basic underlying mathematical processes. Moreover, the MATLAB commands are so closely aligned with mathematical formats that one must "think mathematically" to utilize the program. Of course, under new ABET guidelines, the measurable outcomes rather than credit hours are the major criteria.

IV. Course Objectives

Based on the assumed backgrounds of students entering the course, the following objectives have been established for the course:

- (1) Introduce the MATLAB Command Window at the outset as the primary mode for computational analysis and functional manipulation in much the same manner as a scientific calculator, but with much greater computational and graphing capabilities.
- (2) Develop the capability for creating MATLAB m-files as a valid approach for software programming to support engineering and scientific applications.
- (3) Introduce matrix notation and terminology very early in order to maximize the use of MATLAB software in analyzing and manipulating data.
- (4) Review applied differential and integral calculus concepts at a level suitable for engineering technology students, with the emphasis directed toward **understanding the concepts**, rather than simply memorizing formulas.

- (5) Provide an applications-oriented treatment of constant coefficient linear ordinary differential equations, with some treatment of both the classical approach and the Laplace transform approach.
- (6) Provide a basic treatment of statistics to include probability density functions, probability distribution functions, statistical parameters, and the processing of random variables with MATLAB.
- (7) Provide introductory treatments of the following topics with MATLAB support as appropriate: (a) difference equations (including the z-transform), (b) spatial vector analysis (including scalar and vector products in rectangular coordinates), (c) curve-fitting of experimental data, and (d) optimization principles.
- (8) Develop competency in the use of MATLAB to prepare professional plots that can be exported to other programs.

A somewhat abbreviated three-credit version of the course has been offered twice by the first author to EET students and has received excellent reviews. Typical comments of students seemed to suggest that they really appreciated their newly acquired prowess with MATLAB and many wished to have more exposure to the subject. The course has now been converted to four credits and will be taken by all engineering technology juniors starting in the spring semester.

V. Course Materials

At the time of this writing, MathWorks, inc., the organization that developed and is marketing MATLAB, lists over 500 books, including two circuit analysis books by the first author^{6,7}, that have MATLAB components. Although many different disciplines are involved in those publications, those that integrate MATLAB analysis with engineering mathematical principles appear to be aimed more toward advanced engineering course levels. Consequently, the challenge of developing a MATLAB based technical mathematics book became a major goal and the effort is well underway. Portions of the text will be used in the spring semester for the course instruction. More information concerning the development is available at the first author's web site.⁸

Aside from the MATLAB treatment, one of the guiding factors in determining the level of the mathematical treatment is that of the Fundamentals of Engineering (FE) Examination. Approximately 35 states, including Virginia, allow graduates of TAC of ABET baccalaureate engineering technology programs to sit for this examination. While not the major objective of the text, it is expected that a mastery of the topics should provide a strong preparation for the mathematical content of the FE Examination.

VI. Example of Numerical Integration with MATLAB

The example that follows illustrates a typical problem involving numerical integration with MATLAB.

A test is performed on a hypothetical mechanical part to determine its response to certain stresses. An accelerometer connected to the device provides a reading of the acceleration a in m/s^2 at 0.1-second intervals over the time interval from $t = 0$ to $t = 2$ s. The readings are recorded as follows:

$t, \text{ s}$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
$a, \text{ m/s}^2$	0	9.05	16.37	22.22	26.81	30.33	32.93	34.76	35.95

0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
36.59	36.79	36.62	36.14	35.43	34.52	33.47	32.30	31.06	29.75	28.42	27.07

Use MATLAB to determine (a) the approximate velocity in m/s as a function of time and (b) the approximate displacement in meters as a function of time. Assume that the initial values of both velocity and displacement are zero. (c) Plot the acceleration, velocity, and displacement.

Solution

The preceding values of acceleration are entered into MATLAB as a row matrix or vector \mathbf{a} , and since that is a routine process, the steps will not be shown. The time values, however, assume an orderly step process and can be readily generated. Assuming the Command Window of the Student Version, the value of the time step in seconds is

```
EDU>> delt = 0.1;
```

The time vector can be generated by the command

```
EDU>> t = 0:delt:2;
```

The first-order integration algorithm (trapezoidal rule) then estimates the velocity function \mathbf{v} as

```
EDU>> v = delt*cumtrapz(a);
```

An additional numerical integration can be used to estimate the displacement \mathbf{y} as

```
EDU>> y = delt*cumtrapz(v);
```

The functions may then be plotted by the command

```
EDU>> plot(t,a,t,v,t,y)
```

After additional routine labeling is provided, the three curves are shown in Figure 1. The units are meters/second² (m/s²) for acceleration, meters/second (m/s) for velocity, and meters (m) for displacement.

VII. Differential Equation Example

A typical example involving the solution of a differential equation with MATLAB follows.

A series *RLC* circuit with $L = 2$ H, $C = 0.5$ mF, and $R = 400$ Ω is excited by a dc voltage of value 40 V at $t = 0$, and there is no initial energy stored in the circuit. A differential equation governing the voltage v across the capacitor can be obtained by a node voltage analysis and it is

$$\frac{d^3v}{dt^3} + 200\frac{d^2v}{dt^2} + 10^6\frac{dv}{dt} = 0$$

with initial conditions $v(0) = 0$, $v'(0) = 0$, and $v''(0) = 40 \times 10^6$ V/s². Solve the differential equation using symbolic operations in MATLAB and plot the solution.

Solution

The format for the solution of the differential equation utilizing symbolic mathematics is

```
EDU>> y = dsolve('D3y+200*D2y+1e6*Dy = 0', 'D2y(0) = 40e6', 'Dy(0) = 0', 'y(0) = 0')
```

The solution initially obtained by MATLAB is

```
40-40*exp(-100*t)*cos(300*11^(1/2)*t)-40/33*11^(1/2)*exp(-100*t)*sin(300*11^(1/2)*t)
```

This expression can be simplified by either the **simplify** command or the **pretty** command. However, our major interest is its behavior as a function of time and that can be observed easily by the command **ezplot**. After a slight amount of trial and error to get the best domain and range for investigation, the first command used is

```
EDU>> ezplot(y,[0,0.05])
```

The range is then adjusted by the command

```
EDU>> axis([0,0.05,0,70])
```

A grid is then added by the command

```
EDU>>grid on
```

The result after some additional labeling is shown in Figure 2.

VIII. Summary

A new approach to teaching upper-division mathematical and technical analysis concepts to engineering technology students at Old Dominion University is being implemented. It is based on two important perceptions: (1) Today's curricula are too crowded to teach all the "nice-to-know" but largely irrelevant topics covered in many traditional mathematics courses. (2) Students need to be exposed very early to the power and sophistication of such programs as MATLAB, and it should be integrated into the instruction.

We do not suggest that basic mathematical concepts are not important. Understanding the meaning of a derivative, an integral, or a differential equation is as important as ever. However, students can be taught to understand the meaning of such concepts with simple numbers and examples. At that point, the solutions should be relegated to the power of available software to develop and provide visualization of the solutions.

Although the Department of Engineering Technology at ODU has chosen to utilize MATLAB to support the advanced technical analysis course, there are other software packages (e. g., MATHCAD) that might be preferred by individual institutions.

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William D. Stanley, Eminent Professor Emeritus, retired in December 2000 after about 35 years of service at Old Dominion University, of which he served as a department chair for 27 years. He holds a B. S. degree from the University of South Carolina and M. S. and Ph.D. degrees from North Carolina State University, all in Electrical Engineering. He is a registered Professional Engineer and author of more than a dozen textbooks. Since retiring, he has continued to write, work part-time with the Navy College program, and has developed two asynchronous courses for that program.

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Figure 1. Numerical Integration Example.



