# MATLAB Interactive Programming Basics Applied to Wind Farm Design and Analysis

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## Introduction and Objective:

This poster paper[1]summarizes the methods developed to foster an effective and successful MATLAB[2] learning experience in the two credit hour course, Engineering 1221[3], at The Ohio State University. The focus of this paper is MATLAB applied to successful completion of the term project on wind farm design and analysis.

Students enter the course with some previous MATLAB programming experience. However, the students' MATLAB programming experience varies widely, from two to three weeks of exposure in an entry level engineering fundamentals course, to expertise in MABLAB applications programming in several upper level engineering courses.

Engineering 1221 is a course in engineering problem solving using software tools, primarily MATLAB. Students are expected to learn the fundamental *thought processes* underlying problem solving, the software *tools* required for implementation, the creative thinking underlying *design*, the supporting professional *conduct* and teamwork, and basic engineering *communication* skills. This paper focuses on a specific subset of these expectations. Our goal is to re-establish, advance, and evaluate students' understanding of these fundamental topics through the completion of the wind energy term project[4] where students apply MATLAB basics to wind farm design and analysis.

## Method:

Throughout the term, the course breaks the fundamental skills of MATLAB into five main categories: matrices, display/input, conditional statements, loops, and plotting. Not only will all these skills be needed to complete the final wind energy term project, but they are also the basic building blocks of all programming languages.

Using the iterative, incremental design method[5], we created laboratory exercises to teach MATLAB basics applied to wind energy design and analysis problems. The application of the iterative, incremental design method as applied to teaching MATLAB basics and wind farm design is shown in Figure 1. Initially we designed 12 individual lab and 4 team lab assignments. We evaluated the first set of individual and team lab reports lab reports completed by the students in the first offering of the course and generated concepts for improving these labs. The

second iteration of the labs is described in the results below. These results focus both on the skills taught and how the skills tie into the final term wind energy project.

**Results:**

***Learning Objectives***

Figures 1 through 11 display the results of course design. Each figure is framed in the color corresponding to the primary learning objective exhibited by the figure as follows:

**1. THINK** (coral)**:** *Demonstrate ability in critical, creative and practical thinking through algorithm design, MATLAB software design and evaluation.* **For example**: Understanding simulation, optimization, and data analysis as it applies to wind farm performance.

**2. USE TOOLS** (purple)**:** *Utilize MATLAB software tools to solve engineering problems.* **For example**: Writing simple MATLAB programs performing numerical calculations; Using basic data structures such as numeric and character arrays to evaluate turbine performance; Using interactive programming to develop software tools for wind farm design and analysis.

**3. DESIGN** (lime)**:** *Demonstrate the ability to create and design within the constraints of time, cost, quality, safety, and environmental impact.* **For example**: Employing methods such as "brainstorming" to generate ideas for wind farm design and methods such as "pair and share" to evaluate alternative designs; Utilizing tools including budgets and schedule charts to implement designs.

**4. CONDUCT** (turquoise)**:** *Work individually, in pairs, and on teams to solve engineering design and analysis problems professionally and ethically.* **For example**: Understanding concepts of responsibility and accountability when working as a team on the wind farm team project.

**5. COMMUNICATE** (orange)**:** *Demonstrate skill in technical communication related to engineering and software development.* **For example**: Communicating results of term project in the final presentation of wind farm design-build deliverables.

***Arrays***

Wind turbine performance models are based on parameters represented by multi-dimensional arrays. Since many numerical operations involve the manipulation of values in arrays, teaching the basics of MATLAB must begin with instruction in how these values are stored. We initially define an array simply, describing it as vector with multiple "cells" arranged in a row or in a column. A two-dimensional array is defined as a table of "cells" with both rows and columns. As the semester progresses, we add complexity to the arrays by adding new dimensions.

To help students understand the arrangement of values within these more complex arrays, we encourage students to visualize a two dimensional array as a table and a three dimensional array

as a Rubik's cube, where each layer of the Rubik's cube represents a three row by three column table. Figure 2 shows how students use triply nested for-loops to generate a three-dimensional matrix representing wind turbine tip-to-wind speed ratio.

In addition to these visualization techniques, the use of the MATLAB variable editor is encouraged in order to help students see how matrices are populated in loops. Figure 3 shows MATLAB variable editor view of the tables generated by the MATLAB code shown in Figure 1. By using these tools, students can visualize how these values are stored within an array. The development of this skill is imperative in storing data for multiple wind turbine designs, diameters, and wind speeds in the completion of the final project.

### *Output and Input*

The operation of Displaying and inputting data is not only one of the most basic functions of MATLAB, but also one of the most essential. MALAB has three basic commands that we use to display and input data: ***disp***, ***fprintf***, and ***input***. The ***fprintf*** and ***input*** commands are crucial for any programmer attempting to display the results of a script file. Intense practice through individual homework and lab assignments at the beginning of the term stresses the significance of these two commands to the students. Through these assignments, students are shown the vast options and capabilities that they can utilize to complete the wind energy term project. Figures 4 and 5 show MATLAB input and output applied to analysis of wind speed at US Air Force Base locations. Note that the Air Force Base names are stored as cell arrays, requiring students to understand the special properties of cell arrays with respect to input and output.

### *Condition Statements*

Conditional statements are not a particularly hard topic to teach to students. Since some programming experience is necessary to enroll in the class, most students have a fairly well developed understanding of basic Boolean logic. To further expand these skills, Engineering 1221 introduces some higher level Boolean logic ideas including de Morgan laws[4], if-else structures and multi-term Boolean statements. These new skills are used in many of the supplementary programs created for the wind energy term project, such as the analysis of turbine blade icing shown in Figures 6 and 7.

### *Loops*

We have found that many students do not immediately understand how loops function in MATLAB. Having previous program experience often helps, but since MATLAB loops look very different from other languages, understanding loop operation often requires additional instruction. To help students grasp this topic, this course teaches students the power of using flow charts. By turning loops into flowcharts students can easily step through loops one element at a time. Stepping through each element of the loop allows the students to clearly see how each part of the loop works and can also be followed in the MATLAB variable editor. This understanding of loops is a requirement for every upper level program in the class and for the final course project. Figures 8 and 9 illustrate the use of flowcharts and the MATLAB variable

editor in teaching students the complexities of MATLAB counting and conditional repetition structures.

### *Graphs and Charts*

The plotting capabilities of MATLAB are a vital tool for any engineer. It is not particularly difficult to teach, but the students find that they can easily create effective charts and graphs in MALAB. The approach taken from an instructional point of view was to assume the students basic knowledge of this command and to focus our energy on developing applications to use the advanced plotting techniques and function sin homework and lab exercises. The wind energy term project[6] was designed to give the students an opportunity to apply these plotting techniques to design and analysis of wind farm energy production, and to wind farm financial performance as shown in Figures 10 and 11.

### *Summary*

By focusing on the five fundamentals in MATLAB: arrays, input and output, conditional statements, loops, and plotting, students are provided with a diverse set of basic MATLAB tools to utilize in upper level engineering courses and throughout their engineering careers. The use of the basic tool set is illustrated in the final term wind farm design project, which requires a firm understanding of all these skills for successful completion.

## Conclusions:

Our goal to re-establish, advance, and evaluate students' understanding of these fundamental topics was attained through learning activities supporting student achievement of the course learning objectives. All the course activities that contribute to learning how to apply MATLAB interactive programming basics to wind farm design and analysis support the second course learning objective: *Utilize MATLAB software tools to solve engineering problems*. The first course learning objective: *Demonstrate ability in critical, creative and practical thinking, through algorithm design, MATLAB software design and evaluation,* was supported to a lesser extent by this same set of learning activities. This learning objective is addressed in more depth by another course module teaching critical, creative, and practical thinking with MATLAB Symbolic Math[6].

Some, but not all, of the learning activities in this module address the remaining three course learning objectives: *Demonstrate the ability to create and design within the constraints of time, cost, quality, safety, and environmental impact; Work individually, in pairs, and on teams to solve engineering design and analysis problems professionally and ethically; and, Demonstrate skill in technical communication related to engineering and software development.* These learning objectives are addressed indirectly as a part of activities that they support such as the final presentation of the design-build term project.

The learning activities surrounding application of MATLAB basics to wind farm design and analysis are the most fundamental of all the course learning activities and endure throughout the entire fourteen week span of the course.

## References:


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