CHAPTER 1

ENGINEERING ANALYSIS AND SPREADSHEETS

Engineering analysis is a systematic process for analyzing and understanding problems that arise in the various fields of engineering. To carry out this process successfully you must be familiar with general problem-solving techniques, you must have an overall understanding of the engineering fundamentals that apply to your particular problem, and you must have a working knowledge of the required mathematical solution procedures. It is also very helpful to have available a computer-based spreadsheet program that will solve your problem quickly and easily, once you have defined the problem and set it up properly.

This book discusses the use of spreadsheets to solve a variety of introductory engineering problems. Our emphasis will be on the use of Microsoft Excel—a popular spreadsheet program—to carry out these procedures. Examples are provided illustrating the use of these procedures for simple but representative engineering applications. The associated mathematical solution procedures are also presented clearly so that you have an understanding of what the spreadsheet does and how it goes about its business. In this chapter we begin by explaining what a spreadsheet is, in general terms, and we explain what we mean by general problem-solving techniques, applicable engineering fundamentals, and mathematical solution procedures.

1.1 A SPREADSHEET OVERVIEW

Before the arrival of personal computers, beginning engineering students were required to learn a number of complicated mathematical procedures in order to solve the equations involved in many engineering calculations. Then they were often required to program these procedures for a computer using a general-purpose programming language. Or they might have written programs that would
access a prewritten library of mathematical routines. In either case, the students were required to go through lengthy and tedious procedures. This provided a thorough indoctrination to the use of numerical methods in engineering, but many students would grow impatient and lose interest along the way.

As personal computers became commonplace during the 1980s, spreadsheets emerged as one of the principal types of personal computer applications. Though originally intended for carrying out financial calculations, today’s spreadsheet programs include provisions for implementing many of the commonly used mathematical procedures used by engineers.

In this book we focus our attention on Excel because of its popularity, its widespread availability, and its broad range of features. Excel (and several other competing spreadsheet programs) permits engineers to carry out lengthy calculations very easily, without getting bogged down in complicated mathematical procedures. In addition, Excel allows you to organize your results in a clear and logical manner.

Excel offers other advantages as well. For example, Excel has built-in features that allow you to:

- Import, export, store, process, and sort data.
- Display data graphically.
- Analyze data statistically.
- Fit algebraic equations through data sets.
- Solve single and simultaneous algebraic equations.
- Solve optimization problems.

Moreover, many other mathematical procedures can easily be implemented within Excel, simply by making use of its basic features. Thus, Excel allows you to easily solve many of the problems that commonly arise in engineering analysis. How this is accomplished is one of the major themes of this book.

Before going any further, let’s look at a typical Excel spreadsheet with an eye toward understanding what spreadsheets are all about.

### Example 1.1 Spreadsheet Analysis of a Projectile’s Trajectory

In this example we present an Excel spreadsheet that solves a common physics problem: namely, determining the trajectory of a projectile whose initial velocity is \( v_0 \) and initial angle \( \theta \). To do so, we will make use of the following well-known equations:

\[
x = v_x t
\]

\[
y = v_y t - \frac{1}{2} (gt^2)
\]

where

- \( x \) = horizontal displacement from the original position, ft
- \( y \) = vertical displacement from the original position, ft
- \( t \) = time, sec
\[ v_x = \text{initial horizontal velocity, determined as } v_x = v_0 \cos(\theta), \text{ ft/sec} \]
\[ v_y = \text{initial vertical velocity, determined as } v_y = v_0 \sin(\theta), \text{ ft/sec} \]
\[ v_0 = \text{initial velocity acting at angle } \theta, \text{ ft/sec. (Note that } \theta \text{ is expressed in radians, not degrees.)} \]
\[ g = \text{acceleration due to gravity, } 32.2 \text{ ft/sec}^2. \]

You should understand that \( v_0 \) and \( \theta \) represent known information (input data). We will use Equations (1.1) and (1.2) to process the data, resulting in calculated values for \( x \) and \( y \) as a function of \( t \) (output data).

Figure 1.1 shows an Excel spreadsheet (called a worksheet) for this problem.

![Figure 1.1 – A sample Excel worksheet](image)

Note that the worksheet is subdivided into rows and columns, with each row assigned a number and each column identified by a letter. The intersection of a row and column defines a cell, with a unique address. For example, H3 identifies a cell that contains the numerical value 100; thus H3 is a cell address. Note that the given parameters \( (v_0, \theta, \text{ and } g) \) are entered into the right portion of the worksheet (in cells H3, H5, and H7, respectively), along with the calculated values of \( v_x \) and \( v_y \). The corresponding trajectory is shown as a table in the left portion of the worksheet (columns A through C). Notice that everything is well labeled and units are provided, following good spreadsheet practice.
Figure 1.2 – Adding graphs to the worksheet

Figure 1.3 – Formulas used to generate the values shown in Fig. 1.1
Tabulated data can also be displayed graphically within a worksheet, as illustrated in Fig. 1.2. Here we see two different ways to plot the data, even though they have the same shape in this example: y vs x (the actual trajectory) and y vs time.

Note that the entire worksheet requires only three numerical values as input—the values of \( v_0 \), \( \theta \) and \( g \). The remaining values were all generated using formulas. Fig. 1.3 shows the formulas that Excel uses to generate the worksheet shown in Fig. 1.1. (Excel formulas will be explained in the next chapter.) Note that the formulas shown in columns B and C are Excel interpretations of equations (1.1) and (1.2), respectively.

It is important to understand that the entire worksheet will be automatically recalculated if any of the input parameters is assigned a different value. This important concept is illustrated in Fig. 1.4, where \( v_0 \) has been changed to 120 ft/sec and \( \theta \) has been changed to 40 degrees. Thus, the user can play “what if” by changing various input parameters and immediately seeing the full effects of the changes. This is one of the primary benefits of using a spreadsheet program.

We will discuss the details of entering data and formulas in later chapters of this book. For now, you should focus only on the “big picture”—that is, on what an Excel spreadsheet is, and why it can be useful to engineers and engineering students.

**Figure 1.4 – Effect of changing two parameters**
1.2 GENERAL PROBLEM-SOLVING TECHNIQUES

It is very important that you develop good problem-solving habits early in your career. Here are some general suggestions that will help you in the problem-solving process. These suggestions apply to all engineering problems, irrespective of any particular application or any special mathematical procedure.

1. Your perspective of the problem will change over time. Therefore, you should *set aside some time to think about the problem before you attempt to solve it*. This will help you to understand the problem more clearly.

2. Many engineering problems can be represented graphically or pictorially. Therefore, when solving a problem of this type, *draw a sketch of the problem* before you begin to solve it. This will assist you in visualizing the problem.

3. Be sure that you understand the *overall purpose* of the problem and its *key points*. Don’t allow yourself to become sidetracked by peripheral or irrelevant information.

4. Ask yourself *what information is known* (input data) and *what information must be determined* (output data). List the input and output information in general terms. (Try to do this in terms of specific variables; do not simply write down numbers.)

5. Ask yourself *what fundamental engineering principles* apply to the problem (see Sec. 1.3). Be certain that you understand how these principles apply to the particular problem you are trying to solve.

6. *Think about how you will solve the problem before you begin the actual solution*. Many problems can be solved several different ways. What mathematical method will you use? Will a computer be required? How will you present the results? Some advance planning will save you a lot of time and grief.

7. Take your time when actually solving the problem. *Develop your solution in an orderly and logical manner*. Be sure that the work is clearly labeled, particularly if you are solving the problem by hand.

8. Once you have obtained a solution, *think about it. Does it make sense?* What assurance do you have that it is correct? Incorrect answers can often be detected in this manner.

9. Be sure that your solution is *clear and complete*. Is the solution presented in an orderly manner? Are the results labeled? Are units included with the numerical answers? Is the logic used to obtain the solution clear? (Most professors are interested in how you obtained your answers as well as the actual numerical results.) Is a table or graph required to present the results in a clear and concise manner?
Remember that problem solving is a skill that takes time and practice to acquire. You will become better at it as you acquire more experience with a greater variety of increasingly complex problems.

### 1.3 Applicable Engineering Fundamentals

Many engineering problems are based upon one of the following three underlying fundamental principles:

1. **Equilibrium.** Most steady-state problems (i.e., problems in which things remain constant with respect to time) are based upon some type of equilibrium. The following are some common forms of equilibrium that you are likely to see in elementary engineering problems:
   (a) Force equilibrium.
   (b) Flux equilibrium (see item 3 below).
   (c) Chemical equilibrium.

2. **Conservation laws.** The two common conservation laws are conservation of mass and conservation of energy. A great many problems in all fields of engineering are based upon one or both of these principles. (Certain problems are based upon a conservation of momentum principle, though you are unlikely to encounter these in a beginning-level course.)

3. **Rate phenomena.** There are many physically different rate phenomena, though all are represented in the same manner: i.e., a potential drives a flux. One common example is Ohm's law of electrical current flow \( i = \Delta V/R \), where \( i \) represents an electrical current (a flux) and \( \Delta V \) represents a voltage difference (a potential). Here the voltage difference (potential) drives the current flow (flux).

Another common example of a rate phenomenon is Fourier's law of heat conduction \( q = k \Delta T/\Delta L \), where \( q \) represents a heat flux (expressed as heat flow per unit area per second) and \( \Delta T \) represents a temperature difference (a potential). Thus, the temperature difference (potential) drives the heat flux.

### Example 1.2 Preparing to Solve a Problem

Suppose you wish to analyze the electrical circuit shown in Fig. 1.5.

(a) What is the overall purpose of the problem?

(b) What information is known?

(c) What information must be determined?

(d) What fundamental engineering principles apply to the problem?

(e) What will be the overall solution strategy?
Figure 1.5 – An electrical circuit containing series and parallel resistors

Answers:

(a) The purpose of the problem is to determine all of the unknown parameters that characterize the behavior of the circuit. These include the current flowing through each path and the voltage drop across each resistance.

(b) The known information consists of the circuit configuration, the source voltage ($V = 12$ volts), and the values of the individual resistances ($R_1 = 10 \Omega$, $R_2 = 5 \Omega$, and $R_3 = 20 \Omega$).

(c) The following items must be determined: The currents $i$, $i_1$, and $i_2$ and the voltage drops $V_1$, $V_2$, and $V_3$. (Note that $V_1$, $V_2$, and $V_3$ are the voltage drops across $R_1$, $R_2$, and $R_3$, respectively.)

(d) The fundamental principles that apply are Ohm’s law (rate phenomena) and Kirchhoff’s laws (equilibrium).

1. **Ohm’s law**: The voltage drop across a resistor is equal to the product of the current flowing through the resistor and the resistance: i.e., $V = iR$

2. **Kirchhoff’s law—Resistors in series**: The total resistance is equal to the sum of the individual resistances: i.e., $R_T = R_2 + R_3$

   The overall voltage drop is equal to the sum of the voltage drops across the individual resistors: i.e., $V_T = V_2 + V_3$

3. **Kirchhoff’s law—Resistors in parallel**: The voltage boost provided by the source is equal to the voltage drop across each parallel path: i.e., $V = V_1 = V_T$

   The current provided by the source is equal to the sum of the current flow through each parallel path: i.e., $i = i_1 + i_2$.

   The reciprocal of the overall (equivalent) resistance is equal to sum of the reciprocals of the total resistances for each of the parallel paths: i.e.,

   $$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{(R_2 + R_3)}$$
(e) The overall strategy will be to apply Kirchhoff’s laws to the construction of a new circuit that is equivalent to the original circuit but easier to analyze. Ohm’s law will be used to determine the unknown currents and voltages along the way. The order of the calculations must be determined carefully. At each step, an unknown quantity must be determined in terms of known information. Thus, the calculations can be carried out in the following manner:

Figure 1.6 – Replacing two series resistors with one overall resistor

(i) Determine the overall resistance $R_T$ of the rightmost path as $R_T = R_2 + R_3$. This allows us to replace the original network with the simpler network shown in Fig. 1.6.

(ii) Recognize that $V_1 = (V_2 + V_3) = \text{the source voltage } V$.

(iii) Determine the current $i_1$ flowing through the leftmost path (i.e., across $R_1$) as $i_1 = V_1/R_1$.

(iv) Determine the current $i_2$ flowing through the rightmost path as $i_2 = V/R_T$.

(v) Determine the total current flow $i$ as $i = i_1 + i_2$.

(vi) Determine $V_2$ as $V_2 = i_2 \times R_2$.

(vii) Determine $V_3$ as $V_3 = i_2 \times R_3$.

(viii) **Check:** Does $V_2 + V_3 = V$, as it should? (If not, something is wrong. Go back and find the error.)

(ix) Determine $R_{eq}$ as $1/R_{eq} = 1/R_1 + 1/R_T$. This allows us to replace the network shown in Fig. 1.6 with the simpler network shown in Fig. 1.7.

(x) **Check:** Does $i = V/R_{eq}$, as it should? (If not, go back and find the error.)

Though this problem is simple enough to solve by hand, a spreadsheet solution is shown in Example 1.4.
Example 1.3 Assessing the Accuracy of a Solution

A group of students have obtained the following solution for the problem presented in Example 1.2:

\[
i = 1.68 \text{ amp} \quad i_1 = 0.48 \text{ amp} \quad i_2 = 1.20 \text{ amp} \\
V_1 = 12.0 \text{ volts} \quad V_2 = 9.6 \text{ volts} \quad V_3 = 2.4 \text{ volts}
\]

(a) Is the solution clear and complete?

(b) Does the solution appear to be correct?

Answers:

(a) The solution is clear and complete, though the detailed calculations are not shown. The unknown quantities are labeled with the proper units.

(b) When the students thought about the solution, they realized it was not correct. First, of the two branch currents, \( i_1 \) and \( i_2 \), the larger current (1.20 amps) is flowing through the rightmost path, which has the higher resistance (25 \( \Omega \)). This does not make sense. Furthermore, within the rightmost path, the larger voltage drop (9.6 volts) occurs across the smaller resistance. This also does not make sense (because Ohm’s law states that the voltage drop is proportional to the resistance).

Once the students examined their results more carefully, they realized that their calculations were correct but that their results had been transposed. The correct solution is

\[
i = 1.68 \text{ amp} \quad i_1 = 1.20 \text{ amp} \quad i_2 = 0.48 \text{ amp} \\
V_1 = 12.0 \text{ volts} \quad V_2 = 2.4 \text{ volts} \quad V_3 = 9.6 \text{ volts}
\]