

# A Concise Introduction to **MATLAB**<sup>®</sup>



**William J. Palm III**

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**William J. Palm III**  
*University of Rhode Island*

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## A CONCISE INTRODUCTION TO MATLAB

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**To my sisters, Linda and Chris, and to my parents, Lillian and William**

## ABOUT THE AUTHOR

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**William J. Palm III** is Professor of Mechanical Engineering and Applied Mechanics at the University of Rhode Island. In 1966 he received a B.S. from Loyola College in Baltimore, and in 1971 a Ph.D. in Mechanical Engineering and Astronautical Sciences from Northwestern University in Evanston, Illinois.

During his 36 years as a faculty member, he has taught 19 courses. One of these is a freshman MATLAB course, which he helped develop. He has authored nine textbooks dealing with modeling and simulation, system dynamics, control systems, vibration, and MATLAB. These include *System Dynamics* (McGraw-Hill, 2005) and *Mechanical Vibration* (Wiley, 2007). He wrote a chapter on control systems in the *Mechanical Engineers' Handbook* (M. Kutz, ed., Wiley, 1999), and was a special contributor to the fifth editions of *Statics* and *Dynamics*, both by J. L. Meriam and L. G. Kraige (Wiley, 2002).

Professor Palm's research and industrial experience are in control systems, robotics, vibrations, and system modeling. He was the Director of the Robotics Research Center at the University of Rhode Island from 1985 to 1993, and is the coholder of a patent for a robot hand. He served as Acting Department Chair from 2002 to 2003. His industrial experience is in automated manufacturing; modeling and simulation of naval systems, including underwater vehicles and tracking systems; and design of control systems for underwater-vehicle engine-test facilities.

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# P R E F A C E

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Formerly used mainly by specialists in signal processing and numerical analysis, MATLAB\* in recent years has achieved widespread and enthusiastic acceptance throughout the engineering, mathematics, and scientific communities. Many schools now require a course based entirely or in part on MATLAB early in the curriculum. MATLAB is programmable and has the same logical, relational, conditional, and loop structures as other programming languages, such as Fortran, C, BASIC, and Pascal. Thus it can be used to teach programming principles. In most schools a MATLAB course has replaced the traditional Fortran course, and MATLAB is the principal computational tool used throughout the curriculum.

The popularity of MATLAB is partly due to its long history, and thus it is well developed and well tested. People trust its answers. Its popularity is also due to its user interface, which provides an easy-to-use interactive environment that includes extensive numerical computation and visualization capabilities. Its compactness is a big advantage. For example, you can solve a set of many linear algebraic equations with just three lines of code, a feat that is impossible with traditional programming languages. MATLAB is also extensible; currently more than 20 “toolboxes” in various application areas can be used with MATLAB to add new commands and capabilities.

MATLAB is available for MS Windows and Macintosh personal computers and for other operating systems. It is compatible across all these platforms, which enables users to share their programs, insights, and ideas. This text is based on MATLAB Version 7.4 (R 2007a). Some of the material in Chapter 7 is based on the Control System Toolbox, Version 8.0. Chapter 8 is based on Version 3.2 of the Symbolic Math Toolbox.

## TEXT OBJECTIVES AND PREREQUISITES

This text is intended as a stand-alone introduction to MATLAB. It can be used in an introductory course, as a self-study text, or as a supplementary text. The text’s material is based on the author’s experience in teaching a required two-credit semester course devoted to MATLAB for engineering freshmen. In addition, the text can serve as a reference for later use. The text’s many tables, and its referencing system in an appendix and a three-part index each, have been designed with this purpose in mind.

The reader is assumed to have some knowledge of algebra and trigonometry; knowledge of calculus is not required for the first six chapters. Some knowledge

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of high school chemistry and physics, primarily simple electrical circuits and basic statics and dynamics, is required to understand some of the examples.

This text is a condensed version of *Introduction to MATLAB 7 for Engineers* (McGraw-Hill, 2005), using the same pedagogy and instructional style. For this text, we have removed some of the lengthier examples and the background material in mathematics that may not be needed for some readers or for some courses. *Introduction to MATLAB 7 for Engineers* also contains a chapter on Simulink,<sup>†</sup> which is a graphical interface for dynamic systems simulation.

## TEXT ORGANIZATION

The text consists of eight chapters. The first chapter gives an overview of MATLAB features, including its windows and menu structures. Chapter 2 introduces the concept of an array, which is the fundamental data element in MATLAB, and describes how to use numeric arrays, cell arrays, and structure arrays for basic mathematical operations. Chapter 2 also covers the solution of linear algebraic equations, which arise in many applications.

Chapter 3 discusses the use of functions and files. MATLAB has an extensive number of built-in math functions, and users can define their own functions and save them as a file for reuse.

Chapter 4 shows how to create decision-making programs with MATLAB, and it covers relational and logical operators, conditional statements, for and while loops, and the switch structure.

Chapter 5 treats two-dimensional plots in greater detail, as well as three-dimensional plots. Function discovery, which uses data plots to discover a mathematical description of the data, is a common application of plotting, and a separate section is devoted to this topic. The chapter also treats polynomial and multiple linear regression as part of its modeling coverage.

Chapter 6 reviews basic statistics and probability and shows how to use MATLAB to generate histograms, perform calculations with the normal distribution, and create random number simulations. The chapter concludes with linear and cubic-spline interpolation.

Chapter 7 covers numerical methods for calculus and differential equations. Numerical integration and differentiation methods are treated. Ordinary differential equation solvers in the core MATLAB program are covered, as well as the linear-system solvers in the Control System toolbox.

Chapter 8 covers symbolic methods for manipulating algebraic expressions and for solving algebraic and transcendental equations, calculus, differential equations, and matrix algebra problems. The calculus applications include integration and differentiation, optimization, Taylor series, series evaluation, and limits. Laplace transform methods for solving differential equations are also introduced. This chapter requires the use of the Symbolic Math toolbox or the Student Edition of MATLAB.

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<sup>†</sup>Simulink is a registered trademark of The MathWorks, Inc.

Appendix A contains a guide to the commands and functions introduced in the text. Appendix B is a list of references. Answers to selected problems and a three-part index appear at the end of the text.

All figures, tables, equations, and exercises have been numbered according to their chapter and section. For example, Figure 3.4–2 is the second figure in Chapter 3, Section 4. This system is designed to help the reader locate these items. The end-of-chapter problems are the exception to this numbering system. They are numbered 1, 2, 3, and so on to avoid confusion with the in-chapter exercises. The problems are grouped according to the relevant chapter section.

The first four chapters constitute a course in the essentials of MATLAB. The remaining four chapters are independent of each other, and may be covered in any order, or may be omitted if necessary. These chapters provide additional coverage and examples of plotting and model building, probability and statistics, calculus and differential equations, and symbolic processing, respectively.

## SPECIAL REFERENCE FEATURES

The text has the following special features, which have been designed to enhance its usefulness as a reference.

- Throughout each of the chapters, numerous tables summarize the commands and functions as they are introduced.
- Appendix A is a complete summary of all the commands and functions described in the text, grouped by category, along with the number of the page on which they are introduced.
- At the end of each chapter is a list of the key terms introduced in the chapter, with the page number referenced.
- Key terms have been placed in the margin or in section headings where they are introduced.
- The index has three sections: a listing of symbols, an alphabetical list of MATLAB commands and functions, and an alphabetical list of topics.

## PEDAGOGICAL AIDS

The following pedagogical aids have been included:

- Each chapter begins with an overview.
- **Test Your Understanding** exercises appear throughout the chapters near the relevant text. These relatively straightforward exercises allow readers to assess their grasp of the material as soon as it is covered. In most cases the answer to the exercise is given with the exercise.
- Each chapter ends with numerous problems, grouped according to the relevant section.
- Each chapter contains numerous practical examples. The major examples are numbered. A guide to these examples appears on the inside front cover.
- Each chapter has a summary section that reviews the chapter's objectives.

- Answers to many end-of-chapter problems appear at the end of the text. These problems are denoted by an asterisk next to their number (for example, 15\*).

An Instructor's Manual is available online for instructors who have adopted this text for a course. This manual contains the complete solutions to all the **Test Your Understanding** exercises and to all the chapter problems. The text website (at <http://www.mhhe.com/palm>) also has downloadable files containing PowerPoint slides keyed to the text.

## ACKNOWLEDGMENTS

Many individuals are due credit for this text. Working with faculty at the University of Rhode Island in developing and teaching a freshman course based on MATLAB has greatly influenced this text. Email from many users contained useful suggestions. The following people, as well as several anonymous reviewers, suggested many helpful corrections and additions.

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**William J. Palm III**

*Kingston, Rhode Island*

*May 2007*

# An Overview of MATLAB<sup>®\*</sup>

## OUTLINE

- 1.1 MATLAB Interactive Sessions
  - 1.2 Menus and the Toolbar
  - 1.3 Arrays, Files, and Plots
  - 1.4 Script Files and the Editor/Debugger
  - 1.5 The MATLAB Help System
  - 1.6 Summary
- Problems

This is the most important chapter in the book. By the time you have finished this chapter, you will be able to use MATLAB to solve many kinds of problems. Section 1.1 provides an introduction to MATLAB as an interactive calculator. Section 1.2 covers the main menus and toolbar. Section 1.3 introduces arrays, files, and plots. Section 1.4 discusses how to create, edit, and save MATLAB programs. Section 1.5 introduces the extensive MATLAB Help System.

## How to Use This Book

The book's chapter organization is flexible enough to accommodate a variety of users. However, it is important to cover at least the first four chapters, in that order. Chapter 2 covers *arrays*, which are the basic building blocks in MATLAB. Chapter 3 covers file usage, functions built into MATLAB, and user-defined functions. Chapter 4 covers programming using relational and logical operators, conditional statements, and loops.

Chapters 5 through 8 are independent chapters that can be covered in any order. They contain in-depth discussions of how to use MATLAB to solve several

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common types of problems. Chapter 5 covers two- and three-dimensional plots in more detail, and shows how to use plots to build mathematical models from data. Chapter 6 covers probability, statistics, and interpolation applications. Chapter 7 introduces numerical methods for calculus and ordinary differential equations. Chapter 8 covers symbolic processing in MATLAB, with applications to algebra, calculus, differential equations, linear algebra, and transforms.

## Reference and Learning Aids

The book has been designed as a reference as well as a learning tool. The special features useful for these purposes are as follows.

- Throughout each chapter margin notes identify where new terms are introduced.
- Throughout each chapter short Test Your Understanding exercises appear. Where appropriate, answers immediately follow the exercise so you can measure your mastery of the material.
- Homework exercises conclude each chapter. These usually require more effort than the Test Your Understanding exercises.
- Each chapter contains tables summarizing the MATLAB commands introduced in that chapter.
- At the end of each chapter is:
  - A summary of what you should be able to do after completing that chapter and
  - A list of key terms you should know.
- Appendix A contains tables of MATLAB commands, grouped by category, with the appropriate page references.
- Two indexes are included. The first is an index of MATLAB commands and symbols; the second is an index of topics.

## 1.1 MATLAB Interactive Sessions

We now show how to start MATLAB, how to make some basic calculations, and how to exit MATLAB.

### Conventions

In this text we use `typewriter` font to represent MATLAB commands, any text that you type in the computer, and any MATLAB responses that appear on the screen, for example,  $y = 6*x$ . Variables in normal mathematics text appear in italics; for example,  $y = 6x$ . We use boldface type for three purposes: to represent vectors and matrices in normal mathematics text (for example,  $\mathbf{Ax} = \mathbf{b}$ ), to represent a key on the keyboard (for example, **Enter**), and to represent the name of a screen menu or an item that appears in such a menu (for example, **File**). It is assumed that you press the **Enter** key after you type a command. We do not show this action with a separate symbol.

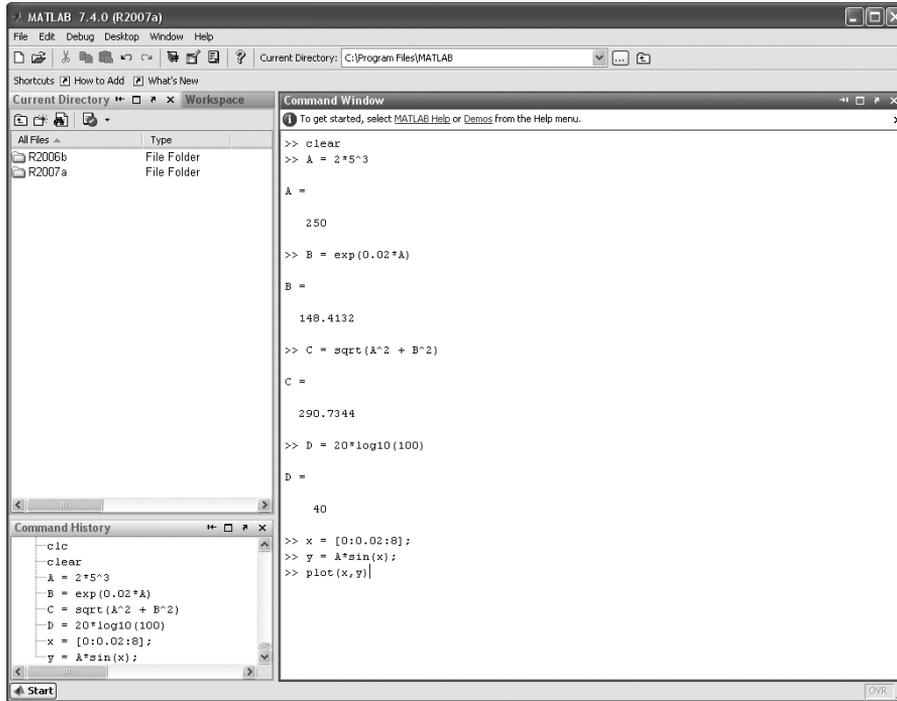


Figure 1.1–1 The default MATLAB Desktop.

## Starting MATLAB

To start MATLAB on a MS Windows system, double-click on the MATLAB icon. You will then see the MATLAB *Desktop*. The Desktop manages the Command window and a Help Browser, as well as other tools. The default appearance of the Desktop is shown in Figure 1.1–1. Three windows appear. These are the Command window, the Command History window, and the Current Directory window. Across the top of the Desktop are a row of menu names, and a row of icons called the *toolbar*. To the right of the toolbar is a box showing the directory where MATLAB looks for and saves files. We will describe the menus, toolbar, and directories later in this chapter.

You use the Command window to communicate with the MATLAB program, by typing instructions of various types called *commands*, *functions*, and *statements*. Later we will discuss the differences between these types, but for now, to simplify the discussion, we will call the instructions by the generic name *commands*. MATLAB displays the prompt (`>>`) to indicate that it is ready to receive instructions. Before giving MATLAB instructions, make sure the cursor is located just after the prompt. If it is not, use the mouse to move the cursor.

---

**DESKTOP**

---



---

**COMMAND WINDOW**

---

The prompt in the Student Edition looks like `EDU >>`. We will use the normal prompt symbol `>>` to illustrate commands in this text.

Three other windows appear in the default Desktop. The Current Directory window is much like a file manager window; you can use it to access files. Double-clicking on a file name with the extension `.m` will open that file in the MATLAB Editor. The Editor is discussed in Section 1.4.

Underneath the Current Directory window is the Workspace window. To activate it, click on its tab to the right of the Current Directory window. The Workspace window displays the variables created in the Command window. Double-click on a variable name to open the Array Editor, which is discussed in Chapter 2.

The fourth window in the default Desktop is the Command History window. This window shows all the previous keystrokes you entered in the Command window. It is useful for keeping track of what you typed. You can click on a keystroke and drag it to the Command window or the Editor. Double-clicking on a keystroke executes it in the Command window.

You can alter the appearance of the Desktop if you wish. For example, to eliminate a window, just click on its Close-window button (X) in its upper right-hand corner. To undock, or separate the window from the Desktop, click on the button containing a curved arrow. You can manipulate other windows in the same way. To restore the default configuration, click on the **Desktop** menu, then click on **Desktop Layout**, and select **Default**.

## Entering Commands and Expressions

To see how simple it is to use MATLAB, try entering a few commands on your computer. If you make a typing mistake, just press the **Enter** key until you get the prompt, and then retype the line. Or, because MATLAB retains your previous keystrokes in a command file, you can use the up-arrow key (↑) to scroll back through the commands. Press the key once to see the previous entry, twice to see the entry before that, and so on. Use the down-arrow key (↓) to scroll forward through the commands. When you find the line you want, you can edit it using the left- and right-arrow keys (← and →), and the **Backspace** key, and the **Delete** key. Press the **Enter** key to execute the command. This technique enables you to correct typing mistakes quickly.

Note that you can see your previous keystrokes displayed in the Command History window. You can copy a line from this window to the Command window by highlighting the line with the mouse, holding down the left mouse button, and dragging the line to the Command window.

Make sure the cursor is at the prompt in the Command window. To divide 8 by 10, type `8/10` and press **Enter** (the symbol `/` is the MATLAB symbol for division). Your entry and the MATLAB response looks like the following on the screen (we call this interaction between you and MATLAB an *interactive session*, or simply *a session*). Remember, the symbol `>>` automatically appears on the screen; you do not type it.

```
>> 8/10
ans =
    0.8000
```

MATLAB indents the numerical result. MATLAB uses high precision for its computations, but by default it usually displays its results using four decimal places except when the result is an integer.

MATLAB assigns the most recent answer to a variable called `ans`, which is an abbreviation for *answer*. A *variable* in MATLAB is a symbol used to contain a value. You can use the variable `ans` for further calculations; for example, using the MATLAB symbol for multiplication (`*`), we obtain

```
>> 5*ans
ans =
     4
```

Note that the variable `ans` now has the value 4.

You can use variables to write mathematical expressions. Instead of using the default variable `ans`, you can assign the result to a variable of your own choosing, say `r`, as follows:

```
>> r=8/10
r =
    0.8000
```

Spaces in the line improve its readability; for example, you can put a space before and after the `=` sign if you want. MATLAB ignores these spaces when making its calculations. It also ignores spaces surrounding `+` and `-` signs.

If you now type `r` at the prompt and press **Enter**, you will see

```
>> r
r =
    0.8000
```

thus verifying that the variable `r` has the value 0.8. You can use this variable in further calculations. For example,

```
>> s=20*r
s =
    16
```

A common mistake is to forget the multiplication symbol `*` and type the expression as you would in algebra, as  $s = 20r$ . If you do this in MATLAB, you will get an error message.

MATLAB has hundreds of functions available. One of these is the *square root* function, `sqrt`. A pair of parentheses is used after the function's name to enclose the value—called the function's *argument*—that is operated on by the function. For example, to compute the square root of 9, and assign its value to

---

**VARIABLE**

---



---

**ARGUMENT**

---

Table 1.1–1 Scalar arithmetic operations

Symbol	Operation	MATLAB form
$\wedge$	exponentiation: $a^b$	<code>a^b</code>
$*$	multiplication: $ab$	<code>a*b</code>
$/$	right division: $a/b = \frac{a}{b}$	<code>a/b</code>
$\backslash$	left division: $a\backslash b = \frac{b}{a}$	<code>a\b</code>
$+$	addition: $a + b$	<code>a+b</code>
$-$	subtraction: $a - b$	<code>a-b</code>

the variable `r`, you type `r = sqrt(9)`. Note that the previous value of `r` has been replaced by 3.

### Order of Precedence

---

#### SCALAR

---

A *scalar* is a single number. A *scalar variable* is a variable that contains a single number. MATLAB uses the symbols `+` `-` `*` `/` `^` for addition, subtraction, multiplication, division, and exponentiation (power) of scalars. These are listed in Table 1.1–1. For example, typing `x = 8 + 3*5` returns the answer `x = 23`. Typing `2^3-10` returns the answer `ans = -2`. The *forward slash* (`/`) represents *right division*, which is the normal division operator familiar to you. Typing `15/3` returns the result `ans = 5`.

MATLAB has another division operator, called *left division*, which is denoted by the *backslash* (`\`). The left division operator is useful for solving sets of linear algebraic equations, as we will see. A good way to remember the difference between the right and left division operators is to note that the slash slants toward the denominator. For example, `7/2 = 2\7 = 3.5`.

---

#### PRECEDENCE

---

The mathematical operations represented by the symbols `+` `-` `*` `/` `\`, and `^` follow a set of rules called *precedence*. Mathematical expressions are evaluated starting from the left, with the exponentiation operation having the highest order of precedence, followed by multiplication and division with equal precedence, followed by addition and subtraction with equal precedence. Parentheses can be used to alter this order. Evaluation begins with the innermost pair of parentheses, and proceeds outward. Table 1.1–2 summarizes these rules. For example, note the effect of precedence on the following session.

Table 1.1–2 Order of precedence

Precedence	Operation
First	Parentheses, evaluated starting with the innermost pair.
Second	Exponentiation, evaluated from left to right.
Third	Multiplication and division with equal precedence, evaluated from left to right.
Fourth	Addition and subtraction with equal precedence, evaluated from left to right.

---

```

>>8 + 3*5
ans =
    23
>>(8 + 3)*5
ans =
    55
>>4^2-12- 8/4*2
ans =
     0
>>4^2-12- 8/(4*2)
ans =
     3
>>3*4^2 + 5
ans =
    53
>>(3*4)^2 + 5
ans =
   149
>>27^(1/3) + 32^(0.2)
ans =
     5
>>27^(1/3) + 32^0.2
ans =
     5
>>27^1/3 + 32^0.2
ans =
    11

```

To avoid mistakes, feel free to insert parentheses wherever you are unsure of the effect precedence will have on the calculation. Use of parentheses also improves the readability of your MATLAB expressions. For example, parentheses are not needed in the expression  $8 + (3 * 5)$ , but they make clear our intention to multiply 3 by 5 before adding 8 to the result.

---

### Test Your Understanding

**T1.1-1** Use MATLAB to compute the following expressions.

a.  $6\left(\frac{10}{13}\right) + \frac{18}{5(7)} + 5(9^2)$

b.  $6(35^{1/4}) + 14^{0.35}$

(Answers: a. 410.1297 b. 17.1123.)

---