

MATLAB Fundamentals

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Reference:

1. *Applied Numerical Methods with MATLAB for Engineers*, Chapter 2 & Teaching material

Chapter Objectives

- Provide an introduction and overview of how MATLAB's calculator mode is used to implement interactive computations
 - Learning how real and complex numbers are assigned to variables
 - Learning how vectors and matrices are assigned values using simple assignment, the colon operator, and the `linspace` and `logspace` functions
 - Understanding the priority rules for constructing mathematical expressions
 - Gaining a general understanding of built-in functions and how you can learn more about them with MATLAB's Help facilities
 - Learning how to use vectors to create a simple line plot based on an equation

The MATLAB Environment

- MATLAB uses three primary windows:
 - Command window - used to enter commands and data
 - Graphics window(s) - used to display plots and graphics
 - Edit window - used to create and edit M-files (programs)
- Depending on your computer platform and the version of MATLAB used, these windows may have different looks and feels

Calculator Mode

- The MATLAB command window can be used as a calculator where you can type in commands line by line. Whenever a calculation is performed, MATLAB will assign the result to the built-in variable `ans`

- Example:

```
- >> 55 - 16
```

```
ans =
```

```
39
```

MATLAB Variables

- While using the `ans` variable may be useful for performing quick calculations, its transient nature makes it less useful for programming
- MATLAB allows you to assign values to variable names. This results in the storage of values to memory locations corresponding to the variable name
- MATLAB can store individual values as well as arrays; it can store numerical data and text (which is actually stored numerically as well)
- MATLAB does not require that you pre-initialize a variable; if it does not exist, MATLAB will create it for you

Scalars (1/3)

- To assign a single value to a variable, simply type the variable name, the = sign, and the value:

```
>> a = 4
```

```
a =
```

```
4
```

- Note that variable names must start with a letter, though they can contain letters, numbers, and the underscore (`_`) symbol

Scalars (2/3)

- You can tell MATLAB not to report the result of a calculation by appending the semi-solon (;) to the end of a line. The calculation is still performed
- You can ask MATLAB to report the value stored in a variable by typing its name:

```
>> a
```

```
a =
```

```
4
```

Scalars (3/3)

- You can use the complex variable i (or j) to represent the unit imaginary number
- You can tell MATLAB to report the values back using several different formats using the `format` command. Note that the values are still *stored* the same way, they are just displayed on the screen differently. Some examples are:
 - `short` - scaled fixed-point format with 5 digits
 - `long` - scaled fixed-point format with 15 digits for double and 7 digits for single
 - `short eng` - engineering format with at least 5 digits and a power that is a multiple of 3 (useful for SI prefixes)

Format Examples

```
>> format short; pi
ans =
    3.1416
>> format long; pi
ans =
    3.14159265358979
>> format short eng; pi
ans =
    3.1416e+000
>> pi*10000
ans =
    31.4159e+003
```

- Note - the format remains the same unless another `format` command is issued

A Summary of the format Commands

<i>type</i>	Result	Example
short	Scaled fixed-point format with 5 digits	3.1416
long	Scaled fixed-point format with 15 digits for double and 7 digits for single	3.14159265358979
short e	Floating-point format with 5 digits	3.1416e+000
long e	Floating-point format with 15 digits for double and 7 digits for single	3.141592653589793e+000
short g	Best of fixed- or floating-point format with 5 digits	3.1416
long g	Best of fixed- or floating-point format with 15 digits for double and 7 digits for single	3.14159265358979
short eng	Engineering format with at least 5 digits and a power that is a multiple of 3	3.1416e+000
long eng	Engineering format with exactly 16 significant digits and a power that is a multiple of 3	3.14159265358979e+000
bank	Fixed dollars and cents	3.14

Arrays, Vectors, and Matrices

- MATLAB can automatically handle rectangular arrays of data - one-dimensional arrays are called *vectors* and two-dimensional arrays are called *matrices*
- Arrays are set off using square brackets [and] in MATLAB
- Entries within a row are separated by **spaces** () or **commas** (,)
- Rows are separated by **semicolons** (;)

Array Examples

```
>> a = [1 2 3 4 5]
a =
     1     2     3     4     5
>> a = [1,2,3,4,5]
a =
     1     2     3     4     5
>> b = [2;4;6;8;10]
b =
     2
     4
     6
     8
    10
```

- **Note 1:** MATLAB does not *display* the brackets
- **Note 2:** If you are using a mono-spaced font, such as Courier, the displayed values should line up properly

Matrices

- A 2-D array, or matrix, of data is entered row by row, with **spaces** (or **commas**) separating entries within the row and **semicolons** separating the rows:

```
>> A = [1 2 3; 4 5 6; 7 8 9]
```

```
A =
```

```
    1    2    3
    4    5    6
    7    8    9
```

Useful Array Commands

- The transpose operator (apostrophe) can be used to flip an array over its own diagonal. For example, if b is a row vector, b' is a column vector containing the **complex conjugate** of b
- The command window will allow you to separate rows by hitting the **Enter** key - script files and functions will allow you to put rows on new lines as well
- The `who` command will report back used variable names; `whos` will also give you the size, memory, and data types for the arrays

Accessing Array Entries (1/2)

- Individual entries within an array can be both read and set using either the *index* of the location in the array or the row and column
- **The index value starts with 1** for the entry in the top left corner of an array and increases down a column - the following shows the indices for a 4-row, 3-column matrix:

1	5	9
2	6	10
3	7	11
4	8	12

Accessing Array Entries (2/2)

- Assuming some matrix C:

```
C =  
  2      4      9  
  3      3     16  
  3      0      8  
 10     13     17
```

- C (2) would report 3
- C (4) would report 10
- C (13) would report an error!
- Entries can also be access using the row and column:
 - C (2, 1) would report 3
 - C (3, 2) would report 0
 - C (5, 1) would report an error!

Array Creation - Built In

- There are several built-in functions to create arrays:
 - `zeros(r, c)` will create an `r` row by `c` column matrix of zeros
 - `zeros(n)` will create an `n` by `n` matrix of zeros
 - `ones(r, c)` will create an `r` row by `c` column matrix of ones
 - `ones(n)` will create an `n` by `n` matrix one ones
- `help elmat` has, among other things, a list of the elementary matrices

```
>> help elmat
Elementary matrices and matrix manipulation.

Elementary matrices.
zeros      - Zeros array.
ones       - Ones array.
eye        - Identity matrix.
repmat     - Replicate and tile array.
linspace   - Linearly spaced vector.
logspace   - Logarithmically spaced vector.
freqspace  - Frequency spacing for frequency response.
meshgrid   - X and Y arrays for 3-D plots.
accumarray - Construct an array with accumulation.
:          - Regularly spaced vector and index into matrix.
```

Array Creation - Colon Operator

- The **colon** operator (:) is useful in several contexts. It can be used to create a linearly spaced array of points using the notation

```
start:diffval:limit
```

- where `start` is the first value in the array, `diffval` is the difference between successive values in the array, and `limit` is the *boundary* for the last value (**though not necessarily the last value**)

```
>>1:0.6:3
```

```
ans =
```

```
1.0000    1.6000    2.2000    2.8000
```

```
>>A=1:0.6:3
```

```
A =
```

```
1.0000    1.6000    2.2000    2.8000
```

Colon Operator - Notes

- If `diffval` is omitted, the default value is 1:

```
>>3:6
```

```
ans =
```

```
     3     4     5     6
```

- To create a decreasing series, `diffval` must be negative:

```
>> 5:-1.2:2
```

```
ans =
```

```
     5.0000     3.8000     2.6000
```

- If `start+diffval>limit` for an increasing series or `start+diffval<limit` for a decreasing series, an empty matrix is returned:

```
>>5:2
```

```
ans =
```

```
Empty matrix: 1-by-0
```

- To create a column, transpose the output of the colon operator, not the limit value; that is, `(3:6)'` not `3:6'`

Array Creation - `linspace`

- To create a row vector with a specific number of linearly spaced points between two numbers, use the `linspace` command
- `linspace(x1, x2, n)` will create a linearly spaced array of `n` points between `x1` and `x2`

```
>>linspace(0, 1, 6)  
ans =  
    0    0.2000    0.4000    0.6000    0.8000  
    1.0000
```
- If `n` is omitted, 100 points are created
- To generate a column, transpose the output of the `linspace` command

Array Creation - logspace

- To create a row vector with a specific number of logarithmically spaced points between two numbers, use the `logspace` command
- `logspace(x1, x2, n)` will create a logarithmically spaced array of n points between 10^{x1} and 10^{x2}

```
>>logspace(-1, 2, 4)  
ans =  
    0.1000    1.0000   10.0000  100.0000
```
- If n is omitted, 100 (50?) points are created
- To generate a column, transpose the output of the `logspace` command

More on logspace

```
>> logspace(-1, 2)

ans =

Columns 1 through 15

    0.1000    0.1151    0.1326    0.1526    0.1758    0.2024    0.2330    0.2683    0.3089    0.3556    0.4095    0.4715    0.5429    0.6251    0.7197

Columns 16 through 30

    0.8286    0.9541    1.0985    1.2649    1.4563    1.6768    1.9307    2.2230    2.5595    2.9471    3.3932    3.9069    4.4984    5.1795    5.9636

Columns 31 through 45

    6.8665    7.9060    9.1030    10.4811    12.0679    13.8950    15.9986    18.4207    21.2095    24.4205    28.1177    32.3746    37.2759    42.9193    49.4171

Columns 46 through 50

    56.8987    65.5129    75.4312    86.8511    100.0000
```

fx >>

Character Strings & Ellipsis

- Alphanumeric constants are enclosed by apostrophes (')

```
>> f = 'Miles ';
```

```
>> s = 'Davis'
```

- Concatenation: pasting together of strings

```
>> x = [f s]
```

```
x =
```

```
Miles Davis
```

- Ellipsis (...): Used to continue long lines

```
>> a = [1 2 3 4 5 ...
```

```
6 7 8]
```

```
a =
```

```
1      2      3      4      5      6      7      8
```

- You cannot use an ellipsis within single quotes to continue a string. But you can piece together shorter strings with ellipsis

```
>> quote = ['Any fool can make a rule,' ...
```

```
' and any fool will mind it']
```

```
quote =
```

```
Any fool can make a rule, and any fool will mind it
```

Mathematical Operations

- Mathematical operations in MATLAB can be performed on both scalars and arrays
- The common operators, in order of priority, are:

^	Exponentiation	$4^2 = 8$
-	Negation (unary operation)	$-8 = -8$
* /	Multiplication and Division	$2*\pi = 6.2832$ $\pi/4 = 0.7854$
\	Left Division	$6\backslash 2 = 0.3333$
+ -	Addition and Subtraction	$3+5 = 8$ $3-5 = -2$

Order of Operations

- The order of operations is set first by **parentheses**, then by the default order given above:
 - $y = -4^2$ gives $y = -16$
since the exponentiation happens first due to its higher default priority, but
 - $y = (-4)^2$ gives $y = 16$
since the negation operation on the 4 takes place first

Complex Numbers

- All the operations above can be used with complex quantities (i.e. values containing an imaginary part entered using i or j and displayed using i)

```
>> x = 2+i*4; (or 2+4i, or 2+j*4, or 2+4j)
>> y = 16;
>> 3 * x
ans =
    6.0000 + 12.0000i
>> x+y
ans =
    18.0000 + 4.0000i
>> x'
ans =
    2.0000 - 4.0000i
```

Vector-Matrix Calculations

- MATLAB can also perform operations on vectors and matrices
- The `*` operator for matrices is defined as the *outer product* or what is commonly called “matrix multiplication”
 - The number of columns of the first matrix must match the number of rows in the second matrix
 - The size of the result will have as many rows as the first matrix and as many columns as the second matrix
 - The exception to this is multiplication by a 1x1 matrix, which is actually an array operation
- The `^` operator for matrices results in the matrix being matrix-multiplied by itself a specified number of times.
 - Note - in this case, the matrix must be square!

Element-by-Element Calculations

- At times, you will want to carry out calculations item by item in a matrix or vector. The MATLAB manual calls these *array operations*. They are also often referred to as *element-by-element* operations
- MATLAB defines `.*` and `./` (note the dots) as the array multiplication and array division operators
 - For array operations, both matrices must be the same size *or* one of the matrices must be 1x1
- Array exponentiation (raising each element to a corresponding power in another matrix) is performed with `.^`
 - Again, for array operations, both matrices must be the same size *or* one of the matrices must be 1x1

Built-In Functions

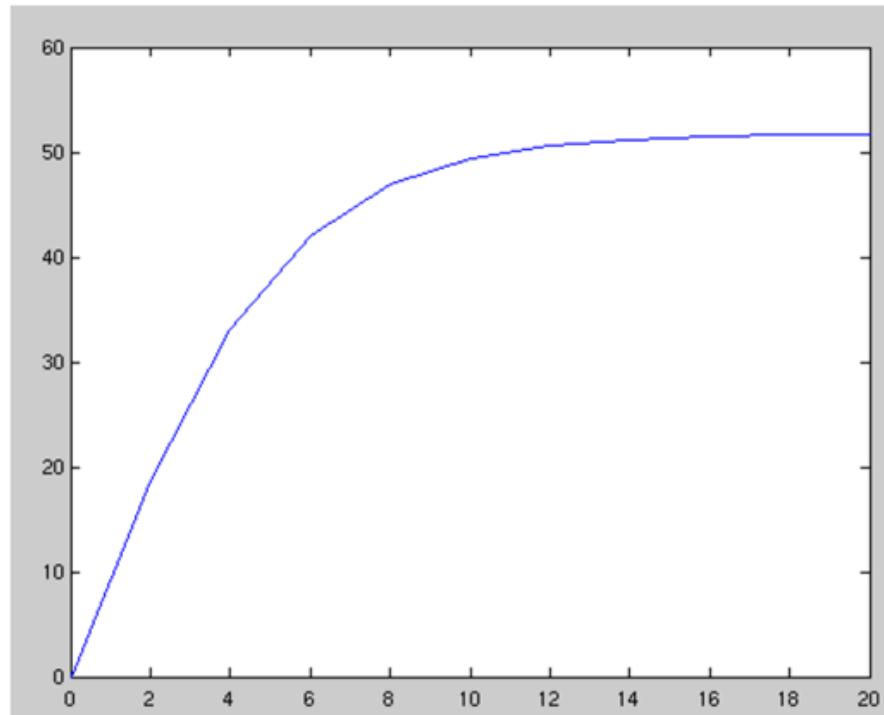
- There are several built-in functions you can use to create and manipulate data
- The built-in **help** function can give you information about both what exists and how those functions are used:
 - **help elmat** will list the elementary matrix creation and manipulation functions, including functions to get information about matrices
 - **help elfun** will list the elementary math functions, including trig, exponential, complex, rounding, and remainder functions
- The built-in **lookfor** command will search help files for occurrences of text and can be useful if you know a function's purpose but not its name

Graphics

- MATLAB has a powerful suite of built-in graphics functions
- Two of the primary functions are `plot` (for plotting 2-D data) and `plot3` (for plotting 3-D data)
- In addition to the plotting commands, MATLAB allows you to label and annotate your graphs using the `title`, `xlabel`, `ylabel`, and `legend` commands

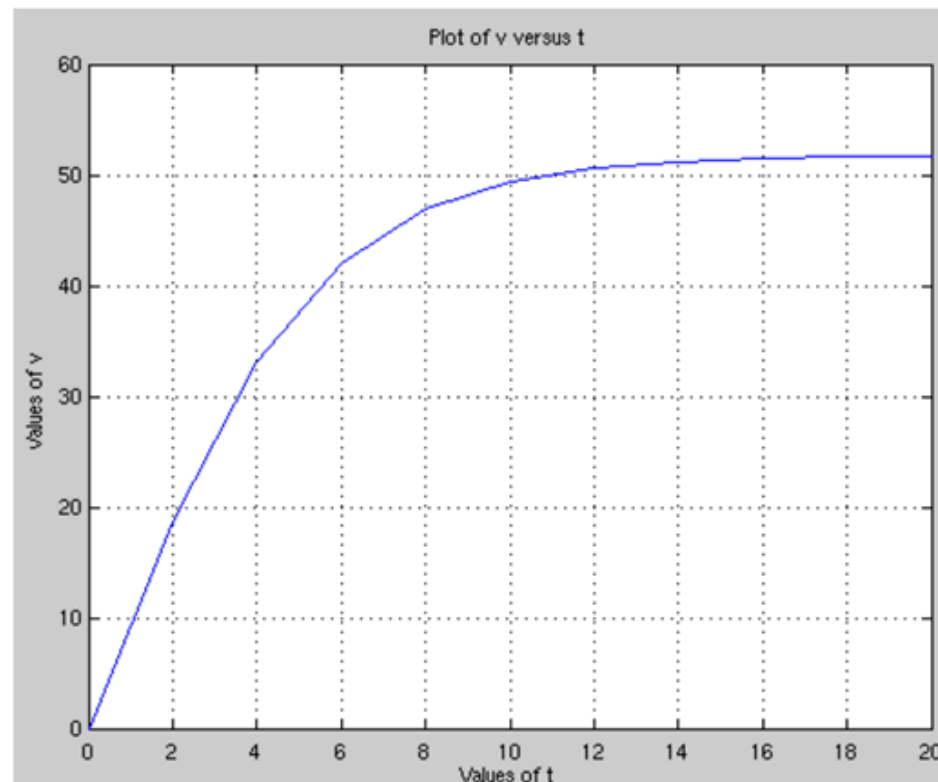
An Example of Plotting

```
t = [0:2:20]';  
g = 9.81; m = 68.1; cd = 0.25;  
v = sqrt(g*m/cd) * tanh(sqrt(g*cd/m)*t);  
plot(t, v)
```



Annotation of a Plot

```
title('Plot of v versus t')  
xlabel('Values of t')  
ylabel('Values of v')  
grid
```



Plotting Options (1/2)

- When plotting data, MATLAB can use several different colors, point styles, and line styles. These are specified at the end of the `plot` command using *plot specifiers* as found in Table 2.2
- The default case for a single data set is to create a blue line with no points. If a line style is specified with no point style, no point will be drawn at the individual points; similarly, if a point style is specified with no point style, no line will be drawn
- Examples of plot specifiers:
 - ‘ro:’ - red dotted line with circles at the points
 - ‘gd’ - green diamonds at the points with no line
 - ‘m--’ - magenta dashed line with no point symbols

Plotting Options (2/2)

TABLE 2.2 Specifiers for colors, symbols, and line types.

Colors		Symbols		Line Types	
Blue	b	Point	.	Solid	—
Green	g	Circle	o	Dotted	⋯
Red	r	X-mark	x	Dashdot	-.
Cyan	c	Plus	+	Dashed	--
Magenta	m	Star	*		
Yellow	y	Square	s		
Black	k	Diamond	d		
White	w	Triangle(down)	v		
		Triangle(up)	^		
		Triangle(left)	<		
		Triangle(right)	>		
		Pentagram	p		
		Hexagram	h		

More on Plotting Commands

- hold on and hold off
 - hold on tells MATLAB to keep the current data plotted and add the results of any further plot commands to the graph. This continues until the hold off command, which tells MATLAB to clear the graph and start over if another plotting command is given. hold on should be used after the first plot in a series is made.
- subplot(m, n, p)
 - subplot splits the figure window into an $m \times n$ array of small axes and makes the p th one active. Note - the first subplot is at the top left, then the numbering continues across the row. This is different from how elements are numbered within a matrix!

Example: Plotting a Helix

```
>> t=0:pi/50:10*pi;  
>> subplot(1,2,1);plot(sin(t),cos(t));  
>> axis square;  
>> title('(a)');  
>> grid  
>> subplot(1,2,2);plot3(sin(t),cos(t),t);  
>> title('(b)');  
>> grid
```

