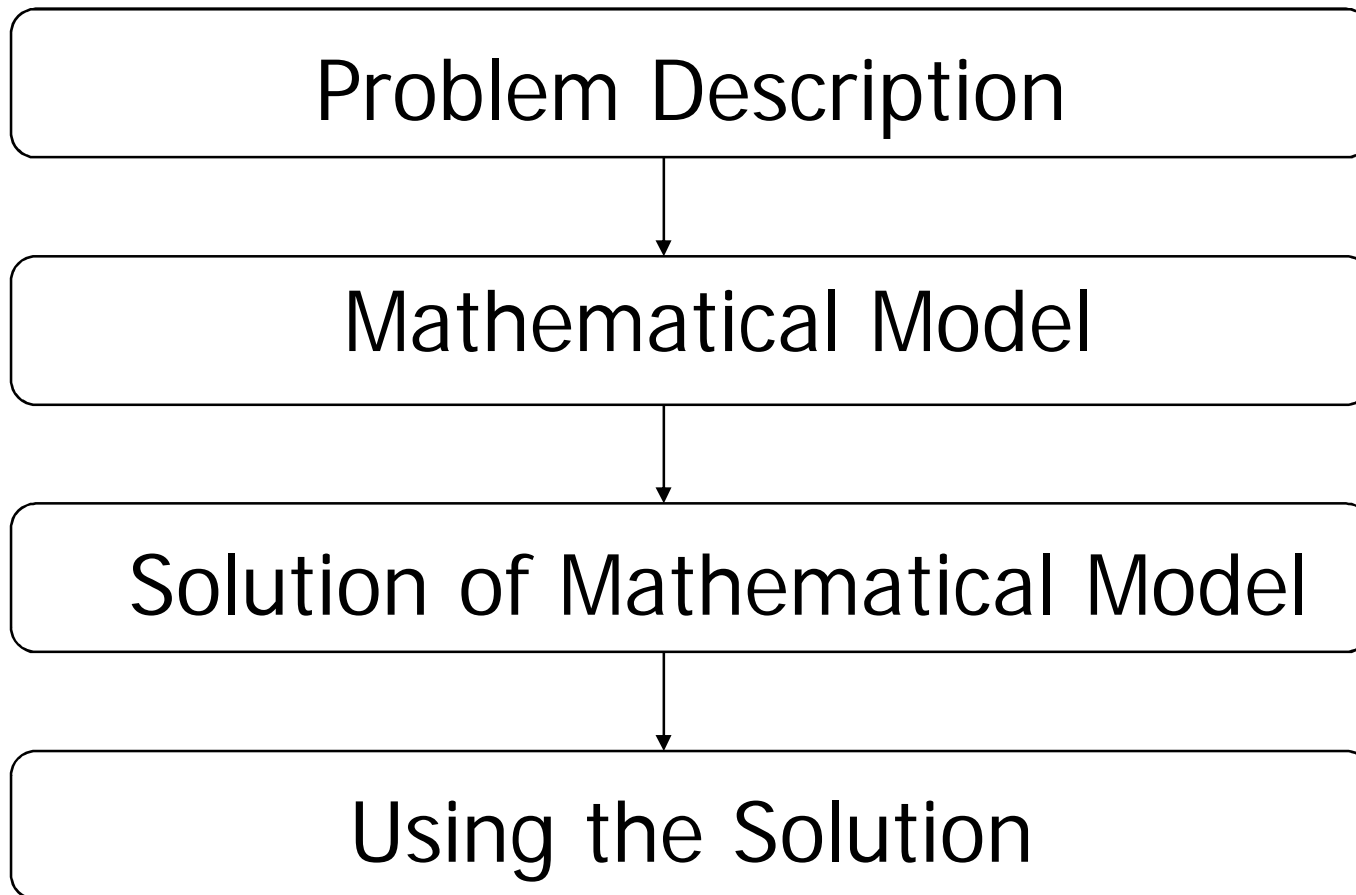


# **Numerical Methods**

## **Introduction**

# How do we solve an engineering problem?



# Introduction

- Consider the following equations.

## ■ Solve

$$\frac{dy}{dx}(x^2 - \sin(x))$$

$$\int x^3 + x - e^x$$

$$ax^2 + bx + c = 0$$

$$F = \int_0^{30} \left( \frac{\cos(z) + z}{5 + z} \right) e^{-2z/30} dz$$

$$\frac{x}{1 + \sin(x)} + e^x = 0$$

# Numerical Methods - Definitions

## Numerical Methods

- Numerical methods are techniques by which mathematical problems are formulated so that they can be solved with arithmetic operations.
- Numerical methods involve large numbers of tedious arithmetic calculations.
- These methods have gained popularity due to the advancements in efficient computational tools such as digital computers and calculators.

# Numerical Methods

## Noncomputer methods

- **Analytical** or exact methods
- **Graphical** solutions used to solve complex problems but the results are not very precise. They are extremely tedious without computers → limited problems.
- **Calculators**

# Analytical vs. Numerical methods

## Examples: Analytical Methods

– Differentiation

$$\frac{dy}{dx}(x^2 - \sin(x)) = 2x - \cos(x)$$

– Integration

$$\int x^3 + x - e^x = \frac{x^4}{4} + \frac{x^2}{2} - e^x + c$$

– Root(s) of an Equation

$$ax^2 + bx + c = 0 \Rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

# Analytical vs. Numerical methods

## Need for Numerical Methods

- In general, there are few analytical (closed-form) solutions for many practical engineering problems.
- Numerical methods can handle:
  - Large systems of equations
  - Non-linearity
  - Complicated geometries that are common in engineering practice and that are often impossible to solve analytically.

Examples:

$$F = \int_0^{30} \left( \frac{\cos(z) + z}{5 + z} \right) e^{-2z/30} dz$$

$$\frac{x}{1 + \sin(x)} + e^x = 0$$



# Reasons to study numerical Analysis

- Powerful problem solving techniques and can be used to handle large systems of equations
- It enables you to intelligently use the commercial software packages as well as designing your own algorithm.
- Numerical Methods are efficient vehicles in learning to use computers
- It Reinforce your understanding of mathematics; where it reduces higher mathematics to basic arithmetic operation.



# Mathematical Modeling

## Mathematical Model

- A formulation or equation that expresses the essential features of a physical system or process in mathematical terms.
- Generally, it can be represented as a functional relationship of the form

$$\text{Dependent variable} = f\left(\text{independent variable}, \text{parameters}, \text{forcing functions}\right)$$

# Mathematical Modeling

$$\text{Dependent variable} = f\left(\text{independent variable}, \text{parameters}, \text{forcing functions}\right)$$

Dependent variable =	A characteristic that usually reflects the behavior or state of the system
Independent variables =	Are usually dimensions, such as time and space
Parameters =	Are reflective of system's properties or compositions
Forcing functions =	Are external influences acting on the system

# Simple Mathematical Model

## Example: Newton's Second Law

(The time rate of change of momentum of a body is equal to the resultant force acting on it)

$$F = ma \quad \text{or} \quad a = \frac{F}{m}$$

- $a$  = acceleration ( $\text{m/s}^2$ ) ....**the dependent variable**
- $m$  = mass of the object (kg) ....**the parameter** representing a property of the system.
- $f$  = **force** acting on the body (N)

# Typical characteristics of Math. model

- It describes a natural process or system in mathematical way
- It represents the idealization and simplification of reality.
- It yields reproducible results, and can be used for predictive purpose.

# Complex Mathematical Model

## Example: Newton's Second Law

$$m \frac{dv}{dt} = F$$

$$F = F_D + F_U$$

$$F_D = mg$$

$$F_U = -cv$$

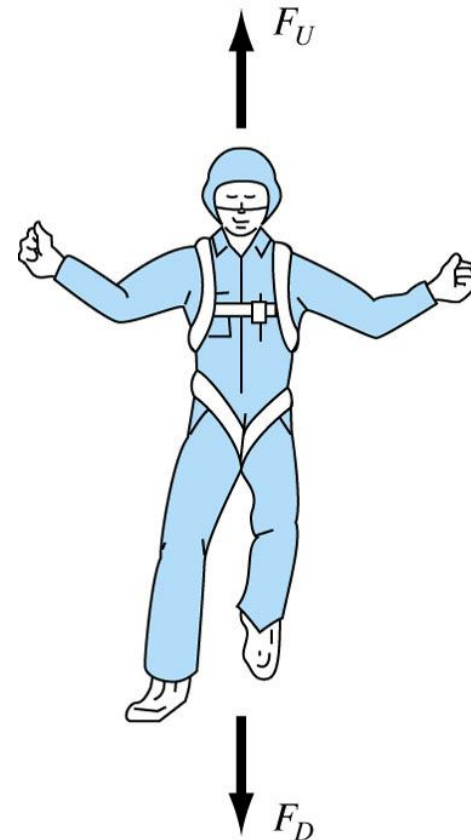
$F_D$  = downward force due  
to gravity

$F_U$  = upward force due air  
resistance

Where:

$c$  = drag coefficient (kg/s),

$v$  = falling velocity (m/s)



# Complex Mathematical Model

$$m \frac{dv}{dt} = F_D + F_U$$

$$= mg - cv$$

$$\frac{dv}{dt} = g - \frac{c}{m} v$$

At rest: ( $v = 0$  at  $t = 0$ ),

Calculus can be used to solve the equation



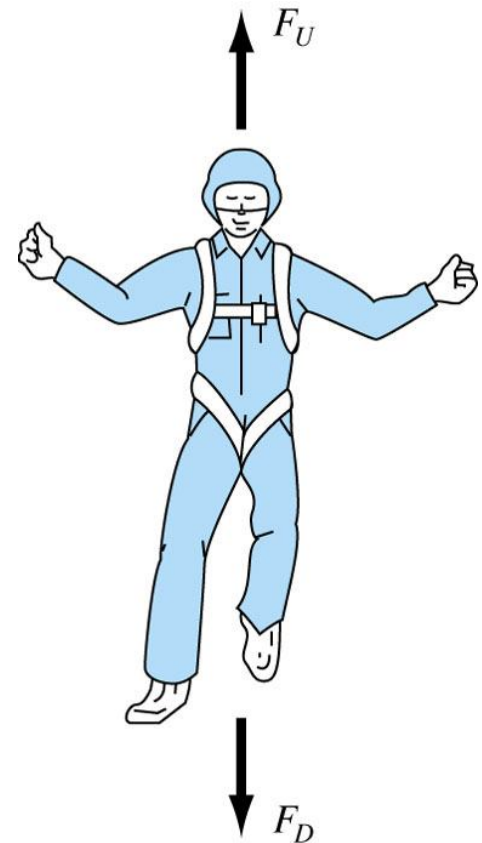
$$v(t) = \frac{gm}{c} \left[ 1 - e^{-(c/m)t} \right]$$



# Analytical solution to Newton's Second Law

A parachutist with a mass of 68.1 kg jumps out of a stationary hot-air balloon. Compute the velocities  $v$  in an increment of 2 seconds prior to the opening of the chute. Use a drag coefficient value of 12.5 kg/s, and tabulate your values.

$$v(t) = \frac{gm}{c} \left[ 1 - e^{-(c/m)t} \right]$$



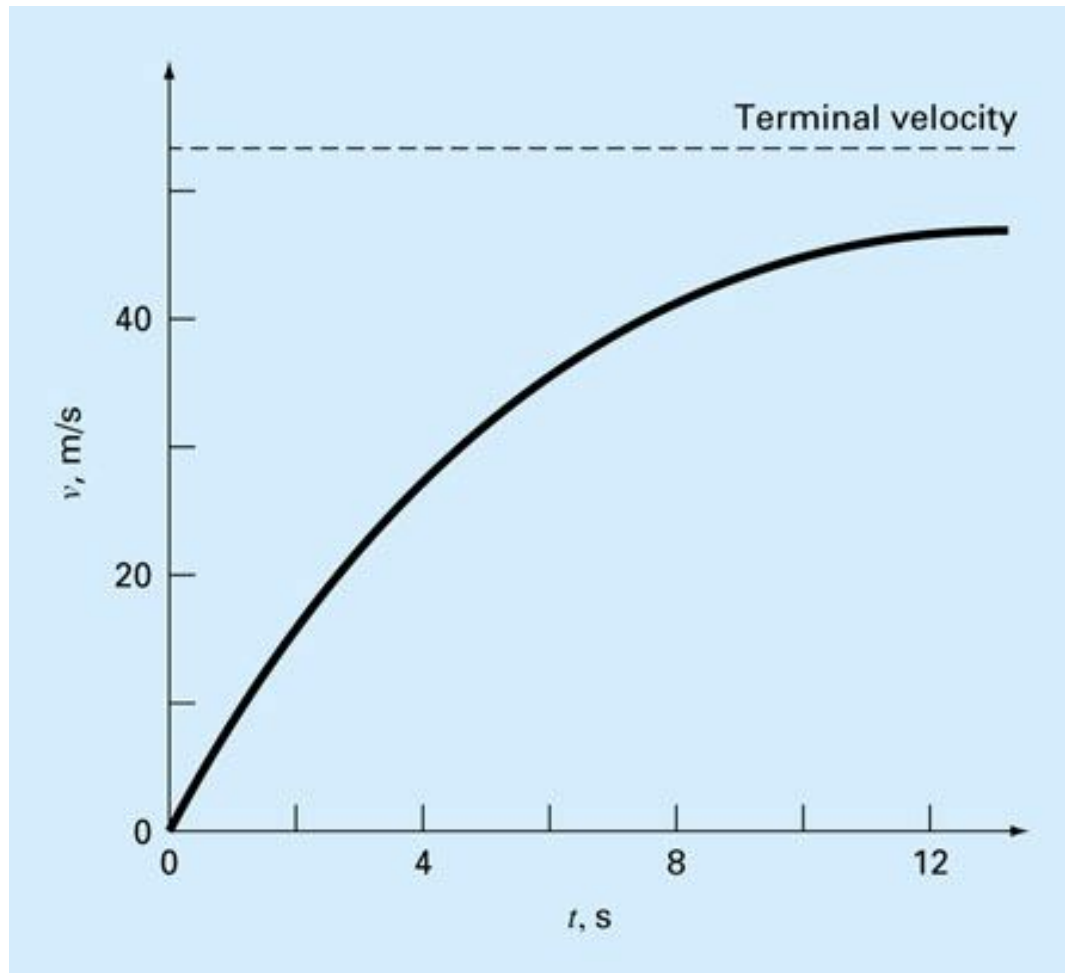


## Analytical solution to Newton's Second Law

$$v = \frac{9.8(68.1)}{12.5} \left[ 1 - e^{-(12.5/68.1)t} \right]$$
$$= 53.3904 \left( 1 - e^{-0.18355t} \right)$$

$t$ (s)	$v$ (m/s)
0	0
2	16.405
4	27.7693
6	35.6418
8	41.0953
10	44.8731
12	47.4902
$\infty$	53.3904

# Analytical solution to Newton's Second Law



## Numerical Solution to Newton's Second Law

- Numerical solution: approximates the exact solution by arithmetic operations.

- Suppose  $\frac{dv}{dt} \approx \frac{\Delta v}{\Delta t} = \frac{v(t_{i+1}) - v(t_i)}{t_{i+1} - t_i}$

$$\left. \frac{dv}{dt} = g - \frac{c}{m}v \right| \Rightarrow \frac{v(t_{i+1}) - v(t_i)}{t_{i+1} - t_i} = g - \frac{c}{m}v$$

$$v(t_{i+1}) = v(t_i) + \left[ g - \frac{c}{m}v(t_i) \right] (t_{i+1} - t_i) \quad (4)$$

New value = old value + slope X step size

## Numerical Solution to Newton's Second Law

$$v(t_{i+1}) = v(t_i) + \left[ g - \frac{c}{m} v(t_i) \right] (t_{i+1} - t_i)$$

At  $t_i = 0$ , the velocity of the parachutist is zero.

Using this information and the parameter values from Example 1, Eq. 4 can be used to compute the velocity at  $t_{i+1} = 2$  seconds, that is

$$v = 0 + \left[ 9.8 - \frac{12.5}{68.1} (0) \right] (2 - 0) = 19.60 \text{ m/s}$$

## Numerical Solution to Newton's Second Law

For the next interval (from  $t = 2$  to  $4$  s), the computation is repeated, with the following result

$$v = 19.60 + \left[ 9.8 - \frac{12.5}{68.1}(19.60) \right](4 - 2) = 32.00 \text{ m/s}$$

The calculation is continued in a similar fashion to obtain additional values as shown the next viewgraph:

$$v(t_{i+1}) = v(t_i) + \left[ 9.8 - \frac{12.5}{68.1}v(t_i) \right](t_{i+1} - t_i)$$

$t$ (s)	$v$ (m/s)
0	0.000
2	19.600
4	32.005
6	39.856
8	44.824
10	47.969
12	49.959
$\infty$	53.390

# Comparison between Analytical vs. Numerical Solution

