EEE 703

CONTROL SYSTEM I

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INTRODUCTION

Control Systems are an integral part of modern society

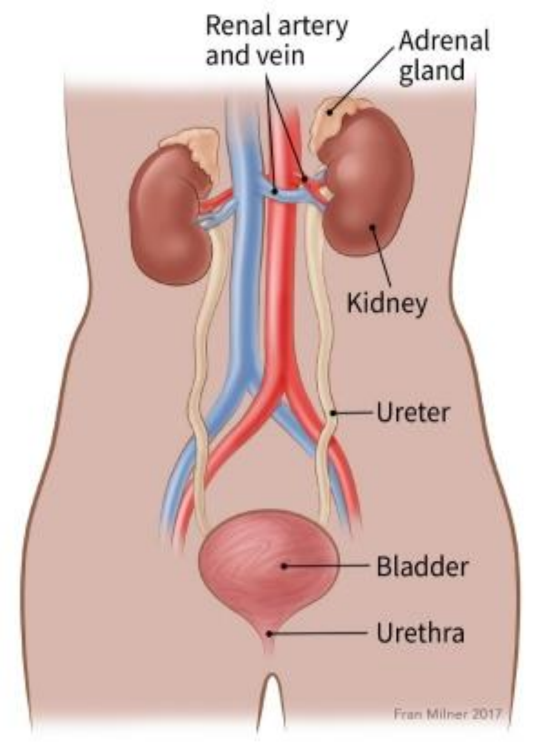
Even our body owns Control System

- **Pancreas**
  - Regulates our blood sugar

Which hormone is secreted when you are afraid?

❑Adrenaline

- Causes increase in heart rate causing more oxygen to be delivered to our cells.



DEFINITION

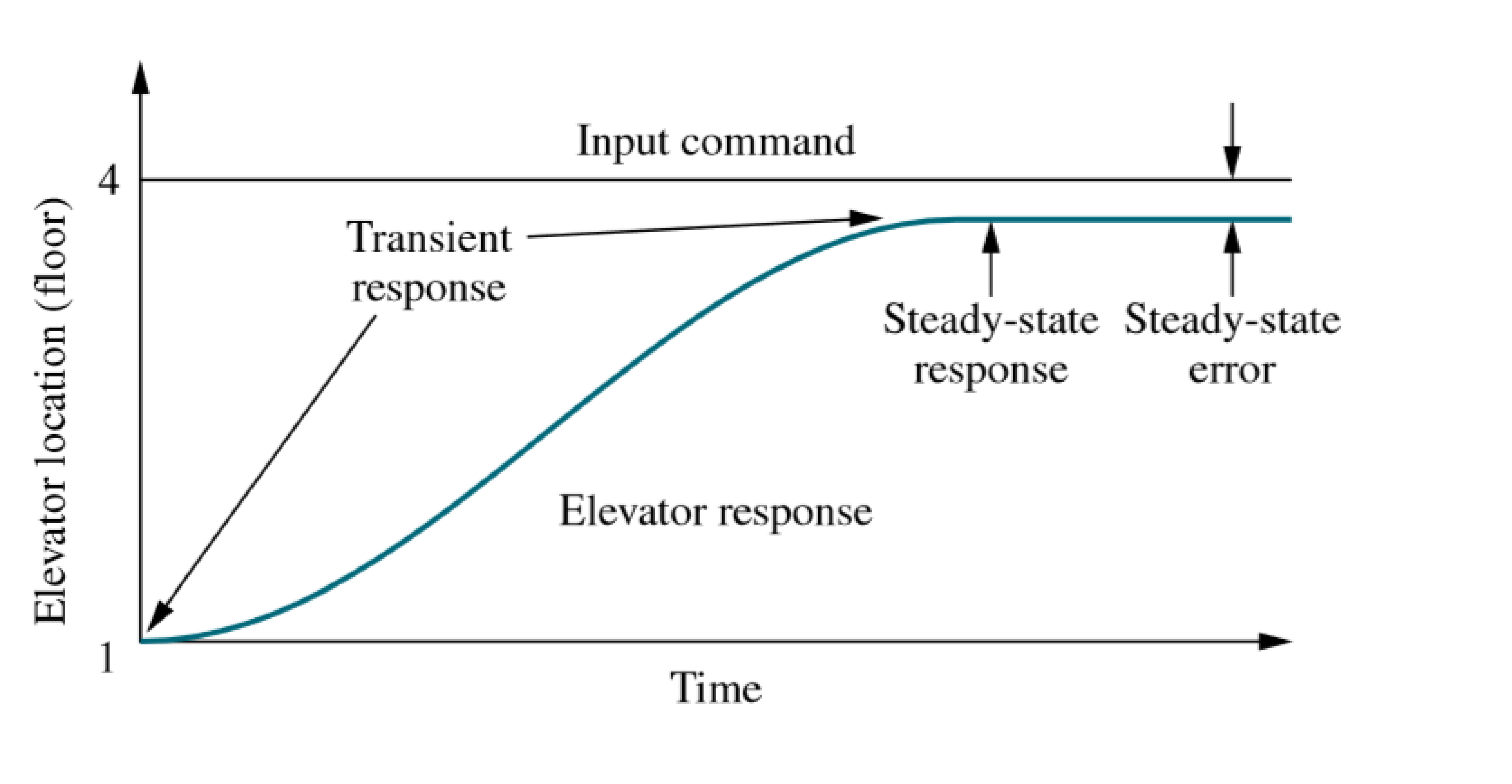
- A control system consists of subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input. Figure 1.1 shows a control system in its simplest form, where the input represents a desired output

FIGURE 1.1 Simplified description of a control system

Two major performances are apparent

1. Transient Response
2. Steady State error

Consider an elevator going at 4th Floor



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Comfort and Patience

If Transient Response is too fast

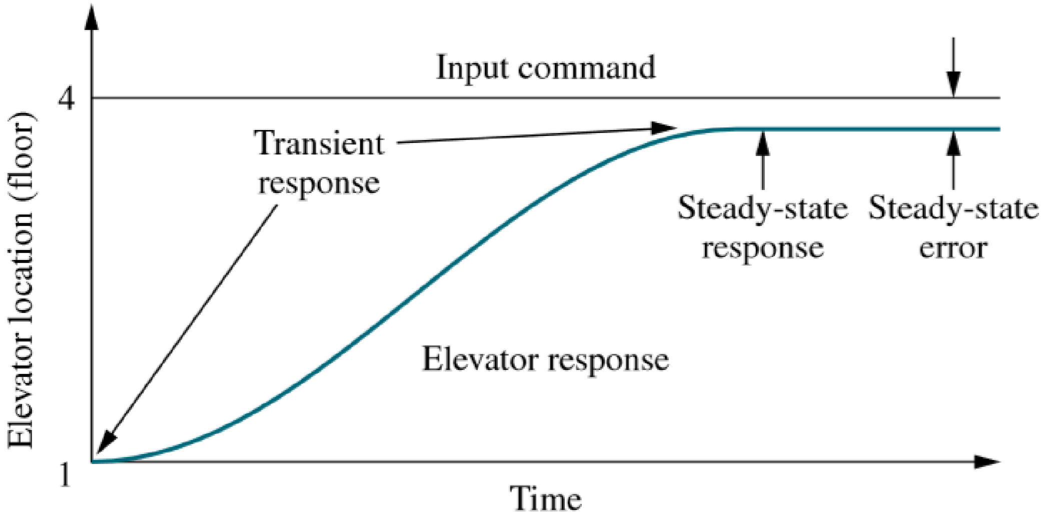
- Good for PATIENCE
- But COMFORT is compromised

If Transient Response is too slow

- Good for COMFORT
- But PATIENCE is compromised

Steady State Error

- Passenger SAFETY would be sacrificed if the elevator did not level properly



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Advantages of Control System

1. Power Amplification

- A radar antenna positioned by the low-power rotation of a knob at the input, requires a large amount of power for its output rotation. A control system can produce the needed power amplification, or power gain

2. Remote Control

- Robots designed by control system principles can compensate for human disabilities. Control systems are also useful in remote or dangerous locations. For example, a remote-controlled robot arm can be used to pick up material in a radioactive environment. Figure 1.4 shows a robot arm designed to work in contaminated environments.

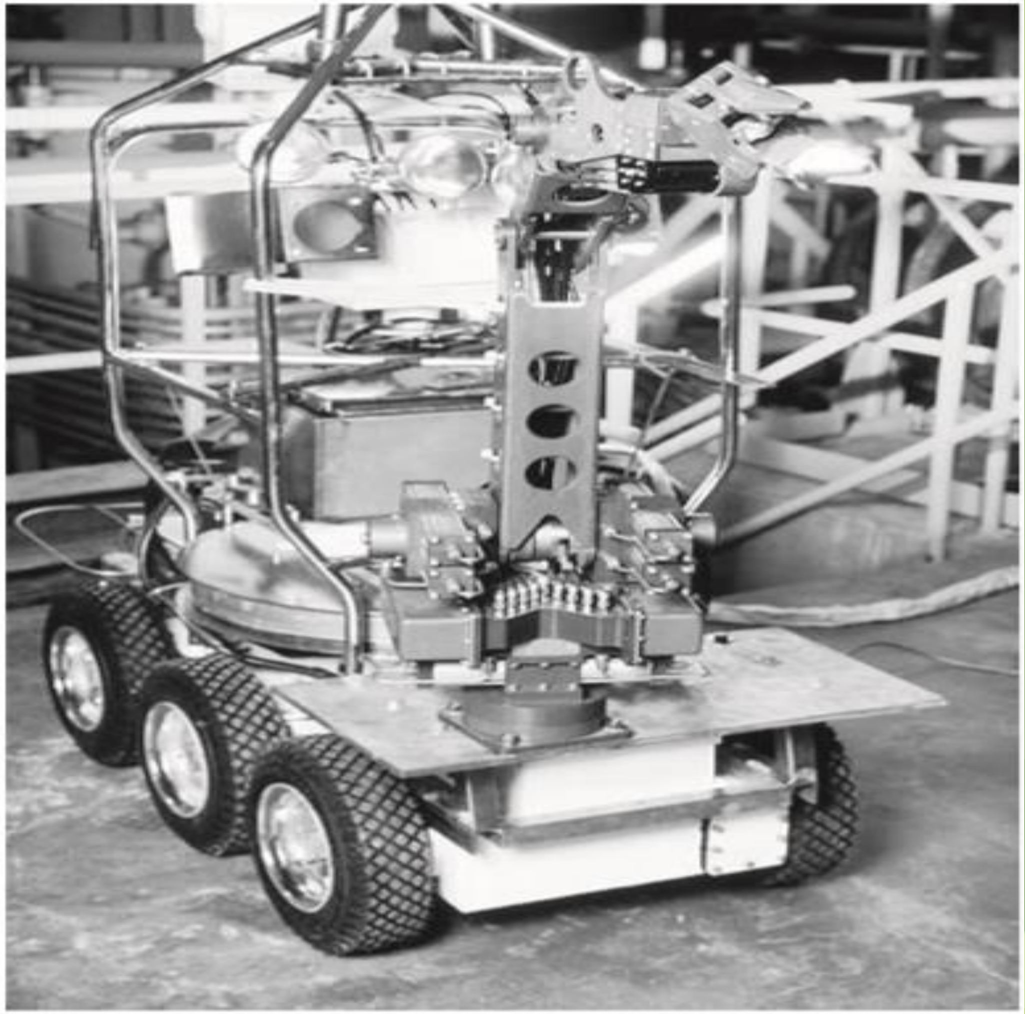


FIGURE 1.4 *Rover* was built to work in contaminated areas at Three Mile Island in Middleton, Pennsylvania, where a nuclear accident occurred in 1979. The remote-controlled robot's long arm can be seen at the front of the vehicle.

3. Convenience of input form

- Control systems can also be used to provide convenience by changing the form of the input. For example, in a temperature control system, the input is a position on a thermostat. The output is heat. Thus, a convenient position input yields a desired thermal output

4. Compensation for disturbances

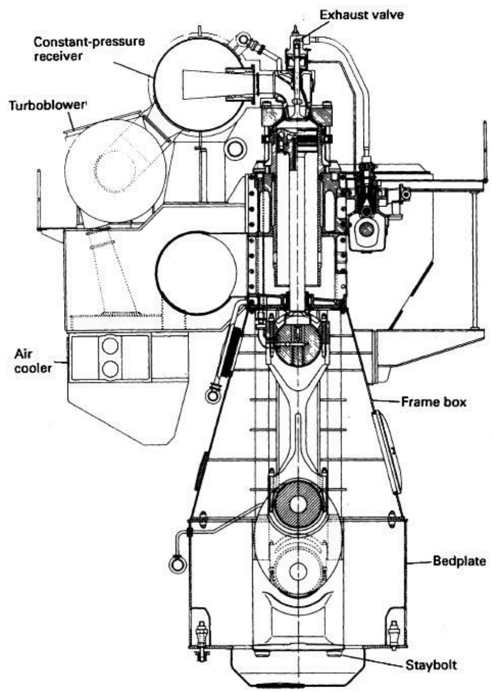
- If wind flow exceeds limits the plant automatically shuts down.

A History of Control System

- In 1745 speed control was applied to a windmill by Edmund Lee.
  - As the wind decreased more blade area was available.

Safety Valve

- During 1681 Denis Papin invented safety valve.



Flyball Governor

- Also in the eighteenth century, James Watt invented the Flyball speed governor to control the speed of steam engines. In this device, two spinning flyballs rise as rotational speed increases. A steam valve connected to the flyball mechanism closes with the ascending flyballs and opens with the descending flyballs, thus regulating the speed

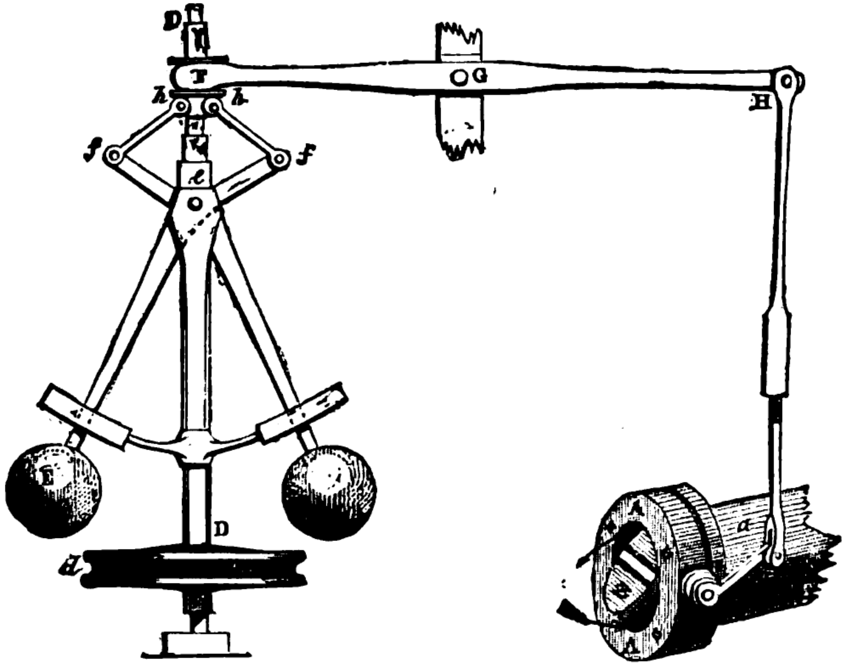
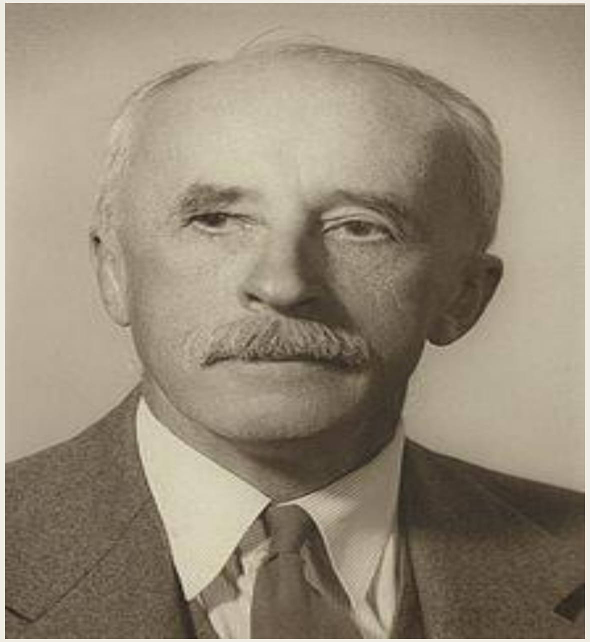


FIG. 4.—*Governor and Throttle-Valve.*

20th Century Developments

- Nicholas Minorsky (Russia)
  - *The theoretical development of automatic steering of ship in 1922 led to what we call now* ***Proportion-plus-Integral-plus-Derivative (PID) or Three Mode Controller.***



Bode and Nyquist

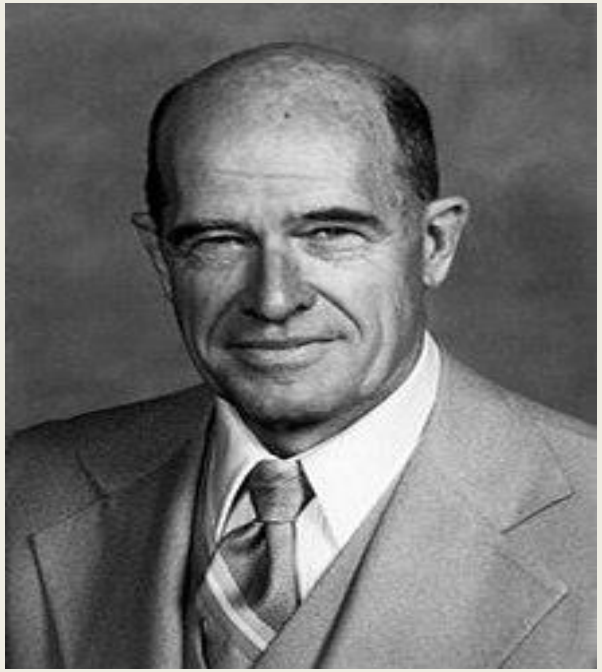
- In the late 1920s and early 1930s, *Hendrik Wade Bode* and *Harry Nyquist* at Bell Telephone Laboratories developed the analysis of feedback amplifiers.

H. W. Bode

H. Nyquist

The Root Locus Method

- In 1948, *Walter R. Evans*, working in the aircraft industry, developed a graphical technique to plot the roots of a characteristic equation of a feedback system whose parameters changed over a particular range of values. This technique, now known as the *Root Locus*, takes its place with the work of Bode and Nyquist in forming the foundation of linear control systems analysis and design theory.



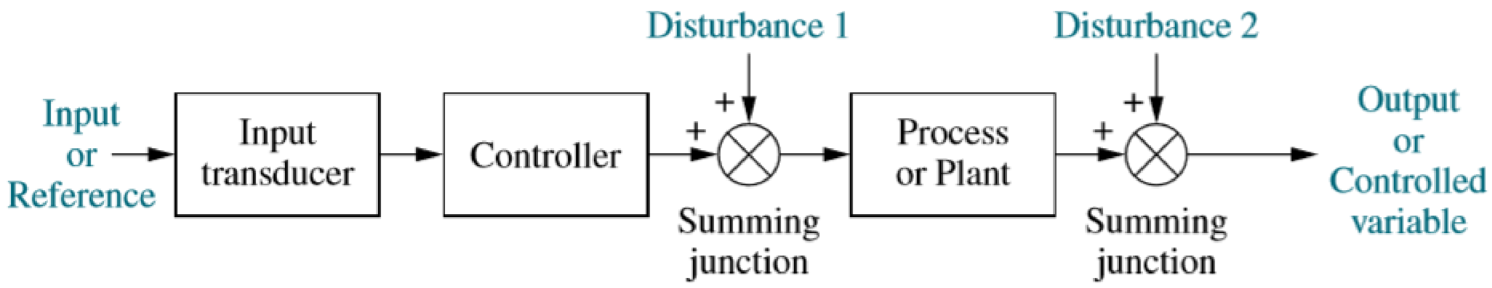
Walter R. Evans

System Configuration

1. Open Loop
2. Closed Loop

OPEN LOOP

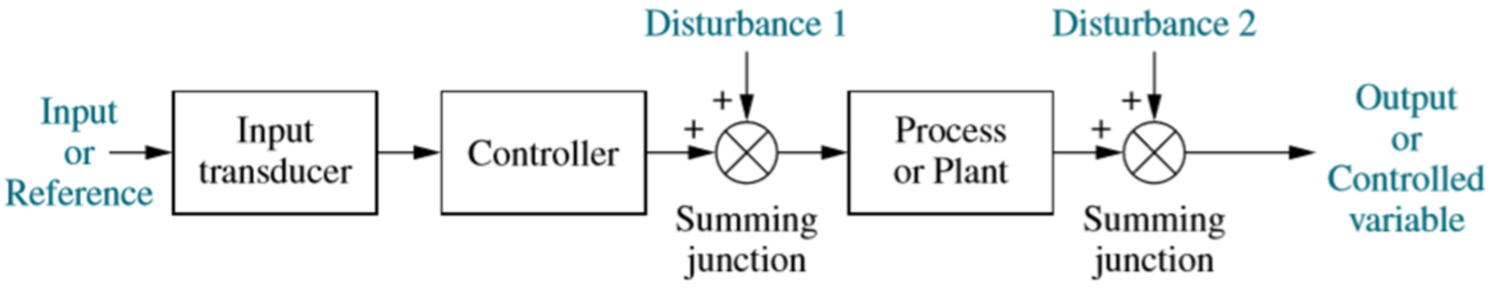
A generic open-loop system is shown in Figure (a). It starts with a subsystem called an *input transducer*, which converts the form of the input to that used by the *controller*. The controller drives a process or a plant. The input is sometimes called the *reference*, while the output can be called the *controlled variable.* Other signals, such as *disturbances*, are shown added to the controller and process outputs via summing junctions, which yield the algebraic sum of their input signals using associated signs.



(*a*)

Open Loop (Contd….)

- The distinguishing characteristic of an open-loop system is that it cannot compensate for any disturbances that add to the controller’s driving signal.



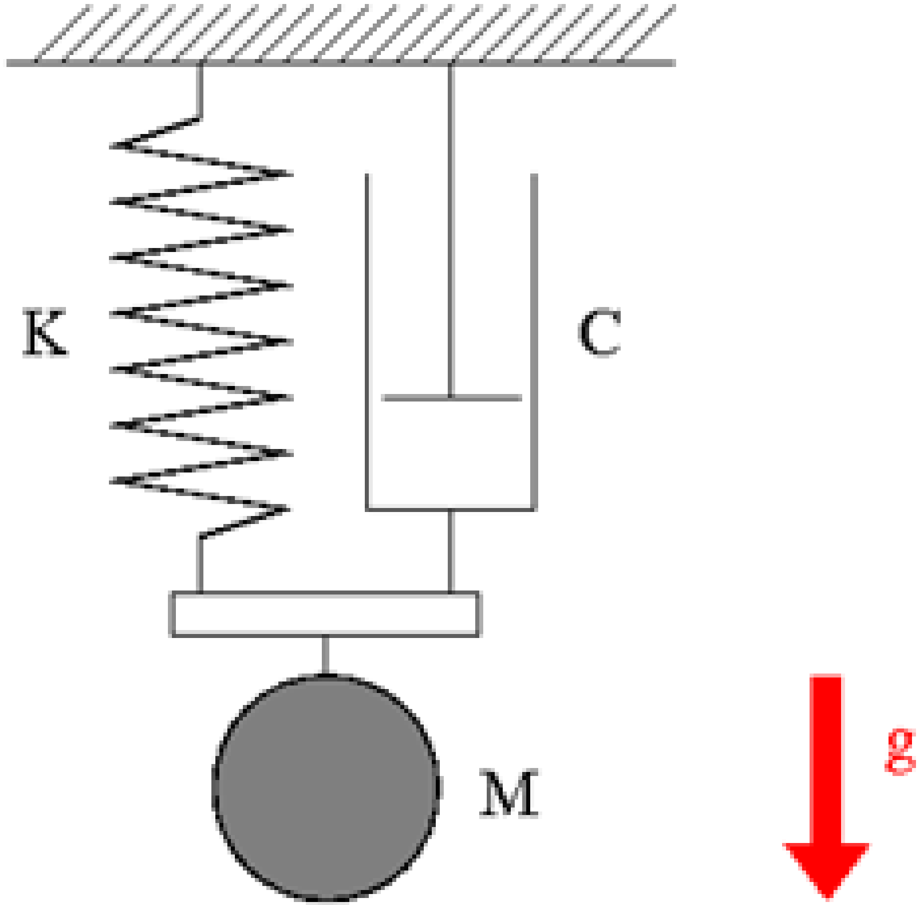
(a)

Open Loop Example

Toasters are open-loop systems, as anyone with burnt toast can attest. The controlled variable (output) of a toaster is the color of the toast. The device is designed with the assumption that the toast will be darker the longer it is subjected to heat. The toaster does not measure the color of the toast.

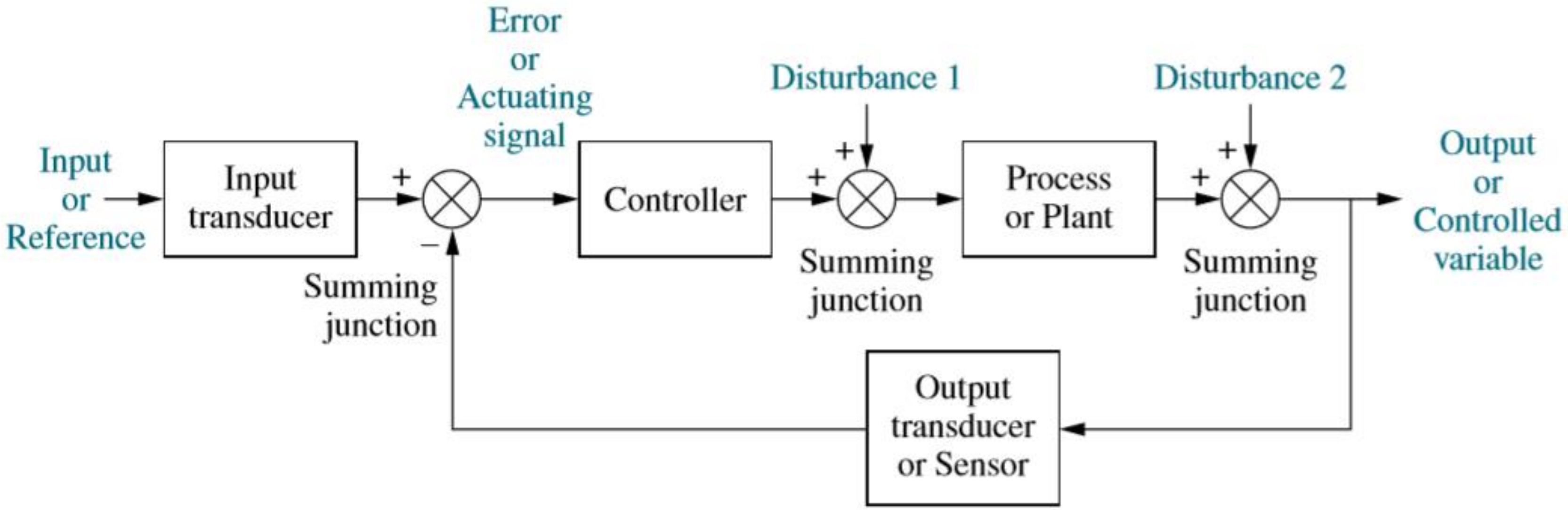
Open Loop Example

Other examples of open-loop systems are mechanical systems consisting of a mass, spring, and damper with a constant force positioning the mass. The greater the force, the greater the displacement. Again, the system position will change with a disturbance, such as an additional force, and the system will not detect or correct for the disturbance.



Closed Loop

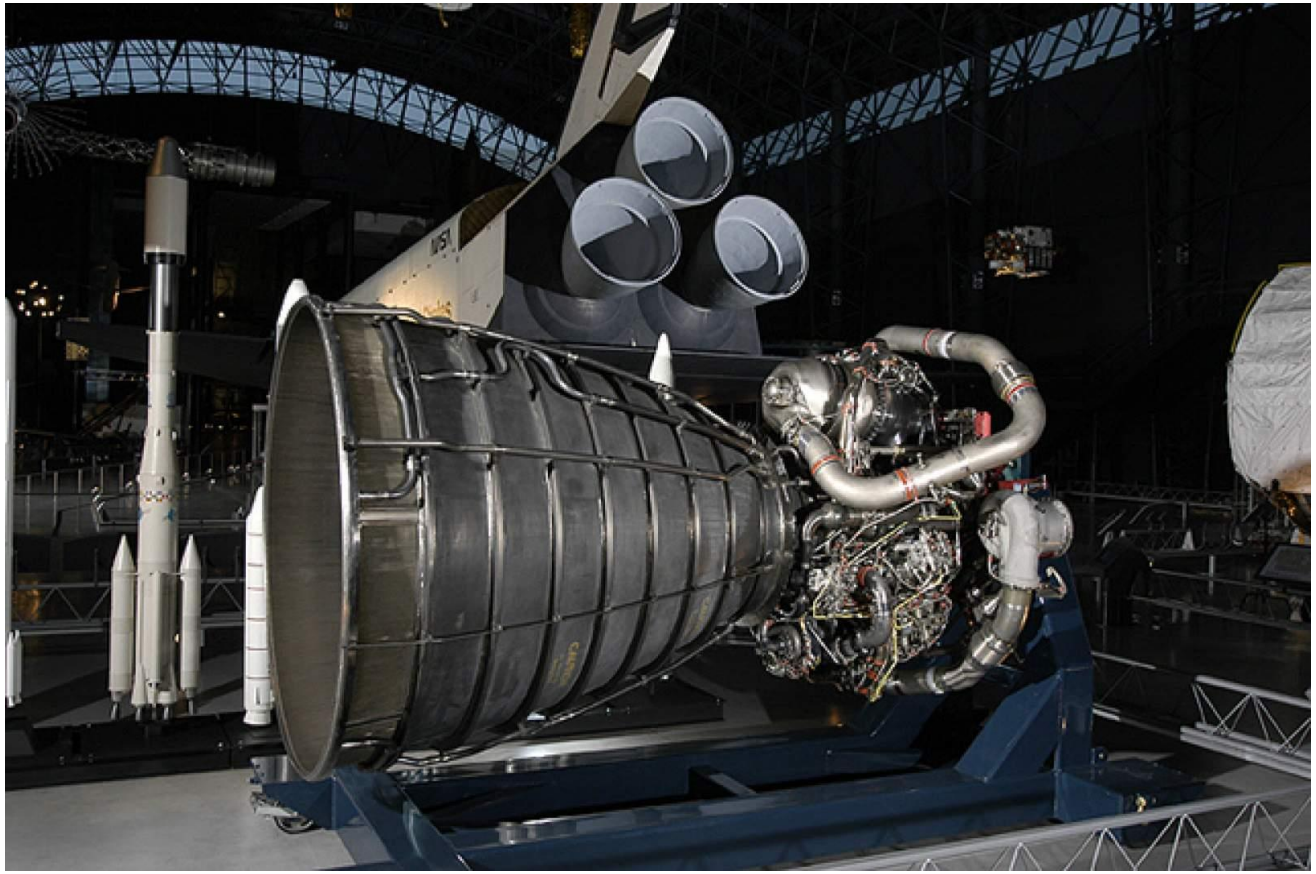
The first summing junction algebraically adds the signal from the input to the signal from the output, which arrives via the feedback path, the return path from the output to the summing junction



(*b*)

Computer Control System

The space shuttle main engine (SSME) controller, which contains two digital computers, alone controls numerous engine functions. It monitors engine sensors that provide pressures, temperatures, flow rates, turbo pump speed, valve positions, and engine servo valve actuator positions. The controller further provides closed-loop control of thrust and propellant mixture ratio, sensor excitation, valve actuators, spark igniters, as well as other functions.



Space Shuttle Main Engine (SSME)

Analysis and Design Objectives

1. TRANSIENT RESPONSE
2. STEADY STATE RESPONSE
3. STABILITY

Transient Response

- Too fast a transient response could cause permanent physical damage. In a computer, transient response contributes to the time required to read from or write to the computer's disk storage (see Figure 1.7). Since reading and writing can not take place until the head stops, the speed of the read/write head's movement from one track on the disk to another influences the overall speed of the computer.

FIGURE 1.7 Computer hard disk drive, showing disks and read/write head

Steady State Response

- We are concerned about the accuracy of the steady-state response.
  - An elevator must be level enough with the floor for the passengers to exit
  - A read/write head not positioned over the commanded track results in computer errors.
  - An antenna tracking a satellite must keep the satellite well within its beam width in order not to lose track.

Stability

- Discussion of transient response and steady-state error is moot if the system does not have stability.
- In order to know stability first we have to discuss the total response.

$$\text{Total response} = \text{Natural response} + \text{Forced response}$$

Stability……..

- For a control system to be useful, the natural response must

1. Eventually approach zero, thus leaving only the forced response, or
2. Oscillate.

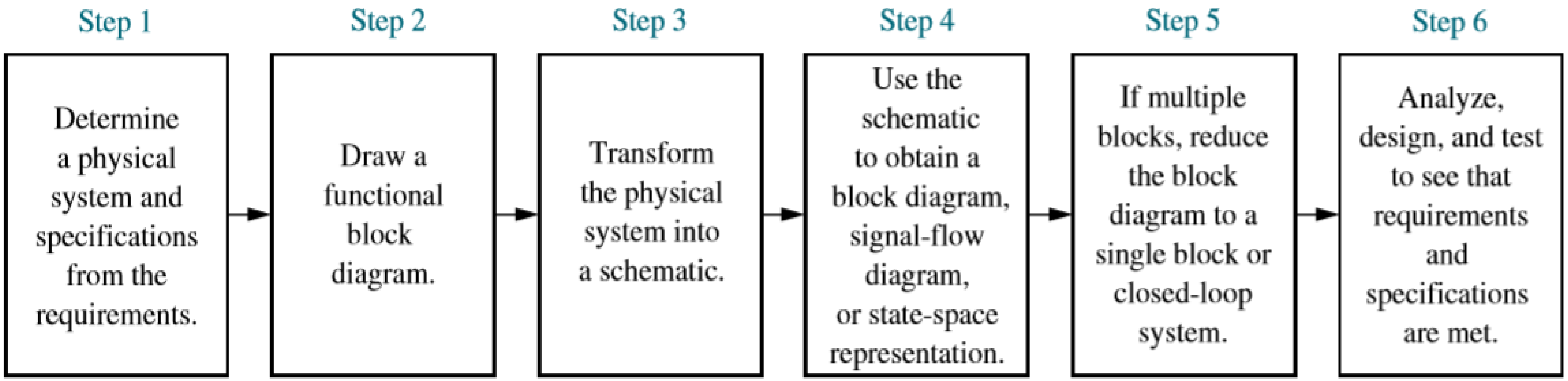
Instability

- In some systems, however, the natural response grows without bound rather than diminish to zero or oscillate. Eventually, the natural response is so much greater than the forced response that the system is no longer controlled. This condition, called instability, could lead to self-destruction of the physical device if limit stops are not part of the design.

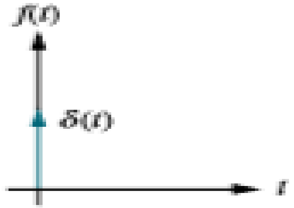
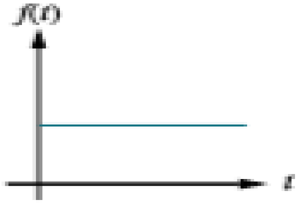
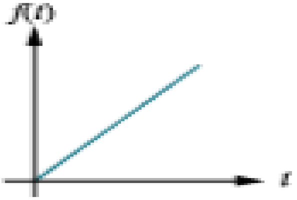
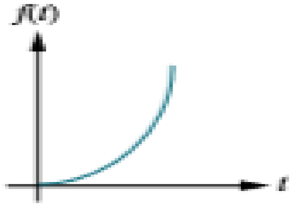
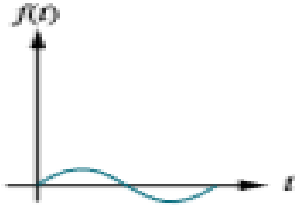
Other Considerations

1. Hardware selection
   - Such as motor sizing, choice of sensor for accuracy.
2. Finance and Budget
3. Robust Design.

The Design Process



Test waveforms in Control System

Input	Function	Description	Sketch	Use
Impulse	$\delta(t)$	$\delta(t) = \infty$ for $0- < t < 0+$ $= 0$ elsewhere $\int_{0-}^{0+} \delta(t)dt = 1$		Transient response Modeling
Step	$u(t)$	$u(t) = 1$ for $t > 0$ $= 0$ for $t < 0$		Transient response Steady-state error
Ramp	$tu(t)$	$tu(t) = t$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Parabola	$\frac{1}{2}t^2u(t)$	$\frac{1}{2}t^2u(t) = \frac{1}{2}t^2$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Sinusoid	$\sin \omega t$			Transient response Modeling Steady-state error

Important Announcement

- Students are highly requested to bring the reference book in the class as the lecture contains huge amount of equations and figures which are tedious and cumbersome to draw in the board with hands.

Reference Books

- Control Systems Engineering
  - Norman S. Nise (Sixth Edition)
- Modern Control Engineering
  - Katsuhiko Ogata
- Modern Control Engineering
  - D. Roy Choudhury

Thank You