CHAPTER 1

INTRODUCTION TO SYSTEM DYNAMICS

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1.1 INTRODUCTION

A system is defined as a combination of components (elements) that act together to perform a certain objective. System dynamics deal with:

- the mathematical modeling of dynamic systems and
- response analyses of such systems with a view toward understanding the dynamic nature of each system and improving the system's performance.

Static Systems have an output response to an input that does not change with time.

Dynamic Systems have a response to an input that is not instantaneously proportional to the input or disturbance and that may continue after the input is held constant. Dynamic systems can respond to input signals, disturbance signals, or initial conditions.

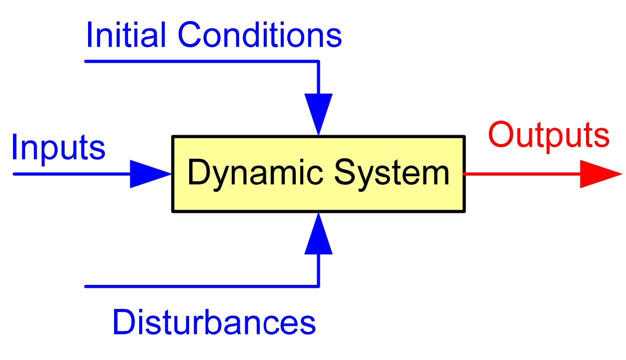

Figure 1-1 Excitation and response of a system

Dynamic Systems may be observed in common devices employed in everyday living, Figure 1-2, as well as in sophisticated engineering systems such as those in spacecraft that took astronauts to the moon. Dynamic Systems are found in all major engineering disciplines and include mechanical, electrical, fluid and thermal systems.

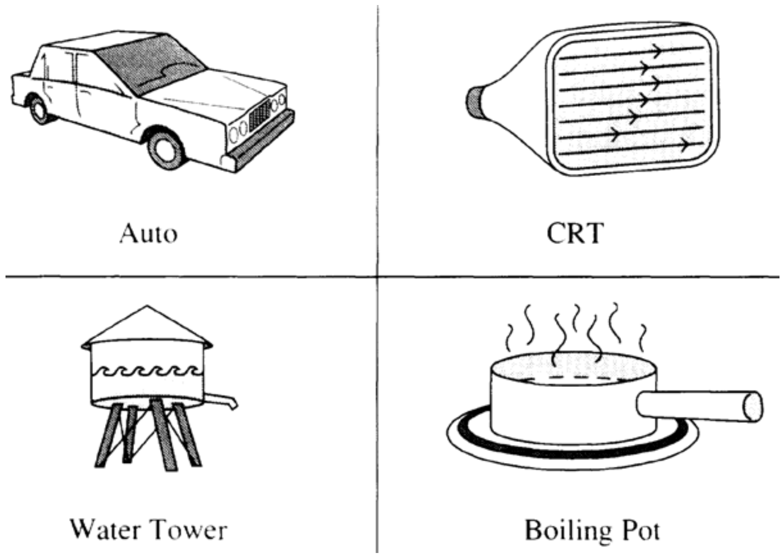

Figure 1-2 Examples of dynamic systems

Mechanical Systems. Systems that possess significant mass, inertia and spring and energy dissipation (damper) components driven by forces, torques, specified displacements are considered to be mechanical systems. An automobile is a good example of a dynamic mechanical system. It has a dynamic response as it speeds up, slows down, or rounds a curve in the road. The body and the suspension system of the car have a dynamic response of the position of the vehicle as it goes over a bump.

Electrical Systems. Electrical systems include circuits with resistive, capacitive, or inductive components excited by voltage or current. Electronic circuits can include transistors or amplifiers. A television receiver has a dynamic response of the beam that traces the picture on the screen of the set. The TV tuning circuit, which allows you to select the desired channel, also has a dynamic response.

Fluid Systems. Fluid systems employ orifices, restrictions, control valves, accumulators (capacitors), long tubes (inductors), and actuators excited by pressure or fluid flow. A city water tower has a dynamic response of the height of the water as a function of the amount of water pumped into the tower and the amount being used by the citizens.

Thermal Systems. Thermal systems have components that provide resistance (conduction, convection or radiation) and a capacitance (mass a specific heat) when excited by temperature or heat flow. A heating system warming a house has a dynamic response as the temperature rises to meet the set point on the thermostat. Placing a pot of water over a burner to boil has a dynamic response of the temperature.

Mixed Systems. Some of the more interesting dynamic systems use two or more of the previously mentioned engineering disciplines, with energy conversion between various components. Figure 3 shows several examples.

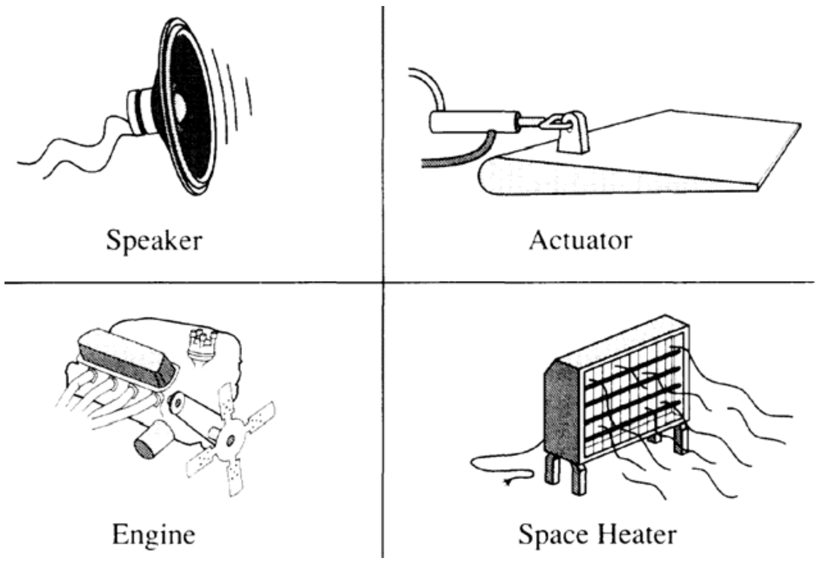

Figure 1-3 Examples of mixed systems.

Electro-Mechanical Systems. Systems employing electromagnetic component that converts a current into a force generally have a dynamic response. Examples are a loudspeaker in a stereo system, a solenoid actuator, and electric motors. In a loudspeaker, electrical current from the amplifier is transformed into movement of the speaker cone and the subsequent air pressure fluctuations that cause us to hear the amplified sound.

Fluid-Mechanical Systems. Hydraulic or pneumatic systems with fluid-mechanical conversion components exhibit dynamic behavior. Examples are a hydraulic pump, a valve controlled actuator, and a hydraulic motor drive. A hydraulic servo system used for flight control in an airplane is a good example of a common electro-fluid-mechanical dynamic system.

Thermo-Mechanical Systems. A combustion engine used in a car, truck, ship, or airplane is a thermo-fluid-mechanical (or simply, thermo-mechanical) device, since it converts thermal energy into a fluid power and then into mechanical power. Thermodynamics, fluid dynamics, and mechanical dynamics are all involved in the process.

Electro-thermal Systems. A space heater that uses electric current to heat filament, which in turn warms the air, has a dynamic response to the surrounding environment. An electric water heater is another common example of an electro-thermal system.

1.2 MATHEMATICAL MODELING OF DYNAMIC SYSTEMS

Mathematical Modeling A mathematical model usually describes a system by means of variables. Usually physical laws are applied to obtain mathematical model. Sometimes experimental procedures are necessary. But no mathematical model can represent a physical system completely. Approximations and assumptions restrict the validity of the model.

Classification of System Models

Type of Model	Classification Criterion	Mathematical Simplification
Linear Time- Invariant (LTI)	Principle of superposition applies	Linear differential. equation with constant coefficients, $\frac{d^2x}{dt^2}+5\frac{dx}{dt}+10x=0$
Linear Time- Varying (LTV)	Model parameters vary in time	Differential. equations with time varying parameters, $\frac{d^2x}{dt^2}+\left(1-\cos(2t)\right)x=0$
Non-linear	Principle of superposition does not apply. Most, if not all physical systems are non-linear	Non-linear differential. equations, $\frac{d^2x}{dt^2}+\left(x^2-1\right)\frac{dx}{dt}+x=0$ $\frac{d^2x}{dt^2}+\frac{dx}{dt}+x+x^3=\sin\omega t$
Continuous	Dependent variables defined over continuous range of independent variables	Differential. equations
Discrete	Dependent variables defined only for distinct values of independent variables	Time difference equations

Approximations Used in Mathematical Modeling

Approximation	Mathematical Simplification
Neglect small effects	Reduces number and complexity of dif. Equations
Assume environment independent of system motions	Same as (1)
Replace distribution characteristics with appropriate lumped elements	Leads to ordinary (rather than partial) dif. equations
Assume linear relationships	Makes equations linear, allows superposition solutions
Assume constant parameters	Leads to constant coefficients in differential equations
Neglect uncertainty and noise	Avoids statistical treatment

Mathematical Modeling Procedure:

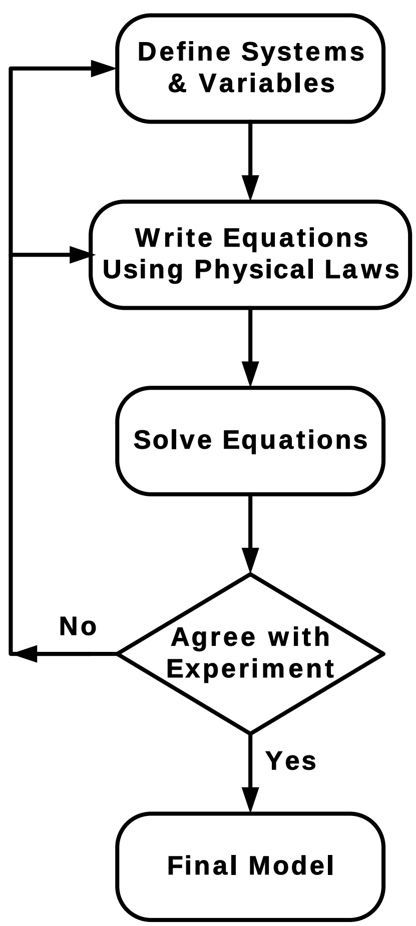

Figure 1-4 Flowchart for the mathematical modeling procedure

1.3 ANALYSIS & DESIGN OF DYNAMIC SYSTEMS

Analysis. Investigation of the performance of a system under specified conditions. The most crucial step is the mathematical model.

Design. Process of finding a system that accomplishes a task.

Synthesis. Finding a system which will perform in a specified way.

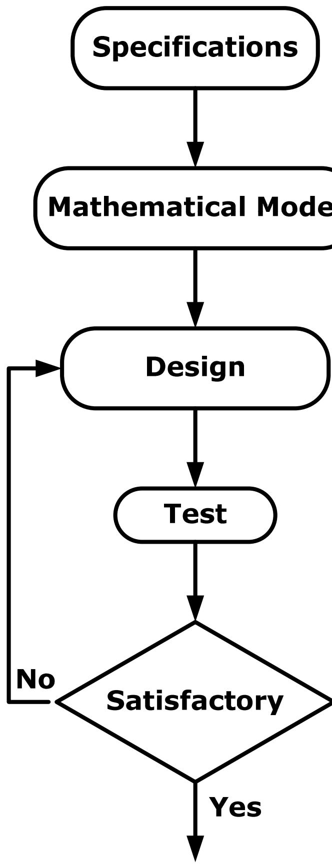

Figure 1-5 Flowchart for the analysis and design of dynamic systems