Instrumentation and Controls

ETM 3301

Lecture 2

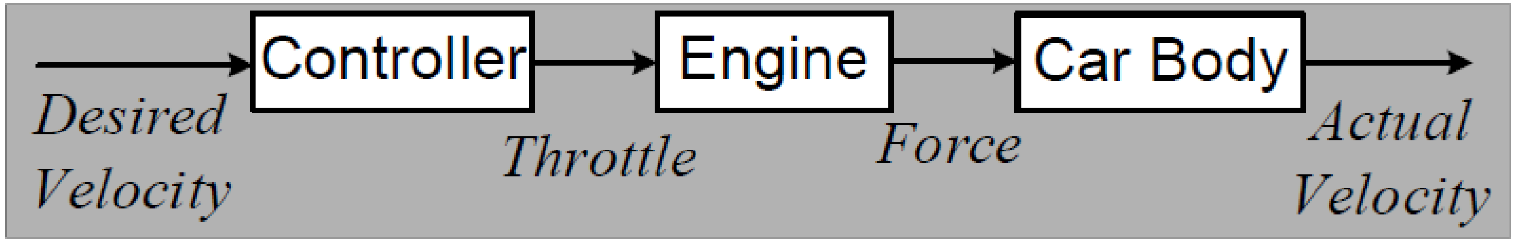
Instructor

Dr. Farbod Khoshnoud

Review

Cruise Control Example

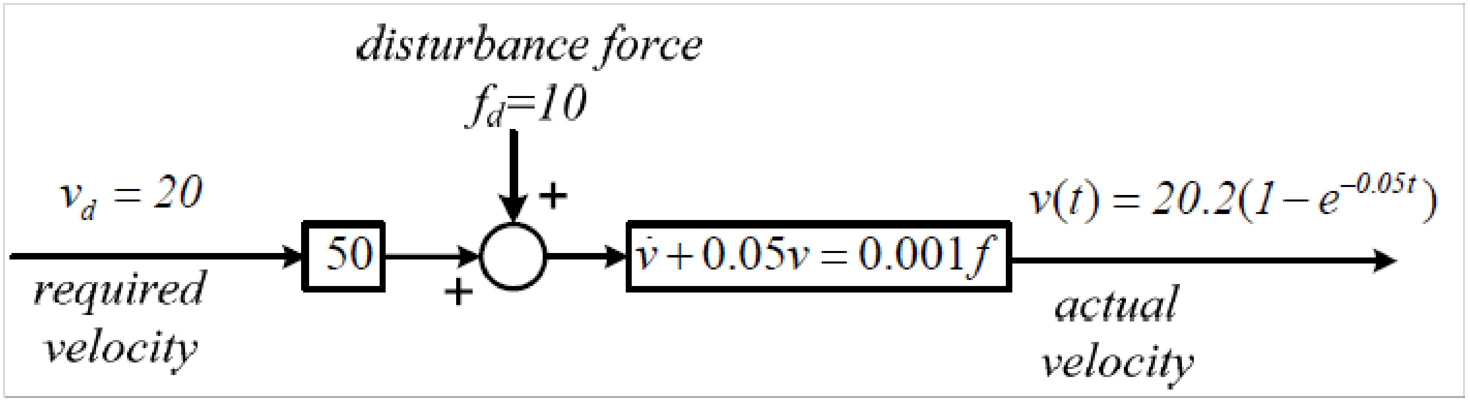
- To maintain a constant velocity of *20m/s*



- How much driving force the engine need to generate?

Review

Disturbance in Open-Loop Control Systems



- Speed control error:

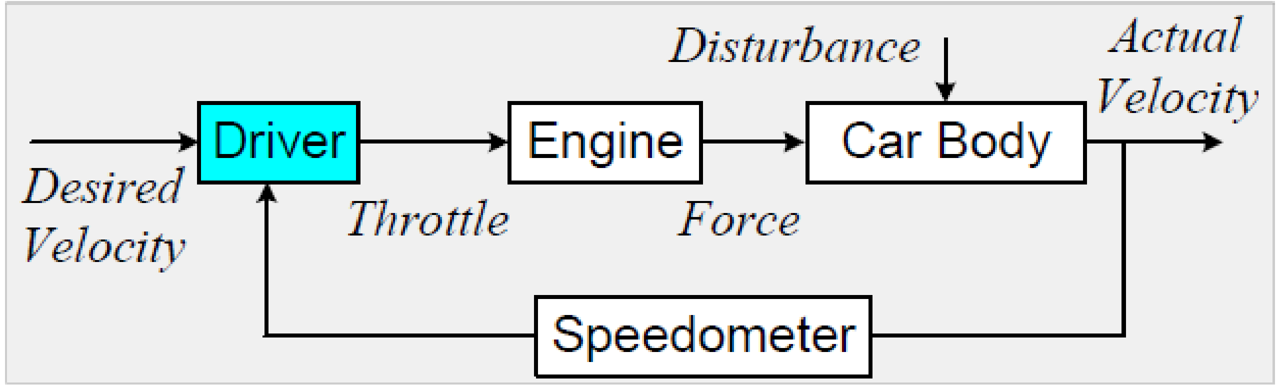
$$v(t) = 20 - 20.2(1 - e^{-0.05t}) = -0.2\,(1 - e^{-0.05t}) \rightarrow -0.2$$

  - No compensation for any disturbance.

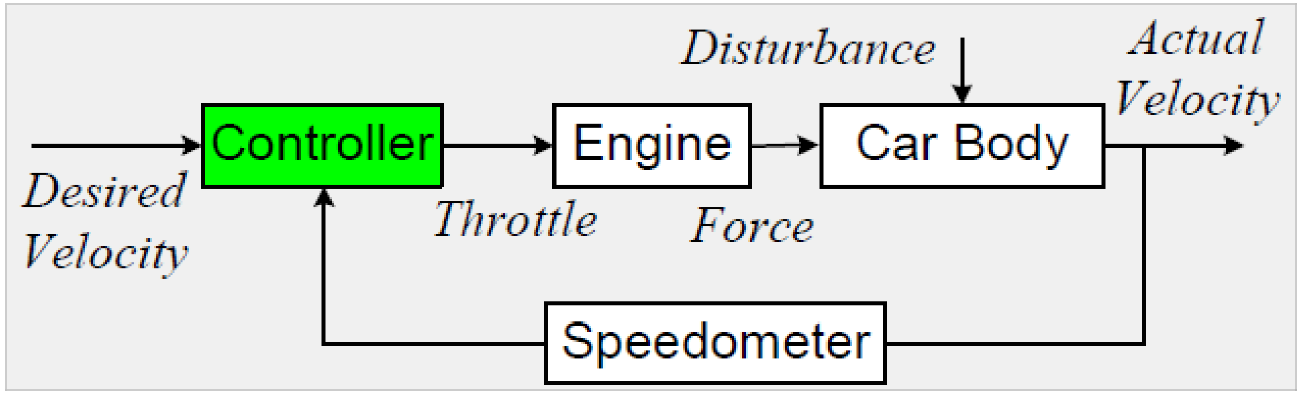
Closed-Loop Control System: Driver and Cruise Control System

- How does a driver maintain a constant car speed?

Driver



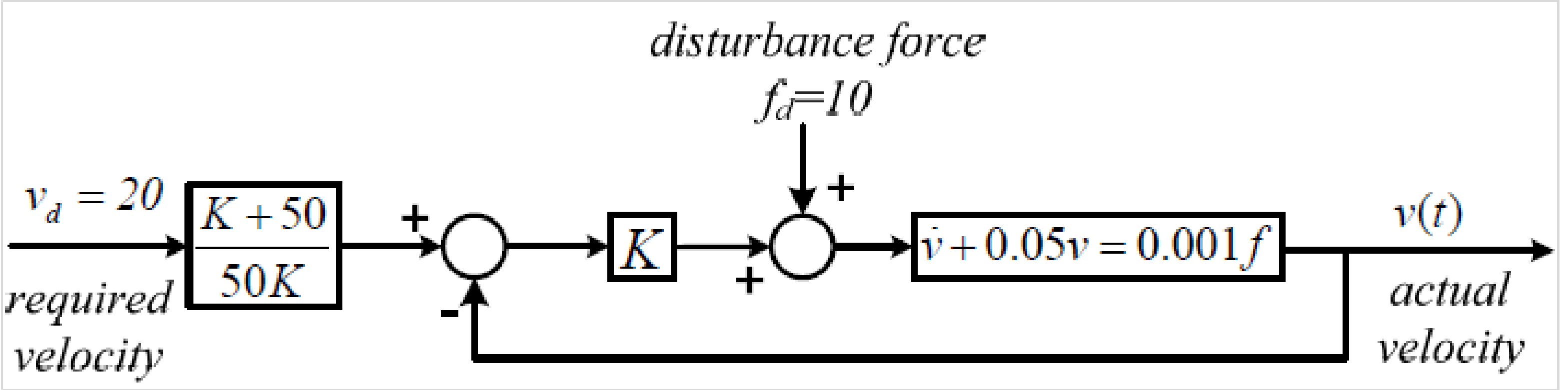
Automatic control



Understanding Control Systems, Part 3: Components of a Feedback Control System

https://www.youtube.com/watch?v=u1pgaJHiiew&list=PLn8PRpmsu08q8CE0pbZ-cSrMm_WYJfVGd&index=4

Disturbance in Closed-Loop Control Systems



- Speed without disturbance force:

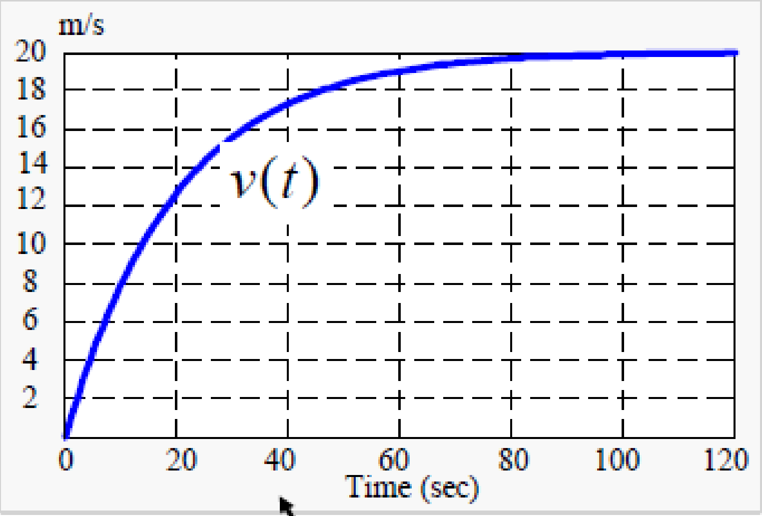
$$v(t) = 20(1 - e^{-(0.05+0.001K)t}) \rightarrow 20$$

- Speed control error with disturbance:

$$e(t) \rightarrow -0.2\left(\frac{50}{50+K}\right)$$

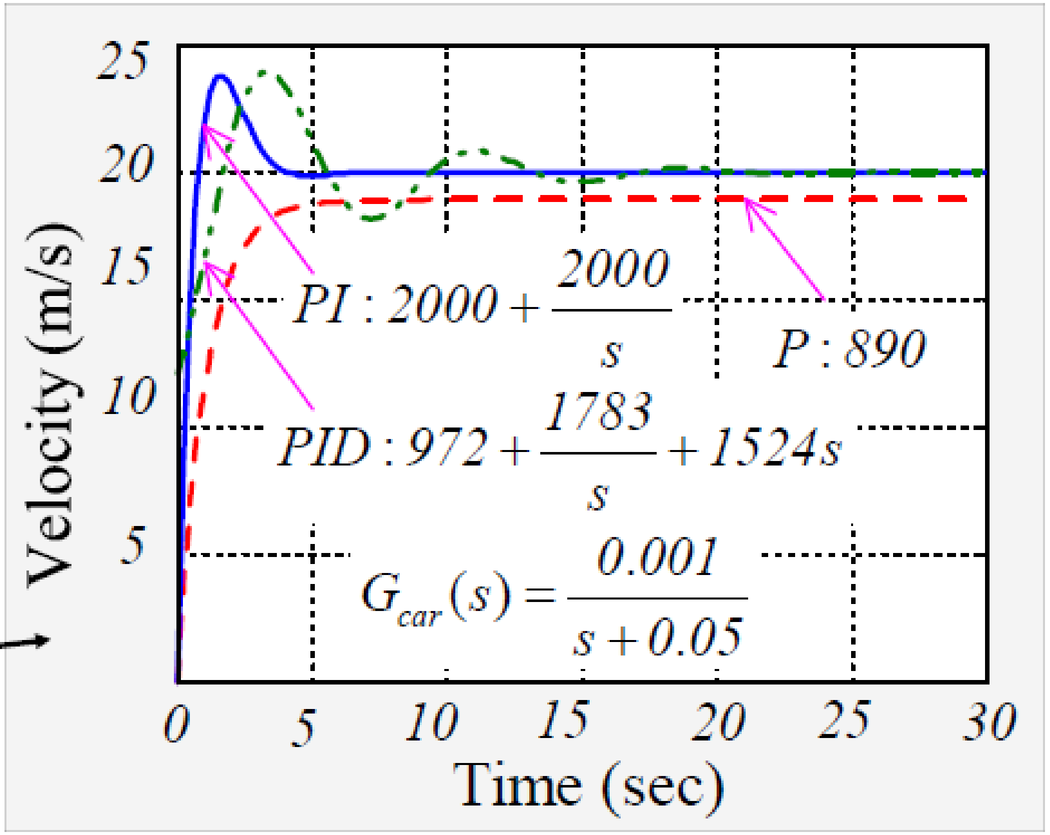
- Error can be reduced by increasing K

Control Performance Improvement



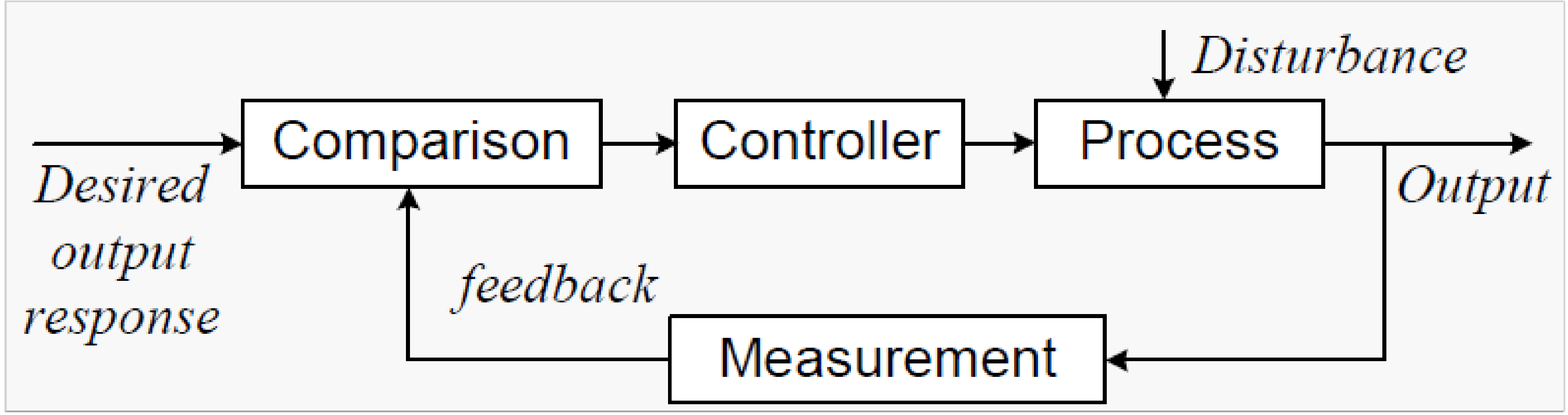
Open-loop control

Closed-loop controls: faster and can cope with disturbances



Closed-Loop Control System

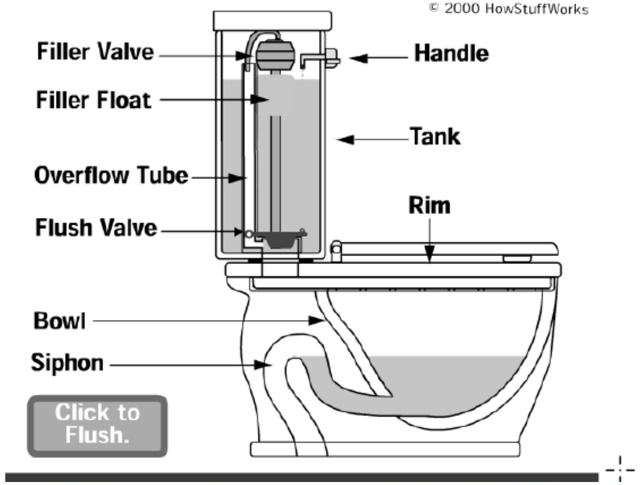
- A *closed-loop control system* uses a measurement of the output and feedback of this signal to compare it with the desired input (reference or command).



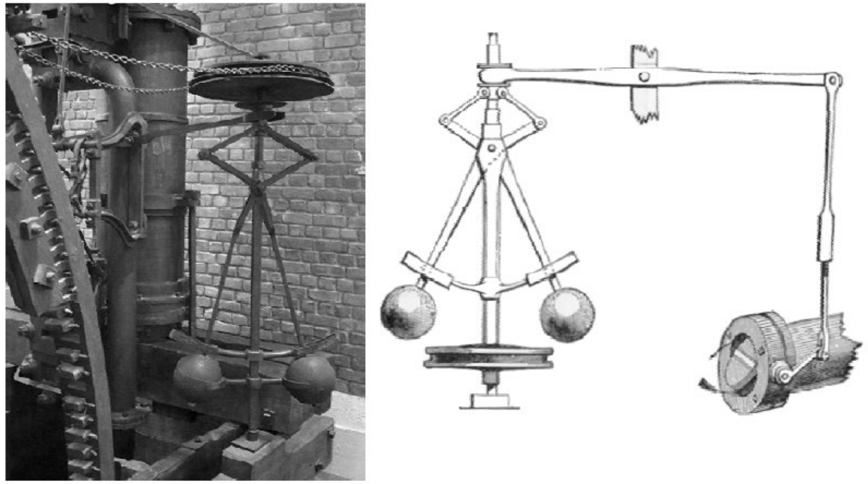
- The controller acts on the difference between the desired and actual outputs!

- Feedback!
  - The essence of control!

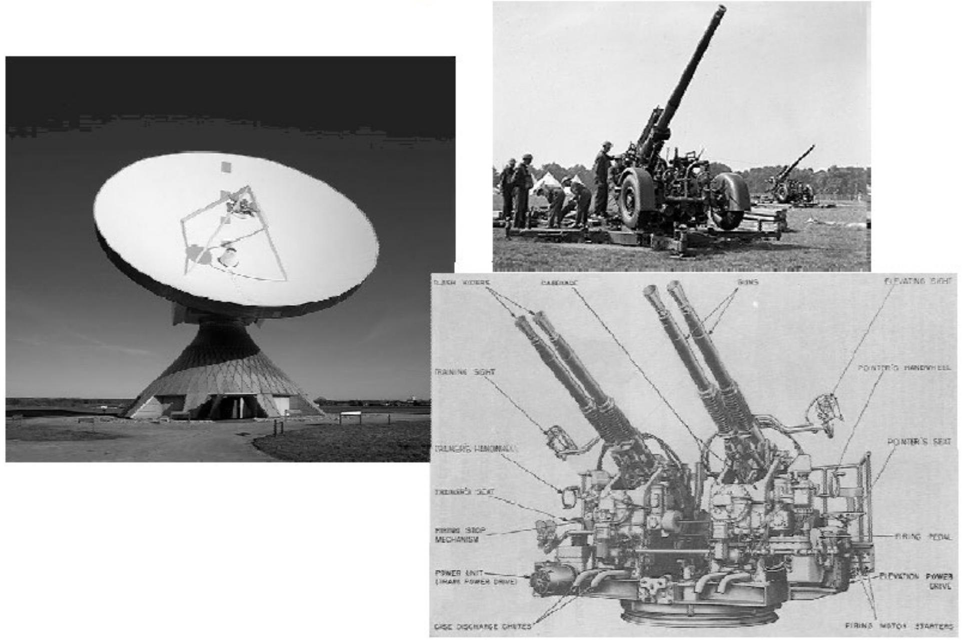
Closed-Loop (Feedback) Control System Example: Toilet Flush



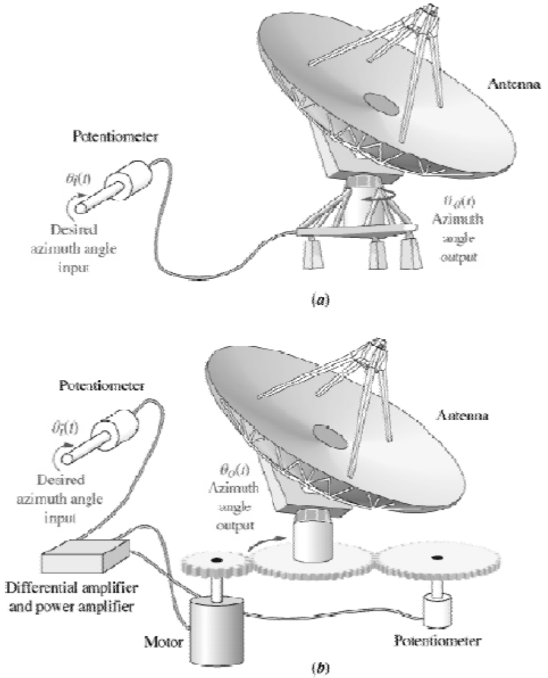
Closed-Loop (Feedback) Control System Example: James Watt Fly-Ball Governor



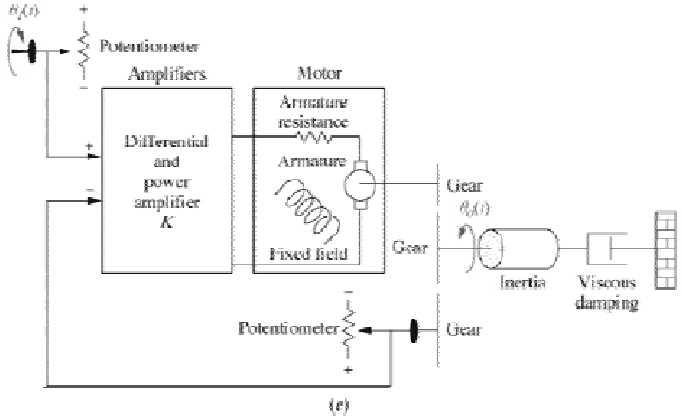
Closed-Loop (Feedback) Control System Example: Antenna

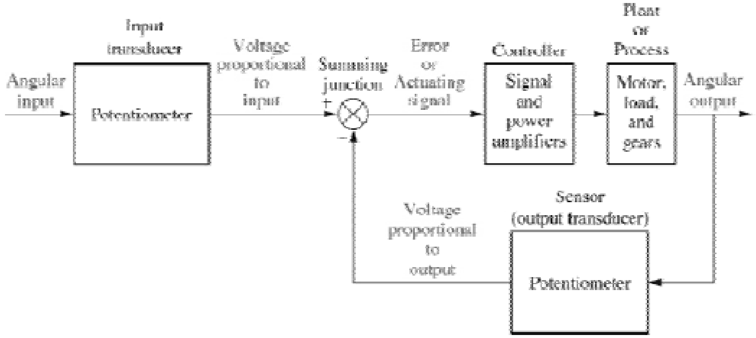


Closed-Loop (Feedback) Control System Example: Antenna



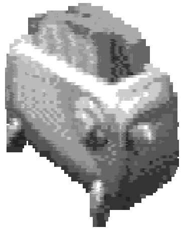
Closed-Loop (Feedback) Control System Example: Antenna





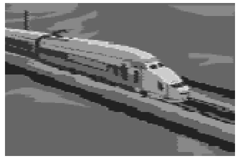
Control engineering is responsible for

Toast popping up at just the right time.



Planes do not fall from sky.

Trains do not go off track.



Control engineering is responsible for

The left turn arrow appearing on a traffic light, upon sensing the presence of a car in the turn lane.

Cruise controls keeping your car at a desired speed up and down hills in rain, snow, and sleet.

Lift door opening and closing and the lift stopping at the right floor.

Control engineering is responsible for

Boilers of central heating systems turning off and on at the right temperature.

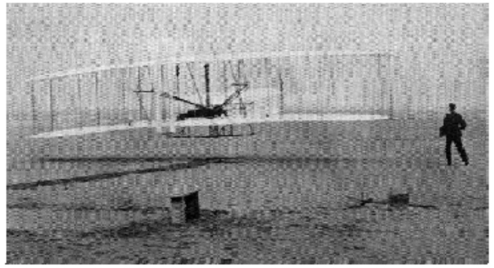
Washing machines run correct washing cycles.

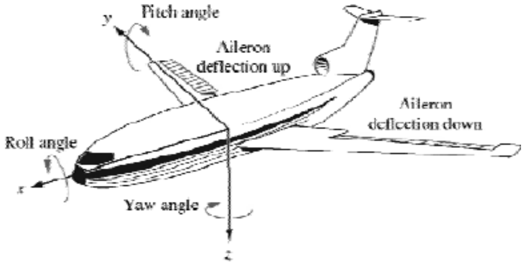
Toilets flushing and their tanks filling to the right level, time and time again.

Control engineering is responsible for

First Controlled Powered Flight (December 17, 1903, Wilbur and Orville Wright)

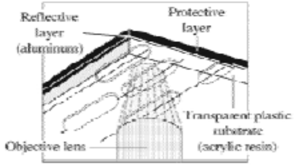
"First and most significant, the brothers recognized that the most important problem they faced was that of *control*. All else was secondary". – R.P.Hallion, "The Wright Brothers: How they Flew", *Invention & Technology*, Vol.19, no.2, Fall 2003.



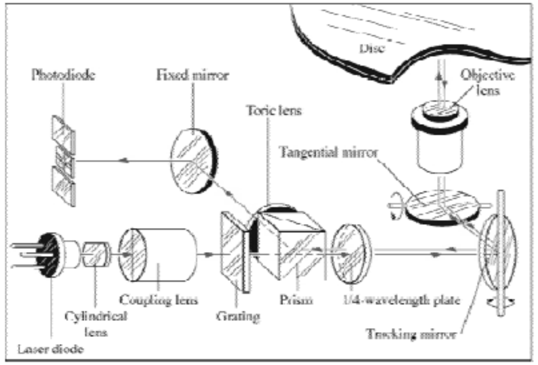


Control engineering is responsible for

(a)



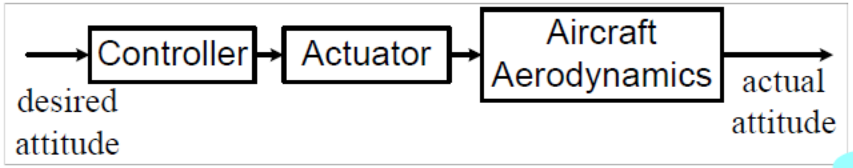
(b)

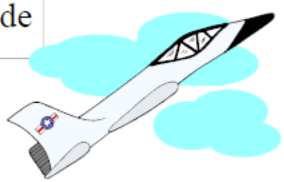


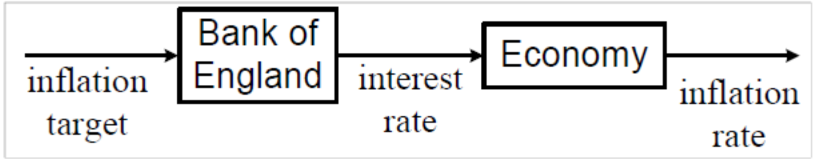
(c)

Control and Control System

- Control is the process of forcing a system to respond to the given command in a desirable way.
- A control system is an interconnection of components forming a system configuration that will provide a desired system response.

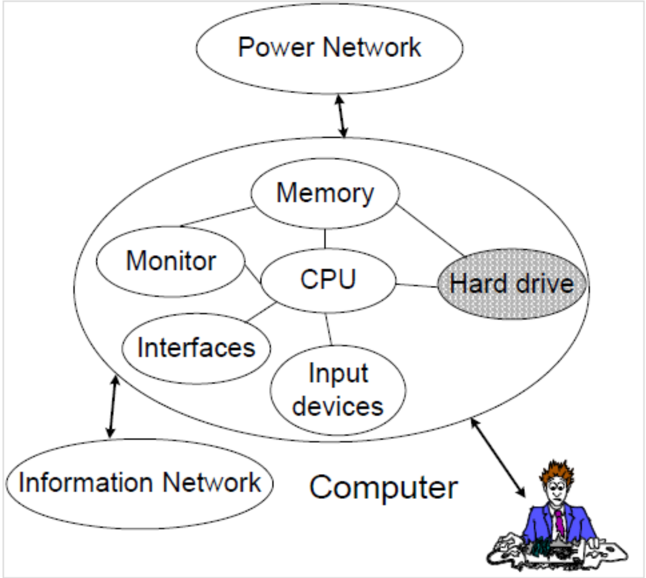






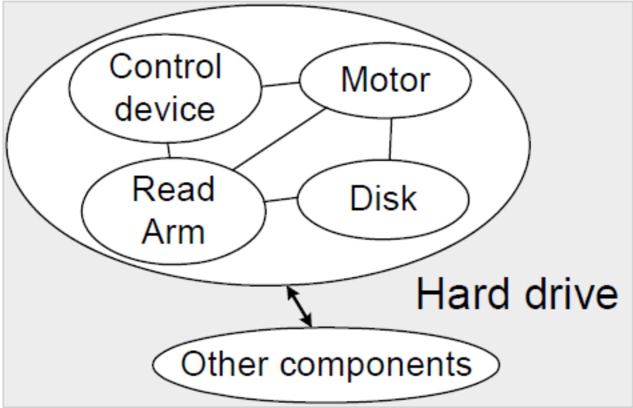
System

- A system is any set of elements connected together by information links within some system ***boundaries***.



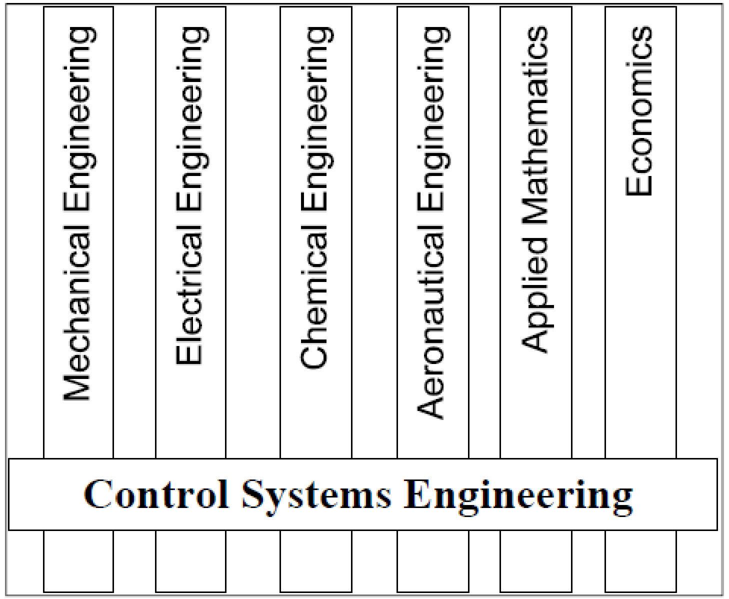
System

- Any collection of interacting objects organised to achieve some desired goal.



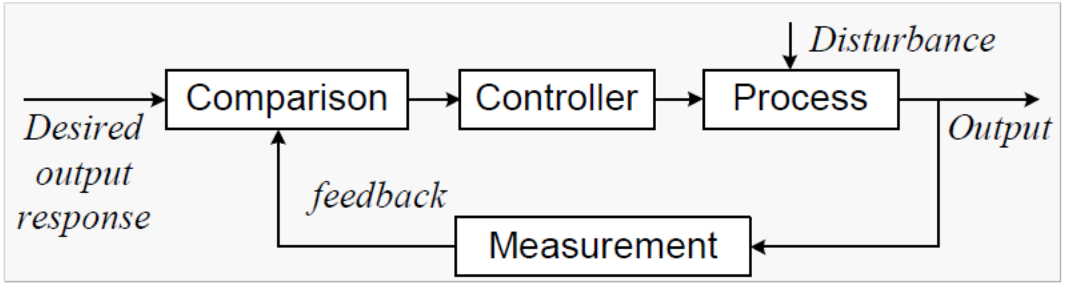
Control System Engineering

- A subject which examines the analysis and design of control systems.
- A multidisciplinary subject!



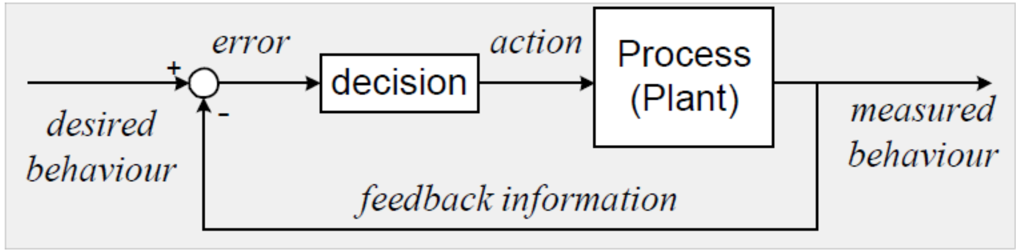
Closed-Loop Control System

- A *closed-loop control system* uses a measurement of the output and feedback of this signal to compare it with the desired input (reference or command).



- The controller acts on the difference between the desired and actual outputs!
- Feedback!
  - The essence of control!

General form of control systems



- Feedback
  - Compare the actual result with the desired result.
  - Take actions based on the difference.
  - This seemingly simple idea is tremendously powerful.
  - Feedback is a key idea in the discipline of control.

Control of dynamic systems

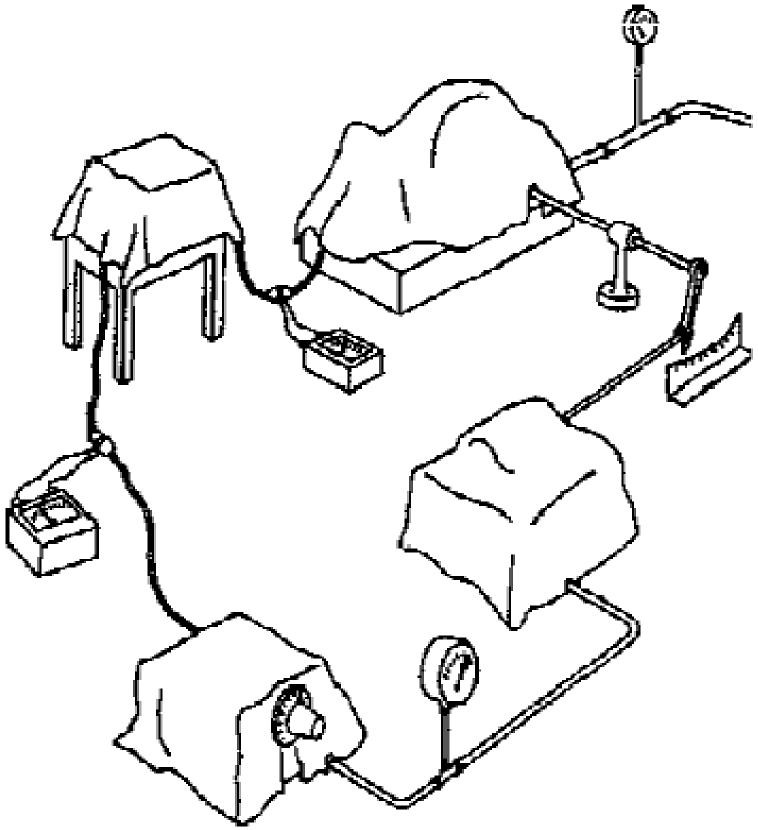
- Control of dynamic systems:
  - To alter future behaviour of a system using information about the current system state and the desired future behaviour.

- Dynamic systems:
  - The system's response varies with time.
  - Finite energy and energy conservation.

Essential Tool: Block Diagram

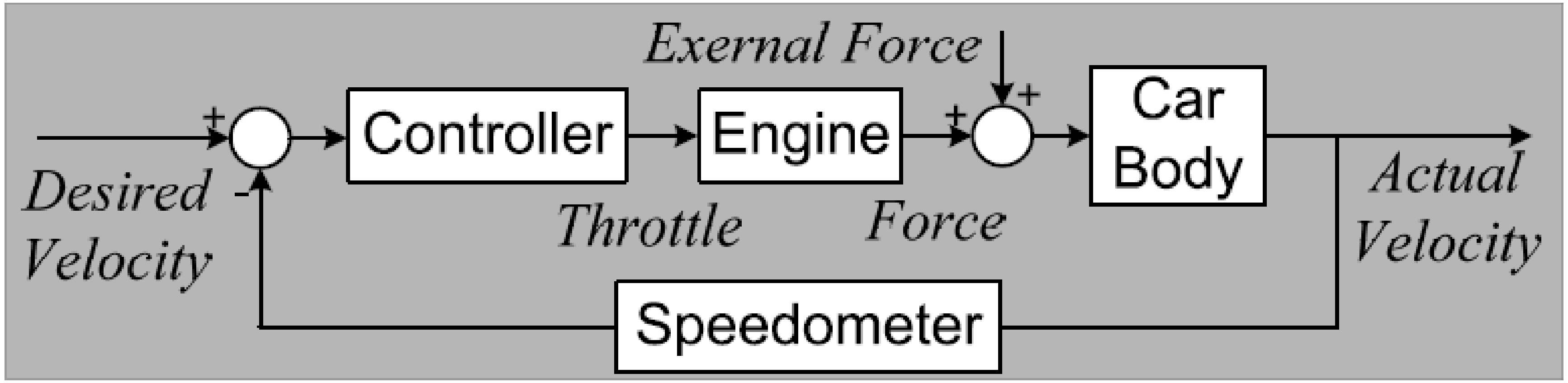
- A block diagram consists of a block representing each component in a control system connected by lines that represent the signal paths.

  - Capture the essence
  - Standard "drawing"
  - Abstraction
  - Information hiding
  - Some limitations



Block Diagram

- Block diagrams made it possible to see the similarity between different types of control systems.



- Understand how the system works!
- What are the important signals?
- Where is the essential dynamics?

Why Control is Used?

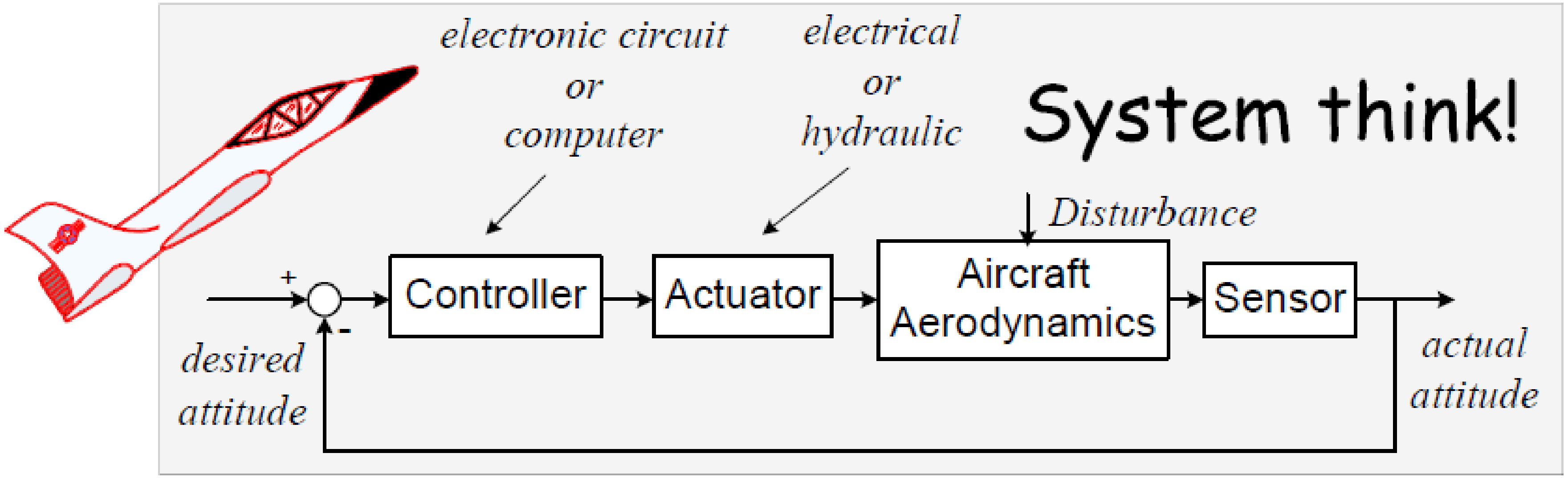
- Automate tasks to assistant people!
- Power and signal amplification.
  - Power steering, flight control & mobile phones.
- Remote control
  - Satellite and space station, nuclear reactor inspection.
- Compensation for disturbances
  - Any control system.

Where Control is Used?

Generation of energy	Industrial processes
Transmission of energy	Discrete manufacturing
Communication	Mechatronics
Transportation	Instrumentation
○ Cars	Consumer electronics
○ Trains	Scientific instruments
○ Ships	Economy
○ Aircrafts	Biology
○ Space-crafts	Medicine

Benefit of studying control system engineering

- Control engineering is used in analysis and design of systems such as those that regulate temperature, fluid flow, motion, force, voltage, pressure, tension, and current.
- Skilfully used, control engineering can guide engineers in every phase of the product and process design cycle.
- It can help engineers predict performance, anticipate problems, and provide solutions.



Tools of studying control system engineering

- Conceptual tool
  - Block diagram
- Mathematical tools
  - Differential equations
  - Laplace transforms.
- Computing tools
  - MATLAB and associated Toolboxes
  - SIMULINK (GUI front of MATLAB).

Course Content

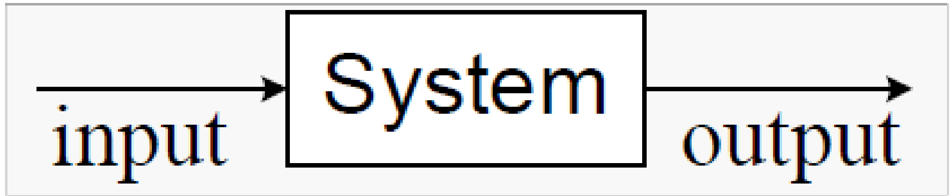
- Introduction to Control
  - System modelling, differential equations
  - Laplace transforms, transfer functions, block diagrams
- Control system analysis and design - time domain
  - Time response, steady state error
  - Stability, Routh-Hurwitz test
  - Poles, zeros, root locus
  - PID control
- Control system analysis and design - frequency domain
  - Bode and Nyquist diagrams, relative stability, gain and phase margins
  - Phase lead and phase leg compensation
  - PID control

Chapter 2: Transfer Functions and System Responses Characteristics

- What is the transfer function of a dynamic system?
- What is the time response?
- Relationship between response characteristics and transfer function characteristics.
- Some concepts in connection with transfer functions, system order, poles and zeros.

Input-Output Approach of Studying Control Systems

- An experimental study of a system can be carried out by applying some know actions to the system.
- The reaction produced by this external action will reveal some of the system properties.
- Cruise control example: apply driving force to the car and then study how the car responses to the force.



Input	Output
Action	Consequence
Cause	Effect
Command	Response

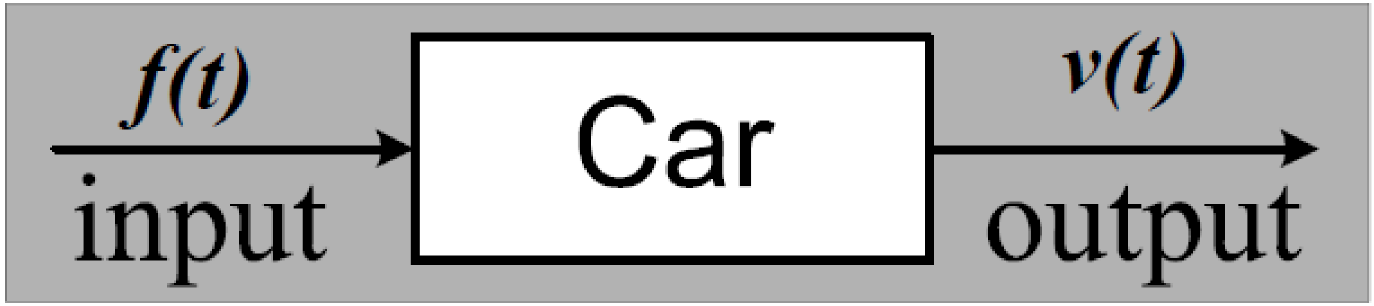
Control System Modelling

- One of tasks in control engineering is to study how a system responds to a control input?
- To study the system's output response when a control input is applied, we need to derive a mathematical model which relates control input to system response.

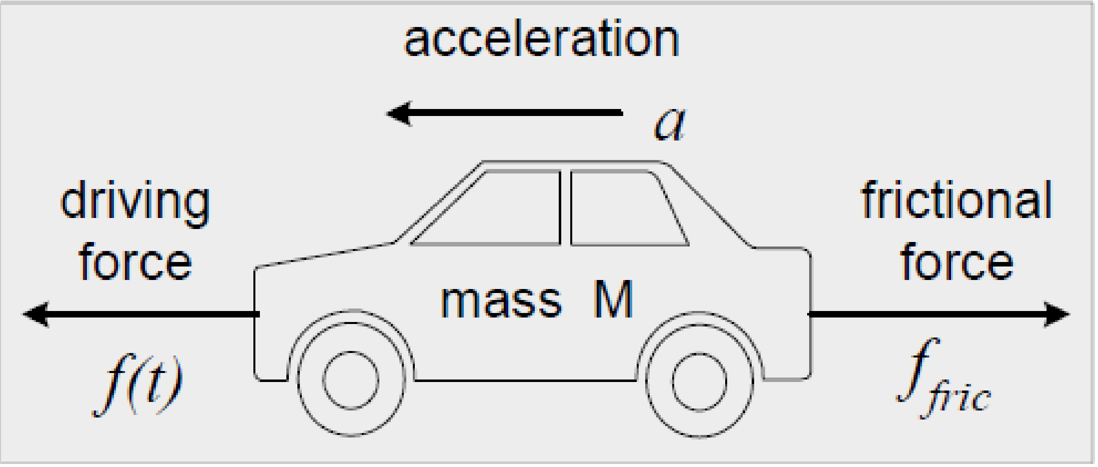
- "*Experiments*" based on Mathematical models can replace some of actual physical testing.

Cruise Control Example

- To find out the car's velocity when a driving force is applied to the car.



Cruise Control System Modelling



$f(t)$: driving force

f_{fric}: frictional force (e.g. air resistance)

Newton's 2nd law: $f(t) - f_{fric} = Ma$

Assume the frictional force is proportional to velocity (viscous friction) $f_{fric} = Bv(t)$

Remember that

$$a = \frac{dv(t)}{dt}$$

Cruise Control System Modelling

$$f(t) - Bv(t) = M\frac{dv(t)}{dt}$$

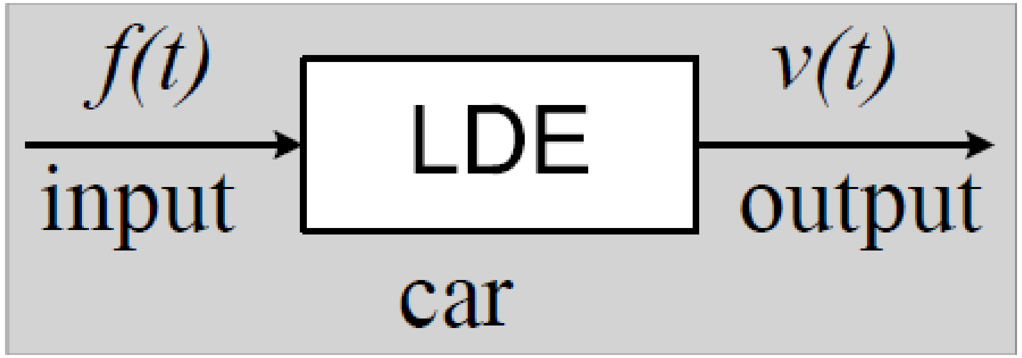
Or

$$\frac{dv(t)}{dt} + \frac{B}{M}v(t) = \frac{1}{M}f(t)$$

Substitute: $M = 1000kg\ ; \quad B = 50Ns/m$

$$\frac{dv(t)}{dt} + 0.05v(t) = 0.001f(t)$$ Model

- The input-output relationship is described by a linear differential equation.



Cruise Control System Solution (1)

$f(t) = 1000N \quad ; \quad v(0) = 0$

- Find $v(t)$

$$\frac{dv(t)}{dt} + 0.05v(t) = 0.001f(t)$$

Applying Laplace Transform of both sides of LDE.

$$\mathcal{L}\left[\frac{dv(t)}{dt}\right] + 0.05\mathcal{L}[v(t)] = \mathcal{L}[0.001 \times 1000]$$

Define $\mathrm{V}(s) = \mathcal{L}[v(t)]$

$$[sV(s) - v(0)] + 0.05V(s) = \frac{1}{s}$$

Cruise Control System Solution (2)

$$V(s) = \frac{1}{s(s+0.05)} = \frac{20}{s} - \frac{20}{s+0.05}$$

$$v(t) = \mathcal{L}^{-1}\left[V(s)\right] = 20 - 20e^{-0.05t} \quad \text{when } f(t) = 1000$$

- How to find the response *v(t)* for other form of control input *f(t)*?
  - Solve a LDE for each form of input?
- We need to find a generalised solution!!!

$$f(t) = 10t$$

$$f(t) = 1000(1 - e^{-10t})$$

$$f(t) = 500(1 - \sin 2t)$$

....

Cruise Control System Solution (2)

$$V(s) = \frac{1}{s(s+0.05)} = \frac{20}{s} - \frac{20}{s+0.05}$$

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$$f(t) = 10t$$

$$f(t) = 1000(1 - e^{-10t})$$

$$f(t) = 500(1 - \sin 2t)$$

....

Cruise Control System General Solution

$$\frac{dv(t)}{dt} + 0.05v(t) = 0.001f(t) \qquad v(0) = 0$$

- We can assume that initial condition v(0) is zero because we are investigating input-output relationship.
- Applying Laplace Transform of both sides of LDE.

$$\mathcal{L}\left[\frac{dv(t)}{dt}\right] + 0.05\mathcal{L}[v(t)] = 0.001\mathcal{L}[f(t)]$$

$$\text{Define} \quad \mathrm{V}(s) = \mathcal{L}\left[v(t)\right] \qquad \mathrm{F}(s) = \mathcal{L}\left[f(t)\right]$$

$$[sV(s) - v(0)] + 0.05V(s) = 0.001F(s)$$

$$(s + 0.05)V(s) = 0.001F(s)$$

Cruise Control System Transfer Function (TF)

$$V(s) = \frac{0.001}{s+0.05} F(s) = G(s)F(s)$$

$$G(s) = \frac{V(s)}{F(s)} = \frac{0.001}{s+0.05}$$

- The function *G(s)* relates the output (car's velocity, *V(s)*) to the input (driving force, *F(s)*) .
  - it is known as the **transfer function**.