AEEM 3022- Modeling and Simulation of Physical Systems

Lesson 1

AEEM 3022: Modeling & Simulation of Physical Systems

- **Instructor Information:** Rajnikant Sharma
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- **TA Information:** Saikat Das (Email: dass9@mail.uc.edu) and Melody Mayle (Email: maylemn@mail.uc.edu), Rohith

- **Office Hours:**
  - Please make an appointment by email

Preferred Communication via canvas and email.

Book

- *System Dynamics, 3rd Ed.,*William J Palm III, McGraw-Hill, New York, NY 10020.
  - There will some reading from the book
  - Some homework assignments will come from the book
  - The book will be a great reference

Grading

- There will be 1 midterm and 1 final.

Midterm	30%
Final .	30%
Homework	30%
Final Project	10%

- Grading will be on a 100 point scale, and partial credit will be awarded when applicable. Late homework will not be accepted. The instructor reserves the right to curve if necessary to achieve appropriate grade distribution.
- [93-100] A, [90-93) A-, [87-90) B+, [83-87) B, [80-83) B-, [77-80) C+, [73-77) C, [70-73) C-, [67-70) D+, [63-67) D, [60-63) D-, below 60 F. The square bracket denotes that the score is inclusive. That is, an 87 is a B+, while an 86.9999 is a B. These are sharp cutoffs, with no rounding.

Assignments

- Should be electronically submitted on Canvas by the due date.
- Late assignments not accepted.

Program in Computational Naval Sciences

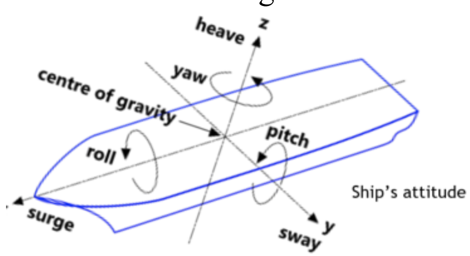
Sponsored by Office of Naval Research

Information session on course offerings starting Spring 2020 (lunch provided)

Modeling and Simulation (with emphasis on Naval vehicles)

Spring 2020

- Mathematical modeling of Naval vehicles - UUVs, ships, surface vehicles, torpedoes
- Developing programing and simulation skills in Matlab
- Sensor modeling



Autonomy and AI for Unmanned Underwater Vehicles

Fall 2020

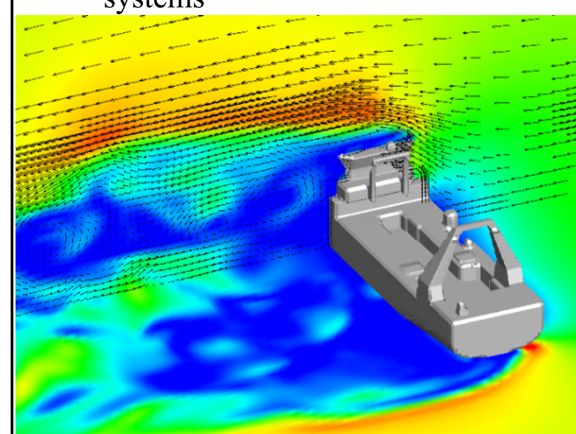
- Machine learning
- Path planning
- Attitude control
- Guidance
- Localization and state estimation

Mark 18. Mod. 2 UUV. Image taken from navy.mil

Fluid Dynamics: Computations, Data Analysis and Visualization for Naval Applications

Spring 2021

- Learn the use of various computer-based simulation tools used in fluid dynamics and apply them to navy relevant problems
- Learn innovative visualization techniques.
- Learn the use of data analysis techniques, such as machine learning to extract system dynamics
- Modeling of atomization and combustion in Naval propulsion systems



Why take these courses?

- Acquire critical skills for high-tech Naval jobs
- Meet and attend sessions conducted by world-renowned experts
- Network with Navy personnel
- Potential to get internships/co-op opportunities at Naval labs/facilities
- Two of the three courses will count as technical electives

Where and when

- Date: Friday, November 15, 2019
- Time: 11.30-12.30 pm
- Location: Baldwin 860D
- Lunch provided

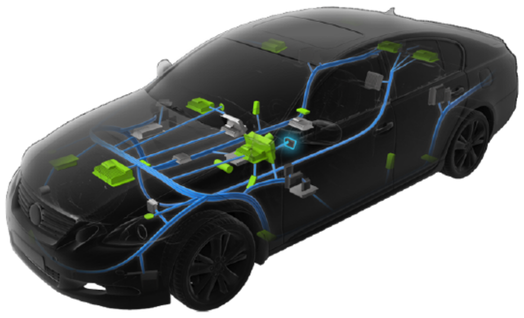
Contact/RSVP

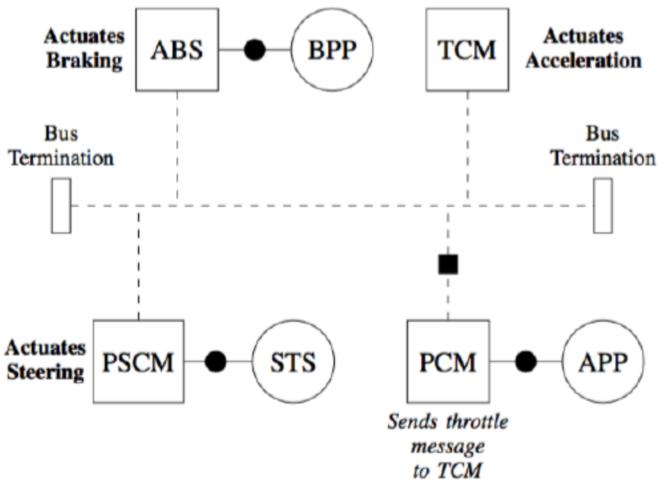
- Dr. Prashant Khare
  - Prashant.Khare@uc.edu
- Dr. Rajnikant Sharma
  - Rajnikant.Sharma@uc.edu

Mandatory Survey

- Here's the link:
- http://bit.ly/Navcert2

System





- There is no one agreed upon definition to the term “system”

- The book says: “A combination of elements intended to act together to accomplish an objective”

System - Definition

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- The book says: “A combination of elements intended to act together to accomplish an objective”

Categorizing Systems

By Domain

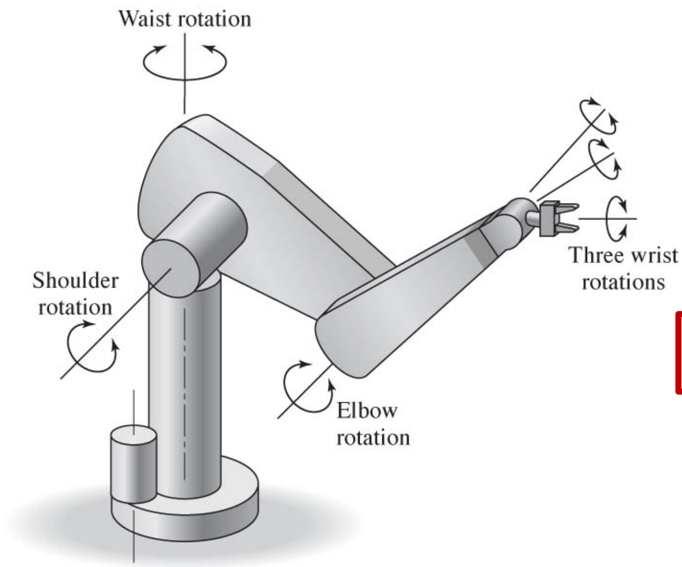
- Social
- Economical
- Biological
- Physical

By Behavior

- Static vs. Dynamic
- Discrete vs. Continuous
  - Digital vs. Analog
- Depends on finite variables (lumped parameter) or infinite number of variables (distributed parameter)

Many systems have analogous systems: Systems from another domain that behave similarly.
This can be used to understand, analyze and model them.

Examples of Physical Systems



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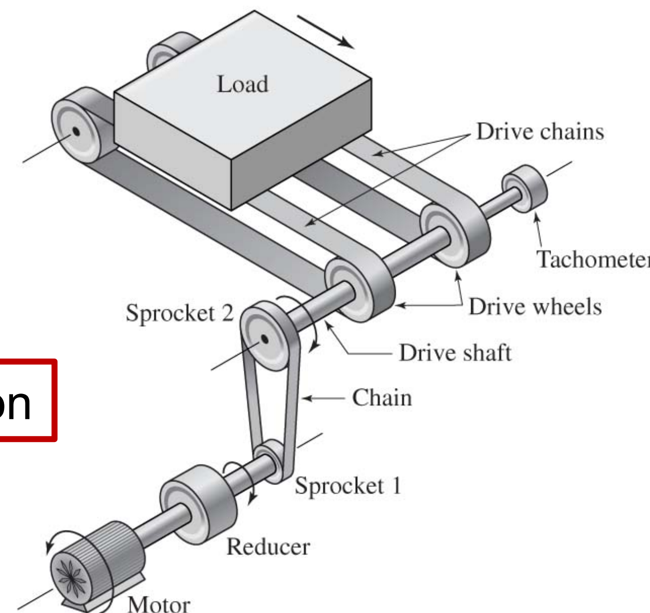

Look at possible motion

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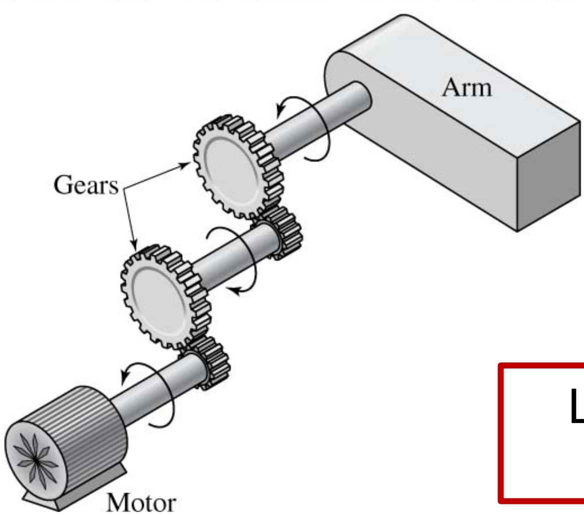
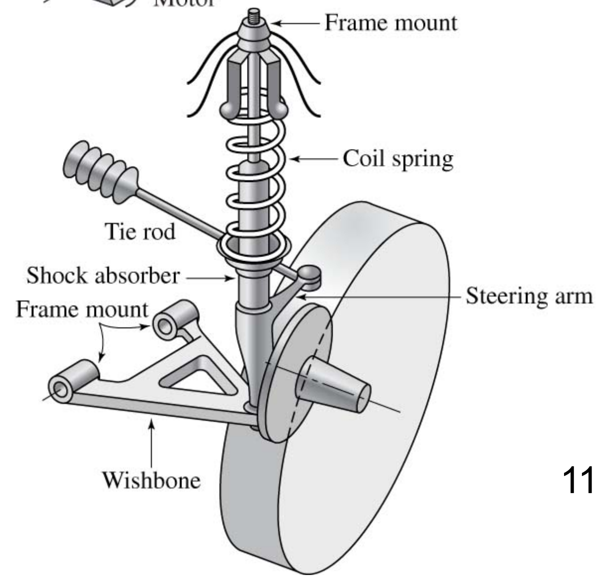
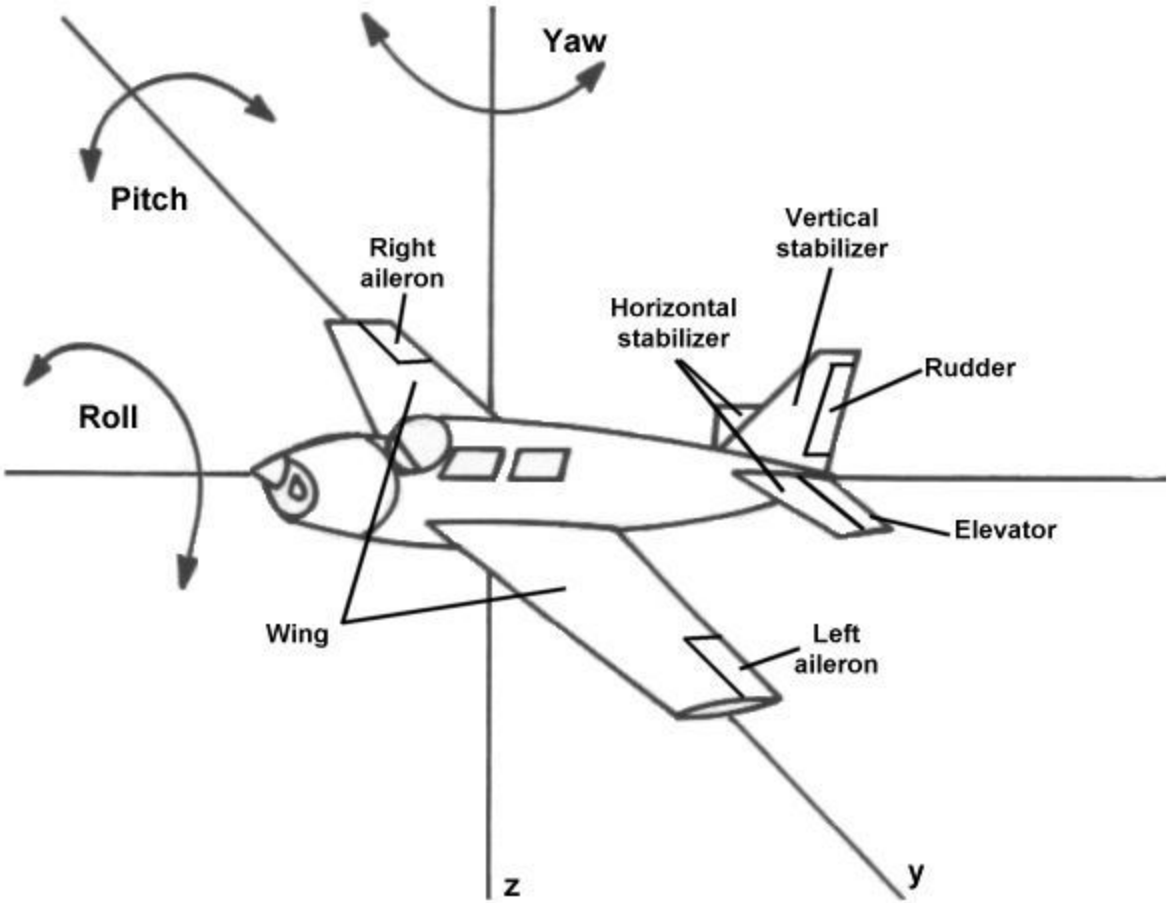
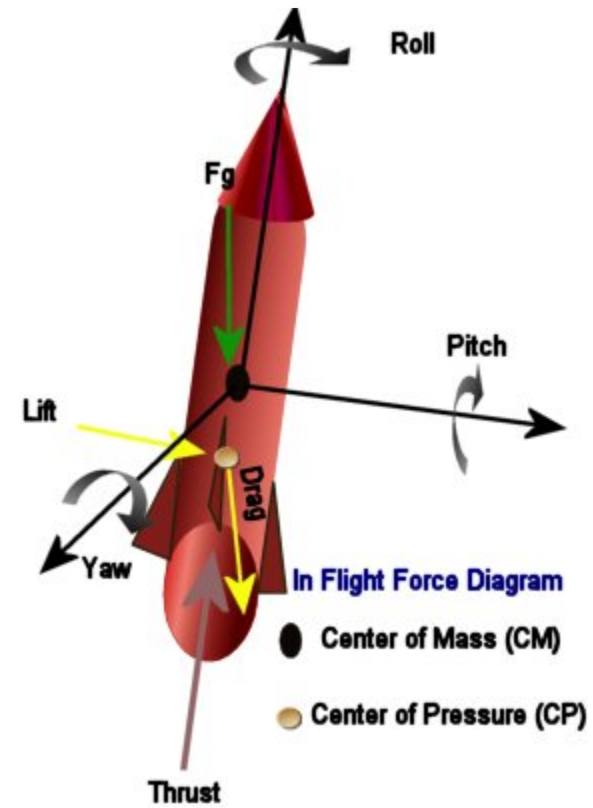




Look at forces and/or moments involved

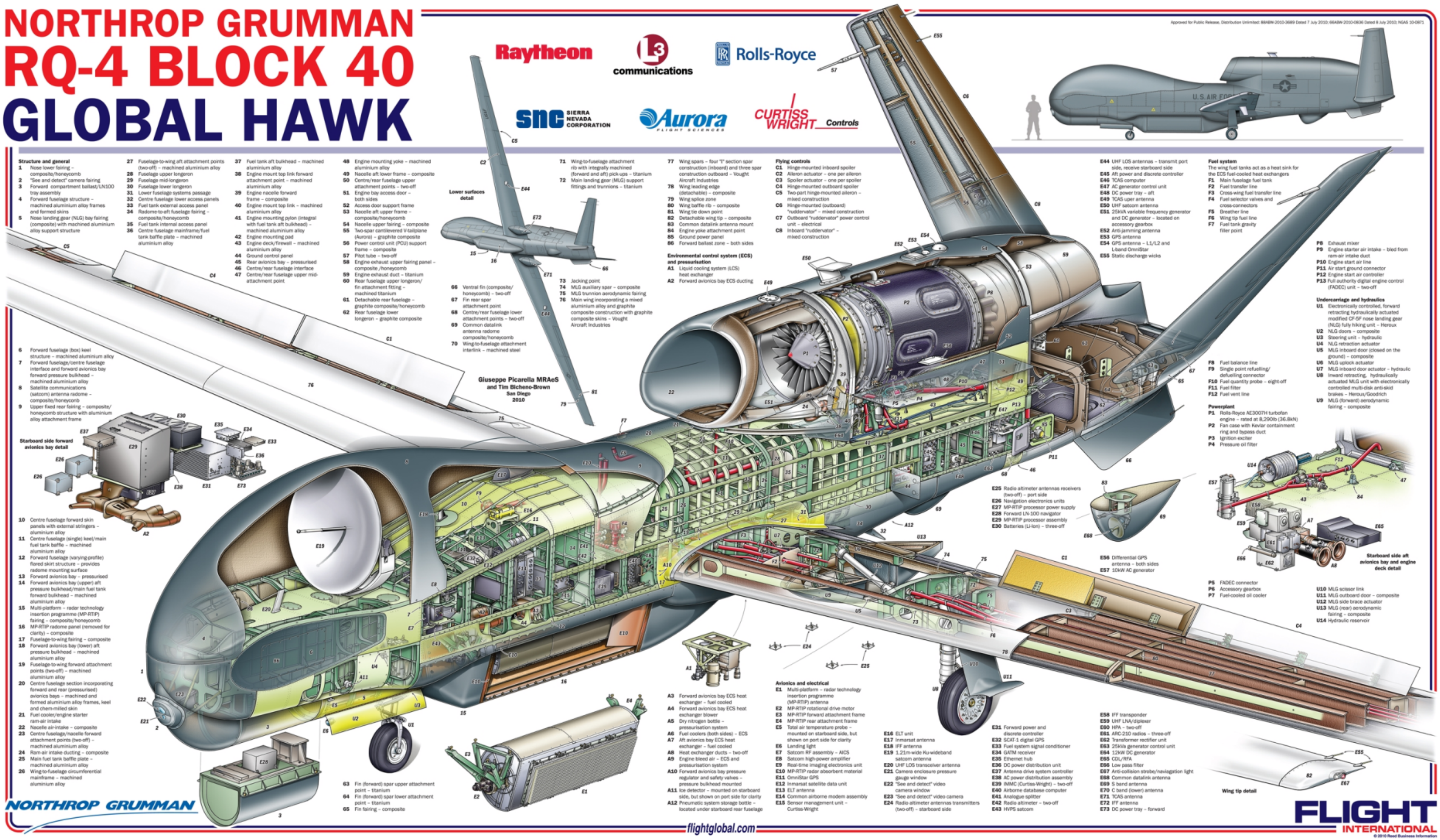
Examples of Physical Systems





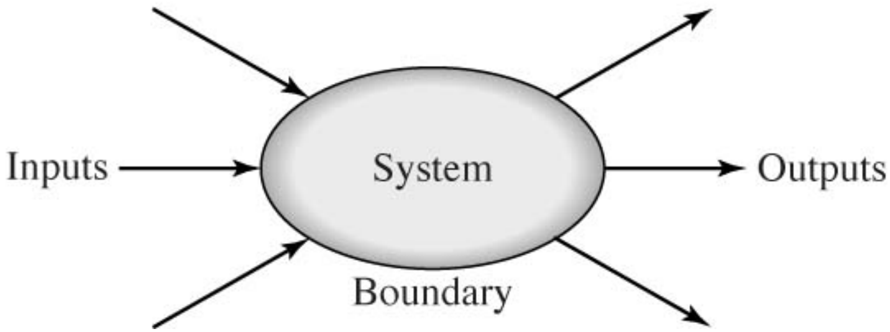
What <u>subsystems</u> can you think about on these two examples?

Systems Hierarchy



http://www.flightglobal.com/assets/getasset.aspx?ItemID=35661

Inputs and Outputs



- Input: External force/signal that causes a change in the system
- Output: Effect of input.
  - System characteristics set how outputs relate to inputs on a given system
- In order to control a system, we need to understand and model how the system reacts to expected inputs.

What are some examples of systems, their inputs, and outputs?

Static vs. Dynamic Systems

- *Static*: the output depends only on the current value of the input (*memory-less*)
  - Example:
    - The voltage (V) is the input in electrical systems
    - The current (I) is the output
    - They are related through: I=V/R *if it is a resistive-only circuit*

      (R- resistance, a parameter of the system)
- *Dynamic*: the output depends on past input values
  - Example:
    - The force (F) is the input in mechanical system
    - The velocity (v) is the output
    - They are related through:

$$v = v_0 + \int_{t_0}^{t} \frac{F}{m}\, dt$$

Dynamic systems

$$v = \int \left(\frac{F}{m} \right) dt$$

- Output depends on its past input
- Three ways to work with these systems
  - Ordinary differential equations
  - State-space equations (time-domain representation)
  - Transfer functions (frequency-domain representation)
- We can obtain the following knowledge from analysis
  - Response over time to given inputs
  - Frequency response of the system

States

- State: A variable used to describe the internal system dynamics:
  – The status of my system. A system can have as low as a single state or up to infinite states.
- Initial states: values of the states at the beginning of the simulation.
  – Initial states are needed as part of computing the time response

States

- Example
  - System: car
  - Inputs: gas pedal & steering wheel
  - States: speed, direction

Are we missing anything to calculate the response of the car?

Perhaps something the driver cannot control?

Introduction

Why Modeling & Simulation?

What is Modeling of Systems

- Modeling is the process of
  - Identifying the important physical dynamic effects to be considered in analyzing a system
  - Writing the algebraic and differential equations from the relevant discipline for each of the components of the system
    - Conservation laws, Newton laws, equation of state, etc.
  - Reducing the equations to a convenient differential equation form
    - Single equations or system of simultaneous equations.

Modelling

The same physical system may have different models, the best choice depends on the problem at hand.

Example

Electronic amplifier

- Low frequency model
- High frequency model

Example

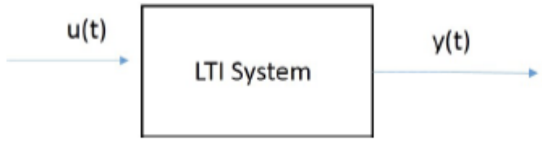
Space ship

- Point mass (trajectory)
- Rigid body (maneuvering)
- Flexible body (docking)

Question

Which model makes the most sense to move the telescope from one point to another?

Types of Models



Convolution

$$y(t) = \int_{\tau=0}^{t} g(t-\tau)u(\tau)d\tau$$

State Space

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t) + Du(t)$$

Transfer Function

$$\hat{y}(s) = \hat{g}(s)\hat{u}(s)$$

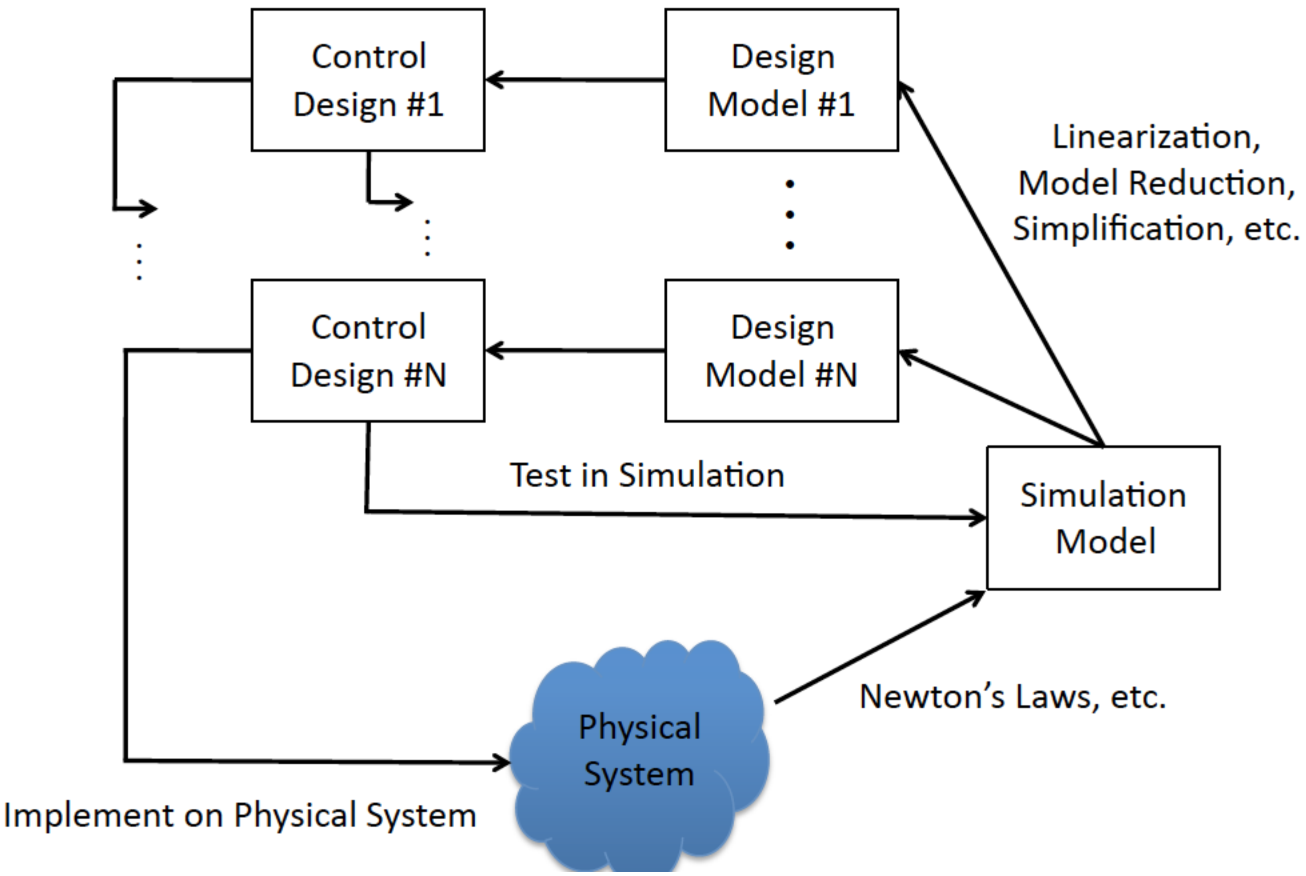
$$e.g\ \hat{g(s)} = \frac{3s^2 - 2s + 5}{s^3 + 4s^2 + 2.5s + 3}$$

Higher Order Differential Equations

$$y^{(3)}(t) + \ddot{y}(t) + 2.5\dot{y}(t) + 3y(t) = 3\ddot{u}(t) - 2\dot{u}(t) + 5u(t)$$

Modeling

Design Process



Modeling of systems

- Model can be obtained from first principles, from test data, or from a combination
- Can be complex or simple, depending on the intended use
  - Typically it is best to keep models as simple as possible for a given goal
- What do we use models for?
  - Analysis: Understand behavior of system to different inputs
  - Prediction: To assist in decision making
  - For control design: Simpler if we have a model of the system
  - To minimize risk and cost in the development cycle
    - Saves money and sometimes lives!

Couple of quick aerospace examples

- GEnx power management logic for Boeing 787
- SpaceX booster landings
- Boeing 737MAX LionAir accident

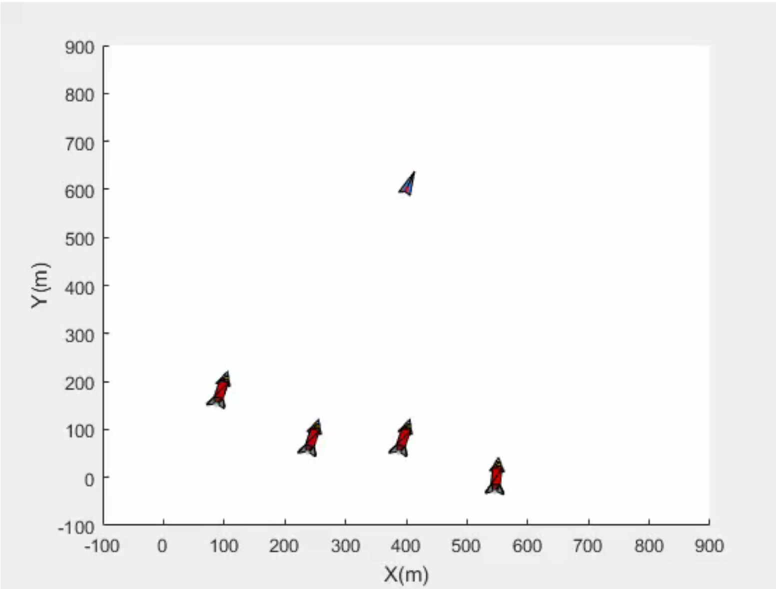
From Modeling to Simulation

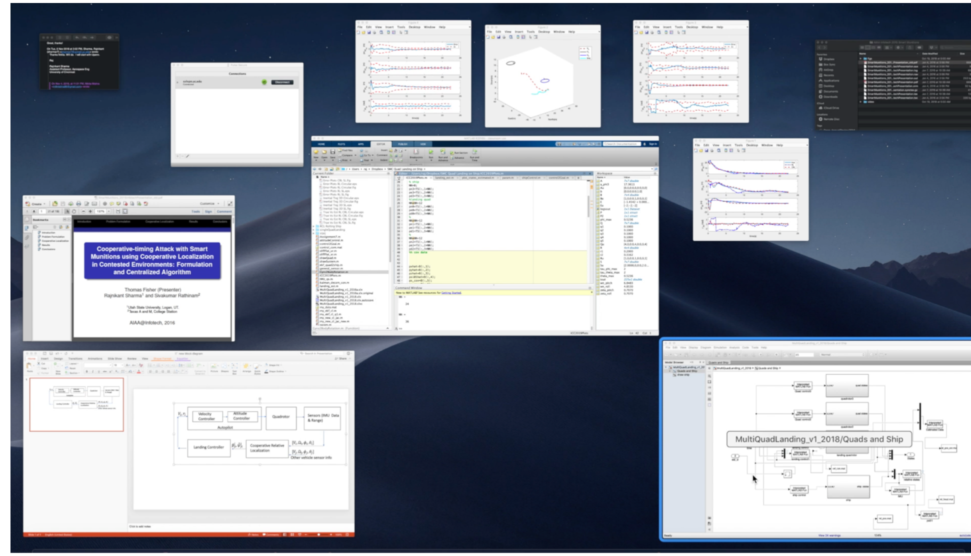
- Always use a model that is just detailed enough for the requirements you need.
  - Not enough details: you are making too many assumptions and losing important attributes of the systems.
    - In some cases, your model will mislead you!
  - Too many details: your model will become insoluble and therefore useless.
    - Model for engine performance is more complex that the one for control
- Remember: your solution is as good as the model you used.
  - When possible, check the fidelity of your model, especially if linearizing non-linear equations
- **Always keep the limitations of your model in mind!**

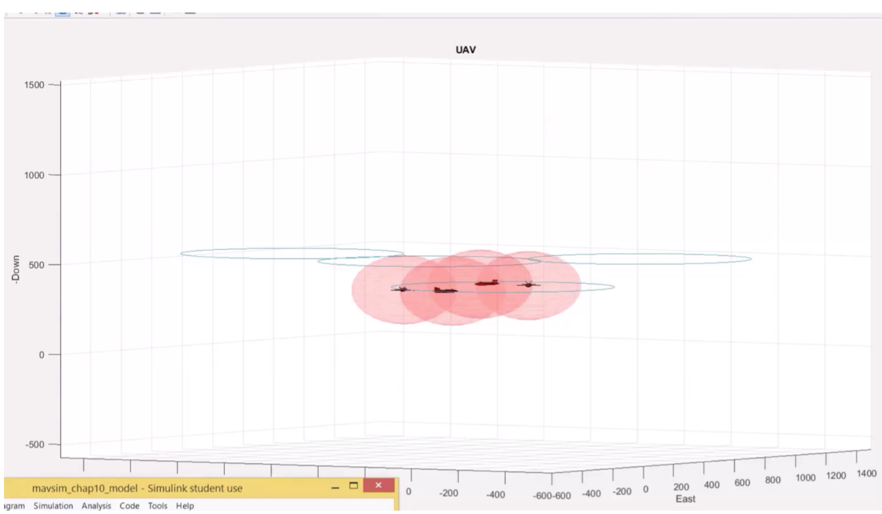
Building the model – Model types

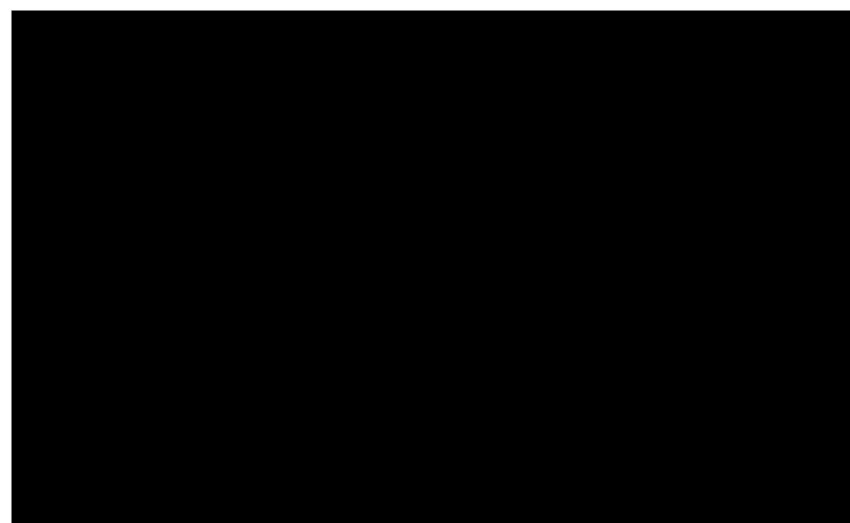
- Continuous-time systems (aka analog systems)
  - All the signals are continuous all the time
  - Everything is defined at each time instant
- Discrete-time systems (aka sampled data systems)
  - Variables are only defined at discrete times
  - If sampled fast enough, a discrete time system very closely approximates a continuous time system
- Hybrid systems
  - Some components are continuous and some are sampled

Some Examples









Simulink simulation: Pendulum on Cart

SI and FPS Units

	Unit name and abbreviation	
Quantity	**SI Unit**	**FPS Unit**
Time	second (s)	second (sec)
Length	meter (m)	foot (ft)
Force	newton (N)	pound (lb)
Mass	kilogram (kg)	slug
Energy	joule (J)	foot-pound (ft-lb), Btu (= 778 ft-lb)
Power	watt (W)	ft-lb/sec, horsepower (hp)
Temperature	degrees Celsius (°C), degrees Kelvin (K)	degrees Fahrenheit (°F), degrees Rankine (°R)

Unit Conversion Factors

Length	1 m = 3.281 ft	1 ft = 0.3048 m
	1 mile = 5280 ft	1 km = 1000 m
Speed	1 ft/sec = 0.6818 mi/hr	1 mi/hr = 1.467 ft/sec
	1 m/s = 3.6 km/h	1 km/h = 0.2778 m/s
	1 km/hr = 0.6214 mi/hr	1 mi/hr = 1.609 km/h
Force	1 N = 0.2248 lb	1 lb = 4.4484 N
Mass	1 kg = 0.06852 slug	1 slug = 14.594 kg
Energy	1 J = 0.7376 ft-lb	1 ft-lb = 1.3557 J
Power	1 hp = 550 ft-lb/sec	1 hp = 745.7 W
	1 W = 1.341×10^{-3} hp	
Temperature	$T^\circ C = 5(T^\circ F - 32)/9$	$T^\circ F = 9T^\circ C/5 + 32$

References

- William J. Palm III, ***System Dynamics, 2nd Edition,*** McGraw-Hill, 2010.
- Dr. Sheng Wan, AEEM 313 – Class notes, Summer 2007.
- Dr. Al Bosse, AEEM 313 – Class notes, Fall 2007.
- Dr. Gary Slater, AEEM 313 – Class notes
- Dr. Kelly Cohen, AEEM 313 – Class notes, Summer 2010