SYSTEM CHARACTERISTICS AND PERFORMANCE

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https://unsplash.com/@cookaynne

Overview

- Admin (10 min discussion)
  – Learning update
  – Quanser lab
- Recap (10 min lecture)
- New material (2x 30 min lecture)
  – Assumptions, limitations, system characteristics
  – (10 min break)
  – Performance
- Practice – CTMS (20+ min self-directed, pair-do-discuss)
- Wrap-up (5 min)

Breaking news

- NB SEDS HyPower launch 9am-12am window, est 10am
  - https://www.youtube.com/watch?v=NkisClwZ2aw

Q: Open vs closed source

- https://survey.stackoverflow.co/2025/technology/#most-popular-technologies
- Aspiration vs pragmatism, prep for industry
- Liability, validation, verification, funding
- c.f. CAD, other software
- Alternatives:
  - https://python-control.readthedocs.io/
  - https://control-toolbox.readthedocs.io/
  - https://octave.org
  - https://www.scilab.org/software/xcos
  - https://openmodelica.org
- No constraint in coursework reqs, but I can't support - apols

Simulink Control Design Onramp

- Congrats on completing
- PLEASE DON'T EMAIL ME
- Progress
  - 48 in dashboard
  - 8 emailed link
  - 7 emailed attachment
  - 63 total (/159)
  - *+5 Simulink Onramp 2h…*
- Strongly recommended, check last week's slides

Reflections on Onramp

- Units - usually not defined - just numbers
- Demonstrated non-linearities – mathematical models, saturation, other
- "Don't worry about the math" - lol we will
- Really useful tools - become fluent, but don't forget the underlying mathematical concepts - I want to see them in your assessments.
- MATLAB kinda opaque sometimes
  - e.g. settling time - 2%? 5%?
  - Default 2, but needed to dig several layers in help files to find out
  - Know your theory!

Lab access and booking

- Linked from Bb/Control/Lab
- Sims not yet available

Quansers and Flight Simulators

QB M.003

Opening Hours: 09:00-17:00

Lab Access is Regulated through a Booking System

Two students are allowed per station per slot.

Each booking lasts one hour; please wrap up your work within 55 minutes so the next two students can start promptly.

Book a Quanser

Book a Flight Sim

Students should leave the stations tidy for the next slot's users.

As this lab is used by students carrying out different activities, please keep noise to a minimum.

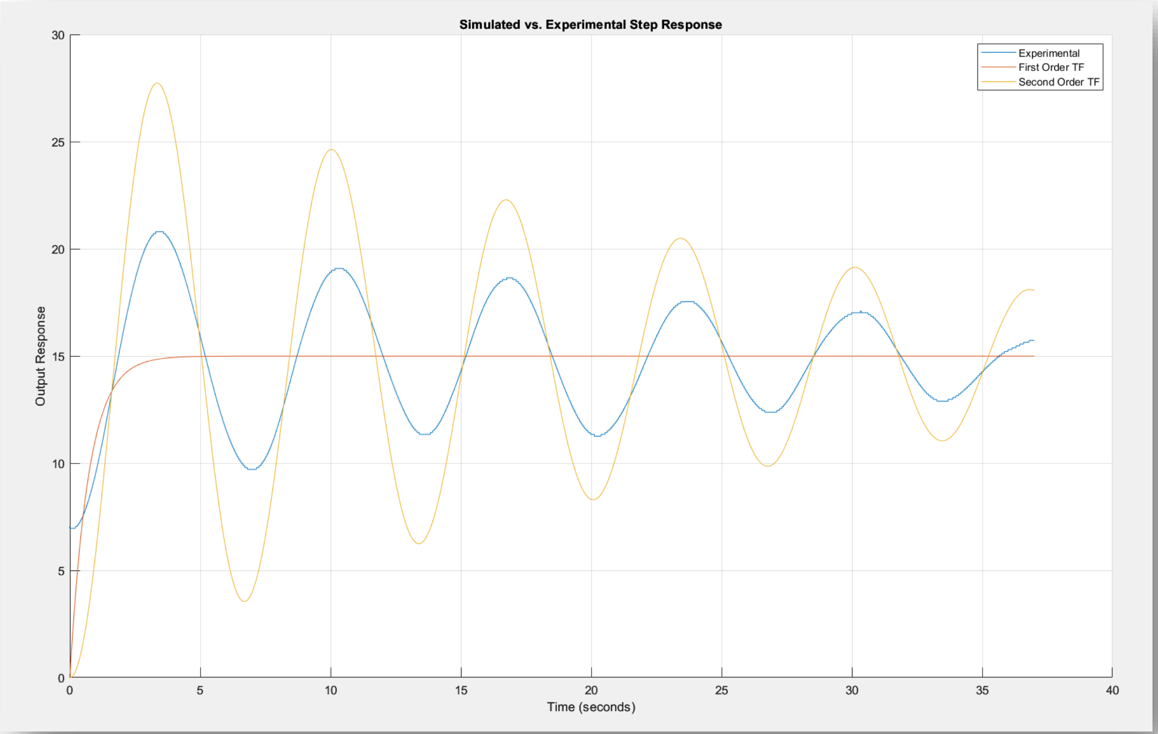
Please comply with the Teaching Labs Codes of Practice shown on the door and by the staff desk.

Technical contacts:

- Quansers: Alex Dunnett or **Dr** Khalid Al Mallak.
- Flight Sims: Sid Reid , Tim Ward, or **Dr** Khalid Al Mallak.

Quanser lab

- Practical shenanigans!
  - Important to experience!!!
- Questions/issues?



Q: how should I study?

- Lectures – immersive(?), linking theory and application
  - Try to see the whole shape, make connections
- Theory – needs to sink in
  - Use texts – Dorf is recommended, other great ones exist
  - Try examples and exercises/problems/advanced problems/ design problems/computer problems – loads in Dorf, solutions on Bb.
- Practice – need to practice!
  - Use design/computer problems
  - Undertake labs
  - Use online resources – CTMS recommended

Q: time allocation

- 20cp = 200h
  - 4 lectures x 10 weeks = 40h
  - 10h labs (5h in-lab, 5h computer? Est.) – Quanser + Sims
  - h_c h coursework
  - (150-h_c) h self-directed
- Coursework
  - Front-load learning and understanding, or n ⬆️⬆️ !
- However…
  - 60cp = 600h; /12wks = 50h/wk!! And NB coursework deadlines wk11.
  - Some units span hols, plan appropriately but take a break
  - UoB working week 35h
  - So actually 140h/20cp unit
  - Still 90-h_c h self-directed – 1:1 lecture:study still leaves h_c=50

Q: there are a lot of resources/content!

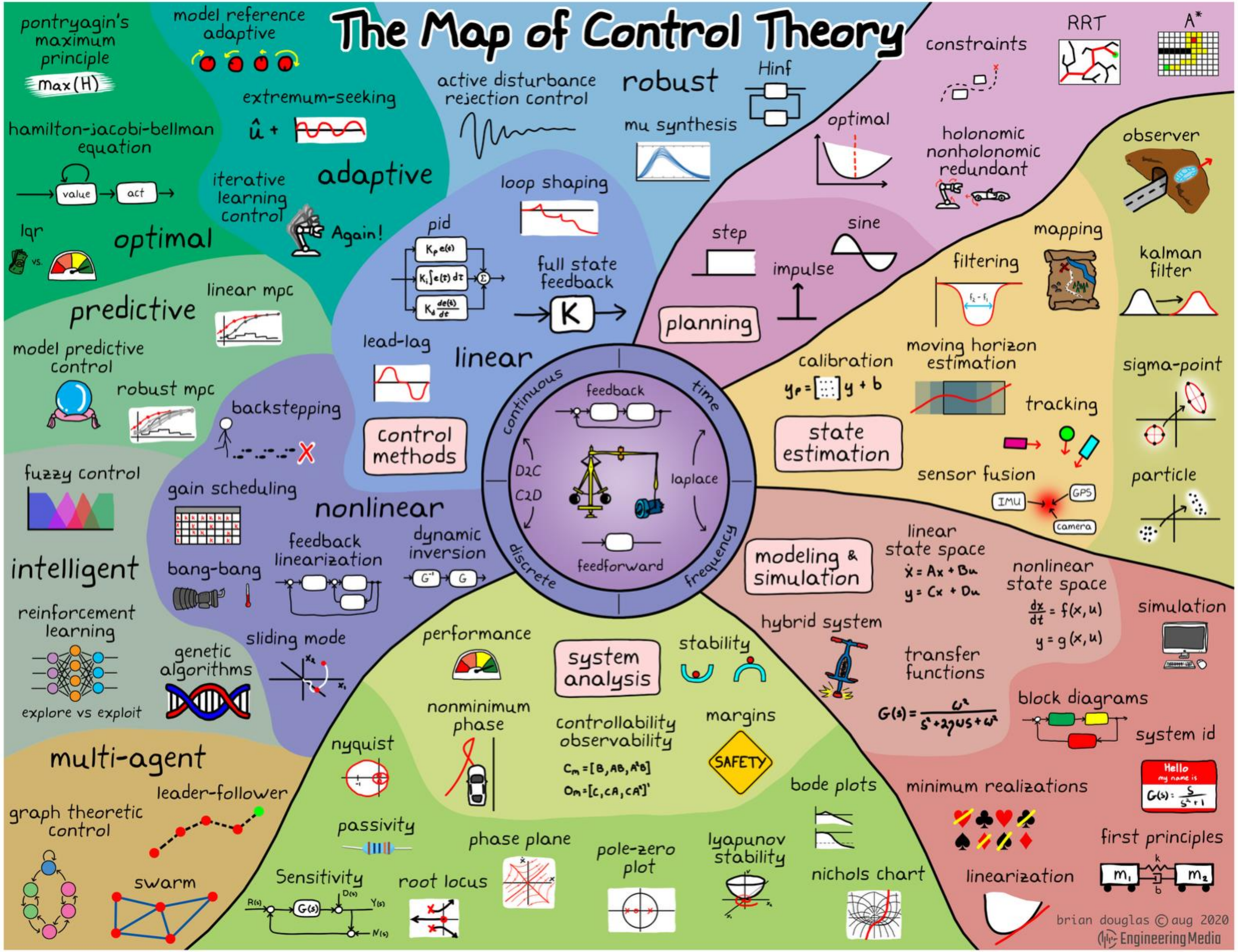
- Don’t try to read them all, dip in and find what you like
- I’m not going to assess you on previously-assessed stuff
  - E.g. no hand-calc Laplace transforms, ODEs, etc.
  - But you need to demonstrate confidence and competence in discussion
- Get interested, geek out, stay motivated
- Coursework out next Friday – deadline wk11

Wider unit progress

- Good noises from Tom/Mark and Steve Burrow
  - Any q’s feedback? Now or via email/Teams

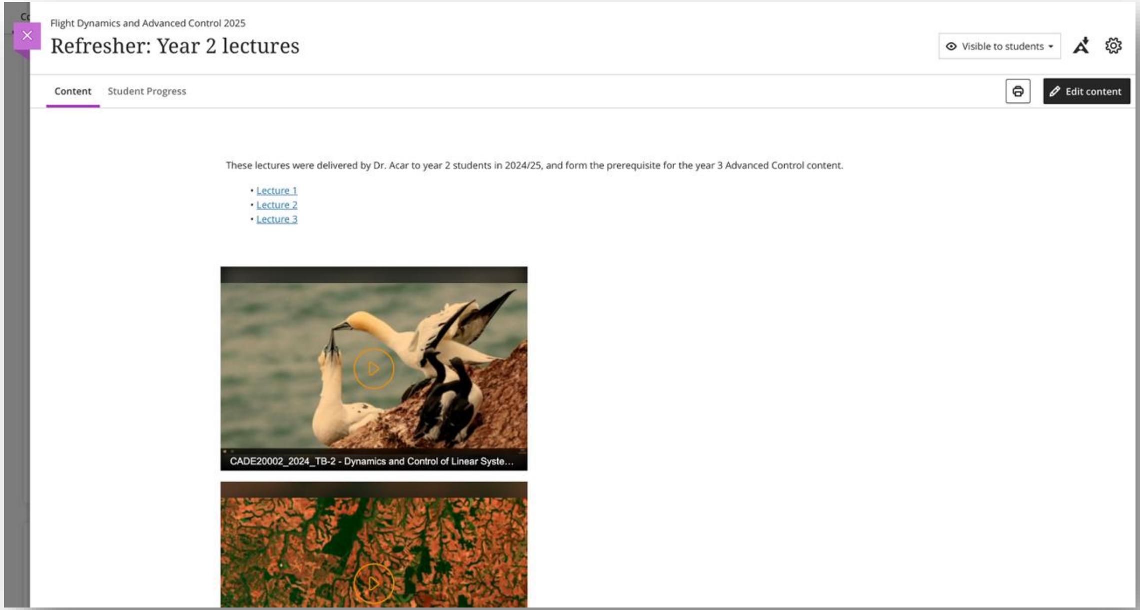
On to a recap…

- BD map
- Dr. Acar yr2 lectures
- Dorf pointers


The Map of Control Theory
pontryagin's maximum principle
max(H)
model reference adaptive
extremum-seeking
hamilton-jacobi-bellman equation
value
act
iterative learning control
Again!
adaptive
lqr
vs.
optimal
active disturbance rejection control
robust
Hinf
mu synthesis
loop shaping
pid
full state feedback
K
linear mpc
predictive
model predictive control
robust mpc
lead-lag
linear
backstepping
control methods
fuzzy control
gain scheduling
nonlinear
feedback linearization
dynamic inversion
bang-bang
intelligent
reinforcement learning
explore vs exploit
genetic algorithms
sliding mode
multi-agent
leader-follower
graph theoretic control
swarm
continuous
time
feedback
D2C
C2D
laplace
feedforward
discrete
frequency
constraints
RRT
A*
optimal
holonomic
nonholonomic
redundant
observer
step
sine
impulse
planning
mapping
filtering
kalman filter
calibration
moving horizon estimation
sigma-point
tracking
state estimation
sensor fusion
IMU
GPS
camera
particle
modeling & simulation
linear state space
$\dot{x} = Ax + Bu$
$y = Cx + Du$
nonlinear state space
$\frac{dx}{dt} = f(x,u)$
$y = g(x,u)$
hybrid system
simulation
transfer functions
$G(s) = \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$
block diagrams
system id
Hello my name is
minimum realizations
first principles
linearization
performance
system analysis
stability
nonminimum phase
controllability observability
$C_m = [B, AB, A^2B]$
$O_m = [C, CA, CA^2]'$
margins
SAFETY
bode plots
nyquist
passivity
phase plane
pole-zero plot
lyapunov stability
nichols chart
Sensitivity
root locus
brian douglas © aug 2020
EngineeringMedia

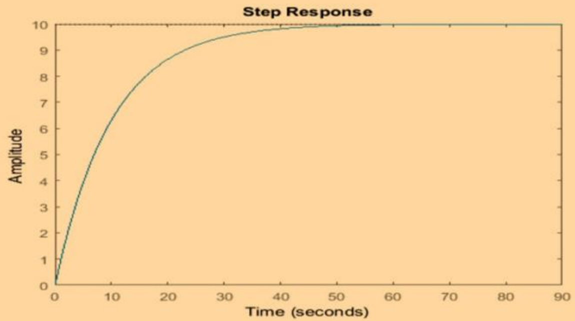
bristol

Prereqs

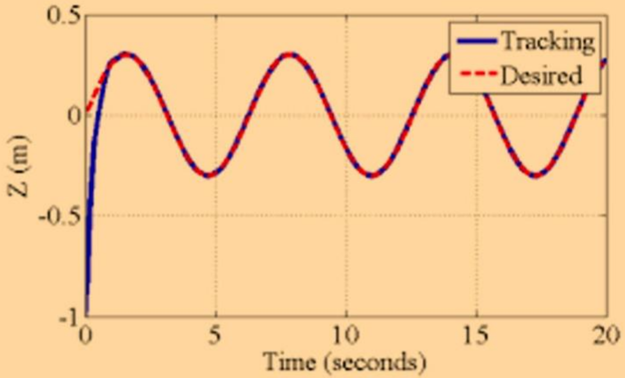

Flight Dynamics and Advanced Control 2025
Refresher: Year 2 lectures
Visible to students
Content
Student Progress
Edit content
These lectures were delivered by Dr. Acar to year 2 students in 2024/25, and form the prerequisite for the year 3 Advanced Control content.
• Lecture 1
• Lecture 2
• Lecture 3
CADE20002_2024_TB-2 - Dynamics and Control of Linear Syste...

The aim in control system either

- Regulation :
  - To maintain system response at CONSTANT desired values
  - Usually ZERO



- Tracking :
  - To make system response follow continually CHANGING desired values



Recap – Dr Acar L1

Representation of Control Systems

- Differential Equations

$$J_{eq}\dot{\omega}_m(t) = \tau_m(t)$$

- Transfer Functions

$$\frac{\Omega_m(s)}{V_m(s)} = \frac{K}{\tau s + 1}$$

- State Space Equations
  - Nth order differential equations → n times 1st order differential equations

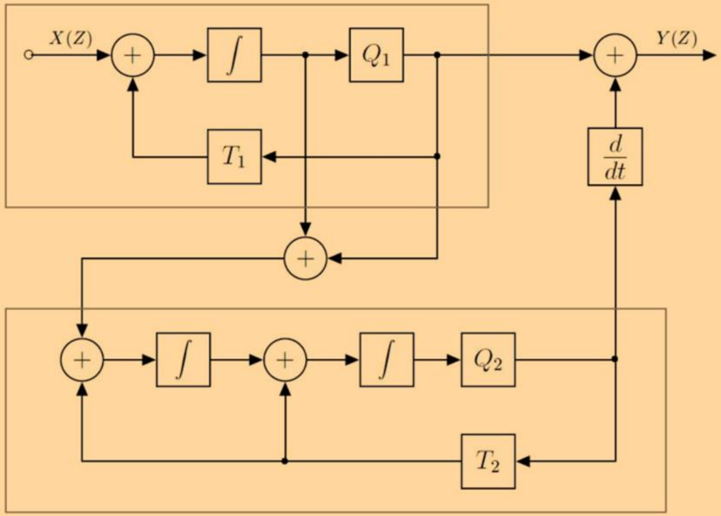
$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

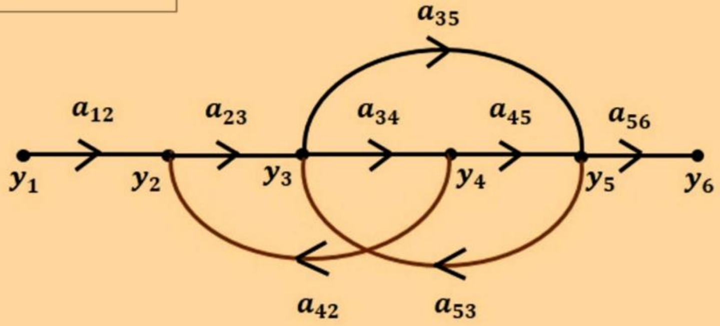
Recap – Dr Acar L1

Representation of Control Systems

- Block Diagram

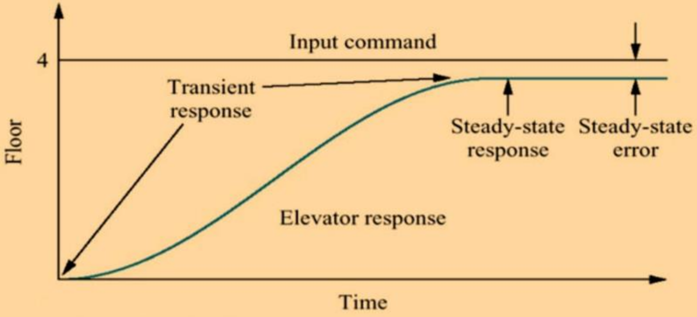


- Signal Flow Graph

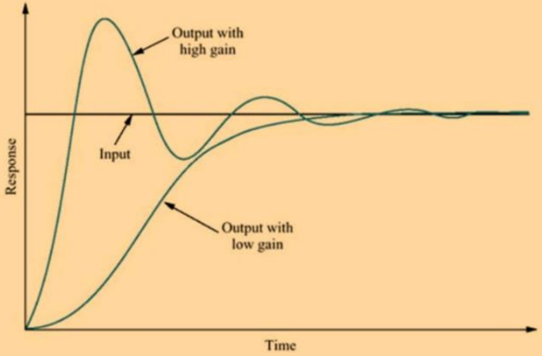


Recap – Dr Acar L1

Some of Analysis and Design Objectives



- Stability
- Steady-State Response (Steady – State error)
- Transient Response (Response Speed , Overshoots , Undershoots, etc)
- Disturbance rejection
- Sensitivity to uncertainities



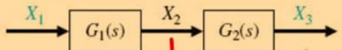
Recap – Dr Acar L1

$$Y = G \times U$$

Table 2.6 Block Diagram Transformations

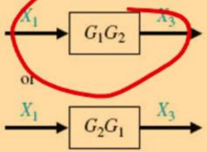
Transformation | **Original Diagram** | **Equivalent Diagram**

1. Combining blocks in cascade

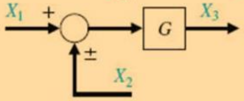


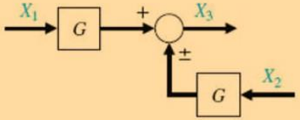
$(G_1 \times X_1)$

1

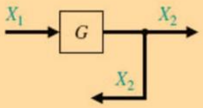


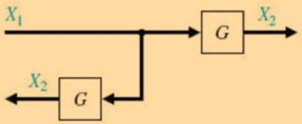
2. Moving a summing point behind a block



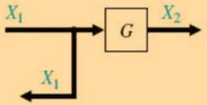


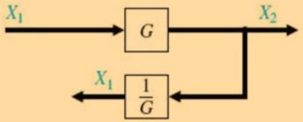
3. Moving a pickoff point ahead of a block



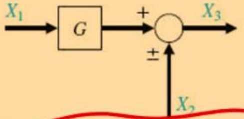


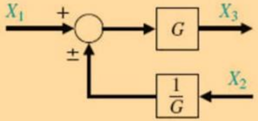
4. Moving a pickoff point behind a block



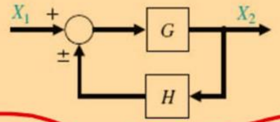


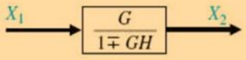
5. Moving a summing point ahead of a block





6. Eliminating a feedback loop





Recap – Dr Acar L2

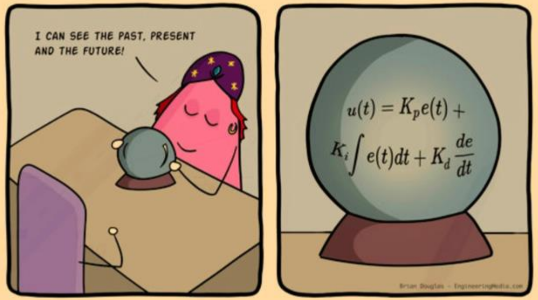
Credit: Modern Control System, Richard Dorf and Robert Bishop

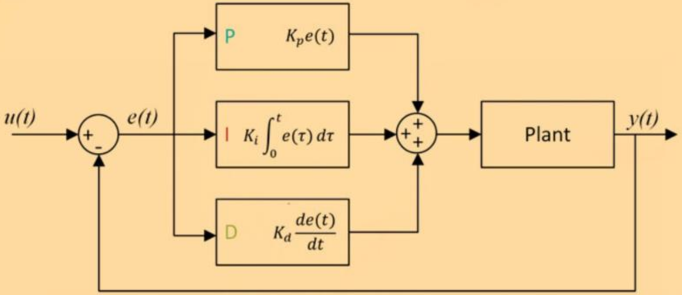
PID Control

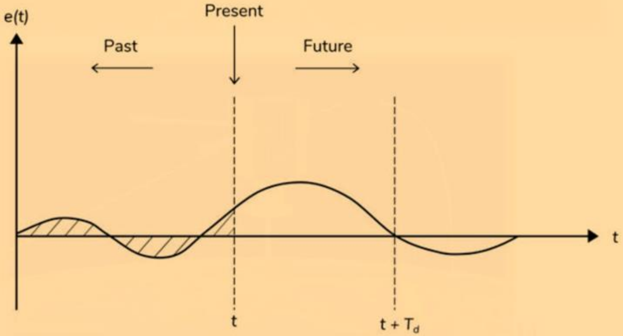
$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt}$$

- The controller is an idealized representation.
- It is a useful abstraction for understanding the PID controller.
- Several modifications must be made to obtain a controller that is practically useful.
- Before discussing these practical issues, we will develop
out PID control.

Recap – Dr Acar L2

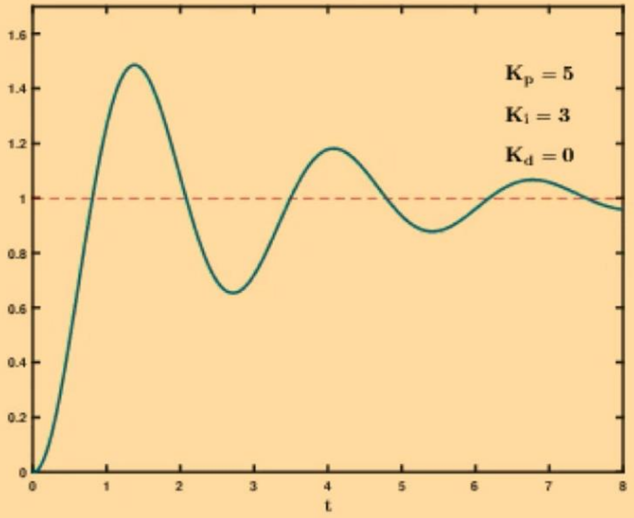




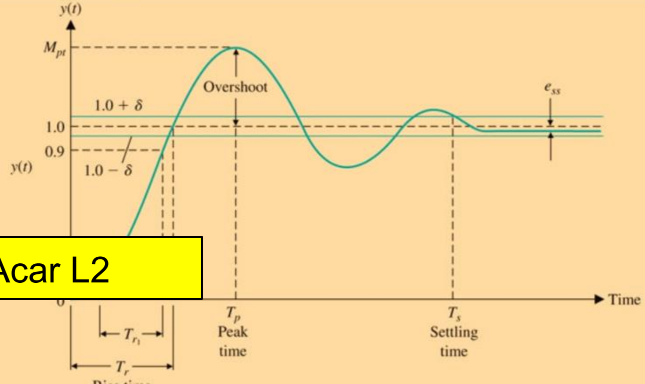


Effects of P, I , D actions

Effects of increasing a parameter independently					
Action	**Parameter**	**Rise Time**	**Overshoot**	**Settling Time**	**Steady S. Error**
P	K_p	Decrease	Increase	Small Change	Decrease
I	K_i	Decrease	Increase	Increase	Decrease
D	K_d	Small Change	Decrease	Decrease	No Change



Effects of varying PID parameters (K_p,K_i,K_d) on the step response of a system



Recap – Dr Acar L2

Antenna Azimuth– Position Control

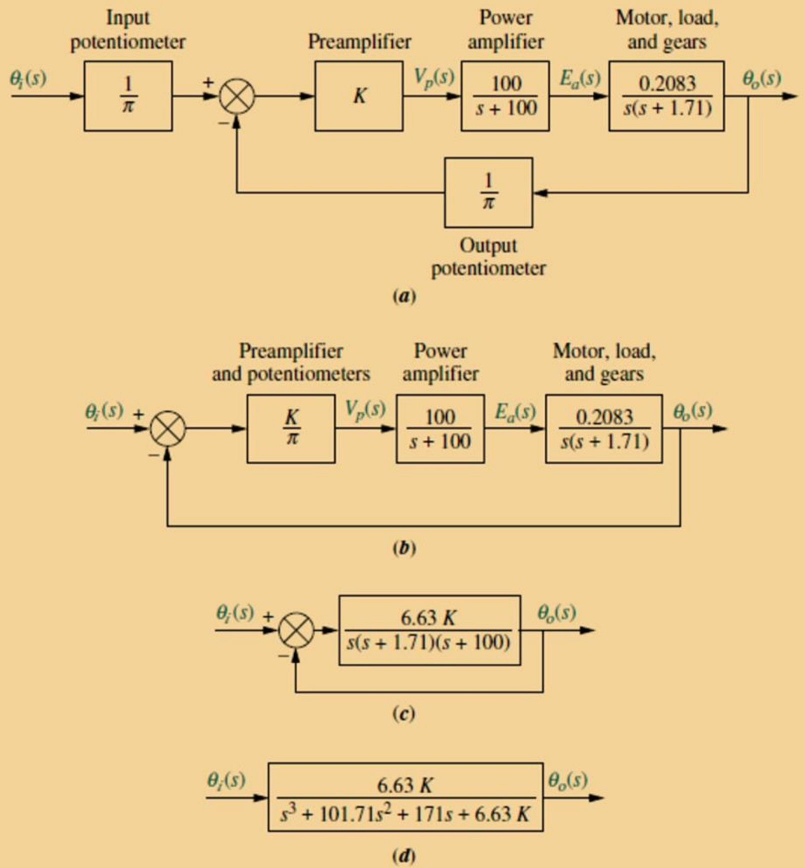
Block diagram reduction for the antenna azimuth position control system:

a. original;

b. Pushing input potentiometer to the right past the summing junction;

c. showing equivalent forward transfer function;

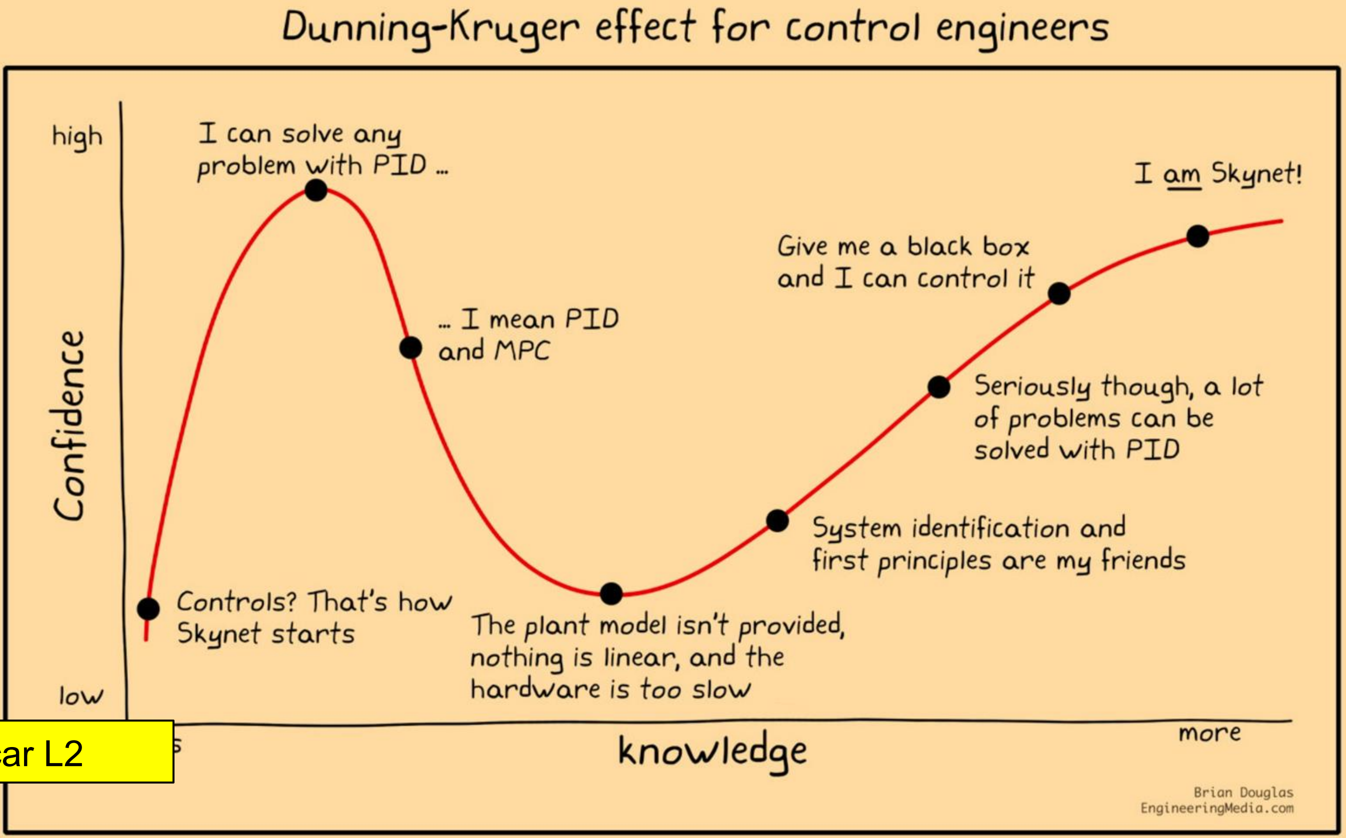
d. Final closed-loop transfer function



Recap – Dr Acar L2

Credit : Norman Nise, Control Systems Engineering

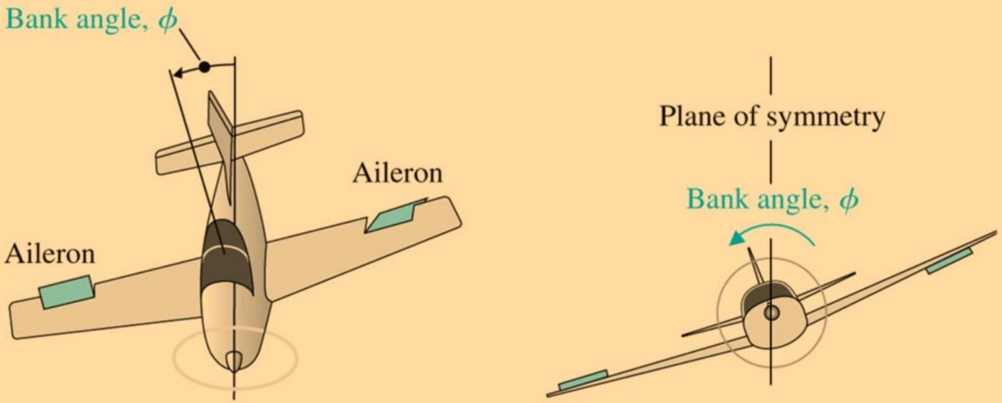
The goal

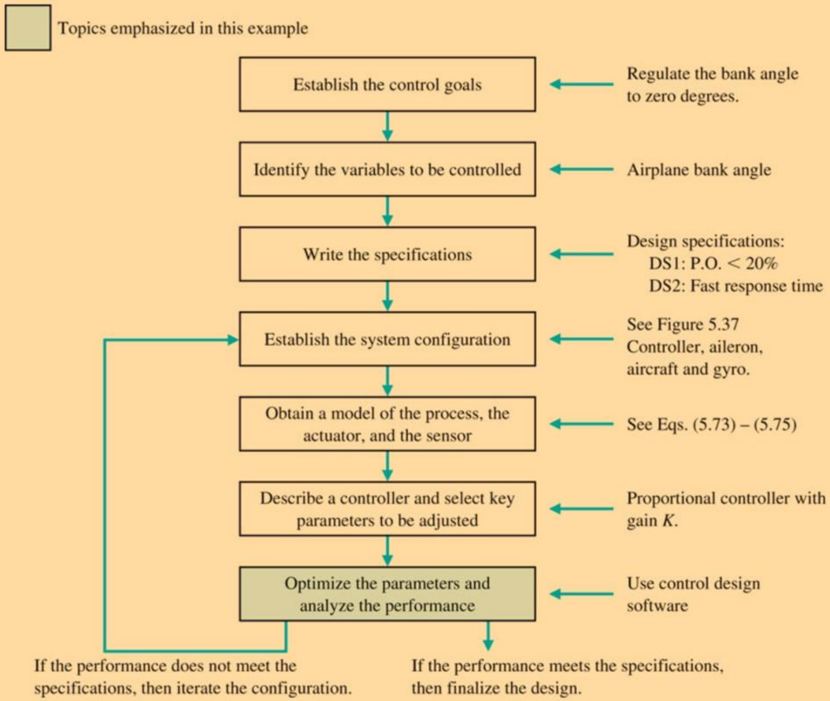


Recap – Dr Acar L2

Control of the bank angle of an airplane

Figure 5.35 Control of the bank angle of an airplane using differential deflections of the ailerons.

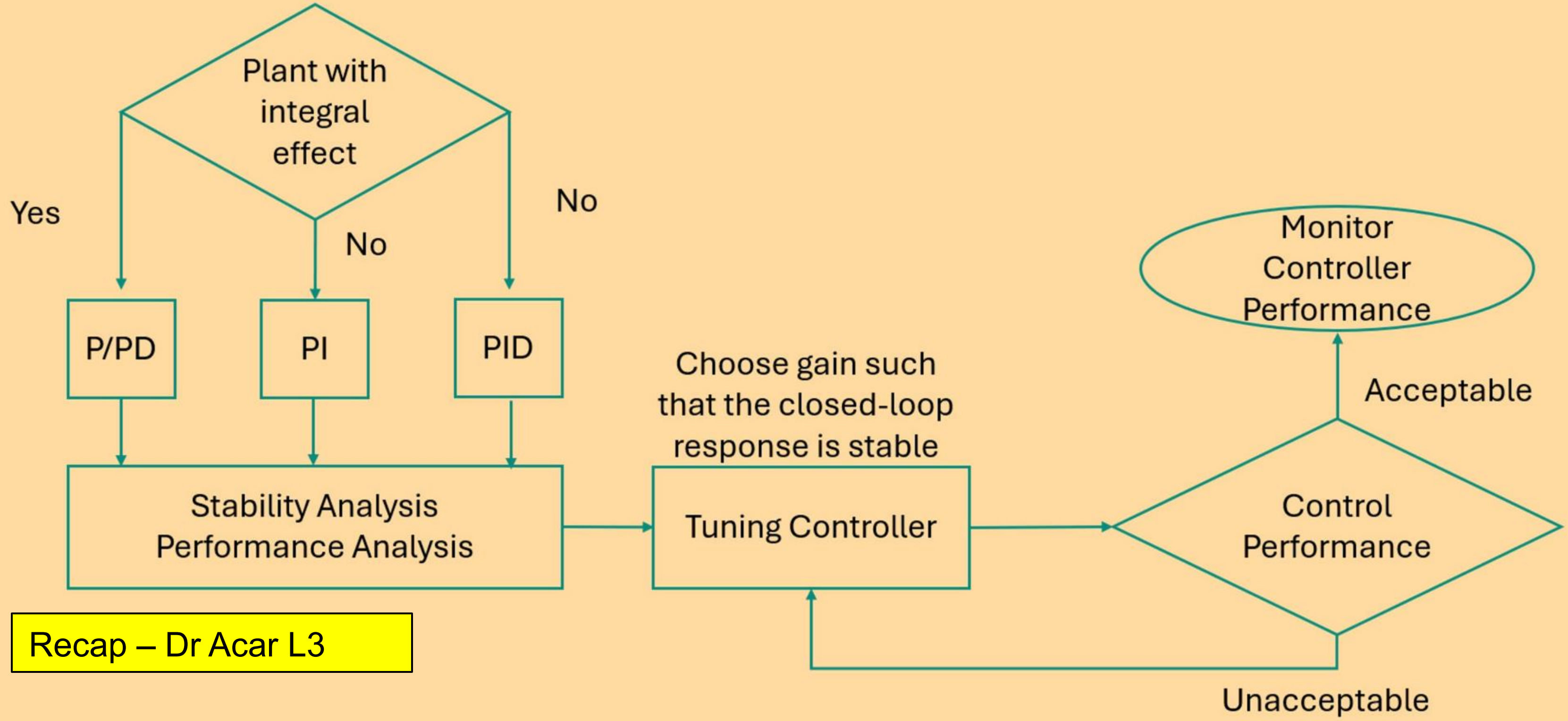




Recap – Dr Acar L2
Dorf 14th ed Ex5.9

Credit: Modern Control System, Richard Dorf and Robert Bishop

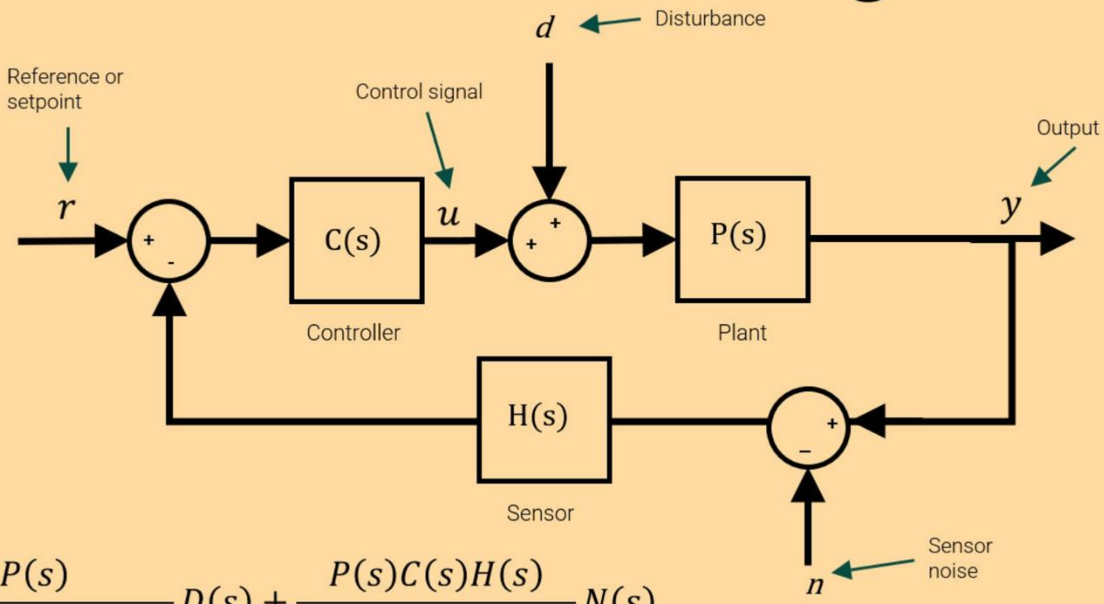
PID Tuning Flowchart



Recap – Dr Acar L3

Charateristic Equation - Model Based Tuning

- If the model is known (estimated or derived by using first principle of physics) , we have plant transfer function



- Find closed loop transfer function

$$Y(s) = \frac{P(s)C(s)}{1+P(s)C(s)H(s)}R(s) + \frac{P(s)}{1+P(s)C(s)H(s)}D(s) + \frac{P(s)C(s)H(s)}{1+P(s)C(s)H(s)}N(s)$$

- Match the characteristic equation of the desired closed-loop transfer function to the actual closed-loop transfer function.

Recap – Dr Acar L3

Example : Charateristic Equation Matching

6.Solve for Gains

Equate coefficients of the actual characteristic equation with those of the desired one to solve for k_D, k_P, k_I.

Characteristic Equation :$1 + P(s)C(s)H(s) = 0$

$$s^3 + \frac{K_D}{J}s^2 + \frac{K_p}{J}s + \frac{K_I}{J} = 0$$

Desired Characteristic Equation :

$$(s + p_o)(s^2 + 2\zeta w_n s + w_n^2) = 0$$

$$s^3 + (2\zeta w_n + p_o)s^2 + (2\zeta w_n p_o + w_n^2)s + w_n^2 p_o = 0$$

$$K_I = J w_n^2 p_o$$

$$K_p = J(2\zeta w_n p_o + w_n^2)$$

$$K_D = J(2\zeta w_n + p_o)$$

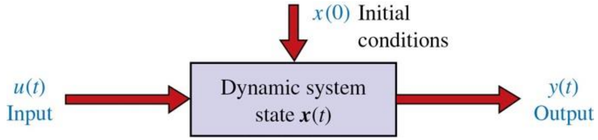
Recap – Dr Acar L3

Practical Issues in Real-Life

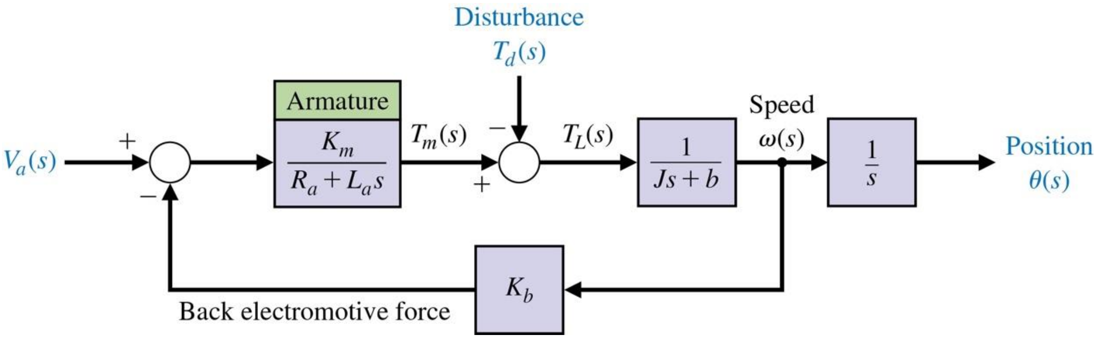
- No pure derivative due to noise (filter required)
- Integral Wind-up (Anti-Wind-up, Reset)
- Saturation (incremental increase)
- Digitalisation (sampling errors) (high resolution and enough margins)
- Nonlinear behaviours and coupling (gain scheduling)

Recap – Dr Acar L3

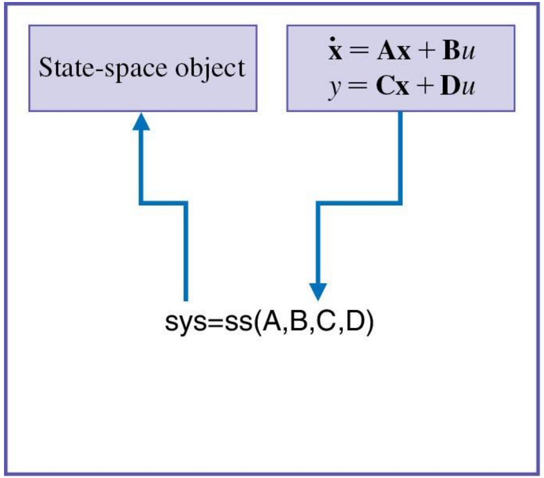
Models



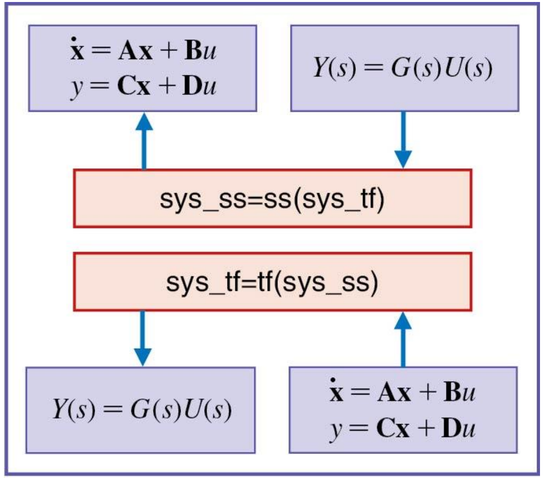
$x(0)$ Initial conditions
$u(t)$ Input
Dynamic system state $\boldsymbol{x}(t)$
$y(t)$ Output



Disturbance $T_d(s)$
$V_a(s)$
Armature
$\frac{K_m}{R_a + L_a s}$
$T_m(s)$
$T_L(s)$
$\frac{1}{Js + b}$
Speed $\omega(s)$
$\frac{1}{s}$
Position $\theta(s)$
K_b
Back electromotive force

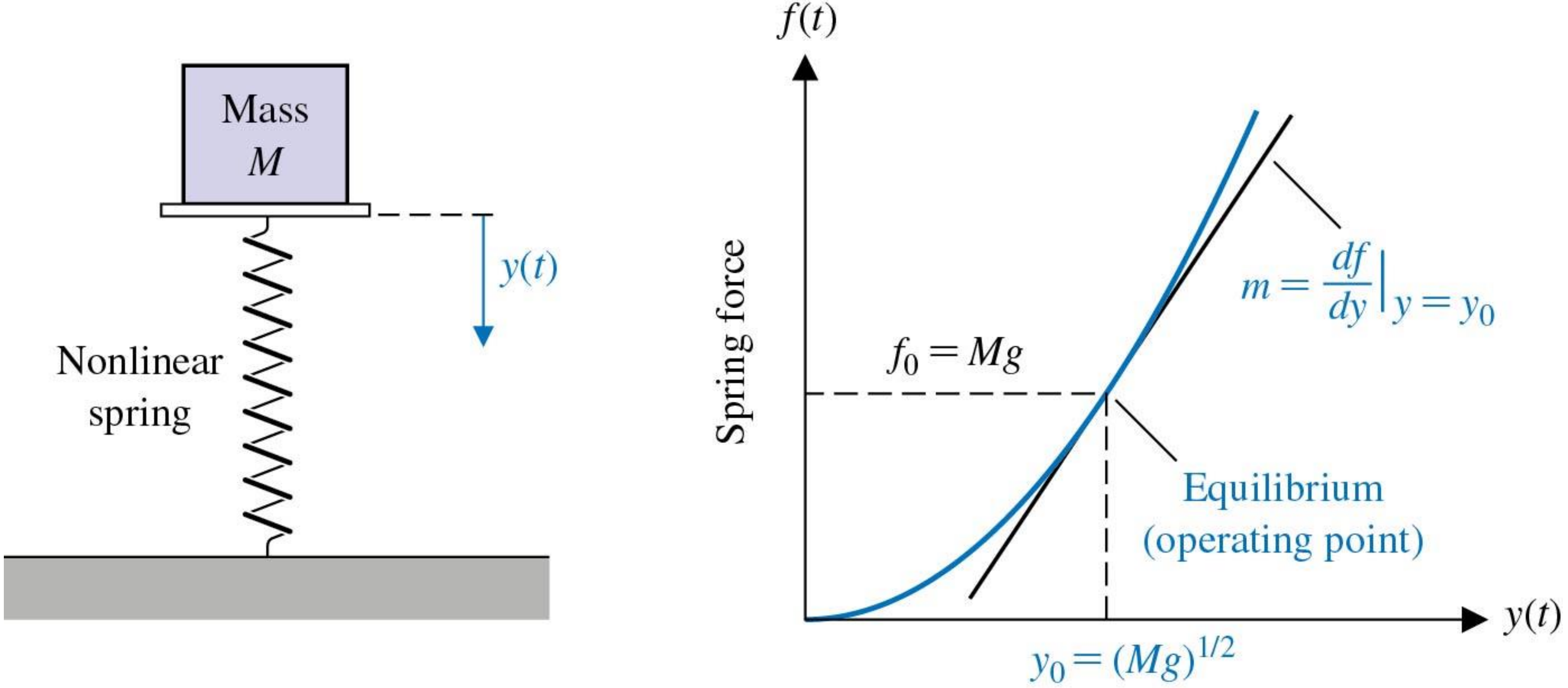


State-space object
$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u$
$y = \mathbf{C}\mathbf{x} + \mathbf{D}u$
sys=ss(A,B,C,D)



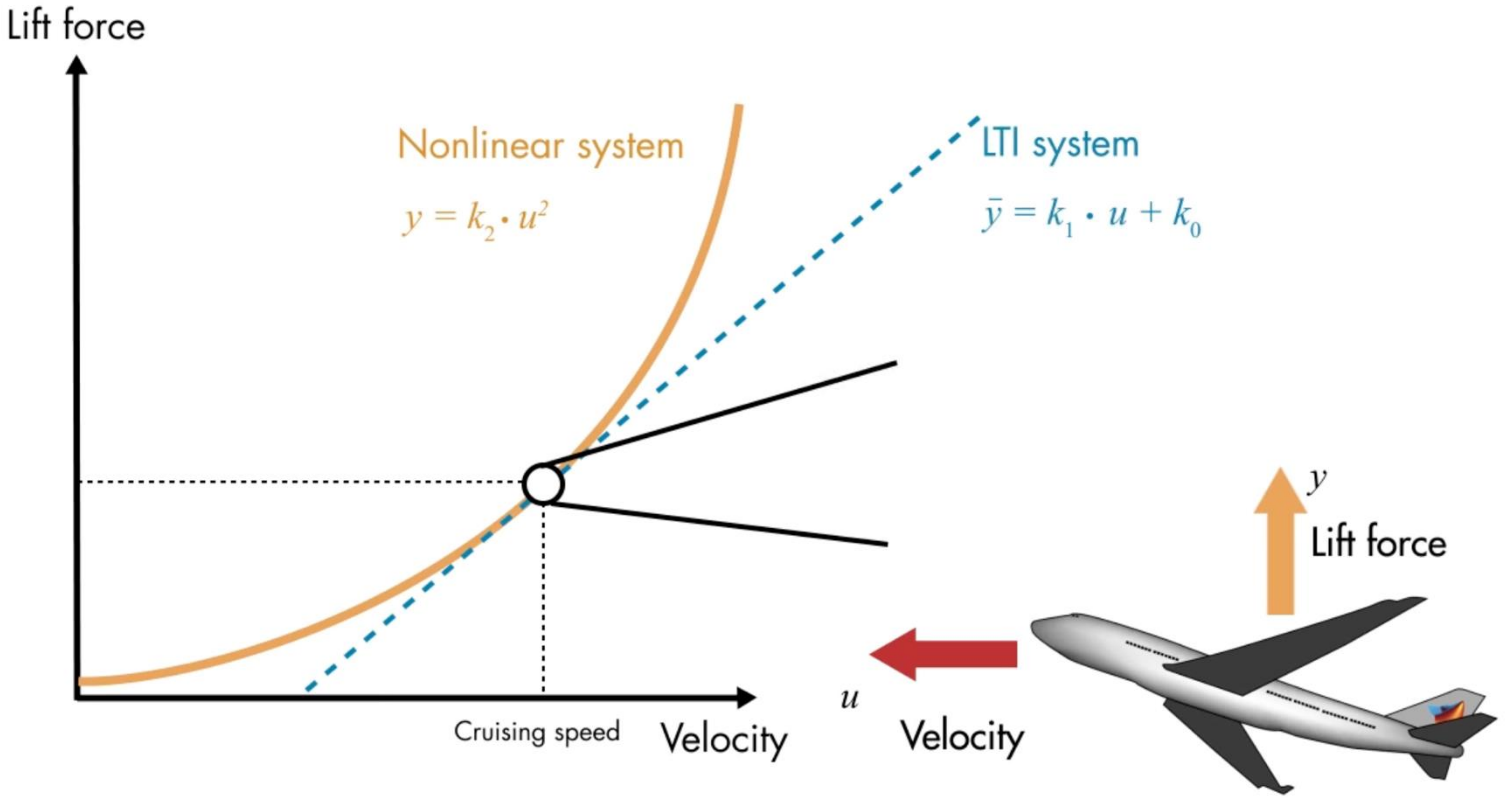
$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u$
$y = \mathbf{C}\mathbf{x} + \mathbf{D}u$
$Y(s) = G(s)U(s)$
sys_ss=ss(sys_tf)
sys_tf=tf(sys_ss)
$Y(s) = G(s)U(s)$
$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u$
$y = \mathbf{C}\mathbf{x} + \mathbf{D}u$

Models

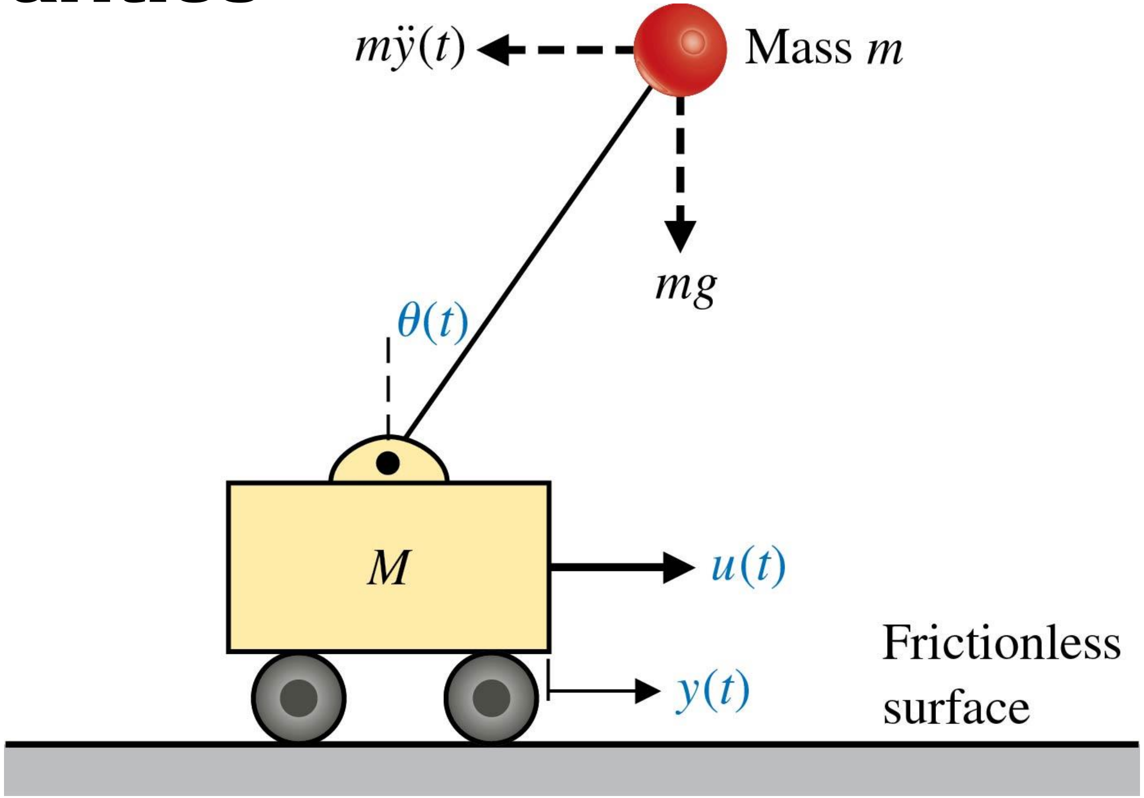


Mass
M
$y(t)$
Nonlinear
spring
$f(t)$
Spring force
$m = \frac{df}{dy}\Big|_{y=y_0}$
$f_0 = Mg$
Equilibrium
(operating point)
$y(t)$
$y_0 = (Mg)^{1/2}$

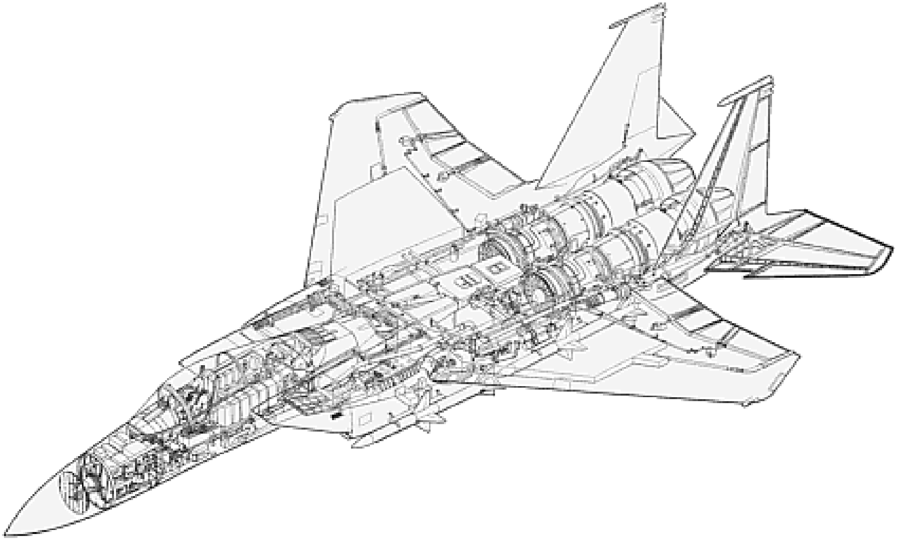
(a) (b)

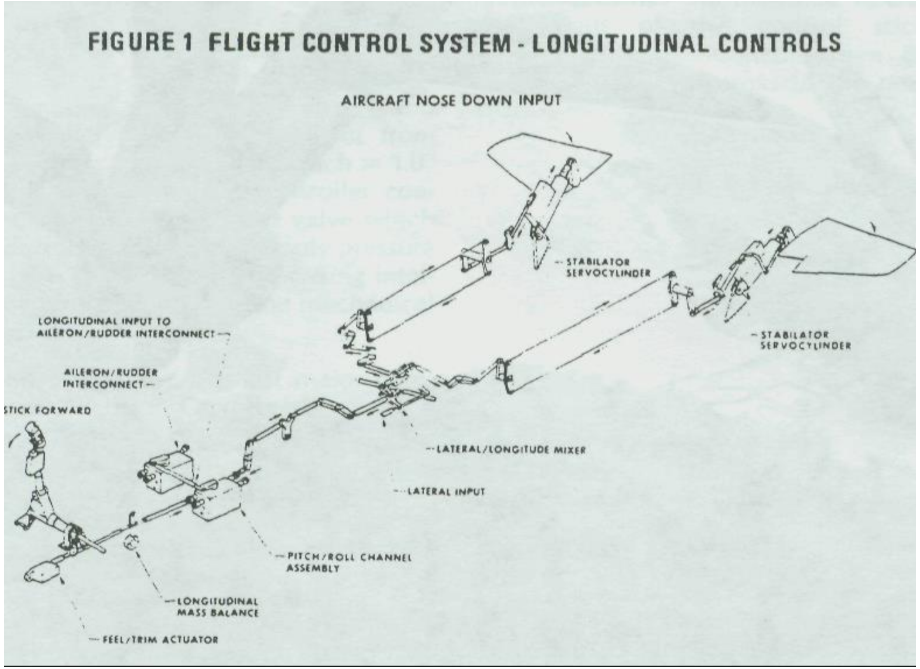

Lift force
Nonlinear system
$y = k_2 \cdot u^2$
LTI system
$\bar{y} = k_1 \cdot u + k_0$
Cruising speed
Velocity
u
Velocity
y
Lift force

Nonlinearities



Nonlinearities

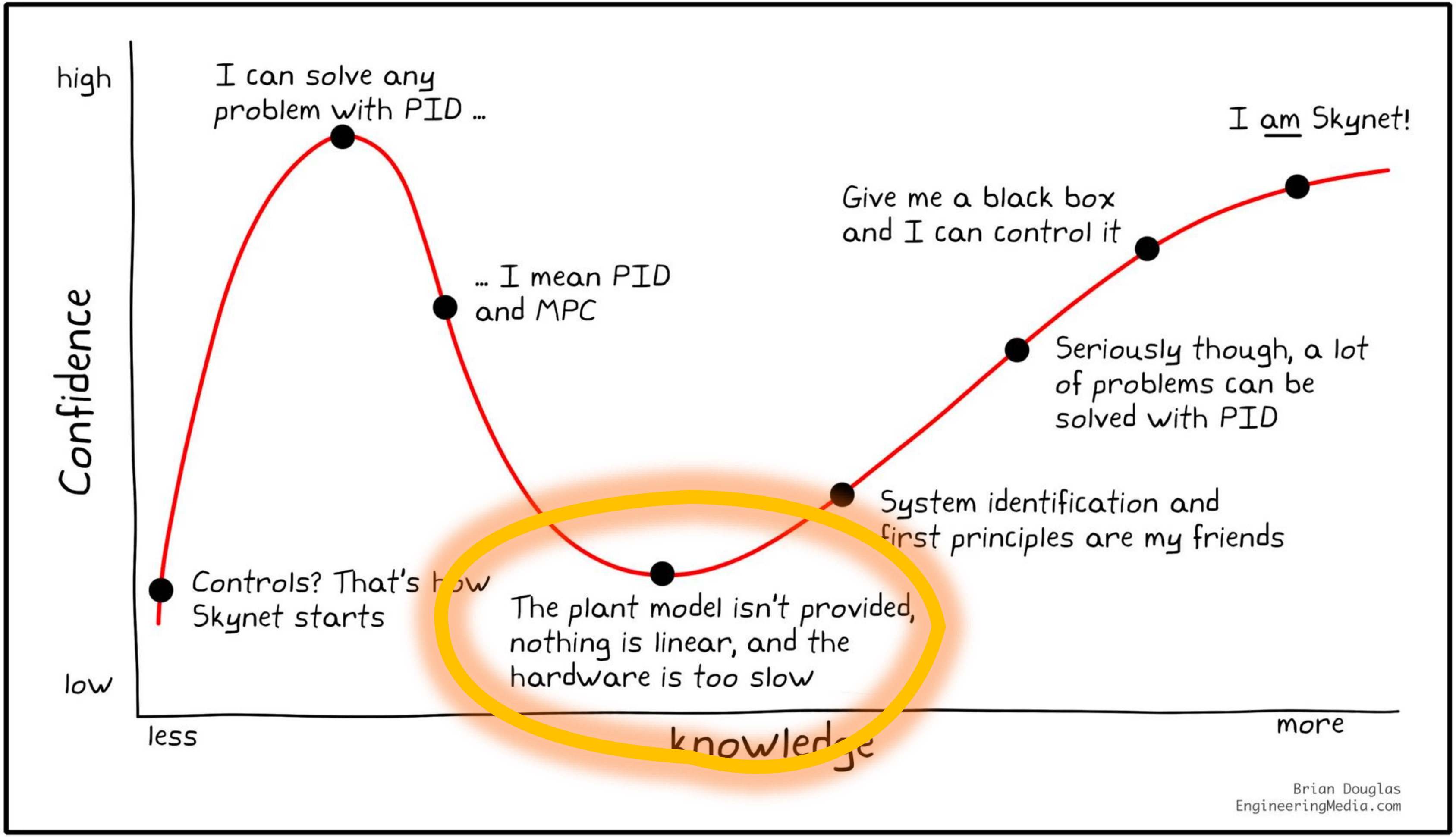




LTI systems

- Linear
- Time-invariant

Dunning-Kruger effect for control engineers



Be reassured

- LTI system approximation is useful and widely used
- And applicable **as long as you pay attention to design point**
- Most systems (even aircraft) generally operate within linear-ish assumption limits
- We’ll talk about robust design later on
- And there are ways around limitations whilst still using linear approaches (more later)
- And there are nonlinear techniques (a little more but not too much in this unit)

System characteristics

- Learn by doing – CTMS aircraft pitch
  - System
    - Modeling
    - Analysis
  - Control
    - PID
    - Root Locus
    - Frequency
    - State-space
    - ~~Digital~~
  - Simulink
    - Modeling
    - Control
    - ~~Simscape~~

Next week

- ToDo
  - Familiarise with texts, videos, other resources
  - Dorf, CTMS recommended (+Douglas/Brunton vids)
  - So far – Dorf ch1-5, this (part of the) unit covers full Dorf plus a little more
- Next time