Control of Systems

ESE 505 / MEAM 513

Spring 2014

Bruce D. Kothmann

About ~~Dr.~~ Bruce

- Decade+ Experience Designing & Testing Rotorcraft Fly-by-Wire Flight Controls @ Boeing Philadelphia
- Dynamics, Controls & Aerodynamics Specialties
- Wife & 2 Kids

My Professional Controls Design Experience

How & Why to Contact Me

- HOW
  - Please Use PIAZZA
  - bruce.d.kothmann@gmail.com
  - Office = Towne 320
  - MEAM Labs (GM Lab & M81) : Very Frequent Lab Sections
  - Cell Phone (Discretion Please) 610-529-9527
  - Don't E-Mail Homework Unless Assignment Says You Should

- WHY
  - Get Help with Lecture / Homework
  - Comments on Course
  - Share Fun Stories / Questions About Controls

Goals of Class

- Familiarity with Key Ideas & Results of "Classical Control"
  - Time Domain
  - Frequency Domain
  - What Do I Want My New Boeing Colleagues to Know?
- Ability to Design & Analyze Typical Student Projects
  - Mechatronics
  - Senior Design
- Development of Good Engineering Skills & Habits
- Have Fun Studying Really Interesting Stuff

Syllabus (Details on Blackboard)

- Part I = Modeling & Mathematics
- Part II = Time-Domain Dynamics & Control
  - Time Response
  - PID Control
  - Root Locus
- Part III = Frequency-Domain Dynamics & Control
  - Frequency Response
  - System Requirements & Design
  - Stability Margins
- Part IV = Brief Intro to “Modern Control”

Course Elements

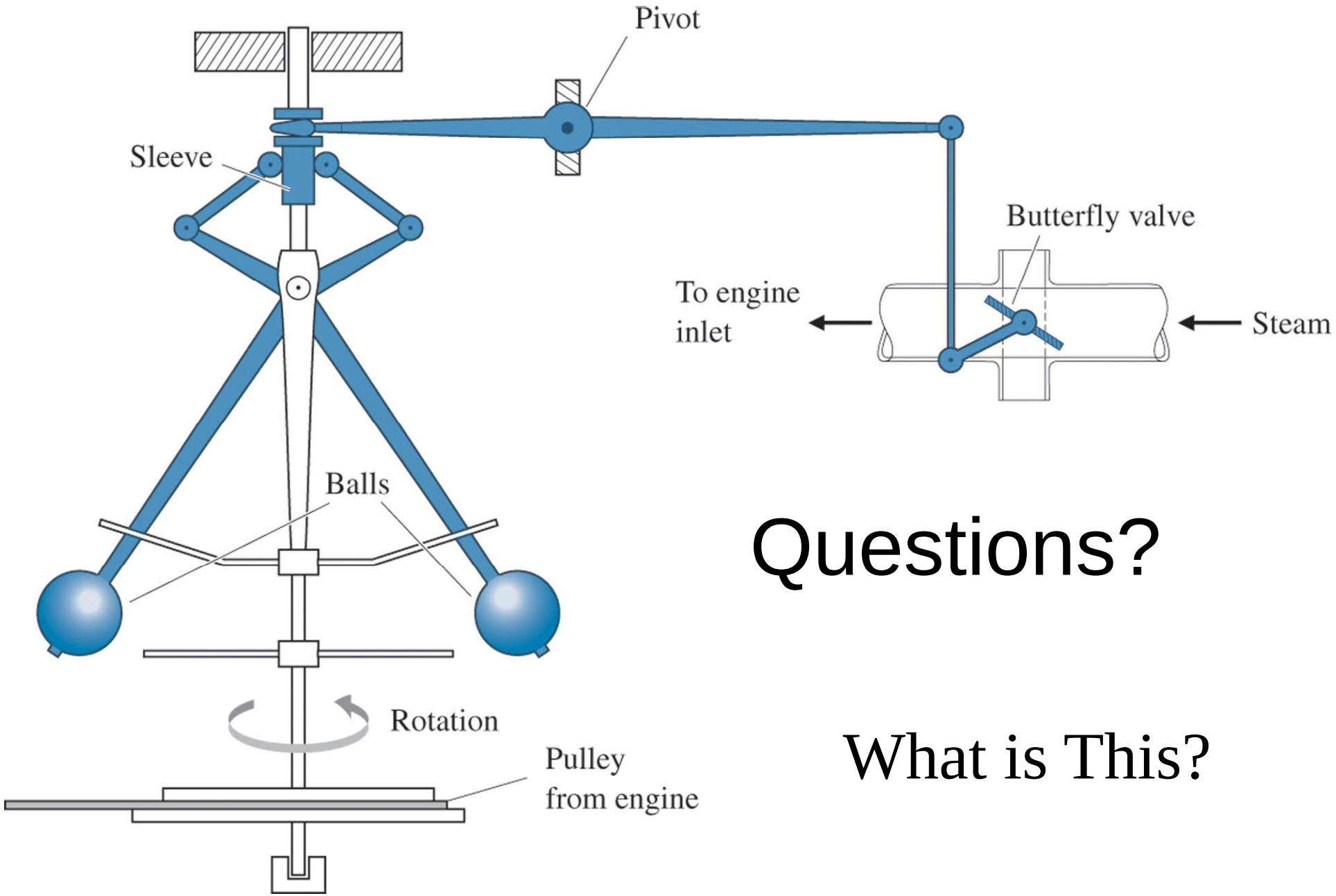
- Lectures (Mon & Wed)
  - Some Demonstrations
  - Mostly Theory with Examples
  - Please Ask Questions!
- Reading Assignments
  - Textbook (Franklin) ~ Continuous
  - Technical Papers ~ Sometimes
- Homework (Weekly)
  - Lots of MATLAB / SIMULINK
  - Mostly “Textbook” Problems; Some “Discussion” Problems
- Projects (2) (Details TBA)
- Weekly Quizzes (Wednesday)
  - Not Intended to be Difficult (5 Multiple Choice Questions)
  - Cover Previous Week’s Lectures & Reading
- Exams = Midterm & Final

Approximate Course Grading

- 30% = Final Exam
- 15% = Midterm
- 10% = In-Class Quizzes
- 25% = Homework
  - Assigned Wednesday & Due Following Wednesday (*Beg* of Class)
  - 2 "Late Passes" Per Student (Worth One Class Extension)
  - "Rogue" Homework Accepted for 50% Credit (Not Graded)
- 15% = Projects
- 5% = Participation (Class & Piazza)
- Final Grades Based on "Floating Curve"
  - ~45% A
  - ~45% B (Note: B- is a flavor of B)
  - ~10% C

Academic Integrity

- Homework & Projects
  - Work Together (You Learn More That Way)
  - You *MUST* Understand What You Submit!
  - Don't Use Past Student's HW or Book Solution Manuals
- Exams & Quizzes
  - MUST Work Completely Independently
- My Experience
  - University of Virginia Honor Code
  - Penn's Office of Student Conduct
- Giving or Receiving Aid of Any Kind on Exam or Quiz
  ➔ F in Course & Referral to OSC



Questions?

What is This?

Penn Engineering

Some Example Systems

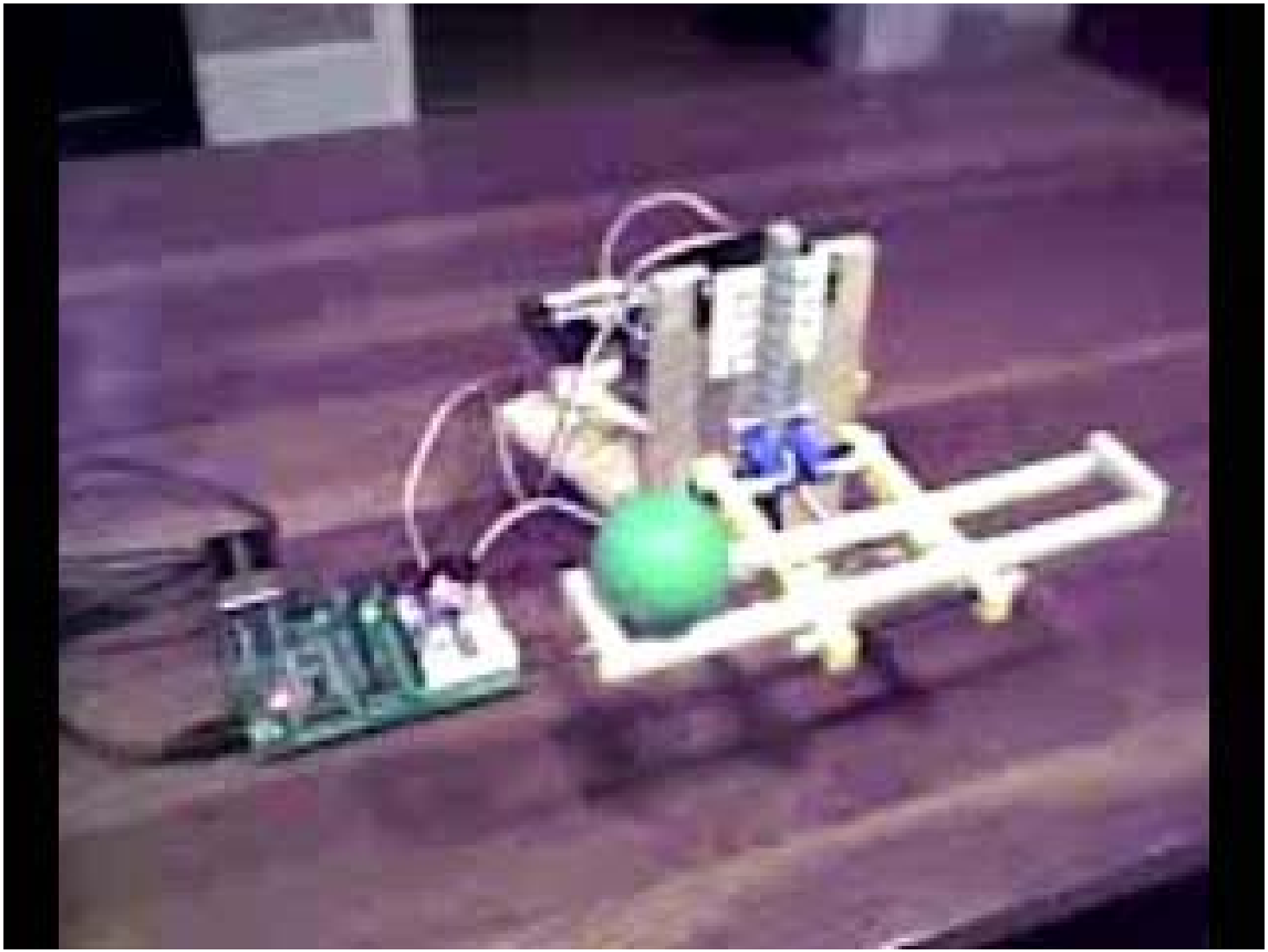
Let's Talk Briefly About What We Think

Are Important Design Goals & Potential

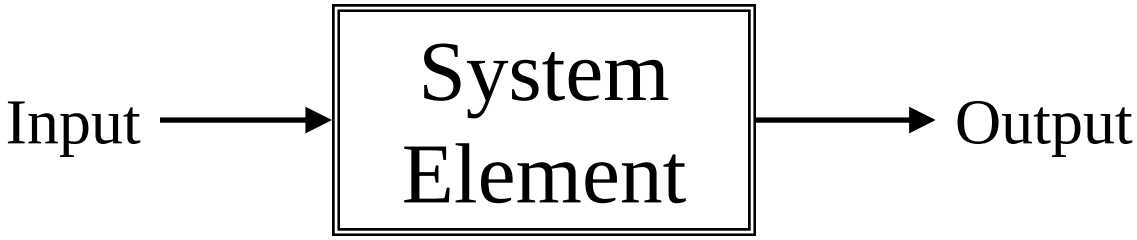
Challenges in Achieving Them

Penn Engineering

Ping Pong Poise



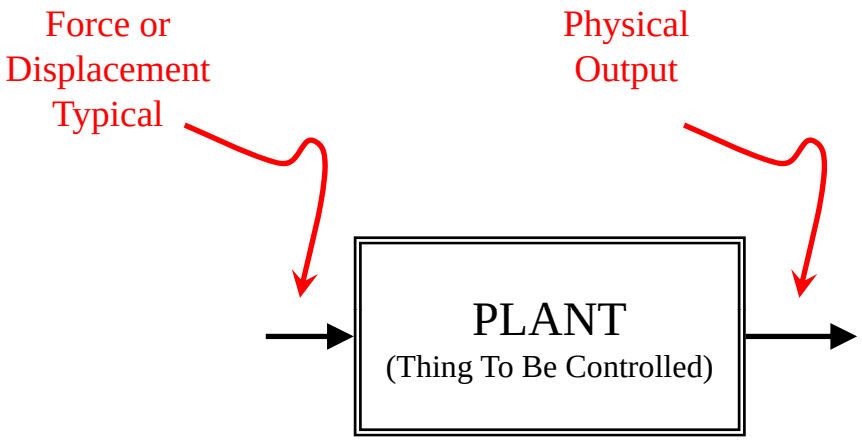
System = Collection of Elements ("Blocks")



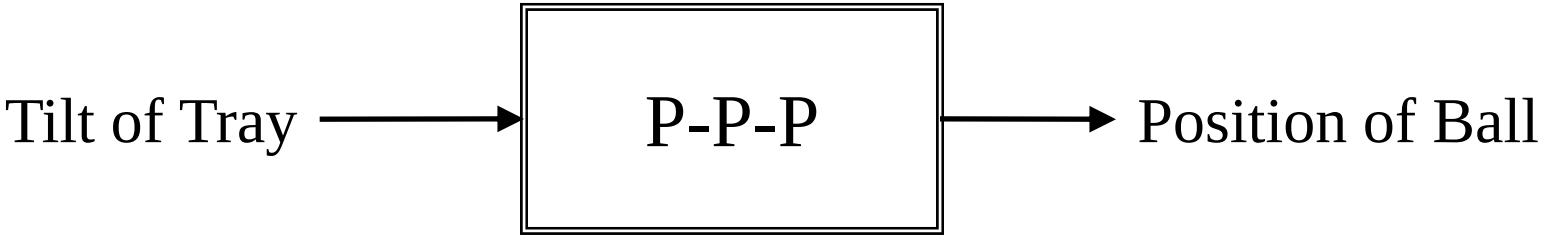
- "Input" and "Output" = Real-Valued Continuous Functions of Time
  - Attitude of a Satellite
  - Temperature in an Oven
  - Position of a Car's Accelerator Pedal
  - Voltage in a Circuit
- Element Defines Dynamic Relationship Between Input & Output
  - Algebraic
  - Differential Equation (Ordinary / Partial)
  - Other Dynamics Relationship

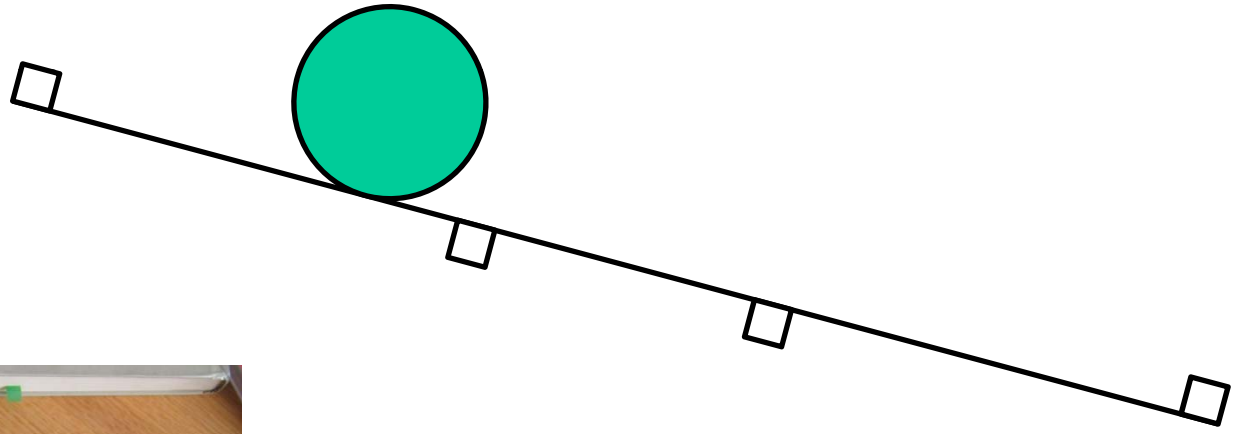
We Need Good Mathematical Tools Here

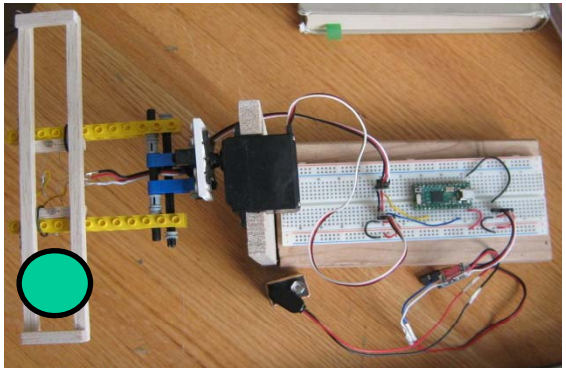
Typical System Elements : Plant



Ping Pong Poise Elements : Plant





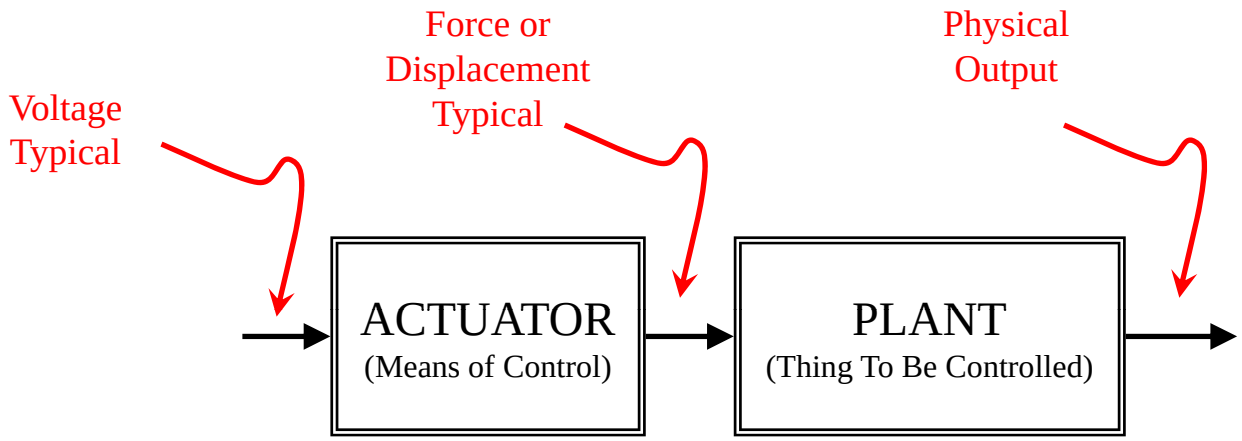


What Sort of
Mathematical Model
Describes This System?

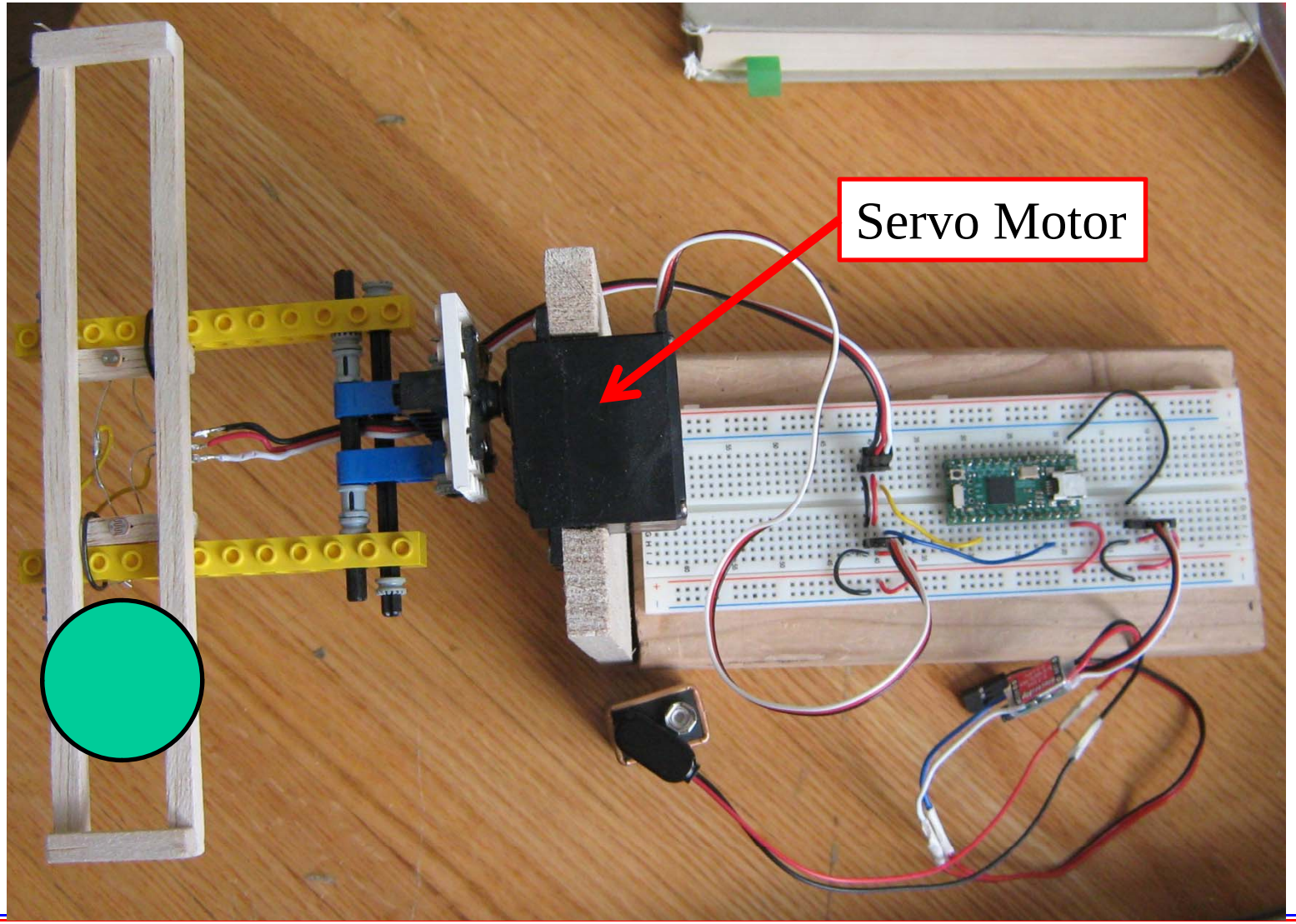
Other Example Plants

- Industrial Process
- Computer Disk Drives
- CD & DVD Players
- Missiles / Bombs
- Autonomous Vehicles
  - Unmanned Aerial Vehicles (UAVs)
  - Urban Grand Challenge
- Temperature (Oven / Refridgerator / Home)

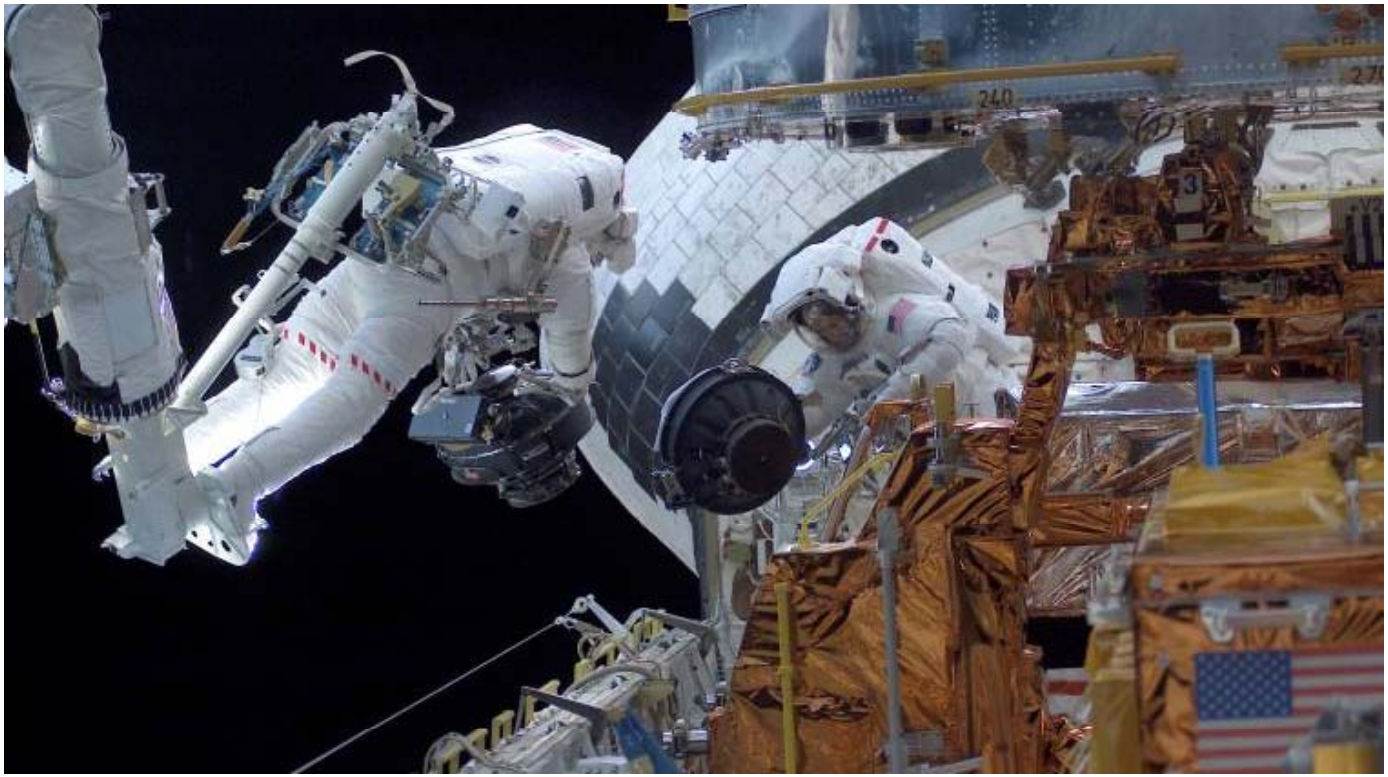
Typical System Elements : Actuator



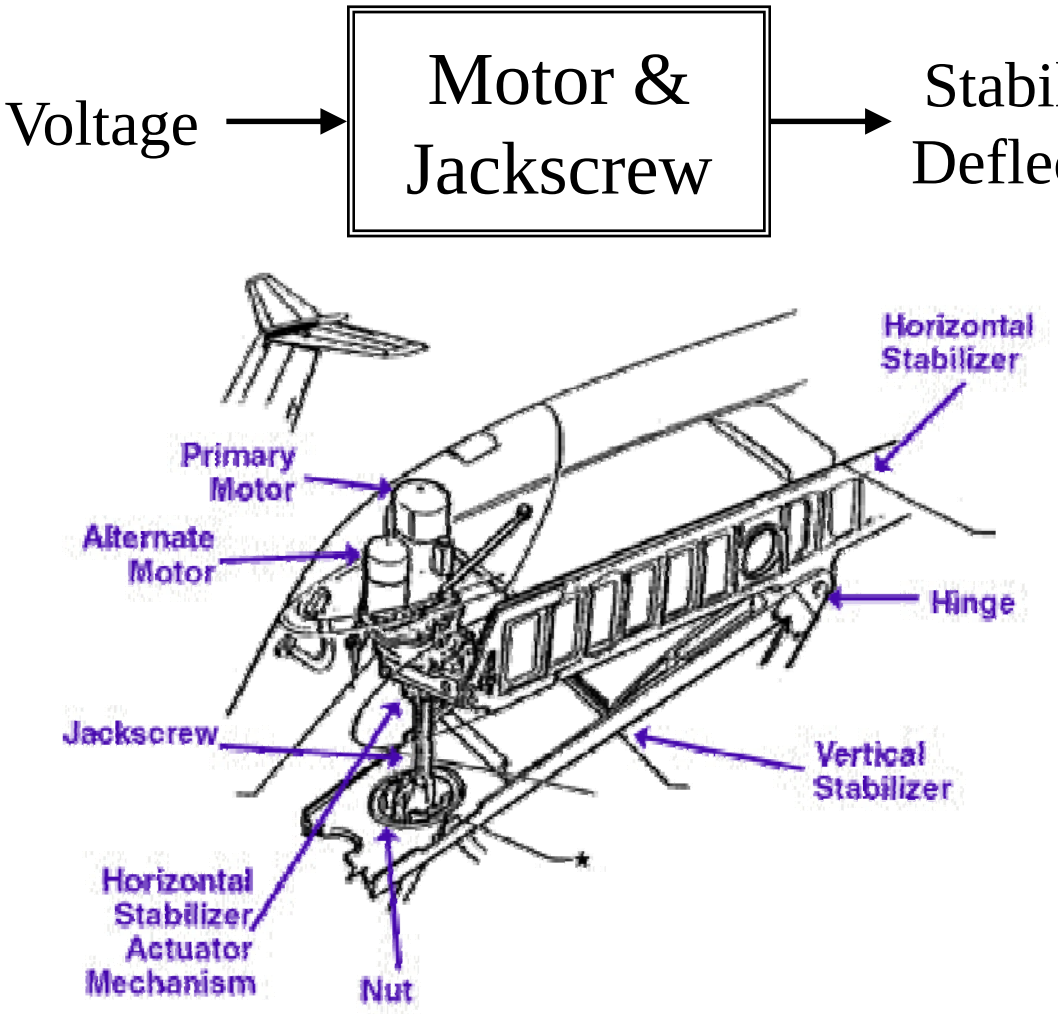
Ping Pong Poise Elements : Actuator



Actuator : Hubble Reaction Wheel

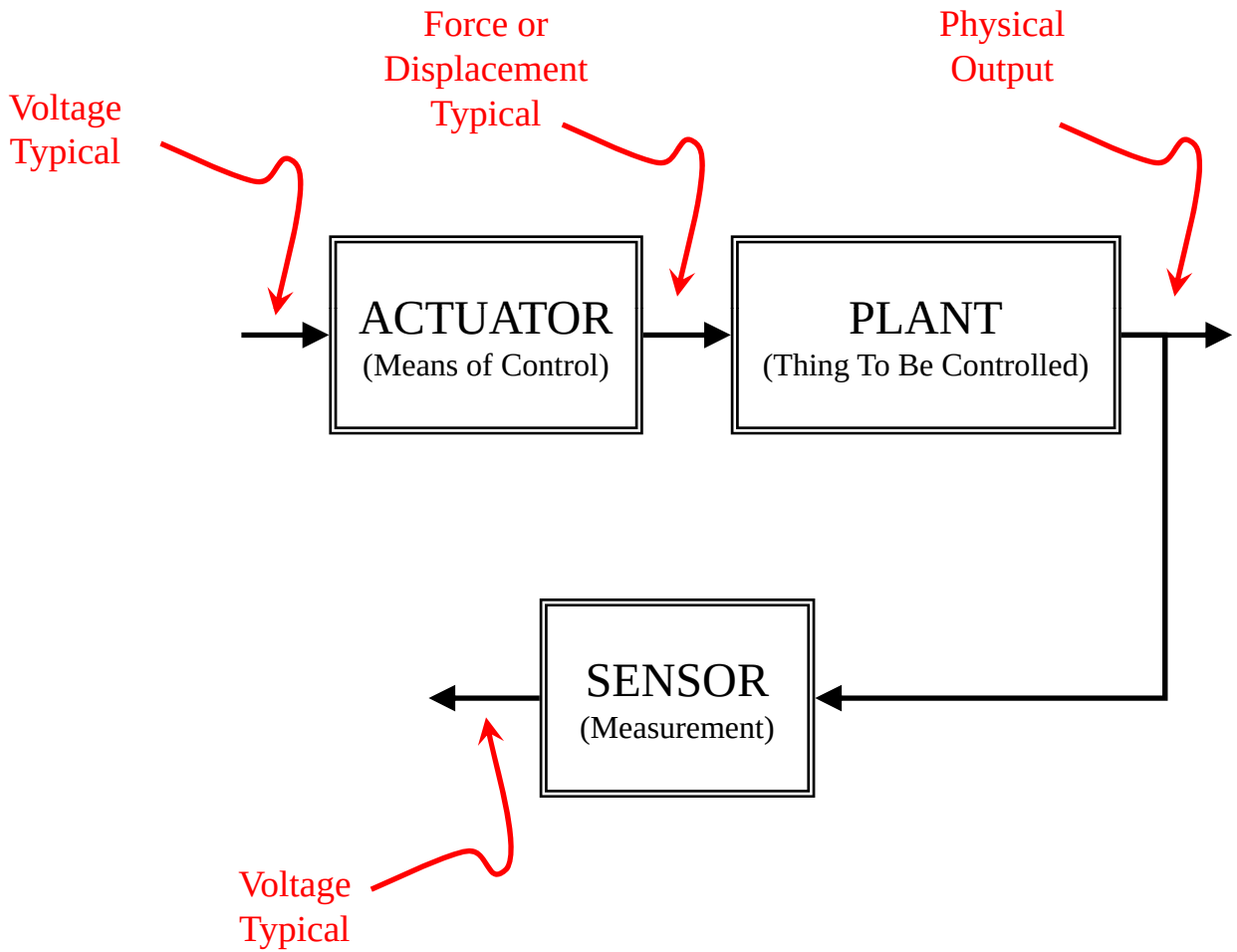


Actuator : MD-83 Elevator "Jackscrew"

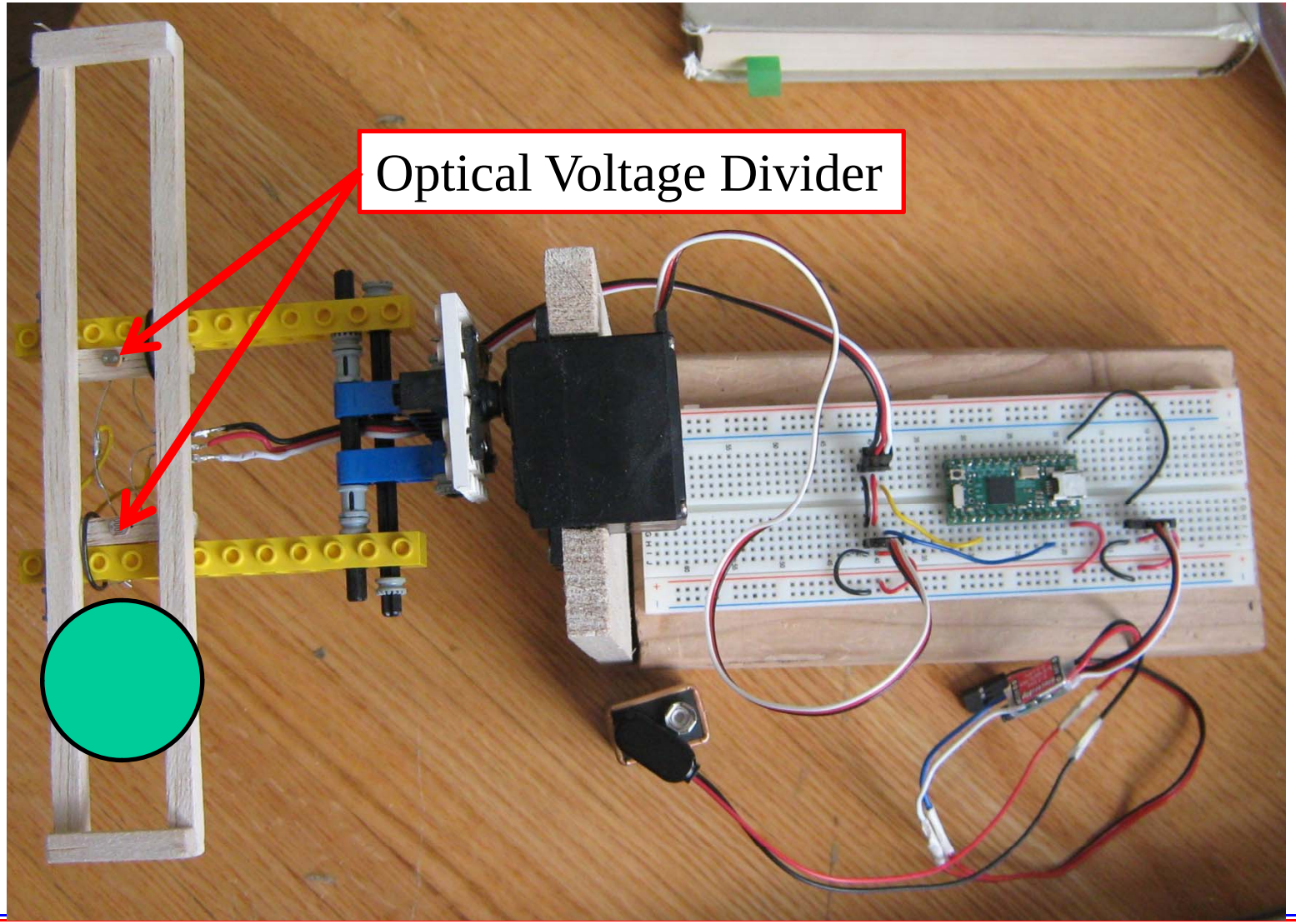


Alaska Airlines Flight 261
31 January 2000

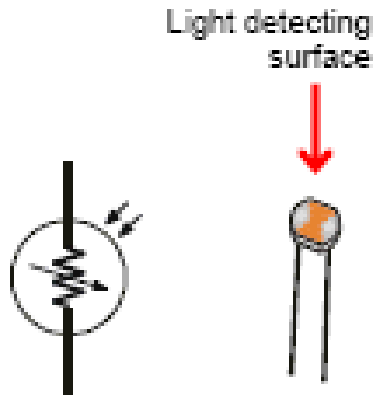
Typical System Elements : Sensor

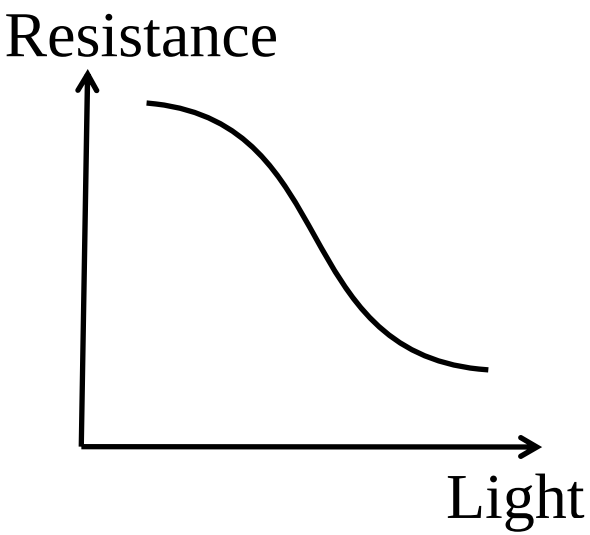


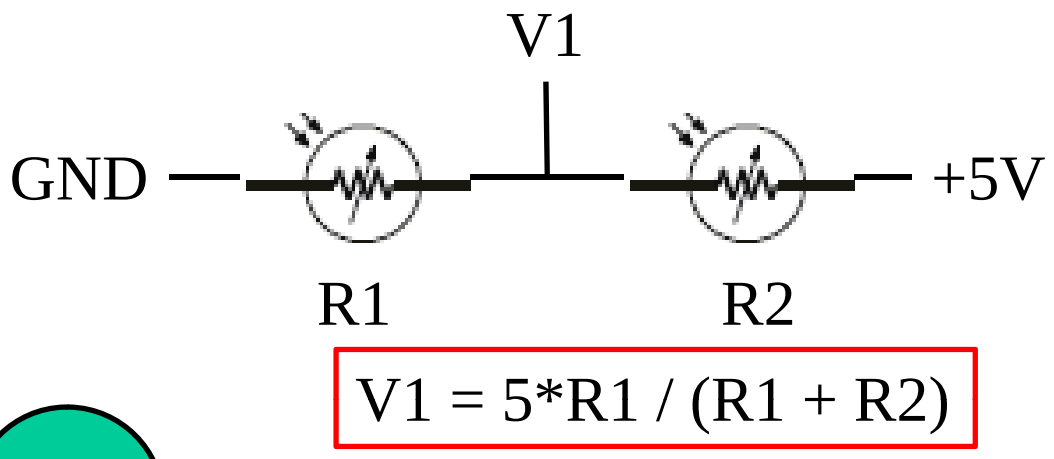
Ping Pong Poise Elements : Sensor



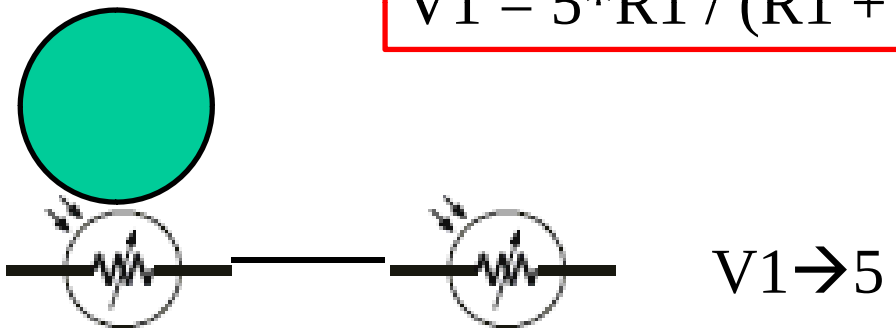
Details of Optical Voltage Divider

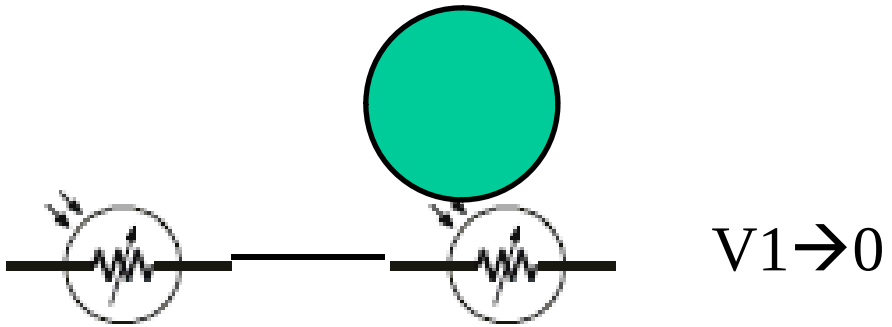






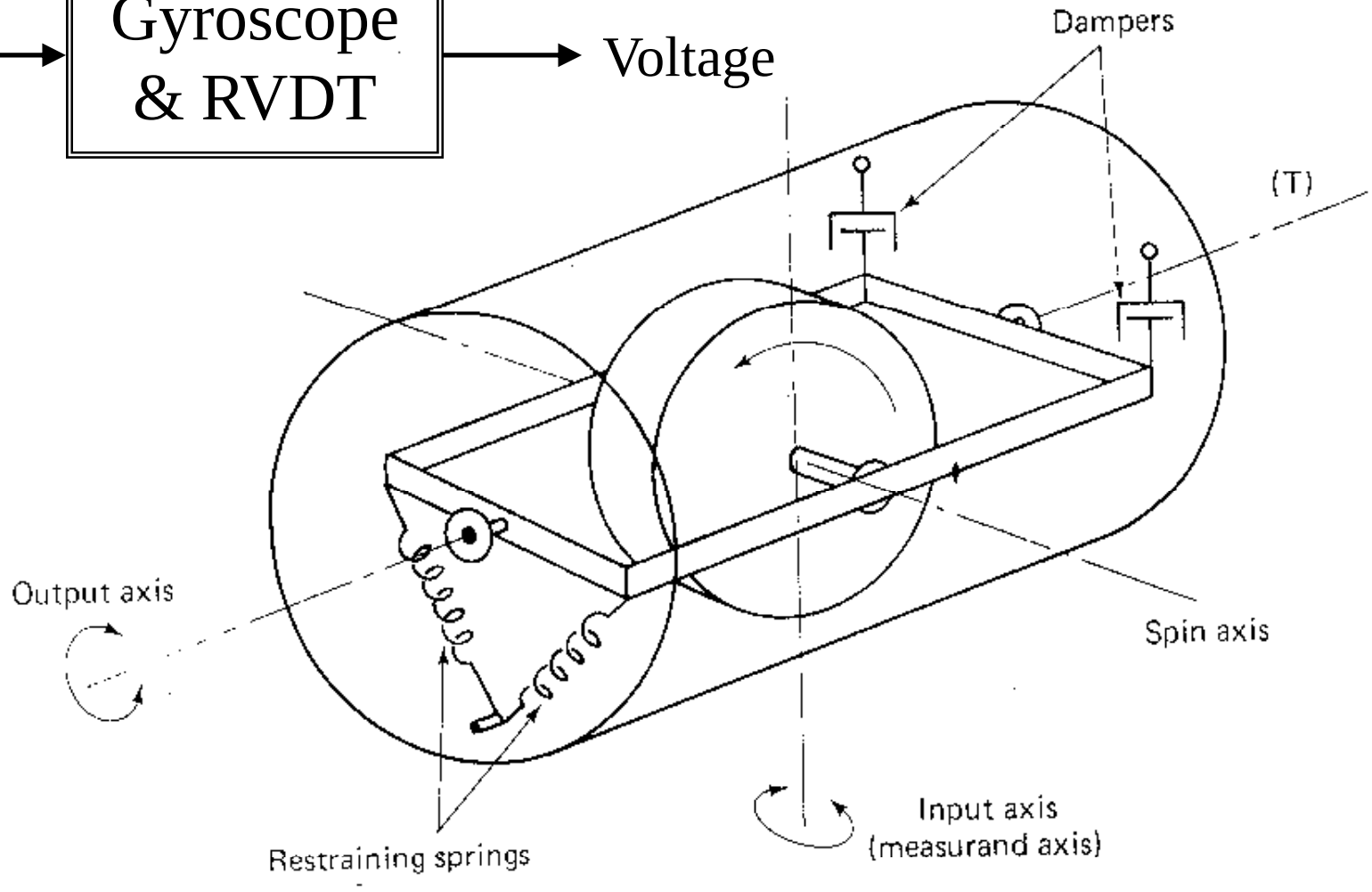
$$V1 = 5*R1 / (R1 + R2)$$



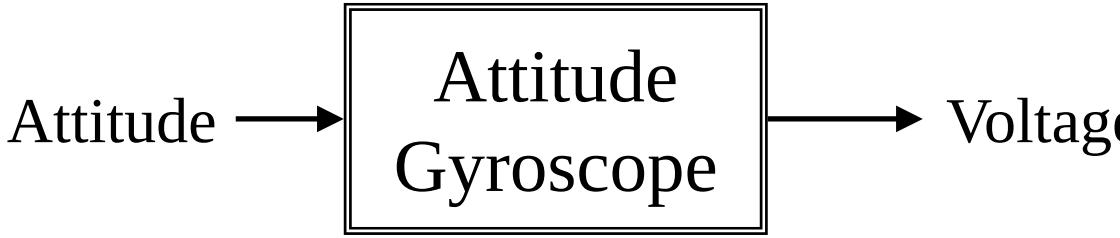


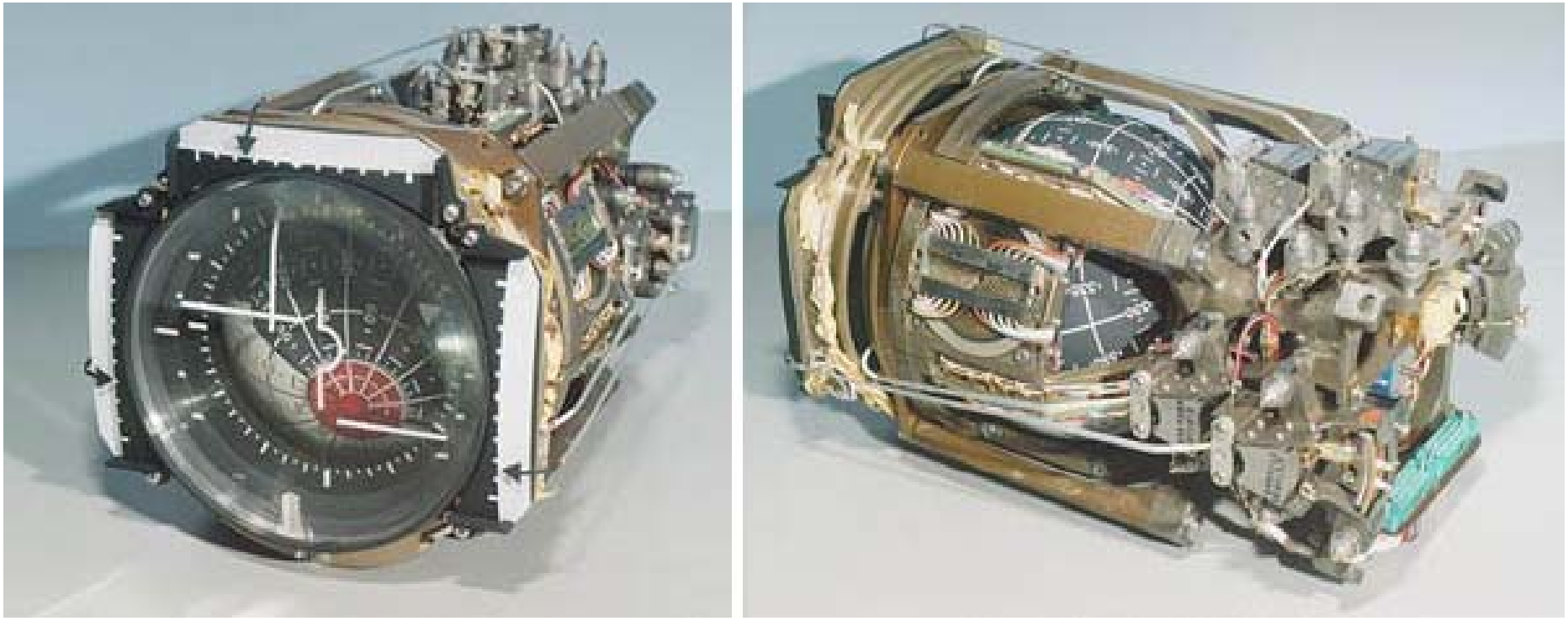
Sensor : Angular Rate Gyro

Angular Velocity → Gyroscope & RVDT → Voltage



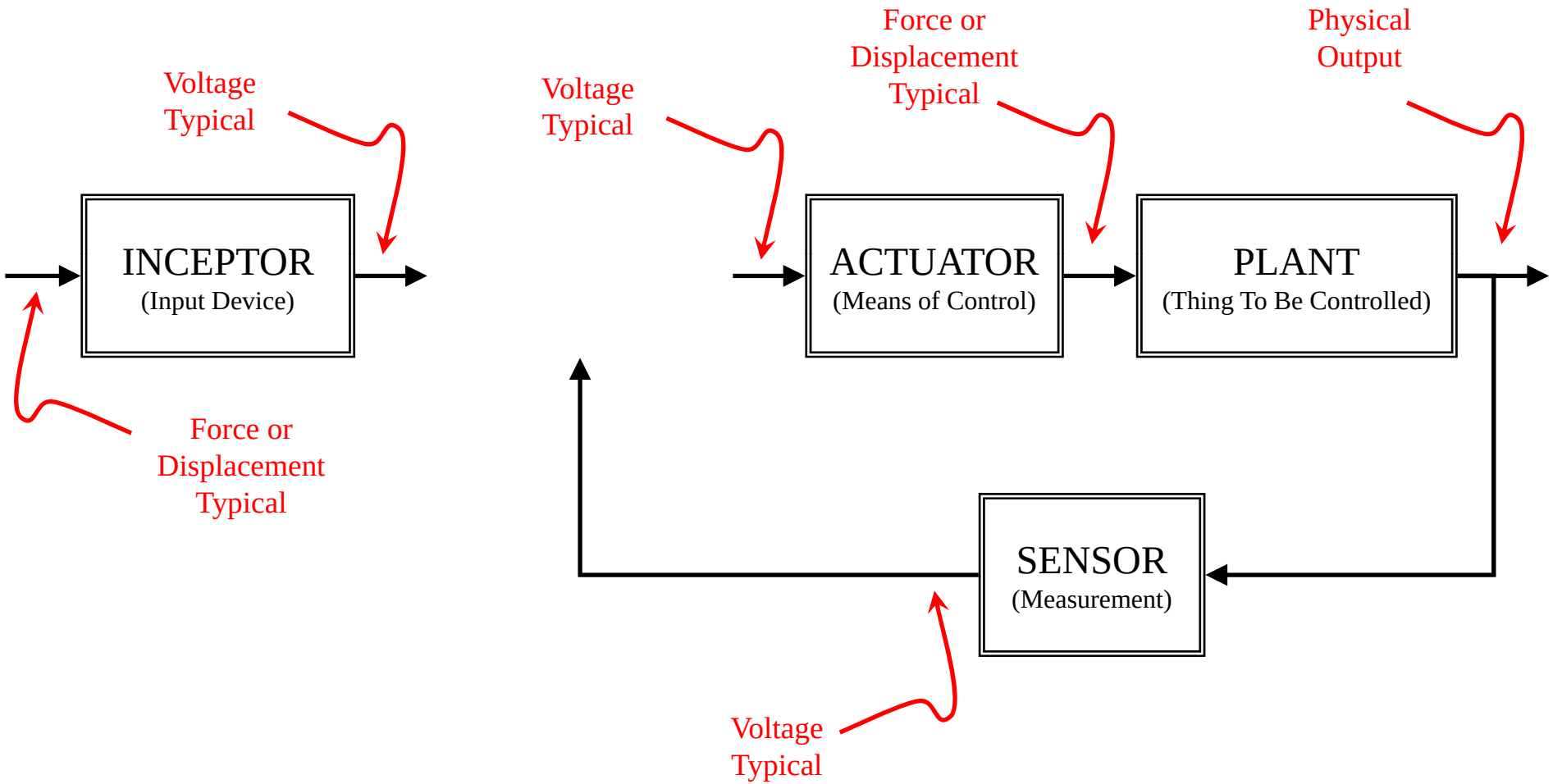
Sensor : Attitude Gyro



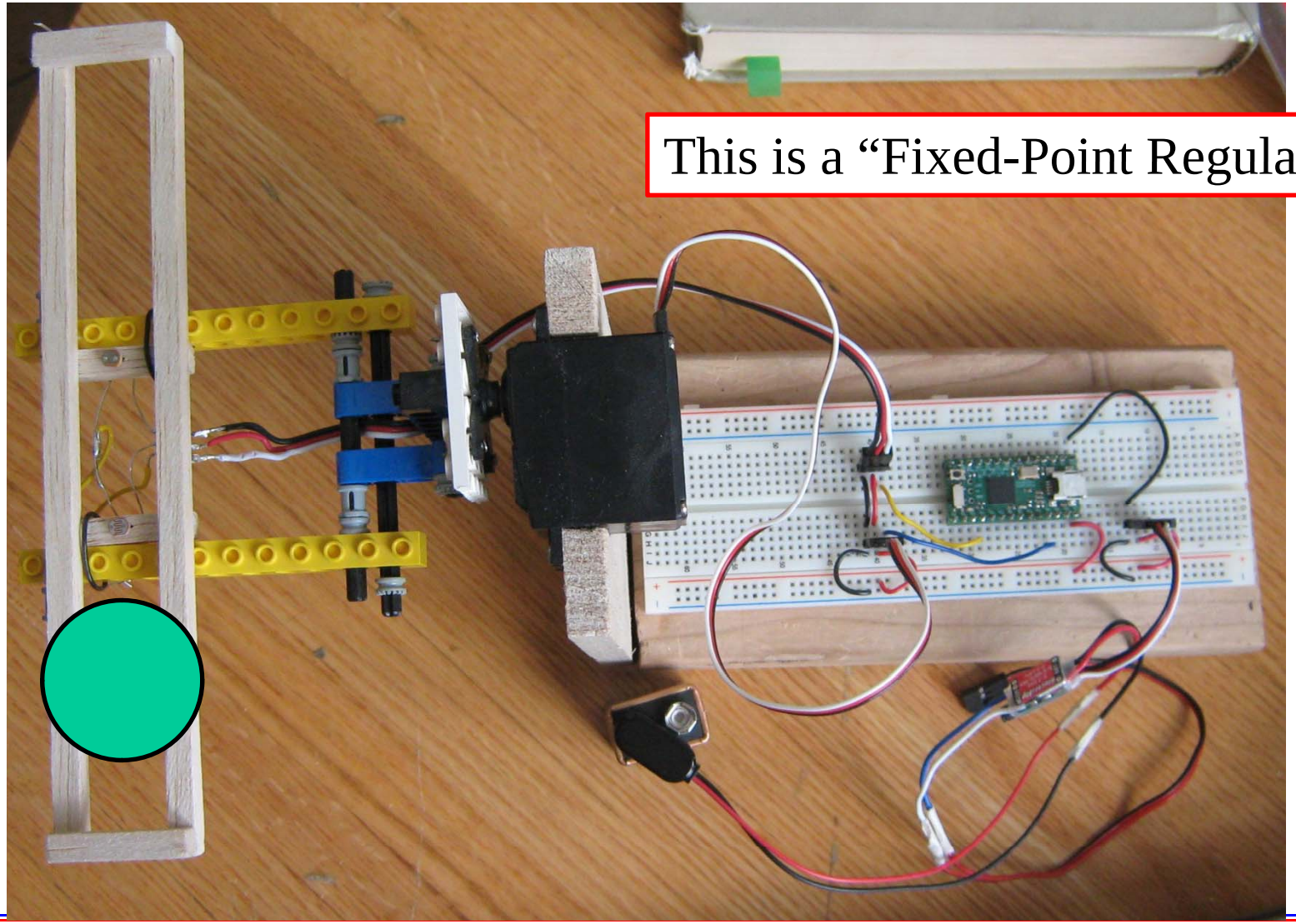


Apollo Flight Director Attitude Indicator Assembly

Typical System Elements : Inceptor

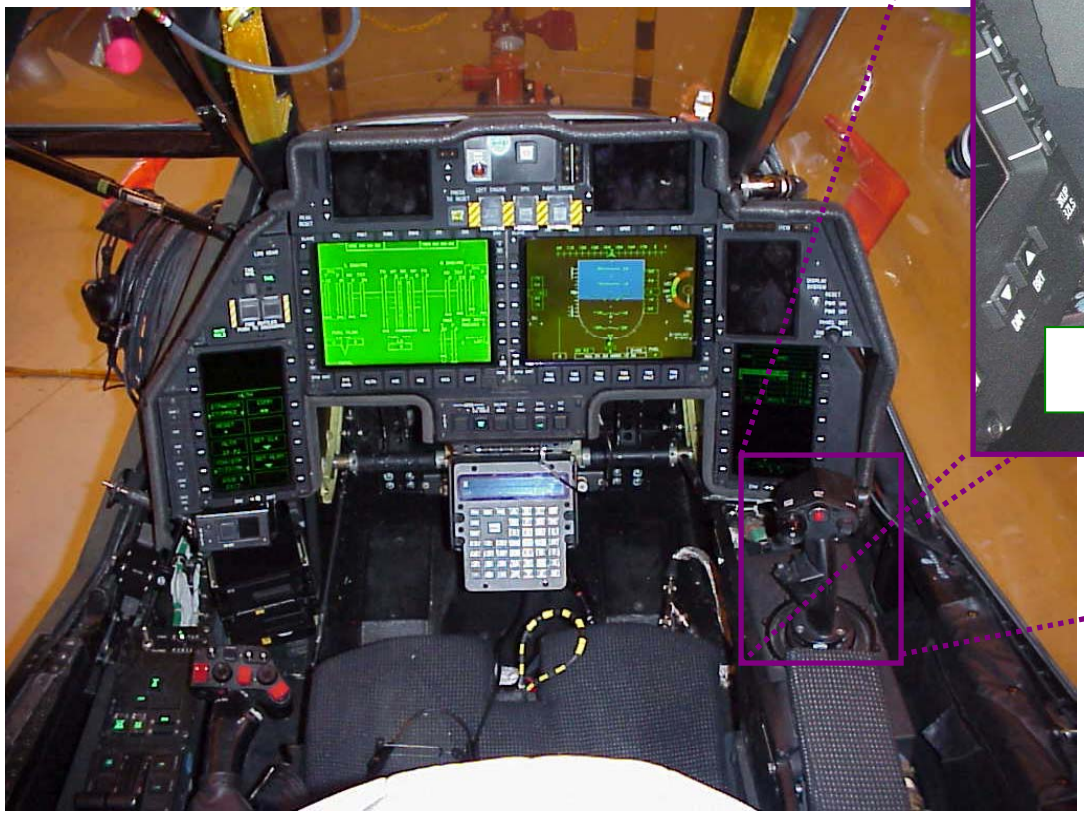


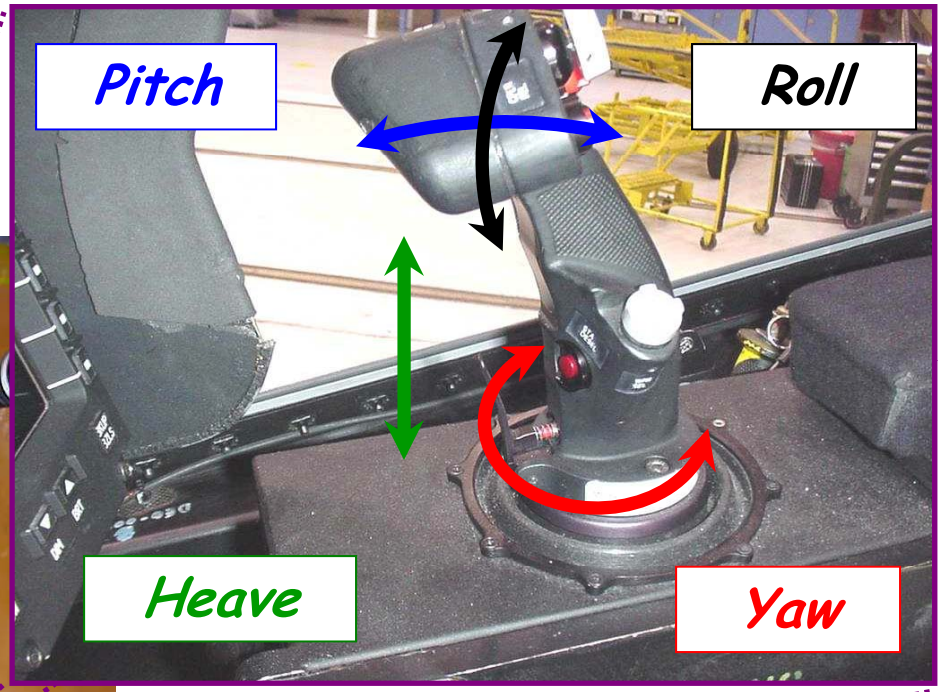
Ping Pong Poise Elements : No Inceptor



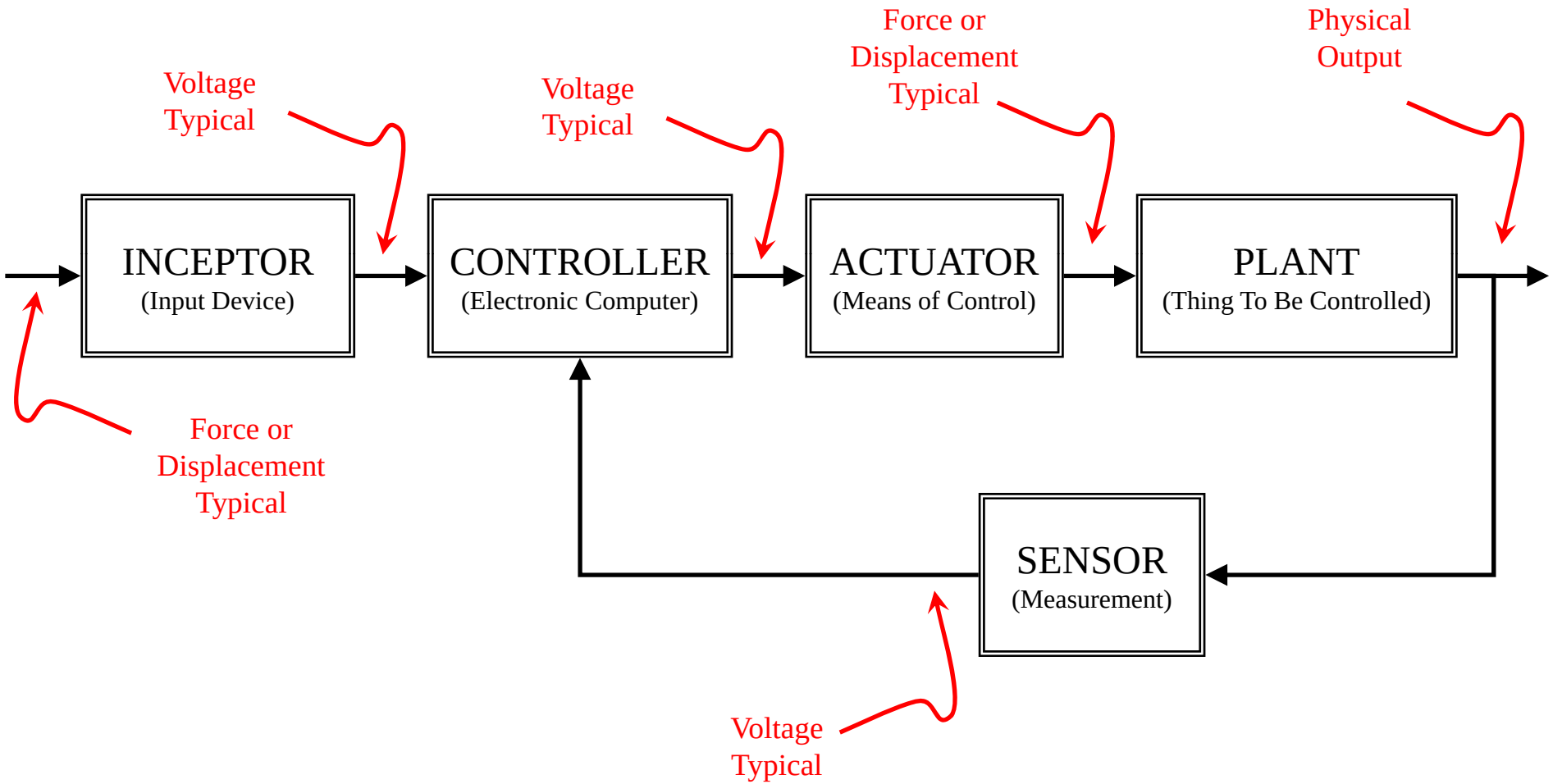
Inceptor : Sidearm Controller

Force → Sidearm & LVDT → Voltage

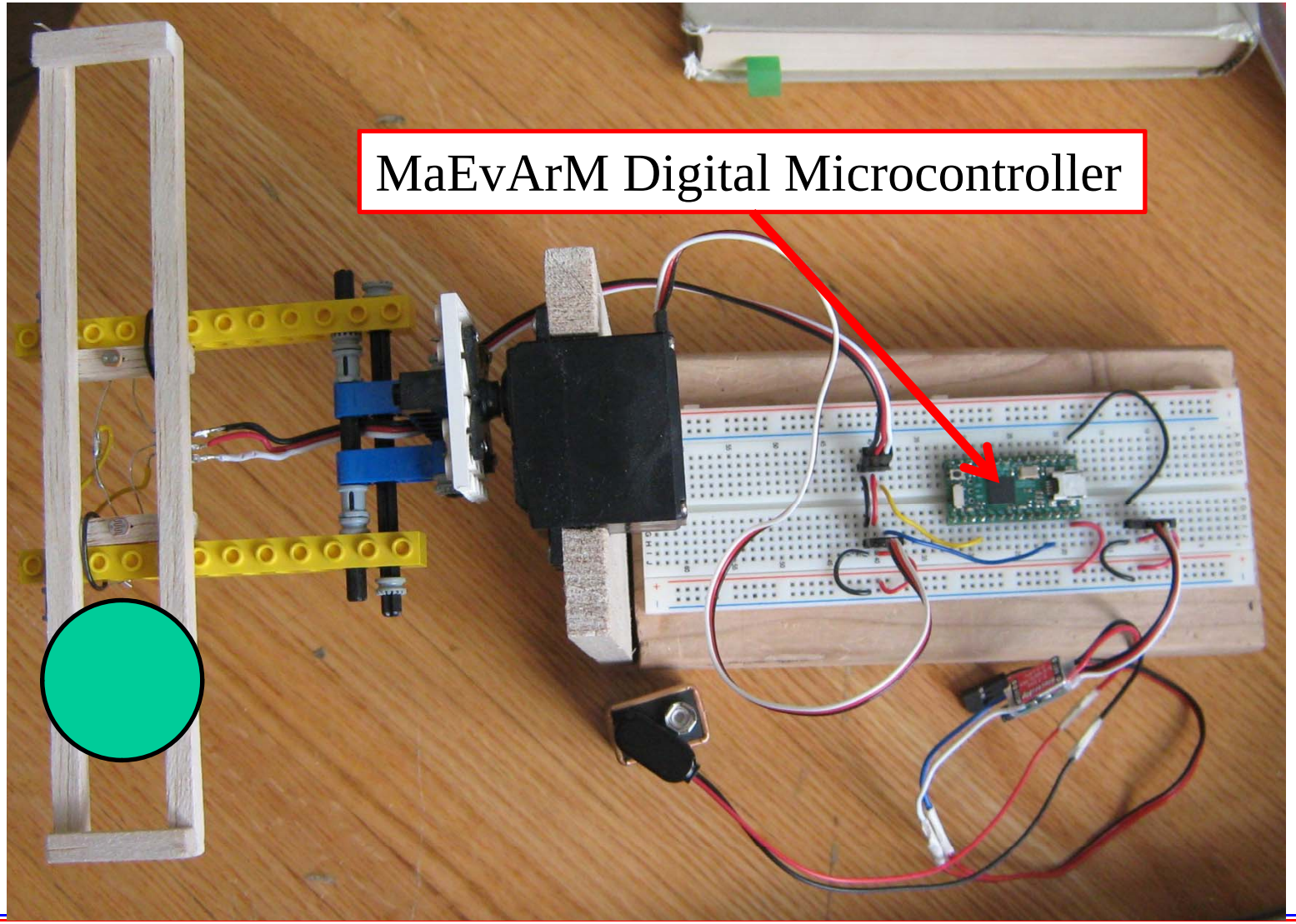




Typical System Elements : Controller

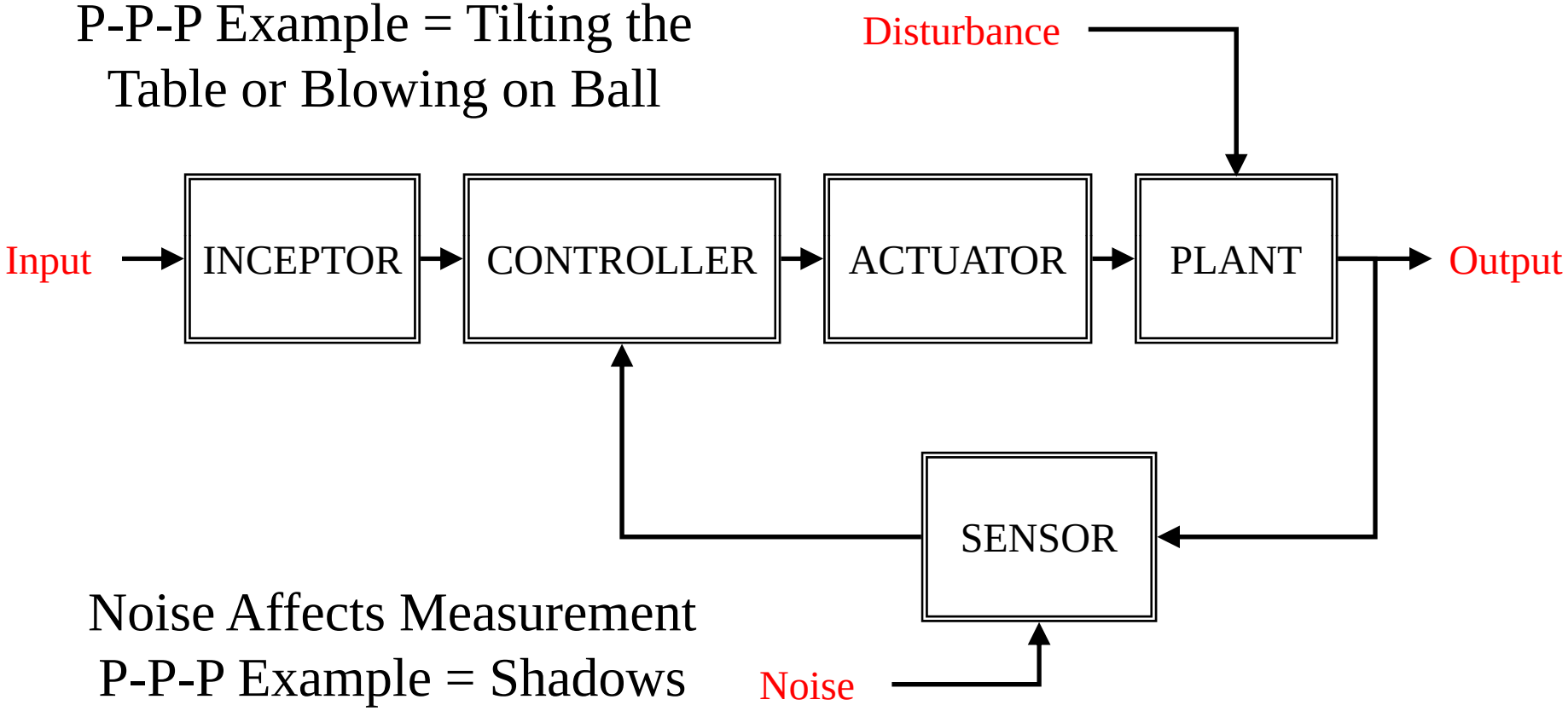


Ping Pong Poise Elements : Controller



Important External Signals

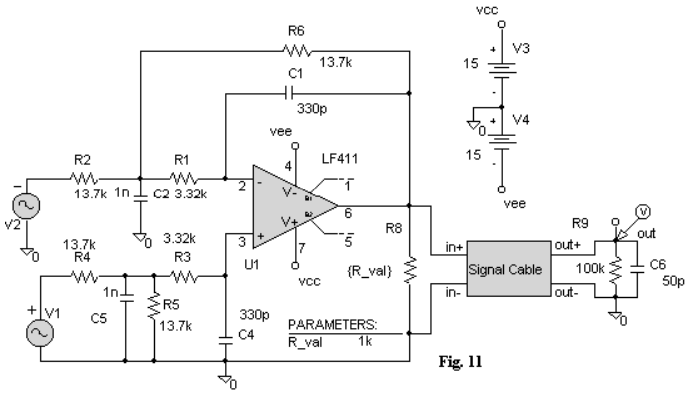
Disturbance Affects Output
P-P-P Example = Tilting the Table or Blowing on Ball



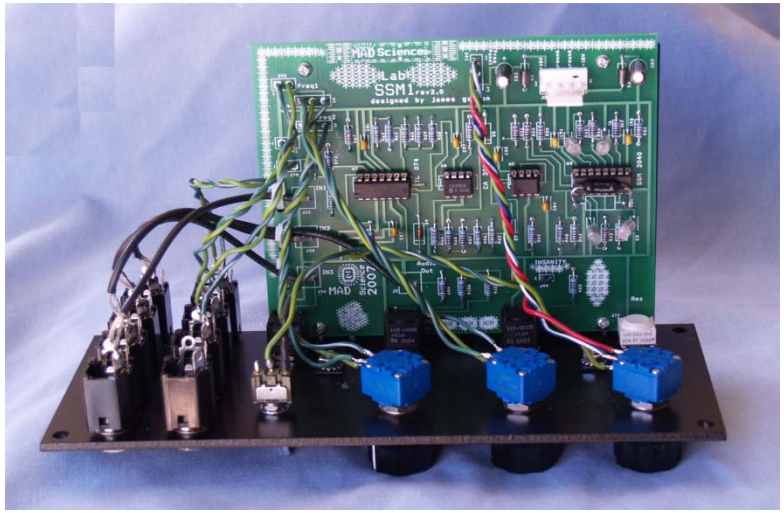
Noise Affects Measurement
P-P-P Example = Shadows Causing Spurious Voltage Changes

Analog Controllers

Op-Amp Circuit

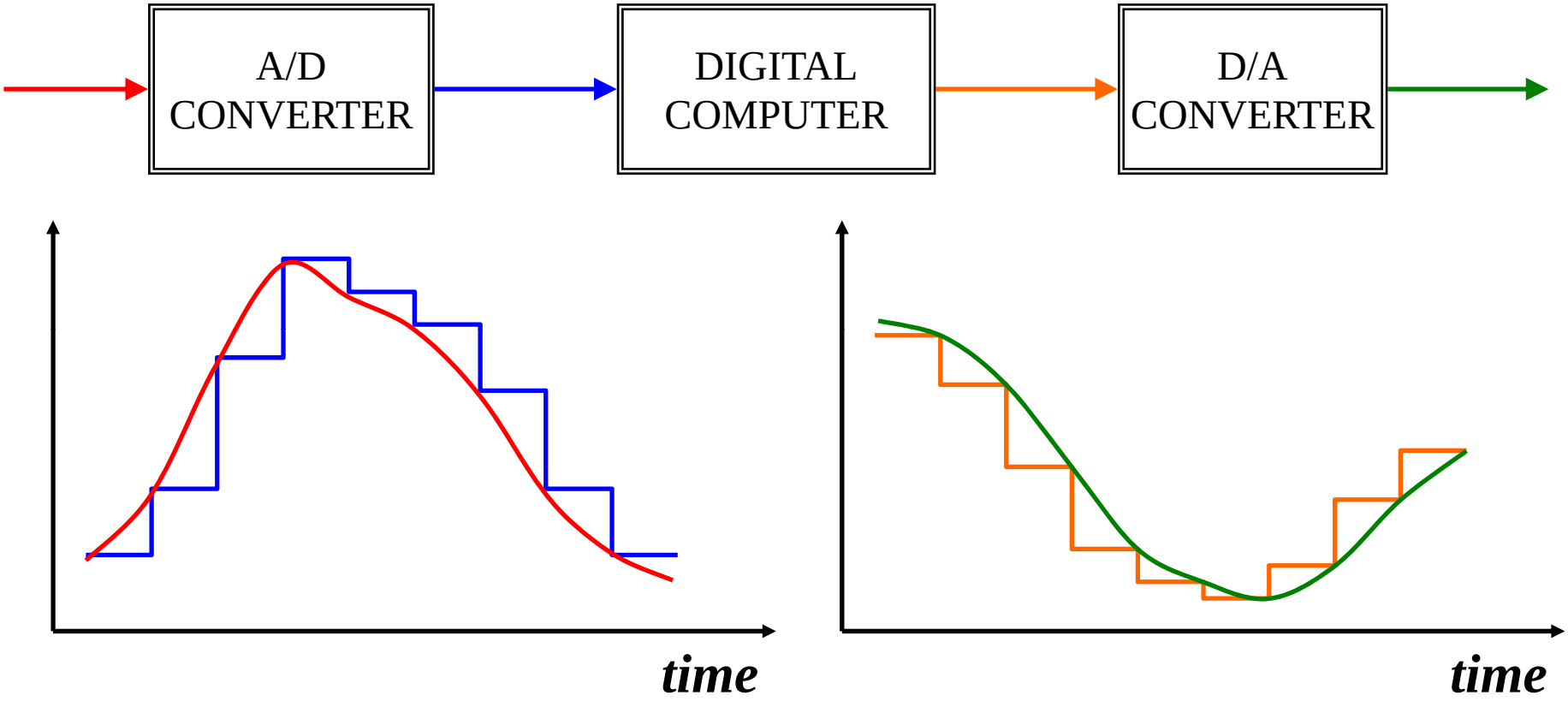


Analog Filter Board



http://www.siliconbreakdown.com/msl/SSM1.html

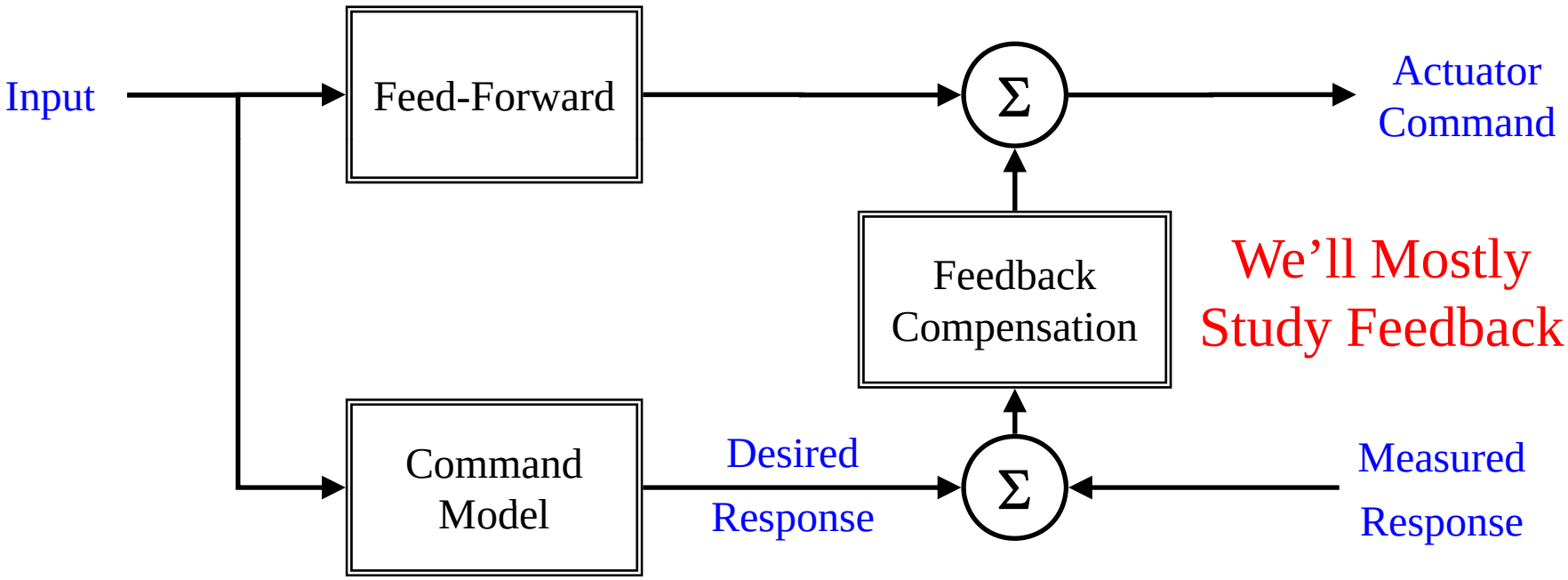
Digital Controllers



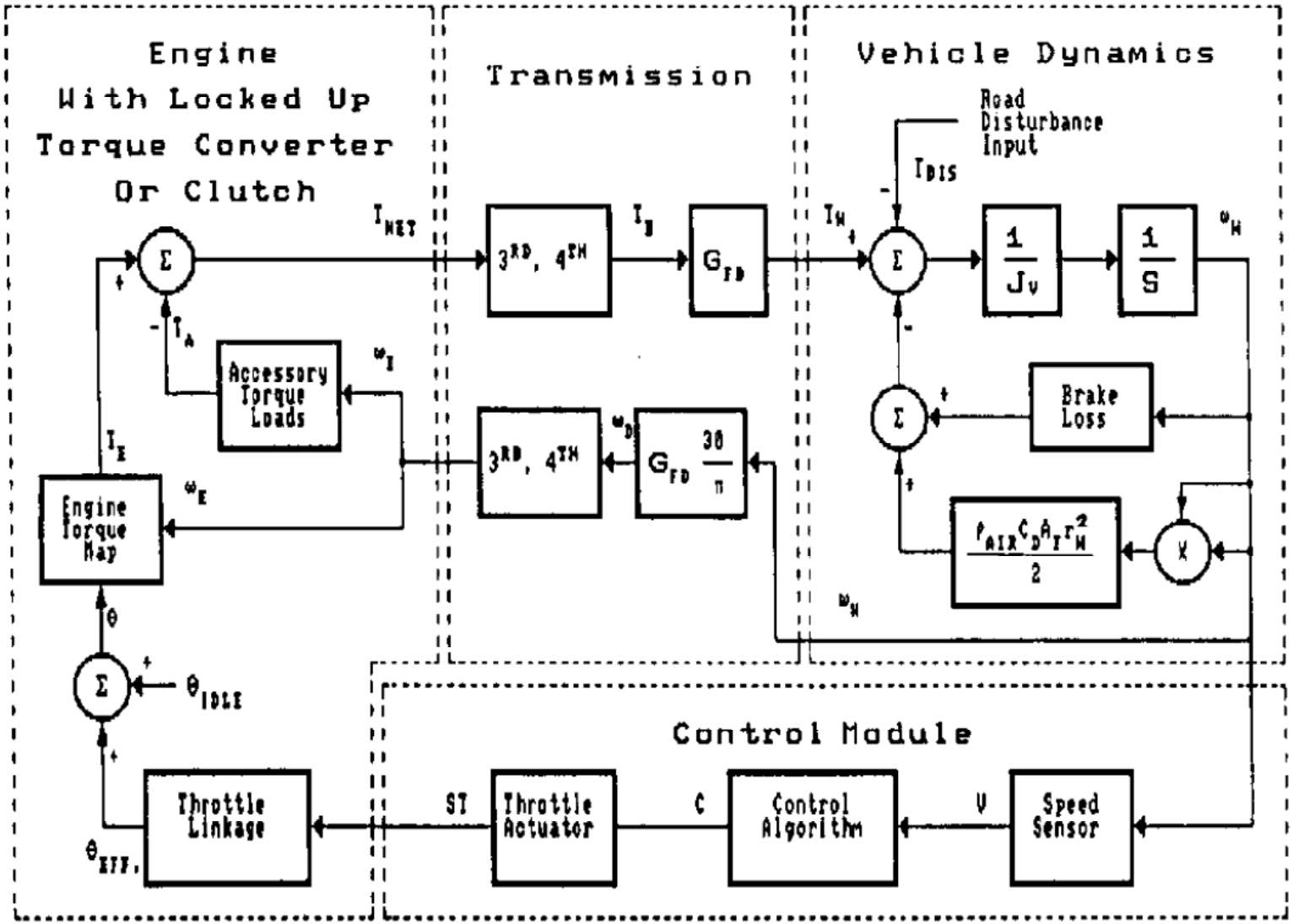
*NOTE: D/A & A/D Introduce **Time Delay***

Critical Element of Control System Design & Analysis

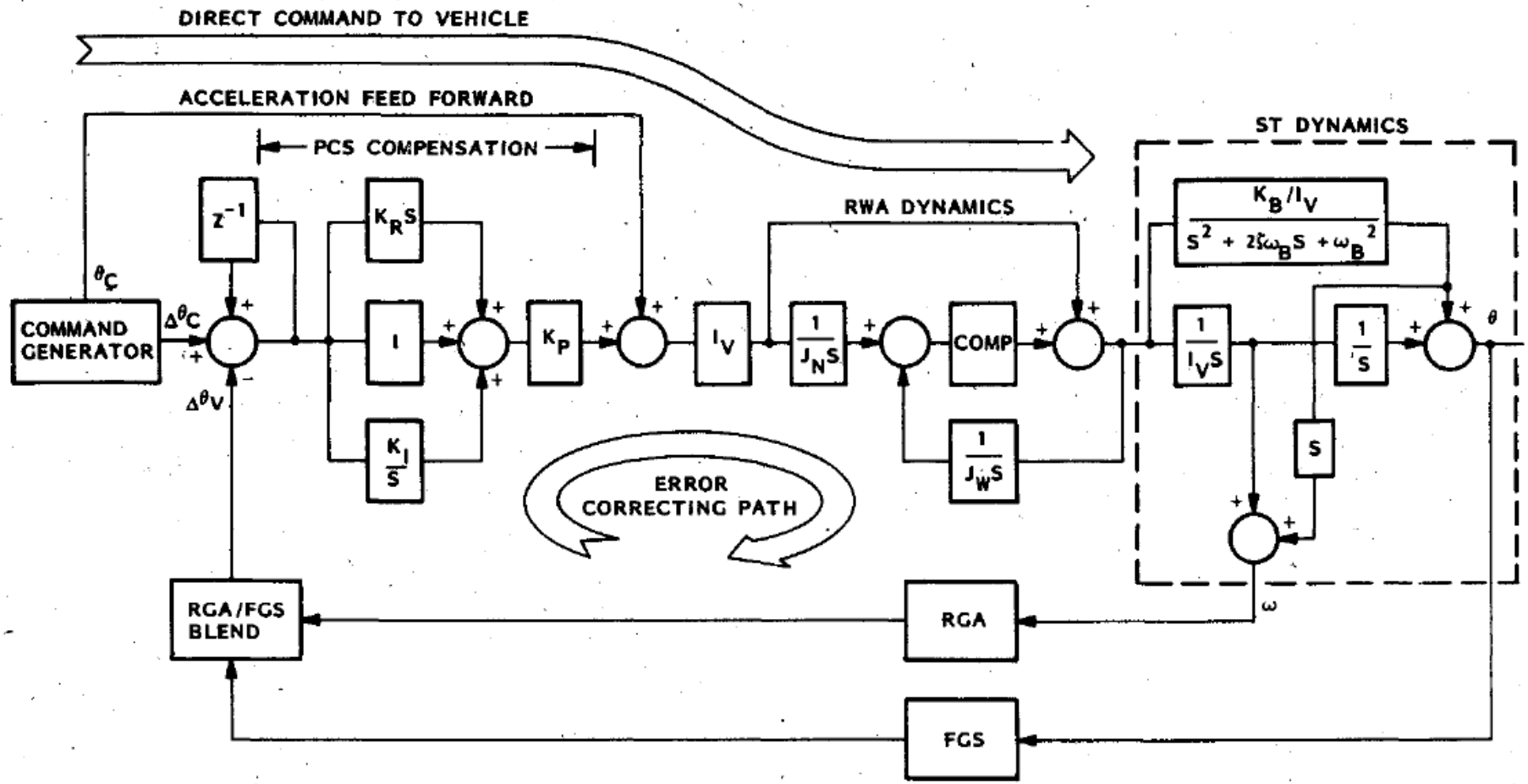
Typical Digital Controller Architecture



Automobile Speed Controller

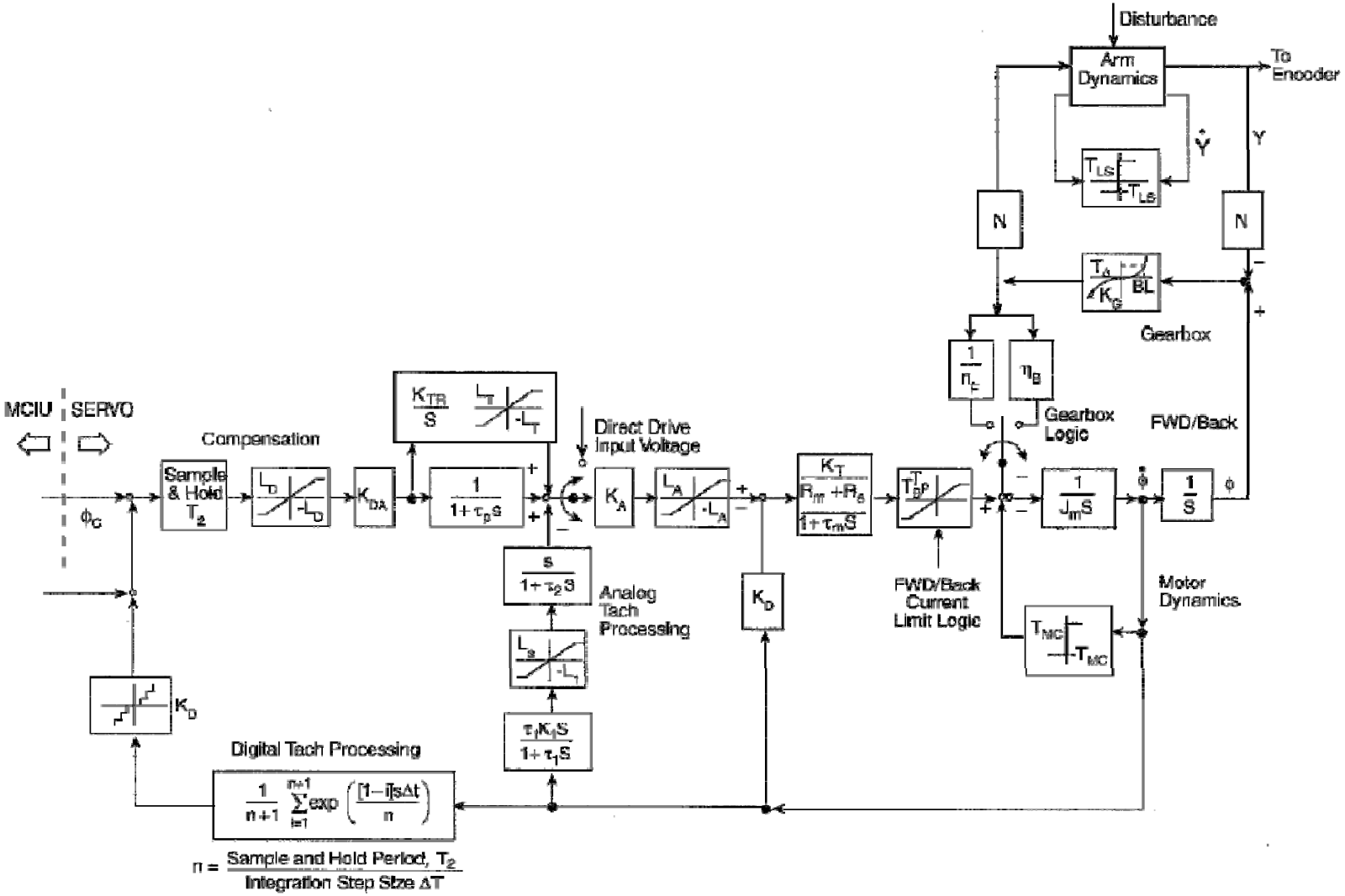


Space Telescope Pointing Controller

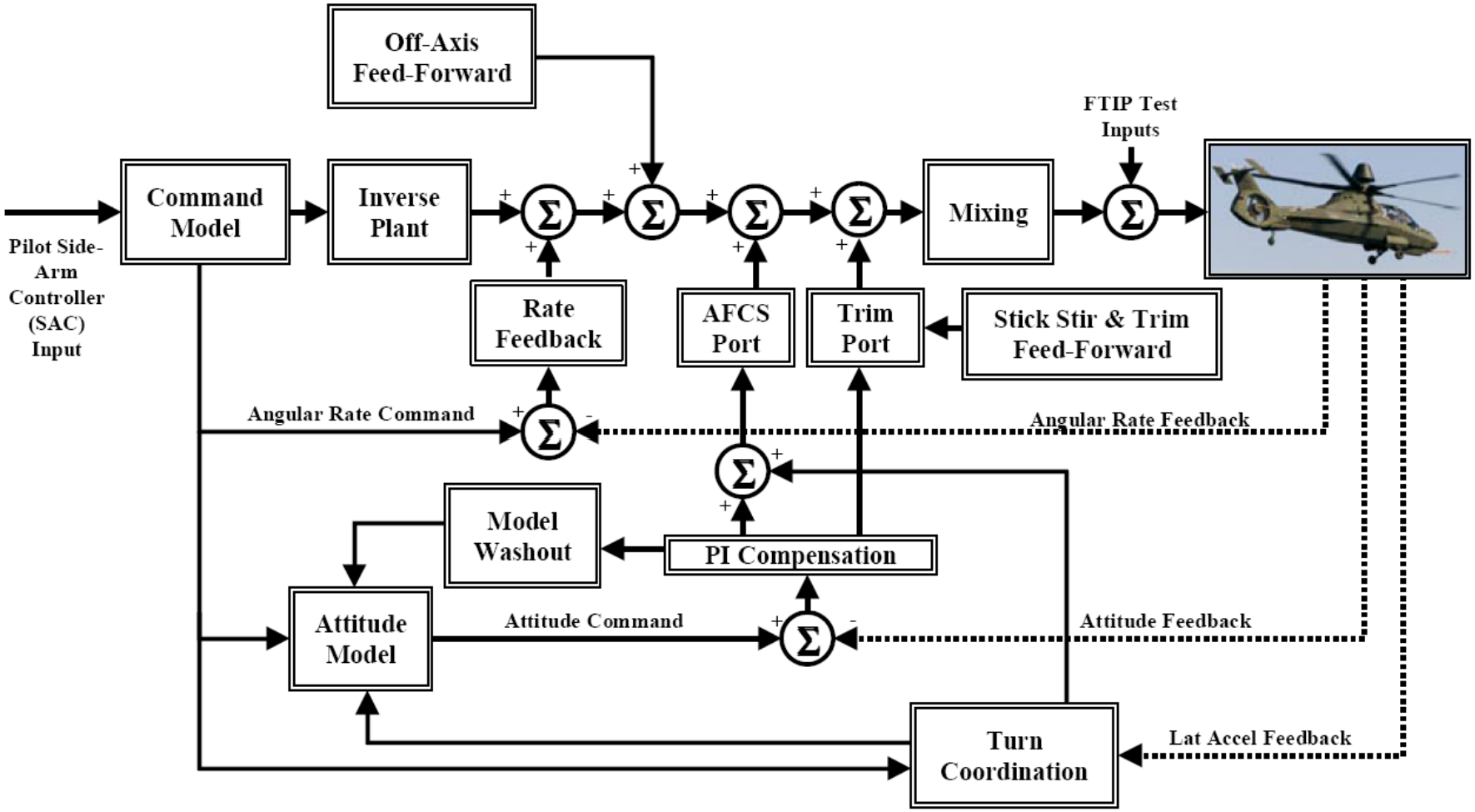



NASA
Canada
Endeavour
ENDEAVOR
DOCKED
YEAR: 2007
MISSION: STS-118
TARGET: EARTH

Robotic Arm Controller



Fly-By-Wire Aircraft Control System



Comanche 4-Axis Control Task

Summary : Control Objectives & Requirements

- Performance Requirements
  - Command Response = Make Output Respond Properly to Inputs
  - Disturbance Rejection = Prevent Output from Responding to Disturbances
  - Noise Suppression = Prevent Output from Responding to Noise in Measurement

- Stability = Tendency to Remain in Steady Condition After Brief Excitation (Input / Disturbance / Noise)

- Robustness = Ability to Maintain Performance & Stability When System Elements (Plant / Actuator / Sensor) Change (or Are Different Than Model Used for Design)