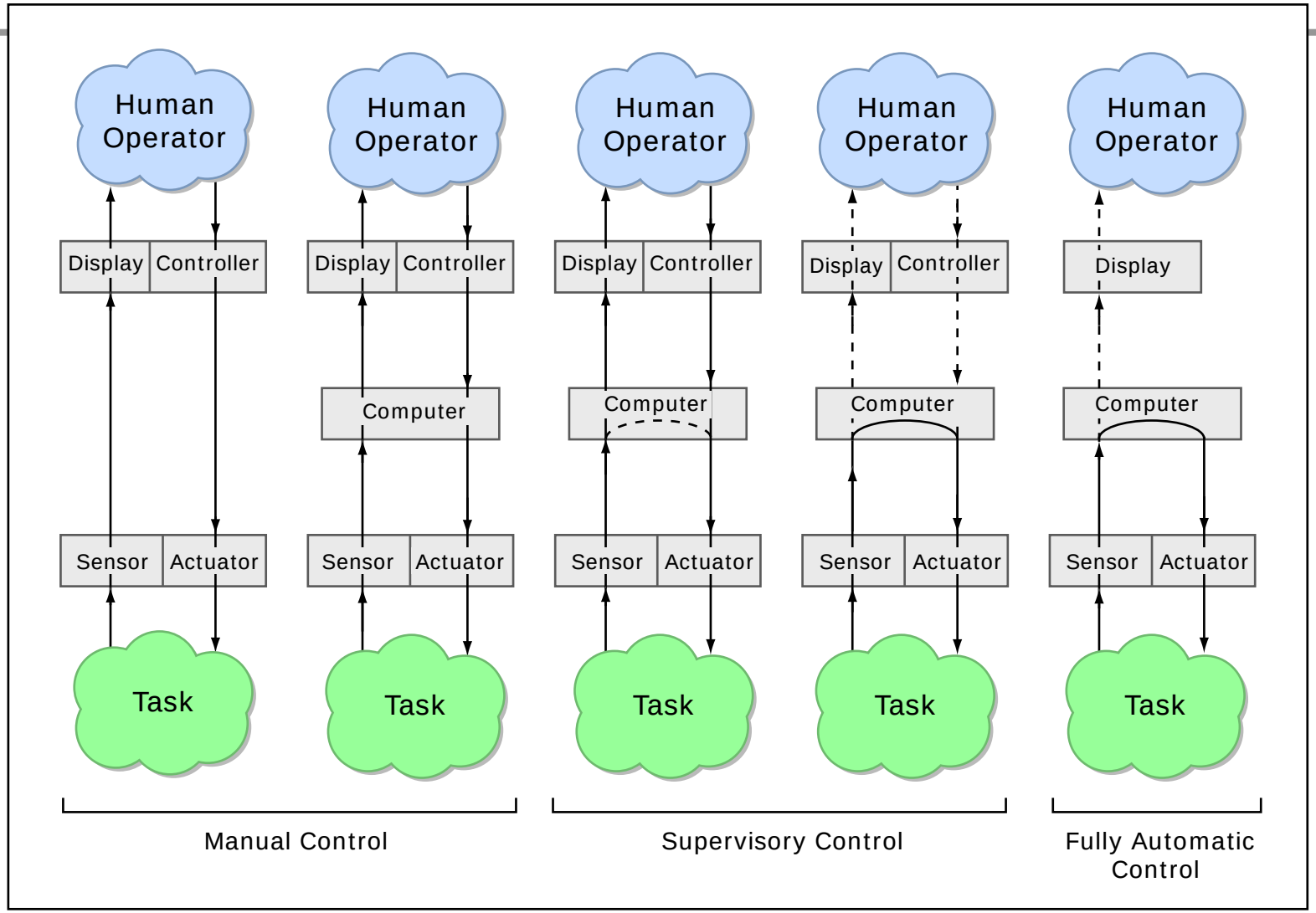
16.400/453J

Human Factors Engineering

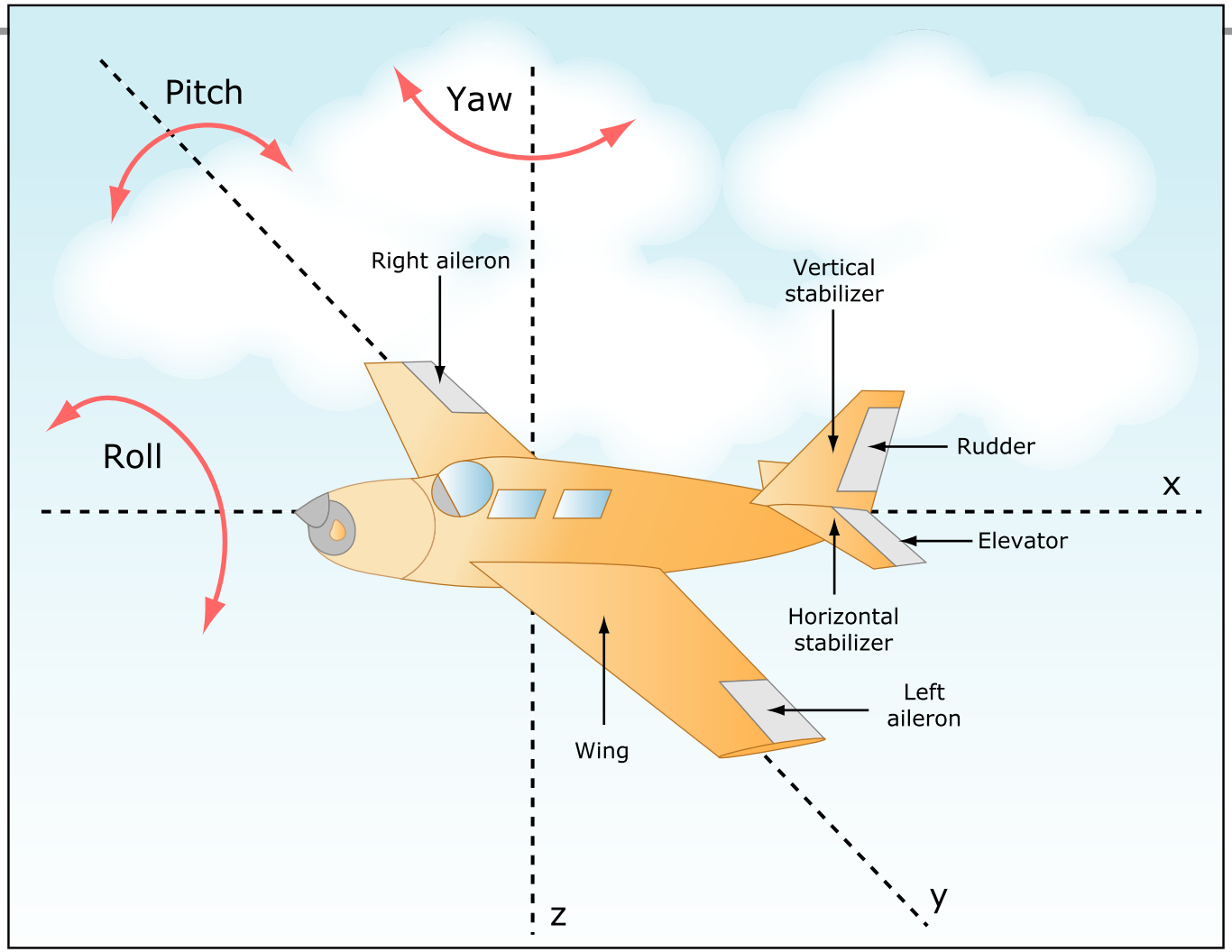
Manual Control I

Massachusetts Institute of Technology

Levels of Control



Aircraft Basics



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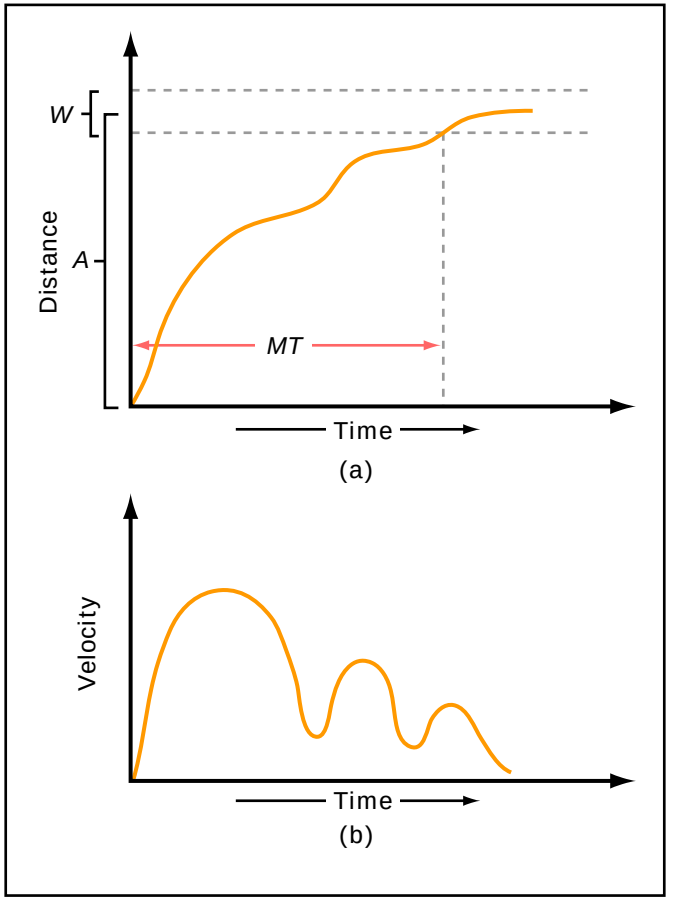
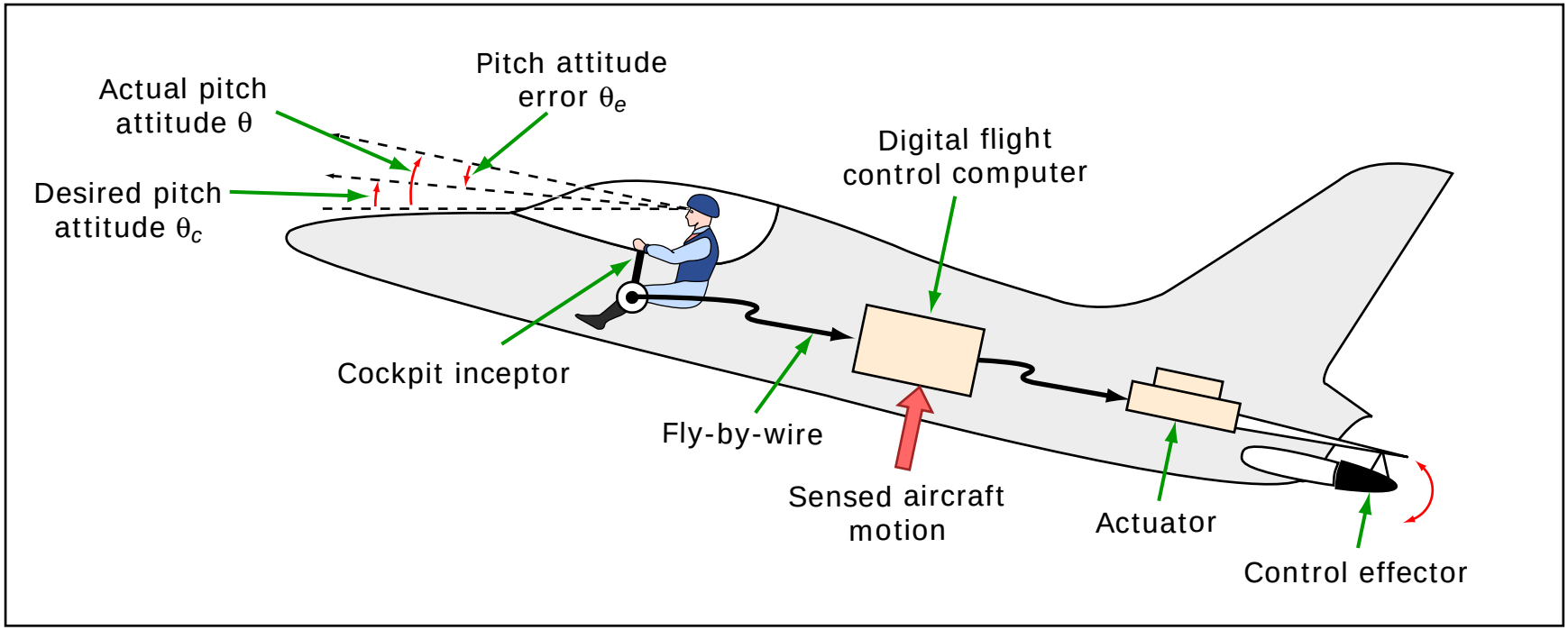
Control of Aircraft

- Forces on an A/C
  - Propulsive
  - Aerodynamic
  - Gravitational
- Control responses
  - Stabilization
    - Handling qualities
  - Disturbance regulation
  - Maneuverability
- Reactive vs. proactive human response
  - The innate human response to “home in” on a signal



Pilot Input



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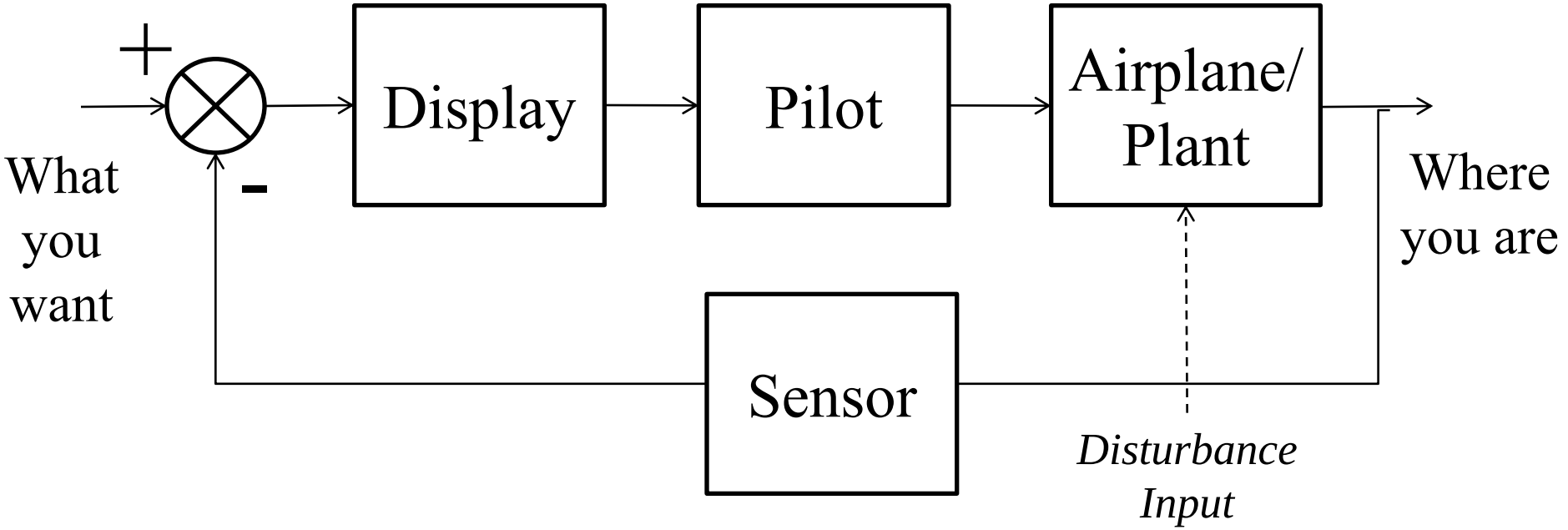
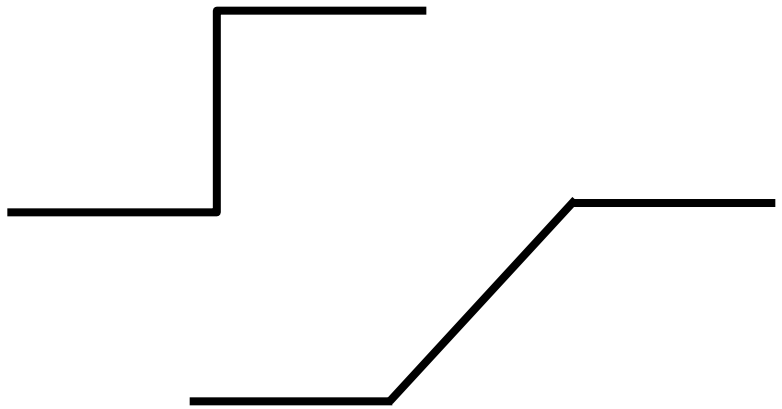
The Basic Pilot/Plant Feedback Loop



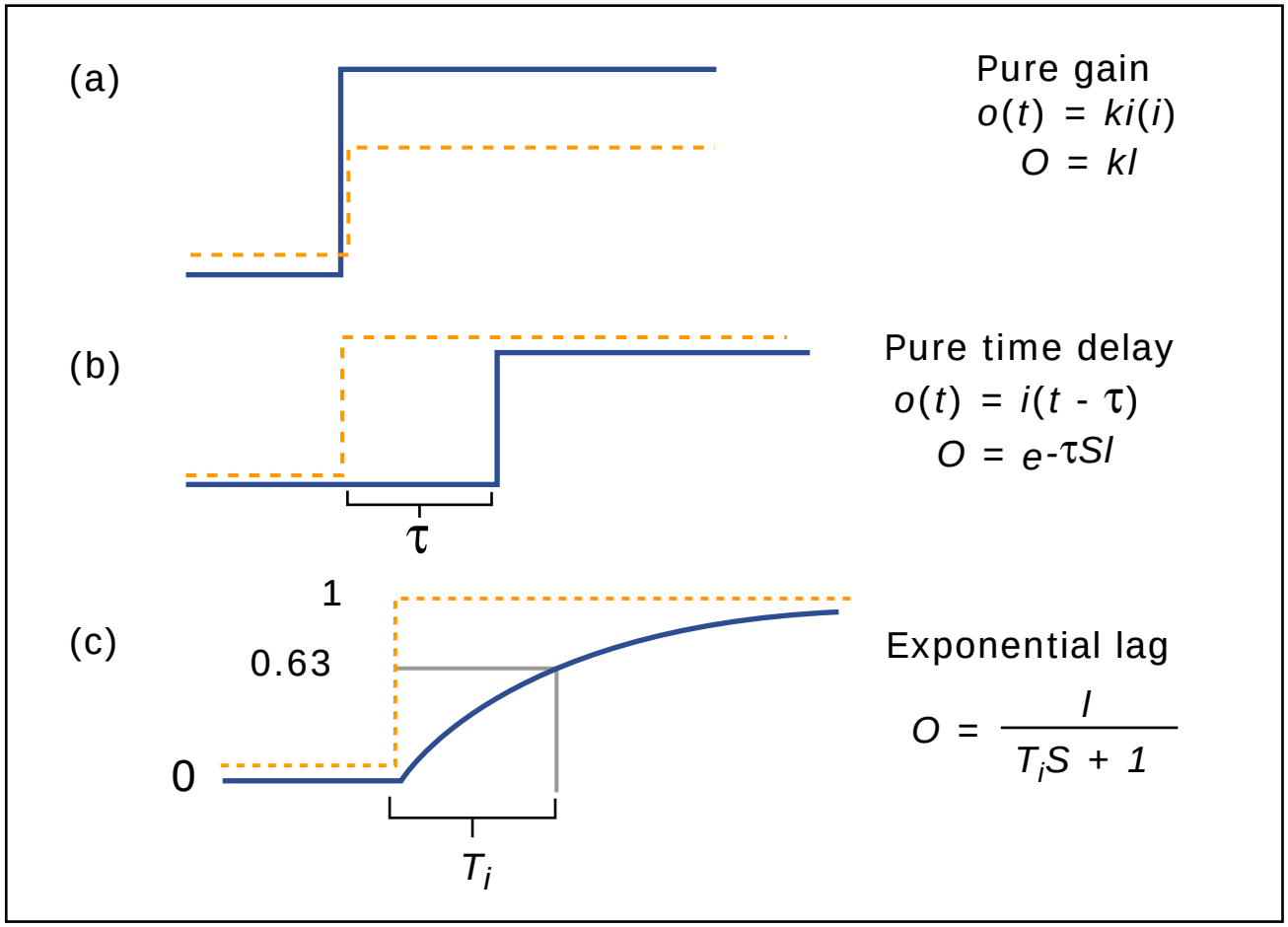
- Pilot sees error state (i.e., not on altitude, heading, etc.)
- Pilot understands what must be done to correct for error
- Pilot corrects
- Airplane corrects
- Sensed state is communicated to pilot…

Some important definitions

- Pilot/operator never needs to respond as long as there is no error…
- Two input types
  - Command
  - Disturbance
  - Transient vs. continuous
- Continuous
  - Periodic vs. random
    - Can model these in the frequency domain
    - A good assumption?
- Pursuit vs. compensatory displays
- Linear vs. non-linear
- Transfer function
  - Mathematical relationship between input and output



Transfer Function Interpretation



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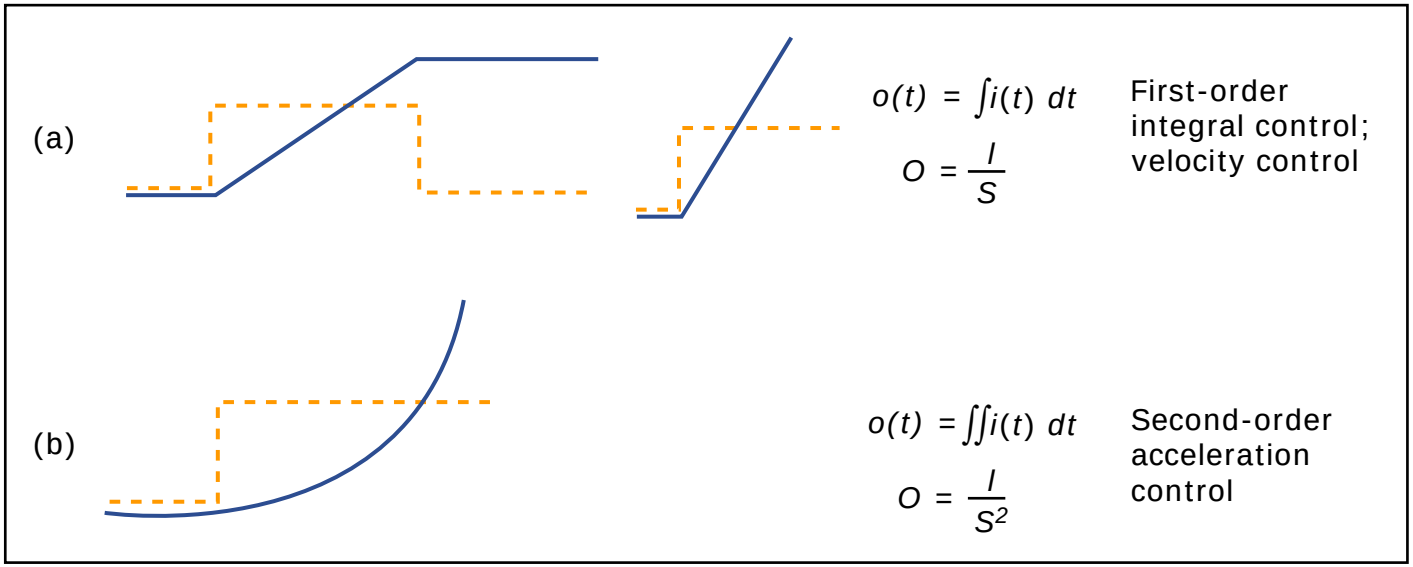
- These are for step response input – why is this a good assumption?
- Pure gain and pure time delay have no effect on each other

Transfer Function Interpretation, II

- Constantly held position produces constant rate of movement
- Input withdrawn, velocity =0, but new position is achieved



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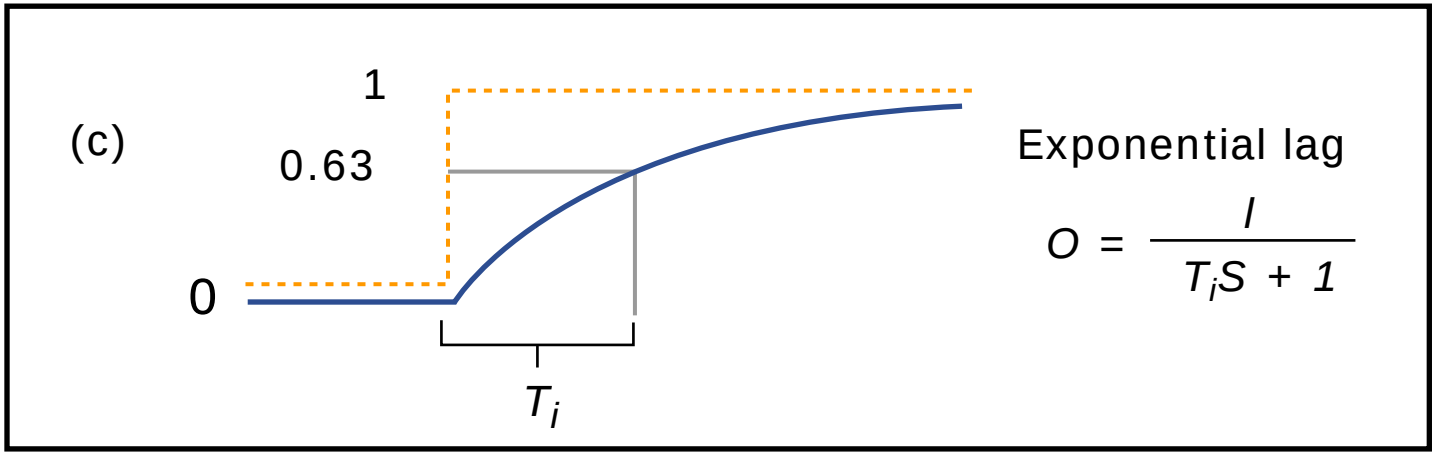
- Typical pure 2nd order systems are large mass/high inertia for constant input force
  - Sluggish, unstable when tracked, &requires a series of reverse corrections

Transfer Function Interpretation, III



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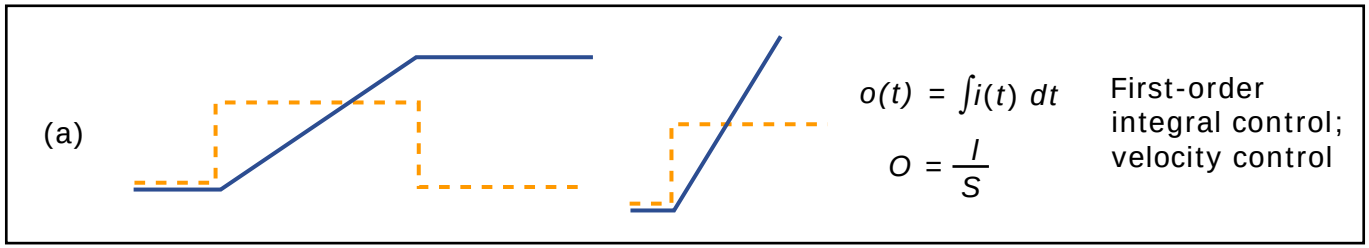
First order response to error (as opposed to commanded input) will look like lag (response velocity is proportional to response error)



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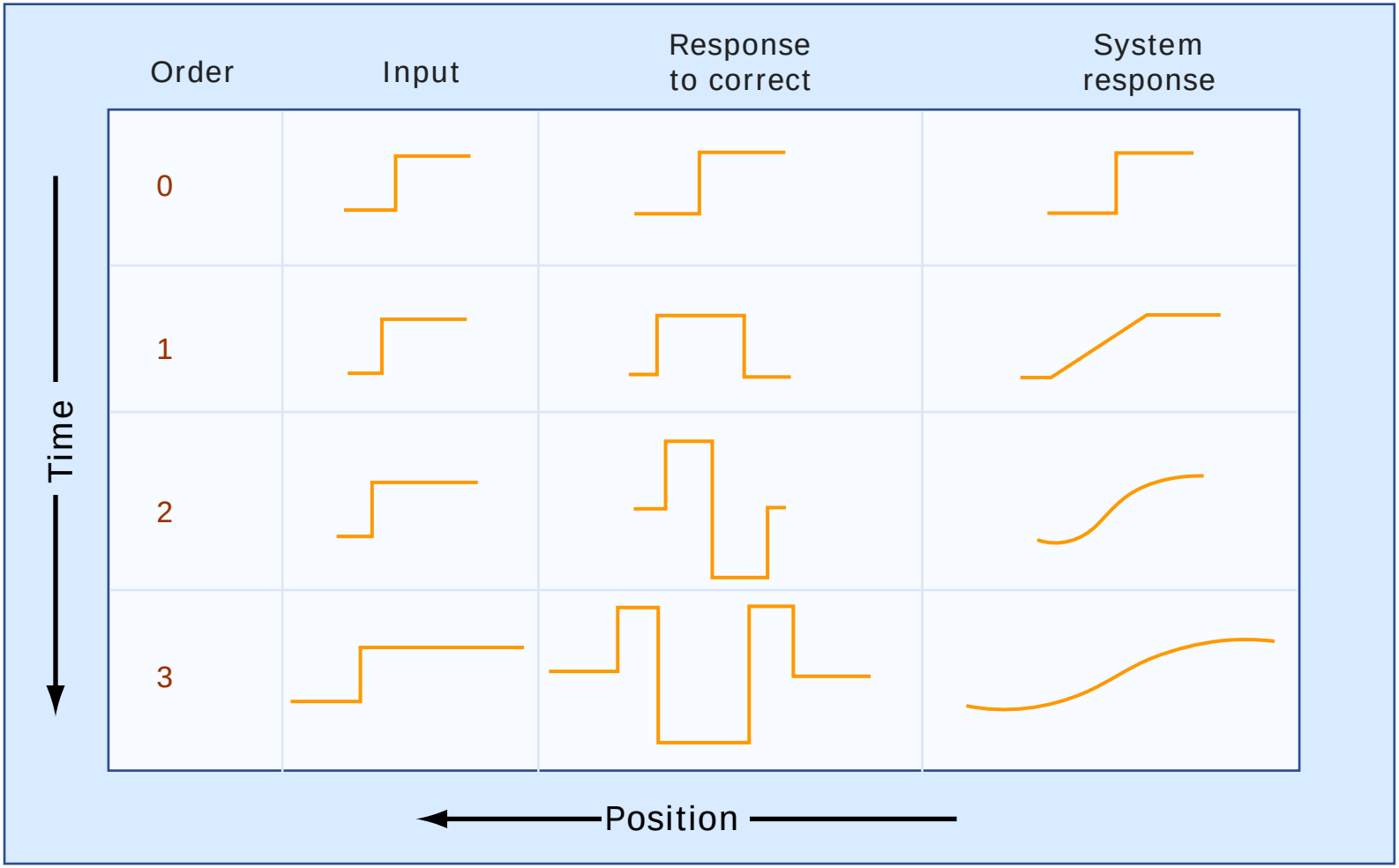
Human Performance & System Order

- Human information processing causes a delay
  - Perceptually humans track position, velocity, and acceleration changes the best (in that order)
- 0^{th} and 1^{st} order systems are tracked with time delays of ~150-300ms
  - 2^{nd} order systems: 400-500ms
- Systems can cause delay
  - Computationally
  - Communication
- Best human can do is 2 corrections per second
  - Serial reaction time experiments show people can make 2.5 decisions per second
- Countering inherent human delays with display preview/prediction

Demo

- http://studiolab.io.tudelft.nl/controltheory/demo.html

Order and System Response



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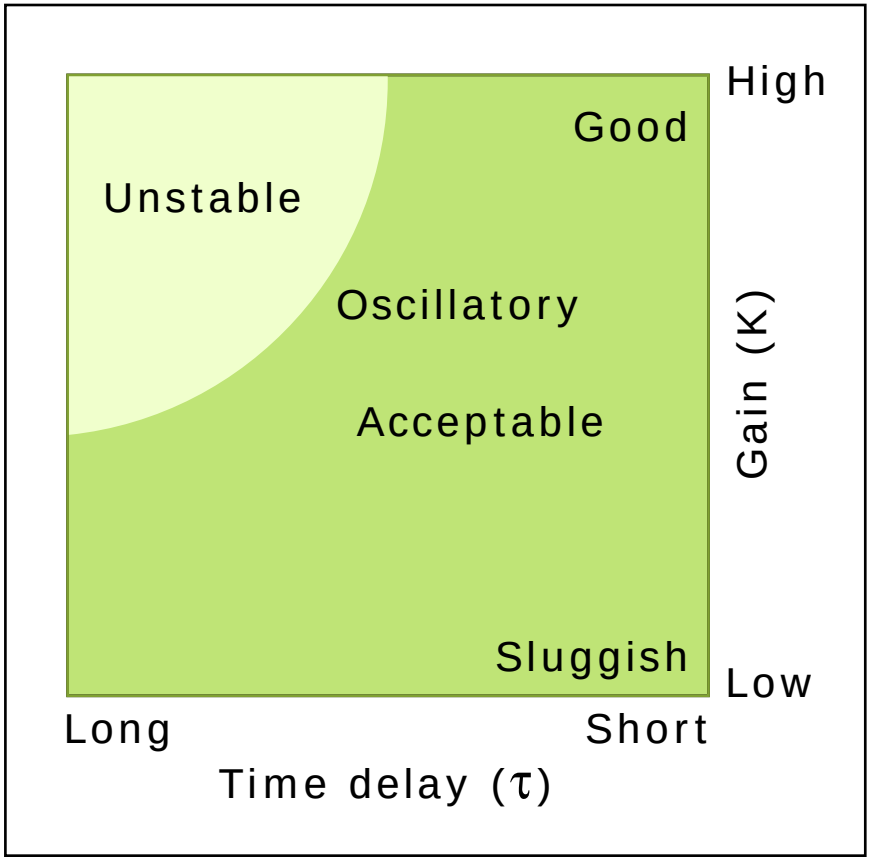
System Order Design Considerations

- Which system order is best for humans?
  - 0^{th} and 1^{st} equivalent
    - Cost-benefit analysis (time vs. magnitude of response)
    - Economy of movement & space
    - Level of expertise
  - Not mutually exclusive, rate aided displays are a combination
- 2^{nd} order and higher should be avoided
  - Operators must perceive higher-error derivatives continuously
    - Near-constant monitoring reduces cognitive capacity for other tasks
  - Error and subjective workload increase significantly

Stability Design Considerations

- Systems with intermediate gains have lowest error and easiest to track
  - High gain = minimal effort but high likelihood of overshoot
  - Instability exacerbated by system lags
  - Finding the right gains
- PIO
  - Caused by high gain & large lags/time delays in loop closure
  - Inherent aspect of negative feedback systems



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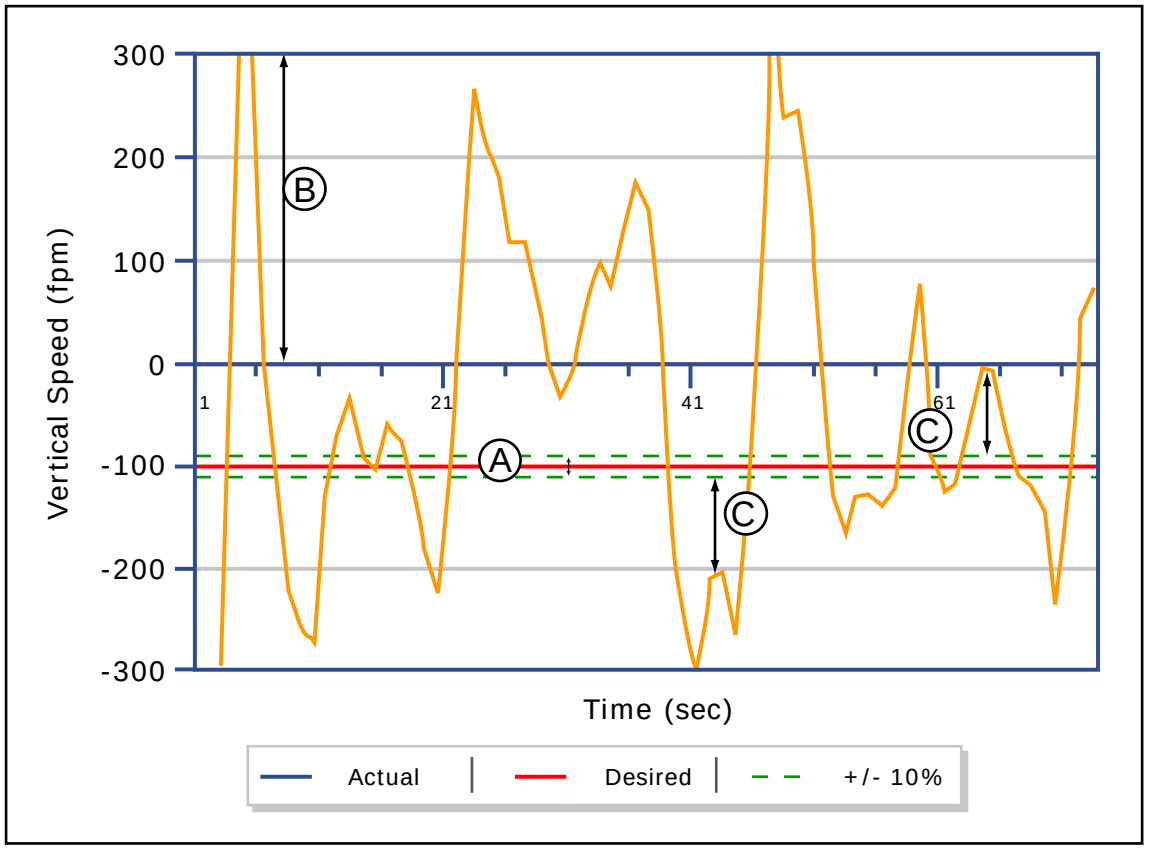
Some PIO footage…

- F-22
  - http://www.youtube.com/watch?v=03rz8vqjGdQ
- Gripen
  - http://www.youtube.com/watch?v=k6yVU_yYtEc
- Shuttle
  - http://www1.dfrc.nasa.gov/Gallery/Movie/STS/640x/EM-0084-02.mov

Predictive Interface Design

- Should control by error rates vs. error values
  - When humans respond to predictive cues, they act as differentiator and cancel out an integrator (reducing order)
- Predictive displays can mitigate consequences of time delay
- Two types
  - Preview
  - Prediction
    - Quickening – where system error is *likely* to be in the future
    - Issues with assumptions

Measuring Pilot Response



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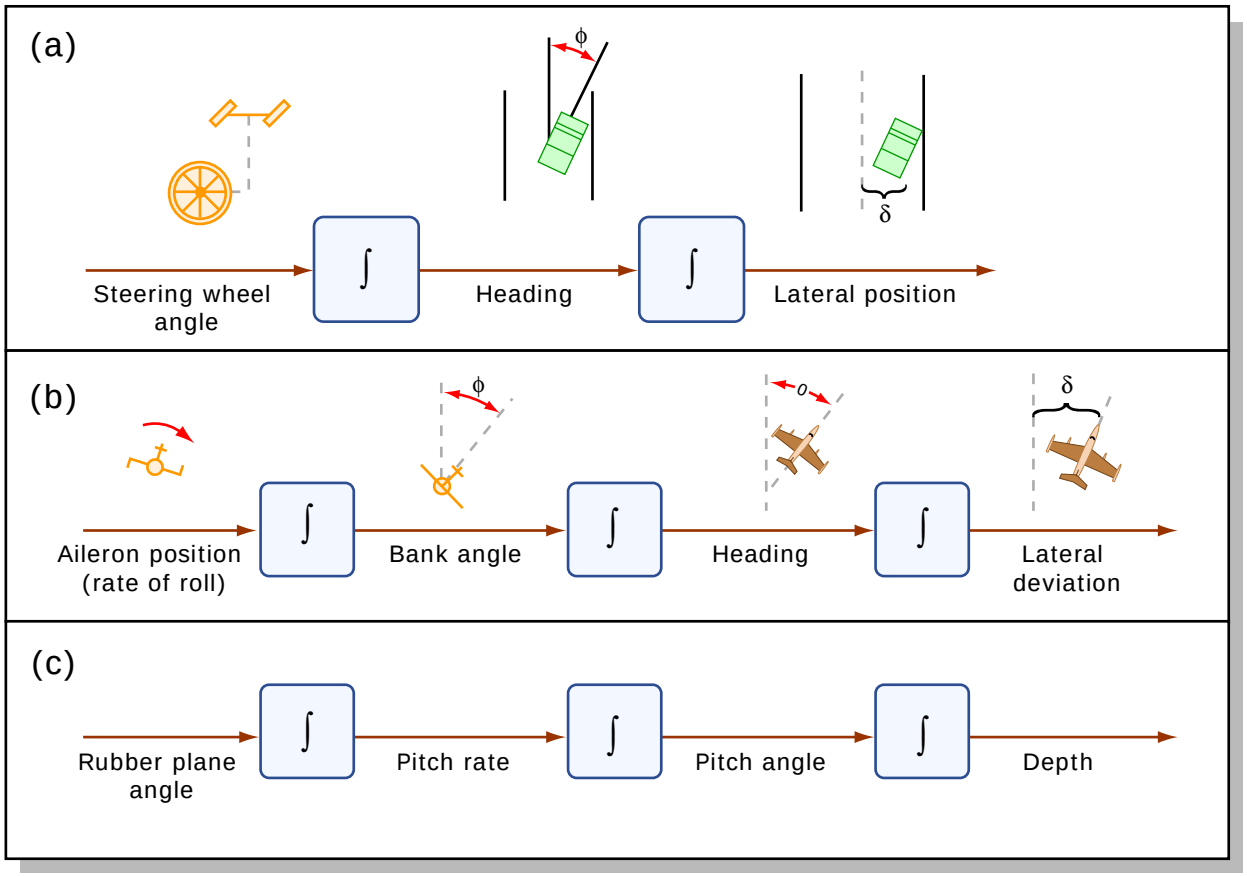
$$RMSE = \sqrt{\frac{\sum (Y_a - Y_d)^2}{n}}$$

- Measuring signal strength as opposed to average values

Multi-axis Control

- Cross-coupled & hierarchical tasks
- Lower order variables must be controlled to regulate higher order variables
- Cognitive workload & design interventions



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Inner Loop ⟷ Outer Loop

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