Embedded Fault Detection for Low-Cost, Safety-Critical Systems (NSF CPS-0931931)

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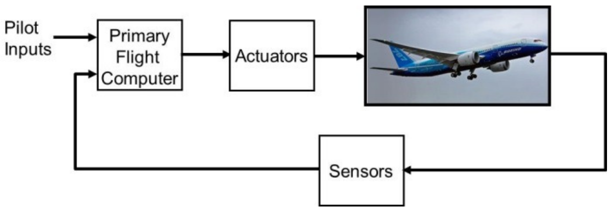
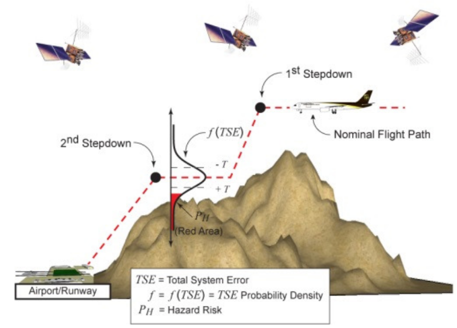
Challenges for Low-Cost Unmanned Aerial Systems (UAS)

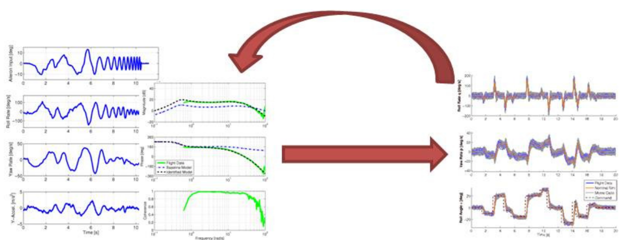


Guidance and Controls

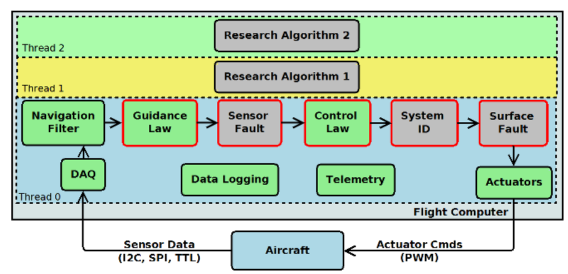
Human Factors



Navigation

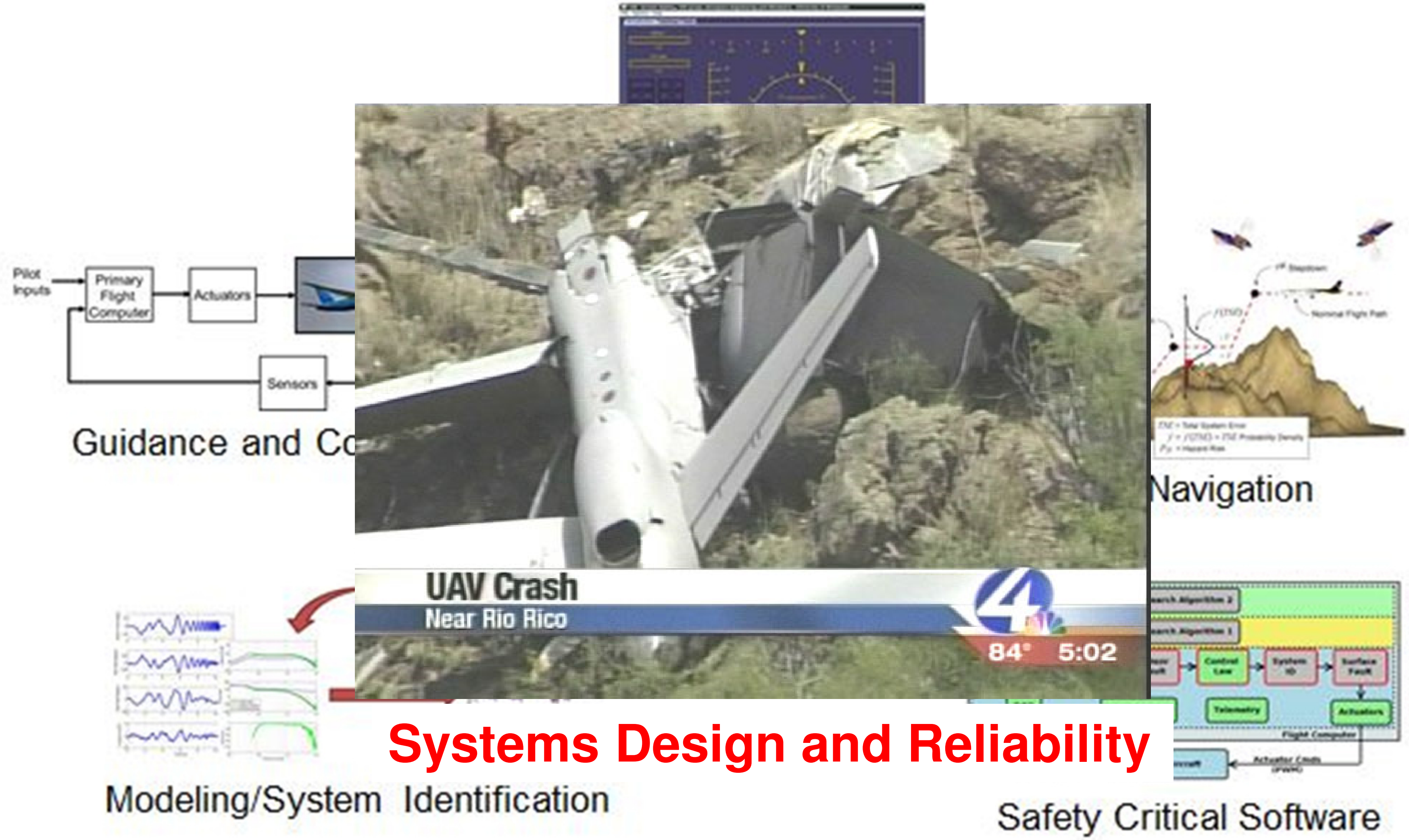


Modeling/System Identification



Safety Critical Software

Challenges for Low-Cost Unmanned Aerial Systems (UAS)



Commercial Fly-by-Wire

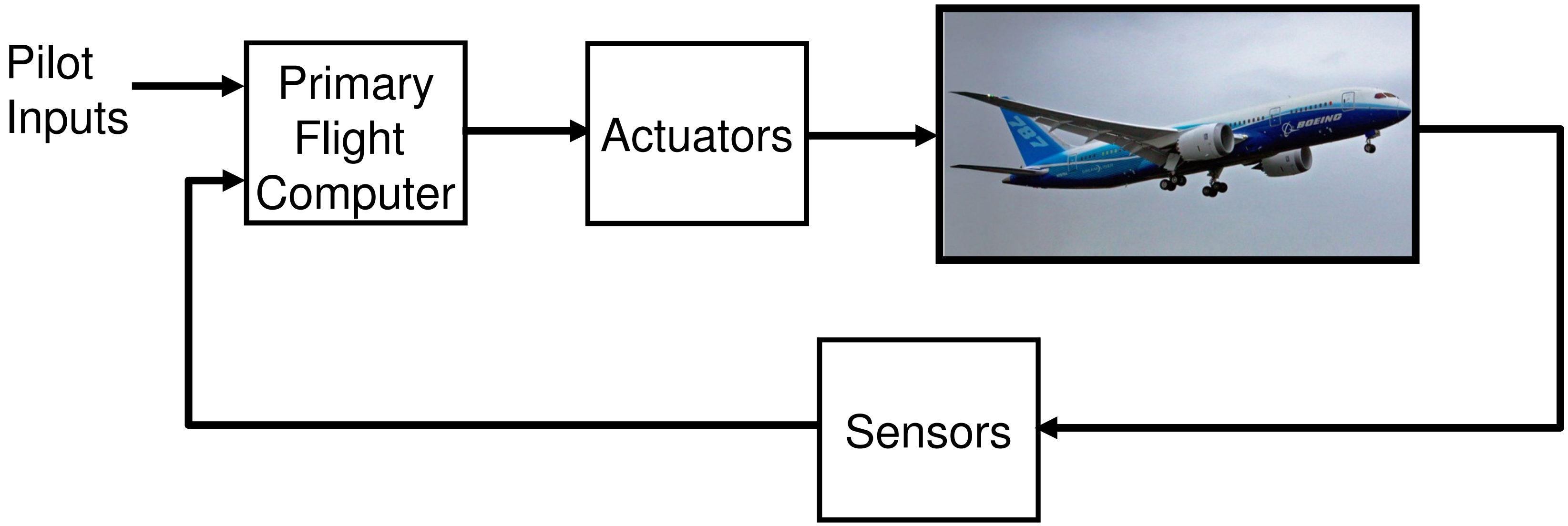
Boeing 787-8 Dreamliner

- 210-250 seats
- Length=56.7m, Wingspan=60.0m
- Range < 15200km, Speed< M0.89
- First Composite Airliner
- Honeywell Flight Control Electronics

Boeing 777-200

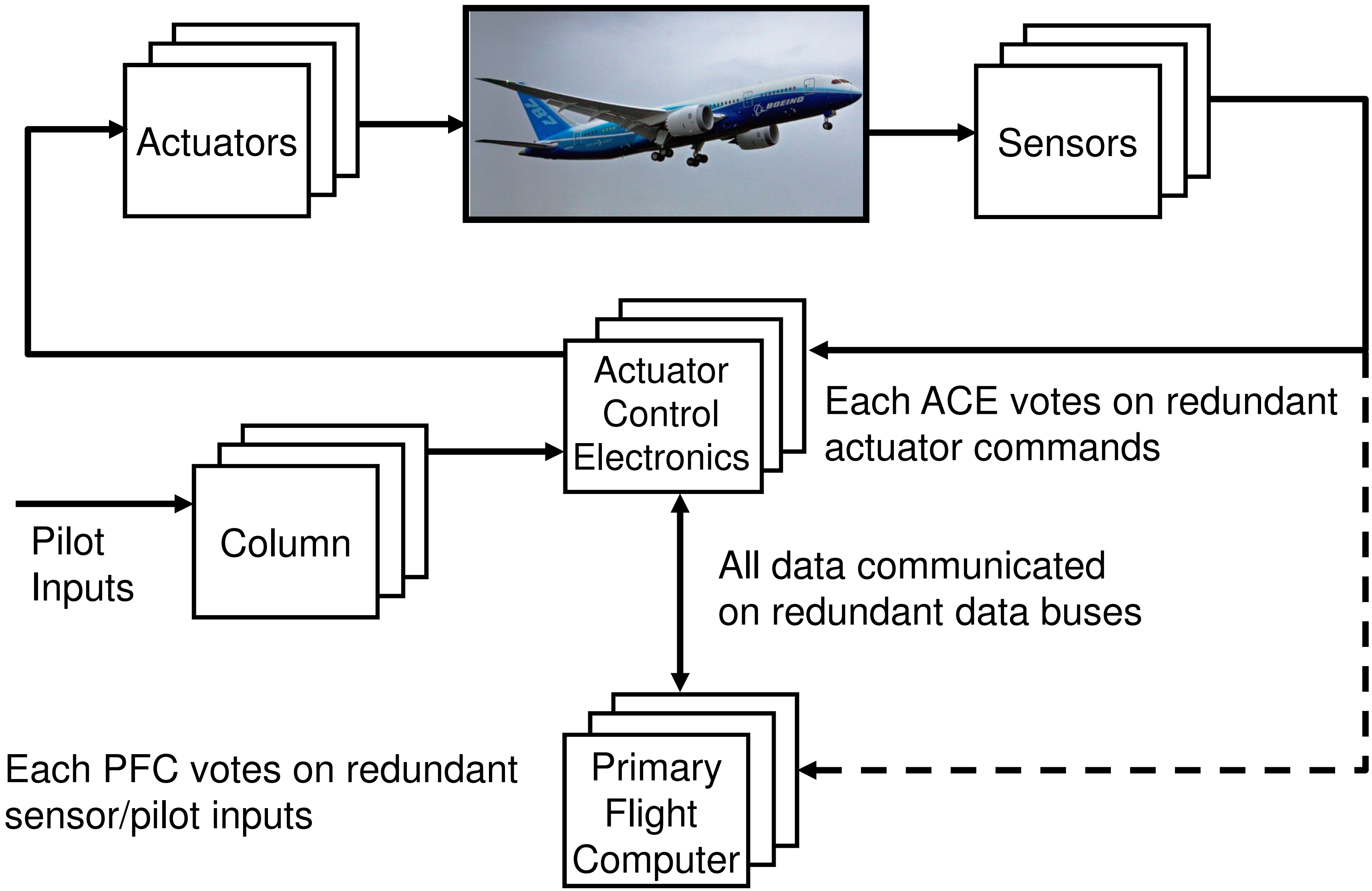
- 301-440 seats
- Length=63.7m, Wingspan=60.9m
- Range < 17370km, Speed< M0.89
- Boeing's 1st Fly-by-Wire Aircraft
- Ref: Y.C. Yeh, "Triple-triple redundant 777 primary flight computer," 1996.

Classical Feedback Diagram

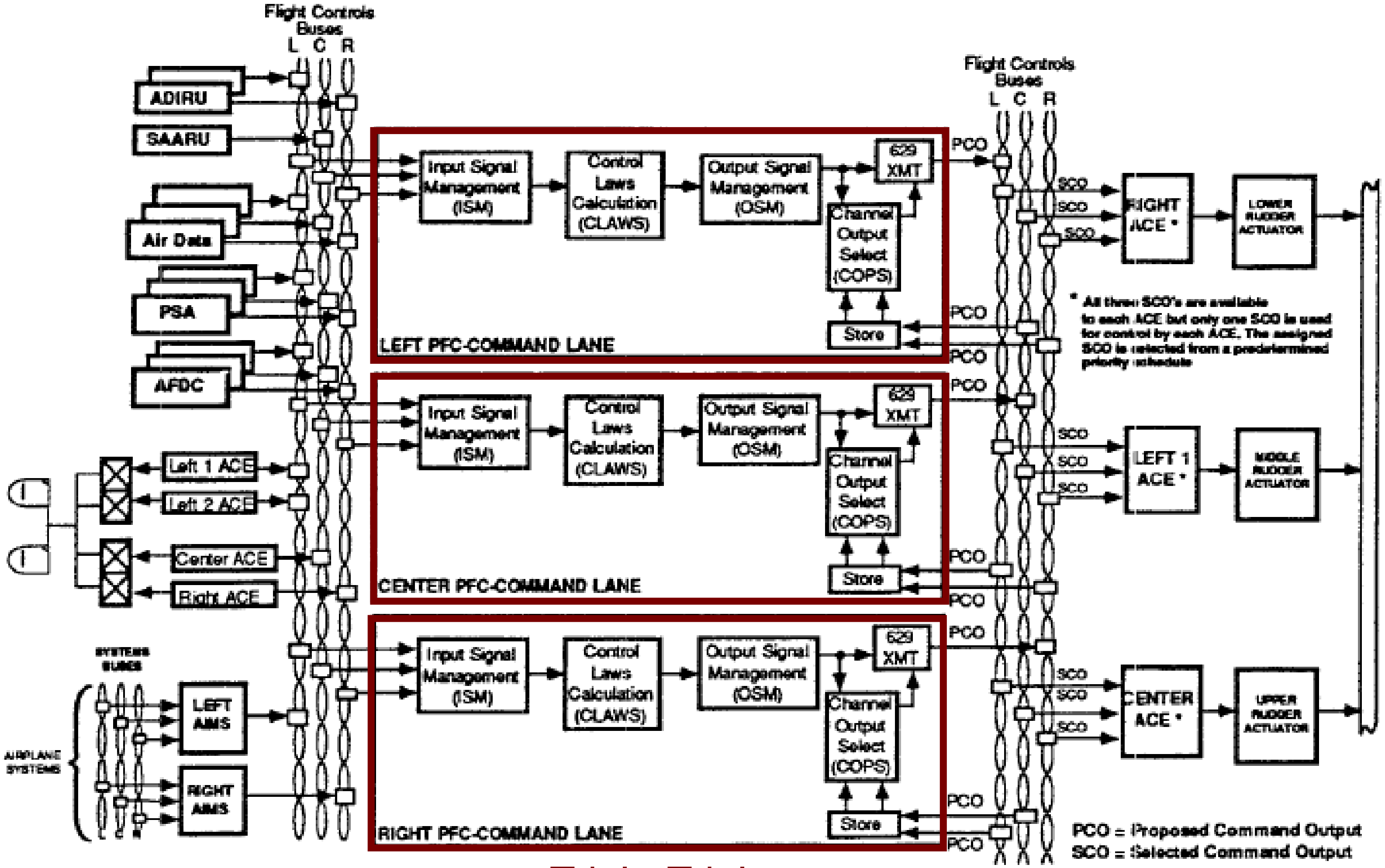


Reliable implementation of this classical feedback loop adds many layers of complexity.

Triplex Control System Architecture



777 Triple-Triple Architecture [Yeh, 96]



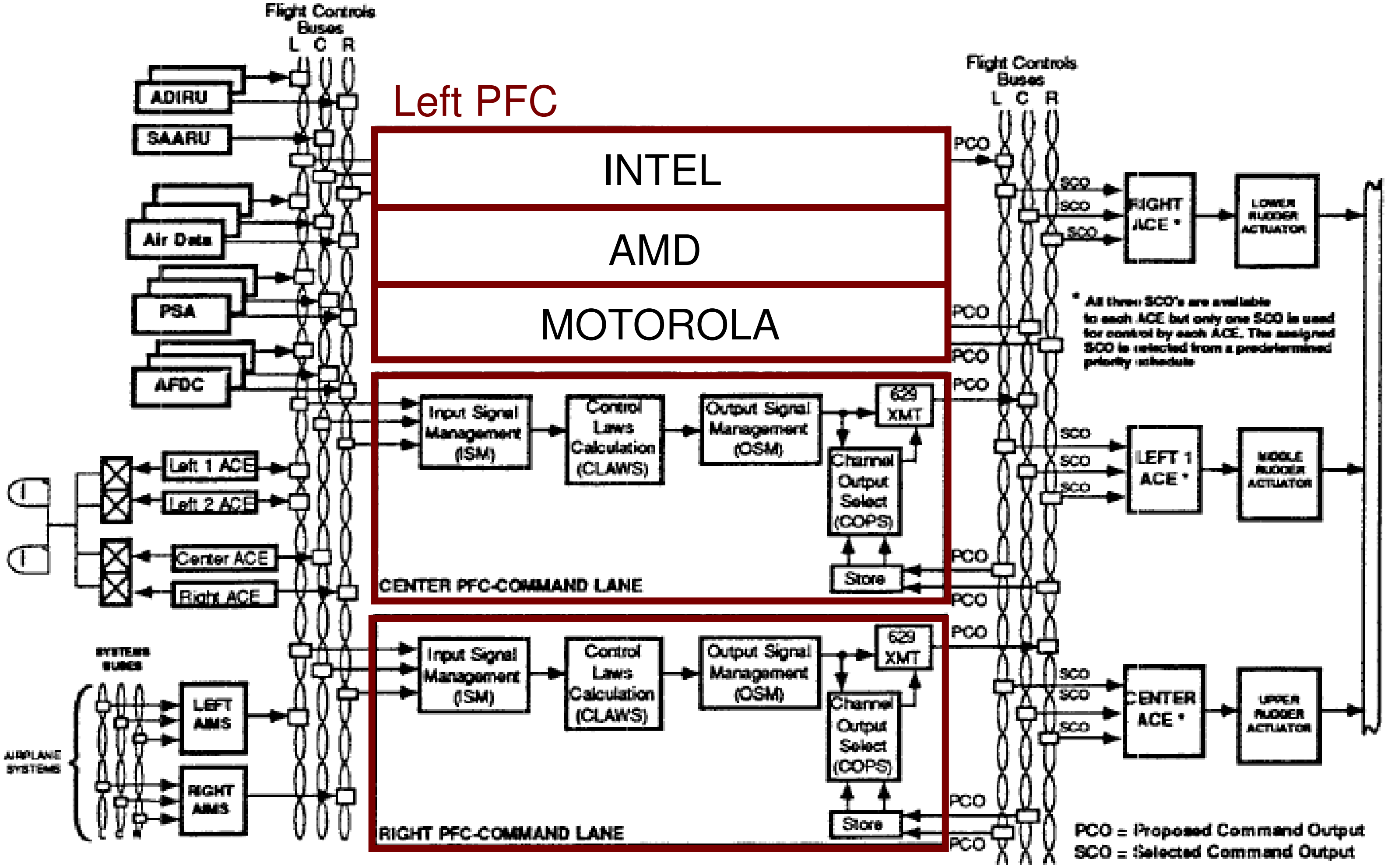
Sensors x3

Databus x3

Triple-Triple Primary Flight Computers

Actuator Electronics x4

777 Triple-Triple Architecture [Yeh, 96]



Sensors x3

Databus x3

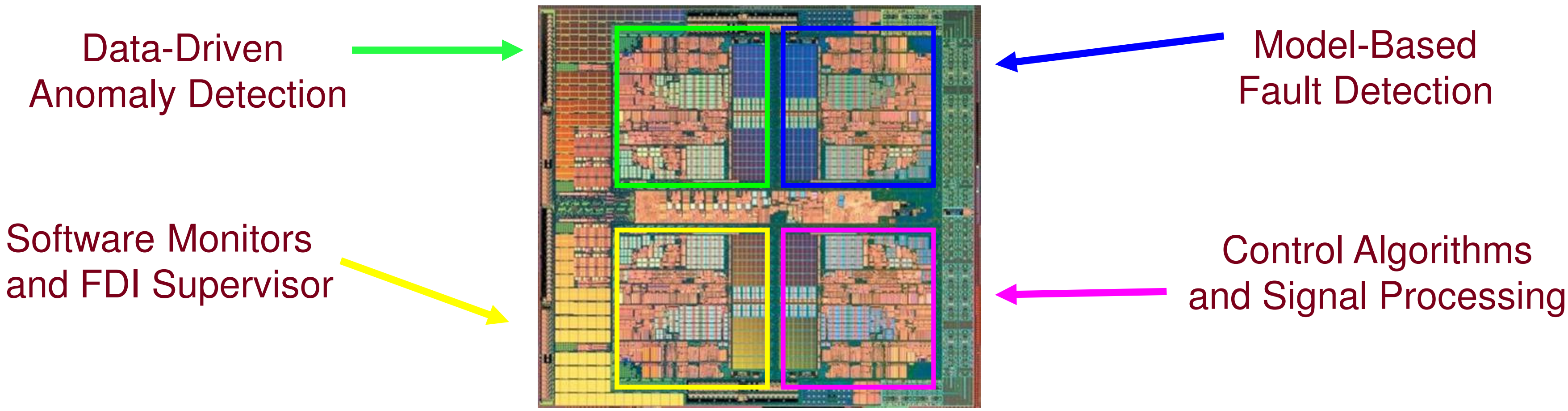
Triple-Triple Primary Flight Computers

Actuator Electronics x4

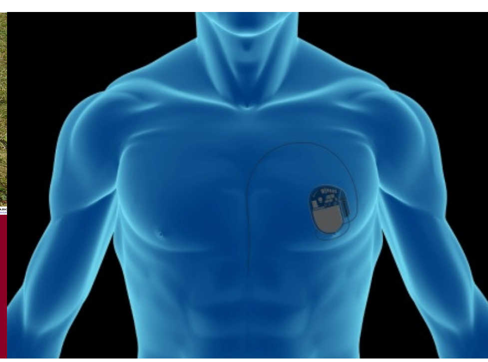
Embedded Fault Detection for Low-Cost, Safety-Critical Systems (NSF CPS-0931931)

Issue: Current safety critical systems rely mainly on physical redundancy but this increases system size, complexity and power consumption.

Objective: Develop algorithms and computing architectures that enable fault detection without relying on physical redundancy



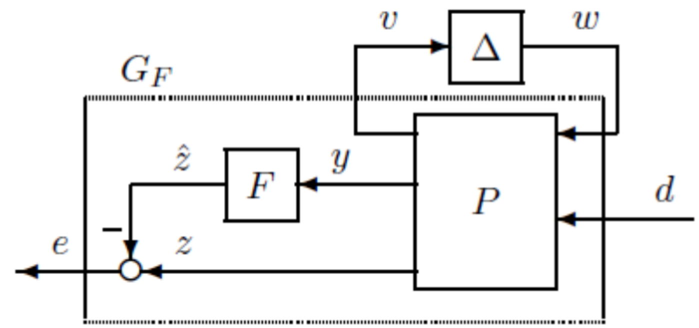
Quad Core Processor

Fault Detection Approaches

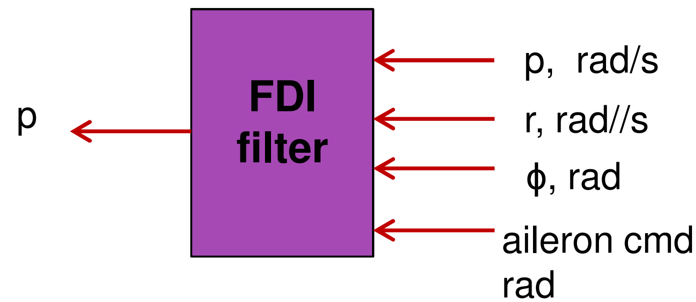
Model-Based Fault Detection:

- Mathematical model
- Uncertainty and error model
- Performance/robustness goals



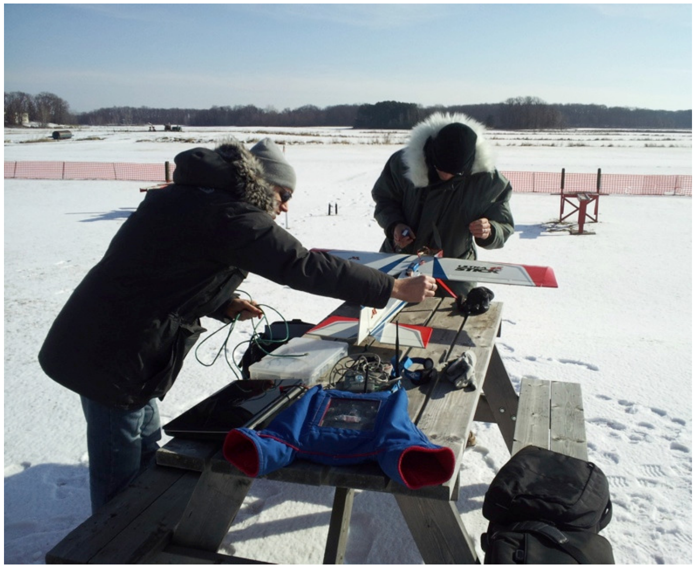
Data-Driven/Statistical Approach to Fault Detection

- Experimental data, command inputs
- Frequency domain test statistics
- z-test for normality, p-value anomaly scores



Freyja Open-Source Software/Hardware Infrastructure

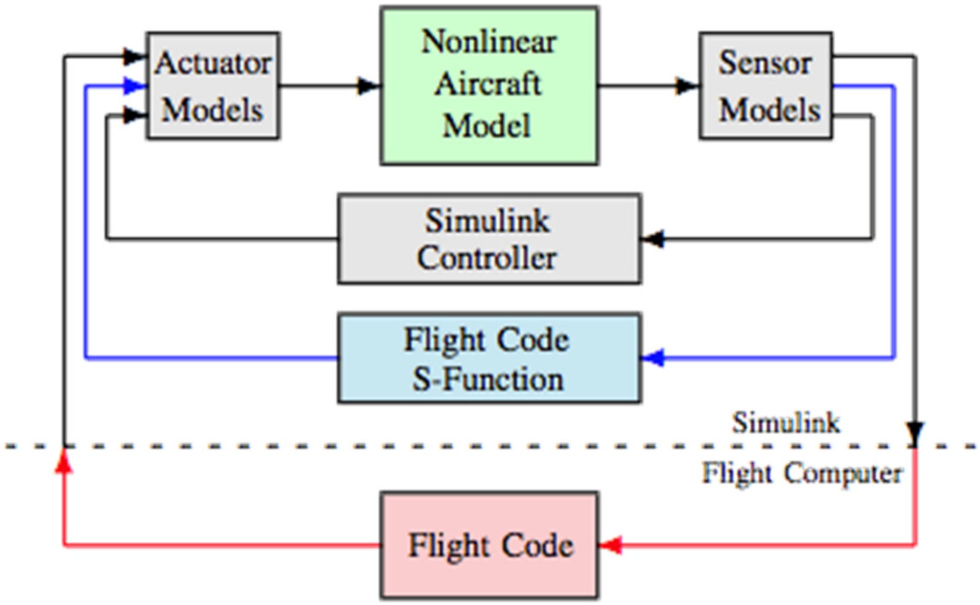
- Expose students to cyber-physical systems
- Take theory to flight
  - Validation and credibility of our research
- Model Based Design
- Open source, low cost flight research infrastructure
  - Flight computer, simulation, flight software
  - Testing techniques, best practices, and analysis tools



- Publicly available documentation and data
  - www.uav.aem.umn.edu
  - Flight, propeller, actuator testing data
  - Procedures, manuals, wiring diagrams, CAD files

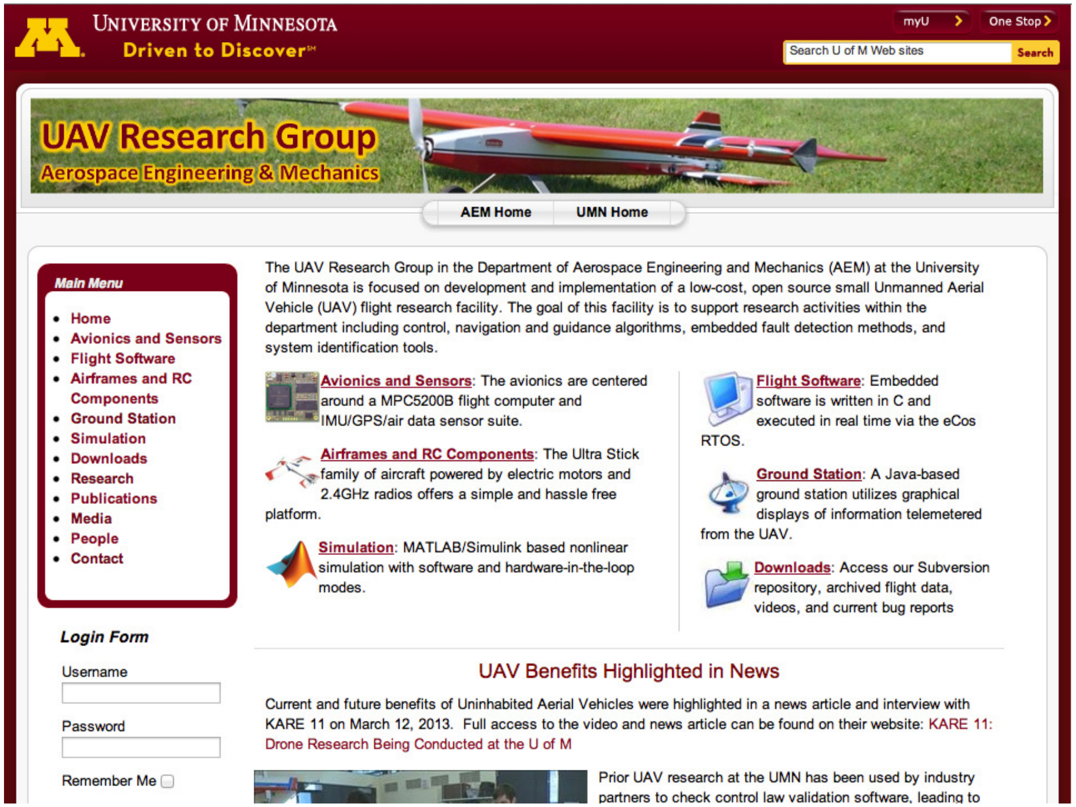
Freyja Simulation and Software Infrastructure

- Non-linear and linear bare airframe simulations
- Simulink controller, software and hardware in the loop capability
- Current flight code implemented in C, future versions will be based on autocoded Simulink
- Hardware-in-the-Loop and Software-in-the-Loop capabilities



Publicly Available Data/Models

- Flight and testing data available on the website
  - Over 180 flights
  - Propeller testing
  - Working on motor and actuator testing
- Documentation
  - Procedures and manuals
  - Project archives
- CAD files
  - All files necessary to replicate our research infrastructure
- Software, simulation, and ground station



Student Involvement

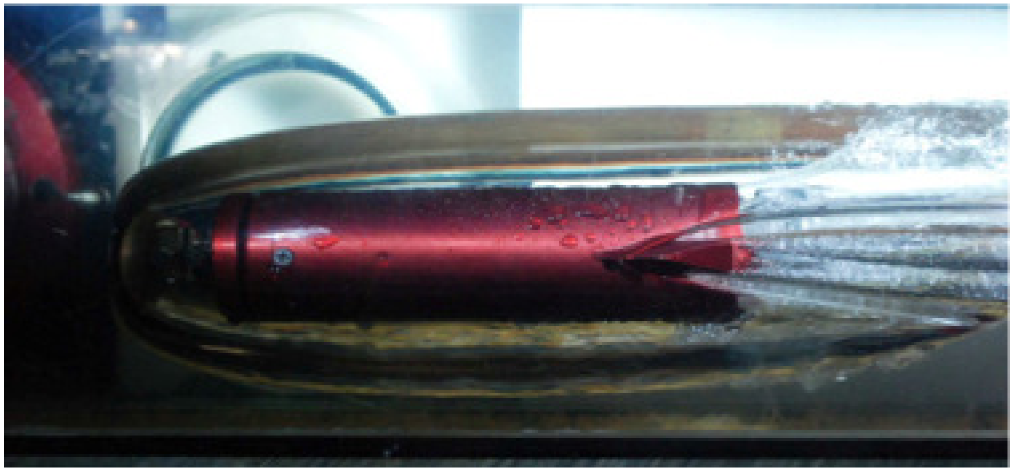
- Graduate and undergraduate student involvement
  - 18 undergraduate students
  - 9 graduate students
  - Volunteer from the National Guard
- AEM 1905 “Freshman Seminar: Model Aircraft Design, Flight Test and Analysis”
  - Validated aircraft performance predictions
- AEM 5333 “Design, Build, and Flight Test a UAV”
  - Design control laws and flight test on Ultra Stick 25e

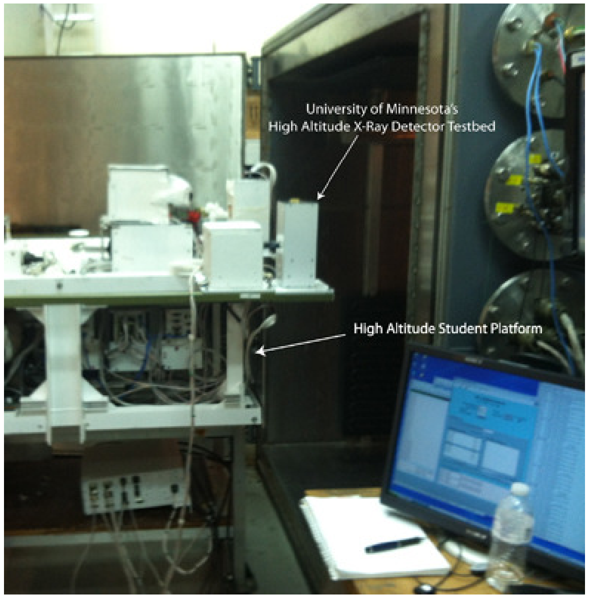
Community Outreach

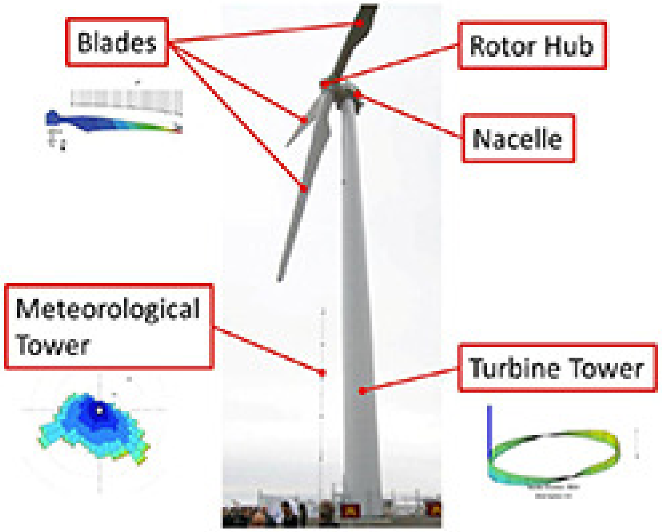
- Developing similar research infrastructures at San Jose State University and NASA Dryden Flight Research Center
- Working closely with the MN National Guard and Camp Ripley
- Provided a research perspective working with the MN state government to respond to the FAA UAS Test Site SIR

Other Applications

- Super cavitation research
- Wind turbine control
- X-ray detection as an alternative to star trackers for satellite navigation







Summary

- CPS continues to evolve.
- A shared/common software infrastructure is important
- Working across discipline boundaries is still a challenge
  - Language/Time
  - Software/hardware
  - Application
- CPS benchmark problems are great opportunities for cross disciplinary collaboration

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