



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

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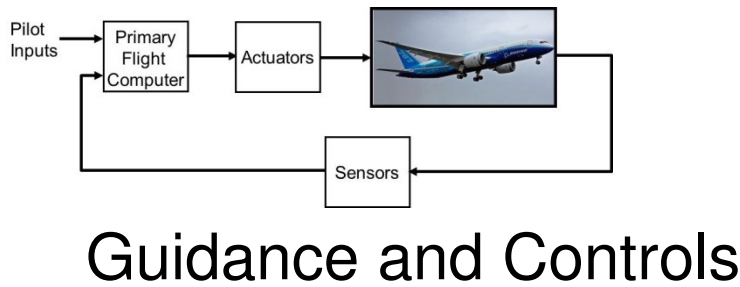
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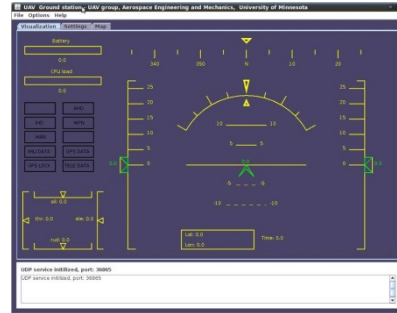


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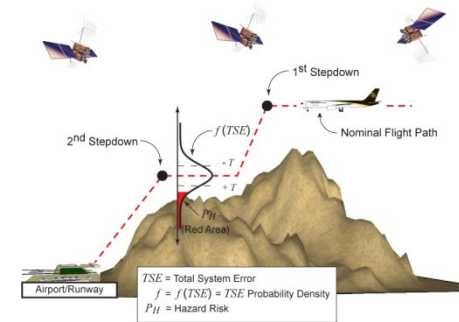
# Challenges for Low-Cost Unmanned Aerial Systems (UAS)



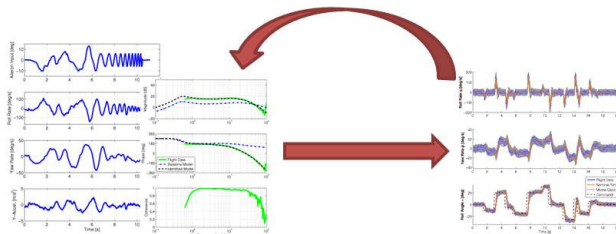
Guidance and Controls



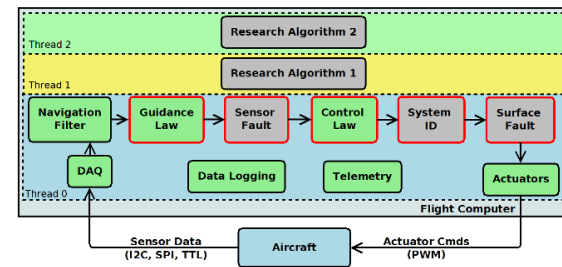
Human Factors



Navigation



Modeling/System Identification



Safety Critical Software



# Challenges for Low-Cost Unmanned Aerial Systems (UAS)

**Guidance and Control**

Pilot Inputs → Primary Flight Computer → Actuators → [UAV] → Sensors → Primary Flight Computer

**Navigation**

UAV Position, Nominal Flight Path, Terrain Map

**UAV Crash Near Rio Rico**

84° 5:02

**Modeling/System Identification**

Graphs showing system response over time.

**Safety Critical Software**

Search Algorithm 2, Search Algorithm 1, Control Law, System ID, Surface Fault, Telemetry, Actuators, Flight Computer, Aircraft, Actuator Fault (AFAC)

## Systems Design and Reliability



# 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

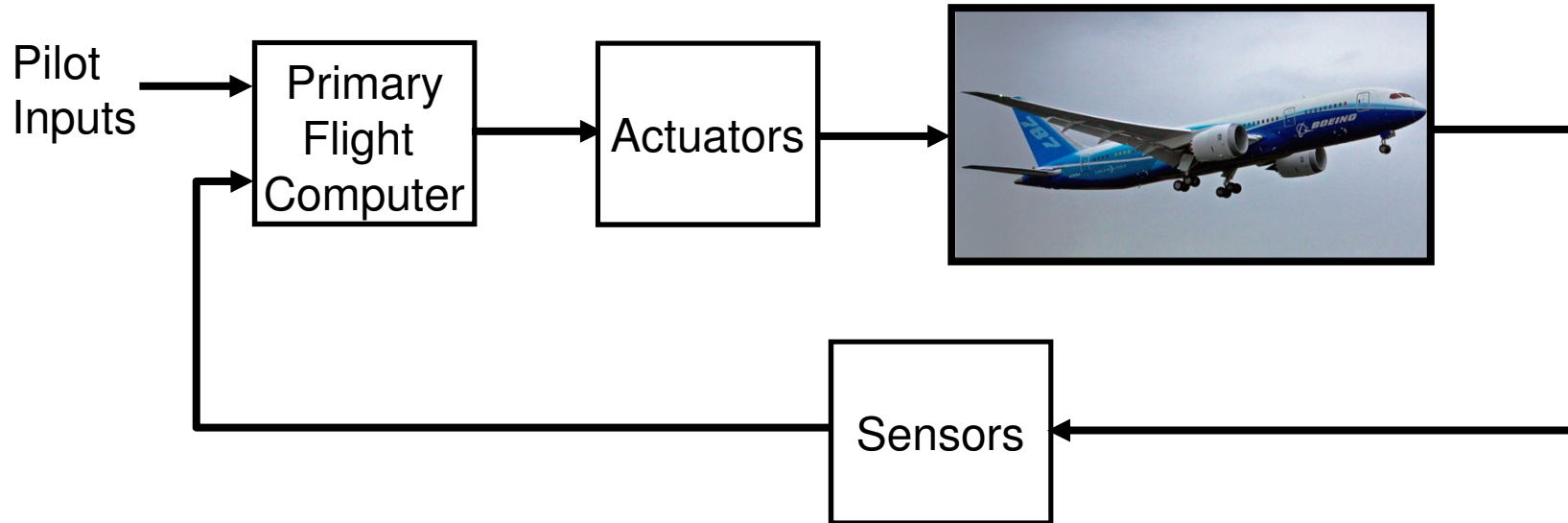
- 301-440 seats
- Length=63.7m, Wingspan=60.9m
- Range < 17370km, Speed< M0.89
- Boeing's 1<sup>st</sup> Fly-by-Wire Aircraft
- Ref: Y.C. Yeh, "Triple-triple redundant 777 primary flight computer," 1996.



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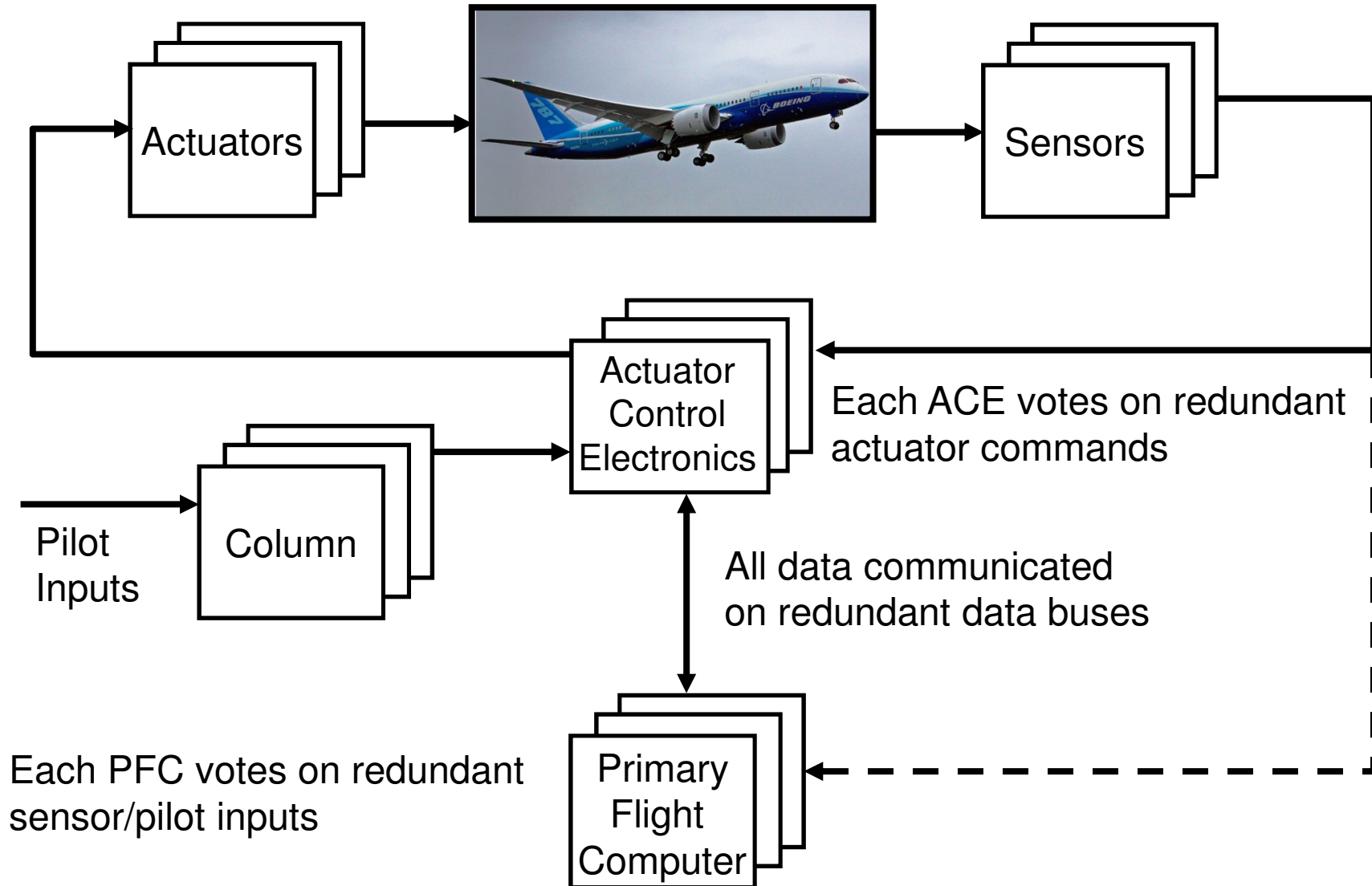
# Classical Feedback Diagram



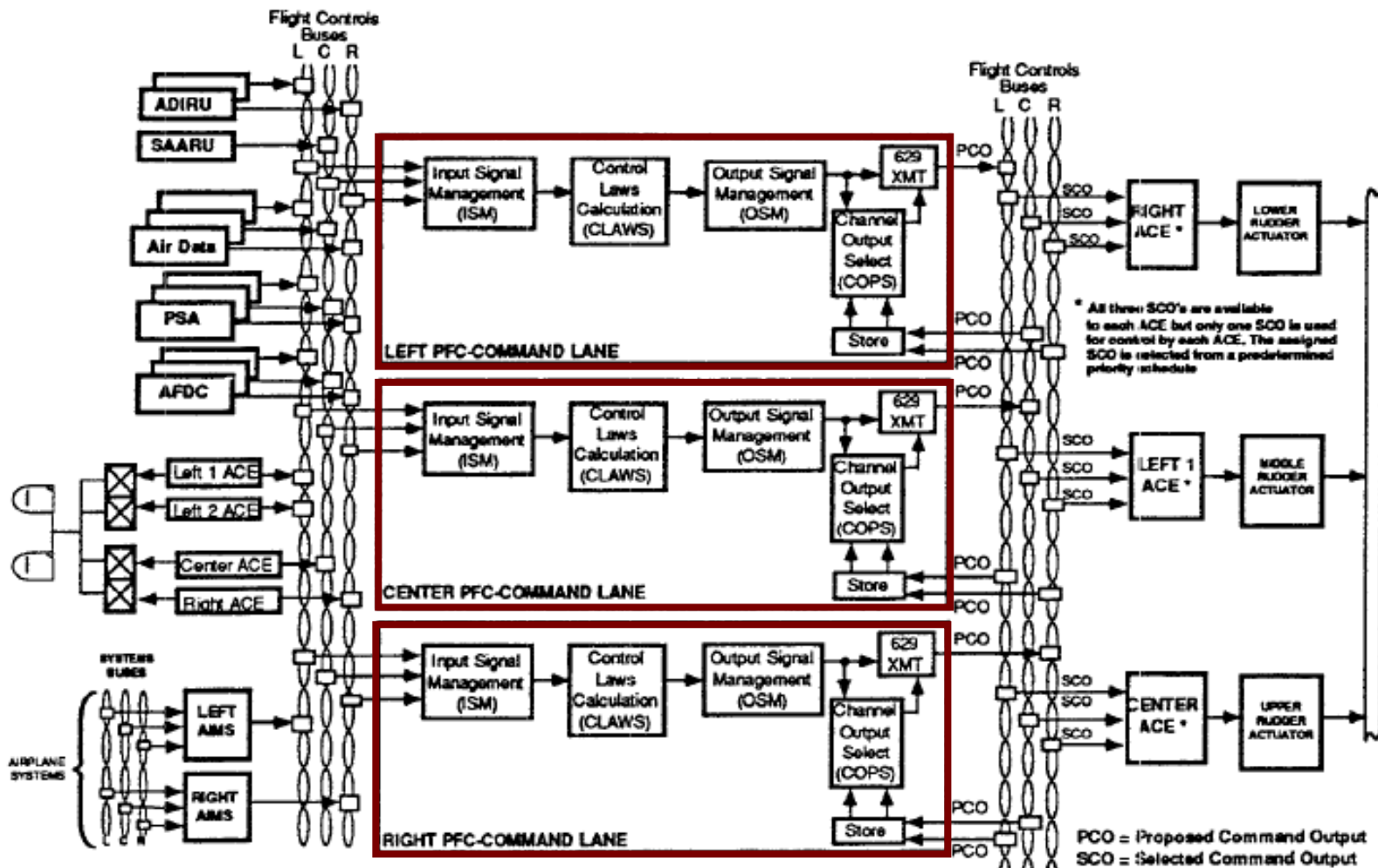
Reliable implementation of this classical feedback loop adds many layers of complexity.



# Triplex Control System Architecture



# 777 Triple-Triple Architecture [Yeh, 96]



Sensors x3  
Databus x3

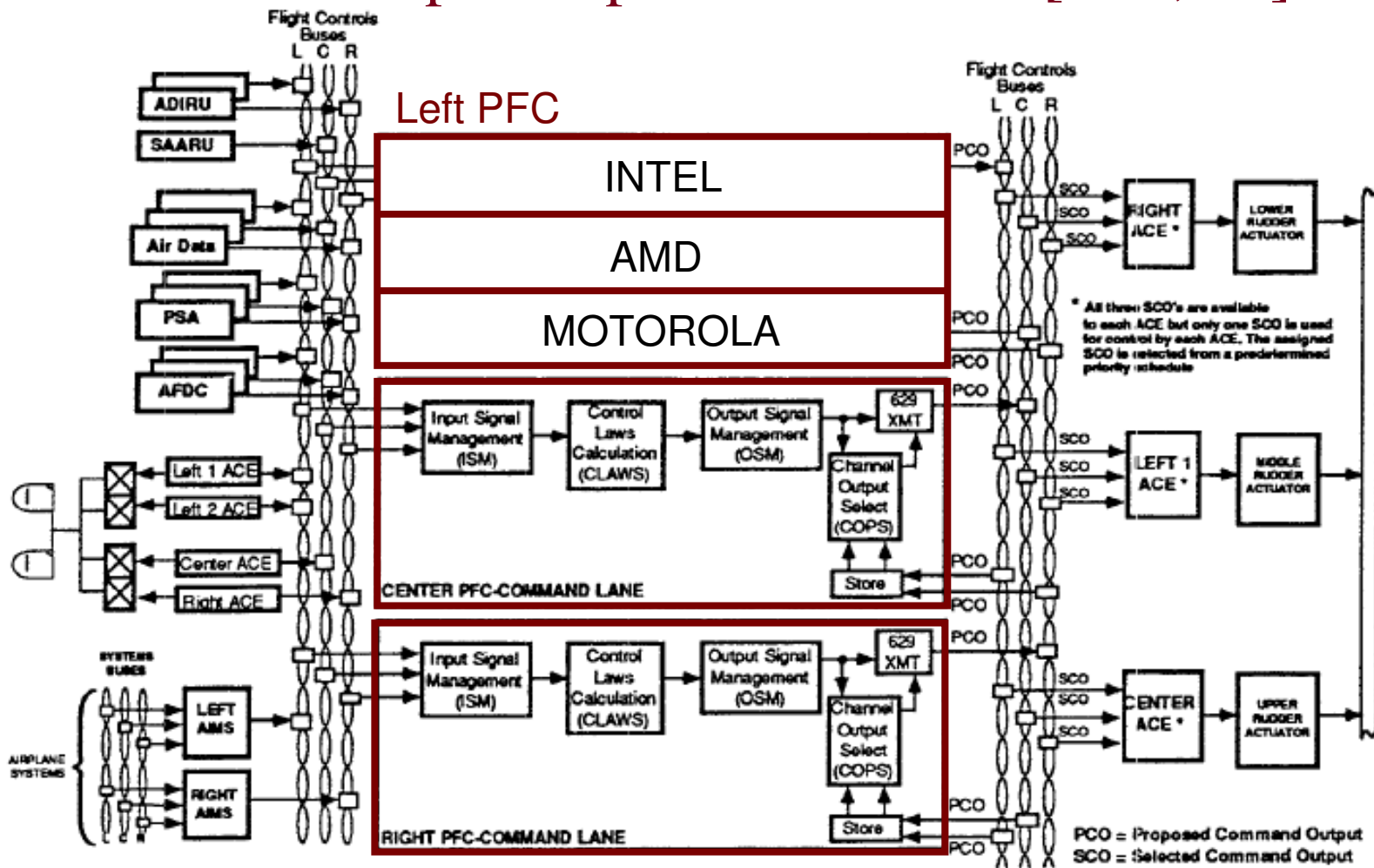
Triple-Triple  
Primary Flight  
Computers

Actuator Electronics  
x4



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# 777 Triple-Triple Architecture [Yeh, 96]



Sensors x3  
Databus x3

Triple-Triple  
Primary Flight  
Computers

Actuator Electronics x4

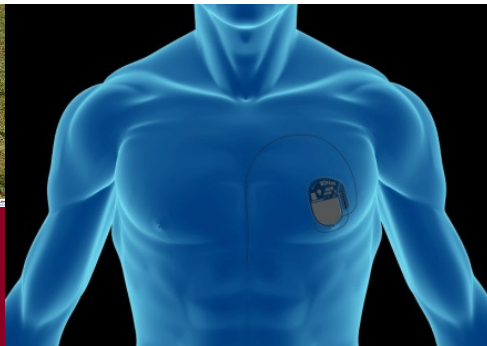
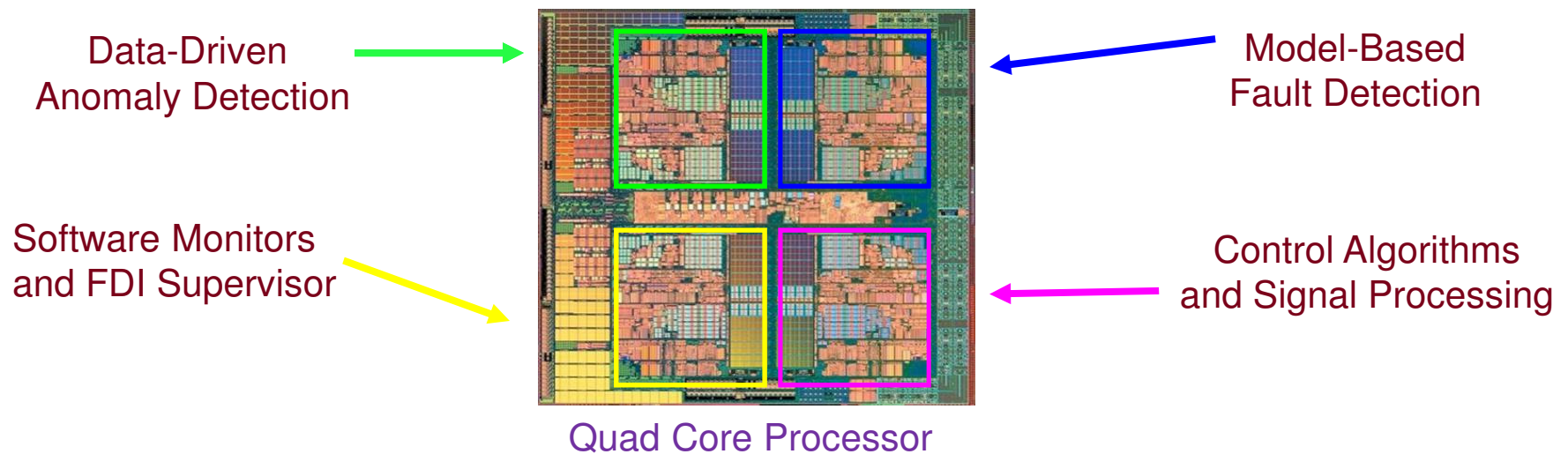




# Embedded Fault Detection for Low-Cost, Safety-Critical Systems (NSF CPS-0931931)

**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



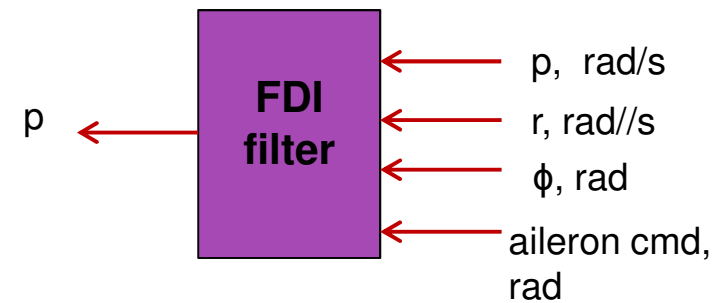
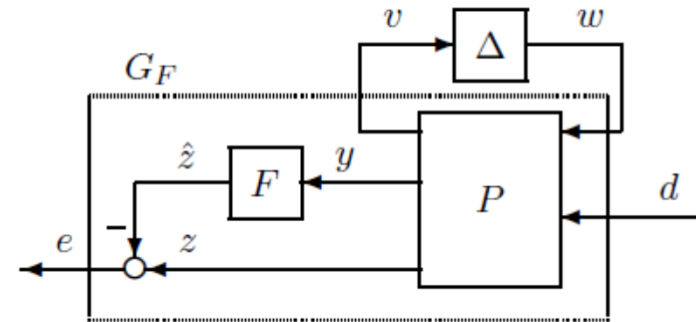
# Fault Detection Approaches

## 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

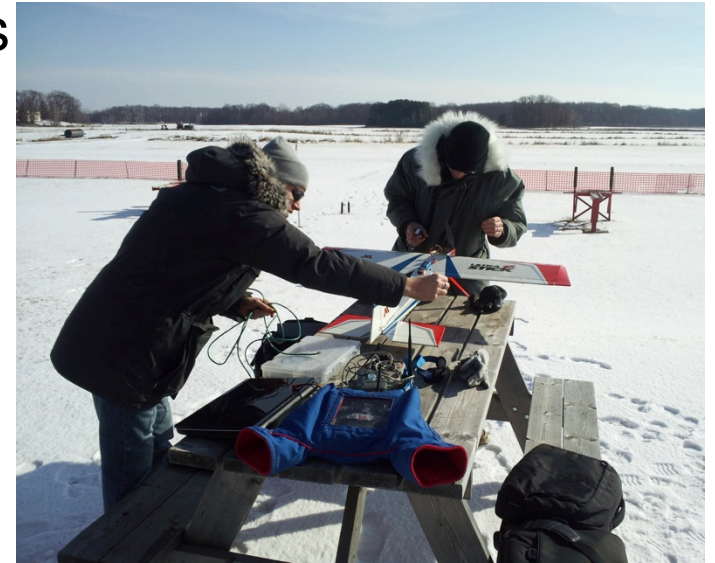


Successful Application to Small UAV



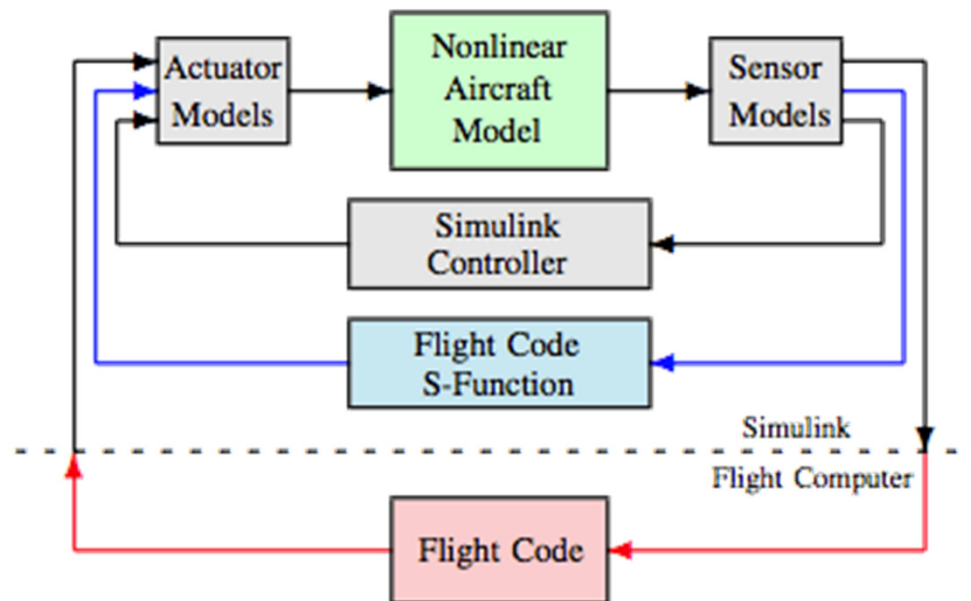
# Freyja Open-Source Software/Hardware Infrastructure

- 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](http://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 autcoded 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

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## UAV Research Group

Aerospace Engineering & Mechanics

AEM Home UMN Home

The UAV Research Group in the Department of Aerospace Engineering and Mechanics (AEM) at the University of Minnesota is focused on development and implementation of a low-cost, open source small Unmanned Aerial Vehicle (UAV) flight research facility. The goal of this facility is to support research activities within the department including control, navigation and guidance algorithms, embedded fault detection methods, and system identification tools.

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- Airframes and RC Components
- Ground Station
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**Avionics and Sensors:** The avionics are centered around a MPC5200B flight computer and IMU/GPS/air data sensor suite.

**Airframes and RC Components:** The Ultra Stick family of aircraft powered by electric motors and 2.4GHz radios offers a simple and hassle free platform.

**Simulation:** MATLAB/Simulink based nonlinear simulation with software and hardware-in-the-loop modes.

**Flight Software:** Embedded software is written in C and executed in real time via the eCos RTOS.

**Ground Station:** A Java-based ground station utilizes graphical displays of information telemetered from the UAV.

**Downloads:** Access our Subversion repository, archived flight data, videos, and current bug reports

**Login Form**

Username

Password

Remember Me

### UAV Benefits Highlighted in News

Current and future benefits of Uninhabited Aerial Vehicles were highlighted in a news article and interview with KARE 11 on March 12, 2013. Full access to the video and news article can be found on their website: [KARE 11: Drone Research Being Conducted at the U of M](#)

Prior UAV research at the UMN has been used by industry partners to check control law validation software, leading to



# 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

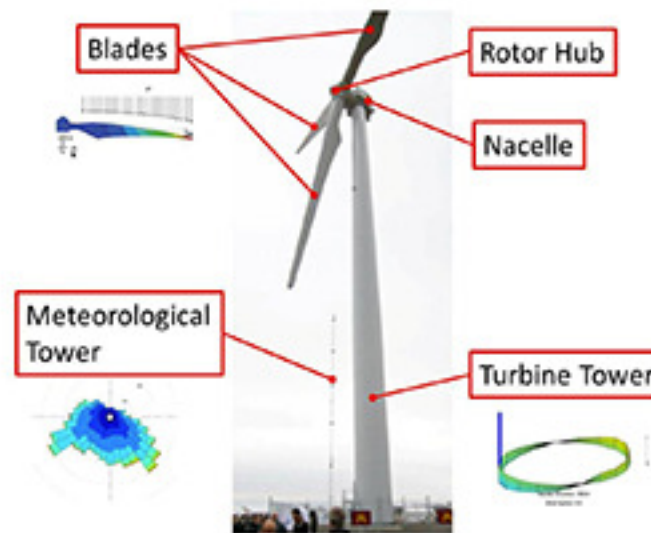
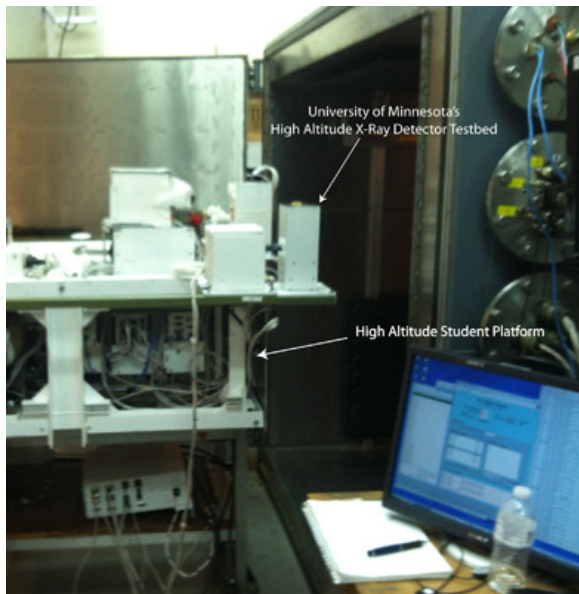
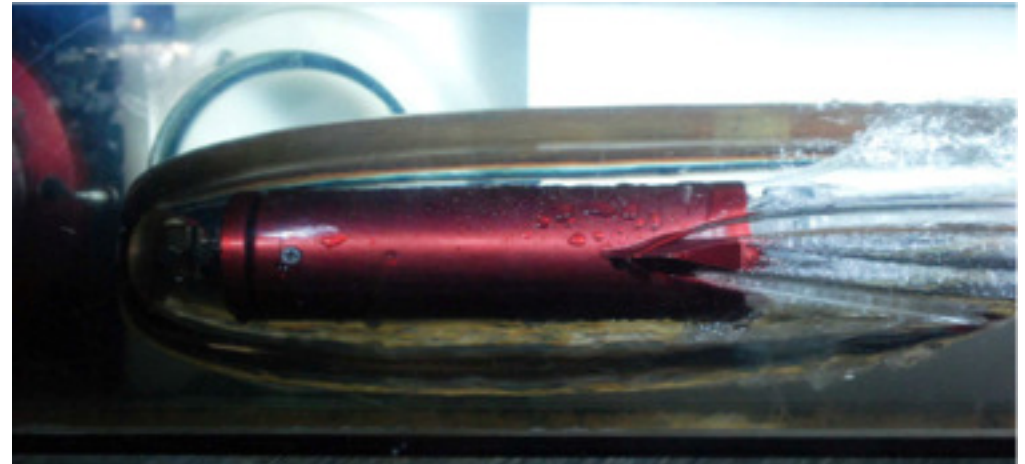


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# Other Applications

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



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# 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

<http://www.uav.aem.umn.edu>

