Multidisciplinary Control Law Design Process Using Mathworks Tools

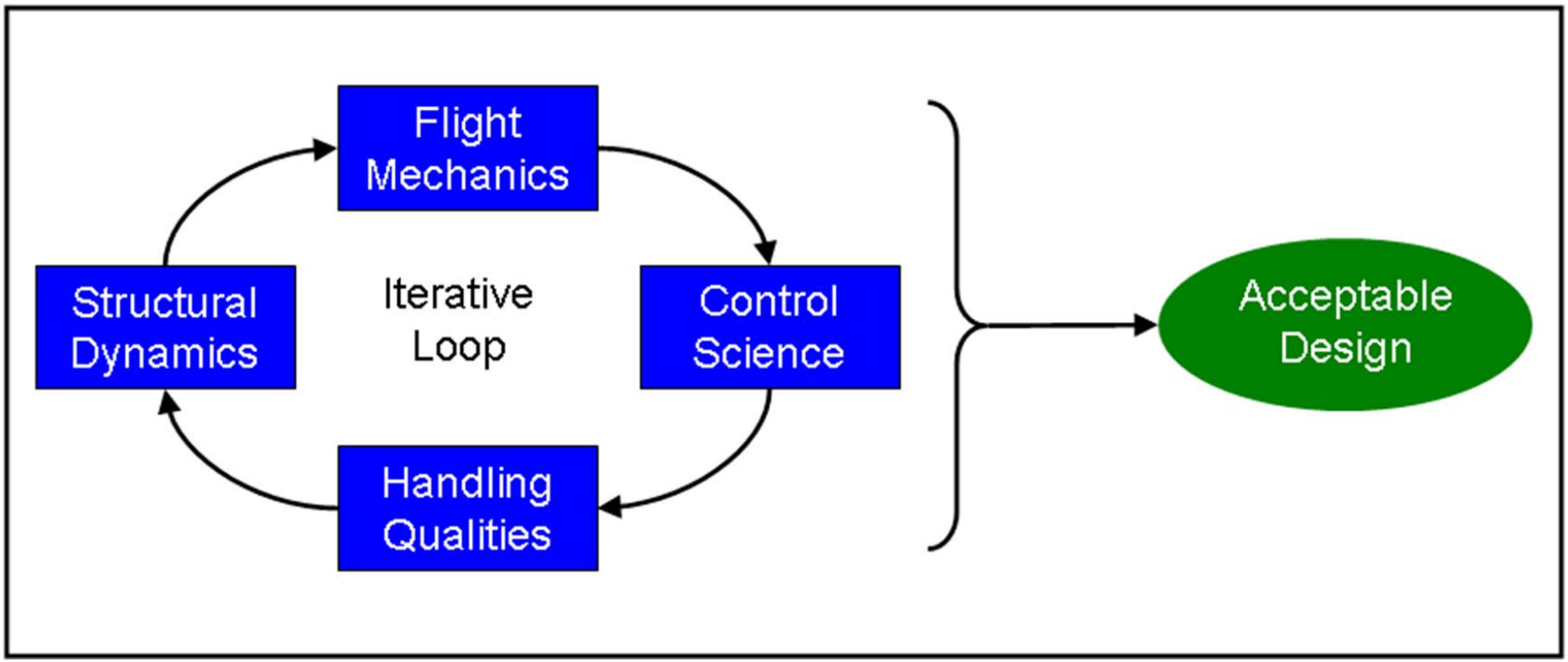
Nomaan Saeed

Gulfstream

A GENERAL DYNAMICS COMPANY

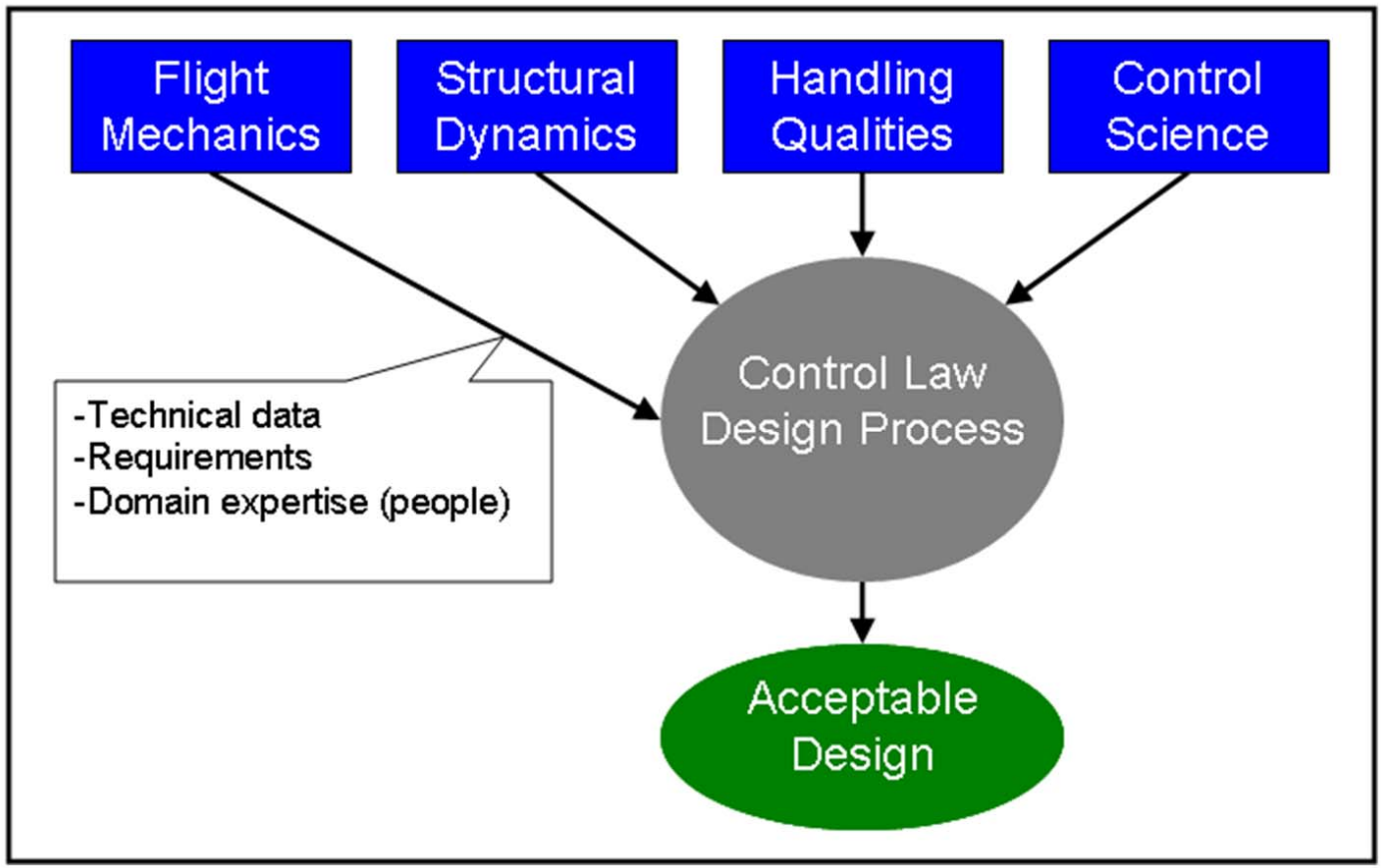
Typical Design Process

Design data are passed from one group to another in an iterative loop



‘Improved’ Design Process

Design elements are captured in a concurrent design environment



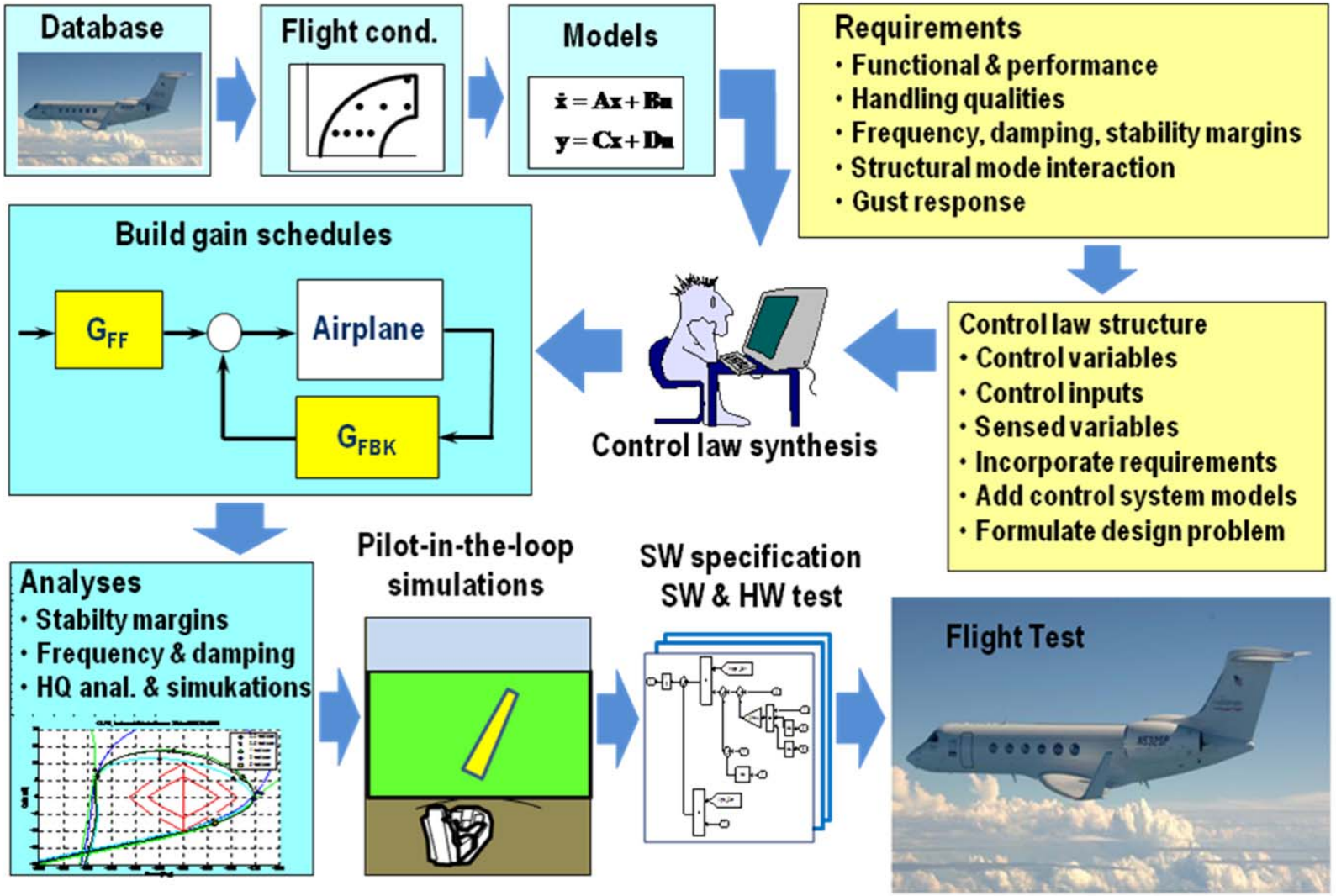
Control Law Design Process

1) Define control requirements
2) Design control law structure
3) Specify operating points within the flight envelope
4) Generate linear models at each operating point
5) Add control system models
6) Conduct control law synthesis at each operation point – the analysis contained in step 8) is now performed concurrently using the gains from the point designs

Control Law Design Process (cont'd)

7) Build gain schedules for the complete flight envelope
8) Based on a gains scheduled control law conduct stability analysis with rigid and flexible body dynamics and nonlinear simulations
9) Conduct pilot-in-the-loop simulations
10) Specify flight SW requirements
11) Perform flight control system SW and HW testing
12) Conduct flight test

Control Law Design Task Flow

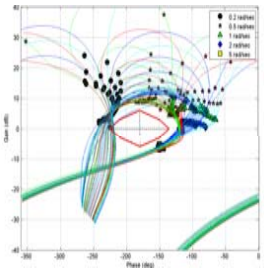


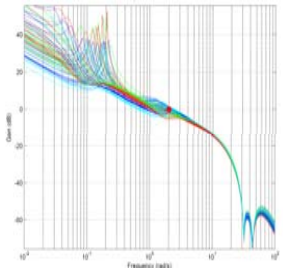
Disciplines Which Affect Control Law Design

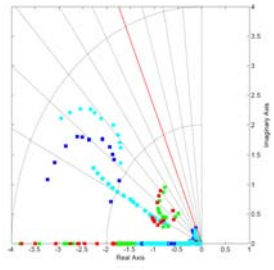
- Control dynamics/control law design
- Aerodynamics - flight mechanics and performance
- Handling qualities
- Flight operations
- Propulsion
- Structural dynamics and loads
- Simulation engineering
- Electrical and electronic systems
- Mechanical systems
- Software engineering
- Safety engineering
- Certification engineering

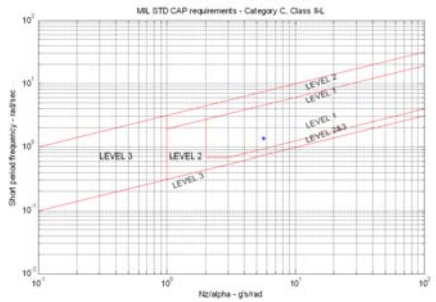
Gulfstream Control Law Design and Analysis Tool

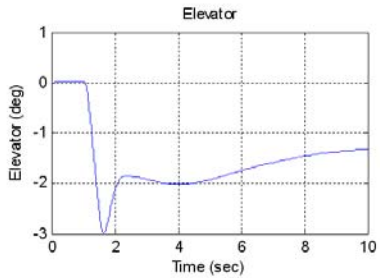
- GUI designed in MATLAB®
- GUI works with Simulink® models
- Design requirements are incorporated in tool
- Control law synthesis
- Parameter variations are easily performed
- Stability/performance analysis
- Handling qualities analysis
- Aeroservoelastic analysis
- Gust/turbulence response analysis

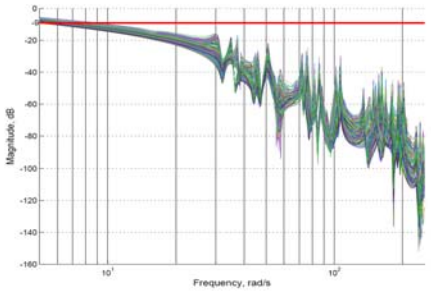




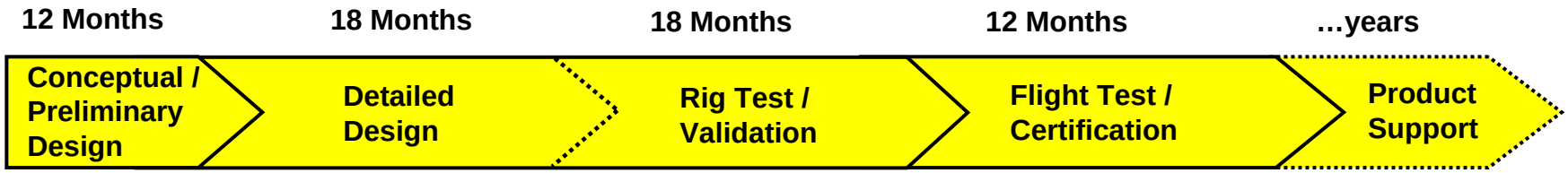








Typical Product Cycle / Use of Simulation



- Trade Studies
- Verification of Key Performance Parameters

- Design Optimization (Weight, Cost, Performance)
- Robustness of Design (Sensitivities, Prediction {Failures}, Reqts. Validation)
- Insight to Design (Risk Avoidance, Integration Evaluation)

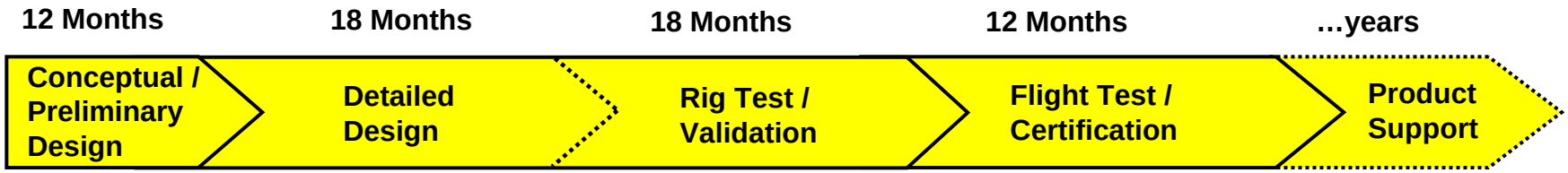
Use of simulation typically reduces as prototype test and real hardware becomes available

- Test Planning Guidance
- Instrumentation Optimization
- Problem Diagnostics – Prescribe Solutions

- Problem Diagnostics
- Match + Envelope Expansion w/o test
- Certification by Analysis

- Problem Diagnostics

Simulation / Key Attributes



- Robustness – meaningful results for wide range of inputs
- Flexibility – able to quickly compile integrated models from readily available component models

- Accuracy – accurate results
- Credibility – high degree of confidence in results
- Adaptability – able to change “tweak” models quickly

- Sensitivity – flexibility to vary inputs
- Efficiency – prototype tests are “preferred” option

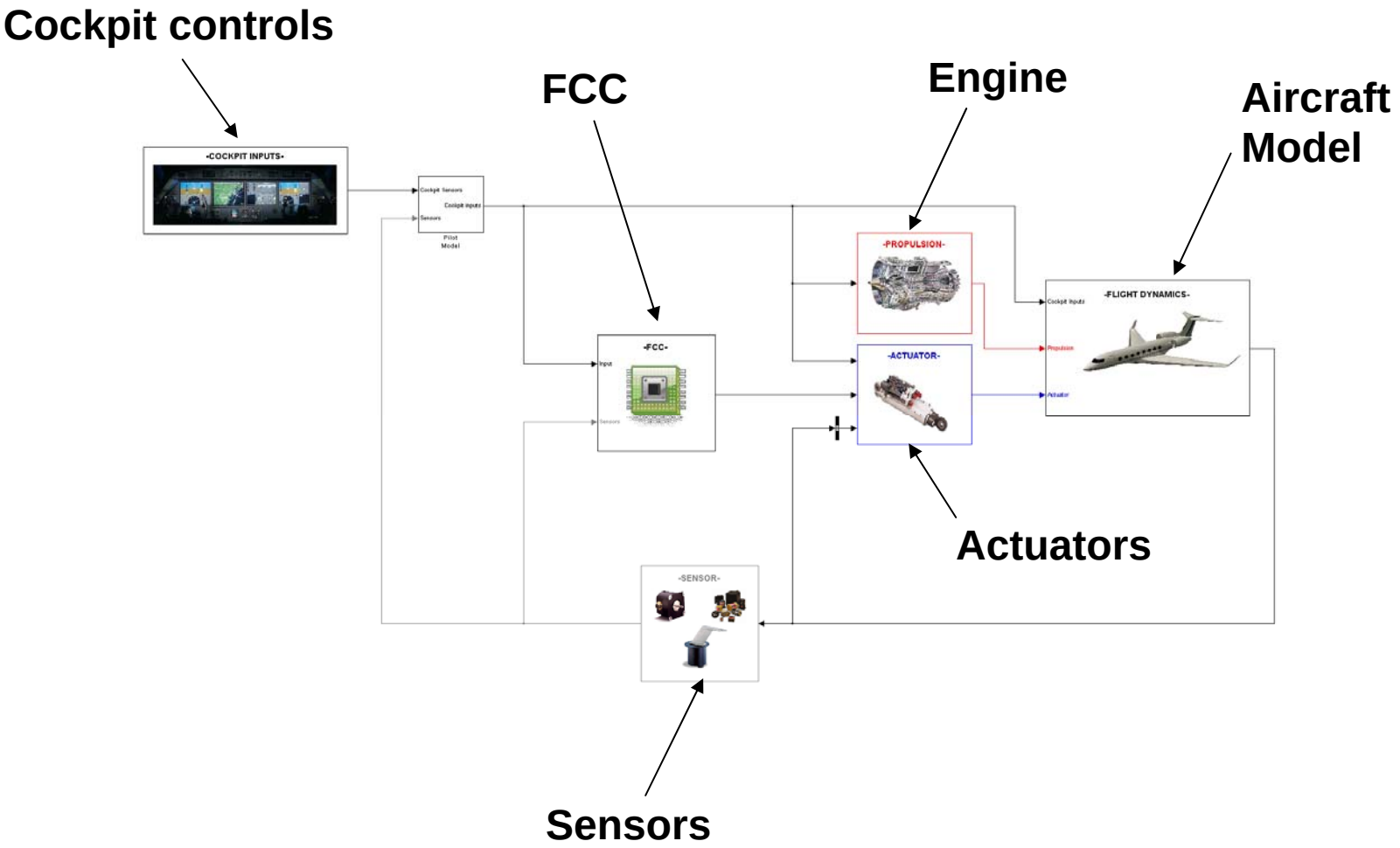
- Validity – ability to prove validation
- Repeatability – formal process / cert

- Timeliness – NOW !

Mathworks Tools Used In Control Law Design & Analysis Process

- Simulink
- Matlab
- Control System Toolbox
- Robust Control Toolbox
- Aerospace Blockset/Toolbox
- Optimization Toolbox
- Real Time Workshop

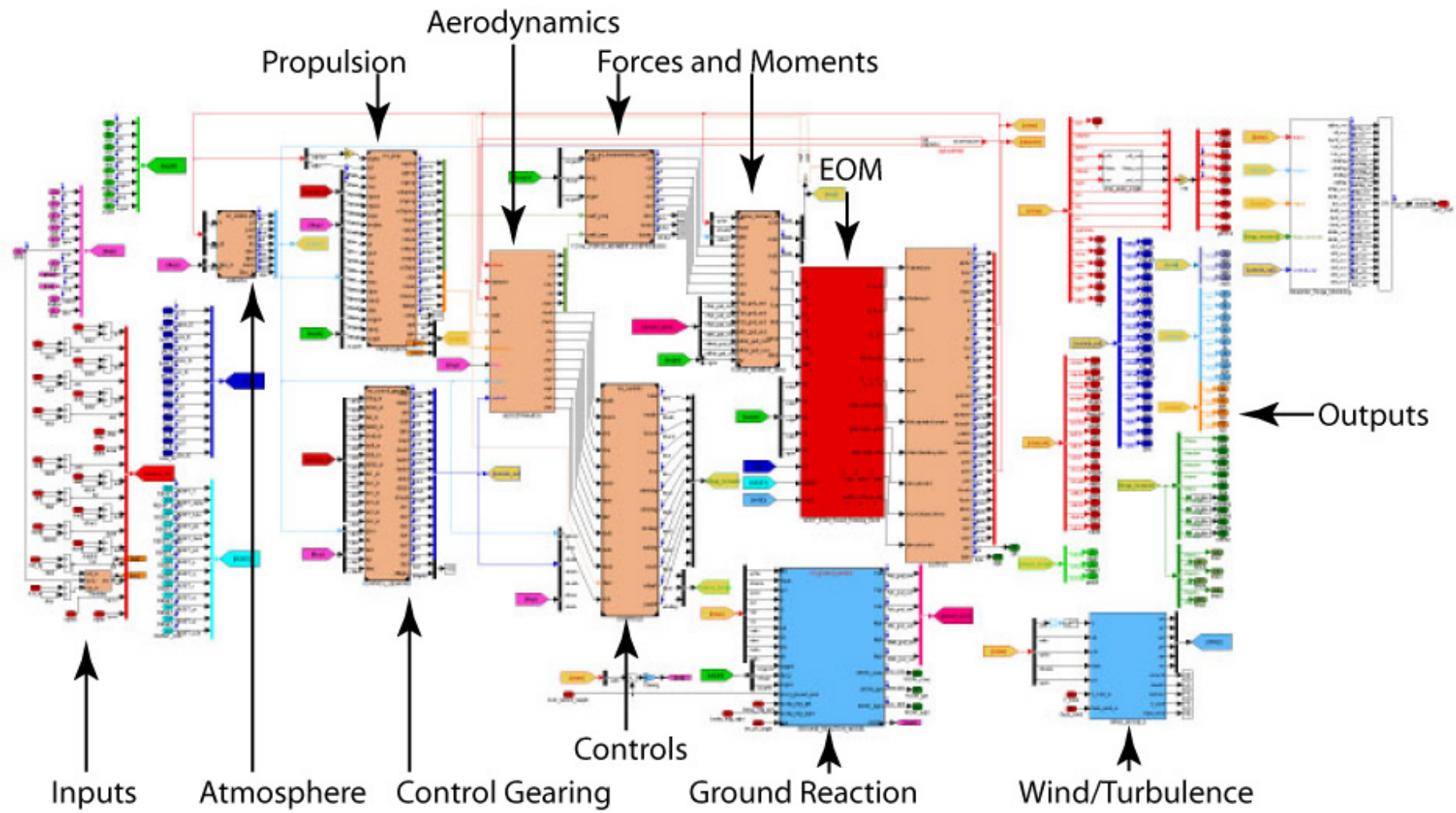
High Fidelity Nonlinear Simulation - Simulink



Simulation building blocks

- Cockpit Controls
  - Primary control inceptors
  - Throtles
  - Flap, gear, speedbrake handles
- Sensor Models
  - Inertial Measurement Unit
  - Angle of Attack/Sideslip Sensor Model
- Flight Control Computer
  - Voting logic
  - Control law
  - Processing delays
- Actuator Models
  - Control surface actuator models
- Engine model
  - System delays
  - Engine spooling
- Aircraft model
  - Aerodynamics build-up
  - Equations of Motion
  - Propulsion model
  - Ground Reaction Model
  - Wind/Turbulence Model

Aircraft Dynamics Model - Simulink



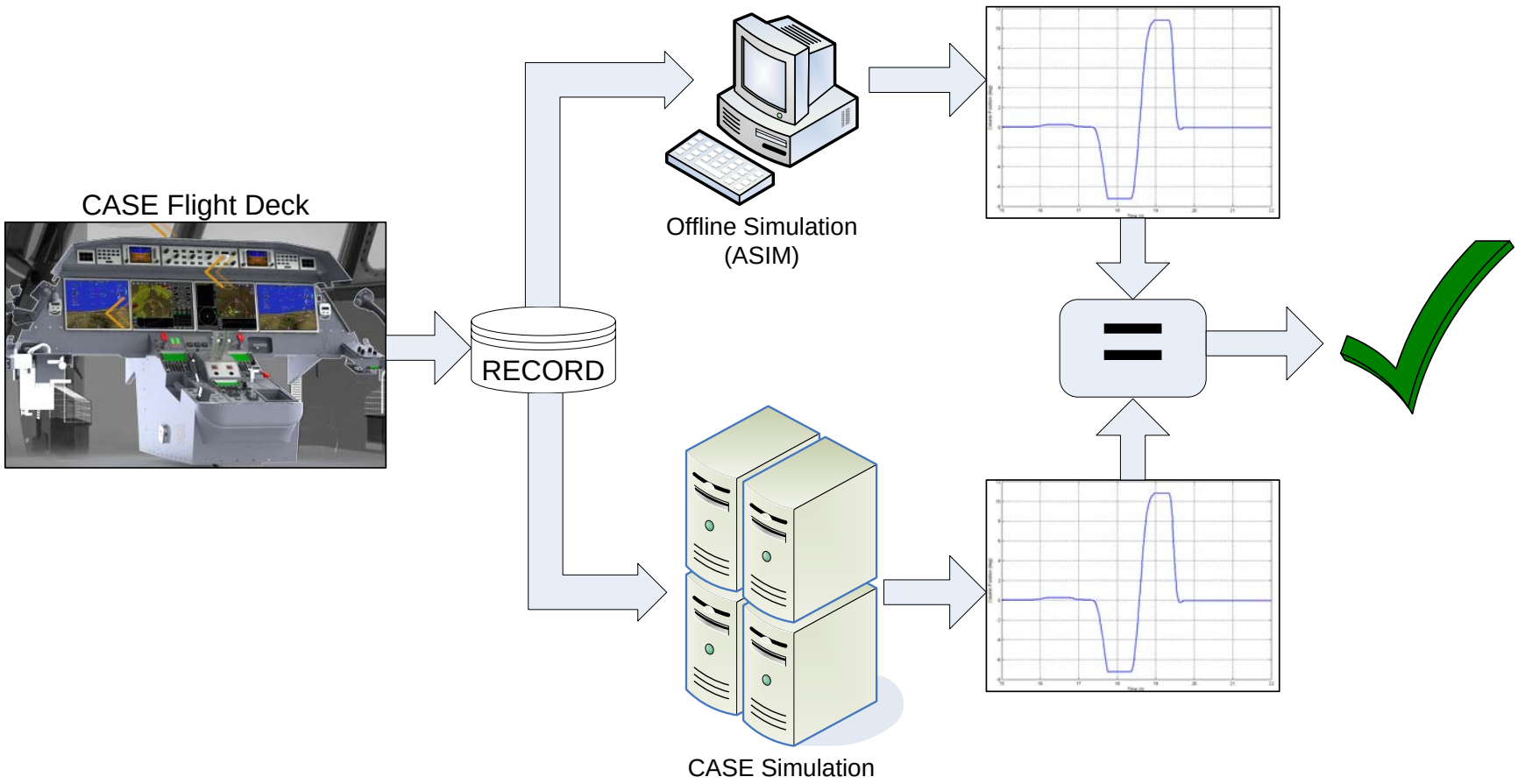
CASE Overview

- CASE – Conceptual Advanced Simulation Laboratory
  - COTS all software lab environment
- Development driven by engineering needs
  - Advanced flight displays and symbology
  - Control law design process
- Utilization
  - Control system design integration
  - Rapid prototyping with the pilot in the loop
  - Handling qualities evaluation
  - Entertainment for the engineering staff

CASE Overview

- **CASE Features**
  - **Cockpit emulation**
    - **Throttles**
    - **Primary control inceptors**
    - **Primary flight displays**
    - **Flap and gear handles**
    - **Speedbrake handle**
  - **Out-the-window visuals**
  - **High fidelity aircraft and systems models**
    - **Reference Modeling**
    - **Real-Time Workshop®**

CASE – Simulation Validation



Conclusion

- **Accelerated development**
- **Realistic flight test preparation environment**
- **Modular simulation**
- **Reconfigurable simulation**

Multidisciplinary control law design process leads to an efficient, reliable, and cost effective solution.