BA609 Tilt Rotor

The MathWorks
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First Civilian Tiltrotor Takes Flight

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BA609 Analytical Integration Leader

BA609 Tilt Rotor

RESTRICTED DISCLOSURE NOTICE

OUTLINE

- What is the BA609 Tiltrotor?
- What can it do?
  - Flight test results
  - Video
- How was it developed?
  - Systems engineering process
  - Extensive use of Model-Based Design & simulation using The MathWorks tools
  - Example: Carefree Maneuvering functions

Bell-Agusta 609: The World's First Civil Tiltrotor

First Flight on 20 March 2003 in Arlington, TX

General Data

Propulsion

Powerplants (2)	
P&W PT6C-67A	1940 shp ea.

Weights

Max Gross Weight	16,800 lb
Empty weight	11,300 lb
Useful Load	5,500 lb

Capacities

Required crew	2
Passenger seating	6-9
Baggage compartment	50 ft^3

Performance

Maximum cruise speed	275 ktas
Maximum range	700 nmi
Operational Ceiling	25,000 ft.

609 Interiors

Standard Utility

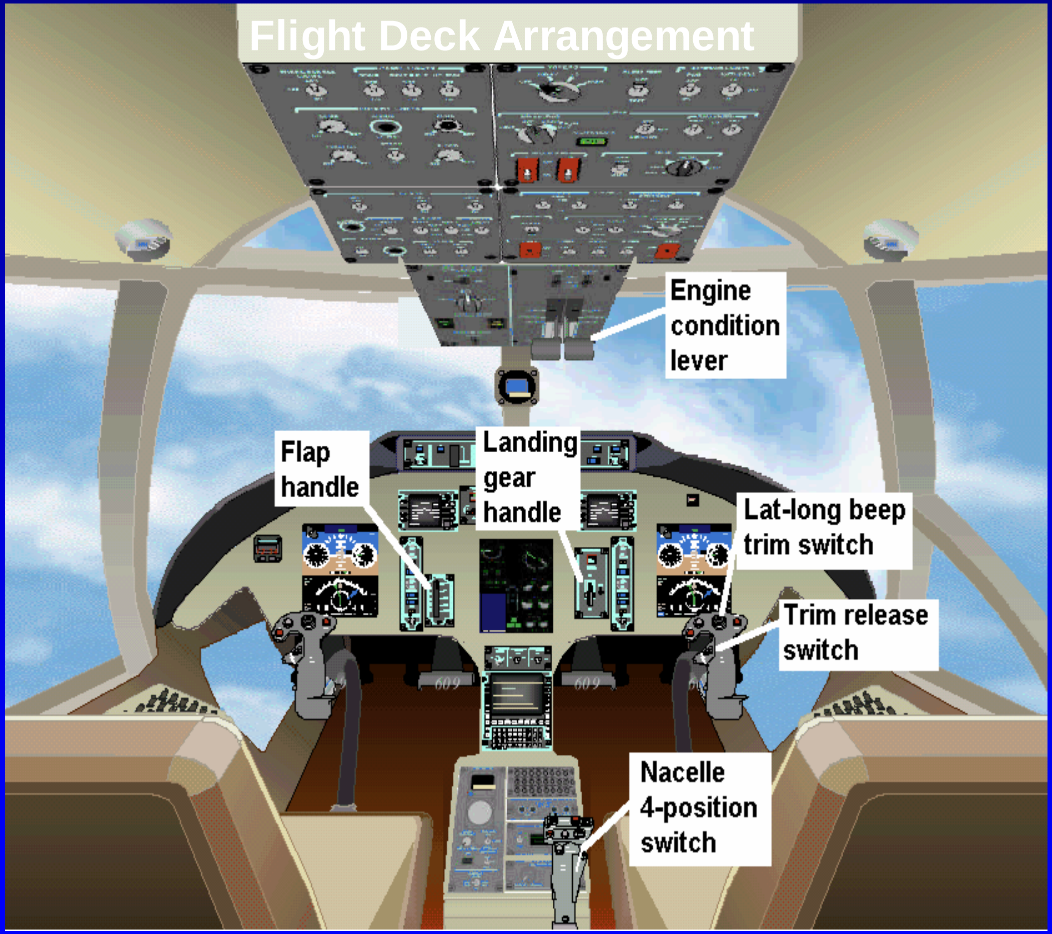
Executive

Standard Club

Air Medical

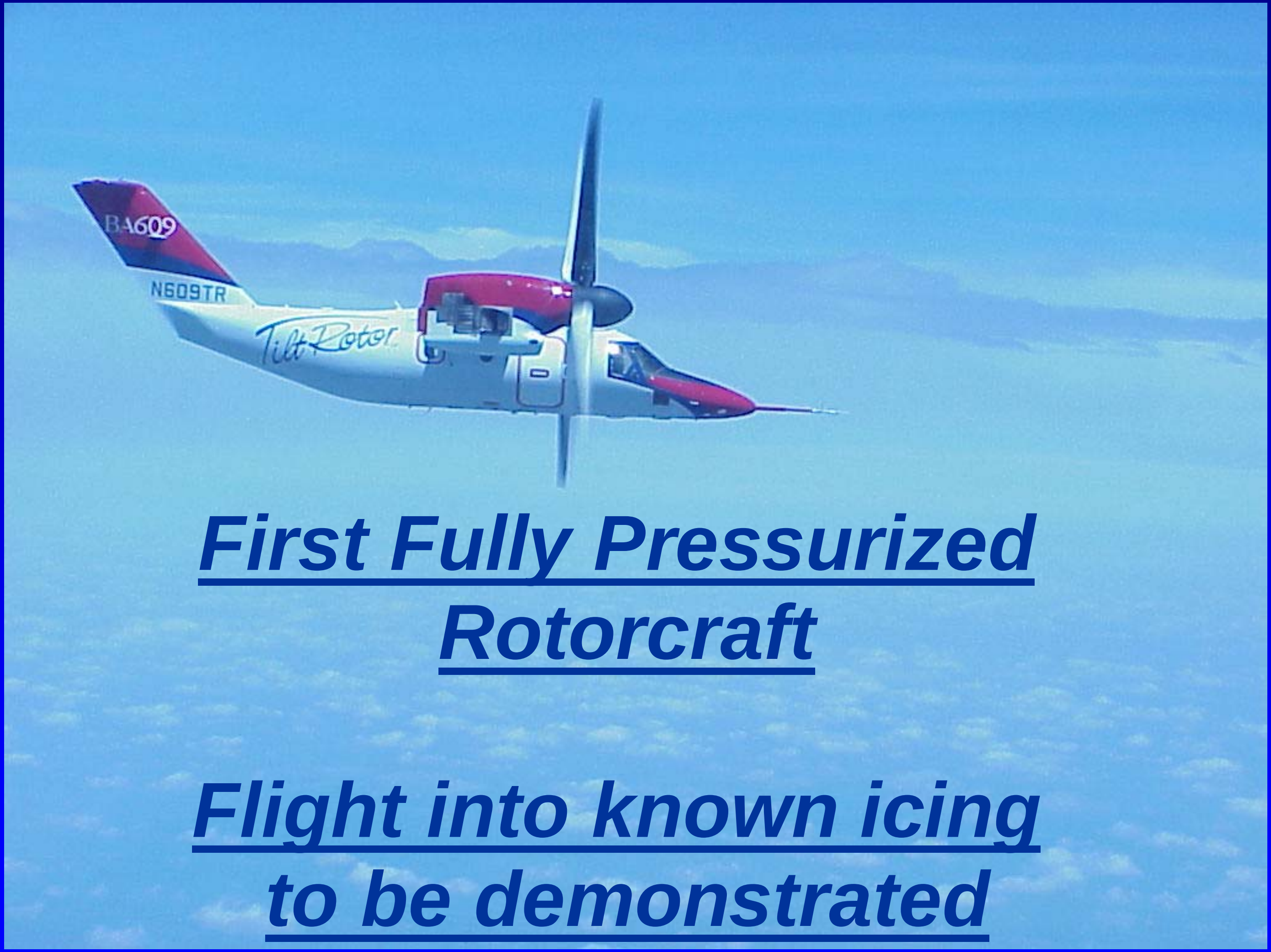
Flight Control System Features

BA609 Front Office



FLIGHT TEST ACCOMPLISHMENTS

25000 Feet


BA609
N609TR
TiltRotor
First Fully Pressurized Rotorcraft
Flight into known icing to be demonstrated

304 Knots True Airspeed

Fastest Civil VTOL Aircraft

350 MPH

Video of Demo Flight at 2006 Heli-Expo

DEVELOPMENT PROCESS

CLEAN SHEET OF PAPER
Development Challenges

- How can first flight risk of a new type of aircraft be reduced?
- How will the complex, highly integrated systems be certified?
- How can the development time and cost be reduced?

BA609 TiltRotor

SYSTEMS ENGINEERING APPROACH

- **Model-Based Design expedites development**
- **Iterative trade study analyses to develop requirements**
- **Structured, iterative design process heavily reliant on simulation**

Stakeholder needs & wants

Requirements Development

Trade Study Analysis

Design Synthesis & Integration

System Test & Evaluation

Certification & Customer Acceptance

Tools & Processes by The MathWorks

- *Modeling*
- *Analysis*
- *Simulation*
- *Test Cases*
- *Drawing Control*

SAFE, EFFECTIVE, & AFFORDABLE

RISK REDUCTION
Extensive Use of Simulation

- Rapid prototyping and simulation/analysis
  - Simulink® models
  - MATLAB® and Real-Time Workshop® to evaluate performance vs. requirements
- Incremental build-up to full hardware in the loop simulation
  - Stress testing of aircraft systems in a realistic, closed-loop manner
  - Piloted validation of emergency procedures and failure mode responses

Full Capability Hardware-in-the-Loop (HIL) Simulation

Electrical Generator Room

Cockpit Rig

Conversion Actuator Rigs

Hydraulic Pump Room

Electrical Sys Test Bench

Flight Control Test Benches

Swash Plate Actuator Rigs

Avionics Test Bench

PROCESS EXAMPLE:

Development of Carefree Maneuvering Functions

CAREFREE MANEUVERING: Motivation

- **40% of helicopter piloting workload derived from monitoring aircraft and flight envelope limits**

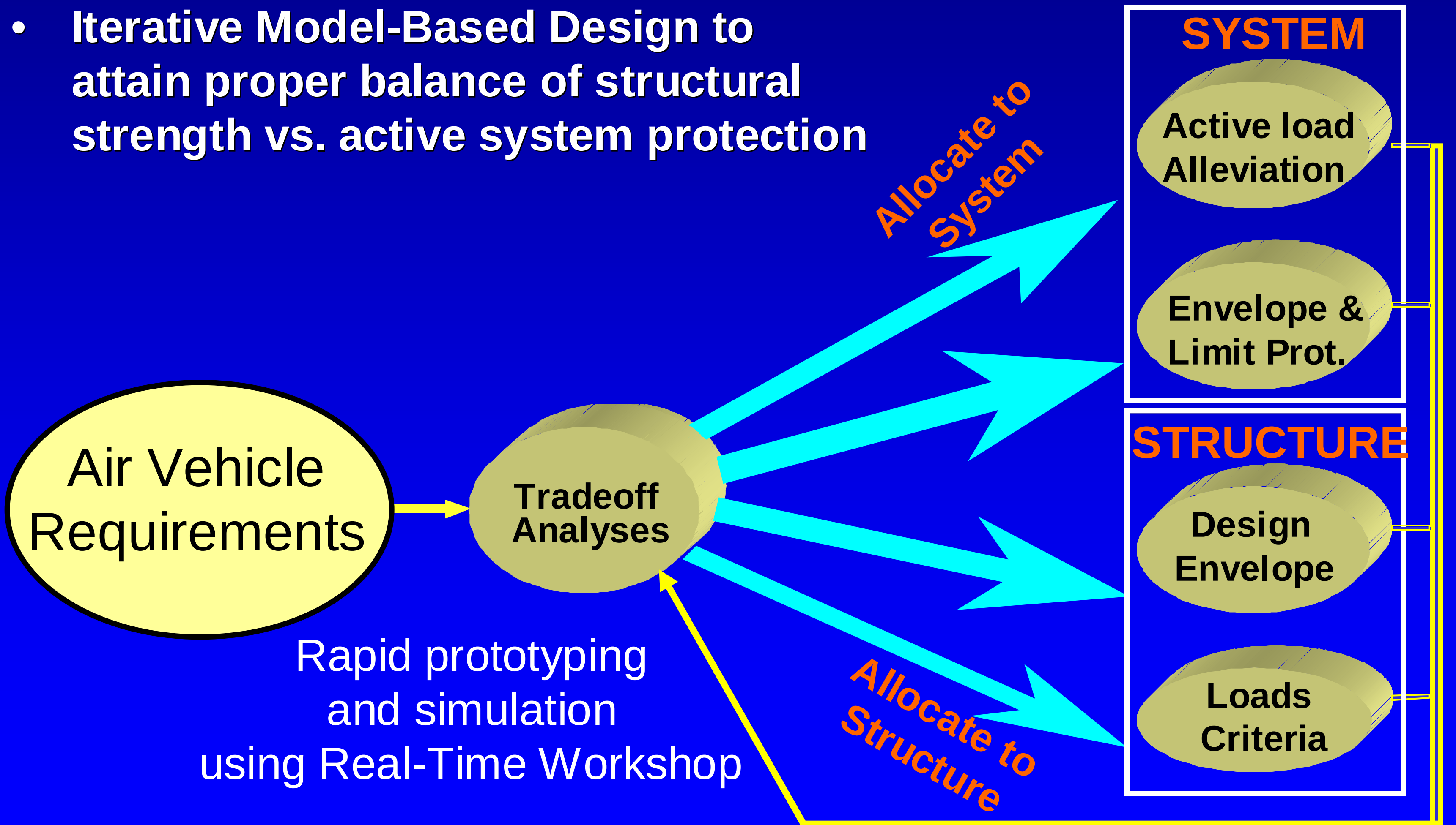
  from G. D. Padfield, Helicopter Flight Dynamics

- **Large # of rotorcraft accidents attributed to abrupt maneuvers, high pilot workload, or violation of limits**

  from Harris, Kasper, and Iseler, "U.S. Civil Rotorcraft Accidents, 1963 to 1997"

Design Requirements defined via Simulation & Analysis

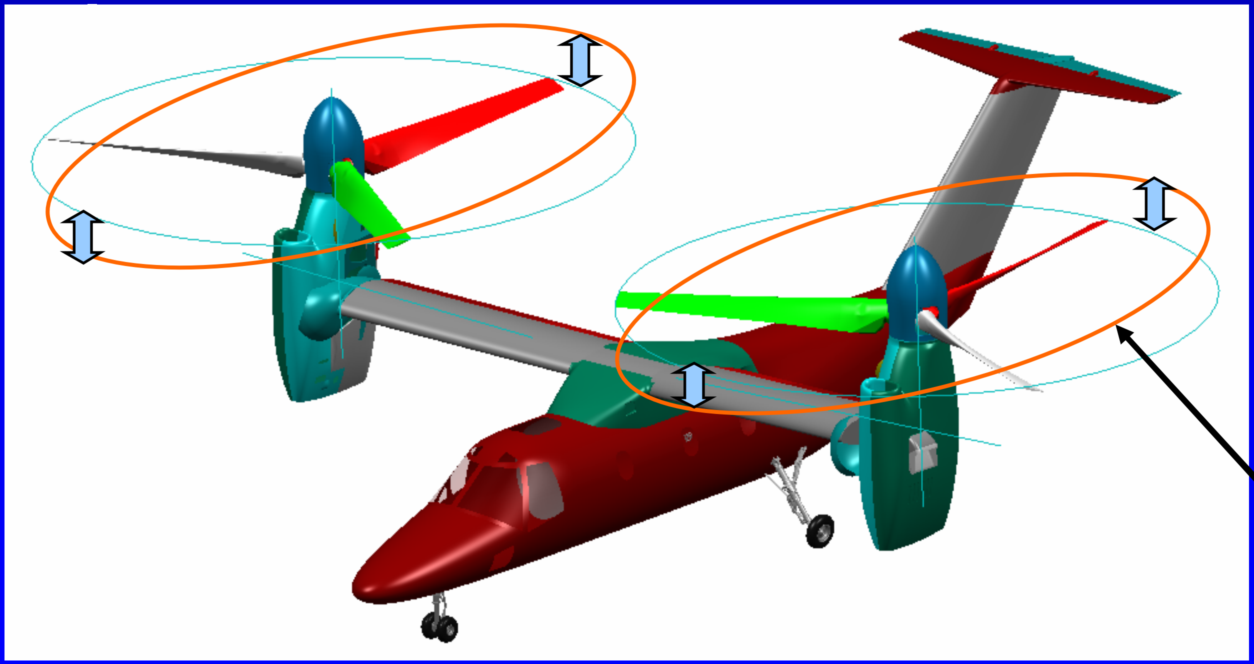
- **Iterative Model-Based Design to attain proper balance of structural strength vs. active system protection**



CFM Example: Flapping Limiting

Description

Rotor flapping is maintained within structural limits through active control of longitudinal cyclic command authority



Max Flapping constrained by structure

Flapping Limiter
Model-Based Design

Requirements Based
Test Cases

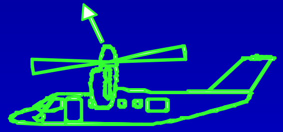
Simulink
Page 1.1

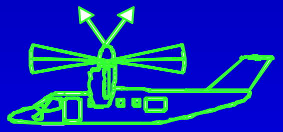
Real-Time
Workshop

High Fidelity
Simulation

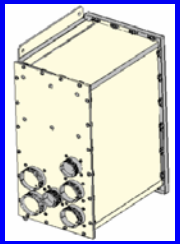
Iterative Model-Based
Design

Cyclic control power
for pitch maneuvers

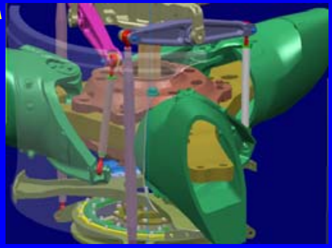




Differential cyclic for
yaw maneuvers

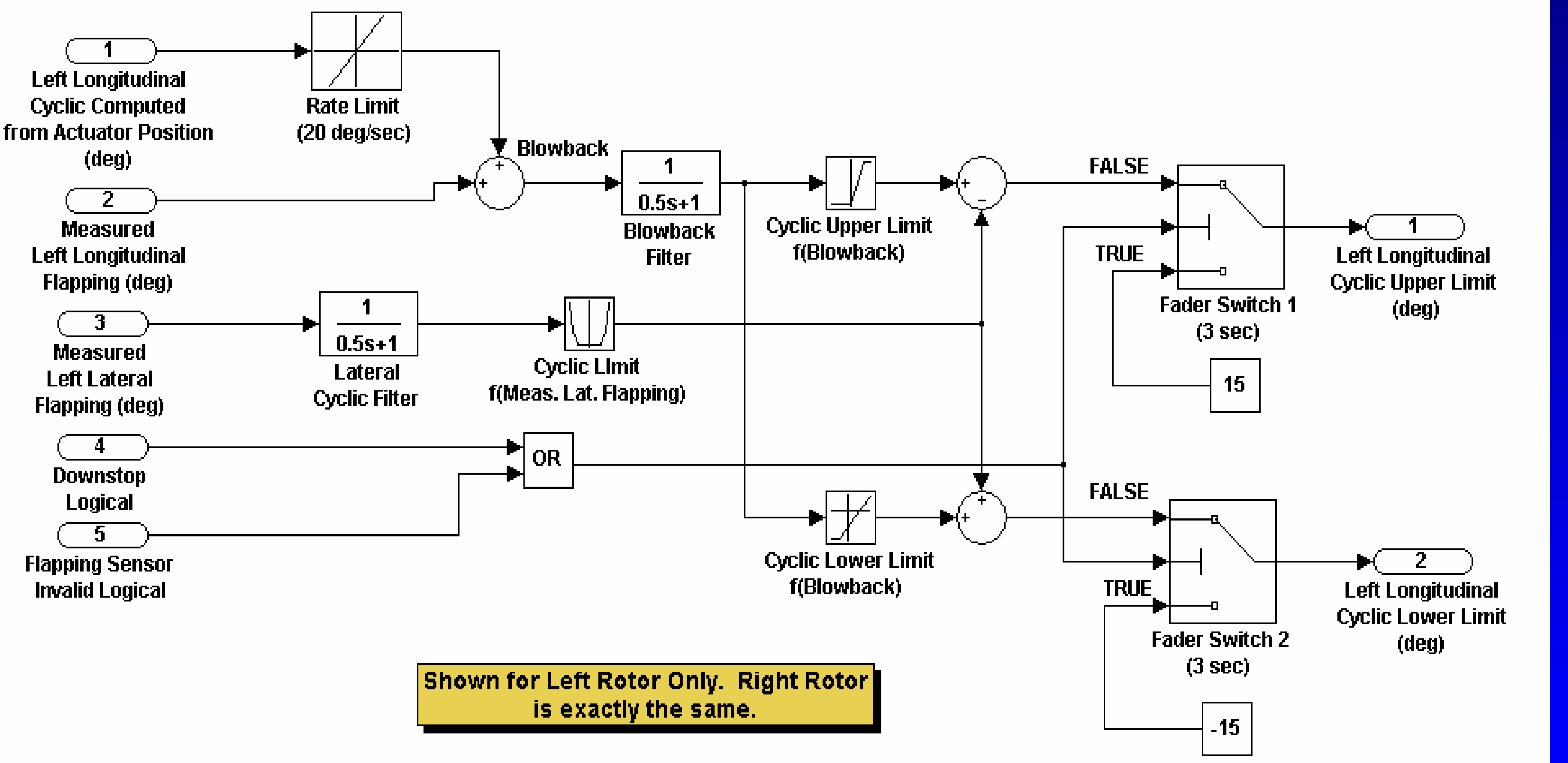


Embedded control law
Limits flapping < 11 º



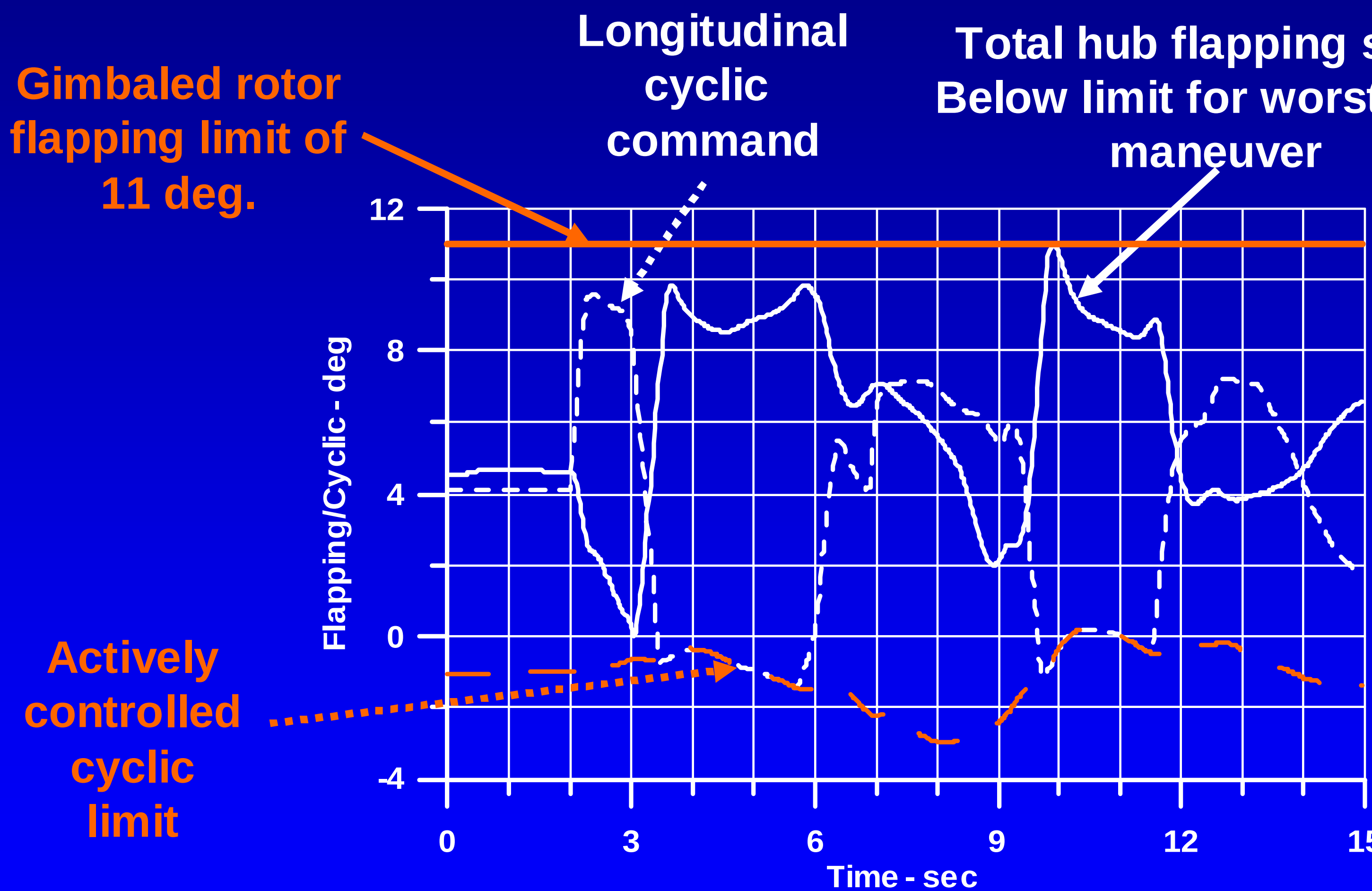
Rotor controls
Allow up to11º
flapping

Flapping Limiting Control Law



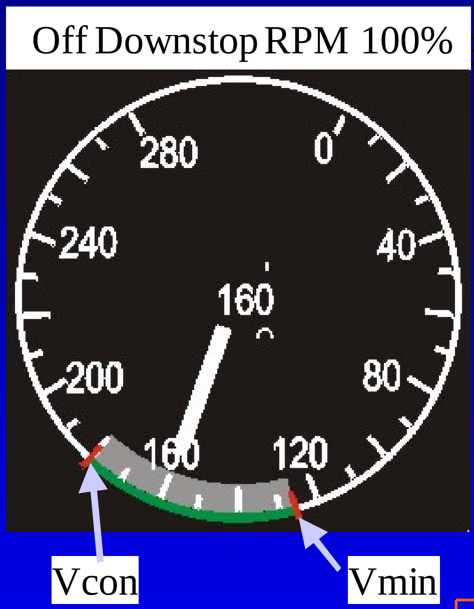
Simulink Model

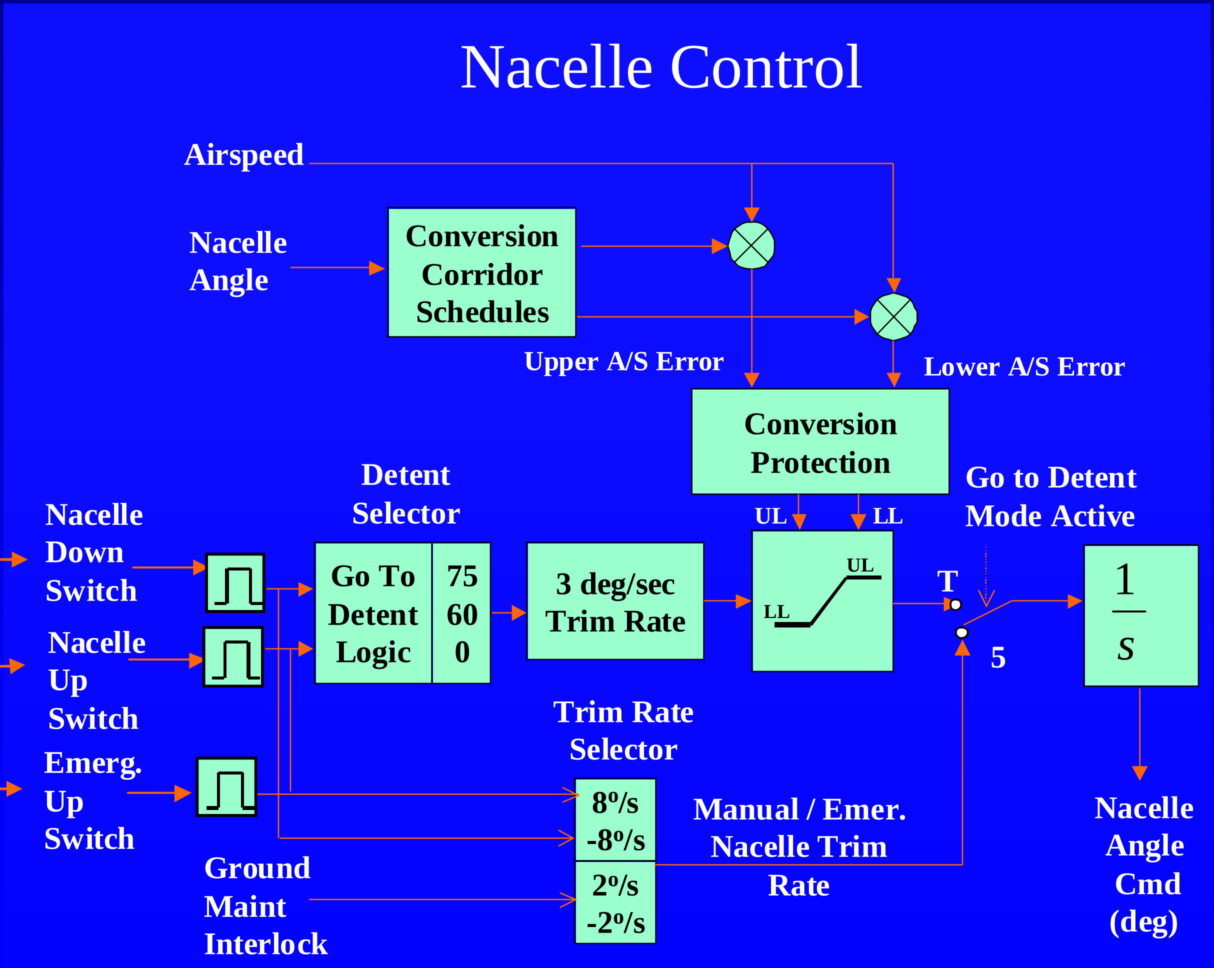
Flapping Limiting Performance



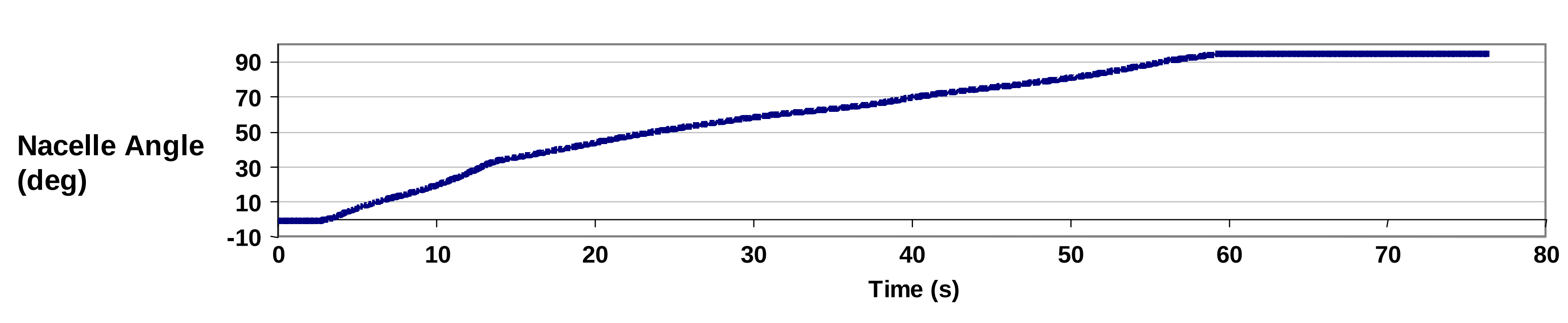
Aggressive roll reversal in conversion mode

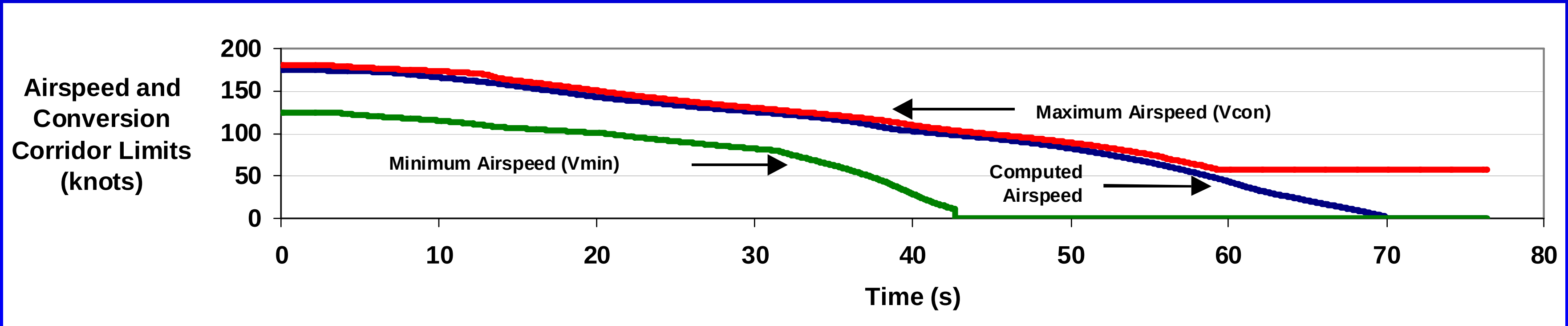
CFM EXAMPLE: Conversion Protection





CONVERSION PROTECTION TIME HISTORY





Aggressive re-conversion from 175 knots (HILS)

CONCLUDING REMARKS

- The BA609--world's first civil tiltrotor--is flying
- Extensive use of iterative, Model-Based Design and simulation has minimized flight test surprises
  - Simulink
  - MATLAB
  - Real-Time Workshop
- Carefree maneuvering functions have been successfully implemented through Model-Based Design

Questions ?