First Civilian Tiltrotor Takes Flight

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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 ft³

**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

- Interconnected Semi-automatic Conversion Control
- Triply Redundant Fly-by-Wire Flight Control System
- Pro Line 21 IFR Glass Cockpit
- Integrated Flight & Engine Controls
- Artificial Force-Feel
- Integrated Carefree Maneuvering Functions

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FLIGHT TEST ACCOMPLISHMENTS
25000 Feet

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?
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

SAFE, EFFECTIVE, & AFFORDABLE

Tools & Processes by The MathWorks

- Modeling
- Analysis
- Simulation
- Test Cases
- Drawing Control
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
- Hydraulic Pump Room
- Flight Control Test Benches
- Cockpit Rig
- Conversion Actuator Rigs
- Electrical Sys Test Bench
- Avionics Test Bench
- Swash Plate Actuator Rigs
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

Air Vehicle Requirements ➔ Tradeoff Analyses ➔ Allocate to System

Rapid prototyping and simulation using Real-Time Workshop

Allocate to Structure

SYSTEM
- Active load Alleviation
- Envelope & Limit Prot.

STRUCTURE
- Design Envelope
- Loads Criteria
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

Real-Time
Workshop

Iterative Model-Based
Design

High Fidelity
Simulation

Embedded control law
Limits flapping < 11°

Cyclic control power
for pitch maneuvers

Differential cyclic for
yaw maneuvers

Rotor controls
Allow up to 11°
flapping

Simulink
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Flapping Limiting Control Law

Simulink Model
Flapping Limiting Performance

Gimbaled rotor flapping limit of 11 deg.

Actively controlled cyclic limit

Longitudinal cyclic command

Total hub flapping stays Below limit for worst-case maneuver

Aggressive roll reversal in conversion mode
CFM EXAMPLE: Conversion Protection

Nacelle Control

- Airspeed
- Nacelle Angle
- Conversion Corridor Schedules
- Upper A/S Error
- Lower A/S Error
- Go to Detent Mode Active

Detent Selector
- Go To Detent Logic
- Trim Rate Selector
- Manual / Emer. Nacelle Trim Rate

Nacelle Down Switch
- Trim Rate
- 3 deg/sec Trim Rate
- 1 sec

Nacelle Up Switch
- Off Downstop RPM 100%

Emerg. Up Switch
- Off

Ground Maint Interlock

Vmin, Vcon

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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?