Predictive Simulation of Helicopter Flight Controls and the V-Cycle

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Overview

- Airbus Helicopters – who are we?

- Model-based multi-level system engineering
  - Early validation, early verification $\rightarrow$ early redesign

- Equipment development
  - a more realistic V-cycle

- Examples
  - Flight control kinematics
  - Hydraulic servo
  - Electro-mechanical actuators

- „Cool“ Tools

- Conclusions
Airbus Helicopters

Who are we?
From Eurocopter to Airbus Helicopters

1992

2000

2014

1992 2000 2014
Airbus Group top management structure (1)

Denis RANQUE  
Chairman des Board of Directors (BoD)

Tom ENDERS  
Chief Executive Officer (CEO)

CHIEF FINANCIAL OFFICER  
Harald WILHELM

CHIEF STRATEGY & MARKETING OFFICER  
Marwan LAHOUD

CHIEF TECHNICAL OFFICER  
Jean J. BOTTI

CEO AIRBUS GROUP INC.  
Allan McARTOR

CHIEF HUMAN RESOURCES OFFICER  
Thierry BARIL

AIRBUS  
Fabrice BRÉGIER (CEO)

AIRBUS HELICOPTERS  
Guillaume FAURY (CEO)

AIRBUS DEFENCE AND SPACE  
Bernhard GERWERT (CEO)

(1) As of 12/31/2014
Airbus Helicopters at a glance

- **22,900** employees
- **6.5 bn €** turnover in 2014
- **3,010** operators
- **29** Customer Centers
- In **152** countries

*A unique global presence*
Airbus Helicopters: a global presence

2,5 billion € in orders in 2014

29 Customer Centers

7.600 employees (incl. Vector Aerospace)

70% of customers
A global fleet

3,010 operators

85% of which own less 5 aircraft

3,217,000 flight hours logged in 2014

in 152 countries
Workforce and activities in the founding countries

La Courneuve: 725 employees
Kassel: 110 employees
Donauwörth: 5,600 employees
Marignane (1): 8,850 employees

Total workforce: 15,285 employees

(1) Airbus Helicopters Headquarters
(2) As of 12/31/2014
Airbus Helicopters priorities

To offer reliable and efficient products and support & services worldwide …

… by working with a very high level of quality and safety …

… by pursuing our innovation roadmap and enhancing our competitiveness to ensure sustainable development and growth
Solid leader in the civil market; strong military market share

Civil & parapublic market > 1,3 t
2014 market: **736 helicopters**

Military market
2014 market: **869 helicopters**
Supporting customers operating the most challenging civil missions

- Emergency Medical Services
- Search and Rescue (SAR)
- Private & business aviation
- Offshore transportation
- Aerial work
- Law enforcement
The civil range

Single

H120 (EC120)

Light twin

AS355

H135 (EC135)

Twin medium

AS365

H155 (EC155)

Medium/Heavy

AS332

H225 (EC225)
The military range

Light helicopter

H125M (AS550)

H135M (EC635)

H145M (EC645)

Helicopter mean weight class

AS565

Helicopter mean weight/heavy class

AS532

H225M (EC725)

Special helicopter

Tiger

NH90
The H160: the first member of Generation H

**NEW CANTED FENESTRON ®**
Increases performance levels, adds to passenger comfort thanks to excellent flight stability, and permits community-friendly sound levels.

**BLUE EDGE® BLADES**
News blades increase performance levels, add to passenger comfort thanks to excellent flight stability, and permit community-friendly sound levels.

**BIPLANE STABILIZER™**
Contributes to agility with improved performance and exceptional handling.

**NEW GENERATION TURBOSHAFT ENGINE**
More powerful than previous generation while reducing fuel consumption and CO₂ emissions.

**FULL COMPOSITE AIRFRAME**
Contributes to the robustness of the aircraft and lower maintenance.

**ELECTRICAL LANDING GEAR**
Designed to allow more payload and helps to simplify aircraft maintenance.
V-Cycle

Development Process & Predictive Simulation
Predictive Simulation

Computational Fluid Dynamics (CFD)

Computational Structural Dynamics (CSD)
→ Finite Elements Metod (FEM)
  • Loads & stress analysis
  • Eigenmodes & vibrations

Rotor aero-mechanics & helicopter performance
Flight law & Automatic Flight Control System (AFCS)

Multi-physics simulation of „systems“
  • Kinematics of flight controls
  • Hydraulic supply & actuation system
  • Thermal heat conduction
  • Electrical power supply system
  • Electro-mechanical actuators

Wake of H135 fuselage: Kinematic Vorticity
V-model of systems engineering process

2 phases can be identified with two different types of development processes:

- **Function** development phase and
- **Item** development phase.
EUROCAE ED-79A / SAE ARP4754A
DEVELOPMENT LIFE CYCLE

1. Function
2. Architecture
3. Design
4. Implementation

Production, test & operation data

Iterative approach

FIGURE 3 - DEVELOPMENT LIFE CYCLE
Model-Based Multi-Level System Engineering

- **System Requirements**
  - Functional Model Development
  - Feasibility
  - Essential Interfaces
  - Architecture
  - Major Interfaces
  - Proto ON Power
  - Proto 1st Flight
  - Serial Design release

- **Sub-System Specification**
  - Behavioural Model Development
  - Early Re-Design
  - Sub-System Verification
  - Late Re-Design
  - Late validation
  - Validation
  - Early verification

- **Component Specification**
  - HW & S/W Development
  - Late Re-Design
  - Early Re-Design
  - Component testing

- **Time**
  - Early validation
  - Late verification
  - Re-Design
  - System Testing
  - Integration

- **Customer Benefit**
  - Size, Cost, Weight, Power, MTBF

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Why Predictive Simulation?

“Front-loading” engineering design process
→ Risk reduction
→ Total cost reduction

Early validation & verification
→ Avoid late & costly re-design

Feasibility & Pre-design
- Requirements
- Safety analysis: failure cases, degraded performance, …
- Supplier proposals

Anticipate update loops for
- Corrective action
- Improvement & re-design

Source: momentum engrg
V-model of systems engineering process

Iterative approach: function – architecture – design
→ Update loops

Predictive simulation to avoid „surprises“ late during test & integration

Equipment Development - a more realistic V-cycle
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„Fuzzy“ front end

Cost saving & value achieved

Value gained

Value lost

Innovation process

Cost to implement change

Information w/o simulation

Information with simulation

Concept & Feasibility

Pre-Design

Detailed Design

Production

Serial ramp-up

Innovation process
Modeling of Flight Controls & Actuators

Examples
Modeling of Flight Controls & Actuators

Why simulation?
• Predictive simulation of supplier equipment during feasibility & pre-design
  → consolidate specification w/o info from suppliers
• Predictive simulation before equipment h/w testing & first flight of h/c prototype
  → risk reduction

Why time-accurate simulation?
• Transient performance
• Nonlinearities: saturation, backlash, friction, ...
• Failure cases
• Systems integration
• Human-machine interaction

Examples
• Flight control kinematics: pilot force feel
• Hydraulic servo actuator: phase & gain response
• Electro-mechanical actuator: braking travel in case of failure
• Electro-mechanical actuator: oscillation failure
Flight control kinematics: pilot force feel

Lateral Cyclic
- Centering spring
- Friction of kinematics (flexballs, …)

Yaw (pedals)
- Friction characteristics (trim)

Measurement / Simulation
- Conservative friction estimates
- Tolerances of trim actuator breakout forces
- Secondary end stops not modeled
- Curves spring gradients = nonlinear kinematics
Hydraulic servo actuator: phase & gain response

Hydraulic Main Rotor Actuator of H145 (EC145)
• Different actuators for collective & longitudinal axes
• Proprietary hydraulics library (Modelon)

→ very good agreement between simulation and qualification measurement by supplier
Flight Control Kinematics

Pilot stick movement prescribed for hydraulic servos
Mixing of longitudinal, lateral and collective axis → swashplate in fixed frame
Pitch links and blades in rotating frame

![Diagram of helicopter flight control kinematics](image)
Electro-mechanical actuator: braking travel (failure case)

Trapezoidal (ACME) screw → high friction and self-locking

In case of any detected failure → EMA is switched off → braking travel

Source: EME
Electro-mechanical actuator: oscillatory failure

Oscillatory failure of flight control EMA
→ prediction of oscillation amplitude as a function of frequency
   based on physical performance limitations of motor, gear & inertia
Electro-mechanical actuator : thermal design
„Cool“ Tools

„Linear Systems“ Modelica library: control design
• White noise
• Resolution of DA/AD converters, e.g. 10bit or 12bit
• Time-discrete controllers, e.g. 40Hz autopilot
→ Realistic constraints for design

„Planar mechanics“ Modelica library
• Nonlinear 2D-multi-body kinematics w/o need of excessive computational resources

„Aerospace EMA“ Modelica library
• EU research project „Actuation 2015“ lead by Airbus

Modelica modeling language is non-proprietary
Modelica Standard Library is open source

Simulation tools:
Dymola (Dassault), SimulationX (ITI), MapleSim (MapleSoft), Wolfram SystemModeler,
Openmodelica.org
Conclusions

Predictive Simulation of Helicopter Flight Controls
• Support feasibility studies, concept/pre-/detailed design
• Complement „real“ testing and reduce cost
• Reduce risk
• Accelerate development cycles

V-Cycle needs to anticipate update loops for
• Improvement & re-design
• Corrective action

Modelica
• Modeling language is non-proprietary
• Modelica Standard Library is open source
• Choice of multiple competing simulation environments
Thank you for your attention

Questions?

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