Predictive Simulation of Helicopter Flight Controls and the V-Cycle

Dr. Boris Grohmann
Expert Mechatronics & Actuation
Flight Controls & Hydraulics - ETMH
Airbus Helicopters Deutschland GmbH, Donauwörth
Boris.Grohmann@Airbus.com

Overview

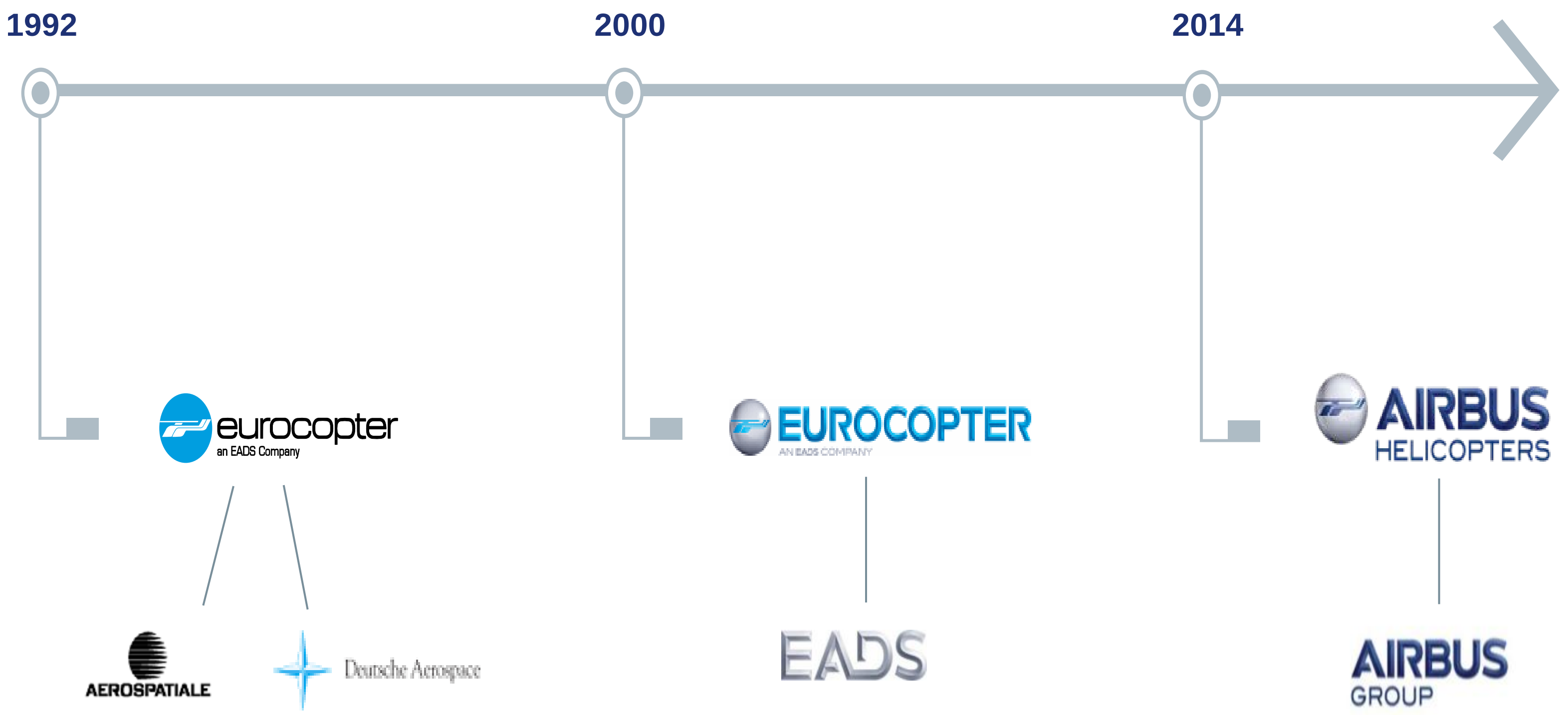
- Airbus Helicopters – who are we ?
- Model-based multi-level system engineering
  - Early validation, early verification → early redesign
- Equipment development
  - a more realistic V-cycle
- Examples
  – Flight control kinematics
  – Hydraulic servo
  – Electro-mechanical actuators
- „Cool“ Tools
- Conclusions

AIRBUS HELICOPTERS

Airbus Helicopters

Who are we ?

From Eurocopter to Airbus Helicopters

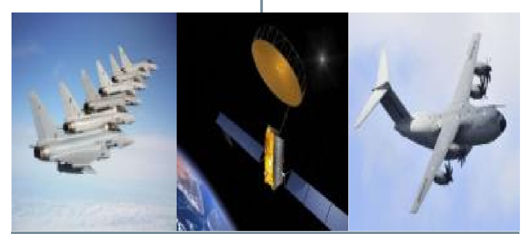


Airbus Group top management structure (1)

Denis RANQUE — *Chairman des Board of Directors (BoD)*

Tom ENDERS — *Chief Executive Officer (CEO)*

CHIEF FINANCIAL OFFICER	CHIEF STRATEGY & MARKETING OFFICER	CHIEF TECHNICAL OFFICER	CEO AIRBUS GROUP INC.	CHIEF HUMAN RESSOURCES OFFICER
Harald WILHELM	Marwan LAHOUD	Jean J. BOTTI	Allan McARTOR	Thierry BARIL

		
AIRBUS	*AIRBUS HELICOPTERS*	*AIRBUS DEFENCE AND SPACE*
Fabrice BRÉGIER *(CEO)*	Guillaume FAURY *(CEO)*	Bernhard GERWERT *(CEO)*

(1) As of 12/31/2014

Airbus Helicopters at a glance

22.900 employees

6.5 bn € turnover in 2014

to serve about 3.010 operators

29 Customer Centers

in 152 countries

A unique global presence

AIRBUS HELICOPTERS

Airbus Helicopters: a global presence

2,5 billion €
in orders in 2014

70 %
of customers

29 Customer Centers

7.600 employees
(incl. Vector Aerospace)

A global fleet

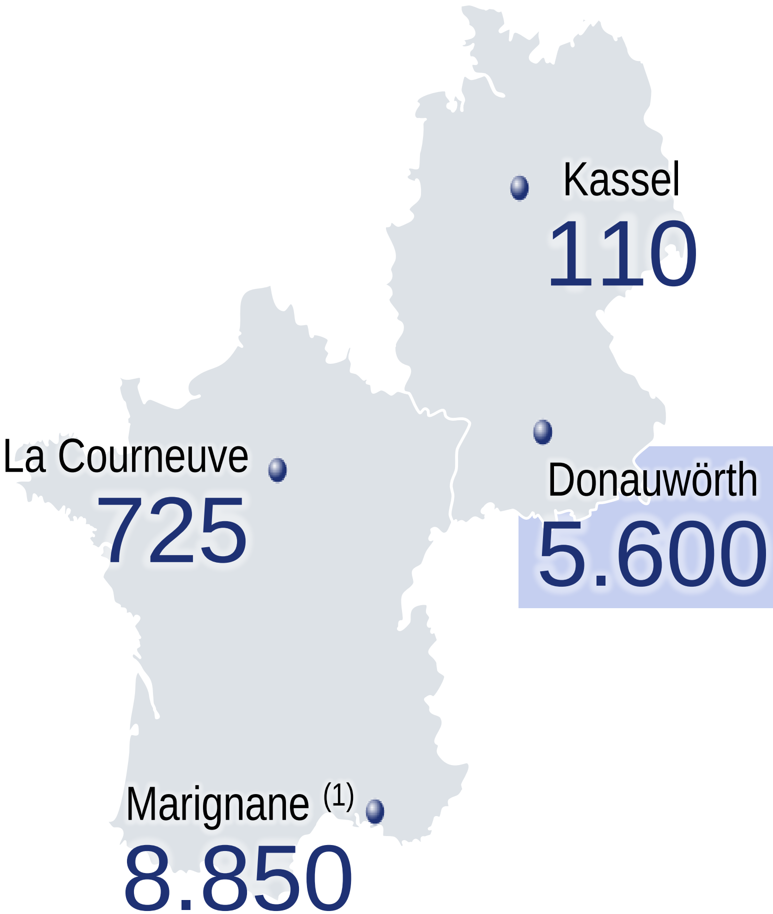
3,010 operators

3,217,000 flight hours logged in 2014

85 % of which own less 5 aircraft

in152 countries

Workforce and activities in the founding countries



15.285
Total workforce (2)

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

Airbus Helicopters priorities

Customer satisfaction

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

Quality & Safety

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

Competitive Products & Innovation

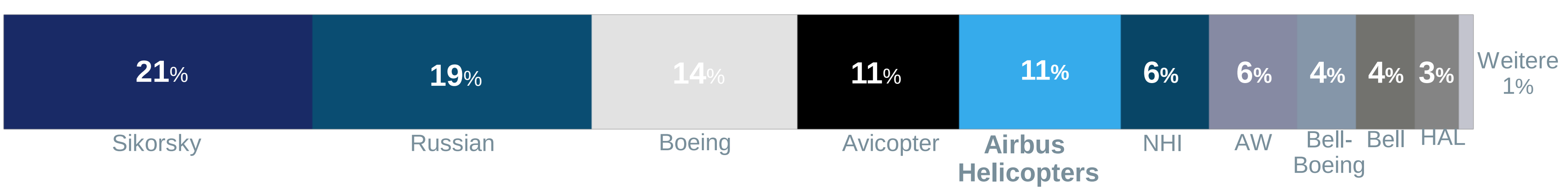
… by pursuing our innovation roadmap and enhancing our competitiveness to ensure sustainable development and growth

AIRBUS HELICOPTERS

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**



AIRBUS 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

AIRBUS HELICOPTERS

The civil range

AIRBUS HELICOPTERS

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.

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.

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 CO_2 emissions.

AIRBUS HELICOPTERS

V-Cycle

Development Process & Predictive Simulation

Predictive Simulation

Computational Fluid Dynamics (CFD)

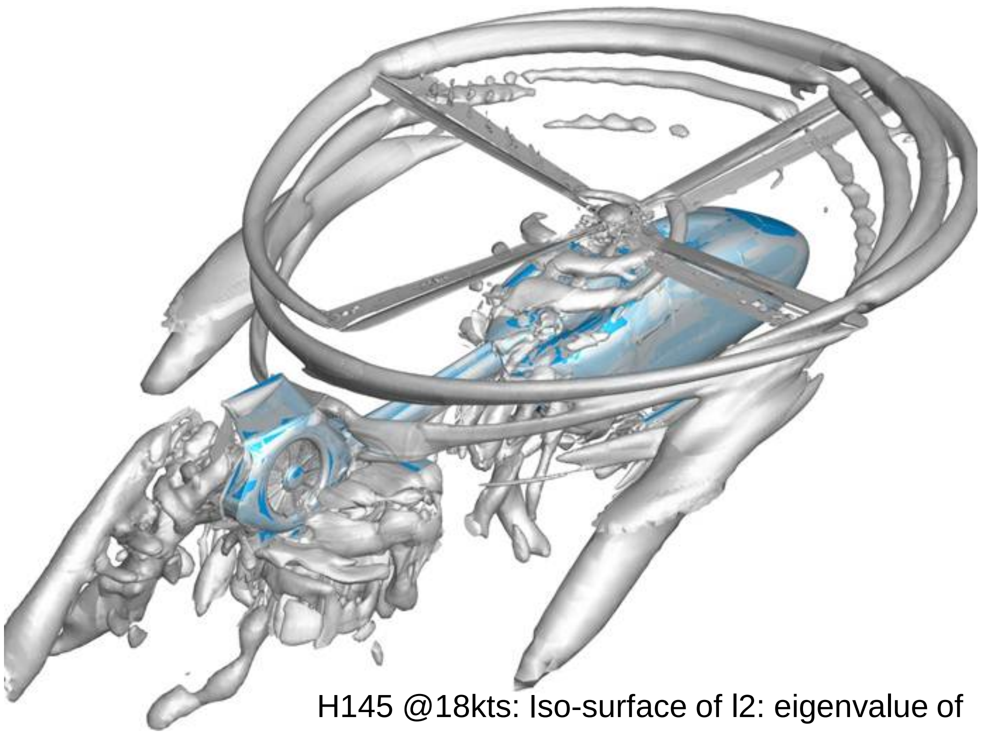
Computational Structural Dynamics (CSD)
→Finite Elements Metod (FEM)

- Loads & stress analysis
- Eigenmodes & vibrations

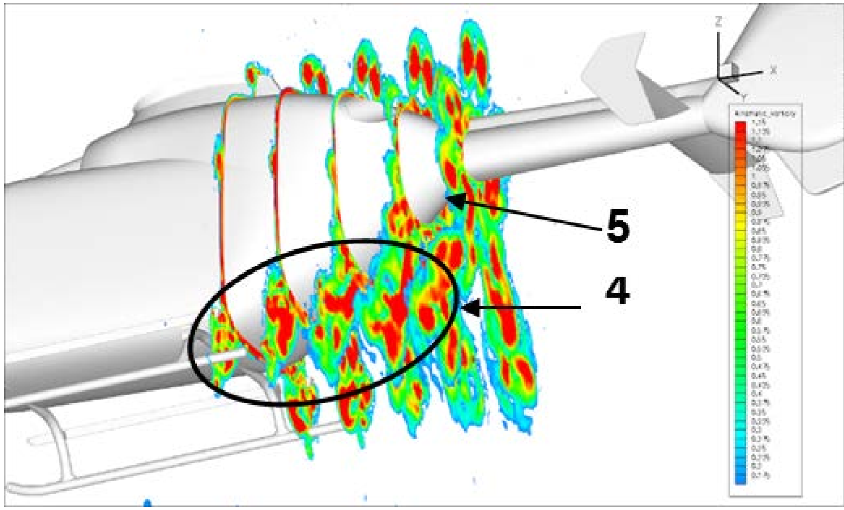
Rotor aero-mechanics & helicopter performance
Flight law & Automatic Flight Control System (AFCS)

Multi-physics simulation of „systems“

- Kinematics of flight controls
- Hydraulic supply & actuation system
- Thermal heat conduction
- Electrical power supply system
- Electro-mechanical actuators

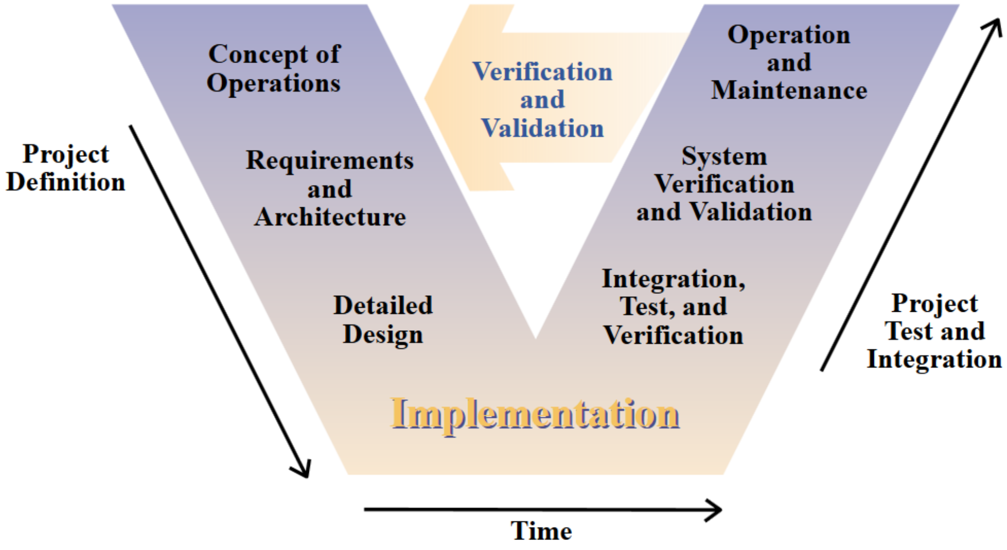


H145 @18kts: Iso-surface of l2: eigenvalue of the symmetry tensor of the velocity gradient



Wake of H135 fuselage:
Kinematic Vorticity

V-model of systems engineering process



Source: Wikipedia

AIRBUS HELICOPTERS

EUROCAE ED-79A / SAE ARP4754A
AIRCRAFT OR SYSTEM DEVELOPMENT PROCESS

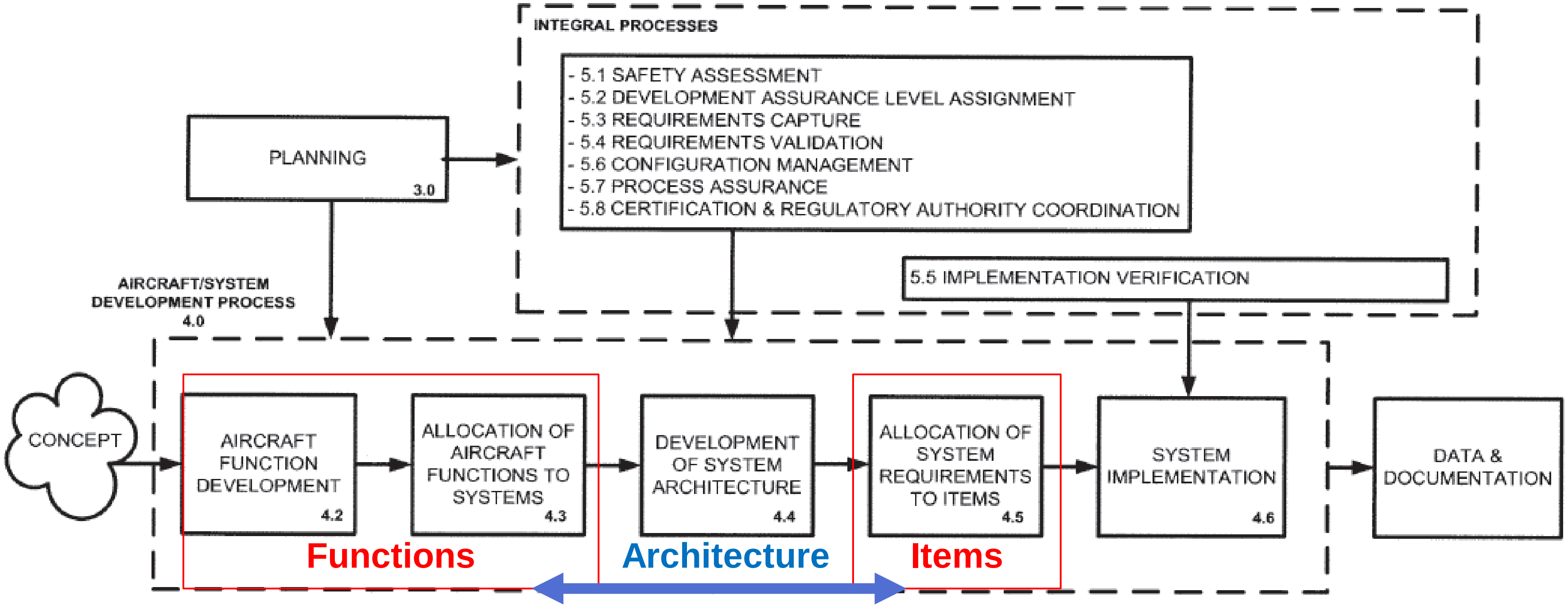


FIGURE 4 – AIRCRAFT OR SYSTEM DEVELOPMENT PROCESS MODEL

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

- **Function** development phase and
- **Item** development phase.

AIRBUS HELICOPTERS

EUROCAE ED-79A / SAE ARP4754A
DEVELOPMENT LIFE CYCLE

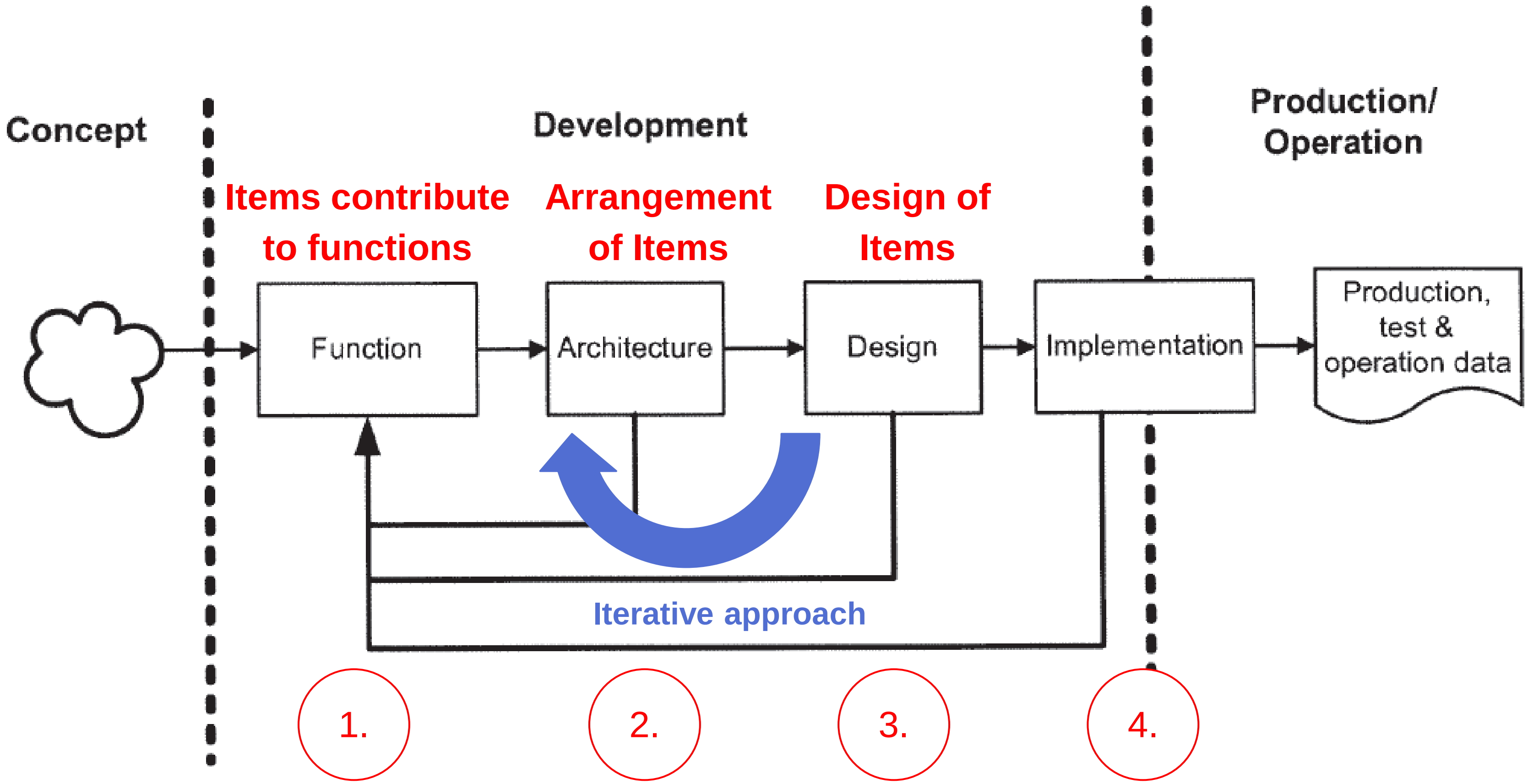
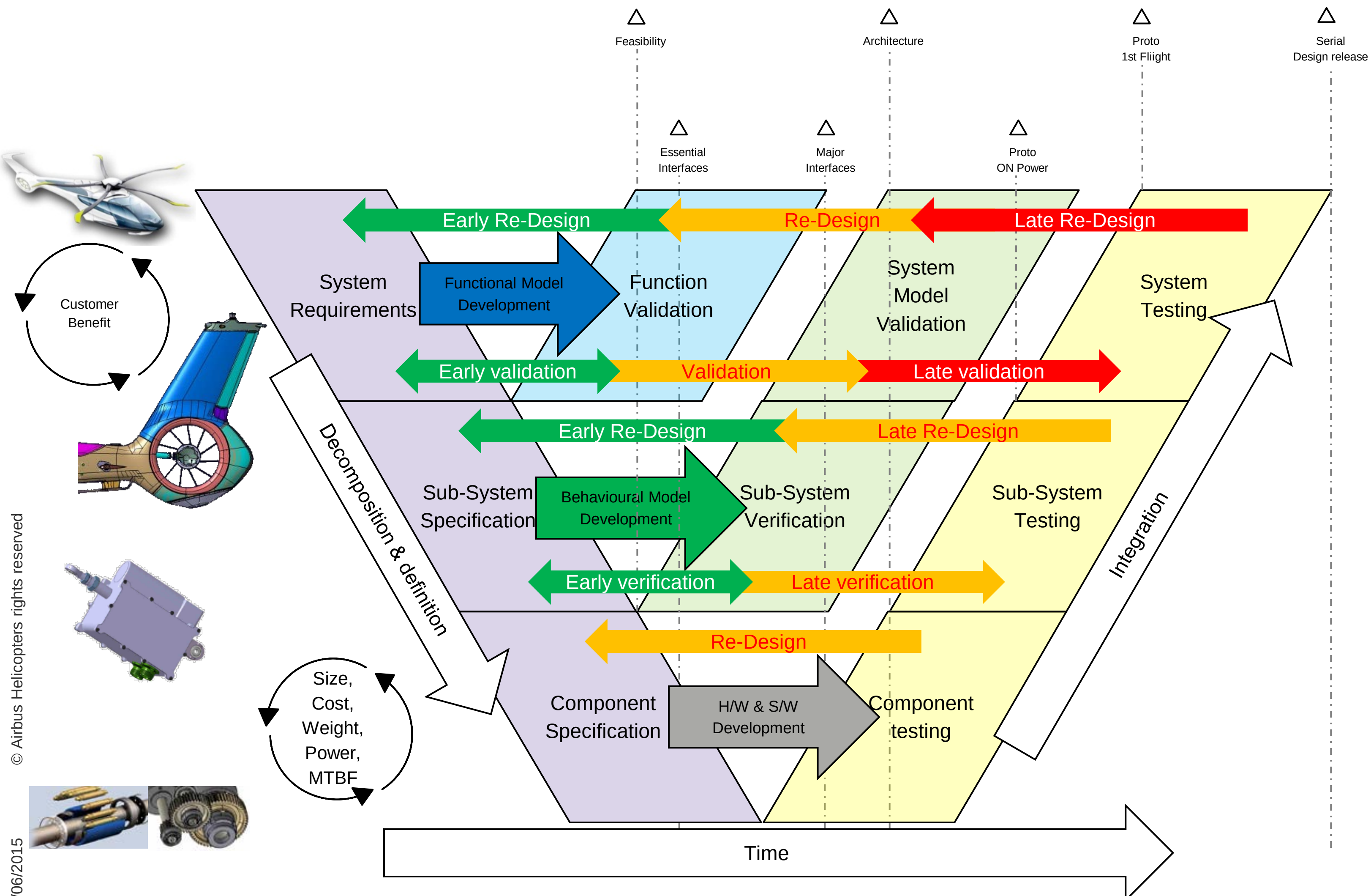


FIGURE 3 - DEVELOPMENT LIFE CYCLE

Model-Based Multi-Level System Engineering

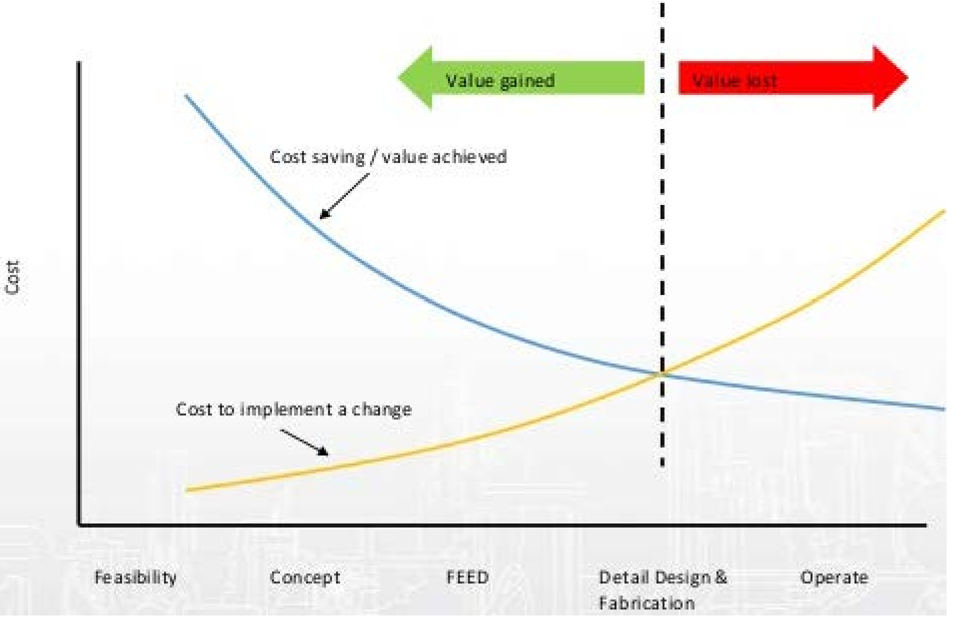


Why Predictive Simulation ?

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

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

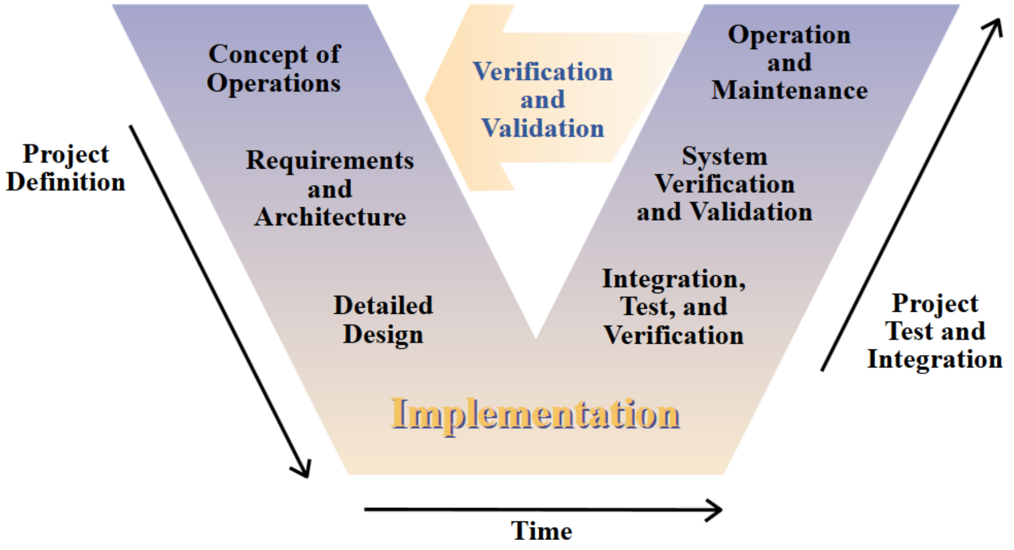
Feasibility & Pre-design
- Requirements
- Safety analysis: failure cases, degraded performance, …
- Supplier proposals



Source: momentum engrg

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

V-model of systems engineering process

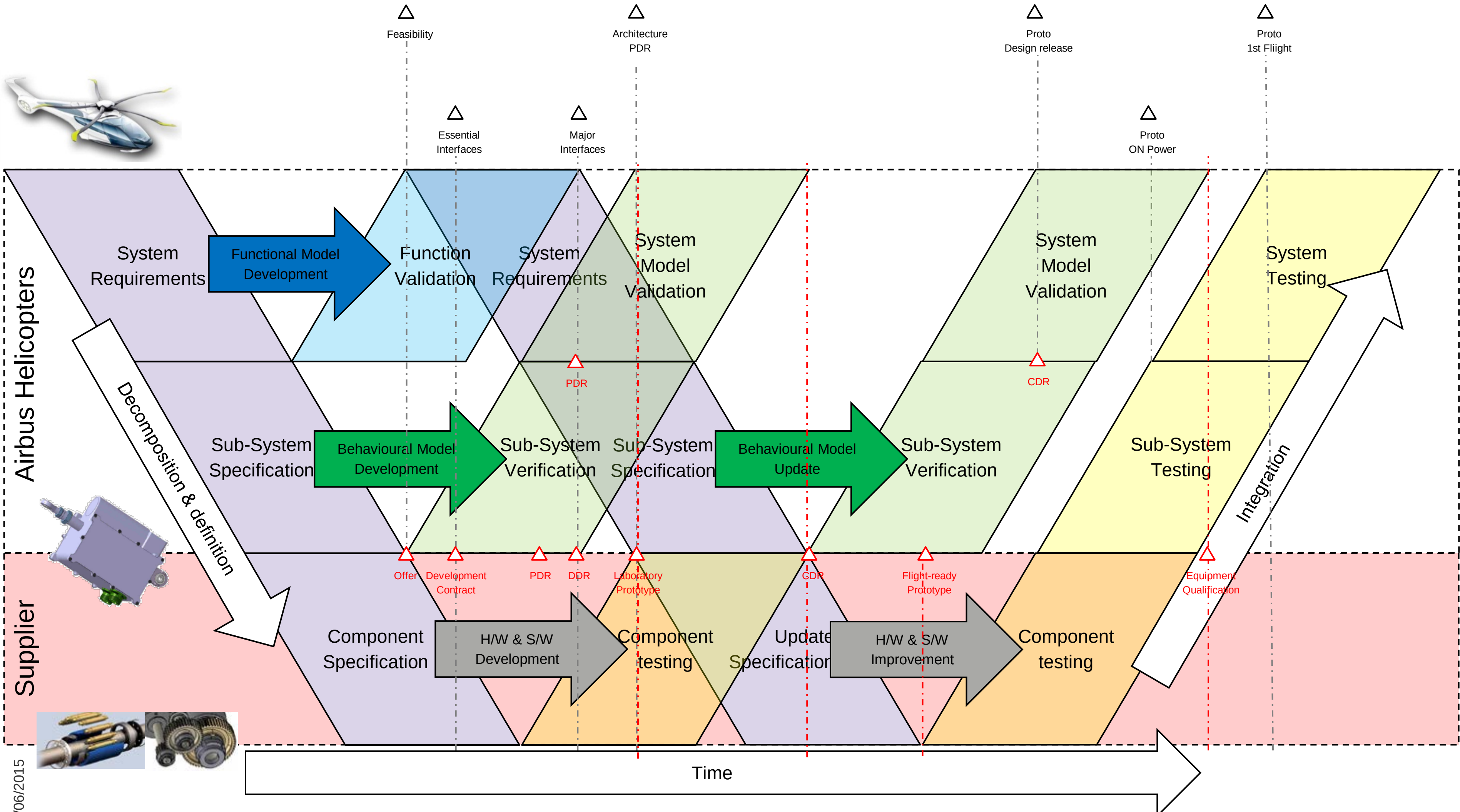


Source: Wikipedia

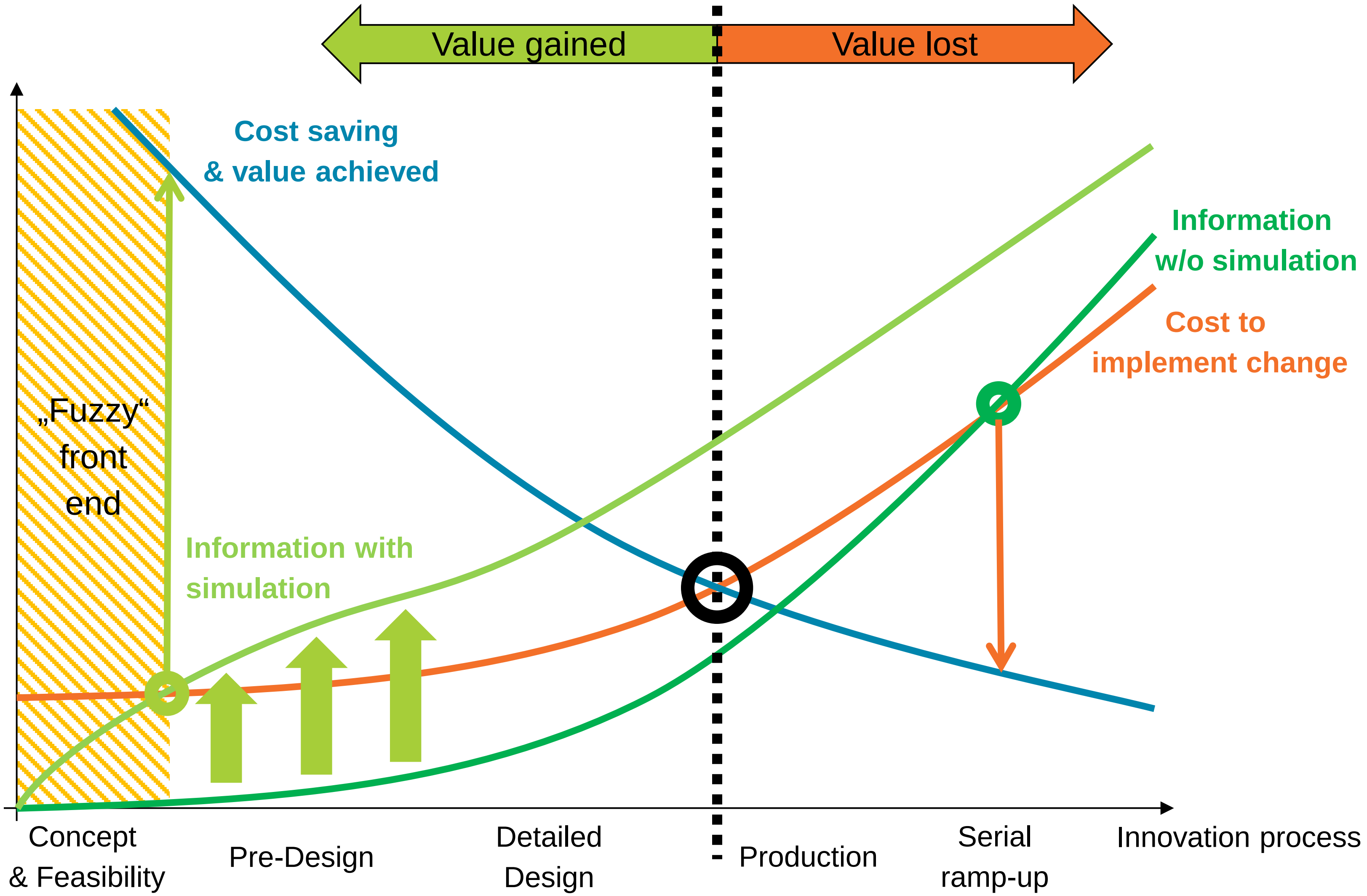
Iterative approach: function – architecture – design
→Update loops

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

Equipment Development - a more realistic V-cycle



„Fuzzy“ front end



AIRBUS HELICOPTERS

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

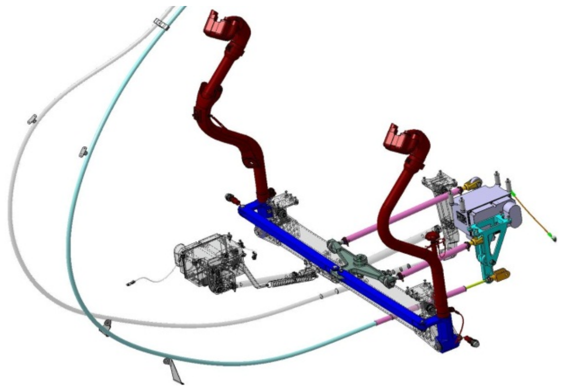
Examples

- 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

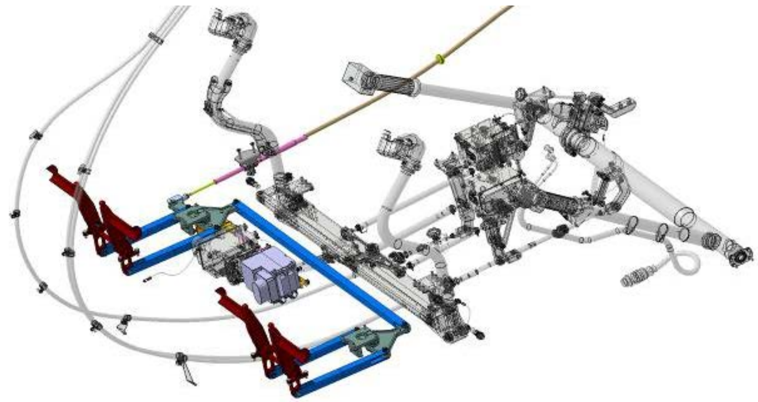
Lateral Cyclic

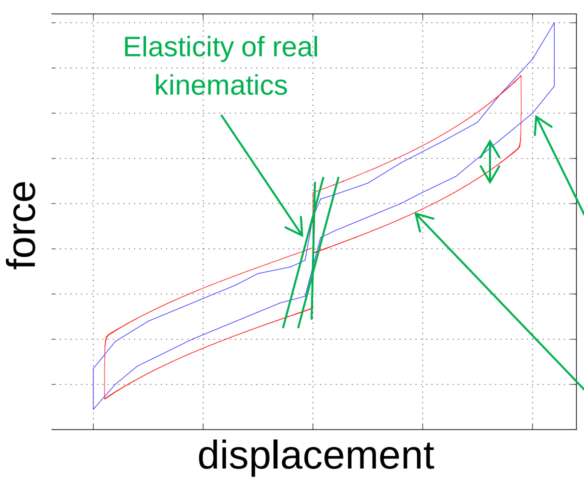
- Centering spring
- Friction of kinematics (flexballs, …)



Yaw (pedals)

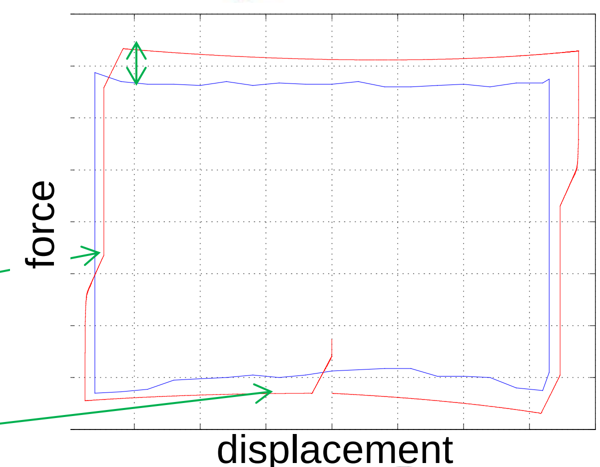
- Friction characteristics (trim)





Measurement / Simulation

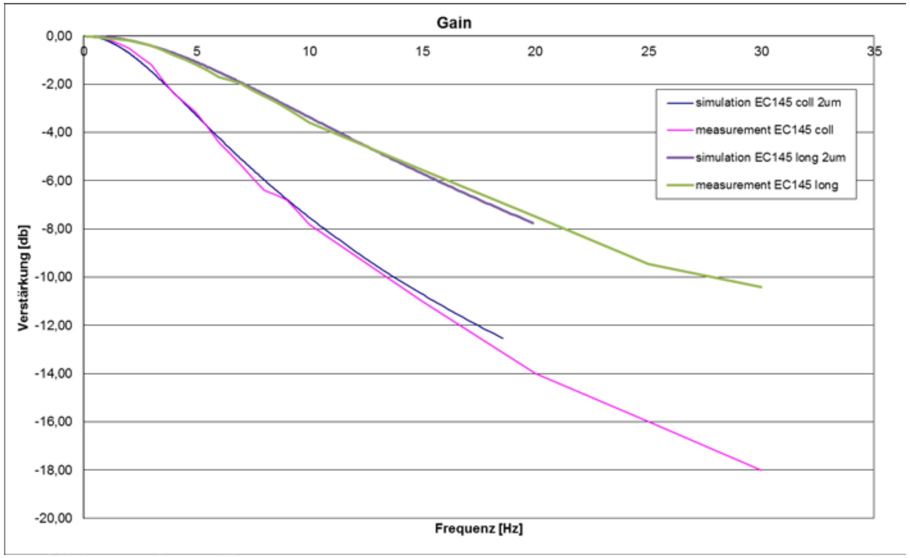
- Conservative friction estimates
- Tolerances of trim actuator breakout forces
- Secondary end stops not modeled
- Curves spring gradients = nonlinear kinematics

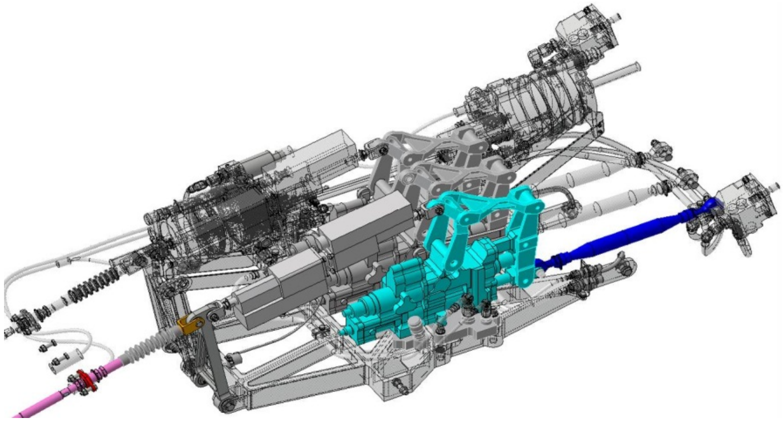


Hydraulic servo actuator : phase & gain response

Hydraulic Main Rotor Actuator of H145 (EC145)

- Different actuators for collective & longitudinal axes
- Proprietary hydraulics library (Modelon)





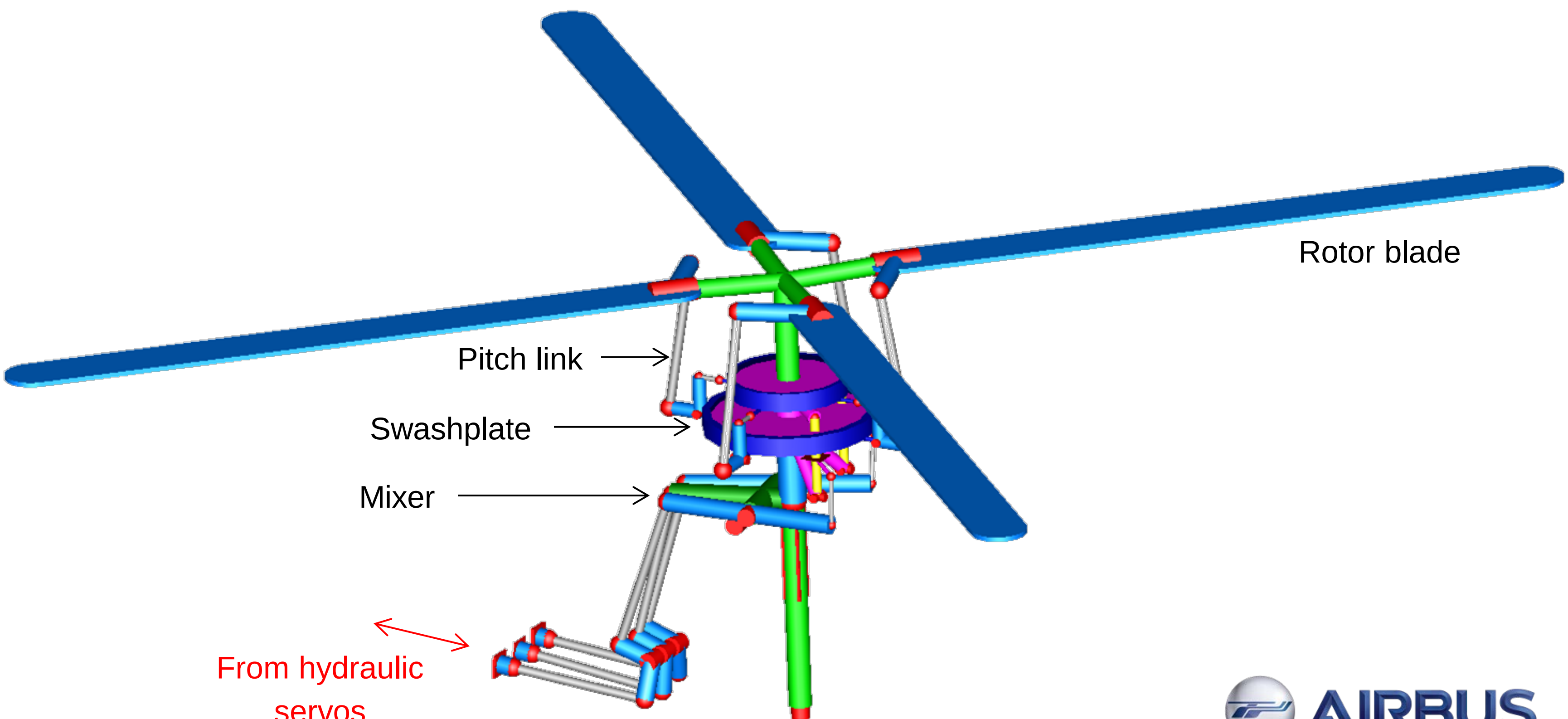
→very good agreement between simulation and qualification measurement by supplier

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

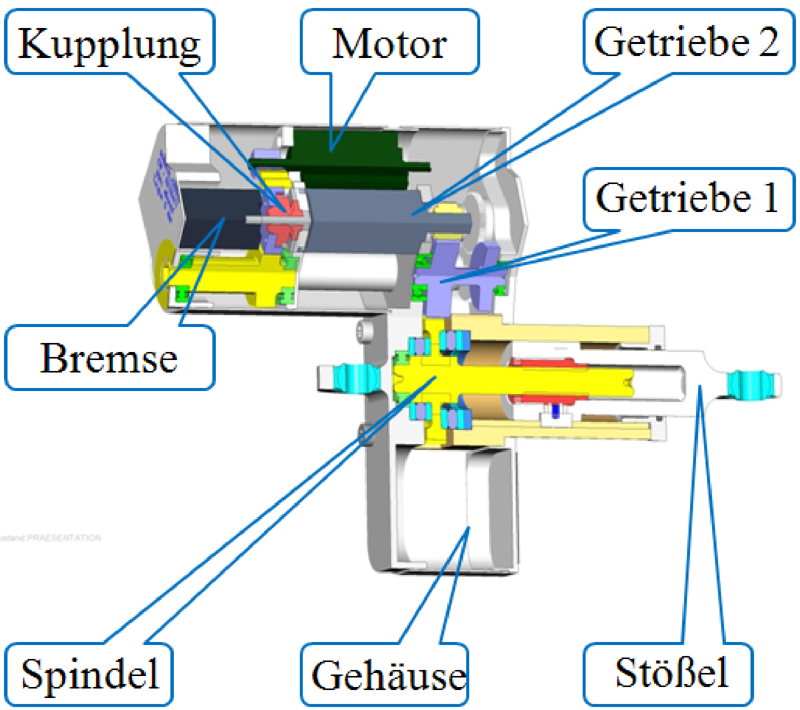


AIRBUS HELICOPTERS

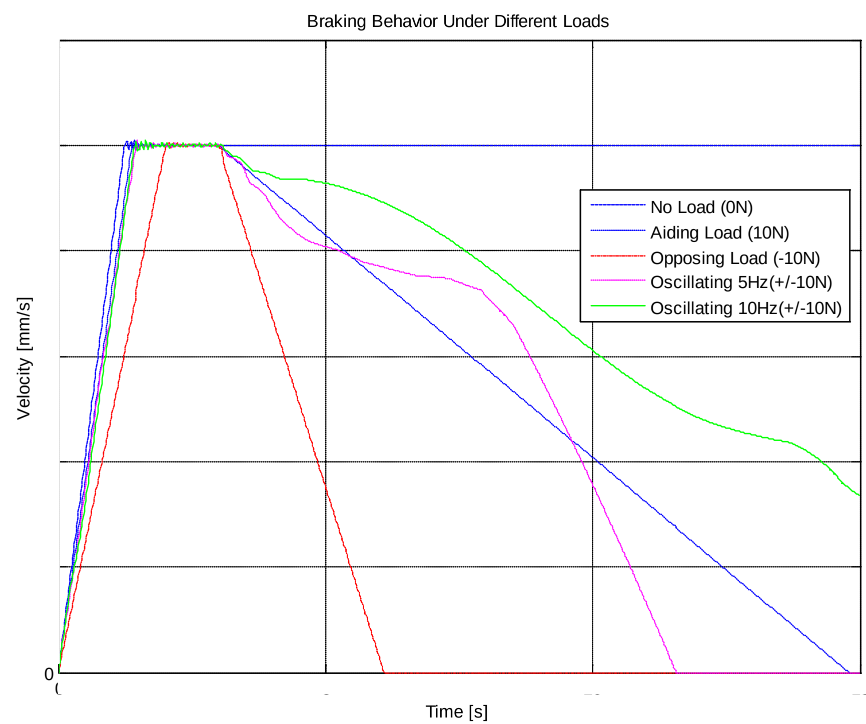
Electro-mechanical actuator : braking travel (failure case)

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

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



Source: EME



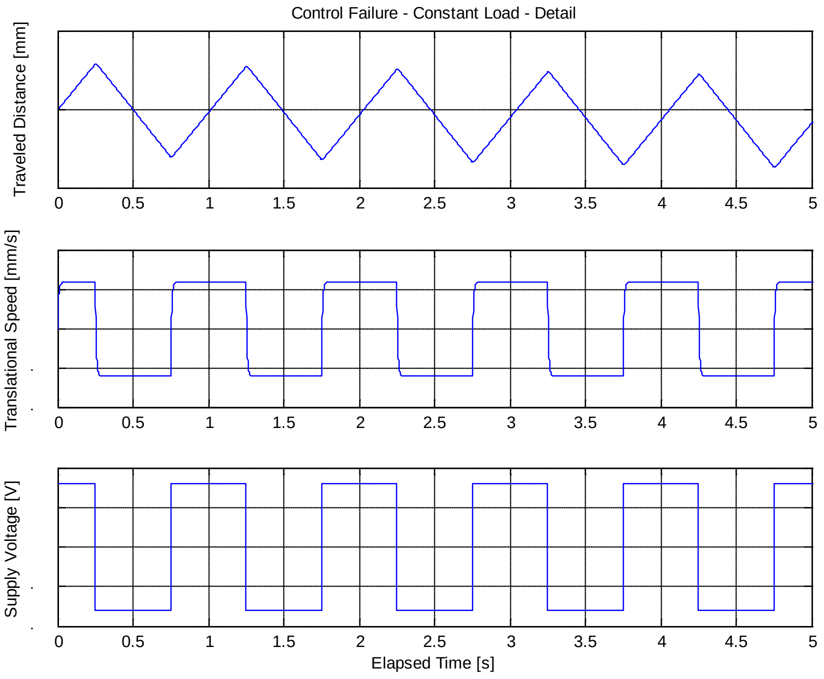
AIRBUS HELICOPTERS

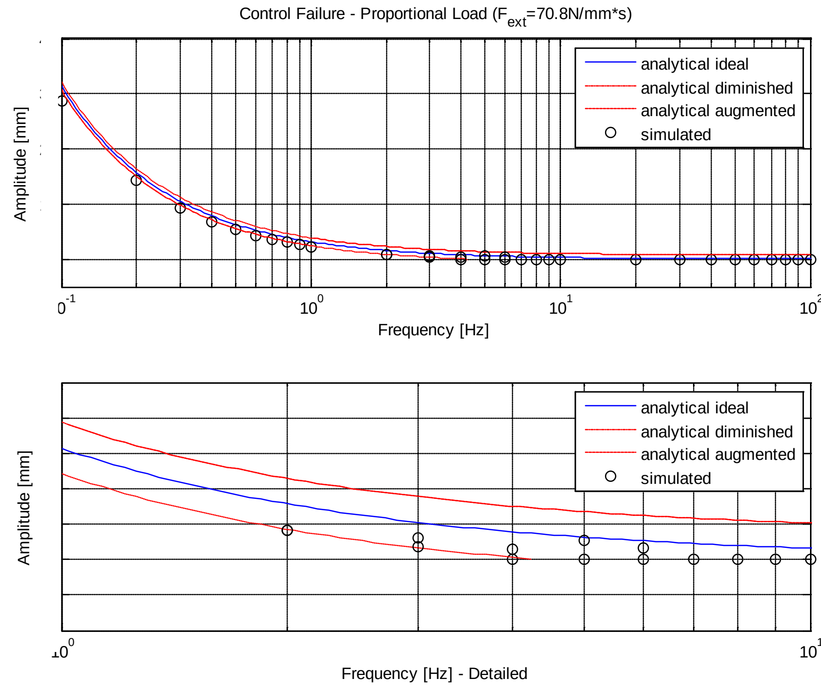
Electro-mechanical actuator : oscillatory failure

Oscillatory failure of flight control EMA

→prediction of oscillation amplitude asfunction of frequency

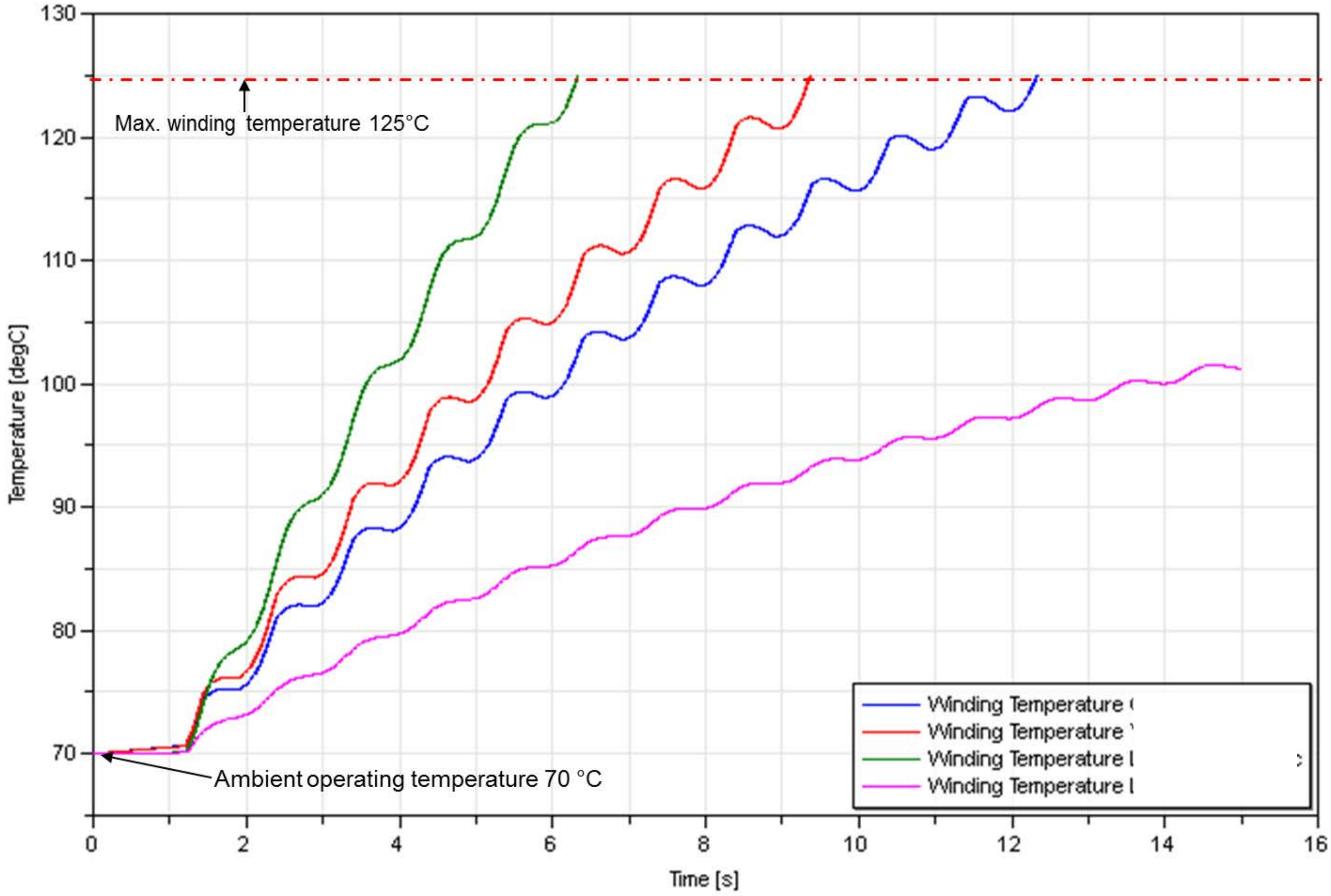
based on physical performance limitations of motor, gear & inertia





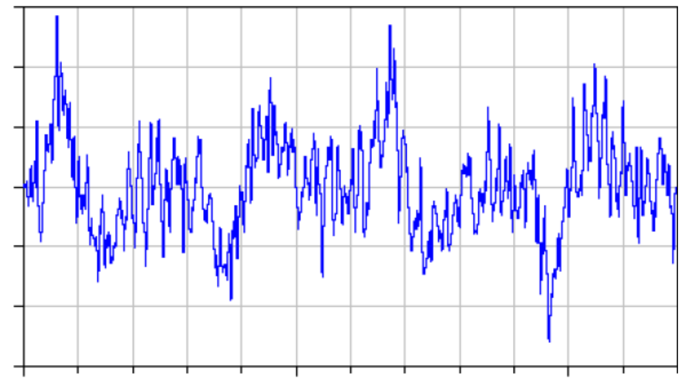
AIRBUS HELICOPTERS

Electro-mechanical actuator : thermal design



„Cool“ Tools

Measurement or simulation ?



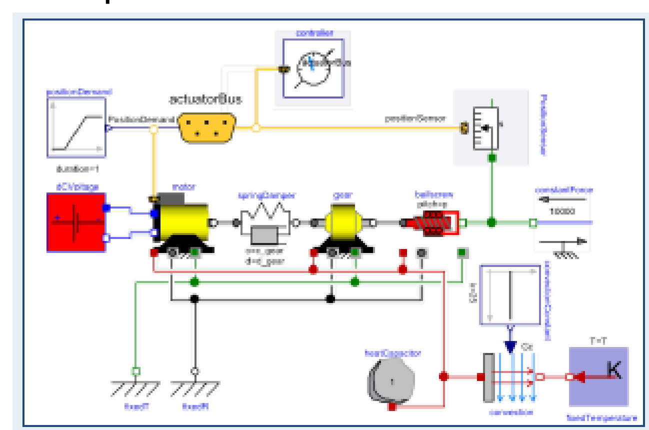
„Linear Systems“ Modelica library: control design

- 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

AIRBUS HELICOPTERS

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 ?

Dr. Boris Grohmann
Expert Mechatronics & Actuation
Flight Controls & Hydraulics - ETMH
Airbus Helicopters Deutschland GmbH, Donauwörth
Boris.Grohmann@Airbus.com