Conversion of a CS-23 Airplane to a fly-by-wire test bed for manned and unmanned flight control research

Florian Holzapfel

TUM Institute of Flight System Dynamics
Technische Universität München, Boltzmannstrasse 15, D-85748 Garching, Germany
Florian.Holzapfel@tum.de, www.fsd.mw.tum.de

Diamond Aircraft DA-42 MPP

Overview

- TUM Institute of Flight System Dynamics
- Motivation
- General Information DA-42MNG
- Conceptual Considerations
- Flight Control Modifications
- Other Modifications and Equipment
- Additional Infrastructure beyond the aircraft
- Current Projects

TUM Institute of Flight System Dynamics

Technische Universität München

TUM has 13 Schools – The largest one is Mechanical Engineering
School of Mechanical Engineering has 7 Departments – one is Aerospace

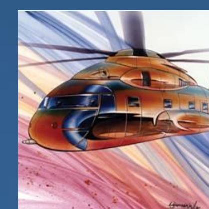
Institute for
Flight Propulsion
Prof. Dr.
Oskar Haidn (interim)

Institute of
Lightweight
Structures
Prof. Dr.
Horst Baier

Institute for
Astronautics
Prof. Dr.
Ulrich Walter

Institute for
Aerodynamics
Prof. Dr.
Nikolaus A. Adams

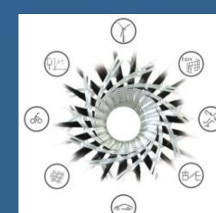
Institute of Flight
System Dynamics
Prof. Dr.
Florian Holzapfel



Institute of
Helicopter Technology
Prof. Dr.
Manfred Hajek

Institute for
Aerospace Systems
Prof. Dr.
Mirko Hornung

TUM aerospace
Technische Universität München
Institut für Luft- und Raumfahrt
www.tumaerospace.de



+Material Engineering:
Institute for
Carbon Composites
Prof. Dr.
Klaus Drechsler

Facts and Figures

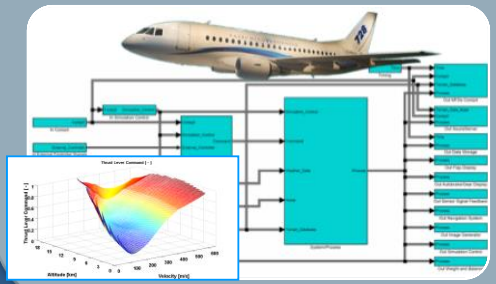
- **Institute of Flight System Dynamics**
  - Established October 2007
  - Former *Institute of Flight Mechanics and Flight Control*
- **Professors**
  - Prof. Dr.-Ing. Florian Holzapfel
  - Prof. Dr.-Ing. Dr. h.c. Gottfried Sachs
  - Prof. Dr.-Ing. habil. Otto Wagner
- **Senior Researchers**
  - Dr.-Ing. Matthias Heller – Rudolf Diesel Fellow
  - Dr.-Ing. Dipl.-Math. techn. Johann Dambeck
- **Researchers**
  - >40 scientific employees / PhD students including five foreign researchers
  - Eight external PhD students

Homepage: www.fsd.mw.tum.de
Address: Boltzmannstraße 15
D - 85748 Garching

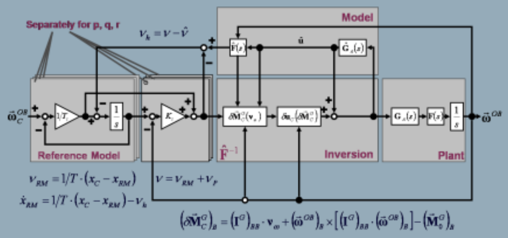
E-Mail: florian.holzapfel@tum.de
Telephone: +49 89 289-16081
Fax: +49 89 289-16058

Main Research Areas

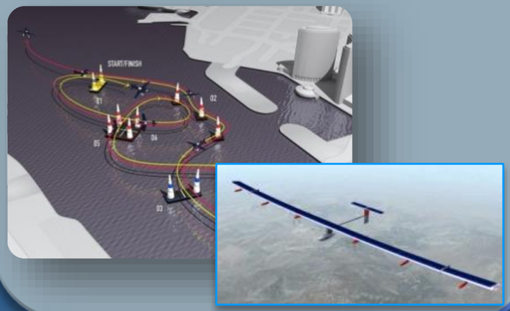
Modeling, Simulation & Parameter Estimation



Flight Control & Flight Guidance

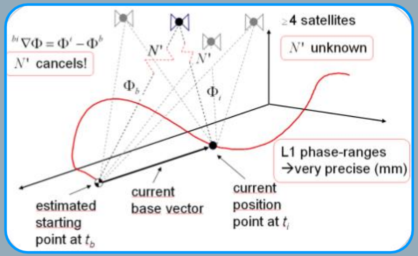


Trajectory Optimization



Avionics & Safety Critical Systems

Sensors, Data Fusion & Navigation



We are not only working on research configurations…

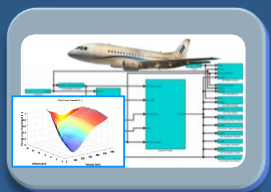
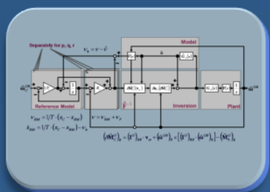
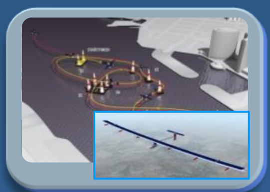
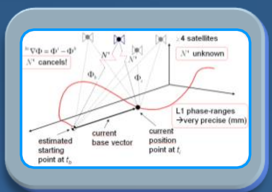
Institute of Flight System Dynamics

…but also on
real life applications and
production systems

Motivation

Background – General demand for in-flight testing

- **Research areas of the Institute of Flight System Dynamics**
  - Flight Control Algorithms & System Level Application
  - Modeling, Simulation & Parameter Estimation
  - Trajectory Optimization & Flight Guidance
  - Sensors, Data Fusion & Navigation
  - Avionics and Safety Critical Systems

Demand for a research aircraft as flying test bed to demonstrate functional capability and market readiness

- **Requirements of FSD**
  - Cost effectiveness is very important
  - Access to flight controls is a must for our research in flight control
  - Aircraft needs to carry various sensor systems for navigation and sensor data fusion research

Background – General demand for in-flight testing

- **Similar requirements from SMEs and Institutes:**
  - Affordability: low & deterministic operating costs and lean management
  - Possibility to flight-test various types of equipment, from sensors to large camera systems
  - Availability of modular compartments reducing installation times
  - Well calibrated system of reference sensors

- **Small and medium-sized enterprises**
  - Drivers of innovation with often short development cycles
  - Subcontractors and suppliers for system integrators and aircraft OEMs
  - For many of those companies: aviation is only a secondary business or emerging market
  - Only very few have access to flying platforms (although required)

➡ **Demand for a flying test bed to demonstrate ideas, products, capabilities and competence in emerging markets**

Joint vision – A new research aircraft for Bavaria

- **Partnership on equal level**
  - Currently >25 interested partners:
    - Universities and Research Institutes
    - Small and Medium Enterprises
    - Larger Companies
  - No partner is better than others!
  - Fair and independent access to aircraft
- **Key operational requirements**
  - Costs per flight hour need to be low: Target price <750 € unsubsidized
  - Lean operation and management concept
  - Availability shall be maximized, no long modification phases
  - Modular equipment compartments adapted to partner needs ⇒ save time, provide flexibility
  - Available service infrastructure including well-calibrated reference sensors (INS, GPS etc.)

General Information
Diamond Aircraft DA-42 MNG

Available platform aircraft

- Cessna Stationair 206H T.

- Diamond Aircraft DA42 MNG

- Cessna Corvalis 350

- Hawker Beechcraft Baron G58

- Cirrus SR22

- Piper Seneca V

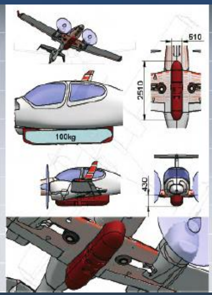
Our choice – A Diamond Aircraft DA42 MNG (MPP New Generation)

- **Decision factors:**
  - Available as EASA certified Multi Purpose Platform
    - External nose and belly storage pods
    - Provisions for mission and sensor equipment
    - Mission power supply
    - Simplified installation of non-certified equipment
  - Aircraft performance and Engines
    - Modern composite aircraft with up to 550kg useful load
    - IFR certification
    - Modern avionics suit G1000, potential to access internal data bus, 10" MFD
    - Twin Diesel engines (AustroEngine AE300, 170hp each)
      - less than 10 gal/hr (BOTH ENGINES!)
      - Special alternator for reliable mission power supply, independent of aircraft power
      - lower fuel costs, potentially tax-free fuel
  - Aircraft manufacturer
    - Diamond Aircraft is a local European manufacturer
    - Distance from FSD to Diamond Aircraft is only 4hrs drive, 1hr flight
    - Great support by Diamond key personnel!
  - Growth potential, active fleet of special mission aircraft

Performance Details DA42 NG

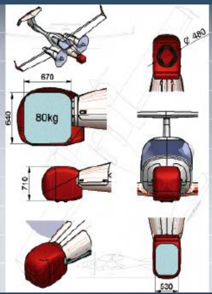
AIRCRAFT ITEM	INFORMATION	
Engine	2x Austro Engine AE 300 turbocharged, common-rail injected 2.0 liter diesel engine with EECDU single-lever control	
Horsepower	170 hp per side 340 hp total	
Propellers	2x MT MTV-6-R-C-F / 190-69 3-blade constant speed	
Airworthiness category	Normal	
Length	28 ft 1 in	8,5 m
Height	8 ft 2in	2,5 m
Wing span	44 ft	13,5 m
Wing area	175.3 sq ft	16,3 m^2
Seats	4	
Empty weight	2,976 lbs	1349 kg
Maximum take-off weight (MTOW)	4,189 lbs	1900 kg
Useful load	1,213 lbs	550 kg
Fuel capacity (standard / long range)	52 US gal / 79 US gal	197 l / 301 l
Fuel grades	Jet A1 / Diesel	
Rate of climb, sea level MTOW	1,150 fpm	5,8 m/s
Rate of climb, 10,000 ft MTOW	1,020 fpm	5,2 m/s
Maximum operating altitude	18,000 ft	5500m
Maximum air speed	192 kts IAS	356 km/h
Maximum cruise speed at 14,000 ft	184 kts TAS	340 km/h
Maximum cruise speed at 55% at 8,400 ft	175 kts TAS	324 km/h
Range, at 60% power, (standard / extended fuel)	700 nm / 1,180 nm	1300 km / 2180 km

Basic Airplane DA 42 MNG



Belly Payload Pod
Laser Scanning
Dimension: 510x2510x430 [mm]
Payload: 100 kg

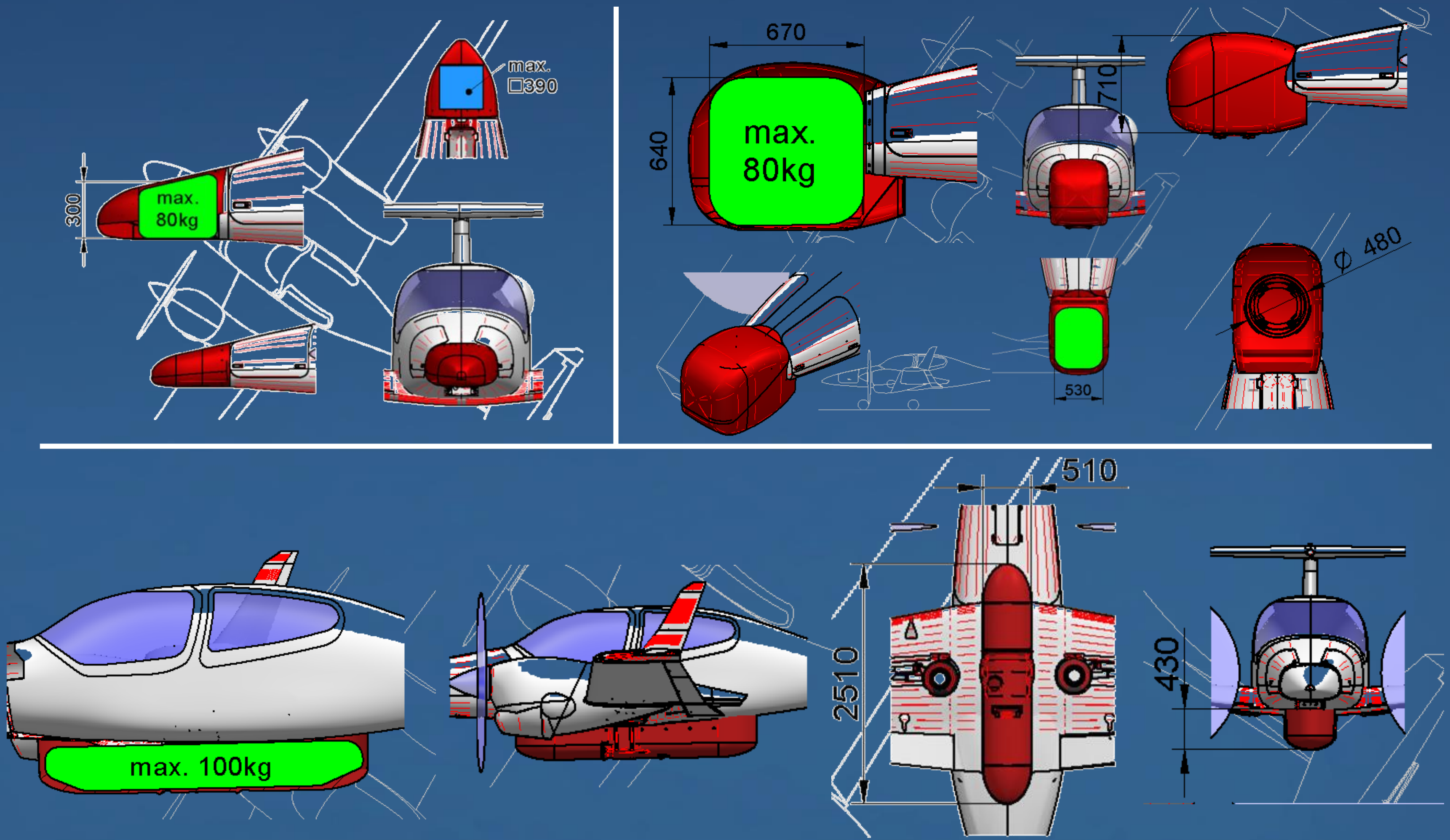
Nose Payload Pod
Turret Cam
Dimension : 300x390x390 [mm]
Payload: 80 kg



Nose Payload Pod
„Photogrammetry“
Dimension : 670x530x640 [mm]
Payload: 80 kg

Technical Concept

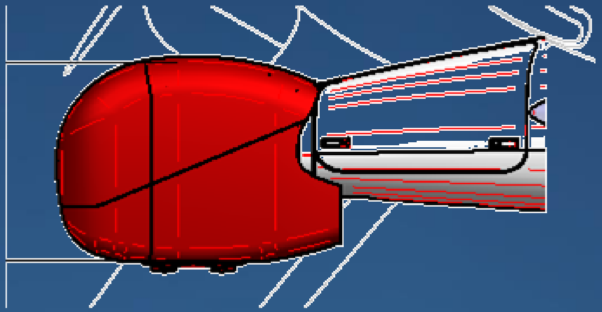
- **Basic Airplane DA 42 MNG**



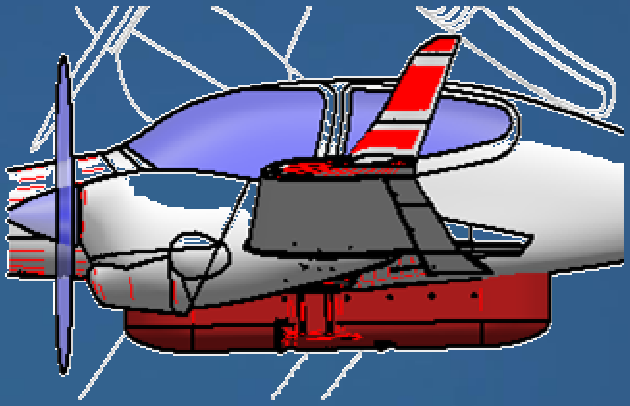
Ordered Aircraft Configuration

- DA42 MNG with Austro Engine AE300
- GARMIN GFC 700 Digital Autopilot
- Long Range Tank (301 l, 79 US gal)
- Integrated TAS 610 (Traffic Advisory System)
- Crew Oxygen System
- Bubble Canopy
- Flight Test Engineering Operator Station (Folding table, rack, twin-monitor)
- Provisions for
  - Nose pod (65kg)
  - Belly pod (80kg)
- Equipment compartments
- 3x Belly Pod
- 1x Universal Nose for Gimbal-Camera (max. 65kg)
- 1x Nose Pod (max. 85kg)
- 2x Pair of Winglets (one pair with ADS Boom)

Nose Pod



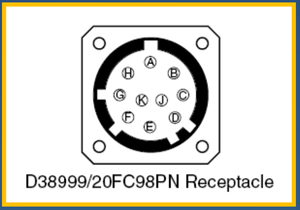
Belly Pod

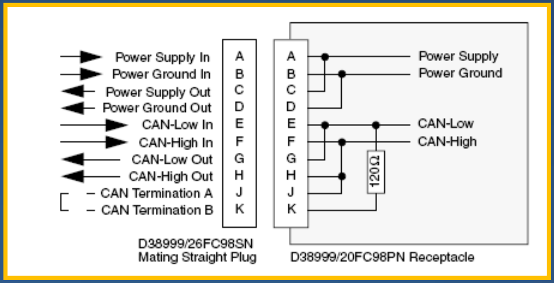


Conceptual Considerations

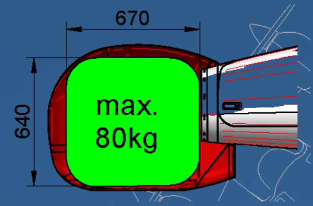
Aircraft operations – Technical requirements

- **High degree of standardization :**
  - Mechanical and electrical interfaces
  - Availability of modular payload containers





- **Maximized availability by stepwise integration :**



Payload Container

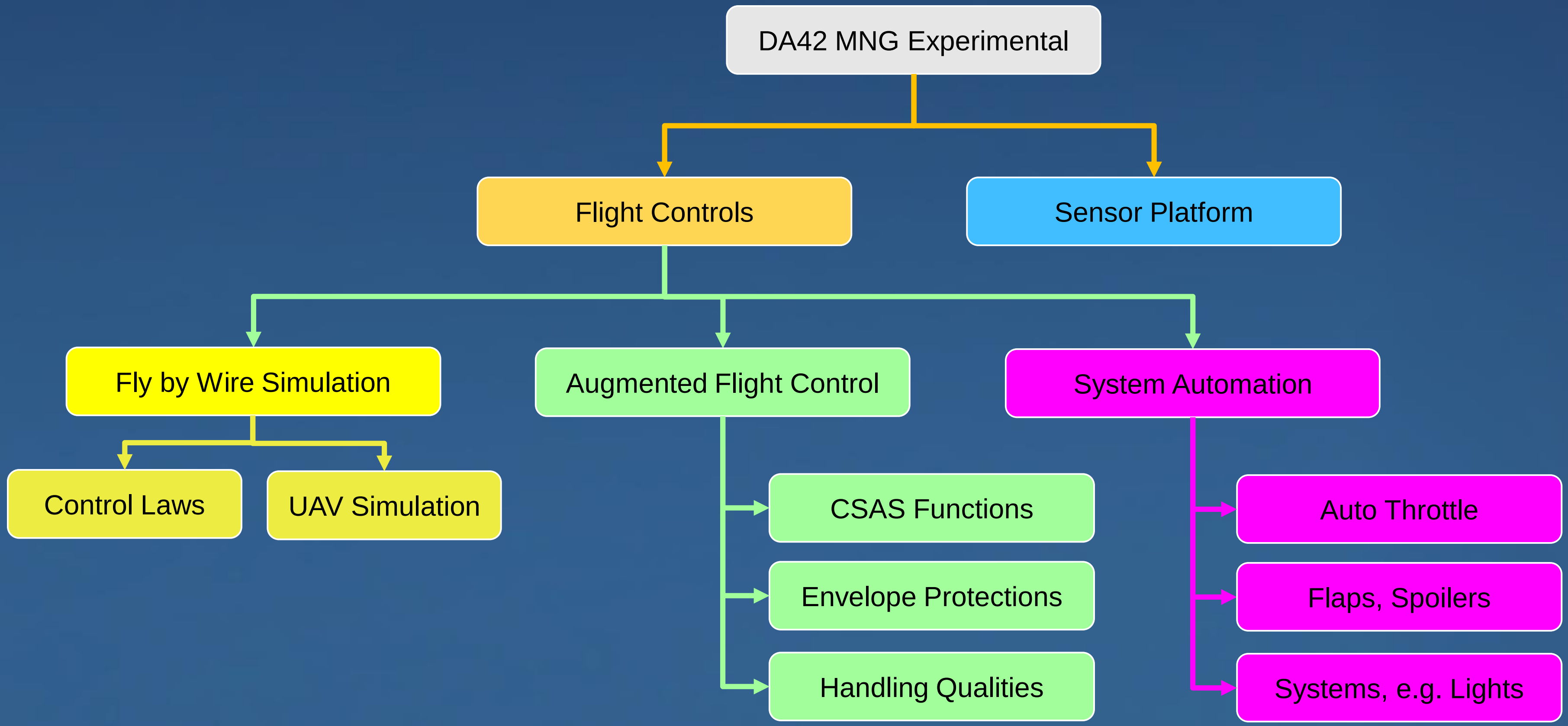
Iron Bird

Flight Simulator

Flight Test

- **User-optimized measurement equipment**
  - Well calibrated reference system for measurements
  - High diversity in available sensor measurements and data busses
  - Open, freely accessible documentation

Aircraft research applications



Experimental Flight Control System (EFCS) - Operation

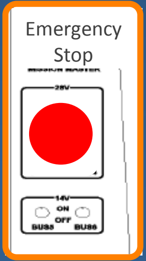
Safety Pilot (PIC)

- enables the EFCS by pressing and holding an activation button
- overrides EFCS via the mechanical control stick and friction clutch

Test Pilot (PF)

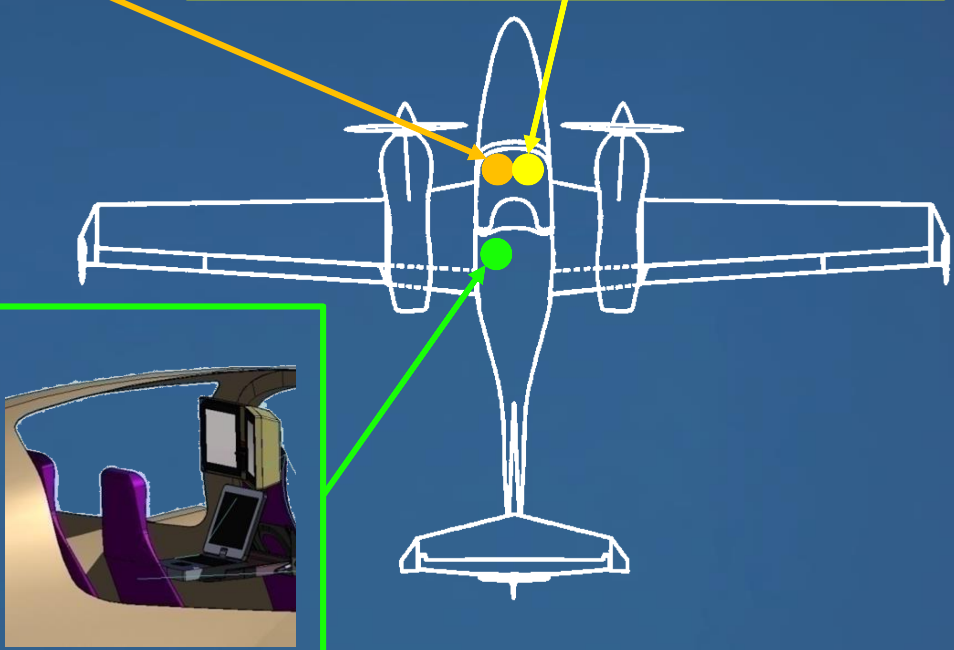
- for EFCS control studies
- flies the aircraft via an active digital center-stick
- deactivates power supply to all experimental mission equipment

Emergency stop for all crew members



Flight Test Engineer

- enables EFCS and other systems
- monitors EFCS system and components
- monitors flight control algorithm and sensor data
- resets EFCS after upsets or failures
- deactivates power supply to all experimental mission equipment

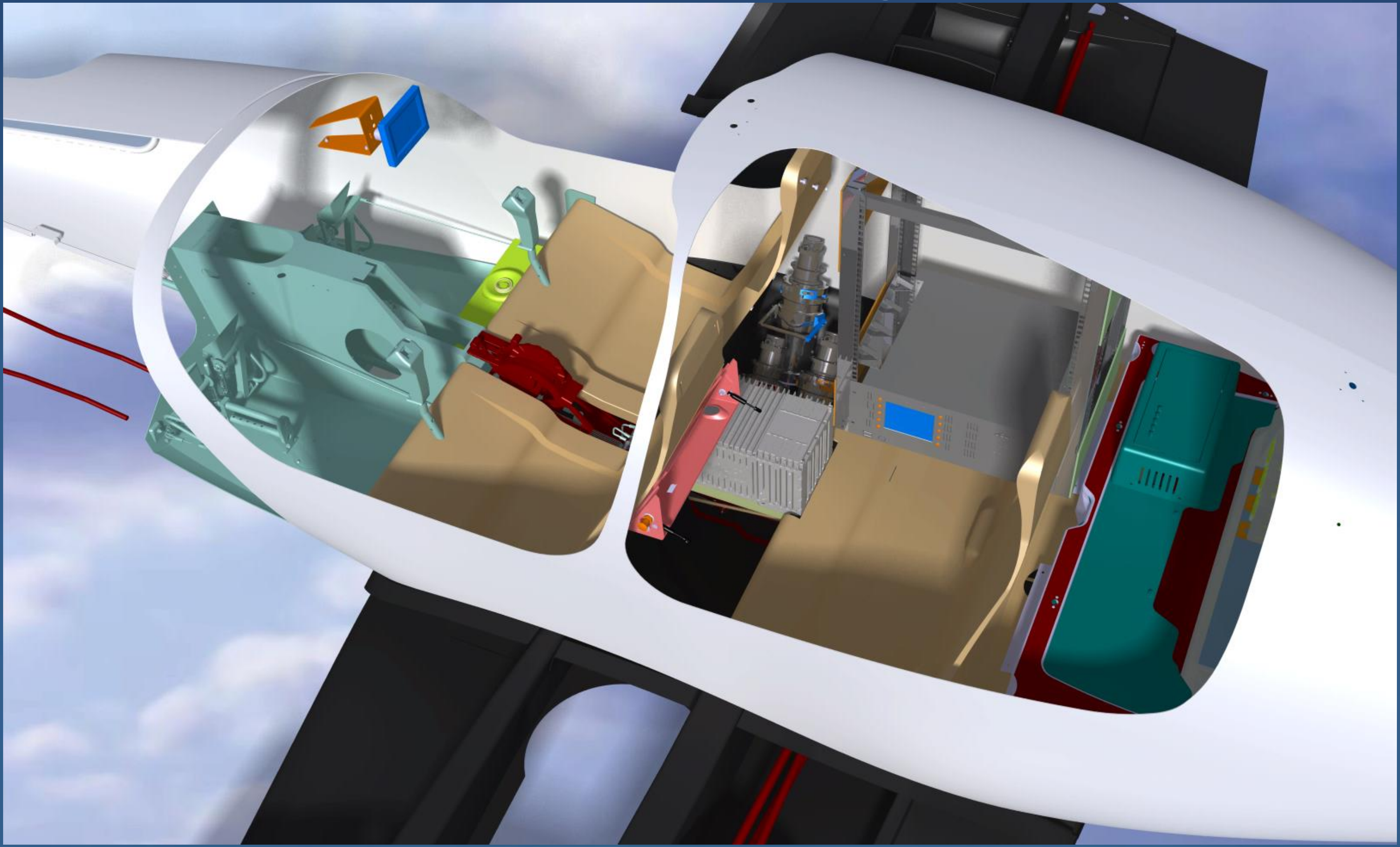


Current Project Status

- **Our DA42MNG base airplane has passed production flight tests**

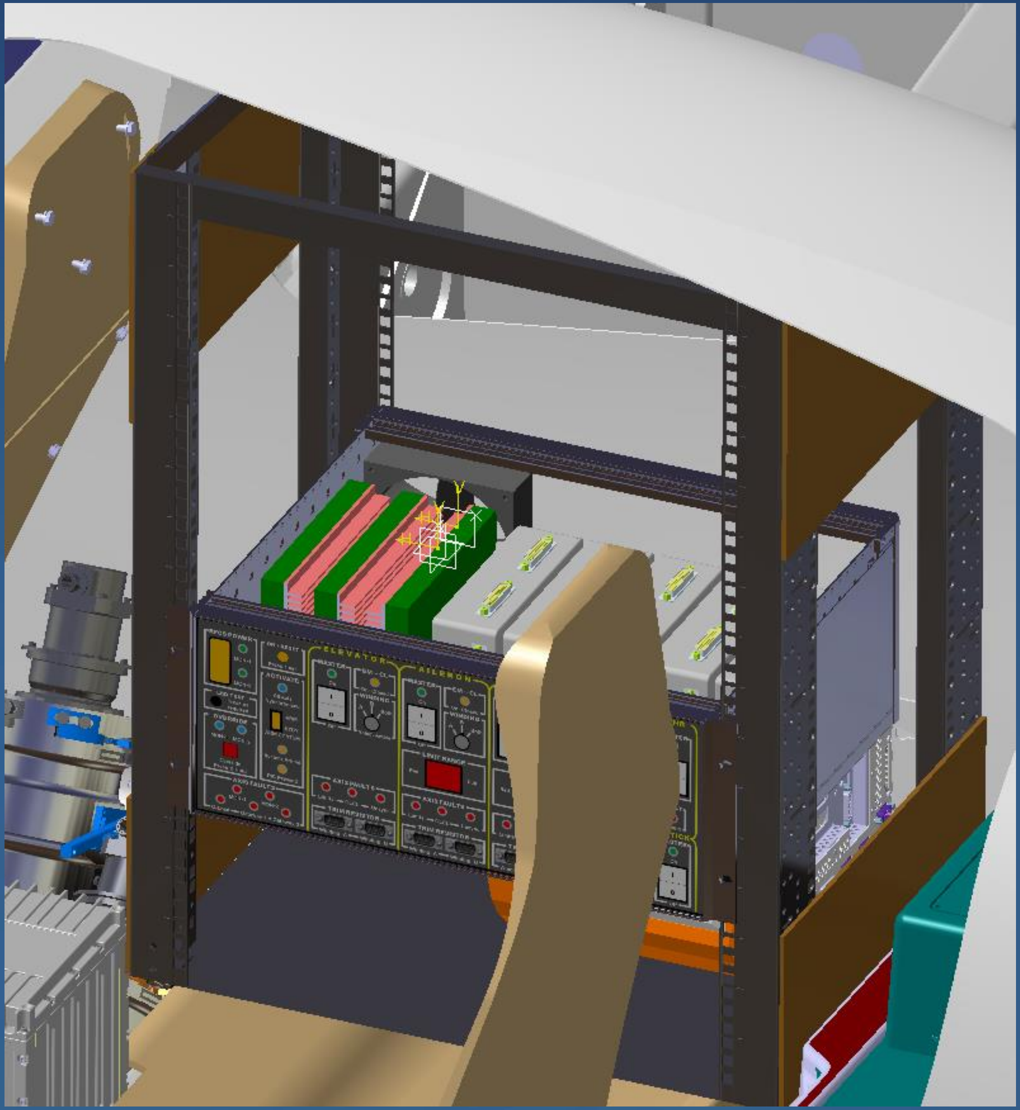
- **Modifications will be performed in multiple batches**
  - Basic equipment provisions and fitting of exterior pods:
    - Design and engineering performed by Diamond Aircraft according to joint specification
  - Reference sensor system
    - Selection and acquisition by FSD, installation and legalization by Diamond Aircraft
  - Modification of control system – experimental flight control:
    - System design and Iron Bird / HILS testing performed by FSD and partner companies
    - Aircraft installation, legalization and initial flight testing by Diamond and FSD

Cabin View, 19” Rack, Actuators and Navigation Grade INS



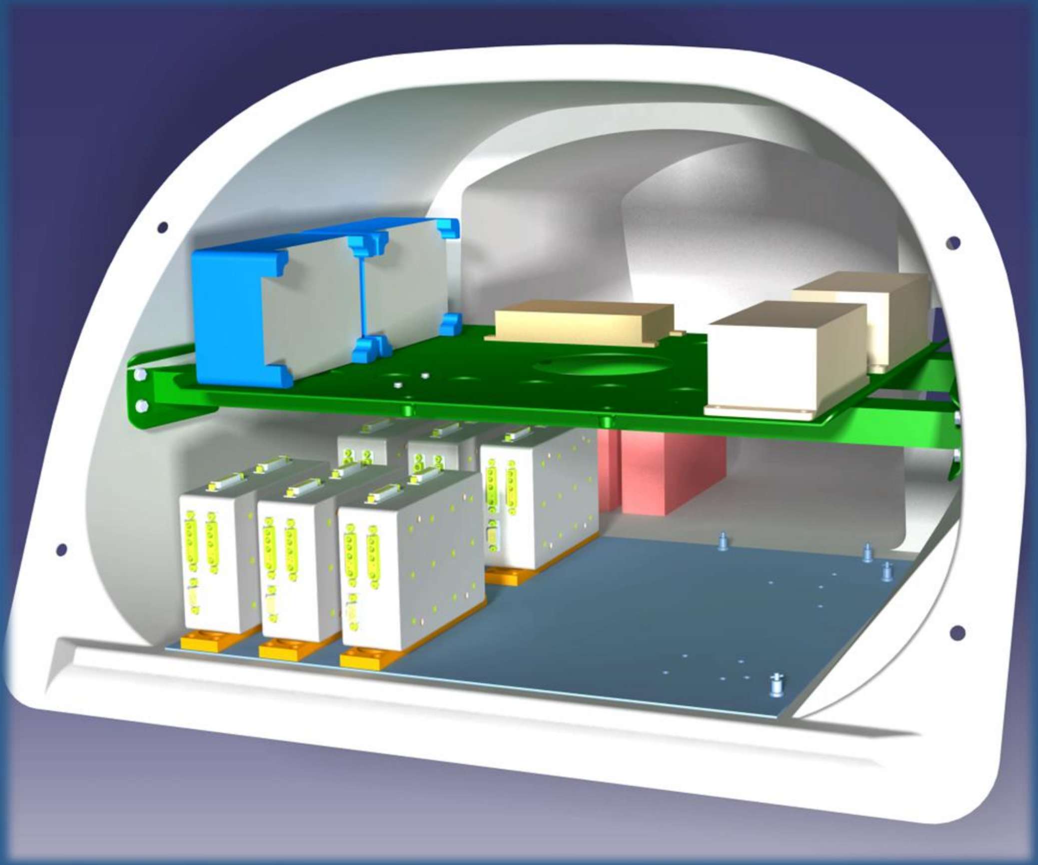
19'' equipment rack

- Standard 19in computer rack
- Useful load: ~65kg
- Total height / available slots:
  ~ 650mm / 15 HU
- Depth:
  ~ 430mm / 5 DU
- Permanent installations:
  - Power Distribution Unit (1HU)
  - Flight Test Installation (4HU)
- Available rack space during EFCS operation: (340mm / 7-8 HU)



Aft baggage compartment equipment rack

- Ideal for small, removable or permanent equipment
- Three available sections for equipment installation:
  - far aft
    - W: 355mm
    - H: 400mm
    - D: 400mm
  - top front
    - W: 580mm
    - H: 200mm
    - D: 455mm
  - bottom front
    - W: 600mm
    - H: 200mm
    - D: 455mm



Flight Control Modifications

Experimental Flight Control System (EFCS) - Overview

Pilots Input via Active Stick

Flight Control Computer
(Control algorithm)

Sensor Inputs:
AD, IMU, INS, GPS, …

Secondary systems

Gateway Computer
(Plausibility check / Limitation)

Actuator

Variable / limited dynamics and torque

Reverse operation by safety pilot

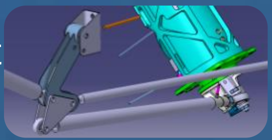
Overload Clutch

Mechanical override / disengage by safety pilot

EM Clutch

Mechanical disengage by crew / safety mechanisms / gateway

Attachment Point



Safety mechanisms

- Hard over detection
- Aircraft overload prevention

Legend:
Red Frame = Safety System

Safety Strategy – Overview & Principles

- **Components to be certified:**
  only based on mechanic & electric solutions – NO SOFTWARE

- **Limitation of effects by dimensioning:**
  - Limited actuator power – deflection, rate, torque –
  - Limits from aircraft dynamics (Stick force per G, CS/FAR23,…)

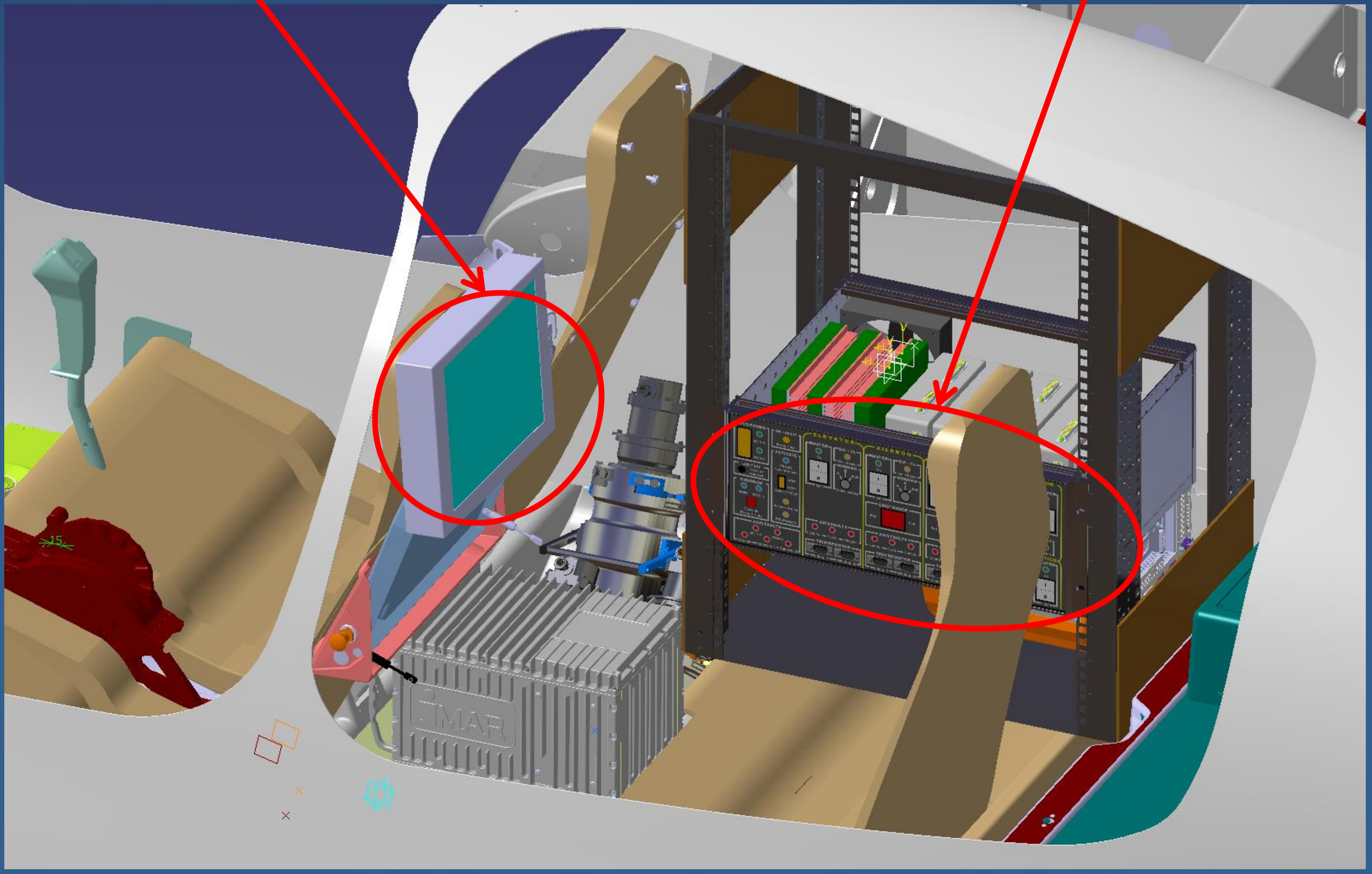
- **Multistage Concept:**
  - Limited Actuator Authority and Reverse Operable
  - Friction Safety Clutch (Max Torque)
  - Electromagnetic Clutch – Permanent Push Button
  - Automated Deactivation of Active EFCS Components: g-switches, Limit switches
  - Emergency Deactivation of whole EFCS – RED EMERGENCY STOP
  - Emergency Deactivation of whole Mission Bus Power Supply

- **Additional Voluntary Steps (Beyond Certification):**
  - Gateway computer with software based limitations
  - System & Software Development Process / Assessment / HIL…

Control and Operation System

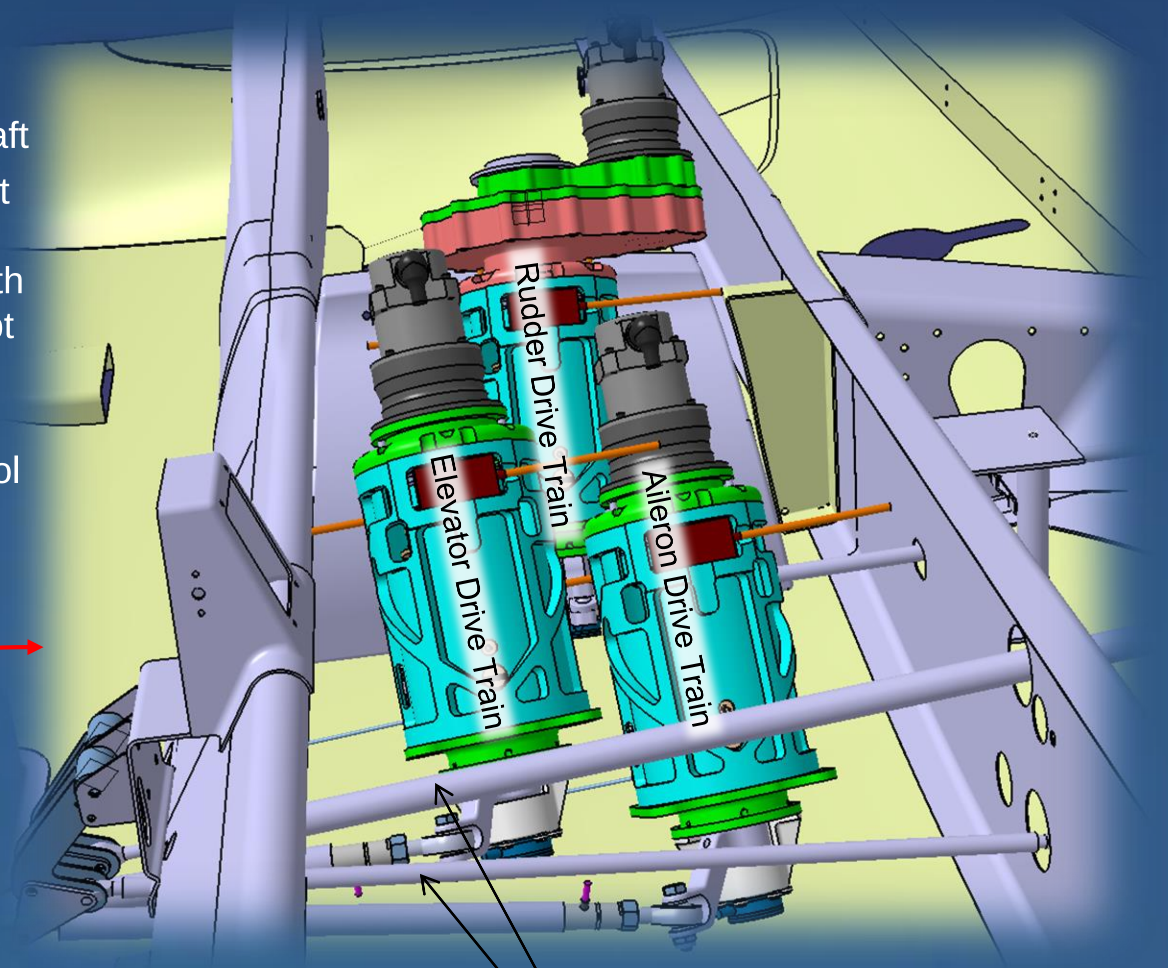
Digital status panel and FTI interface

User panel engages/disengages control axis, indicates status



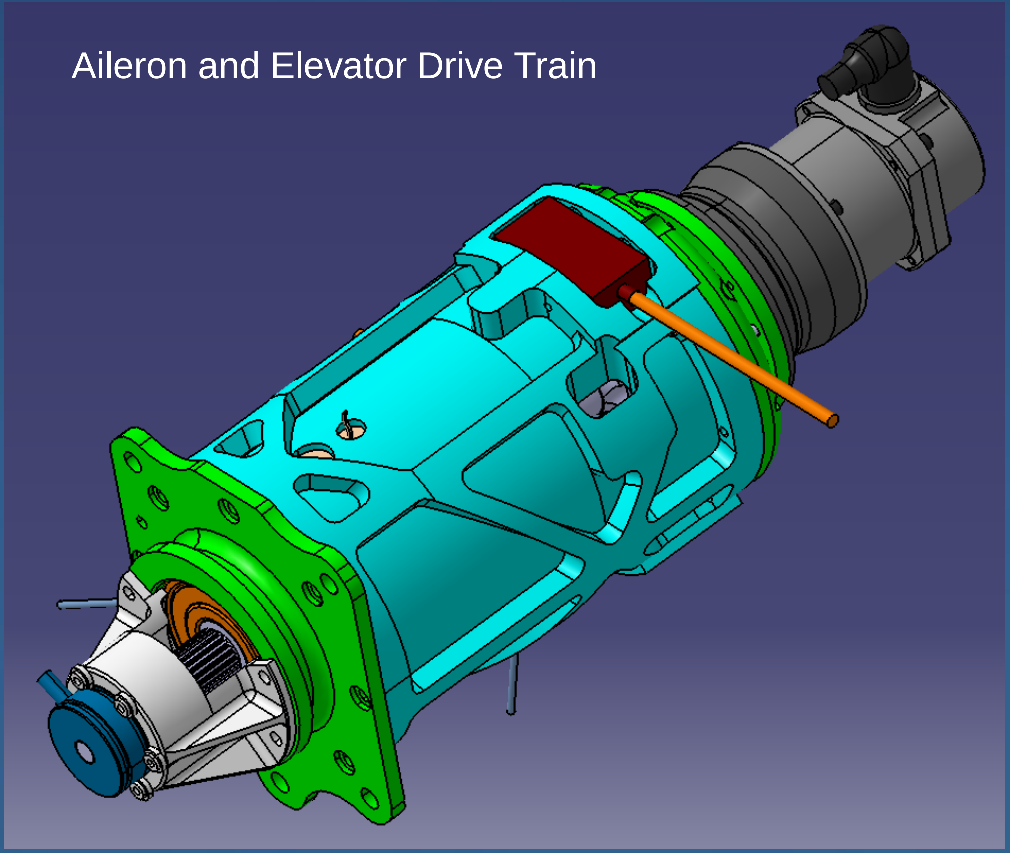
EFCS – Primary Drive Train Integration

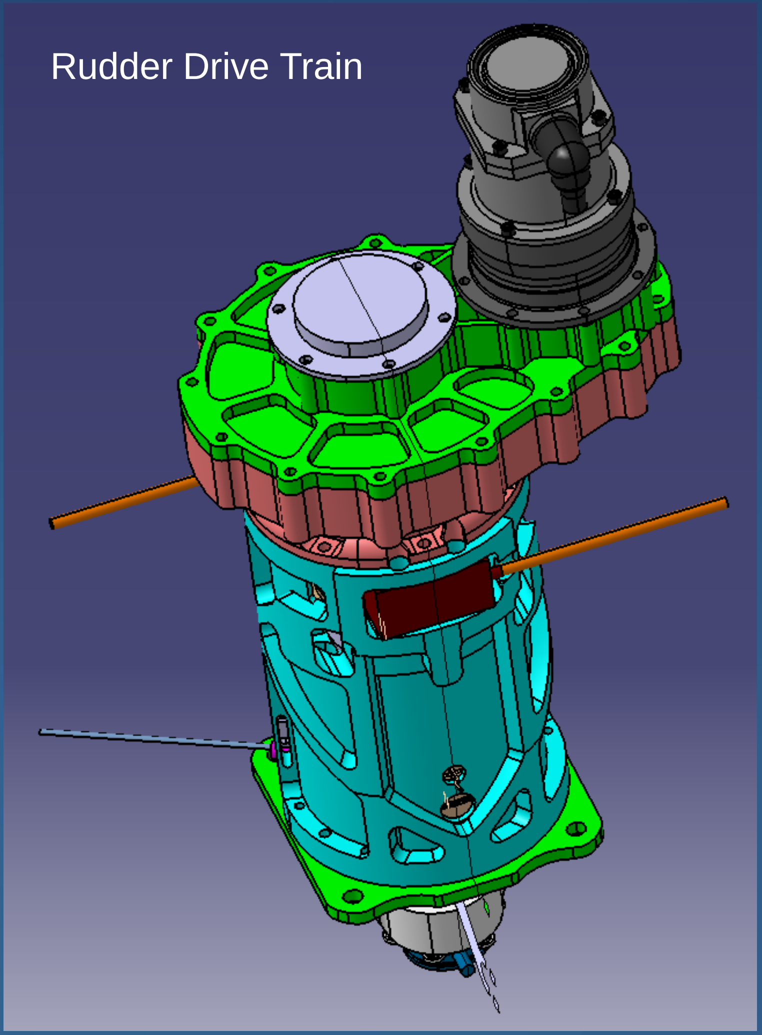
- All Primary Drive Trains are easily accessable in the body of the aircraft
- Primary Drive Trains are carried out as a modular construction system (Rudder Drive Train is equipped with an additional wheel section to adapt rotation speed and drive torque)
- All Primary Drive Trains are connected via an attachment control rod and an idle lever to the basic flight control system of the Aircraft



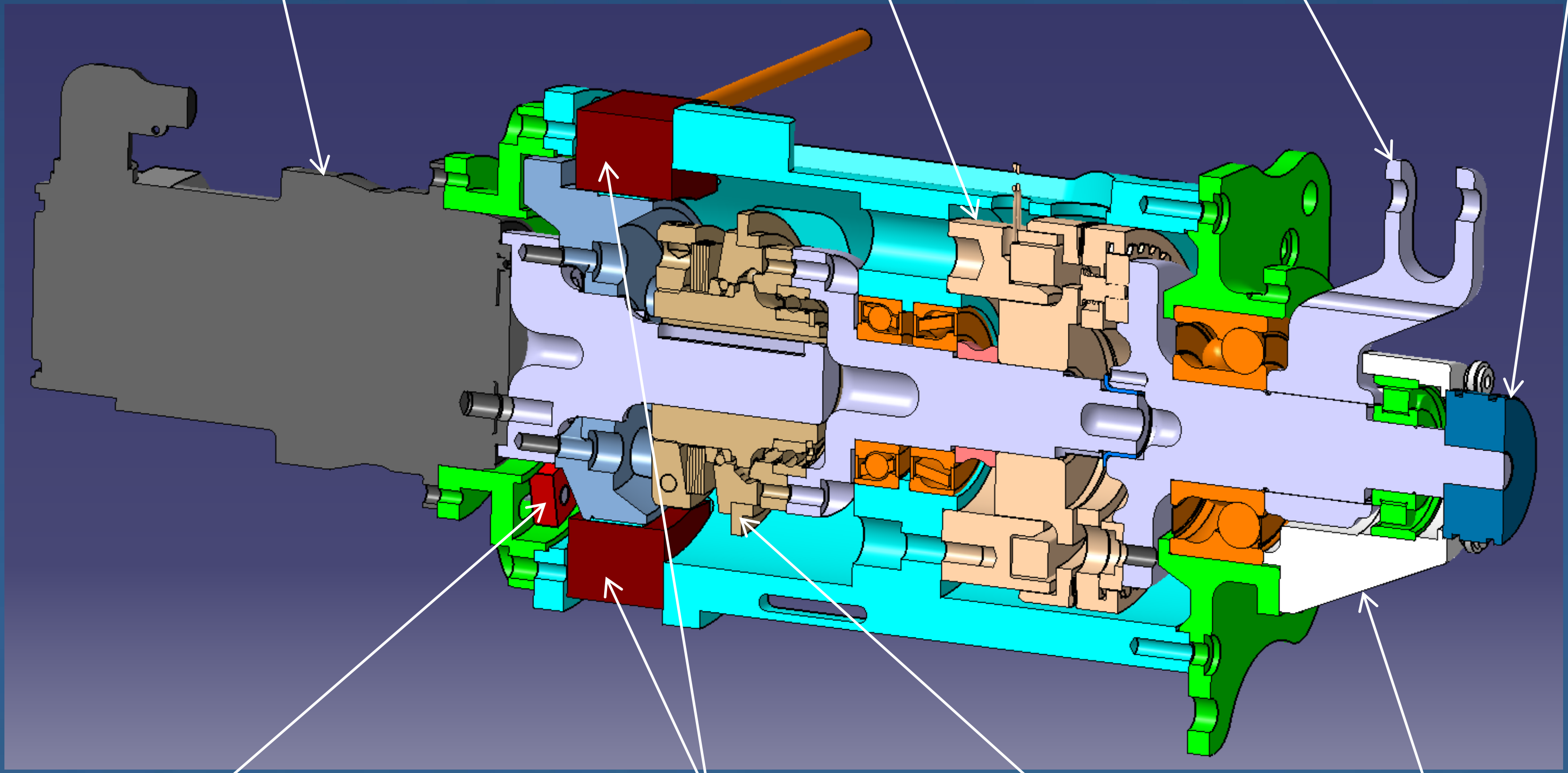
Basic Aileron Flight Control System
Basic Elevator Flight Control System

EFCS – Control System Drive Train

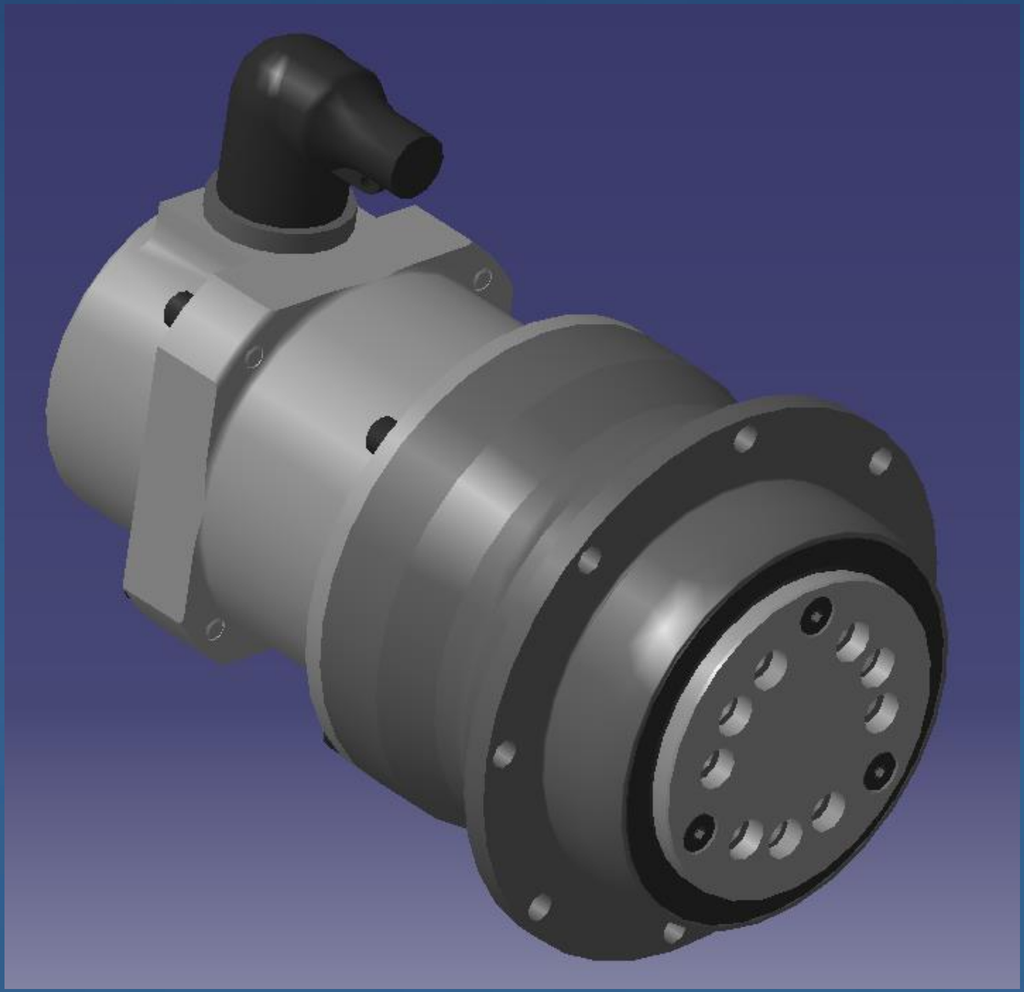




EFCS – Construction of the Drive Train Integration



EFCS – Control System Actuator

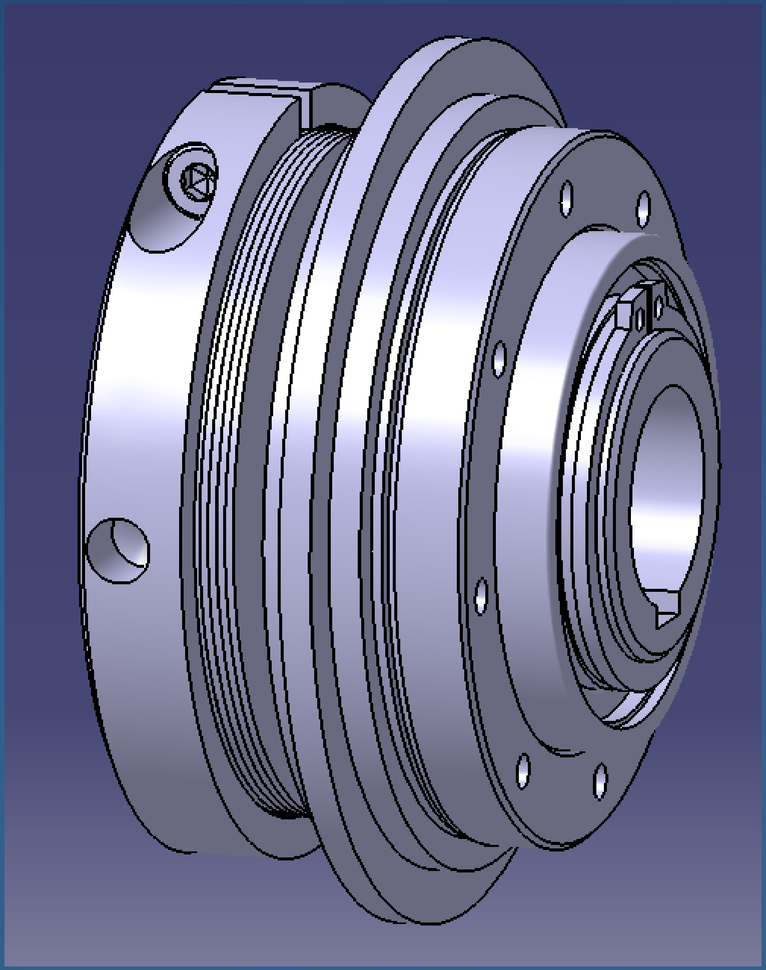


- **Smart Actuator**
  - Internally redundant motor winding
  - Single output shaft
  - Twin-stage planetary gear
  - Max 50Nm
  - Torque and Speed can be limited via power supply

  - External Redundant Electronics
  - 4x Arinc 825 (CAN) interface
  - FPGA/Soft Core controller for smart functions
  - Additional I/O options

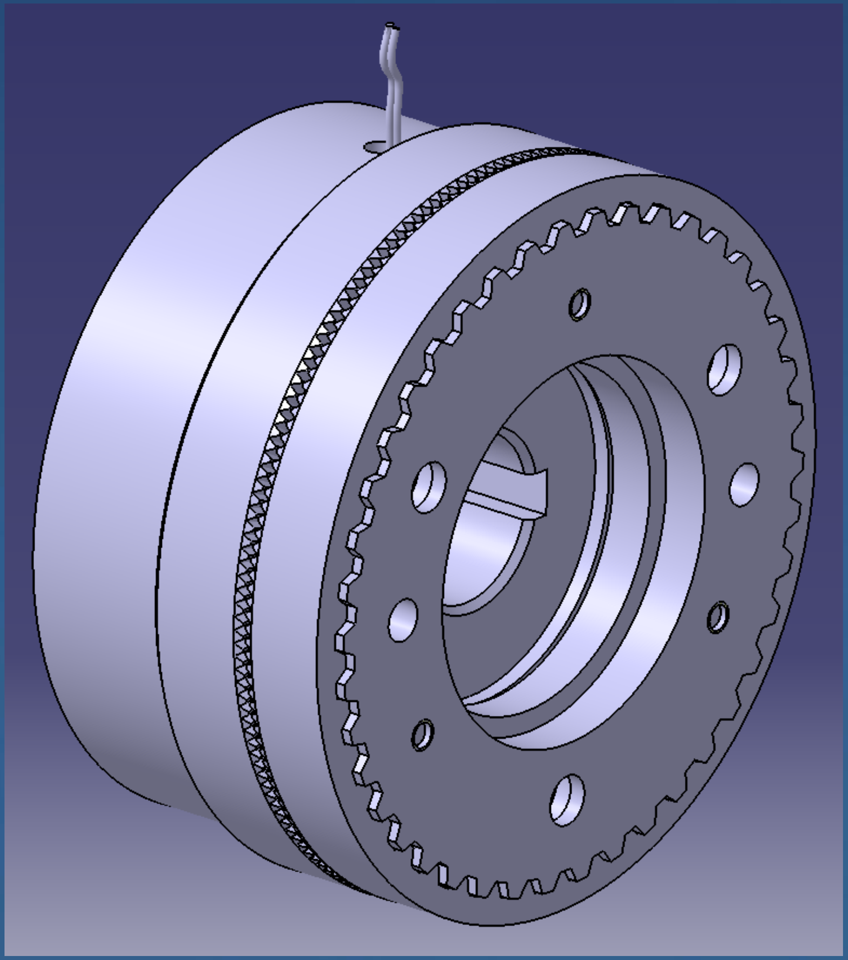
  - 1.7Kg

EFCS – Overload Clutch



- **Overload Clutch**
  - Immediate decoupling in the case of overload
  - mechanically disengaging
  - Permanent free of play (non-wearing) in case of torque transmission
  - Adjustable overload torque
    form 32 [Nm] up to 82[Nm]
    (for every primary control system can by used the same Overload Clutch)
  - Compact and light construction
    0,87 [kg]

EFCS – Electromagnetic Clutch

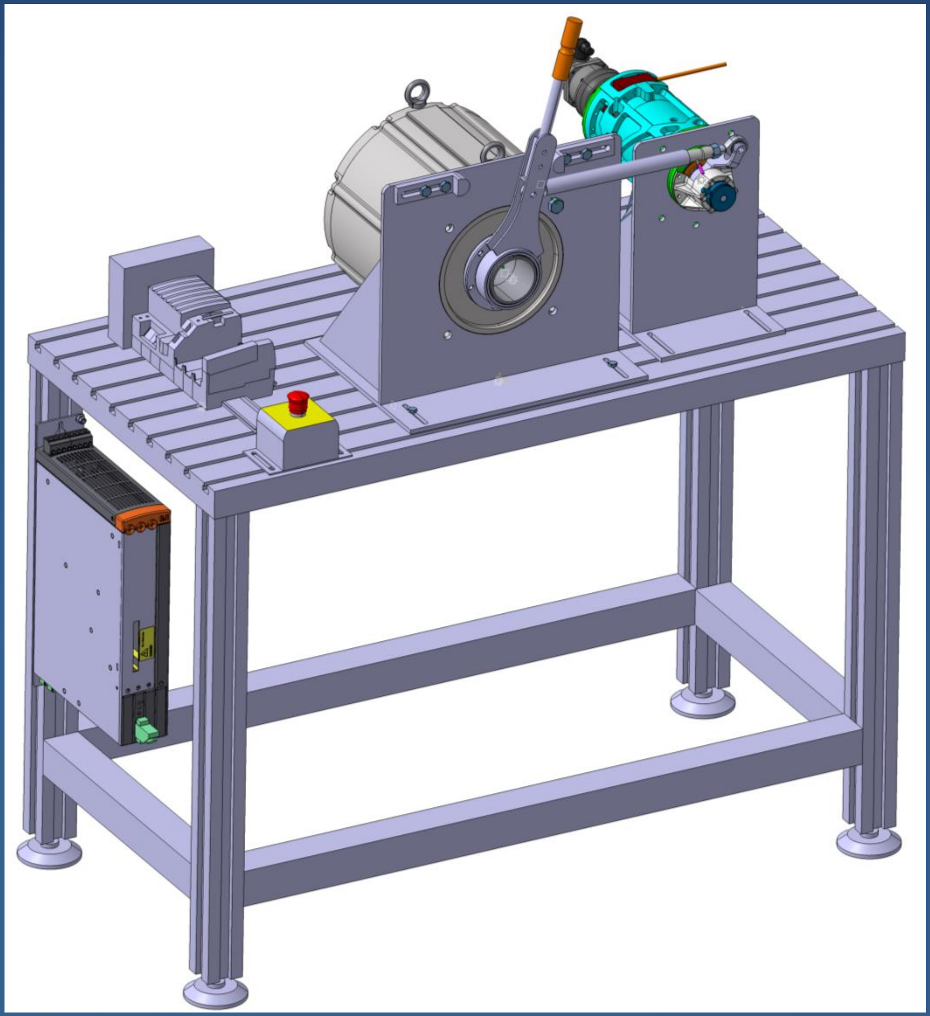


- **Electromagnetic Safety Clutch**
  - Developed for safety-critical applications
    (“critical for personal safety”)
  - Decoupling independent of the load conditions (non self-locking)
  - Permanent free of play in case of torque transmission
  - Non slip ring (non brush sparking)
  - Max. Load torque 90 [Nm]
  - Compact and light construction 1,749 [kg]

EFCS – Drive Train Test Bench

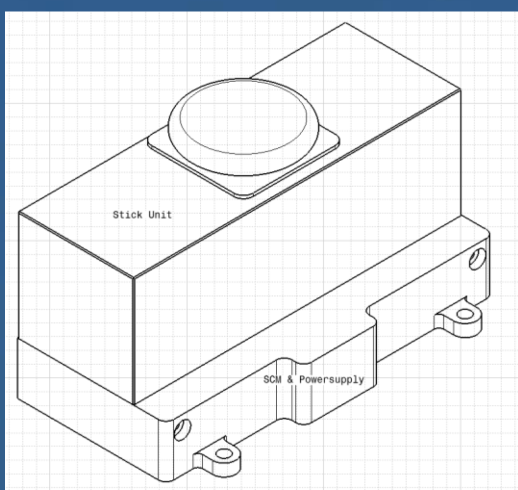
- Based on B&R Automation components
- 100Nm torque motor

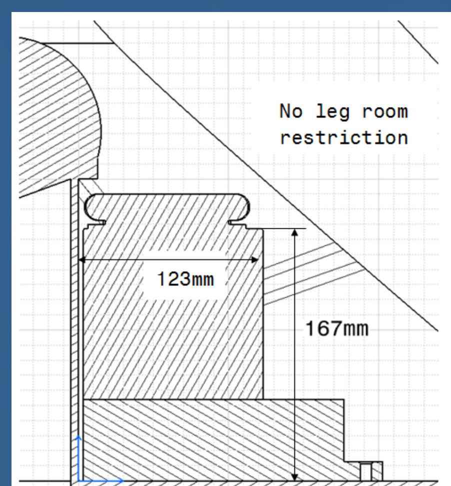
- Designed for
  - Initial operation tests
  - Calibration of sensors
  - Software development
  - Endurance tests
  - Permanent HIL operation

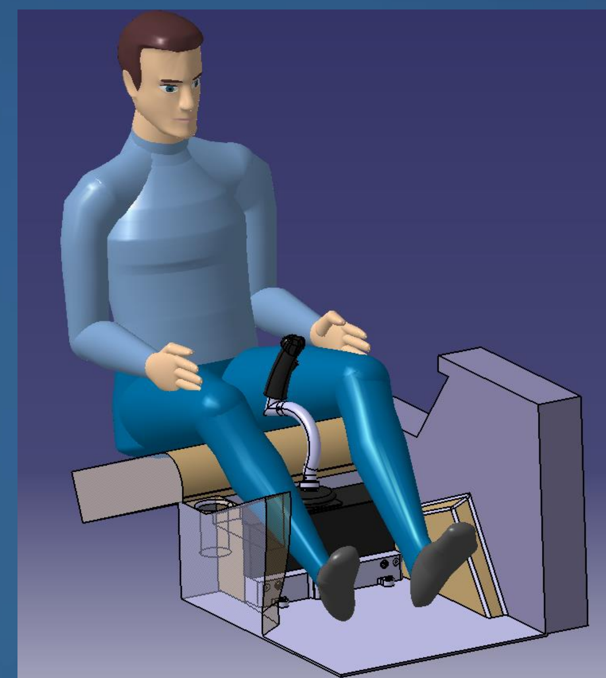


Control System Components - Active Control Stick

- **Technical Data**
  - Based on reconfigurable active sidestick by Wittenstein A&S
    - Peak torque 62 Nm (510 lb.in), continuous torque 24 Nm (212 lb.in)
    - +/- 18° travel in each axis
  - Modified as center stick to replace mechanical control stick
    - Extended stick to maintain position of conventional aircraft control stick
    - Installation in front of right pilot seat
    - Stick force at grip: 200N (43 lbf.) peak, 80N (17 lbf.) continuous
    - Equivalent to Part 23.143:
      - Pitch: 75% peak, 180% continuous / prolonged
      - Roll: 150% peak, 360% continuous / prolonged



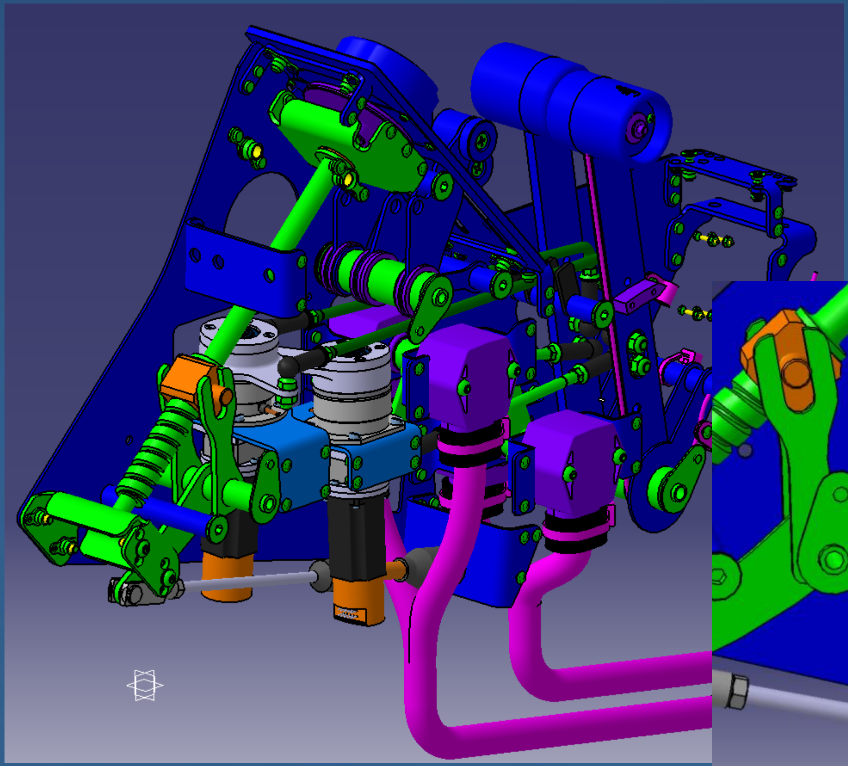


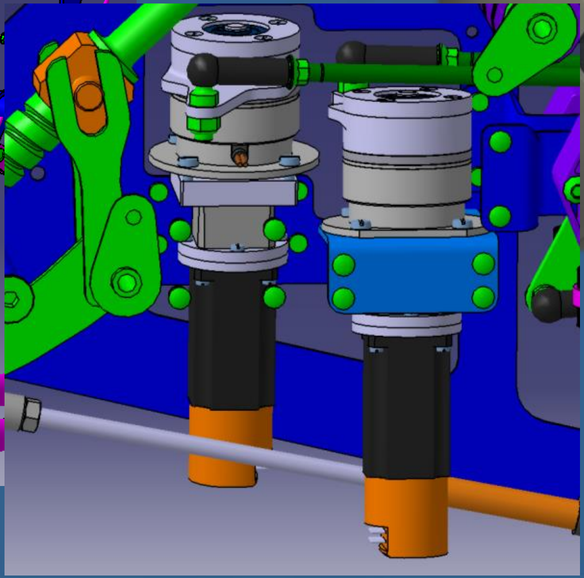


Control System Components - Auto Throttle – driven engine levers

- Compact solution within aircraft center console
- No direct control of power via EECU bus
- Engine control via back driven power levers

- Pilots can always overrule the auto thrust controller
  - Reverse operation is possible at any time
  - Actuators / motors designed for nominal friction lock
  - Tightened friction lock blocks actuator movement
  - Magnetic friction clutch reliably disconnects motors / gear
  - Friction clutch for redundancy and protection of motors

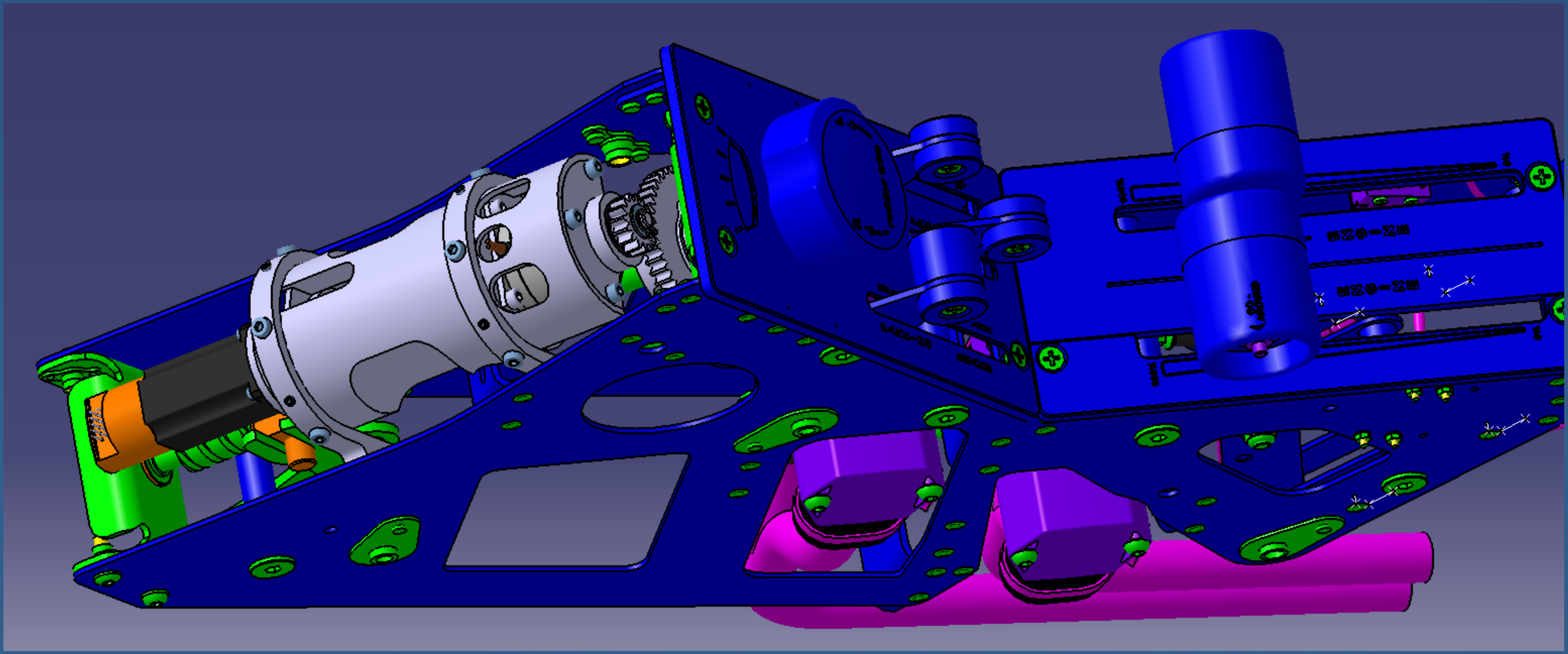




Control System Components – automated rudder trim

- Back driven trim knob
- Integrated within aircraft center console

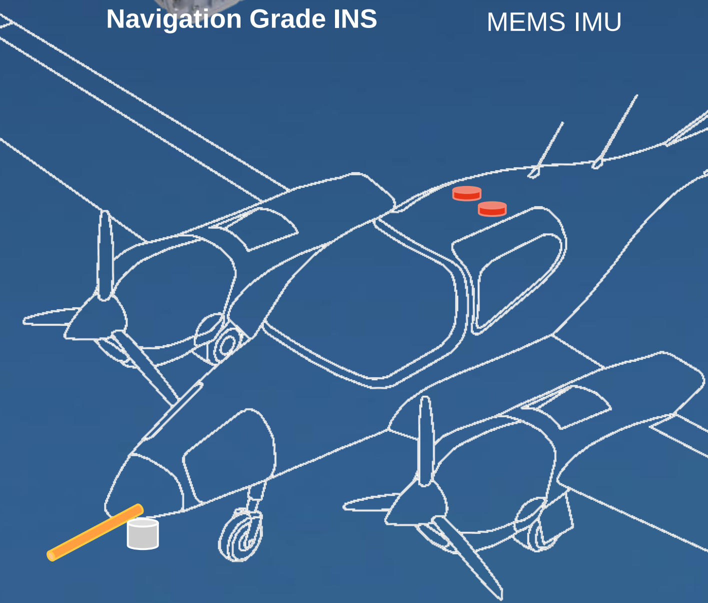
- Pilots can always overrule the auto thrust controller
- Magnetic friction clutch reliably disconnects motors / gear
- Pre-determined breaking point within inner gear attachment



Other Modifications and Equipment

Available Navigation Sensors

4x
multifrequency
GNSS Antenna



Navigation Grade INS

MEMS IMU

3x GNSS Receiver

3-Axis Magnetometer

UHF Data Link

Air Data Boom
Vanes

Radar Altimeter

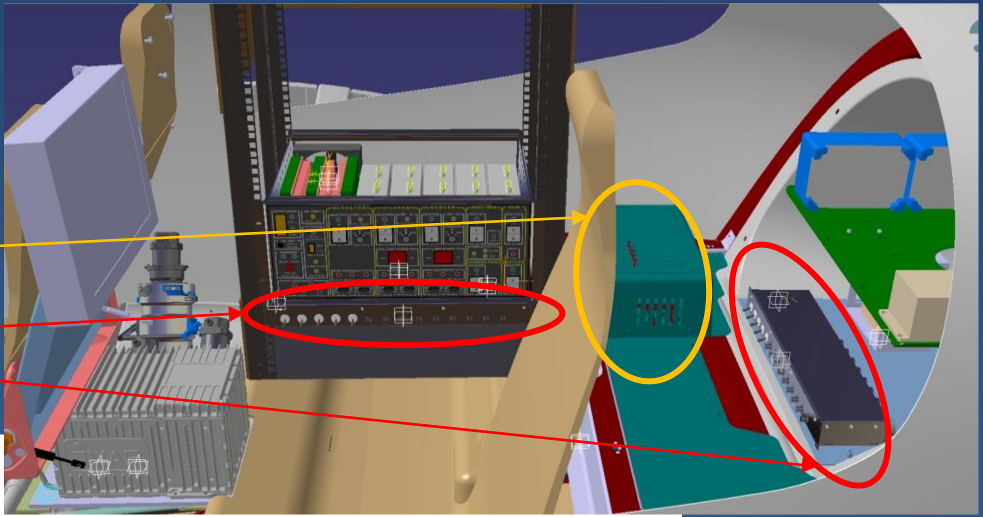
Laser Altimeter

Smart Air Data Boom

Mission Power Supply

- Total Available Power: 100A 28VDC
- Separate Generator on left engine

- Regular Mission Power Supply
- Power Distribution Panels



Mission Power Supply Connector Box

Output Specification	Output-Position		1	2	3	4	5	6	
	Available Voltage	[VDC]	28	28	28	28	14	14	
	Available Current	[A]	35	20	35	20	combined 7,5		
	Fuse	[A]	MS14105-35	MS3320-20	MS14105-35	MS3320-20	MS3320-7,5		
Device Specification	Device Name		EFCS 1	EFCS2	19in PDU	RBC PDU	Laptop PSU	FREE SPARE	Total
	Voltage	[VDC]	28	28	28	28	14	14	28
	Peak Current	[A]	35	15	12,23	9,46	6,5		74,94
	Peak Power	[W]	980	420	342,4	264,8	91		2098,2

19in Rack Power Distribution Panel

Output Specification	Output-Position		1	2	3	4	5	6	7	8	9	10	11	12	13	
	Available Voltage	[VDC]	12	12	12	5	5	28	28	28	28	28	28	28	28	
	Available Current	[A]	combined 6,3A@12VDC			combined 6A@5VDC		2	2	2	3	5	7,5	10	15	
	Fuse	[A]	combined 28VC/5A - MS3320-05 2TC14-5					MS3320-02 2TC14-2	MS3320-02 2TC14-2	MS3320-02 2TC14-2	MS3320-03 2TC14-3	MS3320-05 2TC14-5	MS3320-7,5 2TC14-71/2	MS3320-10 2TC14-10	MS3320-15 2TC14-15	
Device Specification	Device Name		10" TFT	7" TFT	HMR2300	Litef IMU	FREE SPARE	iMAR RQH-1003	PowerNecs AS	DCU Prodynamics	FCC1 & FCC2	FREE SPARE	FREE SPARE	APC incl. PL-Hub	FREE SPARE	Total
	Voltage	[VDC]	12	12	12	5	5	28	28	28	28	28	28	28	28	28
	Peak Current	[A]	4	0,7	0,4	2		1,6	0,6	0,5	1			6		12,23
	Peak Power	[W]	48	8	4,8	10		44,8	16,8	14	28			168		342,4

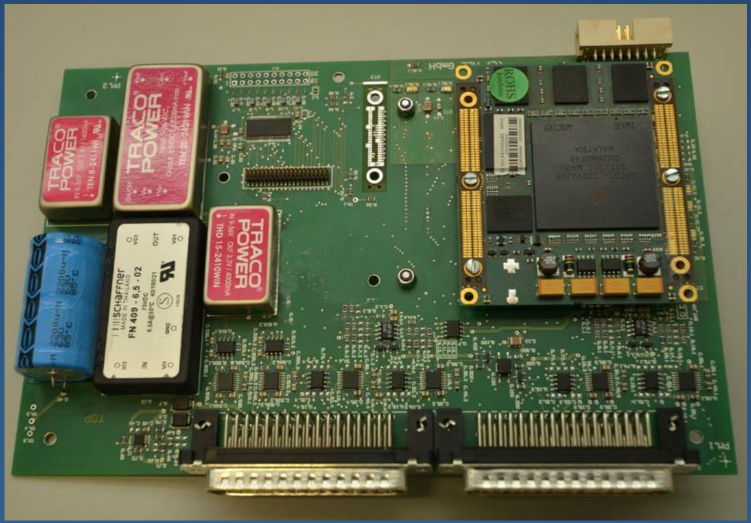
Rear Baggage Compartment Power Distribution Panel

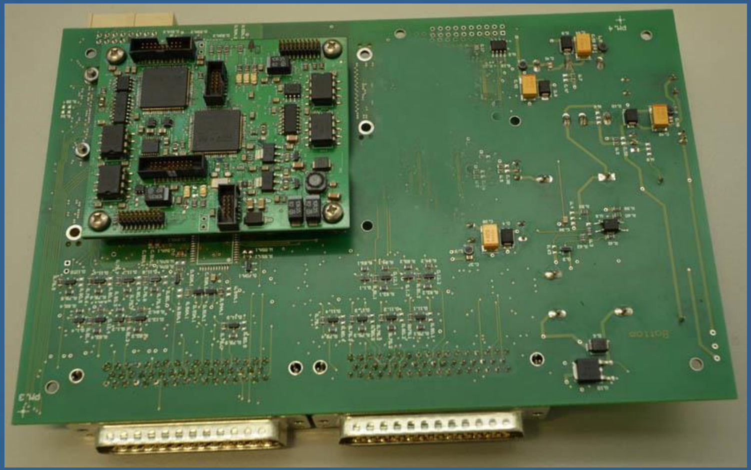
Output Specification	Output-Position		1	2	3	4	5	6	7	8	9	10	11	12	13	
	Available Voltage	[VDC]	12	12	12	12	12	28	28	28	28	28	28	28	28	
	Available Current	[A]	combined 6,3A@12VDC (optional upgrade to 8,8A@12V)					2	2	2	3	5	7,5	10	15	
	Fuse	[A]	combined 28VC/5A - MS3320-05 2TC14-5					MS3320-02 2TC14-1	MS3320-02 2TC14-2	MS3320-02 2TC14-2	MS3320-03 2TC14-3	MS3320-05 2TC14-5	MS3320-7,5 2TC14-71/2	MS3320-10 2TC14-10	MS3320-15 2TC14-15	
Device Specification	Device Name		Laser Altimeter	GPS Master	GPS Rover	FREE SPARE	FREE SPARE	Telemetry	FREE SPARE	PwrNecs G/W	Radar Altimeter	Powerlink Hub	P-o-CAN	FREE SPARE	FREE SPARE	Total
	Voltage	[VDC]	12	12	12	12	12	28	28	28	28	28	28	28	28	28
	Peak Current	[A]	0,5	1,1	1,1			0,2		0,6	0,5	1	6			9,46
	Peak Power	[W]	6	13,2	13,2			5,6		16,8	14	28	168			264,8

Flight / Display Control Computer FCC / DCC

General Description

Development of a certifiable avionics platform for research and demonstration of algorithms in a closed to product environment together with industry partners. The focus is on a scalable and modular system which can be used in different applications.





High Performance Power PC Architecture:
- 670 MHz performance (available with separate graphic controller)
- Double precision floating point unit
- High speed interface to I/O module

Cortex M I/O Interface Module
- Featuring two I/O processors
- Providing up to 10 UART interfaces, 4 ARINC 825 Interfaces, 2 ARINC 429 Interfaces, 4 12 bit analog inputs and multiple discrete I/Os

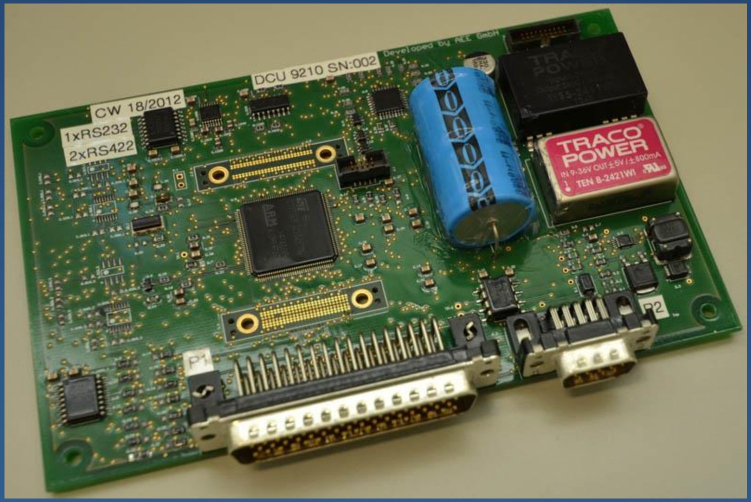
Extendable Platform Configuration
- Single string for simple applications
- Redundant system with high speed interface between two lanes
- Fail operational triplex system with internal redundancy

Certification Aspects
- All used processors and complex elements already in use in aerospace systems (COTS)
- System was design to ensure easy testability

Data Concentrator Unit

General Description

- Bus Interface to supplement FCC / DCC platform with additional interfaces distributed over the aircraft



Cortex M Micro Controller
- 72 MHz fixed point CPU
- Providing 1 ARINC 825 bus interface, 6 analog inputs, up to 5 UART inputs and multiple discrete I/Os

DCU Stack on Board
- If required, an additional stack on board can be mounted, offering additional interfaces like discrete I/Os, interfaces to actuators or to other databusses

Additional Infrastructure beyond the Aircraft

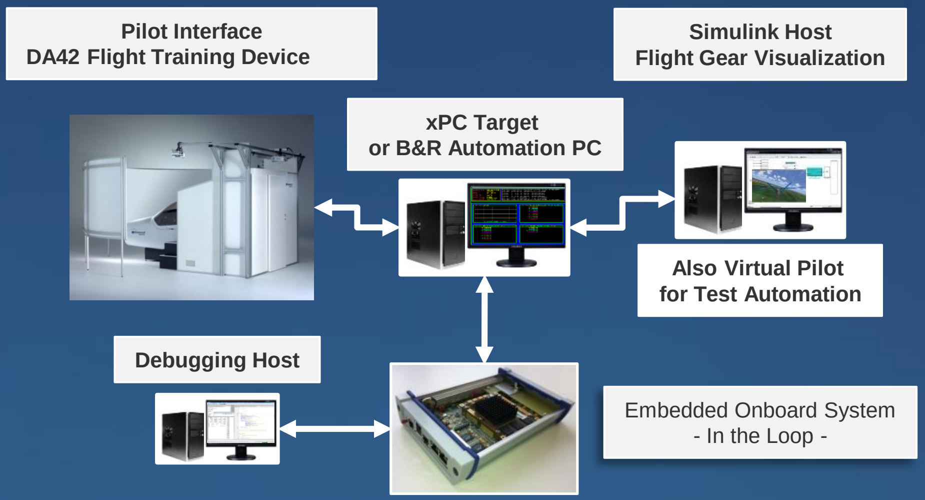
Available Infrastructure at FSD

- **DA42 "Iron Bird"**
  - Original DA42 airframe
  - Includes complete mechanical control system
  - No avionics or systems

- **Diamond Simulation D-SIM-42NG**
  - Type specific DA42NG FTD Level 6
  - Fully equipped simulator including
    - G1000 avionics and cockpit
    - High fidelity control loading system

- **Application Levels**
  - Concept proving and component testing
  - Networked simulation with FTD and Iron Bird linked via data bus, e.g.:
    - HILS and SILS
    - Power consumption
    - Control law test
    - Pilot and operator training
  - Mechanical fitting and ground verification of experimental systems

Hardware in the Loop Testing



General Description

Test bench for integration testing of fly by wire system. Focus on performance, robustness and interface testing. Reuse of controller development plant model and requirements based test cases. Integration of HIL testing and flight simulation through direct interface between DA42 flight training device and HIL test bench

MathWorks xPC Target Simulation Desktop

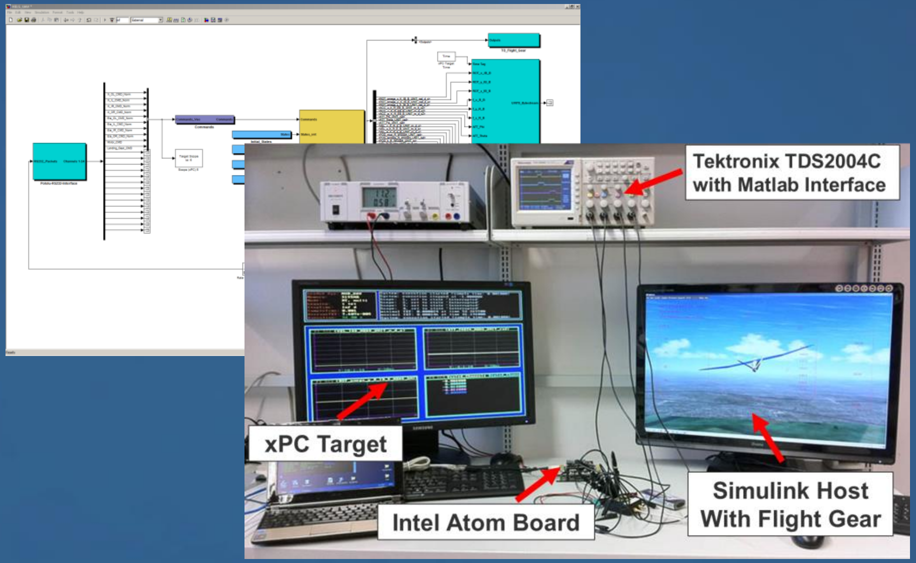
- Real time operating system running on standard desktop computer
- Fully integrated within Matlab/Simulink
- Multiple I/Os through National Instrument PXI System (supported by xPC Target)

B&R Automation PC, PLCs and Load Actuators

- Industry standard automation technology, supporting hard real time applications with up to 200 micro seconds
- Fully integrated within Matlab/Simulink
- Mulitple I/Os through B&R X20 interfaces

Additional Equipment

- Tektronix Oscilloscope
- Vector CANoe for ARINC825 simulation and testing
- Multiple Lauterbach Debuggers, 500MHz logic analyzer and stimuli generator

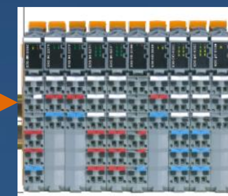


OE-FSD Total System Simulation (HIL)

B&R APCs
Real-Time PCs

B&R X20 I/Os – Output of all simulated data over real physical interfaces using real protocols
(discrete & analog I/O, UART, CAN/A825, or other types as required)

real time



Actuator test bench

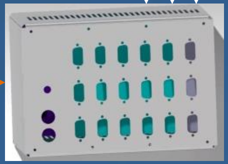
Data Link Simulation

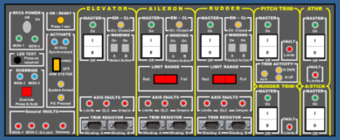
OE-FSD Simulation
- Flight Dynamics
- Exp. Flight Controls
- Sensors
- Other Systems

Real FTI
interfaces

- Physical data link interfaces (CAN, UART, etc) as in aircraft
- Real protocols for data transmission
- Real connectors where beneficial

real time





1:1 OE-FSD Flight Systems Test Installation
- 1:1 Setup **<u>as in real aircraft</u>**
- Data recording of all sensors and systems
- Provision for monitoring of experimental systems
- Data link and telemetry interface

Real FCC Hardware
- real FCC with mission software
- FCCs can be fully tested before flight
- Debugging and programming equipment

Real Safety System Hardware
- real DCU with final software
- permanent verification of system behavior
- significant increase in operational time
- Debugging equipment

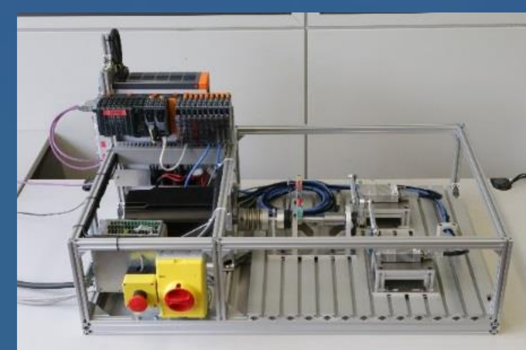
Pilot and Operator HMIs, Simulator Cockpit
- real cockpit controls
- real control panels
- has impact on system simulation
- has impact on real hardware

Further DA42 Relevant Infrastructure

Single Axis FbW-Actuator Testbench
with load machine capable of simulating DA42
control system loads

D-Sim 42NG Cockpit
level 6 flight dynamics for general simulation
(for development simulation only level 5!)
cockpit reflects current layout of OE-FSD

Full size DA42 iron bird
with full mechanical control system



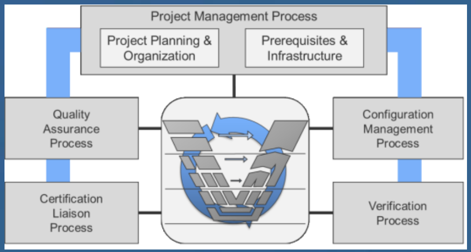
Dual Axis Testbench for smaller actuators
for redundancy testing and development
smaller load machine

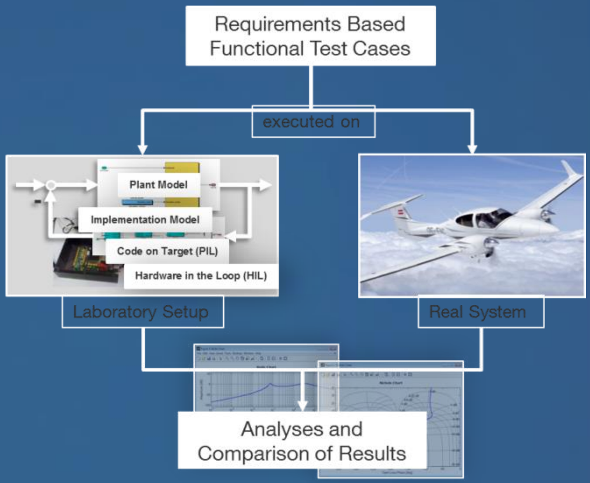
Current Projects

Projects: FLYSMART

Development of an certifiable autopilot for CS-23 Aircraft using modular avionic components

- Optimization of Model-Based Software Development Methods and Techniques
- Formal and Integral Process Definition for Model-Based Software Development
- System and Software Requirements Synthesis, Capture and Validation
- Safety Assessment
- System and Software Development
- System and Software Integration, Test and Verification





Projects: FLYSMART

Development Process & Certification

Aircraft/ System Environment

System Architecture

Sensors 

HMI 

Databus — Databus

Flight Control Computer
- Software
- Hardware

Databus — Databus

Display 

Actuators 

RUAG

WITTENSTEIN

MicroSys

Designed to fly — Michael Stock Flight Systems

aircraft electronic engineering gmbh

SILVER ATENA

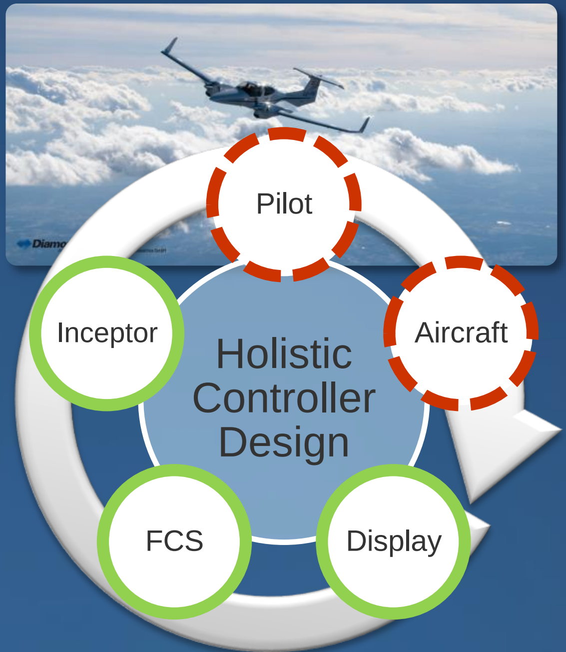
Embedded Office

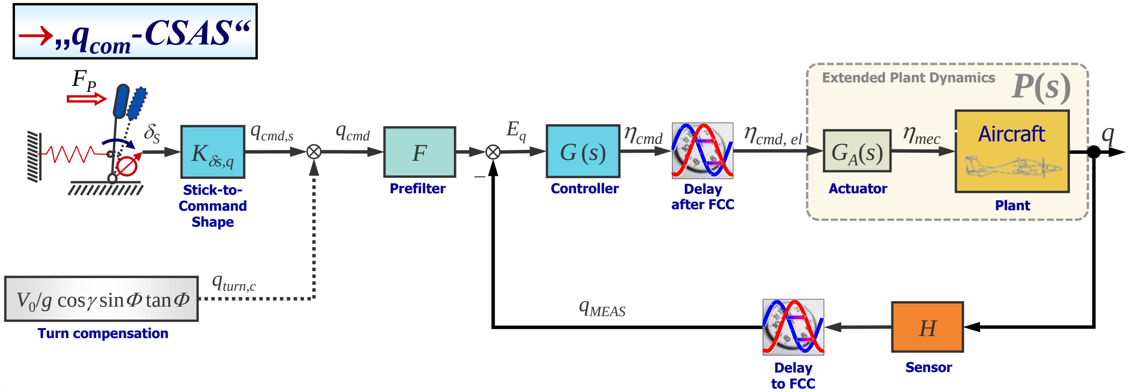
iMAR

philotech

Longitudinal Robust Controller for Excellent Handling Qualities Design

- Beside the fixed subsystems of aircraft and pilot, both inceptor, display and FCS must be setup harmoniously to gain excellent Handling Qualities
- FbW Controller Design with focus on General Aviation (CS 23) Aircraft
- Controller design featuring Handling Qualities based design approach
- Controller design layout must be tailored to the general aviation aircraft constraints (available actuators, sensors and sensor signals, mechanical linkage design, control surface deflection limitations and aircraft dynamics)
- Controller design featuring maximum robustness (w.r.t. the whole flight envelope as well as any configuration changes)





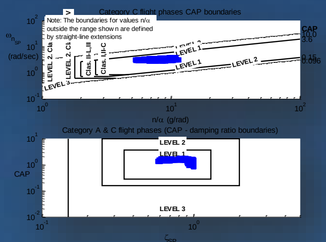
→ Quantitative Feedback Theory (QFT) has been applied to meet the desired criteria

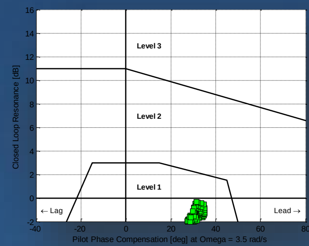
→ Inceptor (feel system design) is addressed explicitly

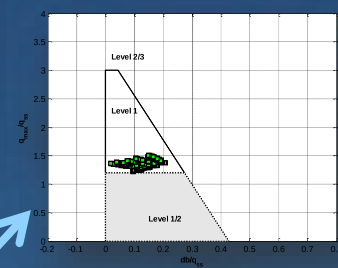
→ Implementation of active automatic safety features

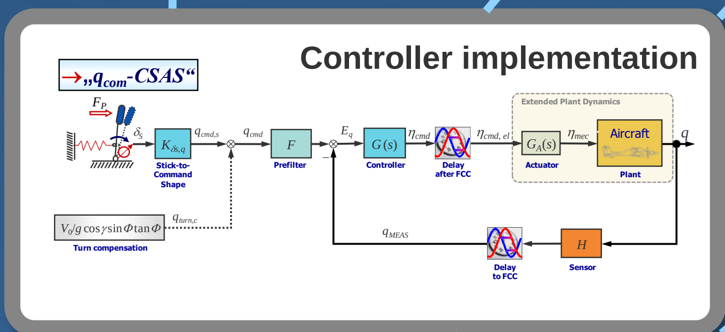
→ **Overall pilot workload reduction**

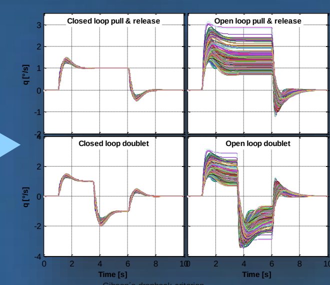
Longitudinal Robust Controller for Excellent Handling Qualities Design

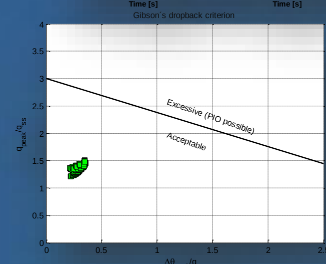


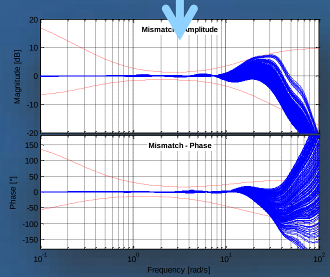


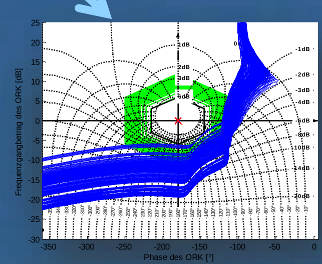








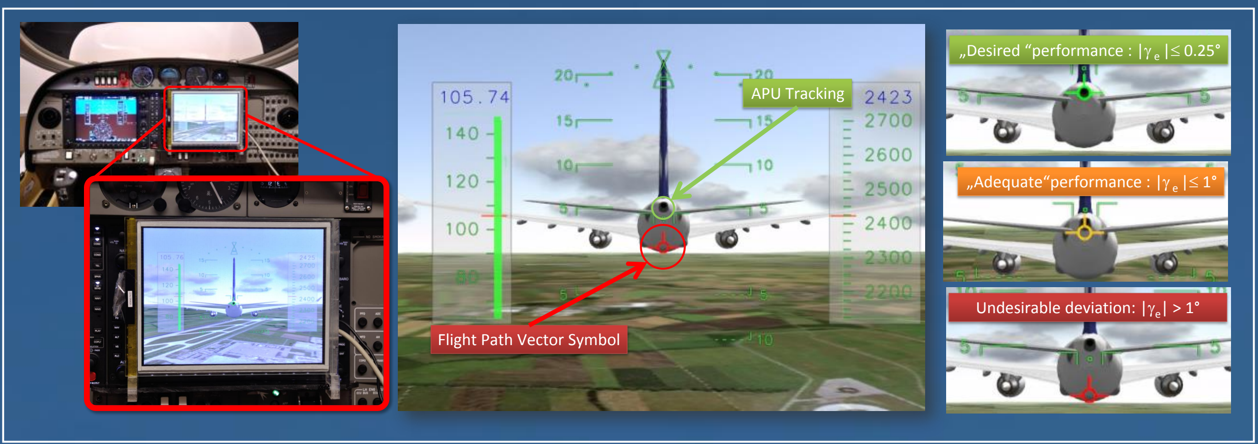


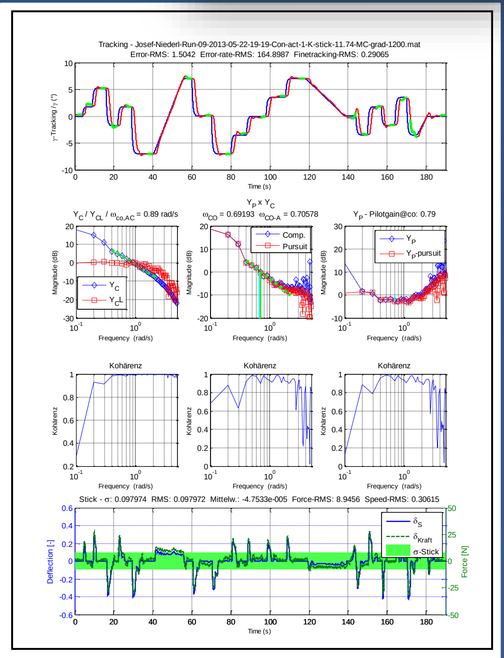


- Rate Command Attitude Hold (RCAH) System with featuring pitch rate feedback
- Representative delays and actuator dynamics included
- Automatic controller stability and Handling Qualities analysis featuring LOES (low order system generation) for all trim conditions and configurations (~12000 points)
- Automatic Gain design for the controller to comply the requirements for all 12000 points.

Longitudinal Robust Controller for Excellent Handling Qualities Design – Simulator Flight Testing

- In order to evaluate the controller together with the feel system as well as stick gain simulator flight tests have been conducted
- In total 8 pilots joined the simulator flight tests (7 of the are hobby pilots, one is a professional test pilot)
- Flight test scenario was a formation flying like flight path tracking task





- Detailed time domain and frequency domain analysis has been performed
- Quantitative error metrics showed high agreement with the pilot ratings
- Presented flight test scenario was highly accepted by the pilots
- Pilots ratings (CHR) were remarkably consistent

Lateral Fly-by-Wire Control System dedicated to Future Small Aircraft (FSA) - Motivation

Fact: "Significant Higher Accident Rate within the General Aviation Sector compared to Common Transport Aircraft!" **[Flight International July,2008]**

- Main Reasons:
  - General Aviation pilots generally have a relative <u>low training level</u> and <u>small number of flight hours</u> compared to airliner pilots
  - General Aviation aircraft do not feature various beneficial pilot assistant systems like Active Flight Control Systems which provide superior Flying and Handling Qualities (MIL Level 1*) and reduce pilot's workload significantly

- Solution:
  - Provide specifically tailored FbW FCS technology suitable and in particular affordable for GA airplanes

- Our Challenge and Duty:
  - Universal Controller Structure for GA aircraft lateral dynamics
  - Provision of an appropriate layout methodology ("MR DEA")

  Provision of excellent Handling Qualities and Pilot's Assistance

  - Development of an innovative approach for stability and robustness assessment (in order to facilitate certification)

Condition: Processes, tools and hardware solutions must be perfectly tailored to the specific needs of manufacturers of small and medium-sized planes

Lateral Fly-by-Wire Control System dedicated to Future Small Aircraft (FSA) – Primary Design Objectives

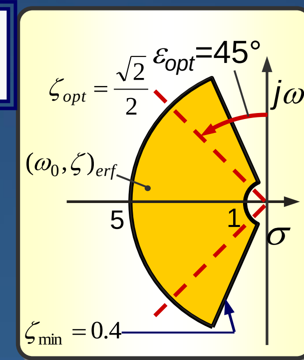
- Modification of Flying Qualities (Aircraft stability characteristics):
  Assignment of “optimal" damping, frequency and time constants

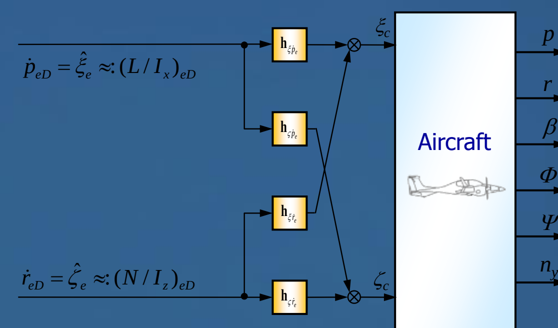
- Command Augmentation:
  - Rate Command / Attitude Hold (RC/AH) characteristics w.r.t velocity vector roll
  - Angle of Sideslip (AOS) Command / Zero Lateral Load Factor Assure
  - The provision of velocity vector roll and angle of sideslip command – in combination with attitude and zero lateral load factor hold, respectively – has shown to be very intuitive and predictable for the pilot.
  - Feed Forward Path Augmentation:
    Implementation of a “Direct Link" feed forward branch improves the aircraft’s control sensitivity and cancels out the integrator poles of the corresponding command transfers to obtain a more "crisp" control response

- Decoupling of control inputs
  (introduction of decoupled "auxiliary control effectors"):
  Maneuver coordination for decoupling of experimental roll and yaw axis shall be accomplished automatically by means of auxiliary control inputs

- Counteracting external disturbances (gusts/turbulence) and compensating for changes of the aircraft configuration:
  External disturbances as well as changes in the configuration (e.g. by deflecting the wing flaps, by a malfunction of an engine or by extending and retracting the landing gear) shall be suppressed efficiently

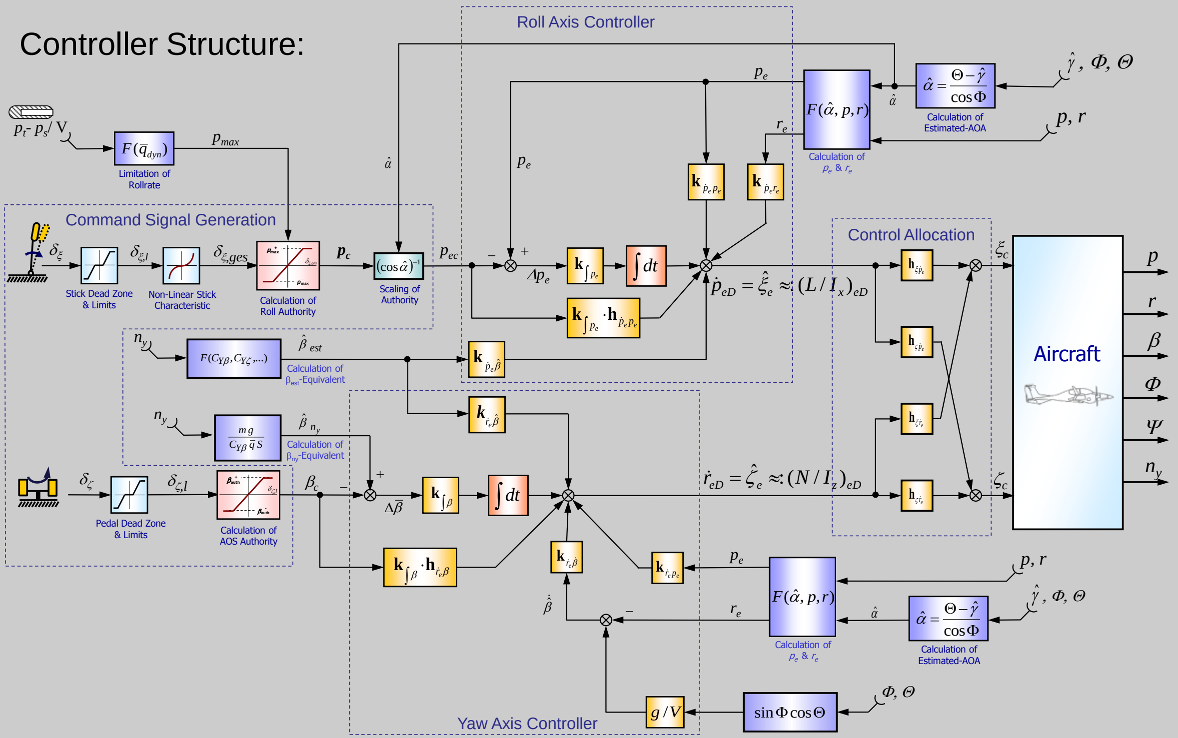
$$\zeta_{opt} = \frac{\sqrt{2}}{2}$$





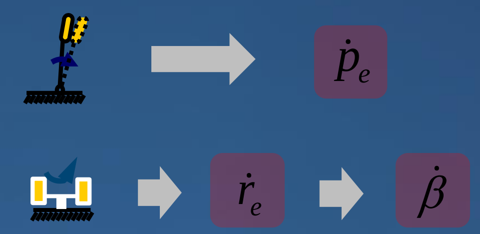
Lateral Fly-by-Wire Control System dedicated to Future Small Aircraft (FSA) – Controller Structure & Assessment

- Controller Structure:



Controller Structure consists of:

- Command Signal Generation



- Roll Axis Controller
- Yaw Axis Controller
- Control Allocation

- Stability and Robustness Assessment
  - *SISO* robustness analysis based on Nichols charts supports and facilitates the certification process
  - *MIMO* robustness prove (μ -Analysis) ensures robust stability and performance along the entire envelope with special regard to typical real-word system delays and parametric as well as dynamic uncertainties

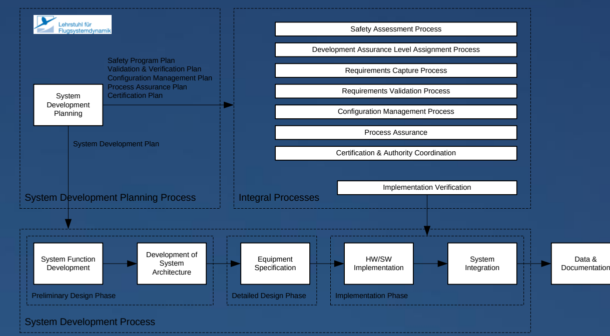
MEzA – Project Objective

Design of a *certifiable* avionics system consisting of an adequate system architecture and functional algorithms taking into account

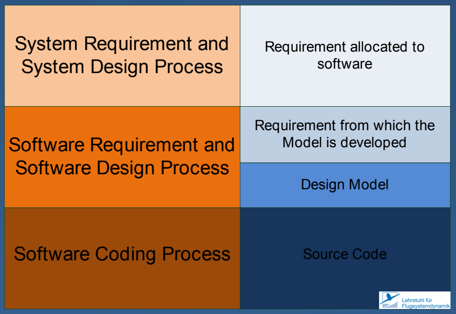
- ARP 4754A development processes and applicable certification regulations and standards
- Model Based Development according to DO-331
- Derivation of physically motivated performance requirements (no limitations due to human body)
- Challenges of unmanned flight (safety, etc.)
- Failures of systems within the system architecture
  - Sensors
  - Actuators
  - Busses
  - Flight Computers
  - Data Link

in order to use the full physics of the system for a good performance and furthermore achieve a high level of safety within the overall system.

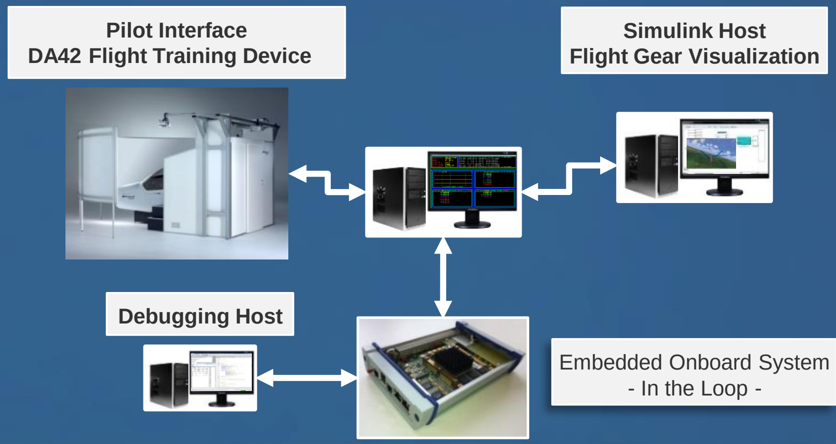
MEzA – Project Overview



- Definition of Process Chain and Tool Chain
  - Generic Process as base for future applications
  - Open to the public
  - Allow for smaller companies to develop certifiable UAVs
- Derivation of Safety and Performance Requirements based on Certification Standards

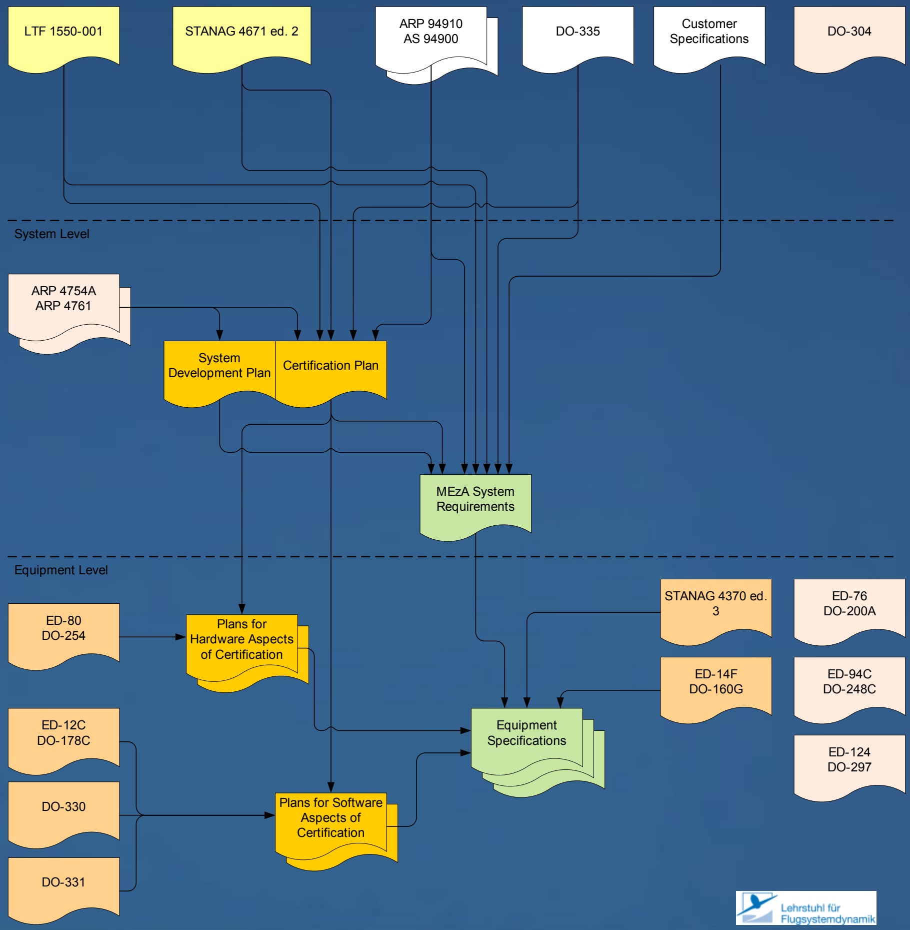


- Model-Based Development of Functional Algorithms for
  - Flight Control
  - Navigation
  - Data Fusion
- Implementation of the Generic Process
  - Reference aircraft: DA42M-NG OE-FSD, research aircraft of the institute
- Safety Assessment
  - Functional Hazard Assessment
  - (Preliminary) System Safety Assessment
- System and Software Integration, Test and Verification
  - Requirement Based Testing
  - Hardware in the Loop (HIL)
  - System and Aircraft Integration
  - Flight Testing
  - Analysis and Verification based on Flight Test Data



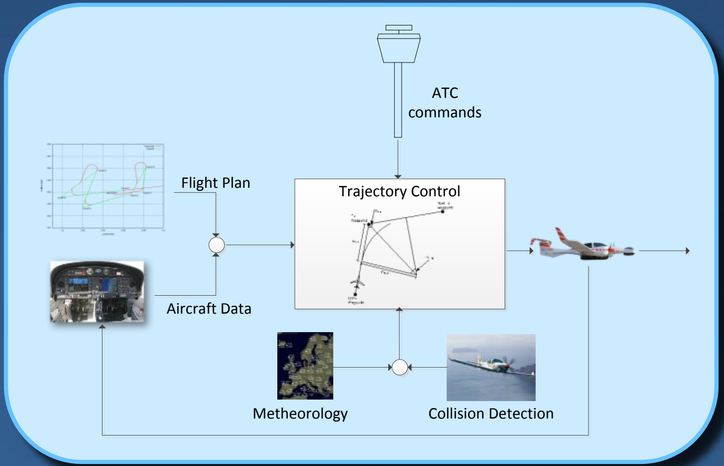
MEzA – Applicable Regulations

- UAV Airworthiness Regulations
  - NATO STANAG 4671 ed. 2
  - Lufttüchtigkeitsforderung LTF 1550-001 of the WTD 61
- Safety Assessment
  - SAE ARP 4754A
  - SAE ARP 4761
- Software Development
  - RTCA DO-178C
  - RTCA DO-330
  - RTCA DO-331
  - RTCA DO-200A
- Hardware Development
  - RTCA DO-254
- Environmental Testing
  - RTCA DO-160G
  - NATO STANAG 4370 ed. 3
- Flight Control System Specifications
  - SAE ARP 94910
  - SAE AS 94900
- Guidance Material for UAVs
  - RTCA DO-304

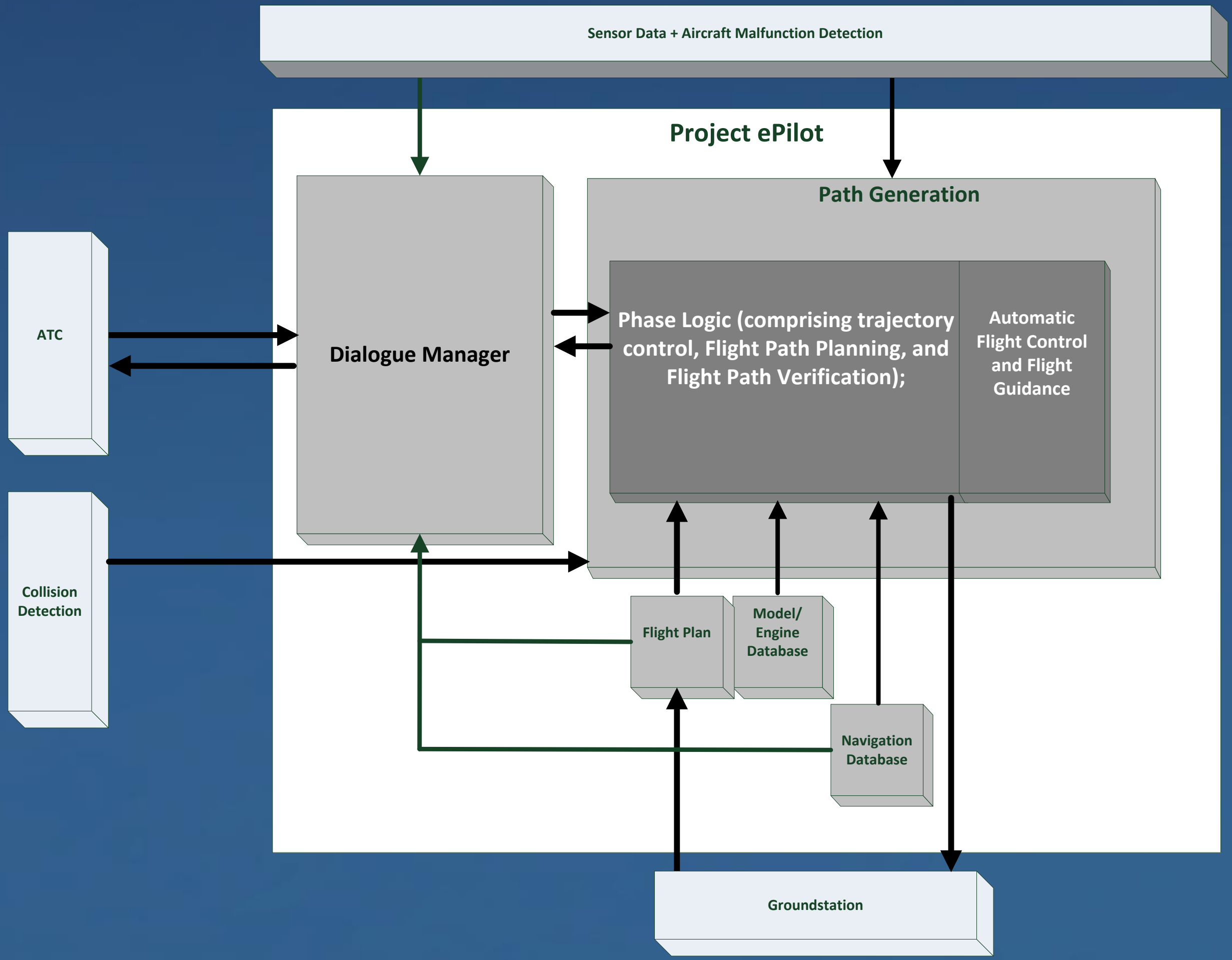


ePilot: Development of a Voice Command Autopilot for an Unmanned Aerial Vehicle (UAV)

- Development of an automatic flight guidance and control system
- Is desired for Unmanned Aerial Systems
- UAV shall operate within civil airspace without Ground Station commands
  - Collision Avoidance
  - Meteorological data consideration
  - Autopilot shall react directly on ATC commands and fulfill communication regulations of civil airspace
- Should be certifiable
- Demonstration on **DA 42M-NG OE-FSD** aircraft by simulation in ground simulator



ePilot

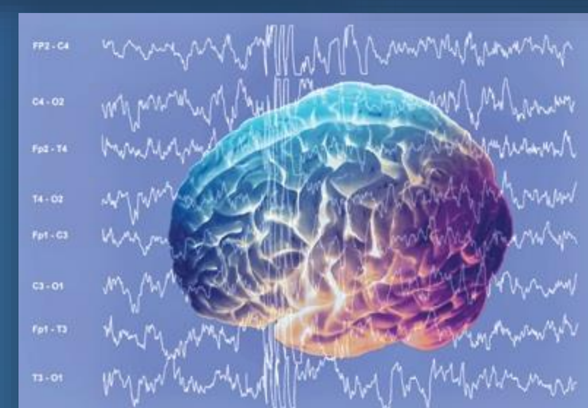


There are two main parts within the project:

1. Dialogue Manager:
   a. Receives and interpretes messages from the ATC
   b. Communicates the messages to the Phase Logic
2. Path Generation
   a. Generation of Controller-Commands out of the Flightplan-Data, ATC-Commands, Collision Avoidance and aircraft data
   b. Automatic Flight Control and Flight Guidance to achieve the commanded trajectory

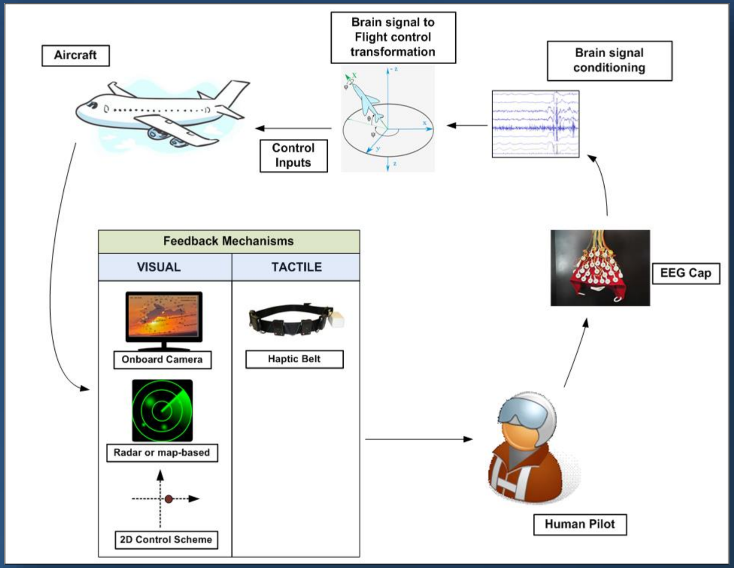
BRAINFLIGHT – BRAIN controlled aircraft FLIGHT using multiple feedback mechanisms

- Funding: 7th Framework Programme (Level 0 AAT)
  European Commission
- Partners: Tekever (PT)
  Fundação Champalimaud (PT)
  Eagle Science (NL)
- Project Duration: 2012 – 2014 (95,5 Man-Months)
- Institute's Share: 25%
- Project Goals:
  - Create a **novel approach** to aircraft control.
    Brain wave measurements (EEG) are used to control the aircraft, the pilot receives visual and tactile feedback.
  - **Assess the performance** of the concept.
    How do brain control and novel feedback mechanisms affect learning, performance and the ability to multitask?



BRAINFLIGHT – BRAIN controlled aircraft FLIGHT using multiple feedback mechanisms

- Brain Computer Interface – 2 approaches:
  - A relatively **new paradigm**, based on the definition of “nearly arbitrary” transformations that are learned and assimilated by the human brain.
  - **Reactive brain control**, using the steady state somatosensory evoked potential.
- Feedback Mechanisms:
  - Assessment and testing of feedback mechanisms for controlling the aircraft – complement visual feedback with vibro-tactile feedback.
  - Vibro-tactile stimuli are used for reactive brain control.
- Flight Control:
  - Formulation, formalization and quantification of **new or modified handling qualities requirements**.
  - Design a flight control system, cockpit displays and specific command filters.
  - Numerical assessment of the flight control system – compliance analysis.
- Validation of the concept:
  - Pilot in-the-loop simulation using the Institute’s DA42 flight training device.
  - Field test with an unmanned aerial vehicle.



Thank you very much !

Questions ?