SAFAR and follow-ons
Small Aircraft Future Avionics Architecture

Fly-By-Wire for CS23 Aircraft
Core Technology for General Aviation and RPAS

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VISION – Personal Air Transport

The ability of personalized air travel through the use of an on-demand, highly distributed air transportation

AUTOMATED AIRSPACE SELF-OPERATED AIRCRAFT

- SAFE
- COST EFFICIENT
- FLEXIBLE
- CAPABLE

*SATS, Nasa 2004
SAFETY – Automotive vs. Aviation

**COMPARISON AUTOMOTIVE VS AVIATION SAFETY**

- **CS25**
  - $P_{\text{VEHICLE}} \{\text{CAT}\} < 10^{-6}$
  - $P_{\text{CONTROL}} \{\text{CAT}\} < 10^{-9}$

- **CS23 / Class 1**
  - $P_{\text{VEHICLE}} \{\text{CAT}\} < 10^{-4}$
  - $P_{\text{CONTROL}} \{\text{CAT}\} < 10^{-6}$

- **Automotive**
  - $P_{\text{VEHICLE}} \{\text{CAT}\} \sim 5 \times 10^{-6}$
  - $P_{\text{CONTROL}} \{\text{CAT}\} < 10^{-7(8)}$

**DIFFERENCES AUTOMOTIVE VS AVIATION**

- **AUTOMOTIVE**
  - Safety (Integrity)
  - Reliability
  - Very High
  - Fail / Operational 10min

- **AVIATION**
  - Safety (Integrity)
  - Reliability
  - Very High
  - Very High

**SAFAR OBJECTIVES**

- **CS23 / Class 2**
  - Scalable to

- **CS25**
  - $P_{\text{VEHICLE}} \{\text{CAT}\} < 10^{-5}$
  - $P_{\text{CONTROL}} \{\text{CAT}\} < 10^{-7}$

  - $P_{\text{VEHICLE}} \{\text{CAT}\} < 10^{-6}$
  - $P_{\text{CONTROL}} \{\text{CAT}\} < 10^{-9}$
Fly-By-Wire - Core Technology

CS23 certifiable Fly-by-Wire

Mechanical backup for safety and certification reasons
Fly-By-Wire - Modules for aircraft control and automation

FBW system based on

- CPM (Core Processing Module)
- IOM (I/O Module)
- ACM (Actuator Module)
- SCM (Star Coupler Module)
- PDM (Power Distribution Module)

Design drivers

- DO 254 compliant design
- Certifiable
- Interfaces to redundant FlexRay busses
- EMI-, lightning protection
- Small, light, robust
- Cost efficient
Fly-By-Wire - Platform Architecture

Capable for

- Attitude hold
- Auto throttle
- Auto take off
- Auto climbing
- Auto cruising
- Auto approach
- Auto landing
FLY-BY-WIRE - Integration on Diamond DA42  1/2

Power Distribution  FBW Avionics

FBW Avionics  Power Distribution

3rd Brake Circuit (FBW controlled)  6x Actuators
FLY-BY-WIRE - Integration on Diamond DA42 2/2

- Power Distribution
- 6x Actuators
- FBW-Avionics
- 3rd Brake Circuit (FBW controlled)
- Test system
FLY-BY-WIRE – Instrumentation of DA42 Cockpit

Multi Functional Flight Control Unit

Emergency Disconnect
Lever
Stick

Safety Pilot
FBW Pilot
FLYFlexible Platform Approach

Integrated Avionics Architecture
- Application: „Law” and system-management API
- Abstraction: Hardware / OS

- Clear Separation of “Laws” and “System Management”
- Generic Approach of System Management (Platform Management)

Advanced Platform Architecture
- Application: “Law” (virtually simplex) API
- Abstraction: System (red. aggregates,..)
- Abstraction: Platform instance (red. modules,..)
- Abstraction: Modules (internally redundant)
- Abstraction: Hardware / OS
FLY-BY-WIRE – Software development via a tool suite

Tool-Suite

- DSL: Platform Architecture & Data Path
- DSL: Plama Structure
- DSL: SW Component

High Level System Specification (YHD)

Model: Platform Archit & Data Path

Model: Plama Structure

Model: SW Components

Parameter Source Code

Transformation

Design-Knowledge (Model)

FLY-BY-WIRE - Software development via a tool suite
FLY-BY-WIRE – Highly automatic software development

Tool-Suite
- DSL: Platform Architecture & Data Path
- DSL: Plasma Structure
- DSL: SW Component
- Code Generation Templates

High Level System Specification
- Model: Platform Archit & Data Path
- Model: Plasma Structure
- Model: SW Components
- Parameter Source Code

Source-Code

System
- SR
- SR

Law
Platform Instance
- SRD
- SDD
FLY-BY-WIRE – AAA Process compliant to DO 178C

Axx
Automatic SW Instantation

Tool-Suite
DSL: Platform Architecture & Data Path
DSL: Plasma Structure
DSL: SW Component
Code Generation Templates

Parameter Source Code
High Level System Specification
Model: Platform Archit & Data Path
Model: Plasma Structure
Model: SW Components

SR

SR

SR

xAx
Automatic Documentation

Model: Platform Archit & Data Path
Model: Plasma Structure
Model: SW Components

SR

Source-Code
System
Law
Auto Testcase Generation
Auto-Testcase Generation
Auto Documentation
Auto Documentation
Auto Documentation

xxA
Automatic Verification

Platform Instance
SDD
SRD
ATC-Gen
ATC-Gen.

Source-Code
SAFAR – Easy Handling Characteristics

Fly-by-Wire technology (handling)
- Decoupling of aircraft states
- Automatic closing of inner and outer control loops
- Automatic disturbance rejection

Flight envelope protection (safety)
- Keep aircraft within safe regions of the flight regime
- Control allocation with system health monitoring

Automatic flight (safety / handling / comfort)
- Automatic operation in critical flight phases
- Emergency safe return
- Full automatic flight
SAFAR – Integration in ATM SESAR 2020+

SMOOTH INTEGRATION OF SAFAR AIRCRAFT WITHIN SESAR

- New Airspace Structure (managed and unmanaged airspace)
- Flexible use of airspace
- 4D Trajectory based operation
- System Wide Information Management (SWIM)
- Datalink
AutoFlight – 4D trajectory planning

- **Global & Standardized**
  - UTM coordinates
  - Holding patterns with procedural entries

- **Flyable Missions**
  - Internal aircraft-dependent plan checks

- **Flexible Missions**
  - Modifiable on board
  - 3D spatial & velocity splines

Ground Track, Auto-Land LOAN

![Map showing AutoFlight trajectories and holding pattern](image)
AutoFlight – Control Laws

Performance and Reliability Verification
- Control theory – Simulations – Iron Bird – Test flights

- Inner Loops
- Actuators and Engine
- Sensors
- Outer Loops
- Planned Trajectory
- Mission Management
- Flap and gear configuration

- Provides ATOL functionality
- Flare mode and consistent transitions
- Monolithic controller for all airborne operations → less effort to certify in the future
- Adapted controller for ground operations
- Provides ATOL functionality
- Flare mode and consistent transitions
AutoFlight – Deviations from trajectory

Time since beginning of autonomous flight [s]

Error [m]

End of turn
Gear extension
Flap extension
Begin of descent
Wind Gust
Wind Gust
Flare triggering

Lateral Error
Altitude Error
AutoFlight – Auto land and roll out

![Graph showing distance and velocity over time during autonomous flight](Image)

- Lateral Error
- Groundspeed

Time since beginning of autonomous flight [s]

Distance [m], Velocity [m/s]

- Touchdown
- Brakes Manually Applied

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SUCCESSFUL TEST FLIGHT PROGRAM
NEW INNOVATIVE AIRCRAFT SYSTEMS

OPALE 42
Optionally Piloted Aircraft Long Endurance based on Diamond DA42

- Airborne sensor platforms based on existing general aviation (GA) aircraft
- Flexible missions (manned, unmanned with safety pilot, unmanned) using Fly-By-Wire Technology
- Cost efficient, highly reliable technology
CONCLUSIONS

- **STABLE TECHNOLOGY PLATFORM**
  Time is ready to realize full authority fly-by-wire avionics on small aircraft based on experience in the automotive industry.

- **ATC/ATM INTEGRATION**
  Based on SAFAR fly-by-wire avionics architecture main SESAR functionality will be available for Small Aircraft as well.

- **SMALL AIRCRAFT**
  A lot of aircraft with modern design and low lifecycle costs exist which are potential candidates for such a fly-by-wire avionics.

- **NEW MARKET OPPORTUNITIES**
  From improving safety, comfort and efficiency of general aviation aircraft up to new innovative aircraft systems.
THANK YOU FOR YOUR INTEREST!

PROJECTS (2008-2015)

- SAFAR (FP7)
  Airbus DS, DFS, TU Delft, Honeywell, Diamond Aircraft, Septentrio, U Stuttgart (ILS/IFR), GMV

- FLYSMART (LUFO)
  Airbus DS, Diamond Aircraft, Smart Embedded Technologies, U Stuttgart (ILS/IFR)

- eSAFE (Take Off)
  Diamond Aircraft, Airbus DS, U Stuttgart (ILS/IFR)

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