# Fly-by-Wireless (FBWSS): Benefits, risks and technical challenges

## CANEUS Fly-by-Wireless Workshop

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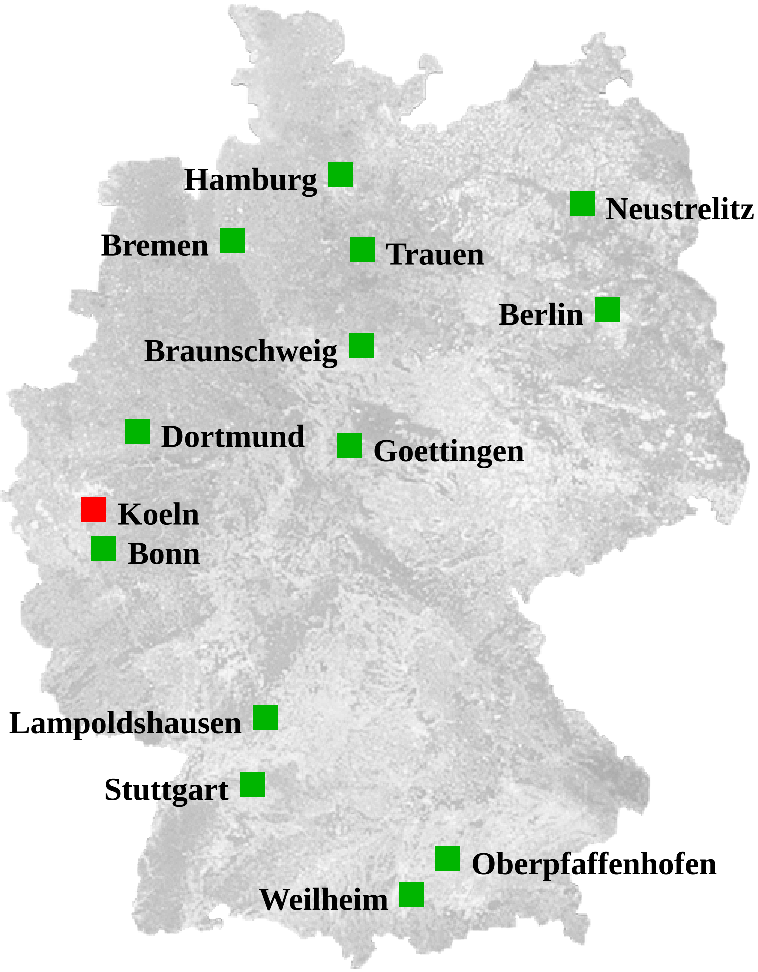
German Aerospace Center (DLR), Institute of Flight Systems

# DLR Locations and Employees

6500 employees across
29 research institutes and
facilities at

- 14 sites.

Offices in Brussels,
Paris and Washington.



# Research Areas and Activities

| Aeronautics | Space | Transport | Energy | Space Agency | Project Management Agency |
|---|---|---|---|---|---|

- Research air vehicles
- Cockpit simulators
- Tower simulator
- Compressor, combustion chamber and turbine test beds
- Autoclaves
- Material and structural test facilities
- Ground vibration test facility
- Wind tunnels*

* Predominantly under the auspices of German-Dutch Wind Tunnels (DNW)

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- Basic considerations
- Benefits
- Risks
- Conceptual wireless flight control system
- System specification
-Technical challenges

# Basic considerations

- Does it deserve/is it reasonable to incorporate wireless technologies in the next-generation aircraft for flight control purposes?

  - Three different parameters to keep in mind at the time of incorporating a new technology on aircraft

    - Efficiency/increase of functional capability
    - Dependability — Reliability / Availability, Safety, Security
    - Cost — Design, Production, Operation cost

- Are wireless technologies feasible for airborne safety-critical applications?

  - Which requirements must wireless technologies fulfil in order to be feasible?

- Is a full-wireless flight control system without a backup system feasible?

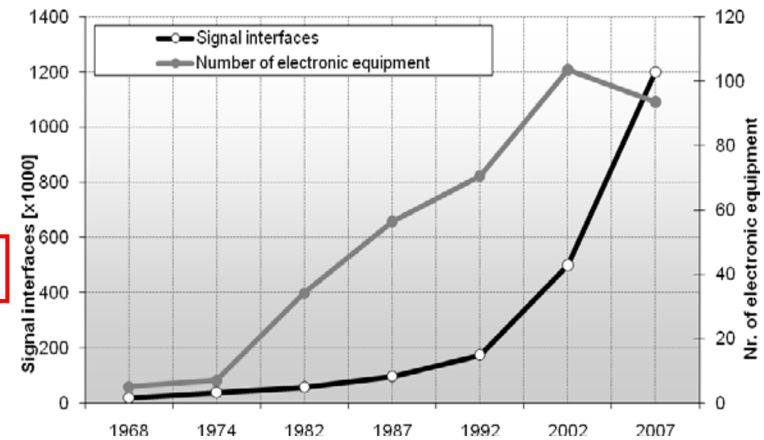
  - If not, is there any technology for back up that does not devaluate the possible improvements derived from full-wireless flight control?

# Benefits

**Efficiency / Increase of functional capability**

- Aircraft's weight
  - → Critical factor ← Kept as low as possible
    - → Design phase
      - Power plant size
      - Airframe robustness
    - → Operative life
      - Fuel amount it can carry
      - Fuel consumption
      - Payload (passengers and/or cargo) it can transport
      - Autonomy given a fixed amount of fuel
      - Maneuverability

[1,2]




- Wiring-related weight and complexity
  - → Exponential growth → Moore's law

**Signal interfaces double every 18 months[2]**

Source:
1) R. Smyth. Design and development of transport aircraft systems.
2) H. Butz. The airbus approach to open integrated modular avionics (IMA): Technology, methods, processes and future road map.

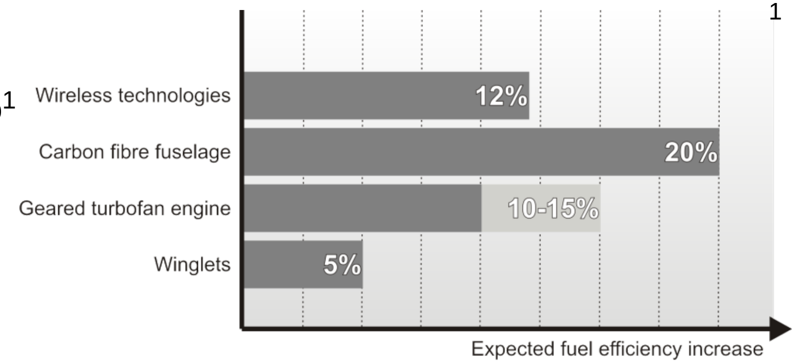
# Benefits

**Efficiency / Increase of functional capability (II)**

- Fly-By-WireleSS (FBWSS) → Signal transmitting cables of FBW no longer needed

- Size-independent relative weight reduction
  - Aluminium fuselage → **15%**[1] A/C total weigth
    - A320/B737-900 → 6,400 kg
  - Composite fuselage → ≈ **20%**
    - A350-900/B787-9 → 23,000 kg

  → Associated consequences:
  - Decreased fuel consumption → 12%[1]
  - Optimized
    - A/C structures (airframe)
    - A/C systems (engine)




- Research catalyst

  → **Indirectly** allows the introduction of new concepts and ways of thinking in the field of flight control impossible due to wiring-related issues

FBW: Fly-By-Wire
A/C: Aircraft

Source:
1) D. Graham-Rowe. Fly-by-wireless set for take-off.

# Benefits

**Safety**

- Civil aviation authorities (FAA & EASA) impose high requirements of safety and reliability on aircrafts
  - → Safety critical systems
    - Redundant
    - Physical dispersion → Single point failure avoidance

- Wireless networks
  - → Redundant nature
  - → High survivability and resilience
    - Nodes active = FCS operative
    - Dynamic system reconfiguration
      - Graceful degradation
      - Hybrid networking
    - Self-repairing capabilities
  - → Absence of cables → No wiring-aging-related concerns
    - Fault location
    - Fire hazard

FAA: Federal Aviation Administration
EASA: European Aviation Safety Agency
FCS: Flight Control System

# Benefits

**Time and cost**

- Aerospace markt has a particular characteristic → Specialized market → No mass production
  - Consequences
    - Manufacturers
      - Extend products life-cycles → 20 - 30 years
      - Decrease design and production costs
    - Airlines → Keep fleet on duty as long as possible during its operative life
- FBWSS bring benefits in all phases of aircraft's life-cycle

**Design, development and production**

- Design → No need of creating and validating wire routing plans
- Development
  - Flexibility against design changes
  - Ease of pre- and post-integration testing
- Assembly → Elimination of wiring-related tasks
  - Cable fabrication
  - Cable installation
  
  → Wiring–related cost → **$2,200 per kg**[1]

- Aircraft-level total cost saving:
  - A320/B737-900 → 6,400 kg x 2,200 $/kg → ≈ $14 million
  - A350-900/B787-9 → 23,000 kg x 2,200$/kg → ≈ $50,6 million

Source:
1) M. Harrington. Introduction to wireless systems in aerospace applications

# Benefits

**Time and cost (II)**

**Maintenance, reparation and overhaul (MRO)** → 13% of a commercial A/C operation cost

- Maintenance
- Reparations
  - Ease of system maintenance
    - Reduced system complexity
    - Simplified access
    - No cable / connector replacement activities
  - Higher system integrity
    - Accessible areas → Wiring mishandling avoidance
    - No accessible areas → No insulator degradation
- Overhaul → Long operative life ≠ Outdated airplanes
  - → Preferred way of keeping fleet up-to-date
  - → Challenging activity
    - Multi-generation systems → Intra-system compatibility assurance
    - Possible relocation of existing equipment
  - → FBWSS benefits in Overhaul
    - Reduced out-of-operation times
    - Increased scalability

# Benefits

**Time and cost (III)**

**Withdrawal from service**

- Storage
- Second hand spare parts sale → Simplified disassembly tasks
- Recycling
  - → Challenges
    - Correct disposal of environment/health threatening substances (Hg, Pb...)
    - Classification and proper separation of materials
  - → Benefits → No wiring-related activities
    - Reduction of material mass to be recycled
    - Reduced recycling tasks

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# Risks

**Electromagnetic susceptibility**

- Source of electromagnetic environment in aerospace applications
  - Natural phenomena
    - Lightning
    - Electrostatic
    - Cosmic radiation
  - Manmade
    - Internal
      - Avionics
      - Portable electronic devices (PED)
    - External
      - Nuclear electro magnetic pulse (NEMP)
      - HIRF
        - Atmosphere
          - Radio/Television
          - Cellular networks
          - Satellite communication
        - Civil/military aviation
          - Radionavigation (GNSS,...)
          - Communications (VHF,...)
          - Surveillance (Doppler radar,...)

- Reduction of mass to be recycled

# Risks

**Electromagnetic susceptibility (II)**

- Effects of Electro magnetic interferences on wireless communications
  - Cochannel interference → interfering signal with the same carrier frequency as the information signal
  - Adjacent channel interference → Interfering signal with a carrier frequency located next to the one of information signal
  - Intermodulation interference → Interfering signals created by nonlinear components like transistors in analog communication systems
  - Intersymbol interference → Interfering signal caused by multipath propagation causing different copies of the same symbol reaching at the receiver at different times
  - Near End to Far End Ratio Interference → interference signal from a close device that overrides the signal between base station and a device located away from it
- Derivated hazards
  - Quality of service (QoS) degradation → Increase of bit error rate (BER)
  - Decreased data transmission rates → Violation of deadlines
  - Network collapse

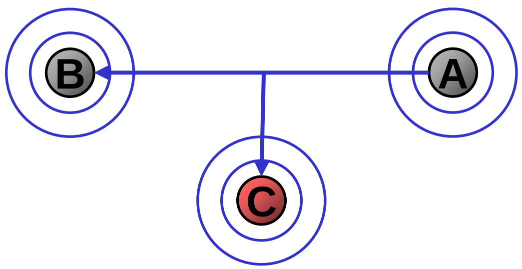
- Simplified disassembly tasks
- Reduction of mass to be recycled

# Risks

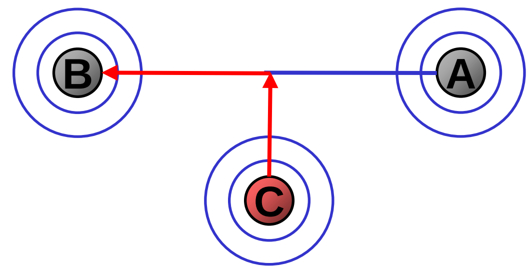
**Security issues**

- Radio signals are propagated through open air
  - → Security threats
    - "Man-in-the-middle" attacks
      - Access to sent information
      - Manipulation of sent information
    - Denial of service (DoS) attacks
      - Jamming
      - Intentional attack (hacking)

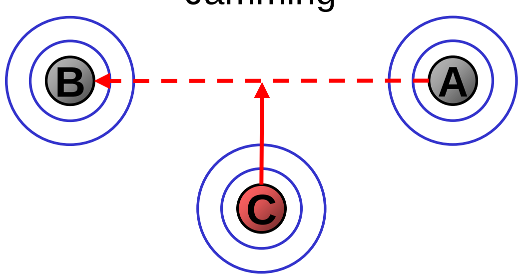
Information access



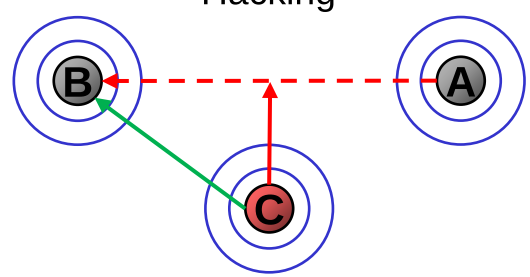

Information manipulation




Jamming




Hacking




- Simplified disassembly tasks
- Reduction of mass to be recycled

# Risks

**Electric power supply**

- Wireless transmissions' peak power during connection's establishment
  - → Multiple connections established periodically = High electric power consumption
- Need of power supply at nodes location
  - → Not always possible/desirable → Devaluates benefits associated to FBWSS

- Simplified disassembly tasks
- Reduction of mass to be recycled

# Risks

## - Comparison of FBWSS benefits and risks

| Advantages | Disadvantages |
| --- | --- |
| **Efficiency**<br>- Weight reduction which implies:<br>▪ Decreased fuel consumption<br>▪ Increased payload capacity<br>▪ Increased flight autonomy<br>- New/increased capabilities (indirect)<br>▪ Dynamically reconfigurable FCS<br>**Safety**<br>- Systems self-redundant nature<br>- High survivability and resilience<br>▪ Single-point-of-failure avoidance<br>▪ Self-repairing capabilities<br>- No wiring-aging-related problems<br>**Cost**<br>-Design & production<br>▪ No need of wire routing plans<br>▪ Flexibility against design changes<br>▪ No wiring-related assembly tasks<br>- Maintenance, reparation and overhaul<br>▪ Ease of system maintenance<br>▪ Higher system integrity<br>▪ Reduced out-of-operation times<br>▪ Increased scalability<br>- Withdrawal from service<br>▪ Simplified disassembly tasks<br>▪ Reduction of mass to be recycled | **Electromagnetic susceptability**<br>- Quality of service degradation<br>▪ Increase of bit error rate<br>- Decreased data transmission rate<br>▪ Violation of deadlines<br>- Network collapse<br>**Security issues related with:**<br>- Confidentiality of transmitted data<br>- Rejection capabilities against intrusions<br>- Survivability against jamming signals<br>**Power supply**<br>- Increased power consumption<br>- Need of power supply at node's location<br>▪ Not always possible/desirable |

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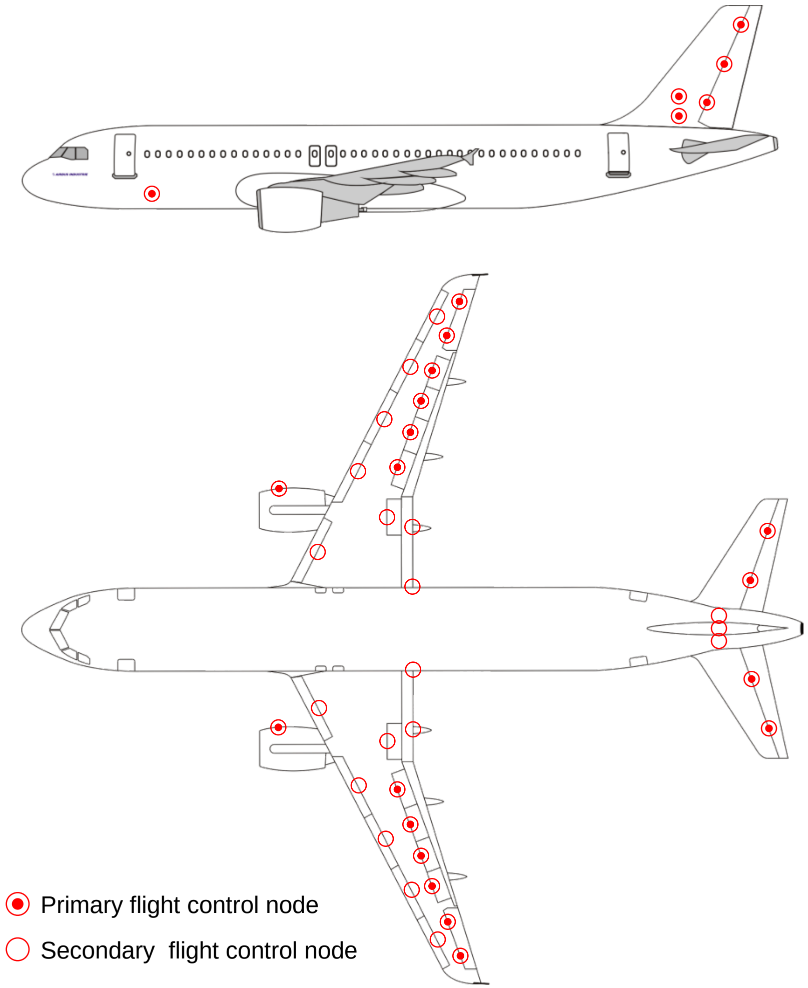
# Conceptual wireless flight control system




- Flight control

- Primary flight control ◉
  - Axis of motion
    - Roll → Ailerons/Roll spoilers
    - Pitch → Elevators
    - Yaw → Rudder/Yaw dampers
  - Full authority digital engine control (not in the current work)
  - Flight computers
- Secondary flight control ○
  - Trimmable Horizontal Stabilizer (THS)
  - Inner spoilers
  - Inner/Outer flaps
  - Slats
  - Airbrakes

# System specification

- Development of requirements in the problem domain
  - Requirements that systems must fulfil in order to accomplish the desired function
    - → Conceptual description of the desired system

↓

**Airborne, real-time, dependable, wireless distributed sensor and actuator network**

- Development of requirements related to:
  - Airborne systems
  - Real-time systems
  - Dependable systems
  - Wireless distributed sensor and actuator networks (WDSAN)

# System specification (II)

- Development of requirements in the problem domain

**Airborne systems**

- Airworthiness
  - FAA JAR 25
  - RTCA DO-160F
  - RTCA DO-254
  - RTCA DO-178B
  - FAA AC 20-156
- Functional requirements
  - Example
    - Bit error rate = 1e-6[1]
    - Transmission range = 100 m
    - Ref. Smart actuator from Liebherr aerospace[2]
      - Data throughput = 224 bit/message
- Non-functional requirements

**Real-Time systems**

- Timing constraints
  - Refresh rate = 1 ms[3]
- System requirements

Source:
1) M. Harrington. Introduction to wireless systems in aerospace applications
2) W. Kiessling. Specification for Aileron ACE
3) J. O'Brien et al. Distributed and remote control of flight control actuation using power line communications

# System specification (III)

- Development of requirements in the problem domain

- Dependable systems
  - Reliability/Availability
    - Fault-tolerance
      - Redundancy
      - Fault detection
      - Fault location
      - Fault containment
      - Fault recovery
      - Testability/ verifiability
    - Maintainability
  - Safety
  - Security
    - Node security
      - Hardware security
      - Software security
    - Communications security
      - Transmission security
      - Emanation security

Example

Wireless network for FCS → Support for safety-critical application → **Network failure probability ≤ 1e-10 /FH[1]**

FCS: Flight Control System

Source:
1) J. Rushby. A comparison of Bus Architectures for Safety-Critical Embedded Systems

# System specification (IV)

- Development of requirements in the problem domain

Wireless distributed sensor and actuator network

- Rapid deployment
- Operational transparency
  - Self deployment
  - Adaptability
  - Scalability
- Interoperability
- Power efficiency
- Cost effectiveness
- Replaceability of technological foundation
- Routing efficiency
- Extensibility

- Summary of a possible wireless flight control system

Data throughput = 224 bit/message
Refresh rate = 1 ms
→ Data throughput [per node]= 224 kbit/s

Transmission range = 100 m
Bit error rate = 1e-6

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# Technical challenges

- Assessment of the technology to serve as wireless transmission medium

→ Physical layer of the ISO OSI standard

- Radio Frequency (RF)
  - → Which frequency spectrum should be used?
    - → Spectrum allocation Vs Spectrum reuse
    - → ISM bands Vs Protected spectrum

      ↓ ↓

      Worldwide availability Vs Interference-free/Secure spectrum

      COTS systems Vs Proprietary systems
  - → Introduction of new radio technologies? → Software defined radio / Cognitive radio
- Free space optics (FSO) → Wireless optical transmission → High inmunity against EMI
  - → Line-of-sight FSO (LoS FSO) → Direct optical connection
  - → Non-line-of-sight FSO (NLoS FSO) → Indirect optical connection
- Magnetic induction → Wireless transmission by generating currents in the receiver through the use of magnetic fields

ISO: International Organization for Standardization
OSI: Open System Interconnection
COTS: Commercial of-the-shelf
EMI: Electro Magnetic Interference

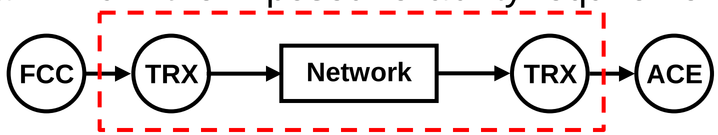
# Technical challenges (II)

- Assessment of the need of a backup system

  - In order to be able to design a system without the need of a backup system the following questions must be answered:

    - Does the wireless network have a reliability level appropiate enough? → ≤ 1e-10 /FH
      - → Does hardware nodes satisfy the imposed reliability requirements?
      - → Does data link fulfil the imposed reliability requirements?

      → ≤ 1e-10 /FH




    - Can the wireless network reconstruct itself fast enough (MTTR)?
      - → Time between network total collapse and delivery of first command after restart
        - Network collapse detection
        - Restart of the transceivers
        - Network construction
        - Command delivery to primary flight control surfaces

**If the answer to one of this questions is "NO" then the use of a backup system is <u>MANDATORY</u>**

MTTR: Mean Time To Repair

# Technical challenges (III)

-Possible backup systems

- Background idea: Availability of wireless technologies cannot be guaranteed. EMI and jamming can make the use of radio frequency link impossible.
- Assumptions:
  - No cable backhaul connecting the nodes of the flight control network
  - No mechanical backup

→ **Power Line communications** → Data transmission through aircraft's power supply network

→ Reuse of existing infrastructure – No additional systems; High reliable system; Wide availability

→ **Hybrid networking** → Data transmission through different wireless technologies/standards

→ Reuse of existing infrastructure

→ Dissimilar redundancy → Robustness against EMI

Thank you for your attention