CENTRO DE COMPETÊNCIA EM MANUFATURA

ITA

COBEM 2025

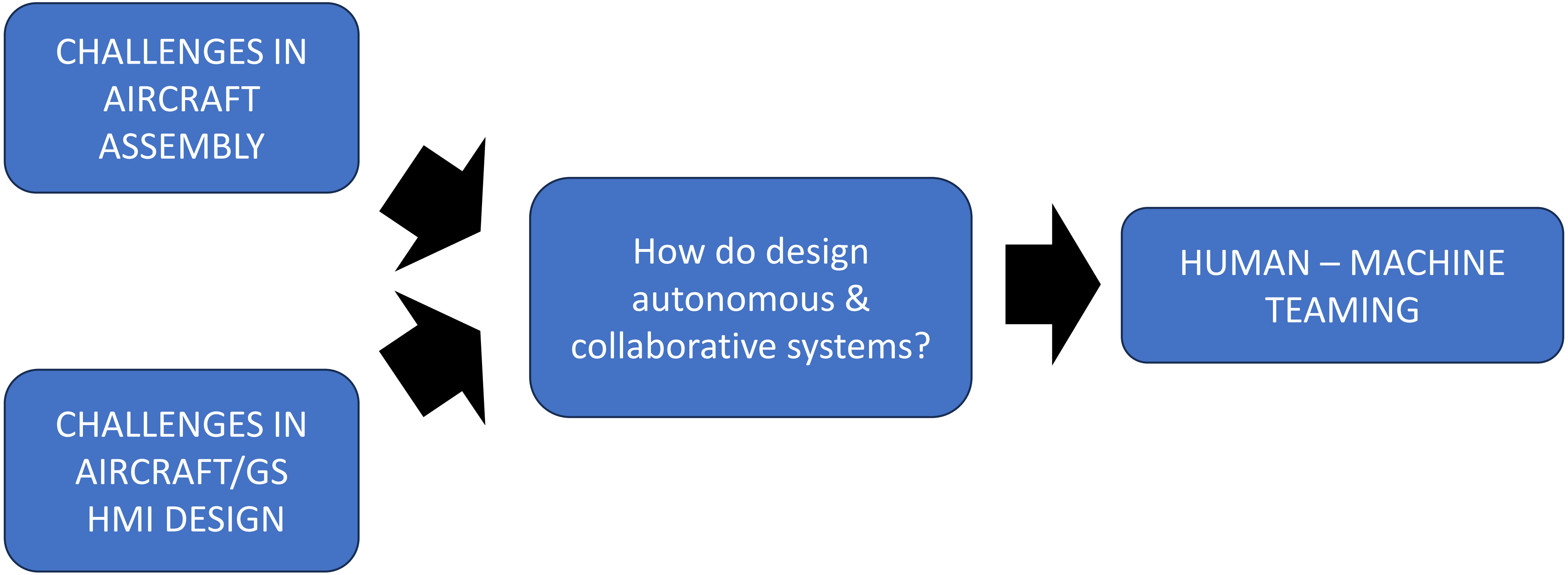
From Automation to Autonomy

New Challenges of Aerospace Industry

Emilia Villani

Nov 13, 2025

This presentation in a nutshell...



Agenda

1. Challenges in aircraft manufacturing
2. Challenges in pilot-aircraft interface design
3. Common approach and on-going activities

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1. Challenges in aircraft manufacturing
2. Challenges in pilot-aircraft interface design
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Aircraft manufacturing & assembly

Google answer to …

Why is the level of automation so different?

Production volume

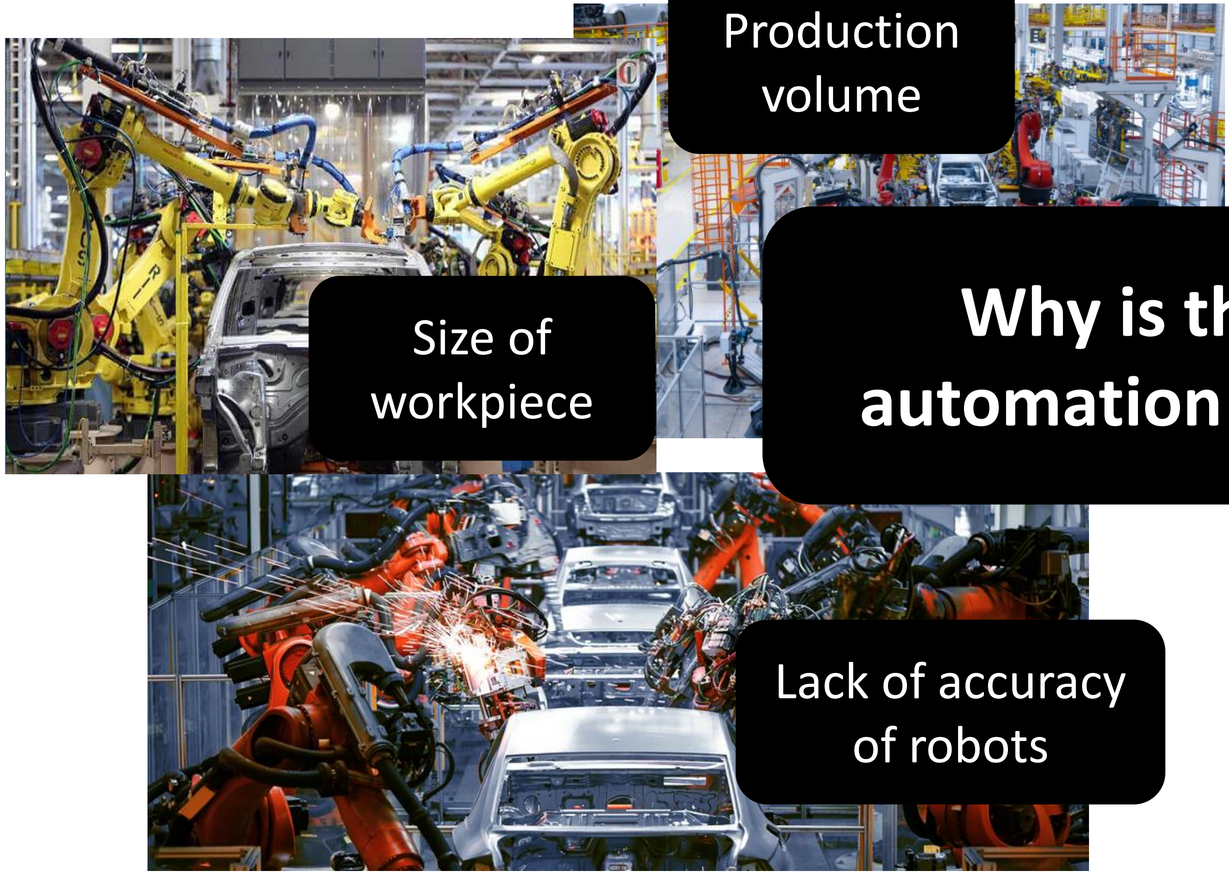
Size of workpiece

Lack of accuracy of robots

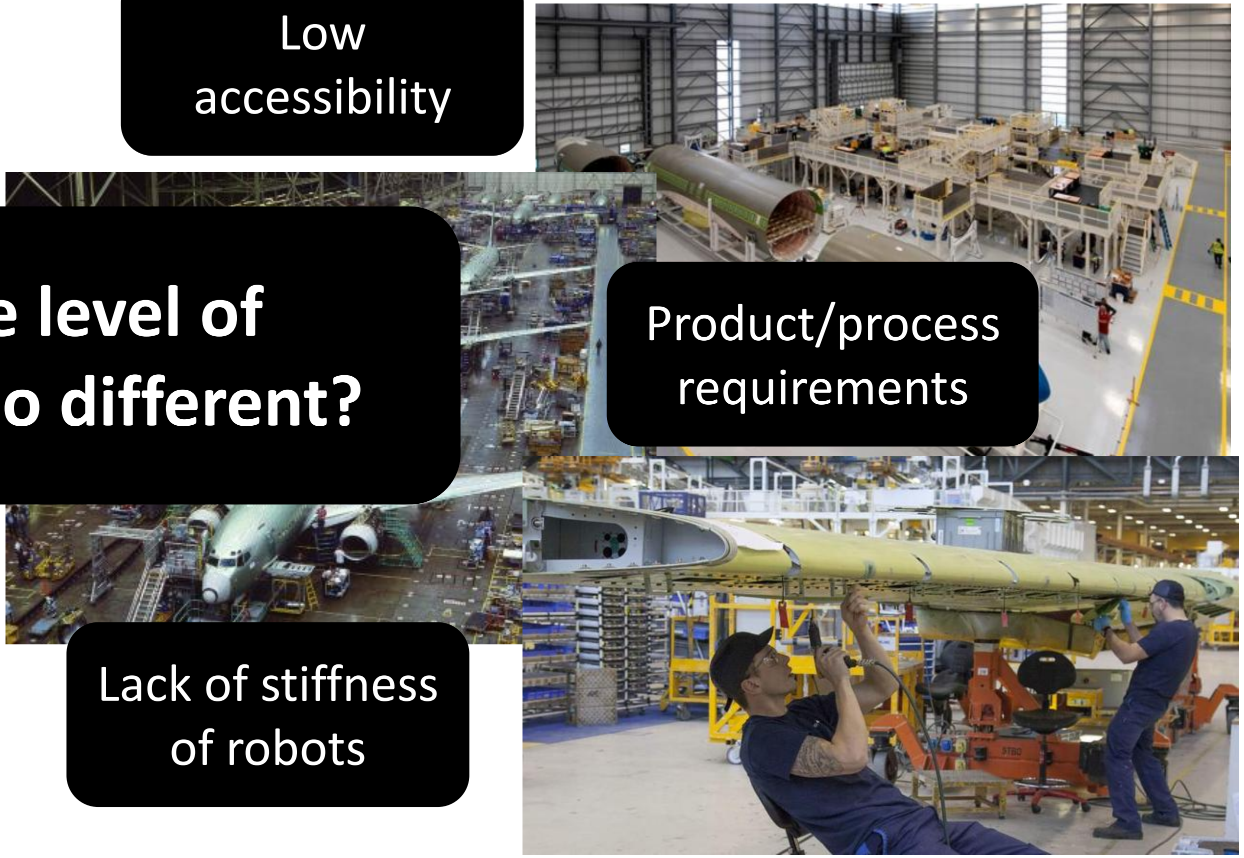
Low accessibility

Product/process requirements

Lack of stiffness of robots



"Automotive assembly line"



"Aircraft assembly line"

Aircraft manufacturing & assembly

Primary component manufacturing	Structural assembly	Final assembly
Primary components are manufactured and combined in structural panels	Structural panels and components are combined into structural segments (empennage, wings, fuselage segments)	Structural segments are assembled and equipped with systems

CENTRO DE COMPETÊNCIA EM MANUFATURA

Aircraft manufacturing & assembly

Primary component manufacturing → **Structural assembly** → **Final assembly**

- **Primary component manufacturing:** Primary components are manufactured and combined in structural panels
- **Structural assembly:** Structural panels and components are combined into structural segments (empennage, wings, fuselage segments)
- **Final assembly:** Structural segments are equipped with systems and assembled

Large riveting machines for structural panels:
- Stiffness of closed chain mechanisms
- Workpiece moves
- Large number of operations

Aircraft manufacturing & assembly

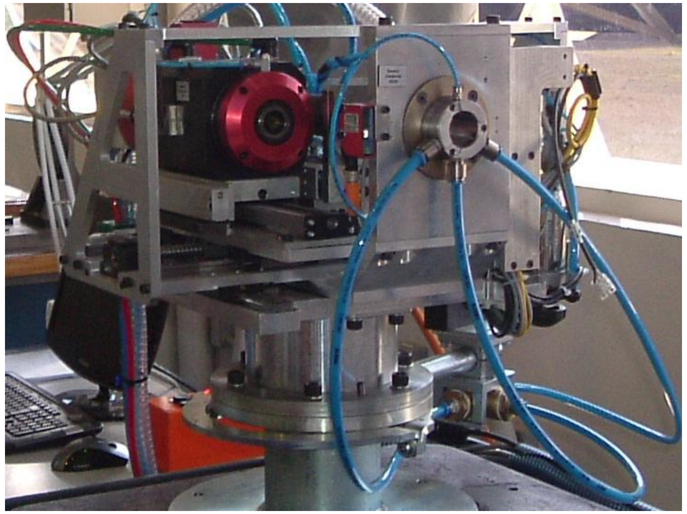
Primary component manufacturing → **Structural assembly** → **Final assembly**

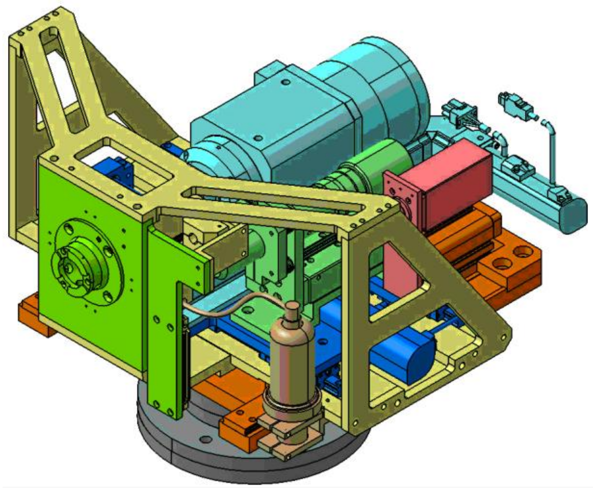
- Primary component manufacturing: Primary components are manufactured and combined in structural panels
- Structural assembly: Structural panels and components are combined into structural segments (empennage, wings, fuselage segments)
- Final assembly: Structural segments are equipped with systems and assembled

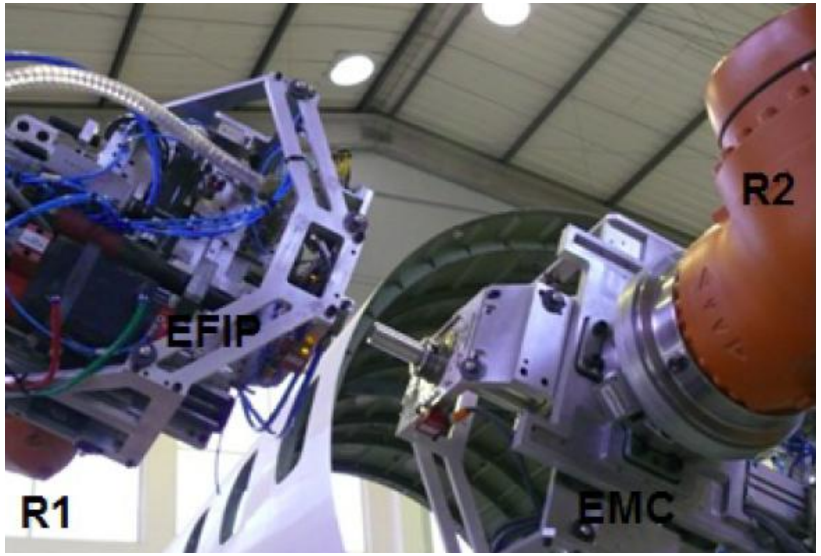
Fuselage segments

Industrial robots + multifunctional end effectors:

- Additional functionalities to compensate for lack of accuracy
- Robot moves, not the workpiece
- Flexible solution for large workpieces







Aircraft manufacturing & assembly

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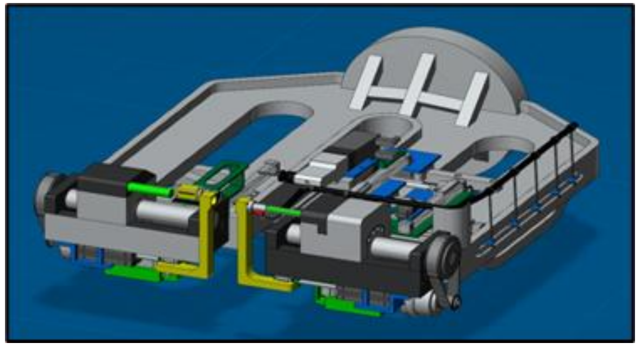
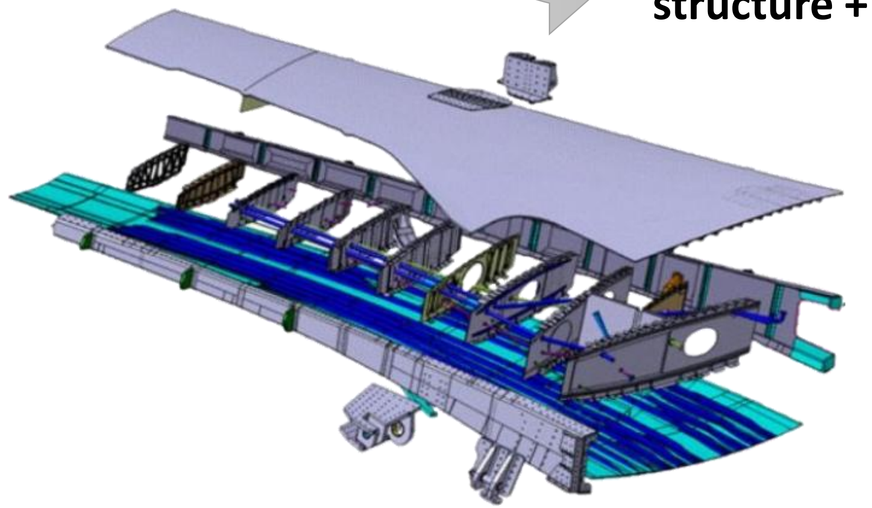
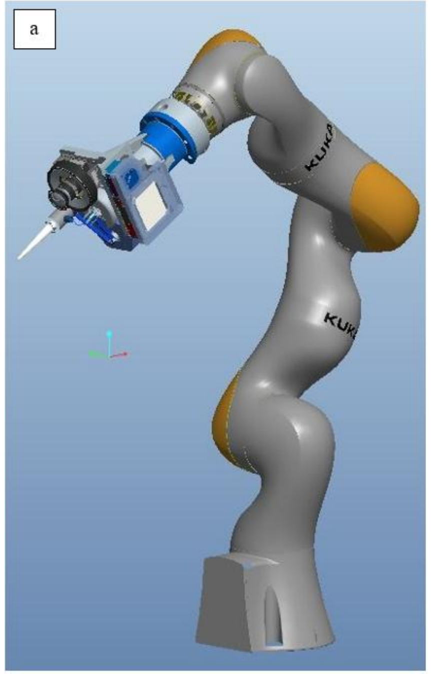
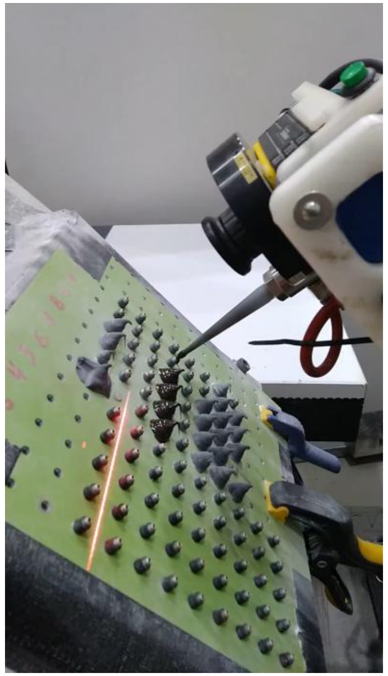



Wing internal structure + panels





Aircraft manufacturing & assembly

Primary component manufacturing → **Structural assembly** → **Final assembly**

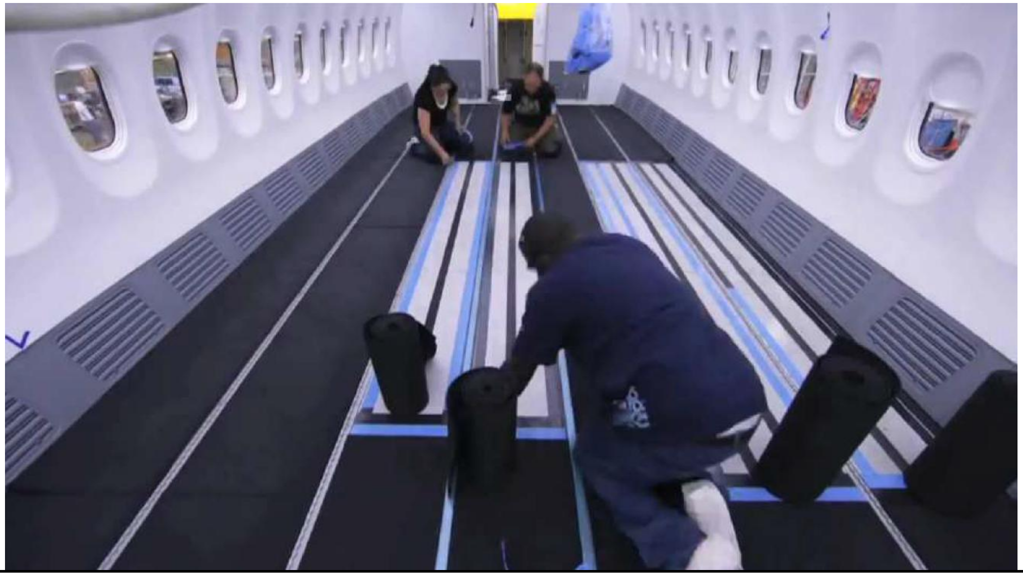
Primary components are manufactured and combined in structural panels

Structural panels and components are combined into structural segments (empennage, wings, fuselage segments)

Structural segments are equipped with systems and assembled

Final assembly

- Installation of mechanical, electrical/electronic systems (brackets, supports, pipes, valves, cables, insulation materials)
- Installation of interior components (bins, ceiling, side panels, seats, floor mats, etc.)



Aircraft manufacturing & assembly

Primary component manufacturing → **Structural assembly** → **Final assembly**

Primary components are manufactured and combined in structural panels

AUTOMATION: Large riveting machines

Structural panels and components are combined into structural segments (empennage, wings, fuselage segments)

AUTOMATION: Robotic solutions

Structural segments are equipped with systems and assembled

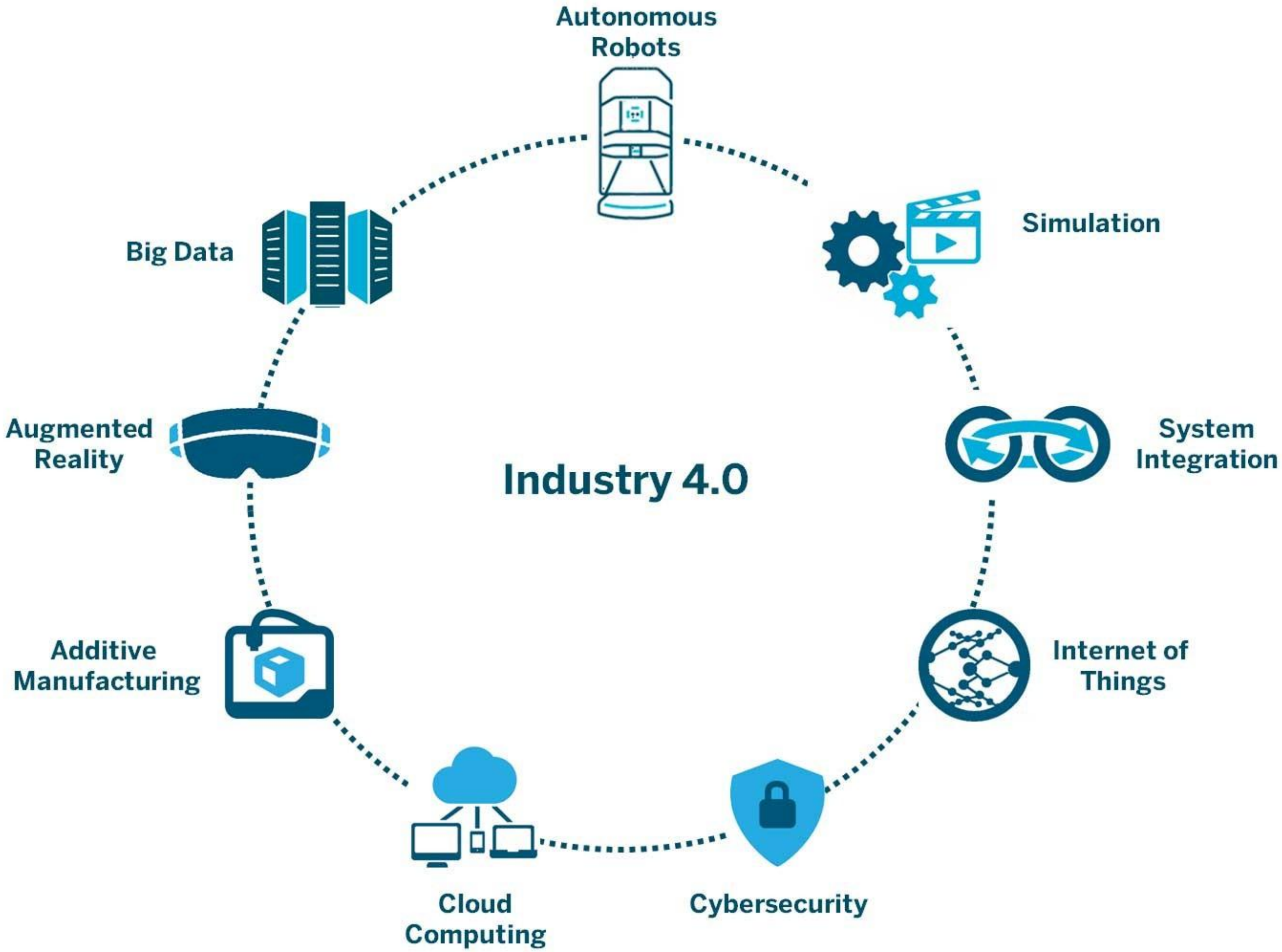
SOLUTIONS UNDER DEVELOPMENT

Aircraft manufacturing & assembly

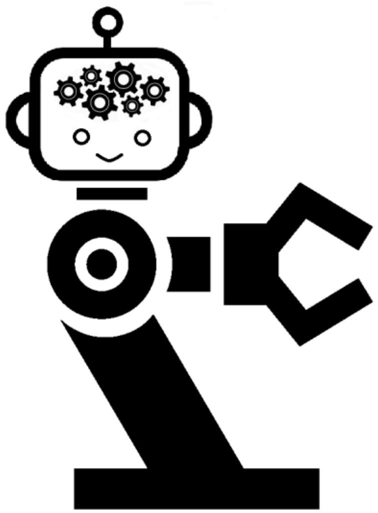
Primary component manufacturing	Structural assembly	Final assembly
Primary components are manufactured and combined in structural panels	Structural panels and components are combined into structural segments (empennage, wings, fuselage segments)	Structural segments are equipped with systems and assembled

Final assembly

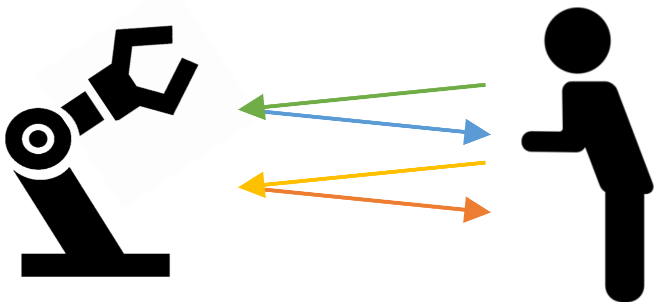
- Autonomous robotics:
  - Robot decide their own trajectory
- Collaborative robotics:
  - Human and robot sharing their workspace and cooperating to perform tasks
- Augmented reality:
  - Provide instruction, perform inspection
- Big data:
  - Collect data, understand process, improve process



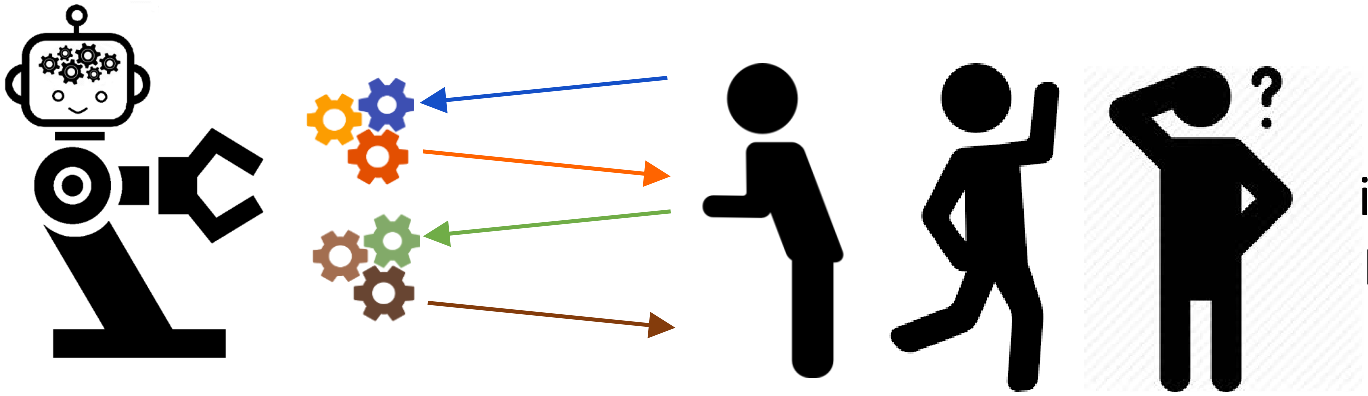
EMBED
‘INTELLIGENCE’
INTO MACHINES



From automation to autonomy



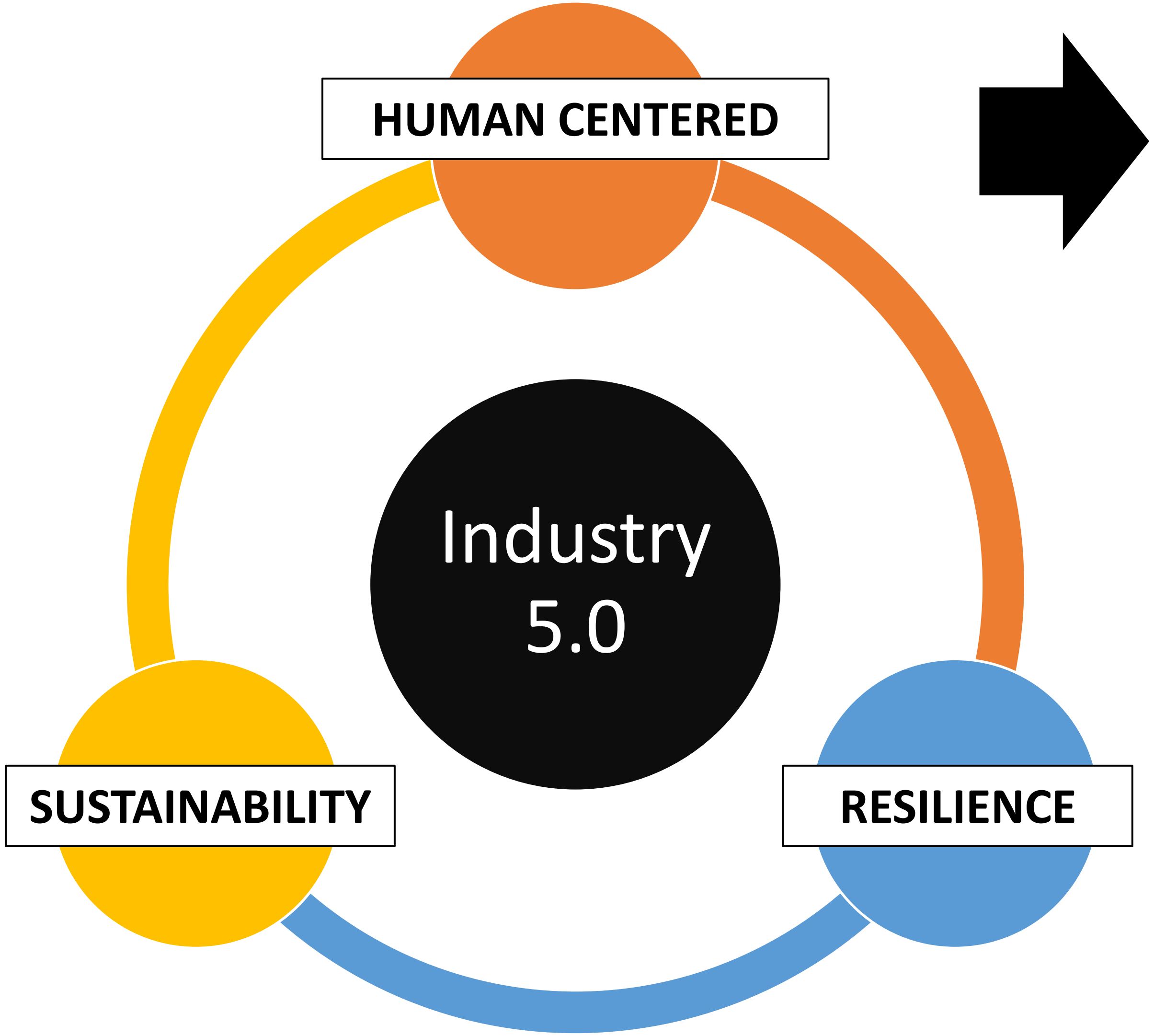
Simple interaction
Easily predictable



Complex interaction
Difficult to predict

How do we design collaborative and autonomous systems?

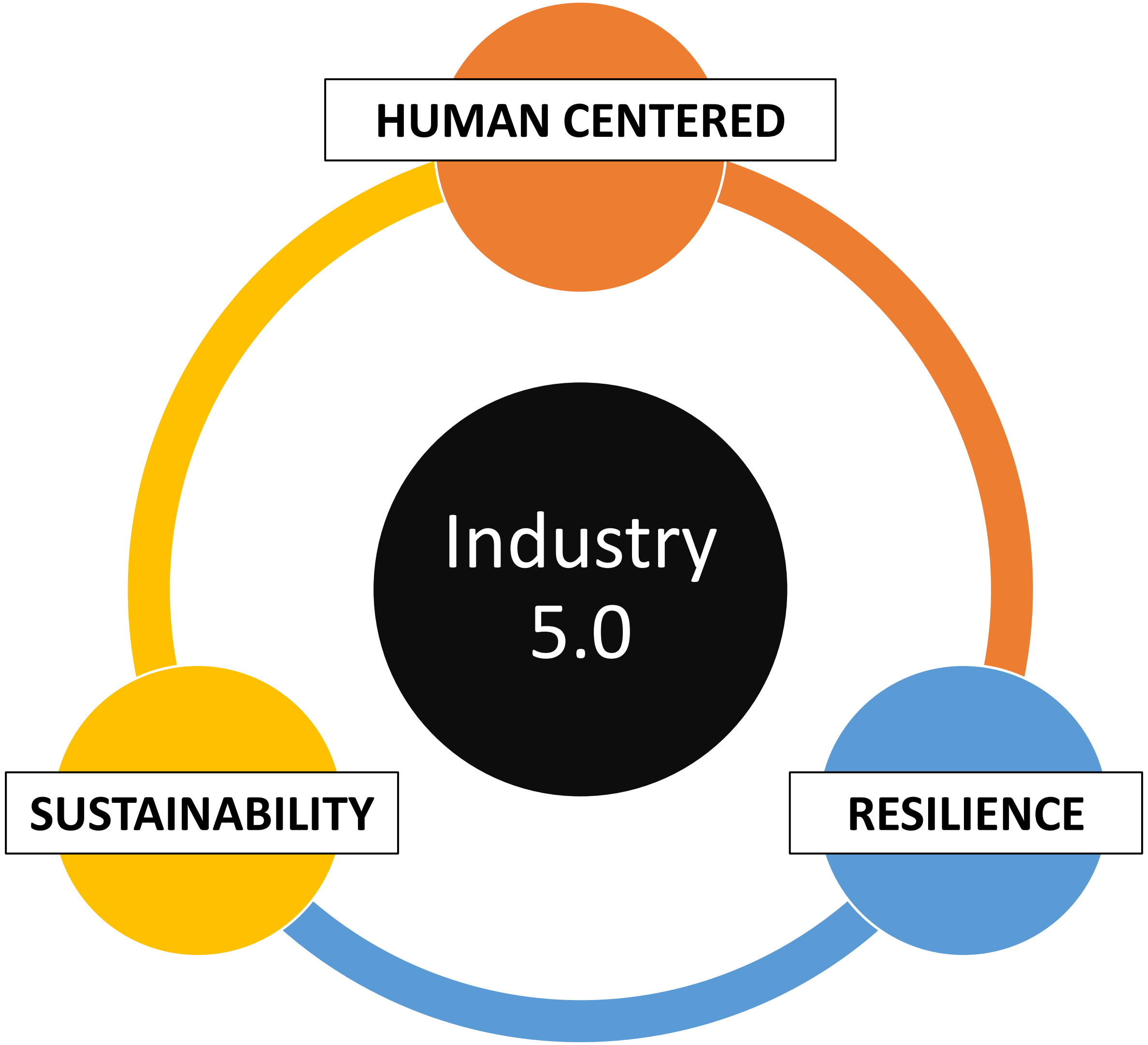
The current challenges of aircraft manufacturing



- **Collaborative & Intelligent Robotic Systems**
  - Trust in Robotics and trust in AI
  - Multimodal interfaces (gesture, voice)
  - Intention recognition models
  - Transparent decision making
  - Adaptative levels of autonomy

- **Wearable Devices** (smart glasses, exoskeletons, haptic gloves, biometric sensors, smart watches, …)
  - Ergonomics
  - Individual privacy *versus* data acquisition
  - Cognitive load and information overload
  - User experience, human factors – evaluation and improvement

The current challenges of aircraft manufacturing



Human Machine Teaming

Agenda

1. Challenges in aircraft manufacturing
2. Challenges in pilot-aircraft interface design
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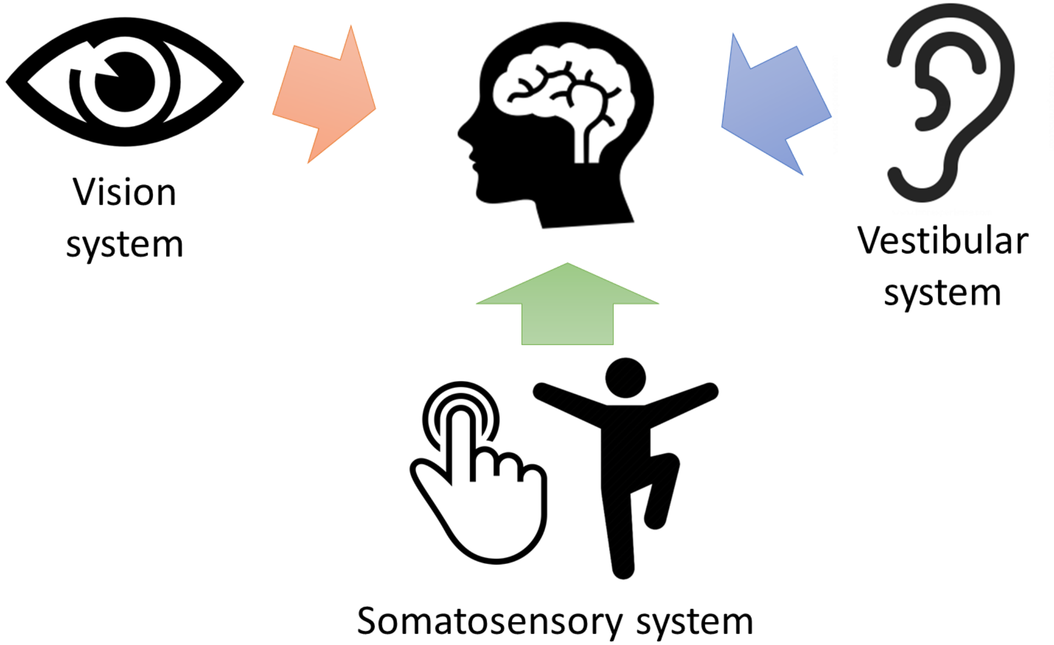
A long time ago...

SIVOR: Robotic flight simulator

How do we evaluate the robot movement?

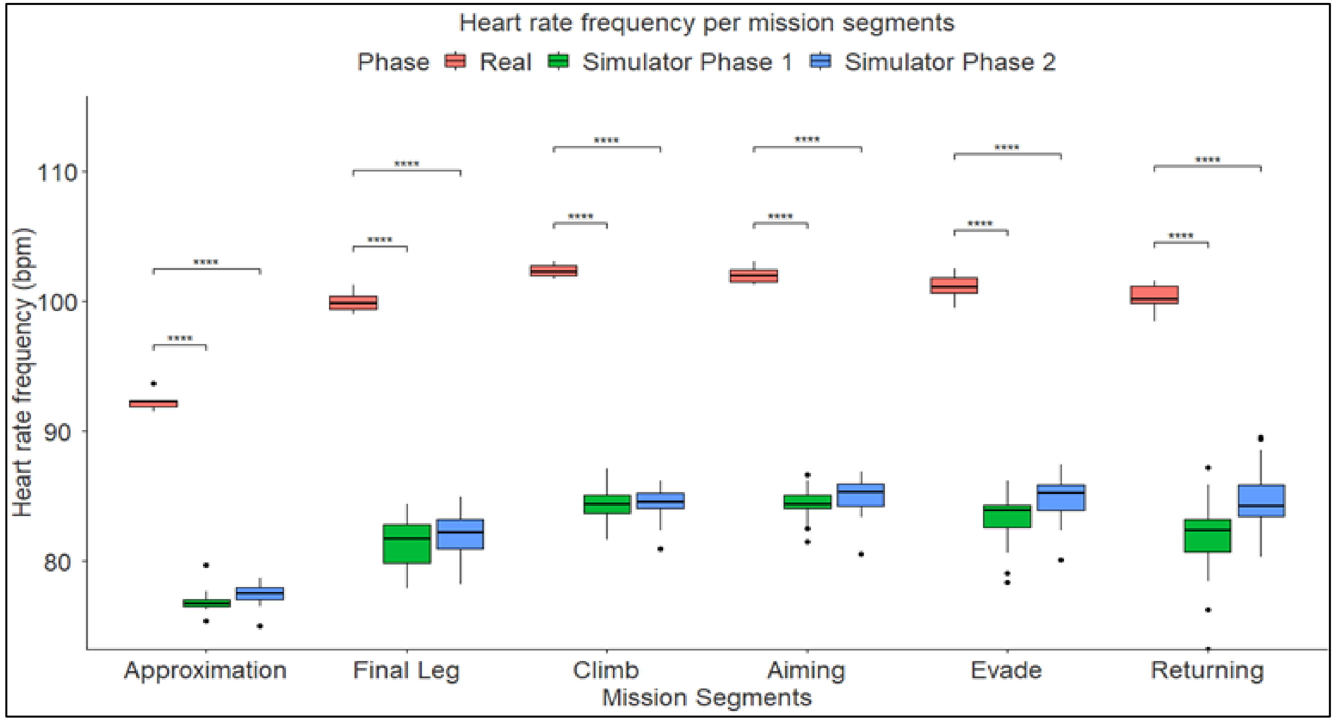


Understand HUMAN FACTORS
Improve HMI DESIGN

Previous works - *comparison of real and simulated flights*

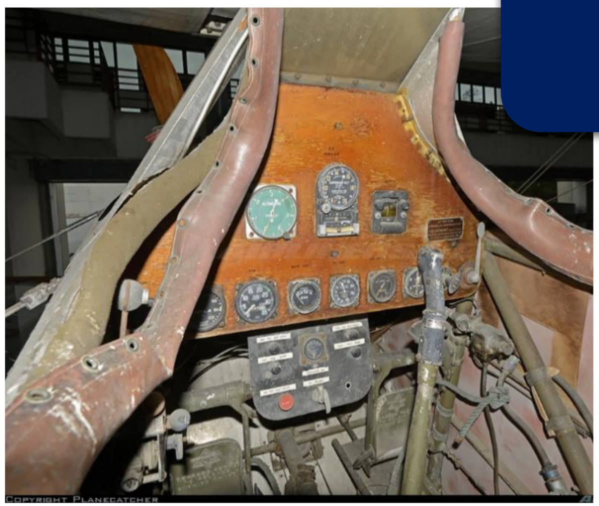
Real flight ✕ Simulator flight

To what extent can we use flight simulators to investigate pilot/aircraft interface?



Previous works - *design of pilot-aircraft interface*

Breguet 14 (1916)



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https://commons.wikimedia.org/w/index.php?curid=1664178
https://www.airliners.net/photo/Thailand-Air-Force/Breguet-14-B2/4930371

Northrop B-2 (1989)

https://aeromagazine.uol.com.br/artigo/o-aviao-mais-caro-da-historia_2013.html
https://www.boldmethod.com/blog/lists/2015/08/21-facts-about-the-b-2-spirit-stealth-bomber/

Sukhoi SU-57 (2010)

By ReaL-FrienD - https://www.flickr.com/photos/realfriend/67875175/, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=2725070
https://www.airplaneupdate.com/2019/04/sukhoi-su-57.html

Can we design more INTUITIVE and SAFE pilot aircraft interfaces?

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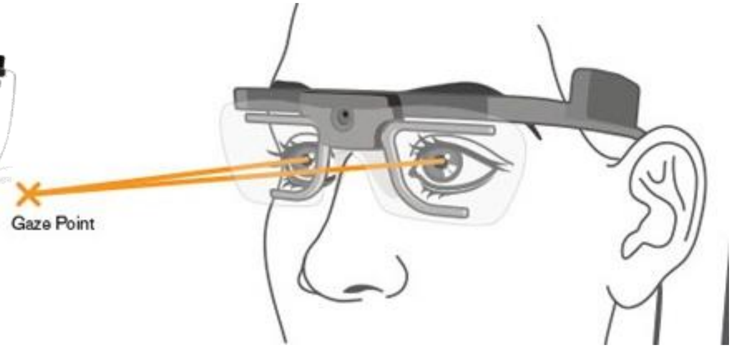
Previous works - *design of pilot-aircraft interface*

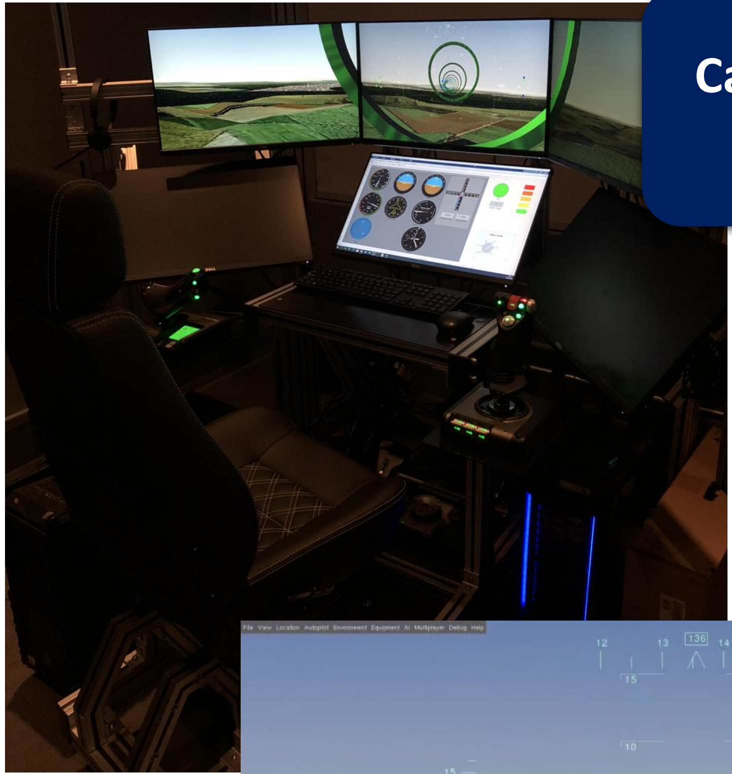
Can we design more INTUITIVE and SAFE pilot aircraft interfaces?

In-flight use of augmented reality for training

Gaze-based interface for flight control

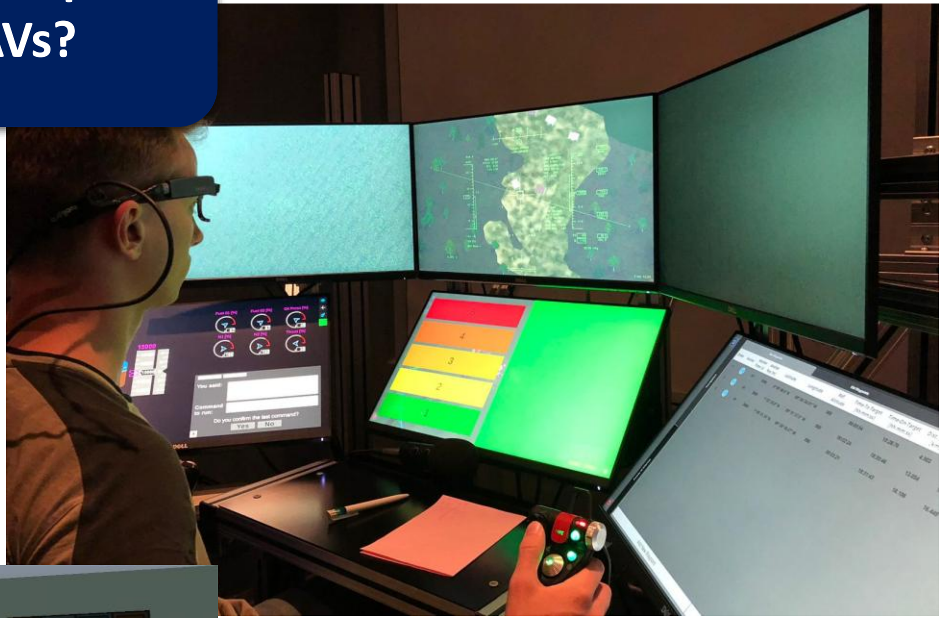


Previous works - *design of pilot-aircraft interface*



Can we design more INTUITIVE and SAFE pilot aircraft interfaces for RPAS and UAVs?

Predictive HMI for compensating communication time-delay



Workload for cumulative roles (pilot/sensor operator) + contribution of voice commands

From automation to autonomy

AUTOMATION → AUTONOMY

EMBED
‘INTELLIGENCE’
INTO AIRCRAFTS

Human Machine Teaming

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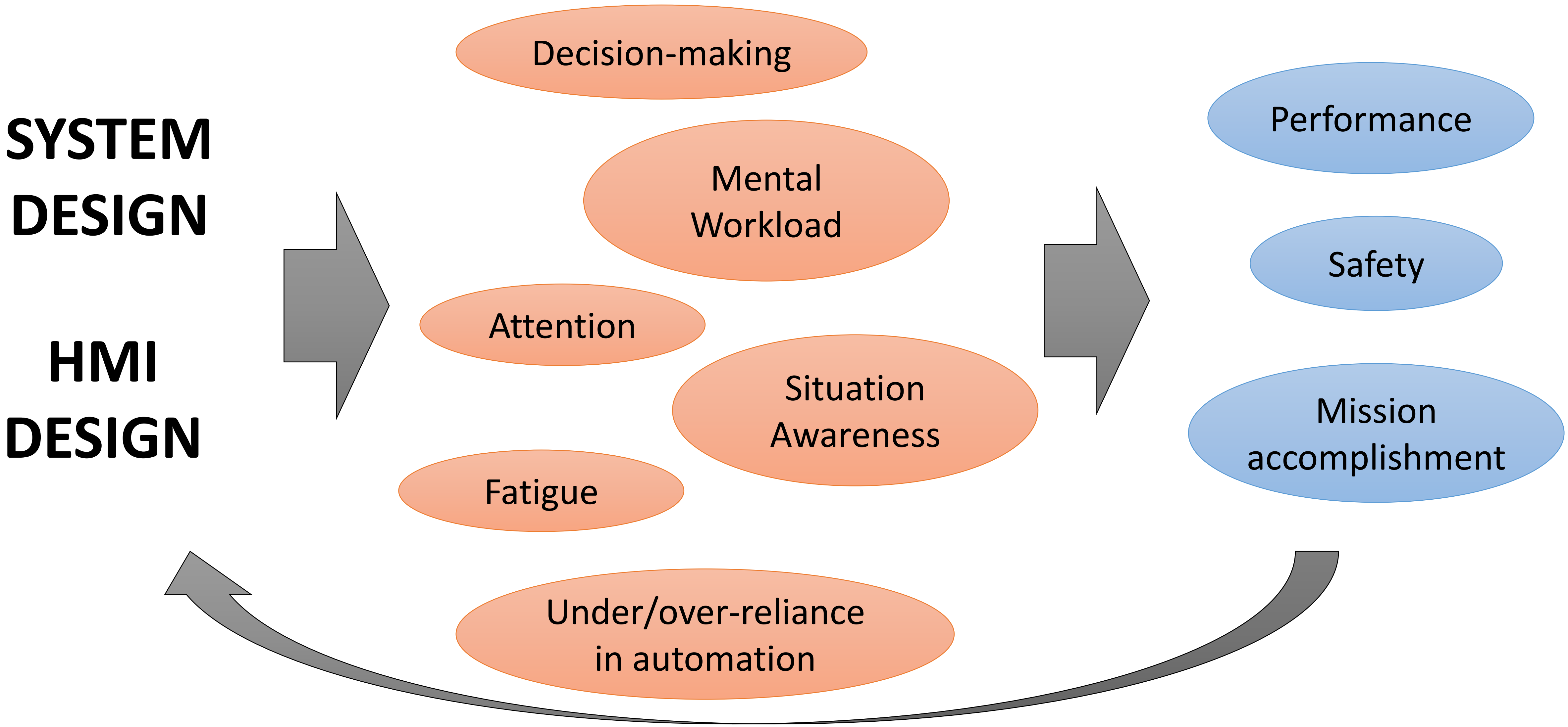
Human Factors Approach



Human Factors Approach

Problem definition

- Demand from industry
- Review of literature
- Definition of context

Proposal of HMI options
Scenario specification
Proposal of hypotheses

HMI prototyping

- Existing infrastructure
- Available funding

Selection of simulation tools
Design and implementation of HMI

Experimental evaluation

- Specification of inputs and outputs
- Design of experiment

Execution of experiment
Data analysis

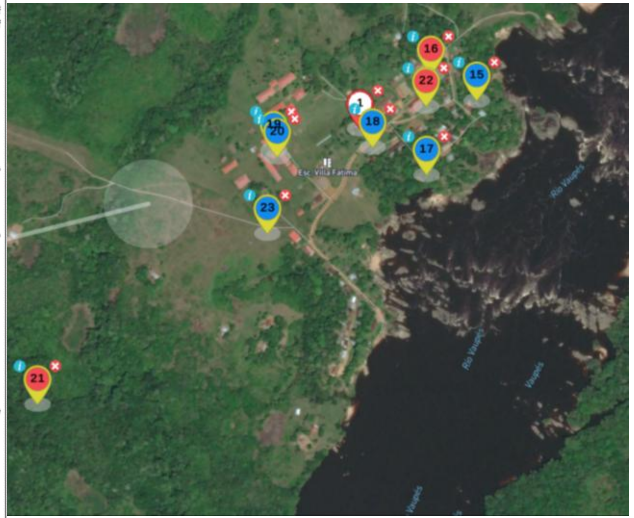
Conclusions and next steps

- Hypotheses proved
- Inconclusive results

Next steps: how to improve the HMI, how to improve the experimental evaluation

- Experimental evaluation

Performance evaluation



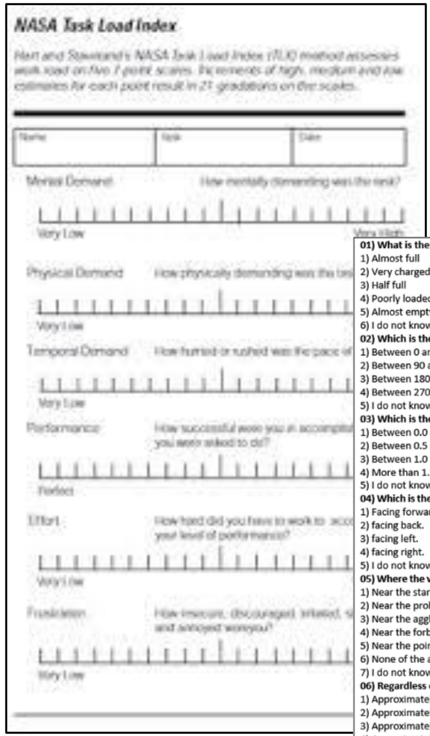
Neurophysiological sensors

ECG, EDA

EEG

Eye-tracker

Workload, situational awareness and other questionnaires



NASA Task Load Index

Mental Demand

Very Low

Very High

Physical Demand

Temporal Demand

Performance

Effort

Frustration

01) What is the battery level?
1) Almost full
2) Very charged
3) Half full
4) Poorly loaded
5) Almost empty
6) I do not know.

02) Which is the vehicle's direction?
1) Between 0 and 90 degrees.
2) Between 90 and 180 degrees.
3) Between 180 and 270 degrees.
4) Between 270 and 359 degrees.
5) I do not know.

03) Which is the vehicle's speed?
1) Between 0.0 and 0.5 m/s.
2) Between 0.5 and 1.0 m/s.
3) Between 1.0 and 1.5 m/s.
4) More than 1.5 m/s.
5) I do not know.

04) Which is the orientation of the camera, related to the vehicle?
1) Facing forward.
2) facing back.
3) facing left.
4) facing right.
5) I do not know.

05) Where the vehicle is in relation to the elements of the terrain?
1) Near the starting point.
2) Near the prohibited zone 1.
3) Near the agglomerate of barrels.
4) Near the forbidden zone 2.
5) Near the point of arrival.
6) None of the alternatives.
7) I do not know.

06) Regardless of distance, where is the vehicle pointing?
1) Approximately towards the starting point.
2) Approximately towards the forbidden zone 1.
3) Approximately towards the agglomerate of barrels.
4) Approximately towards the forbidden zone 2.
5) Approximately towards the point of arrival.
6) None of the alternatives.
7) I do not know.

07) Regardless of distance and from the direction of the vehicle, to which side is the arrival point?
1) Approximately in front of the vehicle.
2) To the right of the vehicle.
3) Approximately to the left of the vehicle.
4) Approximately behind the vehicle.
5) I do not know.

08) Regardless of the distance and from the direction of the vehicle, to which side is the agglomeration of barrels?
1) Approximately in front of the vehicle.
2) To the right of the vehicle.
3) Approximately to the left of the vehicle.
4) Approximately behind the vehicle.
5) I do not know

09) Is the vehicle close to an object, obstacle or leak?
1) No.
2) Yes.
3) I do not know.

10) To which side is this object, obstacle, or leak nearer?
1) Approximately in front of the vehicle.
2) To the right of the vehicle.
3) Approximately to the left of the vehicle.
4) Approximately behind the vehicle.

11) What is the distance to this object, obstacle or leak?
1) Less than 10 cm.
2) Between 10 and 30 cm.
3) Between 30 and 60 cm.
4) More than 60 cm.
5) I do not know.

12) How many leaks are occurring?
1) Between 1 and 3.
2) Between 4 and 6.
3) Between 7 and 9.
4) More than 9.
5) I do not know yet.
6) There is no leakage.

13) Is the vehicle contaminated or has it already collided?
1) No.
2) Yes.
3) I do not know.

14) What task is running?
1) Navigate and find the cluster of barrels.
2) Find and count leaks.
3) Navigate and locate starting point / beacons.
4) Bypassing the beacons.
5) Navigate and locate arrival point.

15) Does the vehicle's location match the current task?
1) No.
2) Yes.
3) I do not know

The FlyMov Research Center

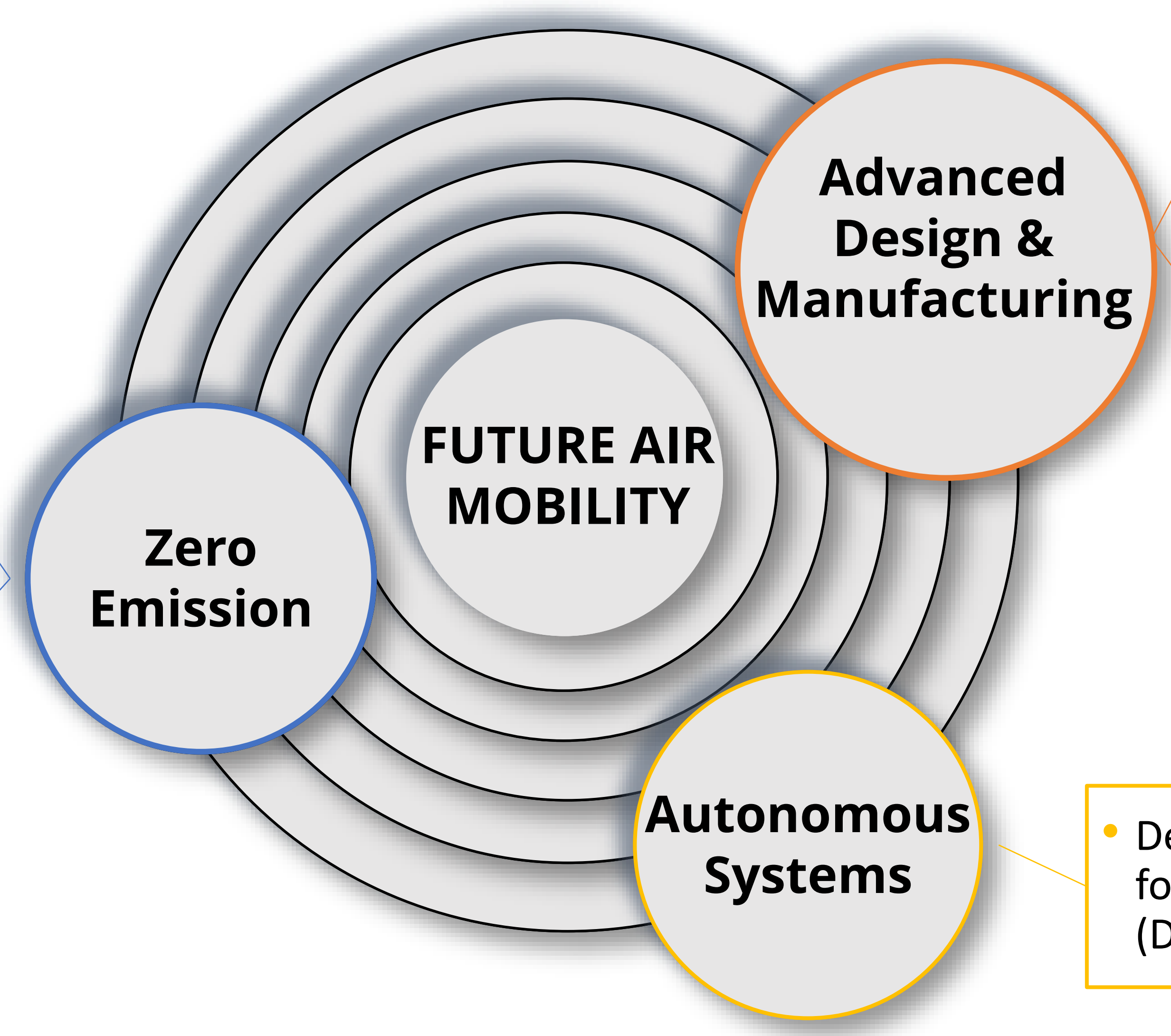
FLIGHT AND MOBILITY INNOVATION CENTER

A PARTNERSHIP OF

- Purpose:
  - Develop **innovative** and possibly **disruptive** technologies;
  - Develop **pre-competitive** solutions;
  - Approach industrial problems that requires **interdisciplinary** investigation;
  - Transform the future of **air mobility**.

The FlyMov Research Center

- Aero-propulsion Integration in Electric Aircraft (APIE)
- Machine Control for Electric Propulsion (MCEP)



- Advanced Design for Metallic Additive Manufacturing (ADAM)
- Intelligent Aircraft Final Assembly (IAFA)

- Decision Making Methods for Autonomous Systems (DMAS)

Advanced Design & Manufacturing

Intelligent Aircraft Final Assembly (IAFA)

RESEARCH TOPICS – IAFA
Development of ROS-nodes for integration of a collaborative robotic cell
Experimental modeling of an automated aircraft sealing cell
Creation of door assembly scenarios for proof-of-concept
Conceptual design of multi-functional collaborative robotic cell
Human and task mapping and detection using computer vision
Systems integration in a multi-functional collaborative robotic cell
Aircraft door assembly process: modeling, simulation, and optimization
Aircraft door assembly process intelligence: generative adversarial network and neural network
Parametric optimization based on Artificial Intelligence (AI) and in-process inspection
Human-robot task-sharing in a collaborative robotic scenario
ROS multi-task architecture and programming

- Collaborative robotics & human factors
- Use of AI for process optimization and data processing
- Etc...

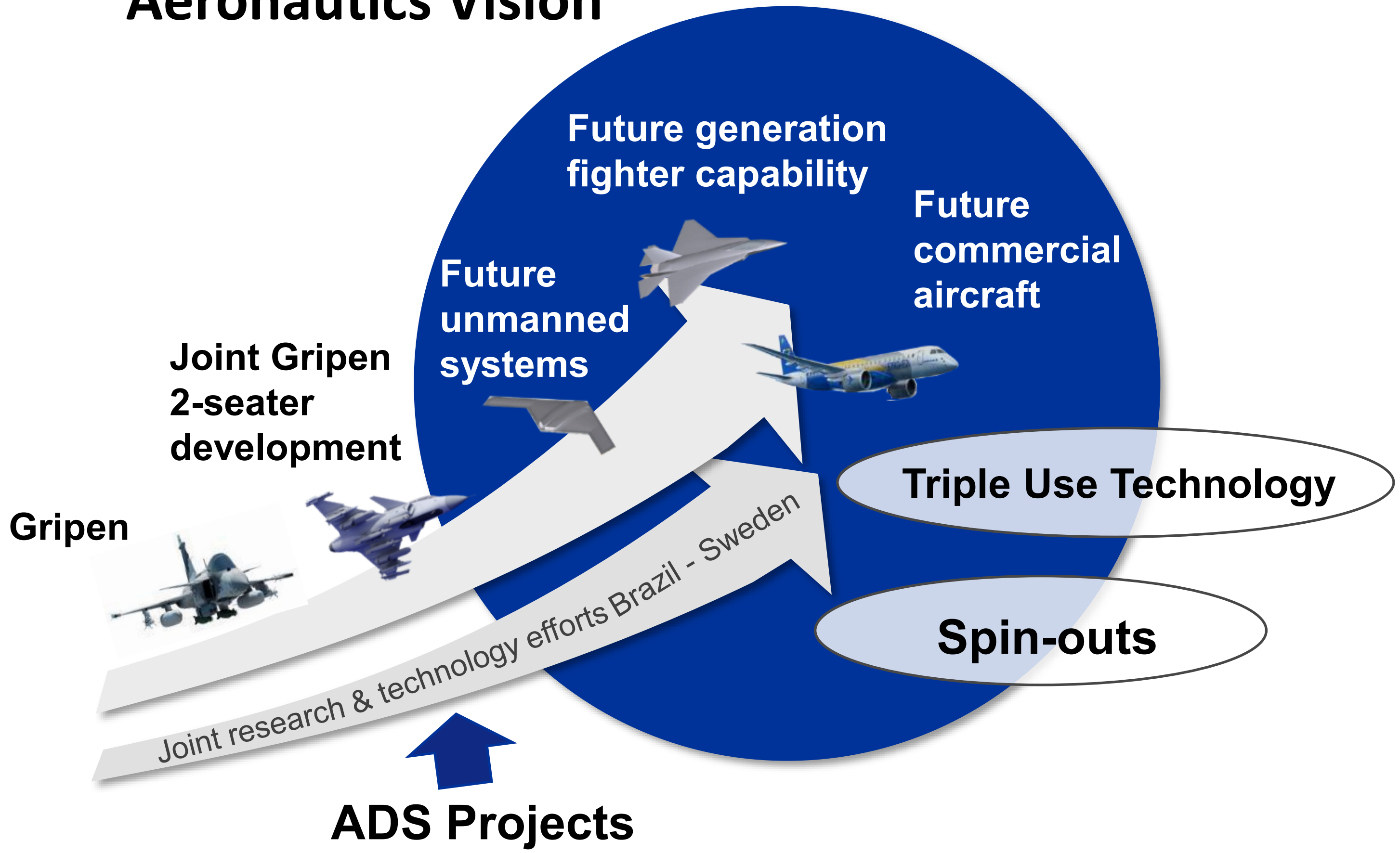
Decision Making Methods for Autonomous Systems (DMAS)

RESEARCH TOPICS – DMAS
Implementation of a common simulation framework for projects on autonomous systems
Framework for the acquisition of tasks for human-centered automation
Evaluation of pilot/operator condition for human-centered automation
Convolutional neural networks for situational awareness of urban autonomous aerial vehicles
Explicable decisions in semi-autonomous systems
Virtual reality simulation of semi-autonomous system with digital twin
Sensor fusion system for localization and situational awareness of urban autonomous aerial vehicles
Investigation on novel approaches to the design of runtime reconfigurable embedded systems for future aerial mobility
Trajectory planning for multiple UAVs using model predictive control
Human-centered approaches to semi-autonomous systems

- Semi-autonomous system
- Human-centered automation
- Situational awareness

The Future Air Domain Study (ADS) Program

The Brazilian–Swedish Aeronautics Vision



ADS – Future Air Domain Study Group

- Different levels of autonomy and embedded intelligence
- System-of-systems
- Human-autonomy teaming
- Human-machine interface

What do we mean by “Future Air Domain”?

- Concept
  - Combination of aerial operations, technologies, and strategic considerations that will shape how air power is projected and managed.
- Relevance:
- Key features:
  - System of systems:
    - Integration of next-generation aircraft with drones;
    - AI enabled real-time data collection and processing;
    - Collaboration with legacy platforms.
  - Manned-Unmanned Teaming (MUM-T):
    - Shift beyond traditional pilot or operator roles.
    - Humans will collaborate dynamically with intelligent agents.
    - Operations will span human-in-the-loop, on-the-loop, and out-of-the-loop modes.

ADS Projects

- *Human Machine Interface and Human Factors Laboratory* - HMI-HUFLab:
  - Development of human-machine interface prototypes and evaluation of human factors for future air domain scenarios.
- *Cooperative Threat Engagement with Heterogeneous Drone Swarms* - CTEDS:
  - Developing cooperation and interaction strategies for drone swarms, with the goal of responding to threats.
- *Autonomous Search Systems* - AUSSYS:
  - Development of an automated system to support aircraft search and rescue operations through image processing.

ADS Projects

- *Safe Integration of Different Unmanned Aircraft into Non-segregated Airspace* - SIMUA:
  - Development of an approach to detect and avoid aerial or ground obstacles, in order to enable operations beyond the line of sight of unmanned aircraft.

- Virtual Demonstrator - VD:
  - Development of a simulation environment for future operations concepts, supporting the creation of simulation scenarios involving manned and unmanned systems.

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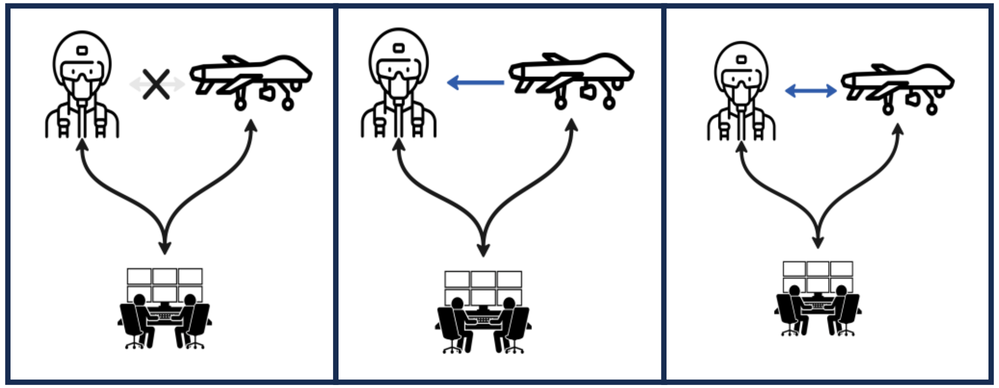
The ADS Program - *on-going works at HMI-HUFLab*

- AI-assisted HMI with **different levels of autonomy** for multiple UAS mission reconfiguration
  - Investigate the impact of adopting different levels of autonomy:
    - **Human operated** (manual reconfiguration)
    - **Human delegated** (pilot choose among a set of options provided by the AI)
    - **Human supervised** (the AI choose and informs the pilot, which may interfere or not)
  - Support the development of adaptative HMI for controlling multiple UAVs

- Design of **multimodal interfaces** based on generative AI for **manned-unmanned teaming**
  - Multi modal HMI: speech, touch, gestures, eye movement, physiological signals, sound, vision, vibration, physical elements, touchscreen elements.
  - Framework integrating 3 design methods (Delphi; Ecological Interface Design (EID); Function-Behaviour-Structure (FBS))



Thanks!!

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