EU-Japan Collaborative Research Project in Aeronautics

Validation of Integrated Safety-enhanced Intelligent flight cONTrol

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## Basic Information

<table>
<thead>
<tr>
<th><strong>Acronym</strong></th>
<th>VISION</th>
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<tbody>
<tr>
<td><strong>Full name</strong></td>
<td>Validation of Integrated Safety-enhanced Intelligent flight cONtrol</td>
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<tr>
<td><strong>Starting date</strong></td>
<td>01/03/2016</td>
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<tr>
<td><strong>Duration</strong></td>
<td>36 months</td>
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<tr>
<td><strong>Budget</strong></td>
<td>1.8 M€ (EC) + 1.8 M€ (NEDO)</td>
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| **Grant no**    | (EU) EU-H2020 GA-690811  
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                  | MG-1.8-2015 International cooperation in aeronautics with Japan |
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                        | (JP) Mr. Hiroyuki Hirabayashi (NEDO) |
| **Coordinators** | (EU) Dr. Yoko Watanabe (ONERA/Dept. of Information Processing and Systems)  
                      | (JP) Prof. Shinji Suzuki (the University of Tokyo/School of Aeronautics and Astronautics) |
## Consortium

<table>
<thead>
<tr>
<th>EU Participants</th>
<th>Japan Participants</th>
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<tr>
<td>1. <strong>ONERA</strong></td>
<td>7. <strong>University of Tokyo</strong></td>
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<tr>
<td>Dept. of Information Processing and Systems</td>
<td>Dept. of Aeronautics and Astronautics</td>
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<td>FR</td>
<td><strong>JP</strong></td>
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<td>2. <strong>University of Exeter</strong></td>
<td>8. <strong>JAXA</strong></td>
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<tr>
<td>College of Engineering Mathematics and Physical Sciences</td>
<td>Aeronautical Technology Directorate</td>
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<td>UK</td>
<td><strong>JP</strong></td>
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<tr>
<td>3. <strong>University of Bristol</strong></td>
<td>9. <strong>RICOH Co. Ltd.</strong></td>
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<tr>
<td>Department of Aerospace Engineering</td>
<td>Photonics R&amp;D Center</td>
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<td>UK</td>
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<td>4. <strong>SZTAKI</strong></td>
<td>10. <strong>Mitsubishi Space Software Co. Ltd.</strong></td>
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<td>Systems and Control Laboratory</td>
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<td>HU</td>
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<td>5. <strong>Unmanned Solutions</strong></td>
<td>11. <strong>ENRI</strong></td>
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<td><strong>ES</strong></td>
<td>Dept. of Air Traffic Management</td>
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<td>6. <strong>Dassault Aviation</strong></td>
<td><strong>JP</strong></td>
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<td>Flight dynamics department</td>
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Global objective

Investigation, development and validation of “smarter” aircraft Guidance, Navigation and Control (GN&C) solutions to automatically detect and overcome some critical flight situations

- Increase tolerance of the aircraft auto-pilot system to flight anomalies (actuator/sensor failures)
- Reduce the pilot’s task and stress in difficult situations

Contribute to the aircraft accident rate reduction
Motivation

- More than half of the commercial aircraft fatal accidents occurred during near-ground operations (take-off, final approach, landing).
- Enhancing airplane flight safety during such critical operation phases is an important key to the accident rate reduction.
Motivation

Two accident types

1) Accidents due to **flight control** performance failure
   - Loss of aircraft controls due to bad weather, mechanical failures, etc.
     - ex.) AF447 (Rio-Paris) crash in June 2009 (228 fatalities)
     - Airspeed indicator error due to Pitot tube icing
     - Pilot’s incorrect reaction resulted in aerodynamic stall

2) Accidents due to **navigation and guidance** performance failure
   - Lack of visibility, pilot’s situational awareness
     - ex.) OZ162 (Seoul-Hiroshima) crash landing in April 2015 (27 minor injuries)
     - Manual approach guidance with GNSS navigation data
     - Bad visibility condition with rain

Needs to improve robustness and self-adaptability of the current aircraft flight system to both types of failures
Motivation

- **Onboard vision sensors**
  - Effective tool to increase the pilot’s situational awareness during near- or on-ground aircraft operation
    - ex.) Wing-tip cameras for on-ground anti-collision
      - Fin-tip and belly cameras for taxi-aid on A380
  - Used for cockpit display only
    - Not used in the flight GN&C system
  - Significant potential of 3D Lidar and IR camera in degraded visibility condition (night, fog, etc.)
Technical Objectives

- Recovery from flight anomaly during the final approach phase
  1) Flight control performance recovery
     - Actuator failure (jamming, authority deterioration)
     - Sensor failure (loss of airspeed data)
  2) Navigation and guidance performance recovery
     - Sensor failure (lack of SBAS, lack of ILS)
     - Obstruction (object/aircraft on a runway, air traffic cut-in on the final path)

- “Smarter” GN&C technologies
  1) Fault Detection and Diagnostic / Fault Tolerant Control (FDD/FTC)
  2) Vision-based control surface monitoring system
  3) Vision-aided local precision navigation system
  4) Vision-based obstacle detection and missed approach guidance
Background

• Fault Detection and Diagnostic / Fault Tolerant Control (FDD/FTC)

EU-FP7 ADDSAFE (2009-2012) / RECONFIGURE (2013-2016)
- Integrated FDD/FTC solutions
- Validations through pilot-in-the-loop simulations with real flight avionics
- Airbus’s participation to define real and wide-covered fault scenarios

- Integrated FDD/FTC solutions
- Flight validation on JAXA MuPAL-alpha aircraft
Background

- Vision-based guidance and navigation

**EU-FP6 PEGASE (2006-2009)**
- Vision-based runway (helipad) detection and relative navigation
- Automatic landing guidance
- Evaluation through simulations with synthetic images

**EU-FP7 ALICIA (2009-2014)**
- Visible / IR cameras and 3D Lidar systems for runway and obstacle detection during the taxi phase in all conditions
- Cockpit display only

- Online flight trajectory optimization and collision avoidance guidance
- Flight validation on FHI FABOT RPA
Project Aims

- To capitalize on both Europe and Japan’s complementary research activities and experiences, as well as their industrial strengths

- To propose operation-oriented integrated GN&C solutions for each of the scenarios

- To mature the TRL of the proposed GN&C solutions by performing flight validations on real aircraft platforms

- To promote the collaboration between EU – Japan researchers and students
Organization

WP 2: Specification of fault scenarios (ONERA)
- WP2.1: Flight control performance recovery scenario
- WP2.2: Navigation and guidance performance recovery scenario

WP 3: Flight control performance recovery scenario (UExeter)
- WP3.1: Development of FDD algorithms
- WP3.2: Development of FTC algorithms
- WP3.3: System implementation and validation
- WP2.4: Performance analysis

WP 4: Navigation and guidance performance recovery scenario (SZTAKI)
- WP4.1: Development of vision systems
- WP4.2: Development of navigation & guidance algorithms
- WP4.3: System implementation and validation
- WP4.4: Performance analysis

WP 5: Dissemination (UBristol)
- WP5.2: Roadmap and Exploitation (UBristol)
WP3: FDD/FTC controller designs

- Development of advanced FDD/FTC controllers
  - Sliding-mode FDD/FTC (Fault Tolerant Control) controller design for aileron & rudder actuator failure (loss of efficiency)
  - Structured H-infinity FDD/FTC controller design for aileron & rudder actuator failure (saturation, constant bias)
  - Adaptive gain-scheduled FTC controller with online parameter estimation for FDD (Fault Detection and Diagnostic) for elevator actuator failure (loss of efficiency) / sensor failure (loss of airspeed)
  - Neural Network-based simple adaptive FTC controller design for actuator failures and CG shift

Implementation and in-flight validation on real aircraft for raising TRL of those techniques
WP3: Flight experimental platform

- MuPAL-alpha aircraft
  - Dornier Do228-200
  - Experimental Fly-By-Wire system
  - Hardware-in-the-Loop Simulation (HILS) setup
  - First operation at Chofu airfield in Tokyo, Japan
WP3: Flight test campaigns

- First flight test campaigns (12/2016 – 03/2017)
  - 3 EU partners had 2-weeks flight test sessions at JAXA
  - C-code implementation and HIL simulation validation
  - Preliminary flight tests (fault-free cases)
  - 4 scientific EU-Japan joint publications

Hardware-In-The-Loop Simulation (HILS)

UBRISTOL + JAXA Flight test trajectory (near Tokyo, Japan)
WP3: Flight test campaigns

- **Example of test results**
  - **UNEXE**: Flight test with emulated aileron & rudder actuator faults
  - **ONERA**: HILS test with emulated elevator actuator fault

### UNEXE: Flight test with emulated aileron & rudder actuator faults
- Sideslip angle
- Roll angle
- 20% loss of efficiency
- 50% loss of efficiency

### ONERA: HILS test with emulated elevator actuator fault
- Nominal case without failure
- Case of 30% loss of elevator efficiency
- Expected behavior of the control law
- Reference measured
- Without adaptation
- With adaptation
WP3: Vision-based control surface monitoring

- Aileron deflection angle detection by onboard camera to assist pilots and/or FDD/FTC controller
  - On-ground test with a camera installed on JAXA MuPAL-alpha aircraft
  - Preliminary results of image processing
WP4: Onboard vision-based navigation

- Development of integrated Vision/ILS, Vision/GNSS navigation system for cases of sensor failure

In-flight validation on real aircraft
WP4: Flight experiment platform

« K50-Advanced » UAV platform

- Manufactured within the project
- High payload capacity (100L, 20kg)
- ONERA flight avionics
  - GPS RTK (dual antennas)
  - AHRS (Attitude & Heading Reference System)
  - Pressure sensors
  - Inclinometers
- First flight expected in Oct. 2018

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<th>Dimensions</th>
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<tr>
<td>Wingspan 4.00 m</td>
<td>Max Take-off Weight 50 kg</td>
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<tr>
<td>Length 3.09 m</td>
<td>Max Zero-fuel weight 30 kg</td>
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<tr>
<td><strong>Typical Speeds at 1500m ISA and 50 kg</strong></td>
<td><strong>Useful load 20 kg</strong></td>
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<tr>
<td>Dash Speed 142 km/h</td>
<td><strong>Take-off at 0m ISA and Flap 0°</strong></td>
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<tr>
<td>Loiter Speed 72 km/h</td>
<td>Take-off distance 90 m</td>
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<tr>
<td>Stall Speed Flap 0° 65 km/h</td>
<td>Take-off rotation speed 79 km/h</td>
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<td>Endurance 5 hours</td>
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WP4: Obstacle detection & avoidance

- Development of vision-based obstacle detection and trajectory modification/go-around decision for collision avoidance

- Numerical simulation
- In-flight validation on small UAVs

![Diagram of obstacle detection and avoidance system](image-url)
WP4: Onboard vision system

- **Stereo-vision system under the belly**
  
- **Monocular-vision systems under each wing**
  
  - First camera installation on K50 and calibration test
  - Preliminary flight tests for image recording
  - Preliminary validation of image processor for runway marker detection

Images taken from multi-copter (RICOH)

Obstacle

Imitated runway markers

Synthetic image

Runway marker detection (SZTAKI)
WP4: K50 flight controller

Approach guidance & flight controller design

- ILS-based approach guidance and basic flight controller design
- Nonlinear simulation framework
- Refinement of the aircraft dynamic model by flight test data and re-adjustment of the flight controller (early 2018)
WP4: Integrated navigation

Integrated Vision/GNSS, Vision/ILS navigation systems with Integrity monitoring function

- Multi-sensor fusion by Error-State Kalman Filter (ESKF) with time-delayed measurements
- Tight integration of GNSS / INS / Vision
- Integrity monitoring function by AAIM (Aircraft Autonomous Integrity Monitoring) algorithms
Next steps…

- System development and Flight test campaigns continue …
  - Further flight test campaigns planned to start early 2018 at JAXA for FDD/FTC algorithms validation
  - First flight test campaign of K50 with the vision systems onboard planned in early 2018

- Analysis of industrial operational relevance
  - Participation of Dassault aviation
  - Invitation of EU and Japan external experts (Airbus, Mitsubishi HI, EASA, etc.) to the progress meetings

- Dissemination
  - EU-Japan joint publication on the validation results
  - EU-Japan co-organization of special session in international conferences
  - Organization of final international workshop at the end of the project
Thank you!

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