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The Group of Responsables "Flight Mechanics, Systems and Integration (GoR FM)": An Overview of Activities and Success Stories

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Abstract

This paper gives an overview of the activities of the Group of Responsables for Flight Mechanics, Systems and Integration (GopR FM) within GARTEUR (*Group for Aeronautical Research and Technology in EURope*) over nearly half a century of European collaboration. It presents the research fields, some very successful highlights and gives an outlook on future activities.

Keywords: GARTEUR, flight mechanics, systems and integration, UAS, Fault Detection, Flight Control

1. Introduction

The Group of Responsables for Flight Mechanics, Systems and Integration is active in the field of flight systems technology in general.

The GoR-FM is responsible for all research and development subjects starting from the air vehicles and their flight mechanics until their integration into Air Traffic. It covers embedded sensors, actuators, systems and information technology, cockpits, ground control and human integration issues, with reference to automation for both inhabited and uninhabited aircraft, including, but not limited to:

- Aircraft multidisciplinary design aspects;
- Flight performance, stability, control and guidance;
- Aircraft navigation and mission management;
- Air traffic management and control;
- Integration of remotely piloted systems in the air spaces;
- Safety critical avionics functions and embedded systems;
- Scientific and technical expertise for air systems certification and regulatory aspects.

Noticeably, GoR-FM is not active in the rotary wing domain, where the GARTEUR Helicopters GoR is responsible.

More than 80 reports about many aspects have already been published by GoR-FM, covering a variety of the research topics mentioned above, from Handling Quality research, fault tolerant control up to research towards greater autonomy for multiple Unmanned Air Vehicles. These reports are available at the GARTEUR website, but many results have been published in conference proceedings or as scientific books like publication about Nonlinear Analysis and Synthesis Techniques for Aircraft Control (Springer Verlag).

The following section 2 gives a broad overview about the research fields of GoR FM in general, section 3 will give some more details about the research activities of the Action Group FM/AG17 on Nonlinear Analysis and Synthesis Techniques for Aircraft Control and section 4 on results of FM/AG18 Towards greater Autonomy in Multiple Unmanned Air Vehicles.

Finally, section 5 gives an outlook on future activities within GoR FM.

2. GoR FM: General Overview

More than 40 years ago, this GARTEUR group started collaborative research among European partners in the field of Flight Mechanics. Research has been carried out on handling qualities, and flight control. Among others guidelines for handling qualities of future transport aircraft have been published in the early 80s of last century (FM/AG01). Topics addressed have been:

- Definition of piloting tasks, present and future (e.g. MLS approach).
- Definition of workload levels and required performance levels.
- Measurement techniques of workload and performance.
- Appraisal of analytical methods describing the pilot-aircraft system.
- Demonstration procedures.
- Evaluation of concepts for future transport Aircraft primary flight control.

The participating partners profited quite a lot by this collaborative research and further activities within those organizations in the field of handling quality research have been influenced by this GARTEUR activity.

From the very beginning future Air Traffic Management (ATM) concepts have as well been addressed by GoR-FM (FM/AG03). A conceptual model of a future Integrated ATM system has been defined which included 4D trajectory concepts like tubes and trajectory negotiation. The developed concepts already included many aspects that have as well been addressed within EUROCONTROL's PHARE [1] programme and which are still part of the actual SESAR ATM Masterplan [2].

Among other research activities in the field of flight control, GoR FM conducted a design challenge for flight controls by applying different techniques on this benchmark (FM/AG08). Twenty-one teams from seven countries participated in the Design Challenge investigating the following techniques:

- Classical control
- Eigenstructure Assignment
- Fuzzy logic control
- H-infinity Loop Shaping
- H-infinity Mixed Sensitivity
- Linear Quadratic Optimal Control
- Lyapunov techniques
- Model Following
- Multi-Objective Parameter synthesis
- Mu-synthesis
- Nonlinear Dynamic Inversion
- Predictive Control
- Robust Inverse Dynamics Estimation

Further highlights of GoR FM activities include the publication of the PIO (Pilot Induced Oscillation) handbook in 2003 (FM/AG12) and the GARTEUR Handbook of Mental Workload Measurement (FM/AG13).

About 15 years ago, UAS topics have been included in the GoR FM research activities. The name of the GoR FM was then extended by "System Integration" to better reflect as well this new research field (see section 4). For further readings: most reports of the GoR FM Action Groups can be downloaded from the GARTEUR website [3]

3. Action Group FM/AG17 on Nonlinear Analysis and Synthesis Techniques for Aircraft Control

3.1 Background

Despite many significant advances in the theory of nonlinear control in recent years, the majority of control laws implemented in the European aerospace industry are still designed and analysed using predominantly linear techniques applied to linearized models of the

aircrafts' dynamics. Given the continuous increase in the complexity of aircraft control laws, and the corresponding increase in the demands on their performance and reliability, industrial control law designers are highly motivated to explore the applicability of new and more powerful methods for design and analysis.

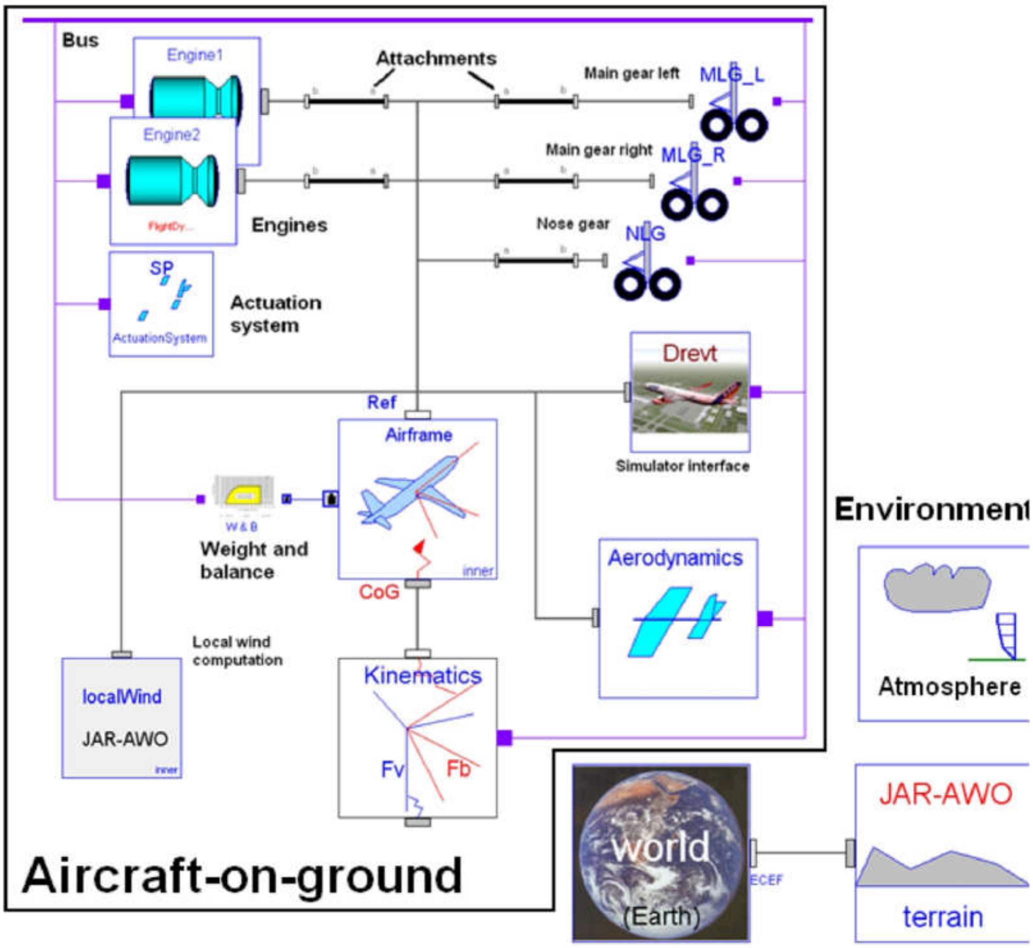

Figure 1 - General Setup of FM/AG17

3.2 Objectives

The overall objective of the Action Group was to explore new nonlinear design and analysis methods that have the potential to reduce the time and cost involved with control law development for new aerospace vehicles, while simultaneously increasing the performance, reliability and safety of the resulting controller. This objective was to be achieved by investigating the full potential of nonlinear design and analysis methods on demanding benchmarks developed within the project, in order to focus the research effort on the issues of most relevance to industry

Main achievements

- LFT modelling tools, including guidelines for LFT modelling, symbolic manipulations, model reduction and nonlinear symbolic LFT modelling.

- On-ground benchmark modelling using LFT's, including aircraft dynamics, actuators saturations, ground forces and time-varying dependencies such as ground velocity or nose-wheel deflection.

- LPV-AW design methods. This parameter varying anti-windup synthesis is coupled with an on-line estimator of the ground forces. Performance in the presence of saturations is guaranteed by design using LMI's.

- Stability and performance robustness assessment for LTI-uncertain and LTV nonlinear systems. The method developed in this action group extends the use of μ-analysis to nonlinear systems. In addition, the method allows systems which are dependent on both uncertain and time-varying parameters to be considered. These results are based directly on the LFT modelling of nonlinearities, uncertainties and time-varying parameters, showing here again the complementarity of the works performed.

- Object oriented modelling. This offers the possibility for interactive modelling with reusable library and easy connection of objects, including the development of specific blocks for the benchmark. Automatic code generation then allows the integration of either a reduced or complete model into a design or simulation environment such as Matlab-Simulink, Dymola or any flight simulation environment. This is of particular interest in a design process requiring iterative loops between synthesis and evaluation.

- Symbolic inversion-based control design tools. These tools come with a proposed process for control laws design and evaluation based on object-oriented modelling and simulation.

3.3 The Programme

In September 2004, GARTEUR Flight Mechanics Action Group 17 (FM-AG17) was established to conduct research on "New Analysis and Synthesis Techniques for Aircraft Control". The group comprised representatives from the European aerospace industry (EADS Military Aircraft, Airbus and Saab), research establishments (ONERA France, FOI Sweden, DLR Germany, NLR Netherlands) and universities (Bristol, DeMontfort, Liverpool and Leicester).

To guarantee the industrial relevance of the project, two highly realistic simulation models were developed, together with demanding design/analysis challenges. These benchmarks in themselves represent significant achievements of the project, since there are still very few industrially relevant aircraft models, with realistic design and analysis specifications, available in the open literature on which control theoreticians can test and validate new techniques and algorithms. An additional benefit of the on-ground transport aircraft benchmark developed by Airbus for the project is that it represents a non-standard control application (at least in the context of aerospace control!) and thus adds another new and challenging set of problems to those traditionally addressed by flight control law designers. Nine different approaches and techniques were applied to the benchmark problems.

- Nonlinear symbolic LFT tools for modelling, analysis and design
- Nonlinear LFT modelling for on-ground transport aircraft
- On-ground aircraft control design using an LPV anti-windup approach
- Rapid prototyping using inversion-based control and object-oriented modelling
- Robustness analysis versus mixed LTI/LTV uncertainties for on-ground aircraft
- An LPV Control Law Design and Evaluation for the ADMIRE Model
- Block Backstepping For Nonlinear Flight Control Law Design
- Optimisation-based flight control law clearance
- Investigation of the ADMIRE Manoeuvring Capabilities Using Qualitative Methods

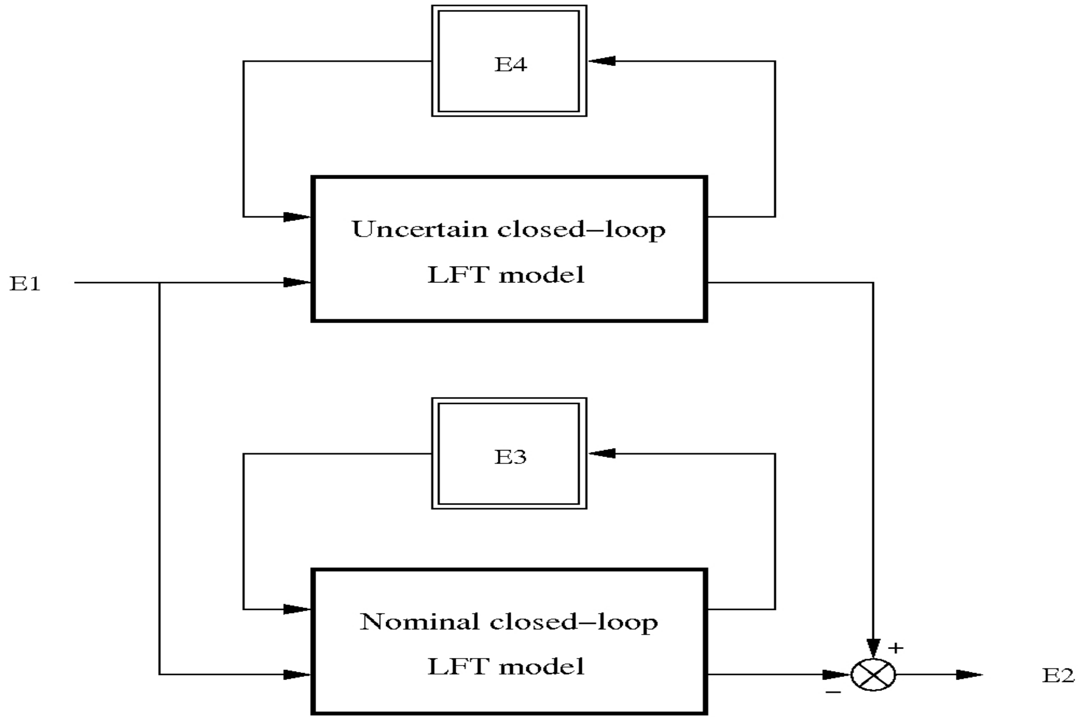

Figure 2 - basic control loop diagram

3.4 The Outcomes

The process of undertaking this research has been beneficial for all the participants, many of whom have taken part in previous related Action Groups and have by now developed effective working relationships. As usual, the information flow has been in both directions, with industrial members providing valuable insight into the real problems and challenges faced by control law designers, and academic researchers highlighting the potential (and potential shortcomings) of the latest nonlinear design and analysis methods. The project has been particularly valuable for the doctoral students and post-doctoral researchers who participated, since it allowed them access to truly challenging problems which are also of particular interest to industry. In these respects, the Action Group has certainly demonstrated the value of GARTEUR research to the European aerospace industry - it has made a significant contribution both to narrowing the ``theory-practice gap'' between academics and industry, and to educating the next generation of aerospace control engineers.

4. FM/AG18 Towards greater Autonomy in Multiple Unmanned Air Vehicles

4.1 Scope, Aim, and Objectives

The scope of AG18 was to identify enabling technologies and methods related to terms such as autonomous reasoning, planning, conflict-resolution and decision making for multiple unmanned air vehicles (UAV). To focus contributory efforts, a design framework was proposed that would provide context for workers in the participating research teams to examine a wide range of different methods applied to problems described by an overarching scenario.

The framework was focussed around a scenario and mission in which it was envisaged UAVs might be deployed in the future. The scenario comprised a number of UAVs introduced into an area of terrain populated by obstacles in the form of various air defence radar sites (threats), no fly zones, airways etc where they must complete a mission. All methods addressed within the AG would be situated within the scope of the mission framework and cooperate with manned platforms as well as being monitored by a human operator.

The aim of the AG was the:

> Collection, implementation and systematic categorization of machine based reasoning and artificial cognition approaches applicable to facilitate co-operation between UAVs and other assets with reduced human intervention. Those other assets will include other UAVs, manned assets and

human operators performing supervisory control. The environment is highly uncertain, the goals may change and the problem may have no unique solution.

Consequently, the objectives of the AG were:

1. The definition and selection of a suitable overarching framework comprising relevant aspects of anticipated future autonomous UAV missions.
2. The application of various methods within the framework.
3. A better understanding of autonomous systems and levels of autonomy (with respect to the information requirements, latency, and robustness for example).
4. An indication of spin-off applications and critical technology research areas for the future.
5. To inform the generation of a toolset and metrics to support the work.
6. Better understanding of human operator requirements for different levels of autonomy.
7. To acquaint the wider UAV community of the current state of the art while proposing emerging approaches and inform the development of a technology roadmap to greater autonomous capability.

4.2 Research Framework

The methodology used to develop the framework began with the presentation of the global scenario as again illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.Fehler! Verweisquelle konnte nicht gefunden werden.**.

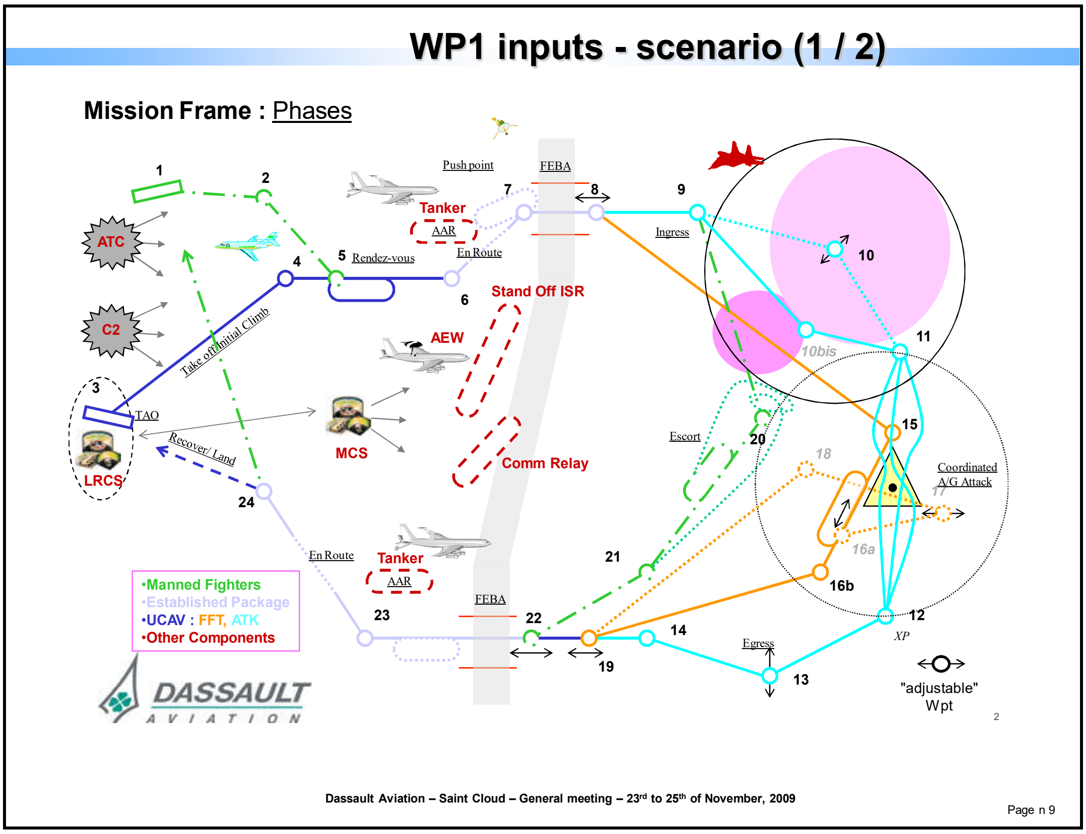

Figure 3 – the scenario

The steps of the methodology to be followed were:

1. To decide/define the different mission phases to focus on the themes of interest motivating further analysis;
2. To identify the major problem areas to focus the research effort;
3. To describe in more detail the mission phases in which the UAV will play a significant role and how each mission segment fits within the overall mission framework (including areas to be considered from the industry perspective);
4. To describe in more detail the environment in which the UAV(s) will operate;
5. To describe in more detail the objects that will interact with the UAV(s) and the requirements for the interactions and interconnections required for the system operational integrity;
6. To specify a timeline, a sequence of events or history of the nominal scenario. This timeline would provide realistic figures in order for technology protagonists to understand constraints on time.

Basically, the research carried out focused on three major themes:

- Global scope - **Mission level**
- **Path generation** – Flight Management System (FMS)
- **Terminal Area** – Mission Management Systems and FMS

4.3 Outcome

FM/AG 18 had been constructed to allow the application of many diverse approaches to parts of the problem space. Main contributions have been provided by

- Universität der Bundeswehr München - Cognitive automation approaches to multi-UAV mission management (see Figure 4)
- University Complutense Madrid - Differential Evolution Trajectory Planner and Target Allocator for Cooperating UAVs
- University of Loughborough - Autonomous Terminal Area Operations for Unmanned Aircraft Systems
- University of Leicester - Cubature H∞ Filter Based SLAM
- DLR - Automated Swarm Landing Assistance for Multi-UAV Missions (see Figure 5)
- CIRA Automatic Guidance through 4D Waypoints with time and spatial margins

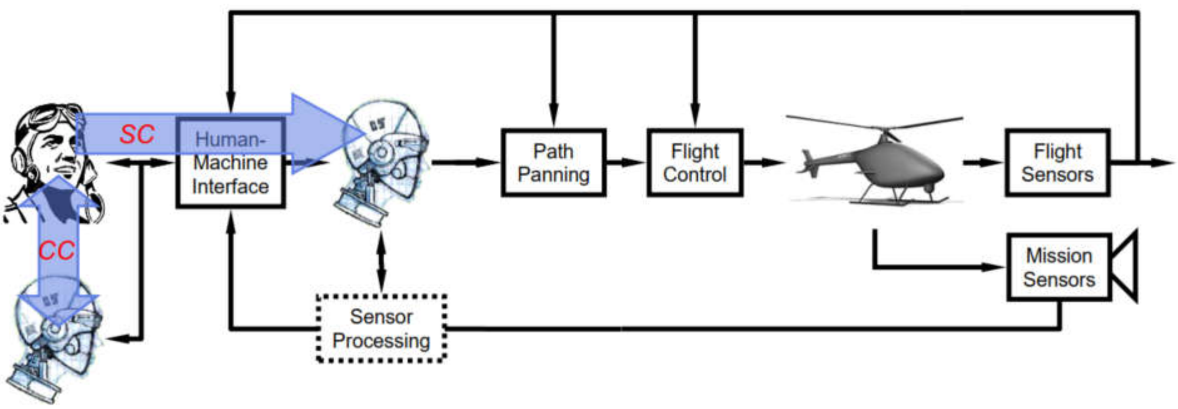

Figure 4 – Integration of "Artificial Cognitive Units" allowing the human to switch between Supervisory Control (SC) of highly automated vehicle and Cooperative Control (CC) in which the human and the artificial cognitive agent work together like a cockpit crew, see [4] for more details.

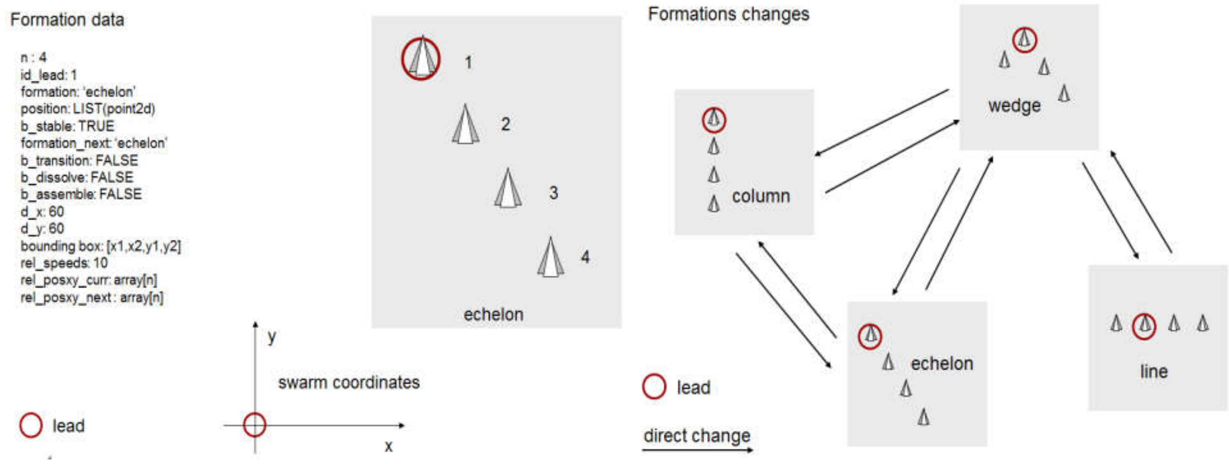

Figure 5 – Formation management as part of swarm flight management system

5. Outlook

Recent activities within GoR FM focused on fault tolerant control and fault detection in general. GoR FM is currently active to define a new Action group on using "Artificial Intelligence for Fault Detection".

It is about investigating the feasibility of AI technics for fault detection onboard aerospace vehicles. The current state of practice generally implies a dedicated algorithm (a.k.a.monitoring) to detect a specific fault, and does not rely on AI technics. A more precise objective is to investigate the benefits of AI-based technics in terms of sensor fault detection and isolation, especially when not relying on the type of fault to detect. In particular, it should focus on learning approaches able to identify the nominal domain of a sensor measurement. Once identified off-line, a real-time monitoring should allow to detect any excursion outside the nominal envelope, meaning the occurrence of a fault. As this "generic" monitoring would trigger for any kinds of fault, an identification step would be needed to determine the fault nature.

6. Acknowledgements

The author is grateful to all the persons involved in current and past GARTEUR activities. The success of GARTEUR is the result of their efforts and dedication. Special thanks to the participants in the Exploratory Groups and the Action Groups: their work and their results are essential to explore new scientific directions and to support the aeronautical community.

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8. Copyright Statement

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