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START

A STABLE AND RESILIENT ATM BY INTEGRATING ROBUST AIRLINE OPERATIONS INTO THE NETWORK

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Abstract

This deliverable contains the proceedings of the participation of the START project at the 12th EASN International Conference on "Innovation in Aviation & Space for opening New Horizons" with the session "Meteorology and Environment in ATM". This session took place in Barcelona, Spain, on the 19th of October 2022 with around 25 attendants.

The conference was organized by the European Aeronautics Science Network (EASN) together with the Universitat Politècnica de Catalunya. It also had the support of SESAR JU, the Clean Aviation programme, the organization Fraunhofer, the Spanish Ministry of Science and Innovation and Centre for Technological Development and Innovation.

The goal of the participation in the EASN International Conference was to disseminate the START research results to the airspace scientific community and stakeholders, leveraging knowledge and creating synergies.

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1 Executive Summary

The START project participated at the 12th EASN International Conference on "Innovation in Aviation & Space for opening New Horizons" with the session "Meteorology and Environment in ATM". It took place in Barcelona, Spain, on the 19th of October 2022.

The main goal of the conference was to act as a forum where innovative ideas, breakthrough concepts and disruptive technologies are presented with the aim to establish new research partnerships and possible synergies. Moreover, it was a place for disseminating the knowledge and results achieved and discussing on current trends and future needs in the frame of research projects of the Aviation and Space field.

The starting time of the session was 10:30 in the morning, as scheduled, with about 25 attendees in total. It was chaired by the START project coordinator, Manuel Soler (UC3M) and organised in seven talks: four of them related to the START project work packages, and the last three held by members of other SESAR 2020 exploratory research projects such as ISOBAR and FlyATM4E, to bring out the latest advances in Artificial Intelligence weather forecasting and climate optimal trajectory planning.

This document contains the abstract of the SESAR presentations, as well as a summary of the other three. It is divided into seven chapters.

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2 Introduction

2.1 The START project

One of the key enablers of Trajectory Based Operations (TBO) is the automated updating of trajectories in reaction to developing uncertainties. However, a high frequency of updates and modifications leads to degraded system stability. The overall goal of START (a Stable and resilienT ATM by integrAting Robust airline operations into the neTwork) is to develop, implement, and validate optimisation algorithms for robust airline operations that result in stable and resilient ATM performance even in disturbed scenarios.

START's goal shall be reached by a suitable combination of methods from applied mathematics, i.e.: mathematical optimisation, optimisation under uncertainty, Artificial Intelligence (AI) and data science, as well as algorithm design. Furthermore, insight into the uncertainties relevant in TBO systems will be gained through simulations. The main focus of the project is the optimization of conventional traffic situations while considering disruptive weather events such as thunderstorms. Specific goals include:

- To model uncertainties at the micro (trajectory) level, assimilate observations (via ADSB/Radar) every 15 min and propagate trajectory uncertainties using assimilated models and a stochastic trajectory predictor.
- To model uncertainties at the macro (ATM network) level, assimilate observations (satellite data for storm, and network status) every 15 min., and propagate ATM network uncertainties using the assimilated models.
- To develop an Artificial Intelligence (AI) algorithm capable of generating a set of pan-European (i.e., considering the whole traffic over Europe) robust trajectories that make the European ATM system resilient when facing these relevant validate ties.
- To implement those algorithms as an advanced fight dispatching demo functionality for airspace users to obtain robust trajectories.
- To validate these concepts through system-wide simulation procedures in order to evaluate their stability.

2.2 Acronyms and Terminology

START Consortium

Acronym	Description
BDG	Boeing Research and Technology Europe-Germany
DLR	German Aerospace Center
ENAC	École Nationale de l'Aviation Civile
FLIGHTKEYS / FK	FlightKeys
ITU	Istambul Teknik Universitesi
UC3M	Universidad Carlos III de Madrid
UPC	Universitat Politecnica de Catalunya

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3 The EASN International Conference

Figure 1: EASN International Conference poster

The 12th EASN International Conference on "Innovation in Aviation & Space for opening New Horizons" was an in-person encounter that took place in Barcelona, Spain from the 18th until the 21st of October 2022.

The conference was located in the Universitat Politècnica de Catalunya at UPC Campus Nord and organized by the European Aeronautics Science Network (EASN) together with the UPC. It also had the support of SESAR JU, the Clean Aviation programme, the organization Fraunhofer, the Spanish Ministry of Science and Innovation and Centre for Technological Development and Innovation.

Like its predecessors, the 12th EASN International Conference on "Innovation in Aviation & Space for opening New Horizons" included a number of Plenary Talks by distinguished personalities of the European Aviation and Space sectors from the academia, industry, research community, and policy-makers. It also had Thematic Sessions, along with Technical Workshops where innovative ideas, breakthrough concepts, and disruptive technologies were presented and discussed with the aim to establish new research partnerships and possible synergies.

The goal of the conference is to become a major European Dissemination event of Aviation & Space-related research, providing a forum for presenting EU funded projects' activities and achieved goals, discussing current trends and future needs, and trying to identify possible collaborations with each other. Additionally, a number of policy development projects also find the floor to present the strategic priorities of the European aviation sector.

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The START project organized the session "Meteorology and Environment in ATM", which had the participation of more than 25 attendees from at least five different countries: Spain, Germany, France, Turkey and Iran.

The conference agenda can be consulted in the following chapter four. There were 7 presentations: conclusions of the different work packages of the START project were discussed in the first 4 presentations (the ones included in this deliverable) and the next 3 introduced topics such as Artificial Intelligence and weather forecast, and climate optimal trajectory planning.

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4 Agenda

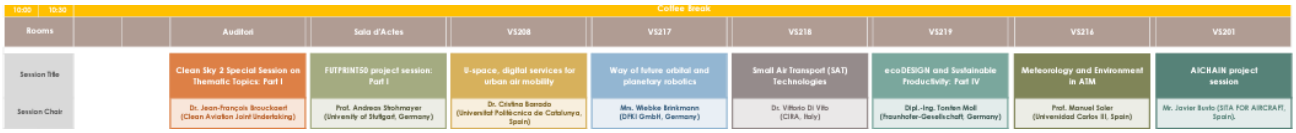

Figure 2: Sessions and rooms on the 2nd Conference day

Session: METEORLOGY AND ENVIRONMENT IN ATM (Room VS2016)

Chair: **Prof. Manuel Soler** (Universidad Carlos III, Spain)

10.30 – 10.50	*Data-driven uncertainty quantification and propagation for probabilistic trajectory planning.* **Andrés Muñoz**, from BOEING Deutschland Gmbh
10.50 – 11.10	*ATM Network modelling for uncertainty propagation under disruptive events.* **Emre Koyuncu**, from Istambul Technical University
11.10 – 11.30	*Network-wide robust and resilient metaheuristic trajectory optimization under thunderstorm disruptions.* **Julien Lavandier,** from ENAC
11.30 – 11.50	*Simulation Exercises for robust flight dispatching solution under thunderstorm disruptions.* **Alexander Kuenz,** from DLR
11.50 – 12.10	*Artificial Intelligence and Weather Forecasting.* **Manuel Soler,** from Carlos III University of Madrid
12.10 – 12.30	*Robust Climate Optimal Aircraft Trajectory Planning within Structured Airspace.* **Abolfazl Simorgh,** from Carlos III University of Madrid
12.30 – 12.50	*Complexity Assessment of Adopting Climate Optimal Aircraft Trajectories at Network Scale.* **Fateme Baneshi,** from Carlos III University of Madrid

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5 Meteorology and Environment in ATM

5.1 Data-driven uncertainty quantification and propagation for probabilistic trajectory planning

Mr. Andrés Muñoz Hernández (Boeing Research & Technology Europe), *Manuel Polaina, Alejandro Güemes, Jordi Pons, Xavier Prats, Emre Koyuncu, Daniel Delahaye, Raimund Zoop, Alex Kuenz, Manuel Soler.*

Figure 3: Andrés Muñoz in the 1st session talk

One of the main objectives of Trajectory-Based Operations (TBO) is to increase the predictability of the aircraft behaviour within the Air Traffic Management (ATM) system. However, most systems involved in TBO (such as flight planning systems) focus on proposing deterministic trajectories in the strategic phase, not taking into account the uncertainty factors that affect the trajectory prediction process in the tactical phase.

Consequently, there is an increased frequency of updates and modifications to trajectories in later planning phases, which leads to degraded stability, resulting in an overall decrease of the performance of the ATM network. In this presentation, a data-driven methodology will be introduced for characterizing the uncertainties affecting the development of an aircraft trajectory, together with their integration into a stochastic trajectory predictor for obtaining robust sets of probabilistic trajectories from an initial flight plan. Additionally, this methodology employs data assimilation models that capture updated information from the air traffic system to reduce the present uncertainty. First, the main sources of uncertainty for aircraft trajectories will be identified and quantified using historical flight instances for a full year of pan-European air traffic. After quantifying these sources of uncertainty, it will be possible to evaluate the potential variations for a flight plan given the probability distributions for uncertain factors affecting the flight. Instead of applying computationally demanding methods, such as Monte Carlo simulations, for calculating all possible trajectories, a stochastic trajectory predictor is proposed that makes use of the characterization of trajectory uncertainty to compute probabilistic trajectories given an initial flight plan.

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The stochastic trajectory predictor uses arbitrary Polynomial Chaos Expansion (PCE) theory and the point collocation method to find polynomials describing the aircraft trajectory for the initial flight plan as a function of the identified uncertain factors. Therefore, the quantified uncertainty sources can be fitted in the polynomials to find a reduced set of probabilistic trajectories that are robust and resilient to potential variations in the tactical phase.

Complementing this, a set of advanced data-assimilation models based on machine learning techniques are integrated to provide accurate estimations for some of the uncertain factors based on the last available status of the air traffic system. These estimates reduce the uncertainty spectrum for important variables in the trajectory prediction process and help adapting the resulting probabilistic trajectories to the current system status. Finally, a study case is introduced in which the proposed methodology is implemented. This study includes the results of analysing the probabilistic trajectories for one city-pair and supports the idea of integrating probabilistic trajectories as a key enabler for envisioned TBO concepts and modern airline operations planning.

5.2 ATM network modelling, uncertainty propagation with thunderstorm disruptions

Dr. Emre Koyuncu (Instambul Technical University), *Muhammet Aksoy, Andrés Muñoz, Jordi Pons, Daniel Delahaye, Raimund Zoop, Alex Kuenz, Manuel Soler.*

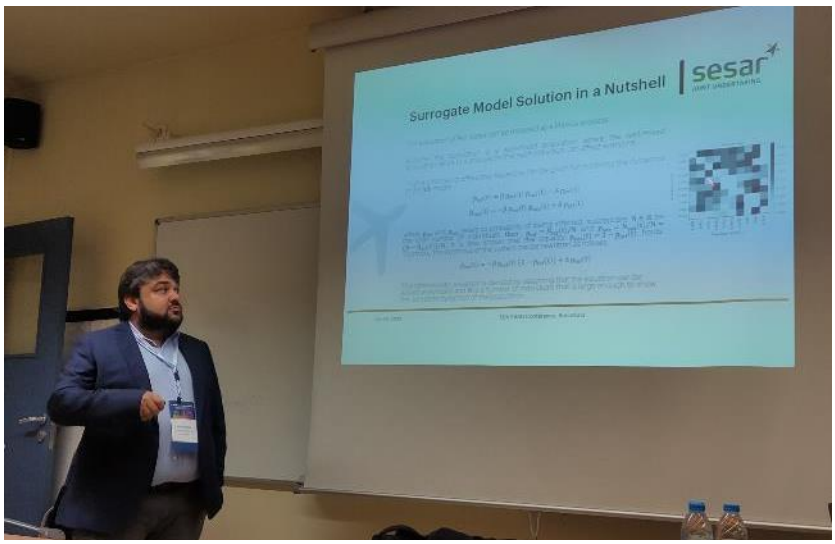

Figure 4: Emre Koyuncu in the 2nd session talk

In this work, as a part of START, we have developed an ATM network macro-model, allowing us to model the propagation of flight trajectory uncertainties and further assess the impact of disruptive events, i.e., thunderstorms. We utilized data-driven analytics models mimicking the dynamics of epidemic spreading, which is analogous to delay or uncertainty propagation over transport networks.

The connections between the operational aspects of the air traffic flow management and the developed meta-model are given as the airports' traffic densities correlated with the infection rates among the individuals; and the capability to absorb the uncertainties of the airports associated with recovery rates. Uncertainties over individual flight trajectories, which are the functions of flight times, have been defined through probabilistic distributions where superposed on the arrival times. Deep learning models have been integrated to capture the nonlinear relationship between the recovery rates, uncertainty accumulation, and disruptive events' attributes. The model allowed us to simulate and analyse the behaviour of the network under uncertainty accumulations coming from trajectory uncertainty. Finally, we have used Reinforcement Learning to explore the best actions to enhance the network resiliency, defined through stability theory. From the operational perspective, resiliency is

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associated with the managing balance between the intervention rate (depending on "the time for washing away the effect of the transition period) and costs. The problem, at this point, transformed into an optimization-based control problem to guarantee convergence over time, meaning the effect of disruptive events dies out eventually. Quick recovery is typically preferred, but it applies significant intervention measures impacting many flights in this case. RL provided us with pinpointing the OD pairs, and the flights require regulatory action such as flight cancelation and aircraft grounding. The case studies are analysed for the selected time windows chosen in the interval of 1-10 June 2018, where thunderstorms affected large areas of North-West Europe with intense local convective activities.

5.3 Network-wide robust and resilient metaheuristic trajectory optimization under thunderstorm disruptions

Mr. Julien Lavandier (ENAC), *Daniel Delahaye, Daniel González-Arribas, Javier García, Manuel Soler, Emre Koyuncu Aksoy, Andrés Muñoz, Jordi Pons, Xavier Prats, Daniel Delahaye, Raimund Zoop, Alex Kuenz.*

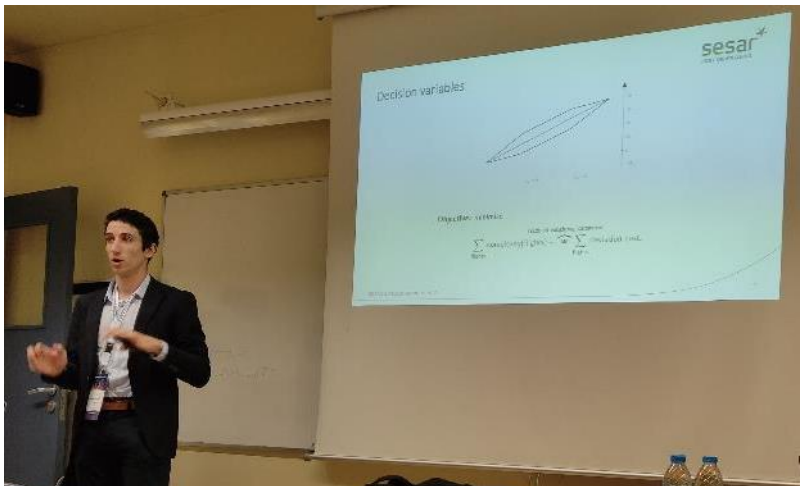

Figure 5: Julien Lavandier in the 3rd session talk

Network-wide robust and resilient trajectory planning is realized after the uncertainty propagations at trajectory and ATM levels. The inputs are the 4D trajectories with uncertainty and the delays applied to trajectories for network resiliency. The delays only shift the trajectories in time. The output is a set of algorithmic solutions for optimal trajectory selection under high complexity situations. According to the START concept, a proposed rerouting and/or rescheduling solution of the user-preferred flight plan is proposed to improve the resiliency and robustness of overall planning. The optimization process is realized using the simulated annealing metaheuristic to find the optimal rerouting and delays for each flight. The objective function of this optimization problem is a complexity metric function, based on Linear Dynamical System. This metric can consider uncertainty in the 4D trajectories. However, the computation of such metric requires extensive computation time. We proposed GPU-based concept to speed up the metric computation. We have found that the proposed GPU-based concept can potentially provide the desired performance and prove the computational viability of the START project.

Nevertheless, our findings are not uniformly positive, as the reliance on single-precision arithmetic (on which current GPUs provide substantially higher throughput) seems to have proved more problematic than our previous expectation. The global air traffic complexity is reduced by a factor of six hundred from around 120 to 0.2. It corresponds to a better organization of the traffic. In fact, the complexity is mainly due to very few flights. The complexity reduction decreases the potential number of conflicts, because there are less converging air traffic situations.

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5.4 Simulation Exercises for robust Flight dispatching solution under thunderstorm disruptions

Mr. Alex Kuenz (DLR), *Emre Koyuncu, Muhammet Aksoy, Andrés Muñoz, Manuel Polaina, Alejandro Güemes, Jordi Pons, Xavier Prats, Julien Lavandier, Daniel Delahaye, Raimund Zoop, Alejandra Frías, Daniel González-Arribas, Javier García, Manuel Soler.*

Figure 6: Alex Kuenz in the 4th session talk

The development, implementation and validation of optimisation algorithms for robust airline operations that result in stable and resilient Air Traffic Management (ATM) performance even in disturbed scenarios are the overall goals of START.

This presentation focuses on the validation part. The validation of the START robust airline operations is performed by comparing the performance of a reference and a resilient scenario under disturbed and undisturbed conditions. The reference scenario is derived from the traffic demand for two days in 2018, June 7th and June 10th with strong convective weather phenomena. The resilient scenario is built on the reference scenario but is prepared for more frequent planning updates due to changing forecasts of capacity shortfalls mainly caused by weather impacts. Resiliency refers to the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances. Within the validation trials performed, disturbances are included by means of convective weather areas which are handled as No-Fly-Zones (NFZ).

Validation of the START results is performed threefold:

1. First, reference and resilient scenarios are compared, mainly focusing on expected duration of overall conflict hours of aircraft with other aircraft and convective weather zones.
2. Second, real life departure uncertainties are added by means of Monte-Carlo simulations with different distributions.
3. Finally, scenarios are resolved with conflict resolution algorithms above FL150 as far as possible. The presentation gives an overview of the validation results, showing an overall low but stable benefit for the adapted aircraft fleet (Star Alliance) of the resilient scenario, with no negative effects for the global scenario.

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6 Impact

The participation in the event was communicated in the START website on the 19th of October, 2022. To spread the knowledge about the conference and the participation of START, it was also published in the project's social media (LinkedIn and Twitter), tagging participants and using the conference hashtag #EASNConference. Here is the link to the web-post:

- https://start-atm.com/2022/10/19/start-participates-in-the-12th-easn-international-conference-on-innovation-in-aviation-space-for-opening-new-horizons/

As a result, we achieved the following impacts:

- A higher engagement than average in **LinkedIn**, reaching 4 shares and 21 reactions from different industry stakeholders, university researchers, members of scientific organizations and representants of European institutions, including the EASN - European Aeronautics Science Network account and SESAR Joint Undertaking. This also increased the page views to more than 20 in a day.

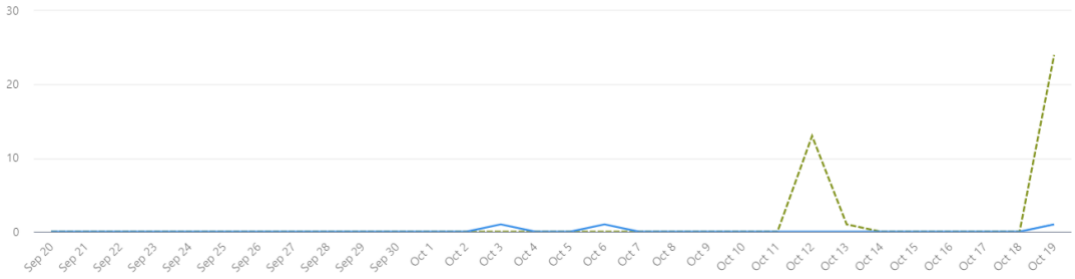

Figure 7: Views of the START project LinkedIn page in the last month.

- More than 240 impressions and 56 engagements in **Twitter** only in the first day, receiving retweets from influencing accounts (+800 followers): companies like Pangea Aerospace, institutions like SESAR or Engage KTN, and individual profiles from Italy and South Africa.

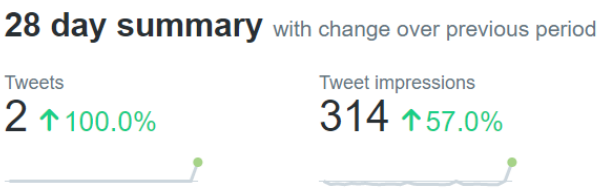

Figure 8: ***Twitter Impact.***

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7 Conclusions

Figure 9: Picture of Start Team after EASN session

The session 'Meteorology and Environment in ATM' at the 12th EASN International Conference on Innovation in Aviation & Space for opening New Horizons was indeed able to create a space for discussion about two of the most crucial topics for aviation in our times: weather uncertainty and environmental impact.

The event had a high participation, filling the room with more than 25 on-site attendees.

The key results of the SESAR JU funded project START were successfully dissemination in such a forum.

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