UTOPIA

Universal Trajectory Synchronization for Highly Predictable Arrivals Enabled by Full Automation

M. Schultz, H. Fricke, M. Kaiser, T.Kunze
Technische Universität Dresden
Dresden, Germany
{schultz, fricke, kaiser, kunze}
@ifl.tu-dresden.de

J. L. Leonés
Boeing Research and Technology Europe
Madrid, Spain
{javier.lopezleones}
@boeing.com

M. Wimmer, P. Kappertz
Barco Orthogon GmbH
Bremen, Germany
{michael.wimmer, peter.kappertz}
@barco.com

***Foreword*— This paper describes a project that is part of SESAR Workpackage E, which is addressing long-term and innovative research. The project was started early 2011 so this description is limited to an outline of the project objectives augmented by some early findings.**

***Abstract* - One of the greatest challenges that the future ATM system will need to face in the next decades is the integration of new airspace users and the continuous increase in delegating capacity and safety critical traffic management functions to automated systems. The accommodation of these new airspace users, which will have to coexist with conventional users, a widely reorganized airspace and the increased level of automation will necessarily need a paradigm shift with regard to the trajectory management functions already foreseen in the SESAR master plan for 2020. The objective of the UTOPIA project is to provide a better understanding of which trajectory management functions will be needed to deal with heterogeneous traffic when those functions are executed by autonomous ATM systems (and humans involved in the decision and execution of the air traffic management actions). In particular, the study executed in this project will focus on the data models, synchronization requirements and algorithms needed to ensure the safe management of merging traffic in an extended TMA, executed by an autonomous arrival management function acting as separator. The converging flows of traffic that will be studied comprise heterogeneous airborne systems, in particular, unmanned air-vehicles and advanced and legacy flight management systems, representing airspace users with different synchronization capabilities.**

Keywords-heterogenous traffic, arrival management, formal languages, disruption, uncertainty, synchronization, multi-dimensional trajectory,

I. Introduction

The UTOPIA proposal is embedded in the SESAR Work Package E (WP-E) which aims at compiling two complementary objectives focused on research and innovation. The first objective is to create research networks in the ATM domain that are maintained beyond the timeframe of the SESAR program [1], and the second deals with the support of any research activity in the ATM domain not considered explicitly in the scope of the SESAR program. The UTOPIA consortium consists of three members Technische Universität Dresden (TUDD), Boeing Research and Technology Europe (BRTE) and Barco Orthogon GmbH (Barco) and is led by TUDD. The UTOPIA consortium will explore several innovative aspects considered in the WP-E research area *Towards Higher Levels of Automation in ATM*. This theme fosters the research in those areas and technologies that will increase the levels of automation, up to and including full automation, of the future ATM system. One of the key elements, as indicated in the WP-E thematic program [2], will be *integration of both airborne and ground-based systems and a heterogeneous user (aircraft) population*, which is the subject matter of this proposal. In particular, this project focuses in two areas outlined in this theme: exploring the *coexistence of subsystems with different levels of automation in an overall system* and *algorithms and control paradigms using high degrees of automation*.

II. UTOPIA - Statement

The solution proposed in UTOPIA is articulated in three innovative key elements: (1) formal models of trajectory data and trajectory synchronization protocols for heterogeneous systems in an automated environment, (2) study uncertainty sources and their propagation in the aircraft n-dimensional trajectories (nDT), considering also system disruptions, and (3) advanced trajectory management algorithms and ground synchronization functions based on the formal n-dimensional trajectory data and uncertainty models.

1) Trajectory Synchronization

We will extend the concept of 4D trajectories to n dimensional trajectories and we will apply this concept to study the different communication mechanisms needed for automated trajectory synchronization. The theory of formal languages will be considered to ensure that these trajectory data models can be unambiguously understood by automated systems during the data synchronization process. This approach will ensure the robustness of the decisions taken by the autonomous trajectory management system supposed to act on ground. Furthermore, this strategy shall trade-off air-ground data transfer volume minimization and precision maximization about aircraft states and intents.

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2) Disruption and Uncertainty

A key requirement for an effective trajectory management is a deep understanding of the uncertainty effects and the different tactical or strategic autonomous measures to manage them. Examples for the former may be on-board separation, for the latter, robust arrival procedures against wind influences. We will build a formal uncertainty and disruption model that can support trajectory synchronization functions executed by automated air and ground systems and communication protocols to ensure predictability, integrity and reliability for heterogeneous traffic environment.

3) Advanced Arrival Management

As a particular case study for this project we will apply the trajectory data and uncertainty models to the design of advanced arrival management algorithms and air-ground communication protocols. This function acts as an innovative arrival management system in UTOPIA, able to incorporate a constant data synchronization procedure between aircraft systems and itself (see trajectory synchronization) to build an optimized inbound sequence. This sequencing will be both robust against short coming plan alterations and far more efficient in reorganizing the sequence when necessary.

4) Demonstrator

In addition to the theoretical research that will be performed in the above areas, we will validate the concepts proposed by means of a demonstrator. The UTOPIA demonstrator will simulate the interaction of different airborne systems with an autonomous arrival manager. These airborne systems represent different possible synchronization levels in terms of the information and protocols used. The arrival manager will use the information derived from the airborne systems and perform separation, sequencing and scheduling of the traffic flow taking into account the associated uncertainty and disruption models. In principle, this demonstrator will include software models of B737 flight management system (FMS) and A320 FMS, validated with real ones, different simulated commercial aircraft and unmanned aerial systems (UAS), and a real arrival management system adapted to this new paradigm.

The crucial objective of UTOPIA is to help understanding what level of integration and robustness is needed to achieve the execution of fully autonomous operations with heterogeneous traffic with regard to aircraft types and equipment installed. We believe our results will be of great interest for the ATM community and the SESAR program. We expect that the conclusions of this project will serve to establish the research agenda to achieve the seamless integration of any air space users with autonomous or semi-autonomous ground tools. Among the high level research objectives considered by the HALA! (Higher Automation Levels in ATM) Research Network [3], the work done in UTOPIA is aligned to as follows:

1) 4D Trajectory Management

In UTOPIA we propose to extend modeling of trajectories at 4D level, as currently considered for the SESAR implementation phases, to n-dimensional business trajectories. In addition, we will study the implications of heterogeneous traffic in the traffic management functions, in particular with regard to air-ground synchronization and arrival management, when these functions are executed autonomously.

2) Integration of UAS in managed airspace

As stated above, UTOPIA will explore the effect of heterogeneous traffic, which includes UAVs, in TM (trajectory management) functions. This study will provide the HALA! research community with requisites over the new technologies and concepts that have to be considered in order to achieve a seamless integration of UAVs in managed airspace.

3) Advanced Decision Support Tools (DST)

UTOPIA will investigate into innovative air-ground synchronization protocols and arrival management functions to make use of nDTs and uncertainty models. The lessons learnt from this research will contribute to establish requisites on the future develop of advance DSTs able to deal with heterogeneous traffic in a highly automated environment.

III. RESEARCH APPROACH

Moving from Airspace based to Time Based Operations (from 2013), evolving to Trajectory Based Operations (from 2017) and finally Performance Based Operations (from 2020) are considered the cornerstone of the European ATM Master Plan [4], which has been the culmination of the SESAR Definition Phase and is the main source of guidance for the European ATM modernization process to be led by the SESAR Joint Undertaking [5].

A. Motivation

One of the main objectives of these evolutionary steps of the ATM Operational Services[1] is to increase the predictability at given reliability levels (confidence intervals in the statistical sense) of the aircraft behavior within the ATM system, thus reducing instabilities and inefficiencies through higher reliability. The aircraft trajectories considered by the ATM systems will be the result of a collaborative planning process. Essentially, these trajectories, called Business Trajectories, capture the business objectives of the users (the user preferences) taking into account the applicable ATM constraints. One of the biggest challenges that have to be tackled to support this evolution is an increment in automation. The main reason for this change is due by the fact that trajectory-related information will become the main piece of data being shared. This trajectory-based information has to contain an accurate description on how a specific trajectory is intended to be flown (regarding user preferences like how a specific airline prefers to fly climb, en-route, and descent profiles based on an individual cost function) and how an aircraft is intended to be operated to follow that trajectory within a timeframe (detailed speed, lateral and altitude profiles as well as aircraft configuration e.g. flaps). It is anticipated that

[1] ATM Operational Services are the operational relationships, defined in service terms, between the actors involved in performing operational processes needed to conduct ATM [6]

humans will not be able to manage such an amount of data, justifying the need for automated systems to assist both the separator and pilots at the beginning until the automated solution shifts the distribution of human workload (both pilot and separator) towards a supervising function while leaving the decision making process and monitoring to the automated systems.

Planning has been a psychological process of thinking about the activities required to create a desired goal on some scale and as such is a fundamental property of intelligent behavior; automated planning is therefore a nontrivial task. That difficulty is further aggravated if the system under consideration is of non-deterministic nature as is the case for air traffic, where a view on the system within a look-ahead time horizon of up to 2 hours is inherently incomplete. The incomplete view, also termed partial observability, of the system is caused by the uncertainty of its predicted states like e.g. unknown meteorological conditions, unknown flight delays, unknown airline behavior, unknown terminal maneuvering area (TMA) and center capacities, unknown military activities etc.

So based on detailed strategies which will form the concept of operation of UTOPIA, the project tries to achieve dynamic trajectory synchronization between the automated systems and ensure that any future airspace user, with different levels of equipment and automation (e.g. UASs, new avionics generation versus legacy airborne systems) can benefit from the services and capabilities built in this future ATM system.

This increment on the level of automation also exposes new interesting challenges to the research community, such as:

- new information data models, since this increase in automation leads to increased data
- volumes to be exchanged, to be handled robustly at equal levels of integrity and availability
- centralized or de-centralized trajectory management functions, in particular air-air, ground-ground and air-ground synchronization services;
- how automated systems can manage disruptions (plan deviations) and uncertainty whilst maintaining high degree of autonomy.

These questions will be addressed in UTOPIA, which will apply the concepts and technologies developed to study automated arrival management functions in the TMA, which may physically be extended to allow consideration of innovative arrival procedures. The managed airspace around the airport, the TMA is and is supposed to remain strategically a major bottleneck as far as ATM system capacity is concerned. It is also the domain that holds high traffic and as such control complexity according to ATFM metrics (Performance Measurement in ATFM) with respect to:

- the traffic density (vehicles per time and space),
- the individual dynamics of all vehicles (aircraft evolving in lateral, vertical, speed and throttle profiles as well as in aerodynamic configuration) and, therefore, in aircraft trajectory management, and
- the probability and severity of traffic conflicts (converging traffic involving maneuvering aircraft, conflicts affecting multiple aircraft in high density operations).

Thus, considering the goal of improving trajectory management within the TMA has an added value from the research stand point, due to its higher complexity, it is likely that the solutions developed to support TMA operations may easily be transferred to less stringent domains, such as en-route.

1) Key Assumptions

The UTOPIA project has been defined based on the following list of assumptions (a-g).

a) Human actors are no longer involved in the direct guidance of air traffic. It is assumed that the different airborne and ground trajectory–based tools considered in the context of this project will execute their functions autonomously.

b) Heterogeneous traffic covering both commercial aircraft and UAVs. For the case study, legacy FMSs of Boeing and Airbus will be used to proof the (backwards) compatibility of the UTOPIA concept, and simulated commercial aircraft and UAVs to model mix traffic with different synchronization capabilities.

c) The uncertainty aspects of the air traffic network will reflect on the individual and combined effects of the following factors:

- Aircraft's navigation performance (ANP) and guidance accuracy, e.g. random navigation and guidance errors, such as those captured by the Required Navigation Performance (RNP) statistics.
- Environment, e.g. random variations of the environmental factors, e.g. wind fields, temperature profiles and humidity, local static and dynamic pressure characteristics
- Operational stochastic factors, e.g. variability among the actual pilot/FMS actions in a given situation as well as among the times at which those actions are implemented.

d) The only ground system considered to perform trajectory management functions will be the advanced arrival management function. Focus will be set to the air-ground information data exchange needs for arrival operations in an automated extended TMA environment with high density traffic patterns.

e) It will further be assumed that a middleware and appropriate air-ground data links are available to allow the transfer of information among the systems considering scalable transmission rates, reliability and capability.

f) The research will be focused on investigating advanced algorithms for robust simultaneous de-confliction and sequencing to manage mixed traffic automatically considering certain uncertainty levels.

g) The demonstrator will integrate a real and a software based state-of-the-art FMS, simulated aircrafts and a hardware-in-the-loop simulated UAS with a robust simultaneous de-confliction and sequencing arrival management function.

B. Technical Description

The basic structure of the project starts with a definition of the future ATM concept, the UTOPIA concept of operations (ConOps), to be studied along the project, performing a detailed analysis of the expected functionality of the automated systems in 2020 and identifying gaps for reaching full automated capability for strategic trajectory management of heterogeneous airborne systems.

To support the objective of full automated managing of heterogeneous traffic, a study of a formal definition of the trajectory information to be handled will be performed. This study will be focused on the identification of the information needed for describing an nD trajectory and the definition of a formal structure to express this information unambiguously, based on the theory of formal languages [7]. This will permit the deterministic interpretation of that information by autonomous systems.

The idea of having a strict means of encoding the trajectory information without ambiguity leans on the assumption of knowing the effect and propagation of the associated uncertainty to the nD trajectory information. A dedicated study is planned to identify the relevant sources of uncertainty that may impact the air-ground synchronization and their effects on the decision making process that will be performed by a fully automated tool. Once (a) a clear understanding of how to express univocally an nD trajectory and (b) the influence of uncertainty factors have been established, the procedures of how a full automated arrival manager will manage them and how this tool will evaluate the different alternatives will be specified. Finally, specific cases for the concept validation will be analyzed using a simulation platform that will be developed accordingly. This platform will serve to validate the concept definition for managing nD trajectories of heterogeneous traffic by a full automated arrival manager tool considering the uncertainty related to this nD trajectory. The simulation to be performed will be circumscribed to converging traffic around the adopted TMA assuming simultaneous de-confliction and scheduling.

C. Work Breakdown Structure

We will describe the main activities that will be carried out in UTOPIA in the following paragraphs. The breakdown structure of the UTOPIA project is parted into five subsections: (1) concept definition, (2) data synchronization, (3) uncertainty, (4) proof of concept, and (5) case study.

1) Concept Definition

The concept's aim is to evaluate higher level of automation in trajectory management functions when applying high integrity nD trajectory synchronization together with advance arrival management algorithms to heterogeneously equipped air vehicles. Further, the fleet composition inside the (extended) TMA is expected to consist on various important types of aircraft ranging from commercial jet airliner, commercial turboprop commuter, and relatively small general aviation to unmanned aerial vehicles. First, the implication of this heterogeneous fleet in future TMA operations will be studied. Second, the descent (and climb) operations that will be considered for the proof of concept are investigated. These mixed operations will lead to a spreading set of trajectories and constraints that will be taken into account for the trajectory data models used for the automatic data synchronization. In order to manage at optimum capacity level all different requirements of the various aircraft types, the predicted nD airborne trajectories have to be continuously synchronized at the ground based arrival management function for optimized decision making. The uncertainty modeling assures an estimation of stochastic variation of synchronization input for an appropriate buffer time setup having in focus a maximum airspace capacity.

2) Data Synchronization

It is anticipated that the implementation of the performance based operations (PBO) paradigm will require of advanced DSTs to facilitate the design, amendment and negotiation of Business/Mission trajectories at the different stages of the flight. Such DSTs will be used on board the aircraft by the pilot and on the ground by both the ATM service providers and the separator. Depending on its operational objectives, each stakeholder may have different requirements as to how its DST models, describes and modifies the aircraft trajectory. Consequently, it is a key aspect that the appropriate mechanisms are in place to facilitate sufficient levels of interoperability between those DSTs, so as to enable all stakeholders to be able to achieve a consistent, synchronized view of the aircraft's Business/Mission Trajectory at any time during the flight.

In summary, the requirement that all stakeholders will be able to have a common, synchronized view of the user's Business/Mission Trajectory is paramount to the implementation of PBO paradigm. In order to generate and adapt business/mission trajectories, the DST's will need to be able to describe, compute and amend intended aircraft trajectories. In practice, due to the differences between the multiple trajectory prediction processes in air and ground automation systems, it may not be feasible for a DST to make meaningful adjustments to the trajectory produced by a different system. Therefore a kind of container of all the flight data is needed to reproduce the intended aircraft trajectory.

The introduction of system-wide PBO requires the definition of the trajectory data to be synchronized [8]and the structure of the data container has to be investigated to support synchronization among ground-based automation systems (e.g., traffic flow management unit, flight data processing systems, flight operation center)) as well as airborne automation systems. It is anticipated that, to that aim, the data to be exchanged [9],[10],[11] should comprise:

- The initial aircraft state that defines the start of the nD business/mission trajectory.
- The flight intent, which describes the constraints and preferences relating to the specific flight. This information defines the limiting conditions that are applicable and the preferences of the stakeholders leading to the optimum nDT.
- The aircraft intent, which describes in an unambiguous way, how the aircraft will be operated within the set of constraints (nD) defined in the flight intent, so that the stakeholder preferences are best met in the given operational conditions.
- Predicted trajectory, which represent the output calculated by any trajectory predictor included in those automation tools that requires the calculation of a trajectory to perform their functions (e.g. a FMS, a flight data processing system (FDPS), an arrival management system, or a conflict detection and resolution (CD&R) tool).

These four types of trajectory related information encompass all the aspects about a trajectory that can be exchanged among automation systems. In order to make full use of these trajectory aspects delivered through automated traffic management functions, it is therefore crucial to develop a formal model that can include all that information. In addition, it has to be ensured, that this formal model does not make any assumption about the type of aircraft (e.g. manned or unmanned, size, equipment) that generate the trajectory and that it covers any aspect of the aircraft motion, i.e., n-dimensional representation of the aircraft trajectory. To be understood by automatons, this nDT model must have the structure of a formal language so the trajectories are described univocally and the interpretation is deterministic [12]. The proposed formal language model of nDT information shall include an alphabet, which will contain a finite set of descriptors of the different types of data, together with a grammar, which will govern how to combine such factors in a meaningful way.

3) *Uncertainty and Disruption Modelling*

Network effects induce system interactions, which results in plan deviation (delay). To evaluate and mitigate their (negative) impact on data synchronization, propagation aspects have to be modeled and appropriate control strategies have to be developed. Since current system designs cover merely deterministic input data, they neglects known effects in the real operational environment, which are stochastic by their nature. Even for a reliable prediction of flight progress data, a stochastic system model is crucial to overcome deficiencies of a deterministic system and data design. Therefore, the UTOPIA project aims at analyzing the system behavior on empirical base and applying statistical approximation to allow for an analytic description of this stochastic system.

The trajectory prediction process and therefore the air-ground data synchronization are influenced by several stochastic factors [13] which produce discrepancies between the real trajectory flown by an aircraft and the predicted trajectory used by the DSTs to evaluate the traffic flow. The current DSTs need to understand and handle the uncertainty associated to the trajectory data to provide a proper decision [14][15] to a human who has the last responsible role.

The objective UTOPIA project is to perform a qualitative and quantitative analysis of the effects of those stochastic factors on the behavior of a fully automated control environment and how it is able to take decisions considering non deterministic information ensuring continuously the safety of operations. The impact of the following factors will be considered:

- Aircraft’s navigation performance (ANP) and guidance accuracy, e.g. random navigation and guidance errors, such as those captured by the Required Navigation Performance (RNP) statistics.
- Environment, e.g. random variations of the environmental factors, e.g. wind fields, temperature profiles and humidity, local static and dynamic pressure characteristics
- Operational stochastic factors, e.g. variability among the actual pilot/FMS actions in a given situation as well as among the times at which those actions are implemented.

The proposed uncertainty model will allow evaluating the expected equivalence between the operator’s process perception (relying on expertise) and the real system behavior. Reaching a high level of equivalence is seen to be mandatory for further levels of automation as one core target in this project. Due to the fact, that the stochastic approach results in probability measures, the structure of the output data differs from the currently used deterministic results. Therefore, appropriate information processing and interpretation methodologies have to be developed as well. The air-air and air-ground processes are particularly coupled and consequently exhibit a high interaction potential. The propagation of uncertainty and local/global mitigation strategies additionally characterize this complex system. To allow for a valid system development, stochastic data sets have to be derived from empirical data analyses of all involved systems. Herein, coupling effects between air and ground will be analyzed in detail to identify major system drivers and their contribution to the system behavior. To analyze current and future operational concepts, the whole system infrastructure and the individual characteristics (behavior) of the system components will be transformed in a consolidated agent based simulation model.

4) *Proof of Concept*

Following the definition of the mixed operations concept for converging heterogeneous traffic around the terminal area, a simulation infrastructure will be designed and implemented. This infrastructure will allow exploring the nD trajectory information exchange schemes for synchronization involving combinations of different on-board capabilities.

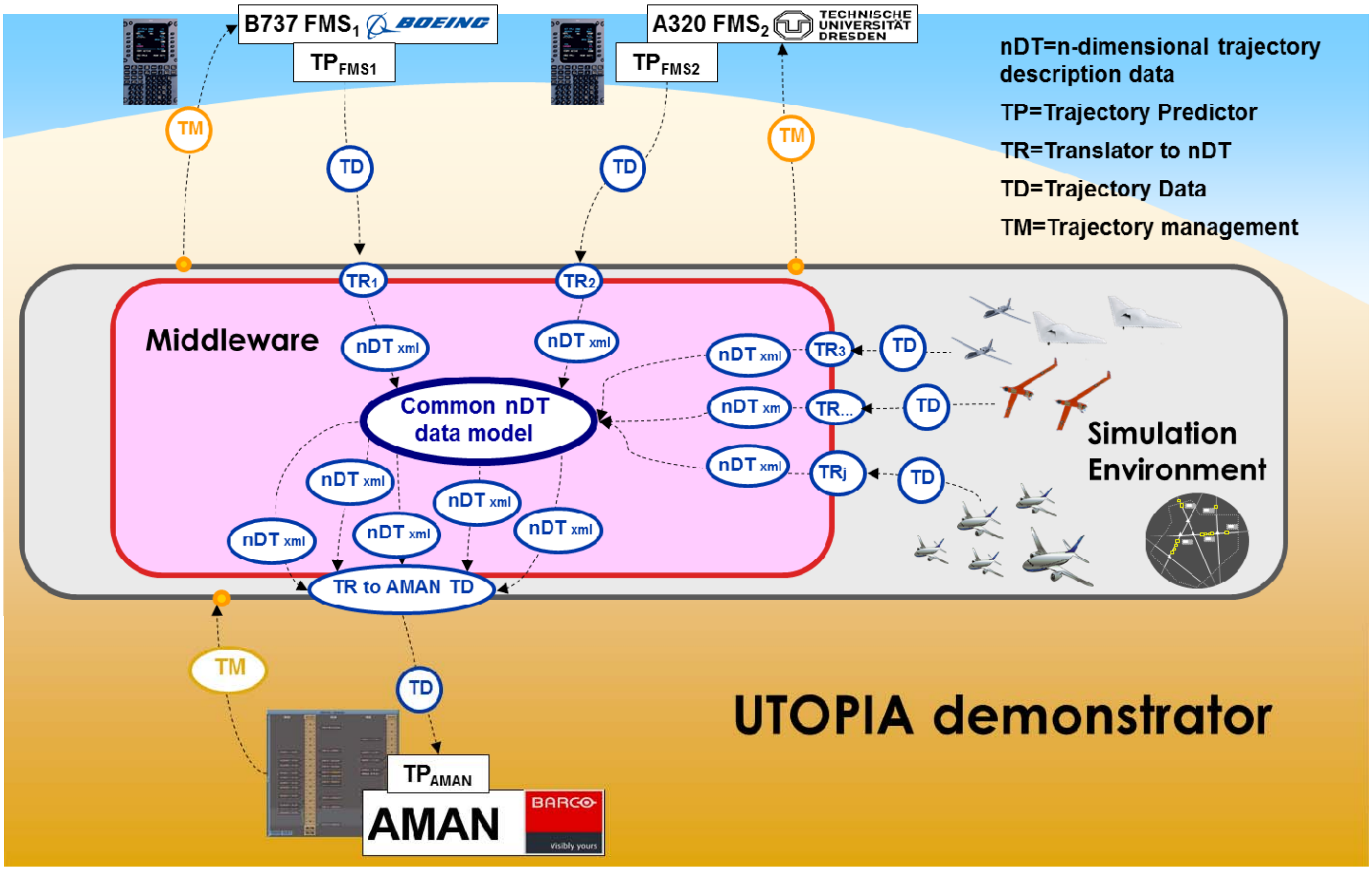

Figure 1. Conceptual diagram of the UTOPIA demonstrator

The objective of the infrastructure is to develop a demonstrator to prove the feasibility and the added value of the use of full automation tools for managing heterogeneous converging traffic.

Considering the scope of the project, this demonstrator (Fig. 1) will be composed of:

- two software models of FMSs with their corresponding navigation capabilities (such as Vertical and Lateral Navigation or Required Time of Arrival function), that will represent two legacy airborne automation systems. One FMS belongs to a B737 (provided by BRTE), and the other corresponds to an A320 (provided by TUDD). Both models and navigation capabilities are validated against two real operational FMSs;
- one ground-based arrival management function with its corresponding interface (provided by Barco), that will implement the simultaneous de-confliction and advanced sequencing algorithms to be used to manage the traffic flow efficiently and safely.
- a middleware layer that will manage the exchange of the different types of trajectory information under certain communication protocols. This middleware layer will include the translators needed to transform trajectory data extracted from the FMSs and the simulated aircraft and UAVs to the common nDT data model.
- an experimental TM layer, in where all the arrival management algorithms based on nDTs and uncertainty models will be implemented. This experimental layer will be built upon a real arrival management environment provided by Barco.
- simulation infrastructure that will coordinate the middleware and TM layers and also it will emulate a set of commercial aircrafts and UAVs with different equipment, and therefore capabilities to interact with other systems;

The demonstrator will be able to manage the identified stochastic factors considering these elements as sources of trajectory information uncertainty. The influence of these factors in the process of simultaneous de-confliction and advanced sequencing is one of the main objectives of the UTOPIA project. The demonstrator will be available to explore, evaluate and compare different approaches to trajectory synchronization for heterogeneous traffic, each based on sharing different combinations of derived trajectory-data (e.g. ADS-B, flight plan, aircraft intent or predicted nD trajectory).

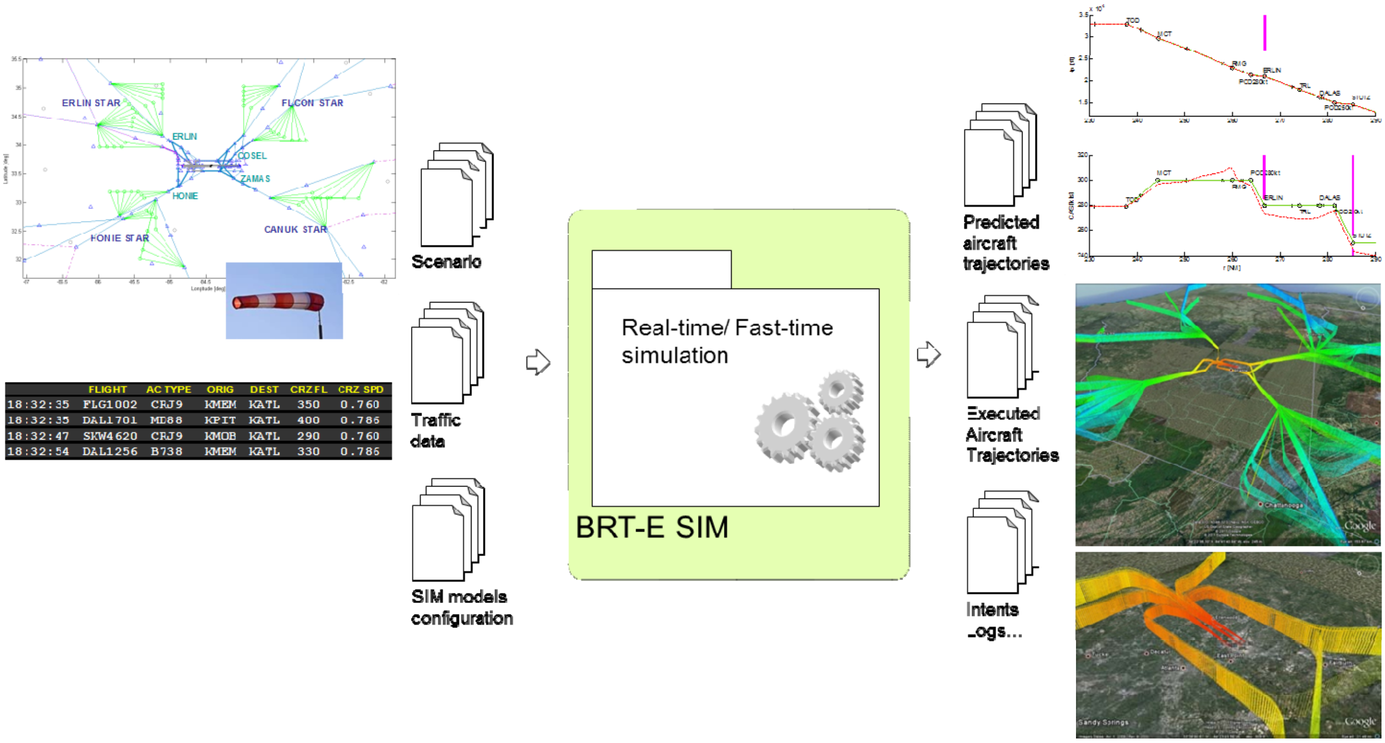

Figure 2. UTOPIA case study simulation

In addition, it will serve to test different automated traffic management algorithms (e.g. arrival management, air-ground synchronization, sequencing and scheduling or conflict detection and resolution) under the conditions of mix traffic. This demonstrator could be used as a test bed within the WP-E network or even within the SESAR Program to validate any challenged initiative form dealing with advanced automated traffic management functions for heterogeneous traffic. The test bed would be accessed from a remote facility through secure remote control protocol.

5) Case Study

The case study will consist of a full automated arrival management procedure simulation for inbound traffic into an extended TMA with heterogeneous traffic patterns and capabilities (Fig. 2). The arrival management function will be implemented using a simultaneous de-confliction and advanced sequencing support tool which will provide active. The case study considers the ground system as centralized separator logic, responsible for the inbound traffic stream with scalable PBO capabilities. The traffic sample created by the synthetic traffic generators will be based on sophisticated aircraft performance models, representing different aircraft types (manned/unmanned) with different capabilities (different on-board equipment) for synchronization, in terms of the trajectory information they can publish, and navigation, according to the specific arrival procedures and uncertainty management.

The case study will identify the effect of a fully automatic centralized arrival management function focused on strategic trajectory planning. The advisories resp. clearances generated by the simultaneous de-confliction and advanced sequencing support functions will be uplinked to the aircraft which will have to follow the advisory as long as it complies with the onboard separation assurance system logic and with the given navigation performance. The simultaneous de-confliction and advanced sequencing support tool will receive trajectory information (e.g., surveillance information, flight plan information or aircraft intent) directly from the aircraft which will be translated into a defined formal structure. The resulting nDT data will be used by the Arrival Management Function to establish the arrival sequence and to generate trajectory modifications if required. These modifications will immediately be sent to the aircraft. Further details of the operational procedures will be developed in the concept of operations definition phase of UTOPIA.

Different scenarios will be designed for analyzing the suitability of the concept of operation based on a fully automated Approach environment. The most relevant topics to be studied are:

- mixed equipage traffic with different data link capabilities;
- heterogeneous traffic including manned and unmanned aircrafts;
- mixed mode operation with departures sharing the arrival runway;

- drop off airport capacity or temporary runway closure;
- loss of communication with a single or all aircraft including recovery procedures;
- conflict solution in case that the FMS trajectory does not match with arrival management planning;

Further, a comparison to current procedures will be done to validate the results taken out of the scenario analyses: it will refer, as sort of baseline to an arrival sequence with time to lose and turn advisories, presented as suggested solutions to the separator, i.e. air traffic controller (ATCO) in managed airspace which will be in charge to give the corresponding clearances to the pilot. If the clearances do not match with this sequence, the ATCO has to update the system or to wait until the system adapts automatically depending on the traffic evolution. With this baseline analysis, the UTOPIA concept may be evaluated very granularly. The design of the demonstrator will allow different configurations of FMSs/ground-based applications to study all pre-set scenarios as developed in the proof of concept phase of UTOPIA.

IV. OUTLOOK

The UTOPIA project foresees to be an important step towards the development of advanced and robust full automation tools for managing heterogeneous traffic made up of different types of aircrafts also differently equipped. According to the prior defined UTOPIA objectives, there have been planned a set of scientific outputs as follows:

- Air-ground nDT synchronization concept based on the use of a formal language.
- Trajectory synchronization patterns and protocols to ensure the applicability of traffic management concepts and its seamless execution for a fully automated ATM system.
- Requirements for information exchange and flight procedures to be implemented in full automation support tools
- Knowledge of uncertainty sources in nDT synchronization and modeling for trajectory management focused on autonomous and heterogeneous operations.
- Formal modeling of uncertainty regarding trajectory information synchronization needed for a robust decision making process.
- Uncertainty management strategies for controlling the uncertainty propagation along the nDT synchronization process.
- Analysis of the added value of the proposed advanced algorithms for robust simultaneous de-confliction and sequencing.

Finally, we are convinced that the UTOPIA results will strongly influence future ATM activities in both operational and research level, and that we will provide a significant contribution to the community in two ways:

a) Identification of requirements for fully automated ground support tools based on synchronization of trajectory information coming from heterogeneous traffic, including the design and development of advanced algorithms for robust simultaneous de-confliction and sequencing. The UTOPIA project will analyze the improvement reached with these tools in terms of airspace efficiency, predictability and capacity optimization compared to today's procedures as a baseline.

b) A clear understanding of the uncertainty sources and their effects along the trajectory synchronization process that will allow defining proper mitigation strategies to ensure that the advisories generated by the automation tools are highly reliable.

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