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INNOVATIVE FUTURE AIR TRANSPORT SYSTEM: SIMULATION OF A FULLY AUTOMATED ATS

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Abstract

Within the project Innovative Future Air Transport System (IFATS) funded by the European Commision within the 6th Framework a new concept for the air traffic organization has been developed. The most significant difference to today's organization is the lack of pilots and controllers. The IFATS concept forsees that each aircraft receives a 4D contract before departure which is calculated and negotiated on a worldwide scale so that it is conflict free. If during flight unforeseen deviations from the contract occure (delayed take-off, unforeseen weather change, reduced engine performance or emergencies) a new contract is negotiated online taking into account the new boundary conditions. DLR provided to this project a tool that simulates a large number of aircraft (approx. 1000) flying such a 4D contract. With this tool one day traffic over Frankfurt airport with all the aircraft arriving and departing in Frankfurt was simulated. Normal situations were demonstrated together with disturbances such as delayed aircraft, thunderstorm, degraded performance aircraft and aircraft facing an emergency. At the DLR Air Traffic Management and Operations Simulator (ATMOS) simulations were conducted with "real" ATC and pseudo-pilots in comparison to this fully automatic IFATS mode.

1 General Introduction

The aim of the Innovative Future Airtransport System (IFATS) project is to design a fully automated air transport system without pilots and controllers. It is an academic approach without taking into account the problems that may arise due to the transition phase from nowadays system to the fully automated system. Since the concept is revolutionary it needed new ways to validate the overall performance of the entire IFATS. DLR developed an air traffic simulation that allows the simulation of such an unconventional airspace in a very accurate way. This paper is going to describe the steps that were taken to validate the benefits of an IFATS airspace compared to the current situation.

2 The IFATS project

The perspective that is considered in the Innovative Future Air Transport System (IFATS) project opens new ways for the overall air transport system management (ATSM). The basic feature of the IFATS concept is to go as far as possible in the ATS automation. Thus the first topic to be discussed is: "what is possible?"

Several answers can be given which are very dependent on the consulted people. Controllers will have their own view, based on their current work, knowledge and career perspective; the same applies for pilots. Dealing with public opinion is far more complicated. This opinion is made from the knowledge it has about the ATS automation. This knowledge is built from the information that can be provided on this type of concept, but this type of concept is not fully defined yet. Instead of being stuck by this hen and egg problem, the approach that has been taken in the IFATS project is purely technical: thus, the concept that has been defined is a "technically possible" extremely automated system and not necessarily a "likely to happen" system.

Considering the IFATS methodology, which is to study a fully automated system in order to derive an acceptable future one, only the technical constraints have been considered. Indeed, cultural constraints (passengers to accept to fly a pilot-free aircraft) and social constraints (pilot and controller jobs not existing any more) bring to much show-stoppers for the IFATS methodology and have no real impact on the high level technical definition of such a system that has been pursued in the project. The main technical constraints are:

For the ground segment: to be able to automatically manage the traffic planning, taking into account the airlines wishes as well as the various uncertainties of the flights. The emergency situations have also to be managed, possibly with a man in the loop.

For the air segment (the aircraft): to be able to fully automate the flight, i.e. the capability of the aircraft to manage all the flight phases and all the pre-planned emergency situations (see this notion later).

At a more global level, the safety and security of the system has to be ensured whatever the situation could be. This is achieved through secured data links and adequate communication protocols.

2.1 Key Notions

The IFATS concept is based on three "key notions":

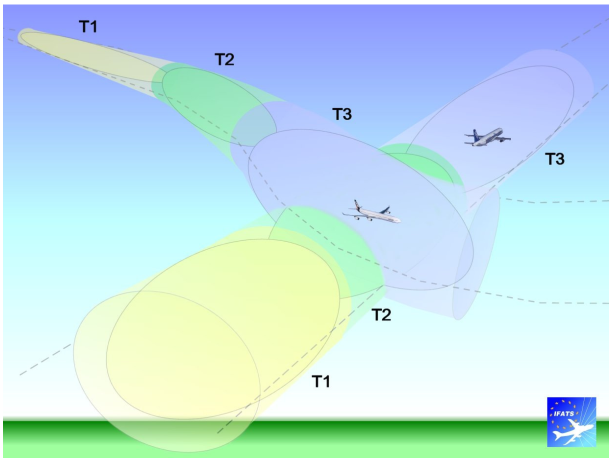

Fig. 1. Contractual 4D trajectories

1. The 4D contracts: each aircraft is given a contract before its flight and it has the responsibility to respect this contract all along the flight (Fig. 1). If the aircraft is not able to respect it for any reason, it has to ask the ATSM for a new 4D contract or, at least, broadcast this information in the vicinity of its current flight zone.

2. The contracts are generated by the centralized ATSM at a planetary scale to be made of conflict-free flight paths. So, as long as all the aircraft are respecting their contracts, no conflict can occur. Those 4D contracts are given to the aircraft with some margins (e.g. in order to be able to manage small differences between the predicted wind and the real one for example). These margins are called *"bubbles"* and are of two types: the so called *"freedom bubble"* on one hand, in which the aircraft can freely fly (small deviations from the 4D contractual trajectory are allowed) and on the other hand the so called *"safety bubble"*, larger, in order to ensure that no collision is possible between two aircraft flying on the edge of their respective freedom bubbles (Fig. 2).

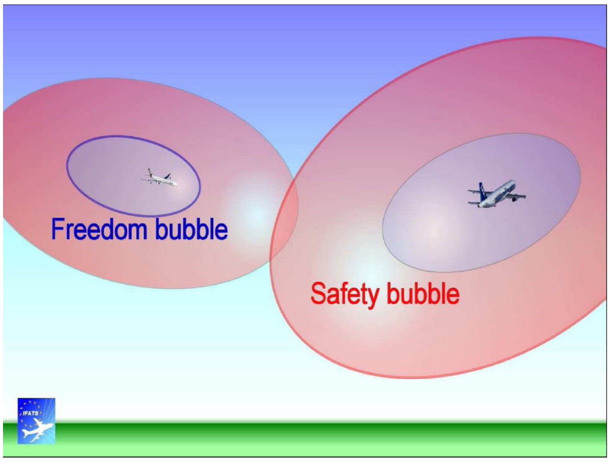

Fig. 2. Freedom in a fully constrained airspace

3. The concept that has been selected for managing the en route and arrival traffic is based on aircraft flying 4 D trajectories: the 3 dimensions of space (x, y, z) and the time (t) as a fourth one (3D+T concept). The guiding principle of the 3D+T concept is to know where the aircraft are to avoid a collision risk, i.e. there are two aircraft at the same place at the same time. The notion of waypoints and airways, which are essential to make a human air traffic control possible, can be abandoned.

2.2 IFATS Structure

2.2.1 Air segment

This is the IFATS aircraft. Input data for this fully automated air segment are the knowledge of its state given by onboard sensors, its long term intentions known through its flight plan, the local air situation perceived through cooperative messages from other air-segments as well as information from destination airport or "en-route" ground segment elements (flight plan updates, problems management…) or information of air traffic and environmental conditions in their neighbourhood.

Short to mid term tasks are performed by the onboard autonomous flight control system including the handling of emergency procedures to be applied in case of critical flight situations. Nevertheless, human being will stay in the loop and will be able to act from the ground to solve problems that cannot be solved by the onboard automatism. The aircraft has to respect the 4D contract. If some difficulties are observed, two degrees of freedom can be used, either a variation in speed or a variation in trajectory, to comply with longer term 4D way points demand.

The aircraft failure management issue has to be considered in two different ways. The occurring problem is known then a palliative strategy has been implemented in the aircraft onboard systems, or the occurring problem is new.

In the first case, the aircraft automatically applies the pre-planned palliative strategy while, as this is already done currently, the airline maintenance team is made aware of the problem through messages sent by the aircraft to the ground. An interesting current situation is that modern aircraft can already send messages to the ground about the state of their systems without giving any information to the pilot if the problem is not considered relevant for the current flight (remote monitoring of the aircraft).

In the latter case, the occurrence of a new problem, the aircraft state is downloaded to a dedicated ground infrastructure, populated by specialists of the aircraft in trouble. These infrastructures are equipped with high capability computers and data bases: the specialists in charge of solving the problem in real time use these resources to find out the best strategy for the aircraft to recover from the trouble and then upload this strategy to the aircraft. Then the aircraft applies automatically the recovery strategy.

As a result of this organisation, two different kinds of ground segments are monitoring the flying aircraft:

- An airlines maintenance and fleet management ground segment;
- An aircraft manufacturer ground segment to deal with unexpected problems (typically at least one for each aircraft manufacturer).

A clear advantage can be foreseen from the network centric architecture of the system. All problematic situations descriptions are sent by the aircraft to its manufacturer, to a single point. So, the number of unexpected problems should decrease with time as experience feed back will be optimized thanks to this architecture.

2.2.2 Ground Segment

The ATM strategic planning function performed by the ground segment concerns all aircraft which have to get flight plans in a co-ordinated manner. It represents the strategic level of the organisation of the overall traffic, world-wide. It has to be widely geographically distributed and to be populated by "flight planners" replacing current non coordinated airlines planners and Air Navigation Services Providers (ANSPs).

When generating long term flight planning, airlines and ANSPs have to make coherent flight plans ensuring a general non-conflict situation at a continent level, considering a standard behaviour for all actors of the system with a level of accuracy which has to be estimated in the project.

Thanks to the overall automation of the system, all air traffic can be managed using an infinite number of routes generated as a function of meteorological conditions and other constraints, and which will be controlled, at the tactical level, by the co-ordinated ground segment elements.

The ATC function performed by the ground segment concerns all aircraft which have to be locally operated in a coordinated manner. It represents the tactical level of the organisation of the overall traffic, at a local level. It has to be geographically distributed and to be populated by "aircraft operators" replacing current controllers and pilots. The geographical distribution can be compared to the present situation where successive handovers are made from the departure ground airport control, tower control, en route-control sectors, etc. to the final destination ground airport control.

Aircraft taking off from an airport would be operated by a local ground segment. Then, en-route ground segments would successively hand-over the operation of the aircraft until its landing at its destination airport. As stated previously, the air traffic is managed using an infinite number of routes which have been generated at the strategic level and then controlled, at a tactical level by the co-ordinated ground segments. This latter control is made far easier thanks to the coordinated strategic flight planning.

In case of a ground to air data link failure between a specific aircraft and the ground segment, the aircraft can recover the situation using another aircraft as a relay via its air to air data link. When no contact can be established, aircraft will have to fly respecting their 3D+T contract up to the time when data link is recovered, in order to keep a conflict free situation.

3 IFATS Traffic Simulation

The objectives of the "IFATS Traffic Simulation" developed at DLR are the demonstration of the air segment of a completely integrated conflict free IFATS environment (without non-cooperative aircraft) and the demonstration of the possibility to handle unpredictable events during simulation. For this reason the different phases of the air segment have been implemented in the simulation software. However the simulation does not cover the entire aircraft movement from gate-to-gate but begins with the aircraft lined up on the runway of the departure airport and ends with the touch-down on the runway at the destination airport.

3.1 Simulation Tools

For the simulation of IFATS airspace extensive use of DLR's "Advanced Flight Management System" has been made [3].

The simulation environment consists of the following components. They are divided into offline components and online components. The offline components were only used to generate databases and configuration files prior to simulation. The online components are needed during simulation.

3.1.1 Offline components

Timetable Conversion Tool

The simulations are based on the official summer timetable of Frankfurt 2005. The timetable conversion tool parses all relevant information for each flight which departs from or arrives at Frankfurt into a proprietary data format and stores it in a "timetable file":

Routeplanner

The Routeplanner plans a realistic route between two airports or waypoints by using a link to a navigational database covering Europe [1].

Scenario Generator

The Scenario Generator processes the output of the Timetable Conversion Tool to feed the Routeplanner with the appropriate information. For each flight that is listed in the "timetable file" the Scenario Generator calls the Routeplanner which returns a list of waypoints representing that particular flight.

This list of waypoints and information about departure and arrival airport is then stored in a "constraint list" where additional constraints for each waypoint may be added. It includes a header with information about Elevation of the departure runway and arrival runway and setting for transition altitudes. At the end of a constraint list, all waypoints of the calculated route are listed. Additionally there can be constraints added to each of the waypoints. These constraints can be an altitude constraint, a time or speed constraint.

3.1.2 Online Components

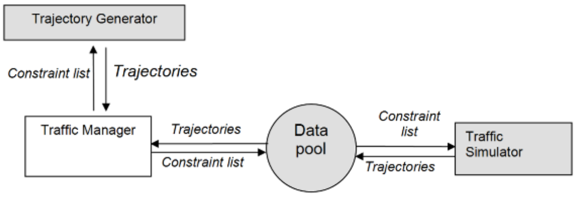

Fig. 3. Online components

The simulation consists of four different modules: datapool, traffic generator, traffic simulator and traffic manager as shown in Fig. 3

Datapool

Information handling between all online components is done by a centralized communication module, called "Datapool". By using this kind of data distribution method it is possible to distribute the online components to different computers and link them through a network in order to improve overall computing performance. Additionally it easily allows adding new clients to the overall simulation environment and keeps track of client health monitoring. To avoid unnecessary use of resources the Datapool performs a so-called "alive check". If a client terminates without a correct "sign off" command, Datapool deletes that client from its client list if for a duration of 5 seconds no communication between the client and the Datapool takes place.

The Datapool takes account to the principle of information hiding, which means the protocol is encapsulated in the interface software and not visible for the other components.

Trajectory Generator

The trajectory generator is based on a 4D Flight Management System called AFMS (Advanced Flight Management System) and is the core module of the simulation. Its development started within the Programme for Harmonized ATM Research in EUROCONTROL (PHARE) [6]. It calculates an exact flight plan (4D-trajectory) considering constraints like aircraft performance parameters, economical criteria, etc. and then guides the aircraft automatically along this trajectory.

Before simulation starts, the AFMS gets a request from the simulation display tool ("Traffic Simulator") to generate a trajectory for each flight. In order to simulate a near realistic behavior of the aircraft, aircraft type specific performance parameters are read out of a database (BADA: Base of Aircraft Data [2]). Additionally wind and temperature information are considered as well. The trajectory shown in Fig. 4 shows an example for a flight from Bremen (EDDW) to Frankfurt (EDDF). The red areas in the vertical profile the right mark an altitude constraint like for example at GED maximum allowed altitude is 11,000 feet.

During simulation these trajectories can be altered partially or completely e.g. in case the aircraft gets late or has to change its planned route due to a thunderstorm in its way.

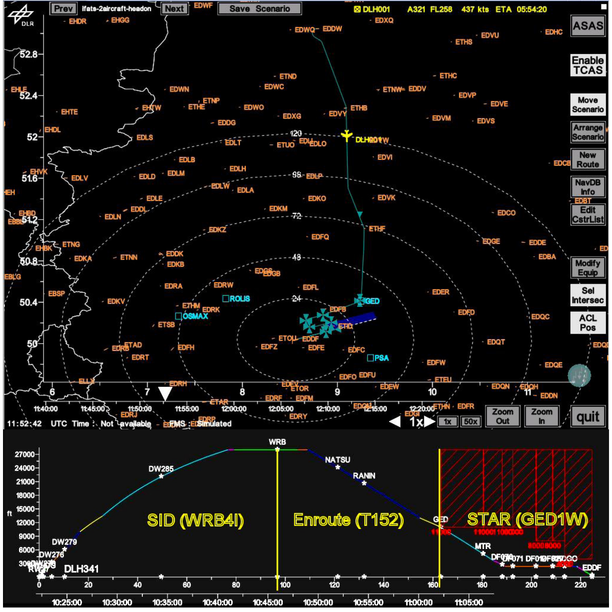

Fig. 4. Horizontal and vertical trajectory for a flight from Bremen (EDDW) to Frankfurt (EDDF)

Traffic Simulator

The Traffic Simulator shown in Fig. 5 is the main visible component of the simulation. It displays the simulated scenario on the screen. The Traffic Simulator generates a 4D-trajectory for each aircraft participating in the scenario and moves the aircraft along the trajectory in real time or fast time. The input data for the generator are a flight plan, the aircraft performance data, aircraft state vector at starting position and meteorological data. The starting position may be on ground, at the departure airport or airborne. The trajectory generator takes account of altitude constraints, speed constraints and time constraints which may be specified in the flight plan.

During simulation the Traffic Simulator sends the current state of each simulated aircraft as an "Aircraft State Vector" message to the Datapool. ADS-B messages are also generated and are stored in the Datapool shared memory.

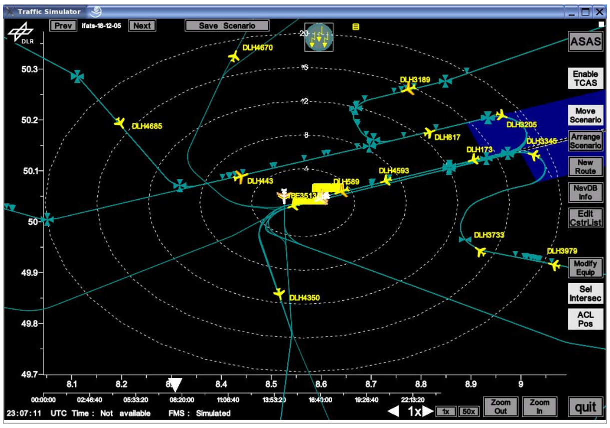

Fig. 5. Traffic Simulator

Traffic Manager

The traffic manager is connected to the Datapool and checks the trajectories of all aircraft for conflicts. Therefore it searches two trajectories for overlapping safety zones as shown in Fig. 6.

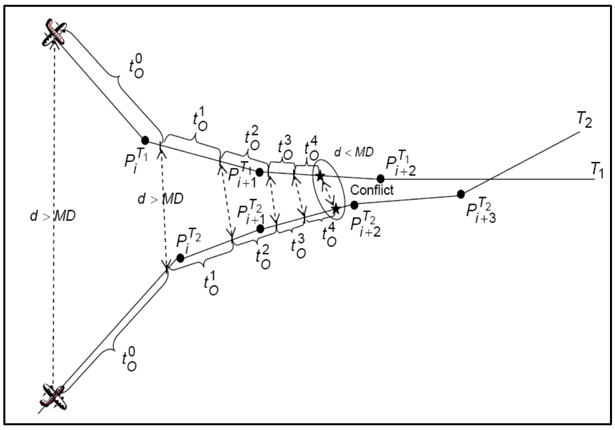

Fig. 6. Conflict detection algorithm

If a conflict is detected, the traffic manager detects the aircraft that has to give way according to the Extended Flight Rules (EFR) developed by Eurocontrol within the Free-Route Experimental Encounter Resolution (FREER) [8] project and alters its trajectory to resolve the conflict [4]. The assignment which aircraft has to give way is considering the maneuverability of the aircraft involved, the availability of the aircraft according to the current flight phase and the distance and speed of each aircraft to the encounter. At the same time the EFR satisfy that the current level of safety in maintained or enhanced, the economy of flight operation is not decreased and the capacity of the air traffic is not reduced.

The conflict resolution is done in an iterative way [7]. The idea to avoid a conflict is to generate one or more new waypoints in the constraint list that the aircraft has to evade. There are three different possibilities to manipulate the constraint list. One of them is to insert a new waypoint with a time constraint so the aircraft is slower or faster and the conflict is solved. Another way is to insert two waypoints for a vertical constraint and the aircraft flies below or above the conflict. Further it is possible to circulate the conflict lateral with four new waypoints in the constraint list. The strategy searching for solutions first tries to generate a time constraint. In the next step it searches for a vertical avoidance of the conflict. And the last step is the search for a lateral avoidance maneuver. After this three steps there are from zero to three solutions found. If more than one solution is found evaluation of the solutions is performed.

The conflict resolution algorithm is adjustable to follow different strategies, like saving fuel as much as possible or being on-time under all circumstances. It than chooses different solutions to solve the conflict like reducing or increasing the speed or altering vertical or horizontal trajectory. In case of disturbances like thunderstorms or emergencies for example it has no choice and has to recalculate a new trajectory to avoid the thunderstorm area or to go directly to the nearest airport. A similar approach has been proposed in [7].

3.2 Scenario

During the simulations the limits of the scenarios have been discovered. One great limitation is the number of aircrafts which can be simulated at the same time. The maximum number of the “traffic simulator” is about 1000 aircraft (depending on the computer’s performance). Due to this limitation it was not possible to simulate the entire airspace of Europe. So the size of the simulation was reduced to the traffic going to or from Frankfurt.

The general scenario consists of one day at Frankfurt Main (EDDF) airport simulating all the aircraft arriving and departing in Frankfurt (approx. 1000). The data were extracted from the official summer timetable 2005 and do not include charter flight or other unscheduled flights. The runways in use are 25L, 25R and

18. All inbound aircraft fly Area Navigation (RNAV) transitions.

Two scenarios were generated for the IFATS simulation. The first one shows a conflict free overall scenario of all aircraft departing from or arriving to Frankfurt:

- All aircraft perform according to their previously planned route and are in time.
- Nevertheless little deviations are possible, due to deviating weather conditions etc.
- There are no emergencies.
- All aircraft are separated properly.
- No deviations have to be flown.

This scenario demonstrates that it is possible to keep an IFATS airspace conflict-free even if some aircraft need to update their trajectory because of minimal changes compared to the previously negotiated trajectory.

The second simulation's purpose was to show the behaviour of IFATS airspace in disturbed conditions. Special emphasis has been taken on to the following occurrences:

- An aircraft has to change its route to evade a thunderstorm. So a new route has to be negotiated.
- An aircraft gets late and triggers a conflict with another aircraft. A new contract has to be negotiated.
- An aircraft suffers from a decrease in performance and therefore cannot comply its previously negotiated contract. So a new contract is necessary.
- An aircraft declares an emergency and diverts from its previously negotiated route to perform a safe approach to the next suitable airport. This aircraft gets priority while other aircraft are kept away from the route the emergency aircraft will be using.

Simulation in ATMOS

To compare the results of the IFATS airspace simulation "Traffic Simulator" with the airspace organization of today a second simulation campaign has been conducted. Therefore DLR's "ATMOS" simulation environment at the Braunschweig site has been used. ATMOS consists of workstations for "real" Air Traffic Controllers with a large radar screen on which a simulated airspace can be displayed. Fig. 7 shows the workstation for the air traffic controller. The white spot on the screen represents the simulated thunderstorm in the TMA (Terminal Maneuvering Area). Air traffic is simulated by using "pseudo-pilots", assistants, who control several aircraft at a time. They are in contact with the controller in front of the radar screen via simulated radio communcation.

This environment was used to simulate the exact same scenario of Frankfurt as it was simulated with the Traffic Simulator for the IFATS airspace.

Fig. 7. ATMOS simulator

The scenarios which have been simulated were: "normal operation", that means, all aircraft are on time as expected. The second scenario included a thunderstorm in the vicinity of the airport. A scenario with two emergency aircraft has also been simulated.

Results

The tables in Tab. 1 and Tab. 2 show some of the results that were obtained during the two simulation campaigns.

The "Duration" column shows the simulation run duration. The fourth and the sixth one give the total flight time of the aircraft between entering the TMA and landing at Frankfurt. The number of aircraft is the total landed aircraft.

With respect to the total time of aircraft staying in the TMA the IFATSystem almost always performed better than the human-controlled ATC. For the total amount of aircraft handled the controllers beat IFATS as they are able to take shortcuts while IFATS had to stick with existing ATC structure.

This first set of results shows that the IFATS lowers the duration of the flight optimizing the landing sequences and with disturbances like thunderstorms is able to land more aircraft as a human controller.

It could be demonstrated that an IFATS airspace in which some aircraft are not able to conform to their contract can be held conflict free. The number of conflicts en-route was relatively small. This was expected since only aircraft approaching to or departing from Frankfurt were simulated. So the airways were less populated. The most drastic events (aircraft with reduced performance, re-planning due to bad weather conditions or an emergency aircraft) could be handled in a satisfying manner.

With this simulation it could be shown how an IFATS controlled airspace could look like and if there is an advantage compared to the usage of airspace of today's control strategy. The simulations however did not exactly give numeric results to measure the amount of improvement. But one advantage could be demonstrated very easily: All approaching aircraft to Frankfurt did not need to follow the s-shaped trombone just before entering final approach course to separate each approaching aircraft from the others. Since this separation has already been performed during the flight planning phase within IFATS, no aircraft has to fly a long final approach or – much worse – enter a holding pattern.

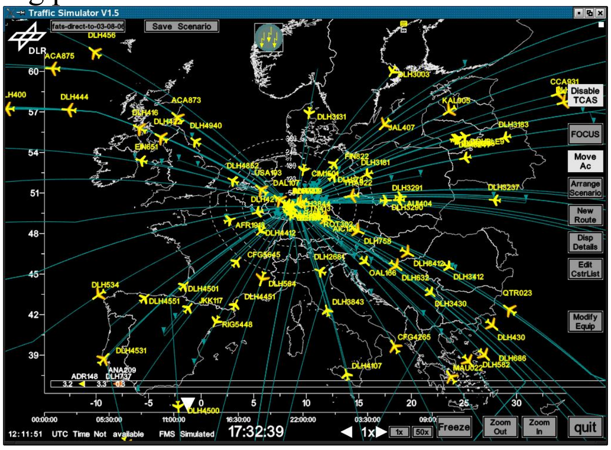

Fig. 8. Direct-to scenario

The routes used did not really make use of all advantages IFATS provides. The routes used for simulation were almost the same as they are used today. With IFATS it would be possible to fly "direct-to" routes without orientating to today's published airways, SIDs or STARs (Fig. 8). Comparison of flight time and flown distance for all 351 aircraft flying to and landing in Frankfurt within this scenario between nowadays routing and direct-to routes show a saving of 7.6 % in flying time and 7.5% in flying distance.

This early stage simulations show the learning curve that has to be followed when defining and developing an automatism. Experience has to be gained patiently to raise the automatism at an acceptable level!

Conclusion

Pioneering the air transport of the future is not a simple issue. Nowadays, a few years after the first flight centennial celebration, the ATS is far from being optimally structured and fully developed to meet the user's needs and comply with the more and more stringent environmental constraints.

Ambitious objectives have been defined in the ACARE Vision 2020 in Europe, and metrics have been defined to assess their level of achievement: the future ATS will definitely have to be more time efficient and highly customer oriented, keeping costs low while being environmental friendly and secure; this has to be valid and proven whatever the evolution of the traffic will be.

Choosing the means to reach these objectives is not so obvious. The ATS is a complex system, which integrates multiple interacting subsystems designed to provide its core functions, i.e. transporting passengers and goods. Huge technical and technological progress has been achieved at the subsystem level, centred on a human controller or operator. Placing the man as the major front-line actor brings both intelligence and weaknesses into the overall system.

In the near to mid term future, i.e. 2020-2030 time frame, no major ATS changes can be expected: in the coming years the ATS will not necessarily be very different from what it is today for evident reasons of continuity.

Looking in the more distant horizon, to really pioneer the future, gives more freedom and flexibility, but also brings some uncertainty. In this perspective, thinking "out of the box" is welcome, and should even be seen as a required methodology.

Indeed, preparing this far future of the ATS is an unchallenged opportunity to promote excellence in scientific and technological research, development and demonstration. Moreover, the international nature of the ATS calls for transnational research and industrial cooperation to take up many of the current European efforts in this field.

For this 2050 vision, the IFATS FP6 STREP has started to pave the way through a rather radical and non-conventional methodology. Instead of analysing how to evolve smoothly from the current ATS to a potential future one, the IFATS consortium has elected to study what could be an extreme long term solution: a fully automated ATS where pilots and ground controllers would be replaced by operators in charge of numerous monitoring functions.

The qualitative results that have been obtained up to now are promising. With such a system, capacity, efficiency, safety and environmental friendliness are improved. Nevertheless, quantitative assessments need further quantitative investigation whereas the analysis some issues such as security has to be detailed and extended.

Acknowledgment

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Run	Type	Duration	Human Controller		IFATS	
			time	No. of aircraft	time	No. of aircraft
1	normal	01h:30m	23h:03m	54	18h:13m	54
2	normal	01h:32m	23h:18m	55	18h:33m	55
3	thunderstorm	01h:32m	21h:13m	52	20h:19m	55
5	normal	01h:11m	14h:45m	40	13h:46m	41
6	thunderstorm	01h:31m	22h:13m	50	19h:57m	54

Tab. 1. ATMOS simulation results - 1st campaign

Run	Type	Duration	Human Controller		IFATS	
			time	No. of aircraft	time	No. of aircraft
2	normal	01h:31m	19h:46m	56	18h:16m	54
4	normal	01h:32m	22h:19m	57	18h:16m	54
5	emergency	01h:33m	22h:46m	57	18h:40m	55
6	emergency	01h:33m	22h:49m	55	18h:41m	55
7	emergency	01h:33m	20h:52m	59	18h:40m	55
8	emergency	01h:30m	23h:35m	58	18h:00m	53

Tab. 2. ATMOS simulation results - 2nd campaign