AIRCRAFT 4D CONTRACT BASED OPERATION: THE 4DCO-GC PROJECT

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Abstract

The European project 4DCo-GC (4 Dimensions Contracts – Guidance and Control) co-funded by the European Commission in the Frame of the 7th Framework Programme (contract 266296) was launched in November 2010.

This 3-year long duration programme aims at exploring the 4D contract-based management of the airspace and the guidance and control of aircraft along those contracts by the mean of simulations. In the 4D contract concept, each aircraft is given a 4 dimensions (x, y, z, t) contract, which is guaranteed to be conflict free, from gate to gate. It is the responsibility of the aircraft to comply with its assigned 4D contract. The generation of these 4D contracts is performed at a continental level. This planning is a constantly updated operation that enables in-flight 4D contract renegotiation in case of deviation from the nominal situation.

The 4DCo-GC project will enable a simulation-based assessment of the 4D contract concept, as well as a comprehensive description and explanation to the public through two simulation campaigns (to be held in July 2012 and October 2013).

The first simulation campaign, which is mainly described in this paper, will be the opportunity to perform first tests of the various software modules developed in the frame of the project. Both a global traffic simulation (several thousands of aircraft at the European scale) and an individual aircraft simulation (at the aircraft scale) will be performed. Their association will cover the full scope of the 4D contract concept, from the 4D contracts generation to their execution.

At the end of the project, recommendations about the use of 4D contracts will be provided to the SESAR programme in order to prepare what could be the far future of the air transport system.

1 Introduction

When speaking about the future of the Air Transport System (ATS), and according to the various traffic growth forecast, there will be a need for an increased airspace capacity and more efficiency in the system. At the same time, in order to keep the number of accidents as low as today, the safety of the ATS should be enhanced.

Current initiatives, like Single European Sky ATM Research (SESAR) in Europe and Next Generation Air Transportation System (NextGen) in the US, are currently ongoing in order to define what could be the future of the ATS. They both have given a comprehensive description of the implementations to be performed up to 2020, and their outputs show that no disruptions have to be anticipated: the short to medium term ATS has to be necessarily not dramatically different from what it is today for obvious continuity considerations.

An alternative method for pioneering the ATS of the future is to look at a more distant horizon (i.e. 2050+) in order to take advantage of the design freedom and flexibility brought by a clear break with the current system. Such a way was followed by the Innovative Future Air Transport System (IFATS) project from the 6th European Framework Programme (FP6).

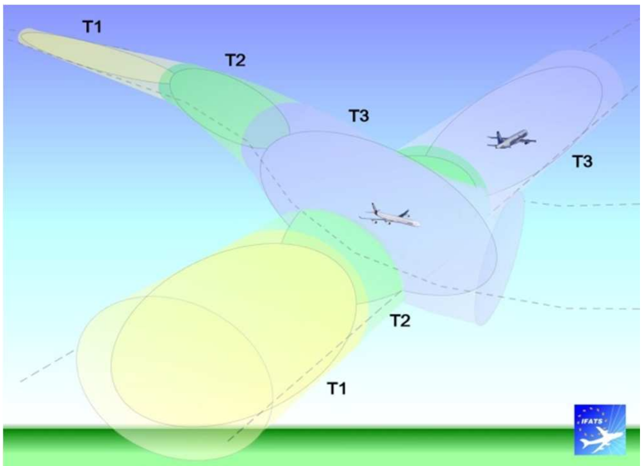

Fig. 1. Use of the 4 dimensions of the airspace

IFATS defined a fully automated ATS based on the so-called '4D contract concept'. But the proof of concept was not supported by anything but project partners' expertise. So it was not possible to clearly characterize the advantages, drawbacks and viability of such a concept. To this end, the IFATS consortium decided to propose a follow-up phase dedicated to the simulation of the 4D contract concept in order to explore its characteristics. The 4 Dimension Contract – Guidance and Control (4DCo-GC) project has been submitted to the European Commission (EC) in the frame of its 7th Framework Programme (FP7).

2 4DCo-GC project details and objectives

The 4DCo-GC project is co-funded by the EC as a FP7 'level 1' project [1]. Its kick-off was given in November 2010 and it will last until November 2013. Its consortium is composed of 13 partners from 7 countries: Onera, France; Alenia, Italy; CIRA, Italy; DLR, Germany; ENAC, France; Erdyn, France; IAI, Israel; Monitor Soft, Russia; NLR, Netherlands; Technion Israel Institute of Technology, Israel; Thales Communications, France; TsAGI, Russia, University of Patras, Greece.

As mentioned in the introduction, most of these entities were already members of the IFATS consortium, but the simulation-oriented objectives of 4DCo-GC led to the need of additional partners.

The total budget of the project is 5.5 M€, including 3.9 M€ funded by the EC.

The 4DCo-GC objectives are twofold:

- Technical: the project aims at defining and modeling 4D contracts in the context of a fully automated ATS, but also at assessing the 4D contract concept of operation viability and performance. It will also enable deriving recommendations for future 4D trajectory system development and performance standards;
- Social: it is a major opportunity to bring together European establishments to collaborate on an innovative future ATS concept.

The main expected outputs of the project are a clarification of most of the questions around the notion of '4D contract' (e.g. required precisions, estimated constraints, requirements for future planning systems, data links, computer performance needs) and the demonstration/illustration of what is a 4D contract-based ATS.

3 4D trajectory versus 4D contract

The entire project is built on the key notion of '4D contract'. In order to give the best possible understanding of the rest of this paper, the following terminology clarification is necessary:

- 4D trajectory;
- 4D contract.

4 The 4D contract concept

As mentioned in introduction, the concept of 4D contracts has been defined by the IFATS project [2]. Nevertheless, additional thinking and discussions were necessary in order to come up with a more detailed definition mandatory for concept modeling, and to put preliminary figures on.

Here is a brief summary of the main elements defining the 4D contract concept.

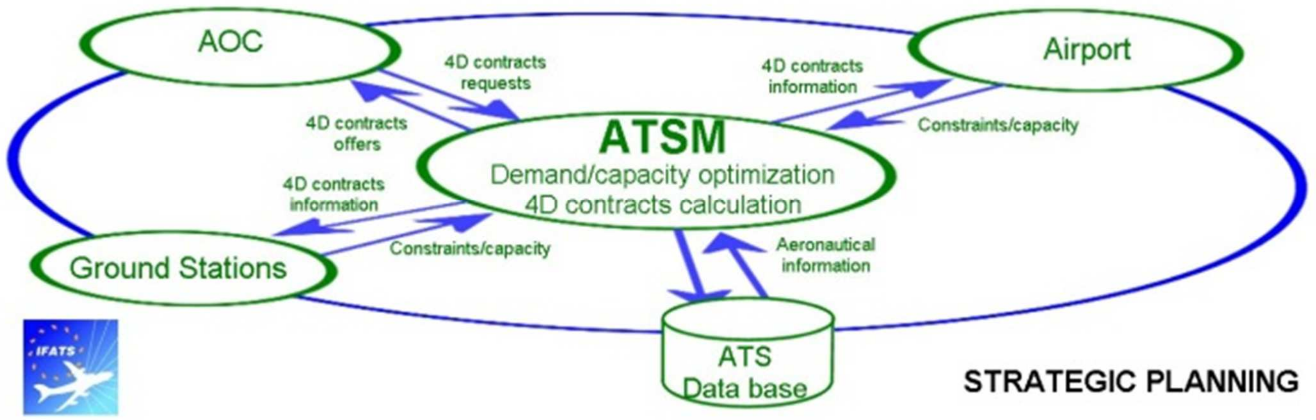

Fig. 2. The strategic planning phase

4.1 Planning phase

A central entity, called Air Transport System Management (ATSM) is in charge of collecting the airlines flight intentions and to compute conflict-free 4D trajectories for all flights (taking into account additional constraints, like airport capacity). These trajectories, once accepted by the airlines are converted into 4D contracts that the aircraft agree to respect. This phase, performed several months before the actual date of the flights, is called the ‘strategic planning’ (Fig. 2).

Once the aircraft is airborne, it must comply with its assigned 4D contract. If this is not possible (e.g. because the actual weather is different from the forecast one used for the 4D contract generation), it must ask the ATSM for a new one. This new 4D contract is computed based on the most up to date weather and aircraft performance data. Indeed, weather data is regularly updated as each aircraft is a sensor of the system. This is the ‘tactical planning’ (Fig. 3).

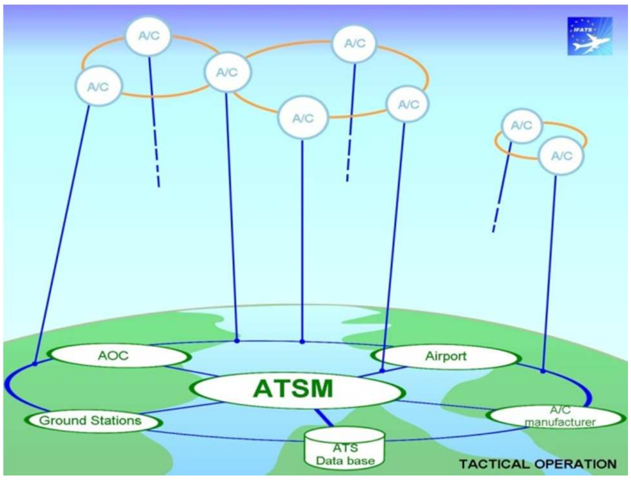

Fig. 3. The tactical operation phase

4.2 Network centric architecture

In order to ensure communication between the various actors of the system, two communication networks are necessary (as illustrated by Fig. 4): the ‘global network’ (blue lines) links all the ground actors together, and each aircraft with this ground segment; the ‘local networks’ (orange lines) are used for communication between neighboring aircraft, mainly for failure or emergency situation mitigation.

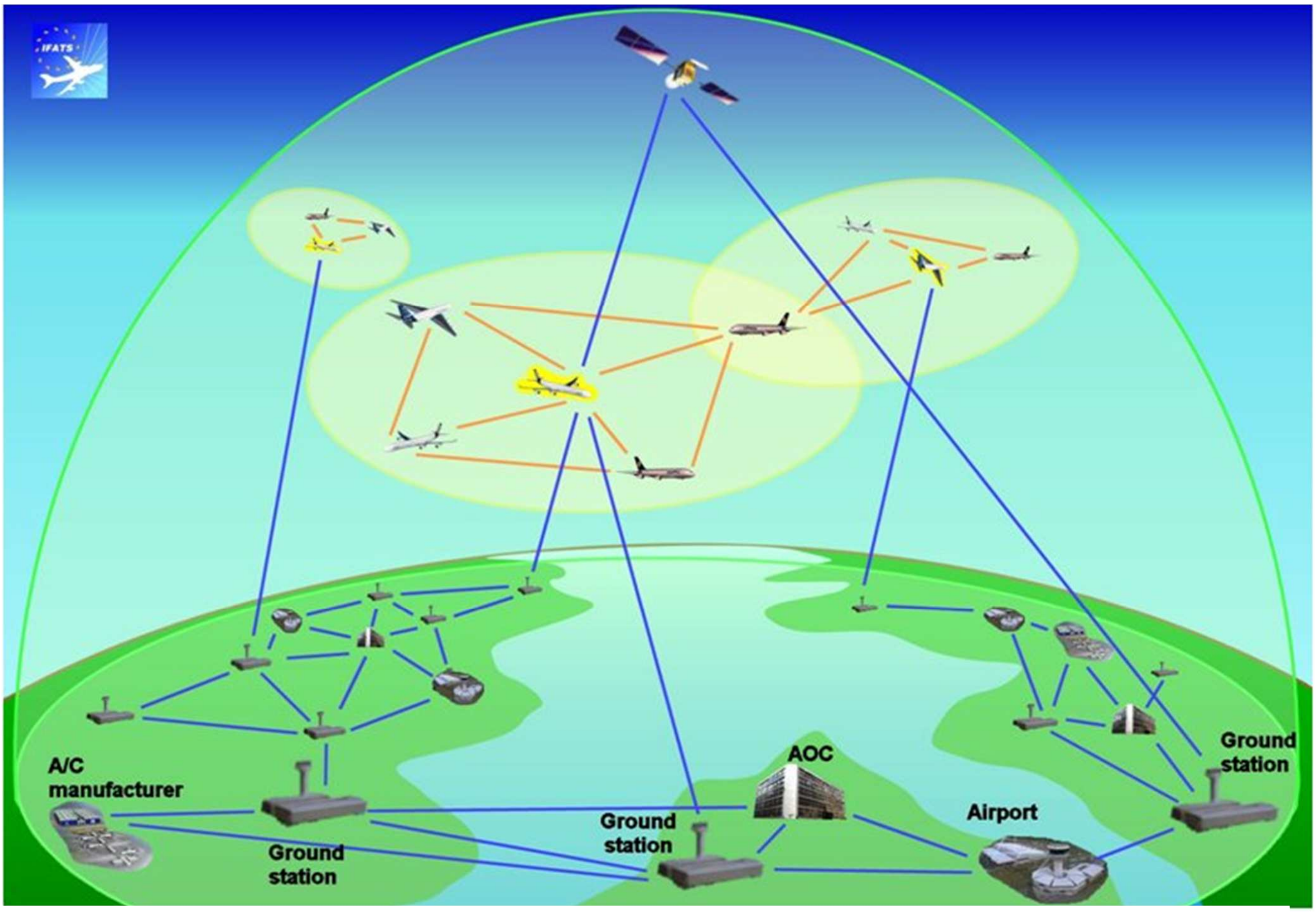

Fig. 4. Illustration of the Network-Centric Architecture

4.3 4D contract decomposition

A 4D contract is not a simple trajectory made of 4D-waypoints (conventional waypoints with an attached time constraint). In order to guarantee the safety of all the flights respecting their 4D contracts and as there is nobody to monitor the separation between the aircraft, some margins have to be added to ensure that aircraft are far enough to each other.

So a 4D contract is composed of 2 main elements: a 'bone trajectory' (basically a 4D trajectory) and margins around the aircraft. These margins – called 'bubbles' – are of 3 types:

- Safety Bubble (SB): the SB is linked to the aircraft and its size is fixed. It corresponds to the minimal separation between two aircraft. At any time, 2 SB must not intersect:
- Contract Bubble (CB): the CB is an area around the bone trajectory aiming at enabling the aircraft to deviate from its nominal trajectory without the need for a contract update. It is calculated by the ATSM to have conflict-free 4D contracts; it means that the size of the CB may vary along the flight depending on the local traffic density (large CB in low density areas, small to no CB in high density areas);
- Freedom Bubble (FB): the FB is an area in which the center of gravity of the aircraft can be. The FB is calculated by the FMS by subtracting the SB from the CB – its size also depends on the traffic density.

These various 'bubbles' are illustrated in Fig. 5.

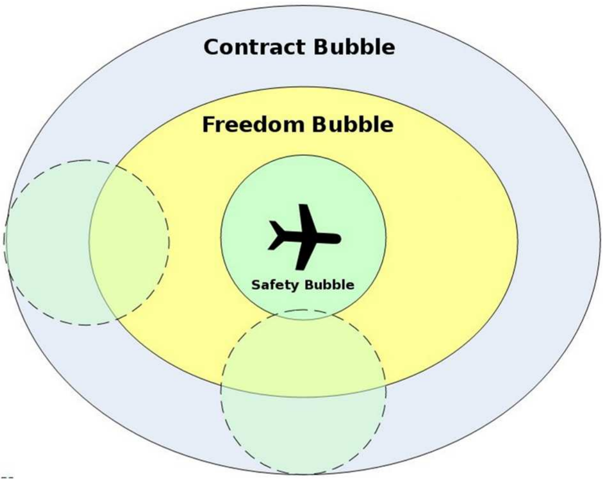

Fig. 5. Illustration of the 3 types of 'bubbles'

To summarize, a 4D contract generated by the ATSM is composed of a bone trajectory, a SB and a CB. The aircraft FMS then calculates the corresponding FB.

The aircraft can take advantage of this FB in order to calculate a trajectory to be flown that is optimized regarding the airline policy. Indeed, the bone trajectory is only used for generating the 4D contract and it is not mandatory (nor even recommended) for the aircraft to follow it (Fig. 6).

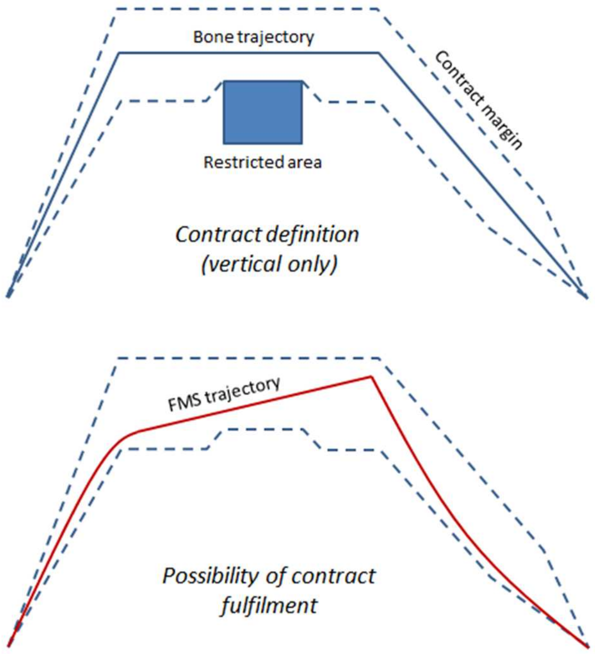

Fig. 6. Calculated trajectory vs flown trajectory

5 The current implementation

The 4DCo-GC project, at the time this paper is written, is a half of its duration. As illustrated by Fig. 7, the first 'definition & modeling' phase is ending and the consortium is preparing the first Simulation Campaign (C1) that will take place a few days after this paper submission deadline. So the following paragraphs will not provide the reader with the first intermediate results, but with a description of the implementation of the 4D contract concept in preparation for C1.

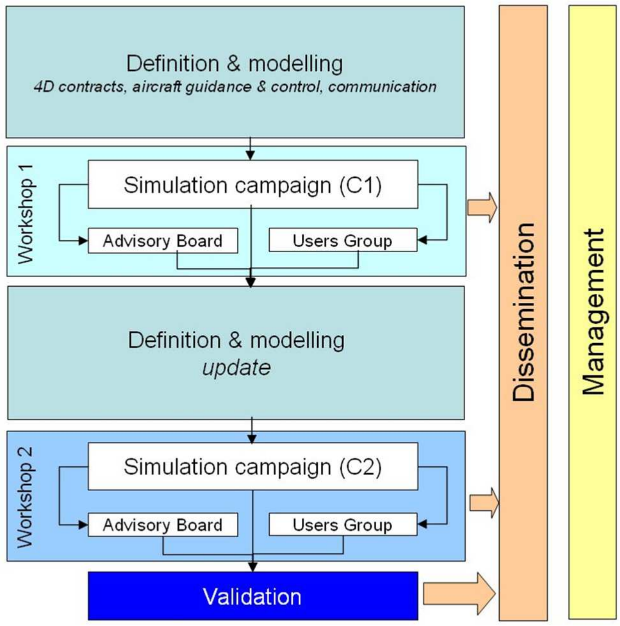

Fig. 7. Project phasing

5.1 C1 scope

As mentioned previously, C1 is not the final demonstration of the project results, but an intermediate milestone used for integration tests and first results analysis to steer the next activities. So C1 scope is limited compared to the general project objectives, especially regarding:

- Geographical zone: the number of simultaneous flights to consider is very high. So, in order to simplify the simulation set up and reduce the computational needs, the consortium decided to perform the first test with a limited number of flights. In order to keep a realistic traffic density, instead of removing some flights of the global picture, it was chosen to restrict the

simulation to a limited geographical zone over Belgium and Luxembourg;
- Aircraft types: the Eurocontrol Base of Aircraft Data (BADA) is used as aircraft performance model. The considered aircraft types are limited to those available in BADA;
- Weather: meteorological phenomena have a high impact on the ability of the aircraft to follow their 4D contracts. So it is mandatory that the weather used during the simulation is different from the one used for the 4D contracts generation. For C1, only a constant wind all over the simulation area will be considered;
- Off-line processing: whereas in a real implementation of the 4D contract concept the airlines wishes (and so the 4D contracts generation) is a continuous rolling process, we will consider only a “picture” of the traffic demand to compute the 4D contracts. This will be an off-line processing done only once.

5.2 Simulation scales

Two types of simulation scales are planned, each bringing different, but significant, inputs towards the general objectives of the project:
- Global traffic: in order to have a global picture of the traffic at the European level;
- Individual aircraft: in order to have a close look at the aircraft guidance.

5.3 Global traffic simulation

The purpose of the global traffic simulation is to study and illustrate the 4D contract concept at a large scale, in order to highlight the interactions of the various actors of the ATS: the airlines, the airports and the aircraft.

Indeed, as the 4D contract concept aims at increasing the airspace capacity and efficiency while enhancing safety, such interactions are of primary importance.

Several constraints must be taken into account:
- All 4D contracts must be conflict-free;
- Airports capacity must be respected (the airports are, and will still be, the main capacity bottleneck);
- The airlines wishes must be satisfied to the largest possible extent;
- The aircraft performance must be realistic.

The global traffic simulation is composed of 2 main phases: the pre-tactical phase and the tactical phase

5.3.1 *Pre-tactical phase*

The role of the pre-tactical phase is to prepare the initial 4D contracts for the whole simulation. So it must generate the 4D contracts in accordance with the airlines wishes (in terms of departure/arrival airports and time) and respect the airports capacity. They are then modified/adapted in order to ensure that the flights are conflict-free.

As it is difficult to simulate the airline wishes, the consortium decided to take real data as input. Eurocontrol can provide real traffic data with a limited access: the Demand Data Repository (DDR – [3]). The DDR provides also Eurocontrol traffic forecast, according to various traffic growth hypotheses. As the 4DCo-GC project goal is to study the viability of the 4D contract concept in a context of traffic doubling (around 60 000 flights per day over Europe, compared to the current average of 30 000 flights), we chose the busiest available day of traffic – July 1st, 2011, 33 617 flights – and applied the highest growth scenario of the DDR forecast. In addition to the departure and arrival airports, the DDR data file contains a lot of additional data not useful to the project. So the file has been processed to keep only necessary data:
- call sign;
- airport of origin (ICAO-code);
- airport of destination (ICAO-code);
- aircraft type;
- departure time (off-block time);
- arrival time (touch down time);
- departure runway;

- arrival runway;
- coordinates for several waypoints of interest;
- flight level for cruise;
- departure runway bearing;
- arrival direction.

The result is a potential set of 78 110 flights to be used as the realistic airlines wishes input for the generation for the 4D contracts (for C1, only a portion of it will be used).

Now that the airlines wishes are available, the next step is the generation of the initial 4D contracts.

First, an initial flight profile (altitude and speed vs time) is calculated for each flight, considering a direct route between departure and arrival airports. This gives a first draft of the trajectory. Of course, at this stage, trajectories can still be conflicting, en route or at the airports. This set of trajectories is then modified in order to make is fully conflict-free. The algorithm used for this deconfliction phase only modified the trajectories laterally (time is considered), trying to keep the optimized flight profile. If conflicts still remain after this route alteration, they are dealt with modifying the departure time. These later calculations are performed taking into account separation margins between the aircraft.

The last step of the pre-tactical phase is to turn the conflict-free 4D trajectories into 4D contracts by adding the Contract Bubbles for each flight. For the time being, these CB have a constant size all along the flight; this may be enhanced to a dynamic size later in the project.

The pre-tactical phase is summarized by Fig. 8. All these calculations are performed off-line.

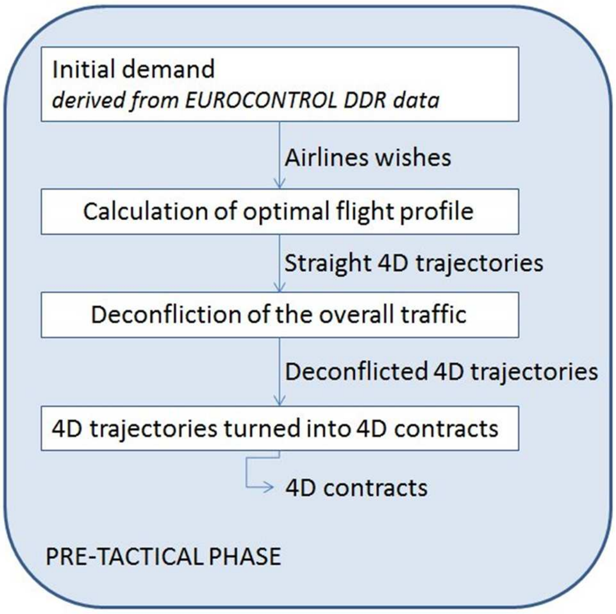

Fig. 8. Pre-tactical phase of the global traffic simulation

5.3.2 *The tactical phase*

The tactical phase is on-line. Each aircraft is simulated and should fly its assigned 4D contract. As it is a large scale simulation, simplifications have been applied:

- Airport data are difficult to obtain and more than heavy to compute, so for C1 it was considered that flights start when the aircraft are 3000 ft high and end at the same height;
- All aircraft use the same FMS model (but each aircraft type uses a specific performance model);
- A generic constant direction / constant amplitude wind is considered for the whole simulation area.

The fact that a wind (even very simplified) is considered will lead to some 4D contract update requests. Such requests will be triggered by a “contract compliance monitoring” module. The role of this module is to anticipate the breach of the 4D contract using a stochastic approach.

When a 4D contract update is requested, a re-planning algorithm is called. Its role is to calculate an alternative “flyable” 4D contract for the end of the flight. To the largest possible extent, other 4D contracts should not be impacted. Nevertheless, it may be necessary to alter the 4D contracts of surrounding aircraft. The tactical phase is summarized by Fig. 9.

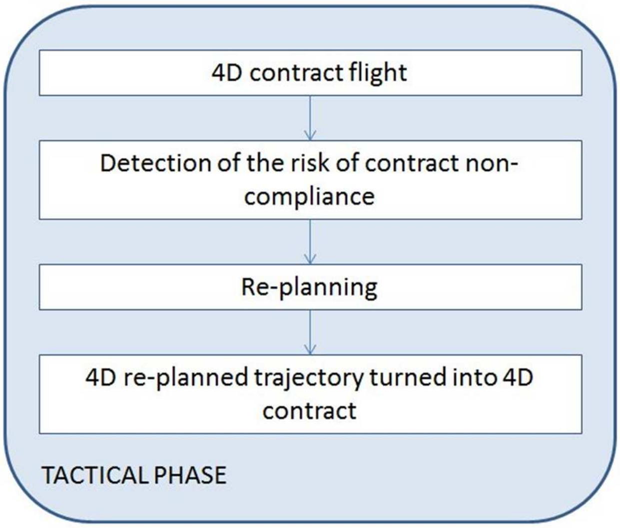

Fig. 9. Tactical phase of the global traffic simulation

5.4 Individual aircraft simulation

As mentioned previously, in order to study and analyze the guidance and control aspects of the 4D contract concept implementation, it is necessary to have a close look at the aircraft performance and behavior. This is not possible at the global traffic scale, as the simulator uses simplified models of aircraft. This individual aircraft simulation is, on the contrary, based on detailed and accurate aircraft models: 6 Degrees of Freedom (6DoF) motion model and 4D-FMS.

For the individual aircraft simulation, one of the 4D contracts of the global traffic simulation is assigned to the 4D-FMS. The 4D-FMS starts by calculating the Freedom Bubble for the whole flight. Then it calculates an appropriate trajectory respecting the contract. It may, as explained previously, be different from the bone trajectory, but the aircraft is supposed to stay in its FB at any time.

The outputs of the FMS are then fed into a 6DoF aircraft model that is in charge of simulating the attitude and behavior of the aircraft. All along the flight, the aircraft model will generate guidance and control commands in order to follow the FMS trajectory. The outputs of this individual aircraft simulation will be used in order to determine the rate of command modification, etc. This will be useful for assessing if such behavior could be transposed to reality (e.g. with regards to passengers comfort).

The flight is displayed using the open-source flight simulator FlightGear [4].

Fig. 10. Example of FlightGear illustration

So the individual aircraft simulation can be summarized by Fig. 11.

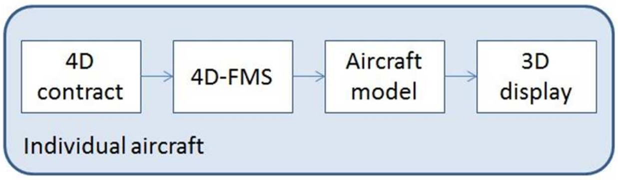

Fig. 11. Individual aircraft simulation

6 Next step activities

As mentioned previously, the very next milestone of the project is the first simulation campaign that will take place in Onera, Toulouse (France) IESTA facilities, during the first week of July 2012. C1 will be the opportunity to make the first integrated trials in order to test most of the basic functionalities of the simulator, especially regarding the interfaces between the various involved modules as well as their interactions in the frame of the integrated infrastructure. First results about the algorithms behavior and the computation needs will also be checked.

After C1, a second ‘definition & modeling phase’ will be performed, taking into account the C1 results, in order to update and enhance the simulator infrastructure, the modules scope and performance, as well as to make the simulation more complete by gathering additional data and elaborating non-nominal situation scenarios.

Then a second simulation campaign (C2) will take place in September 2013 in DLR, Braunschweig (Germany) facilities. This simulation campaign will use the completed simulator and introduce more realistic scenarios in order to assess the 4D contract concept, in terms of performance against the Advisory Council for Aeronautics Research in Europe (ACARE) requirements. The outputs of C2 will enable the 4DCo-GC consortium to derive conclusions about the concept viability regarding the guidance and control of aircraft and to provide the aeronautical community, especially SESAR, with recommendations about the future of the ATS.

7 Conclusion

The 4DCo-GC European project aims at explaining and analysing the 4D contract concept as a possible evolution of the air transport system, by the mean of simulations enabling to guide and control aircraft along those contracts. To this end, the 4D contract concept developed in the frame of the IFATS project was refined, taking into account the current SESAR outputs. The simulation infrastructure is ready and the main simulation modules are available in a first version. They will be connected for the first simulation campaign that is planned to take place in July 2012 in ONERA facilities in Toulouse, France. The purpose of this campaign is twofold:

- to have a first round of simulation, integrating several modules on a common "backbone". This should demonstrate the viability and performance of the simulation architecture;
- to show to an external audience the first "operational" outputs of the project, i.e. preliminary 4D contract generation module, aircraft model suited for 4D contract guidance and control, etc.

The final conclusions of the project are expected in 2013 when recommendations will be proposed to the SESAR programme and to aircraft manufacturers in order to prepare what could be the far future of the air transport system.

Acknowledgement

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