[EN-A-003] Integration of unmanned freight formation flights in the European air traffic management system

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Abstract: Aviation has been facing a lot of challenges regarding the growth of global air traffic passenger demand. Besides that aviation has recently changed greatly. The main challenges appear around the implementation of sustainable technologies and operations in order to ensure a dynamic, safe and reliable ATM system also considering new entrants. The integration of new operations and operators as e.g. formation flights, space vehicle operations, or unmanned aircraft system, is part of new air traffic operations and concepts that have to be taken into account for the current and the future ATM system on an everyday basis. Therefore, DLR has been working on several projects which cope with the growth of global air traffic demand, as well as the demand for integration of different air traffic operations which among others include unmanned freight traffic. All of these ideas and projects are drafting ATM operations in future skies.

Keywords: unmanned aircraft, formation flying, fast-time simulation, air traffic management

1. INTRODUCTION

The challenges of growth demand for a holistic approach to implement sustainable technologies and operations to achieve an efficient, safe and sustainable air transport environment. Current research and operational tests on formation flight indicate a significant fuel saving potential during the enroute flight phase [6]. Beside this technology driven development, the efficient integration into the air traffic management is currently not addressed at research projects. It is expected that a considerable effort is needed to coordinate both formation and normal flights, for both manned and unmanned operations. This coordination has to cover capacity constraints at airports and airspaces (e.g. demands of air traffic control) as well as the interdependencies of the air traffic network (e.g. reactionary delay, weather impacts). To allow for a systematic analysis of the integration effects of formation flights into the air traffic management, a specific performance envelope will be derived and implemented in a relevant air traffic scenario. This scenario consists of an operational concept to reflect the highly segregated airspace in Europe, specific airport characteristics (e.g. hub, non-hub) and required data exchange between the involved parties (e.g. an airport-airport coordination if flights start at different airports). Using the reference scenario of today's operations, the consequences of the additional coordination caused by the formation flight could be quantified in the simulation environment. These analyses will mainly identify operational enablers in the context of the complex and interdependent air traffic system. The implementation of upcoming SESAR technologies (e.g. flight-centered operations) will already provide particular technologies and operations to pave the way for the formation flight, but from the air traffic management perspective the coordination of airports becomes a higher relevance to enable new concepts. Formation flight proves to be a promising candidate for future air traffic operations to achieve the challenging task of highly efficient air transport [8]. To enable formation flight, solutions for several restrictions have to be identified, tested and implemented. These restrictions arise from different aviation domains:

- Safety
- Minimal environmental impact
- Flight mechanics and control, aerodynamics
- Airborne equipment
- Navigation, communication and performance requirements
- Air Traffic Management (air traffic services, air traffic flow management, airspace management)
- Airport management (e.g. delay, capacity, slot, coordination)
- Passenger comfort
- Business cases

If the specific challenges for each restriction are met, an assessment addressing benefits, performance, cost (including cost/effort of aircraft/flightplan/airport coordination) has to point out a significant improvement in daily operations against at least one SESAR performance area: environment, safety, capacity, cost-efficiency [6]. The scope of the presented research is set to the specific requirements of the air traffic management (ATM), airport management and the aircraft specific performance data.

The formation flight could also be combined with the parallel development of unmanned flight systems, where synergy effects can be expected here due to high demands on the reliability and performance of the technical systems of both principles. It can be assumed that over the next decades the development of small systems will lead to larger Remotely Piloted Aircraft Systems (RPAS) for intercontinental long-haul flights, which will initially be limited to the area of unmanned freight transport. The potential resulting from personnel planning, fuel efficiency and network termination is generally assumed to be large. In particular, the fuel efficiency can be increased, for example, due to the lack of human factor on board the aircraft by longer flight times and thus slower flight speeds. It is to be assumed that these systems would be used mainly in regions with a lack of connection to a ground infrastructure, which are often found in developing countries or in crises. In the DLR project UFO, unmanned cargo aircraft are examined as a future addition to the existing transport system. The work presented in the first part of the paper is the novel approach of implementing formation aircraft flights and the second part of the study is part of the work on the unmanned freight formation flight and demonstrate both the influence on today's ATM system by the integration of unmanned freight formation flights in a relief goods scenario as well as the economic benefit of such scenarios [2].

1.1 Objectives and Structure of the Document

Within this paper, we focus of one example addressed in the DLR project “Unmanned Freight Operations” (UFO). Within the UFO project, three example use cases have been developed to address aspects of unmanned freight integration into the ATM system: long-haul freight delivery, company internal transport, and relief flights. Here, we examine the example of relief flights. This example has been designed in order to investigate the impact of unmanned formation flights on the ATM system. The focus on relief flights implies that such a formation may be prioritized. To allow for a systematic analysis of the integration effects of formation flights into the air traffic management, a specific performance envelope needs to be derived and implemented in a relevant air traffic scenario. This scenario consists of an operational concept to test the segregated airspace when the relief flight formation is given priority, especially airport characteristics and required data exchange between the involved parties (e.g. airport-airport coordination). Using a reference scenario of today’s operations, the consequences of the additional coordination caused by the formation flight can be quantified in simulation environments. These analyses will be performed by the common way of using fast-time simulation (FTS) to investigate a scientific question. First, a reference scenario is created, which correctly reproduces the status-quo air traffic situation. To achieve this, recorded traffic data and ATM information is required to calibrate the reference FTS scenario. Afterwards, the specific traffic scenarios are generated and modified according to the research question. Comparing the outputs of these validation scenarios with the calibrated reference scenario, the impact of the changes are assessed and discussed. This allows us to identify the operational enablers in the context of the complex and interdependent air traffic system. The implementation of upcoming SESAR technologies will already provide particular technologies and operations to pave the way for the formation flight, but from the air traffic management perspective the coordination of airports becomes a higher relevance to enable new concepts [8].

2. METHODOLOGY

This part of the paper describes the actions taken to investigate the research question and the rationale for the application of scientific procedures and simulations used to identify, select, process, and analyze the data applied to understanding the problem.

We first begin with the data that was obtained for the analysis and then move on to the method chosen for investigating the research question, which amongst the other includes fast time simulations. The chapter ends with a description of the aircraft model used in the first part of the study and developed by RWTH Aachen [4, 5].

2.1 Air traffic data and applied airspace model

The exercise in the first part simulates formation flight movements from Europe in westbound direction heading to the North Atlantic. For that purpose we have chosen traffic sample that represents a normal weekday in a month with no additional or reduced traffic caused by holiday period or disruption in the ATM system due to severe weather conditions. The total number of flights for that day is 28,545. The flights used in the simulation scenario are limited to only 2,606, because the focus is set to the two departing airports for the formation flight, Amsterdam (EHAM) and Paris (LFPG). The study analyses the effects of the formation flight on the reduction of fuel consumption and tangles the question of the potential impact the formation would have on the airspace and airport capacity/delays.

The airspace model is generated according to the chosen scenario of the respective day. It has been extracted from EUROCONTROL`s Demand Data Repository (DDR2) [5]. The airspace model is represented in Figure 3. It contains around 1,200 individual sector volumes depending on the day and airspace configuration and three types of ATC sectors: collapse sectors, elementary sectors and ACC's. Collapse sectors may tactically be split vertically or laterally. It is rather important to generate a most realistic airspace representation of capacitated sector volumes. The static model also contains elementary sectors representing smallest capacity airspace volumes [1].

The second part of the study covers the integration of unmanned freight formation flights in the European network. For that purpose air traffic data in Europe for 05.10.2016 was chosen. The data used in the second part, same as in the first, has been extracted from EUROCONTROL`s Demand Data Repository (DDR2) for research purposes only. It contains 31,472 flights, which are imported in our fast-time simulation tool for further analysis.

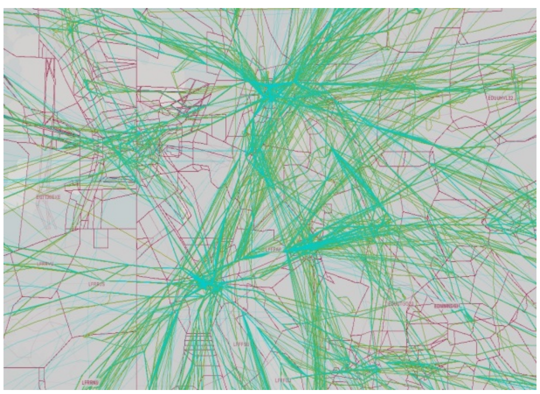

Figure 1 European airspace structure and flight trajectories from the fast-time simulation

2.2 Fast-time simulation

Simulation of the aircraft formation flight in the North Atlantic as well as the unmanned freight formation flight from Europe to Africa is performed with the AirTOp fast-time simulator, which allows a gate to gate simulation of air traffic. In this context, fast-time means that thousands of flights can be computed in less than a minute. Among other properties it includes en-route traffic and ATC modelling, 4D trajectory based operations and air traffic flow management [put reference ATM Seminar]. It is also an open modular and extensible tool, which allowed us writing the aircraft formation flight (AFF) performance data. Fast-time simulation is used in many case studies as a first and reasonable approach to answer questions on how different modifications in the airspace may influence the capacity and traffic flow. Here we implement the common way of using FTS results to investigate a scientific question by first creating a reference scenario, which correctly reproduces the status-quo situation in the air. To achieve this, recorded traffic data and ATM information is required to calibrate the FTS scenario. Afterwards, the specific traffic scenarios are generated and modified according to the research question. Comparing the outputs of these validation scenarios with the calibrated reference scenario, the impact of the changes are assessed and discussed [1].

Additionally, to generate and implement flight trajectories within the AirTOp simulator, a tool named RouGe (Route generator) is used. The RouGe is a tool developed at DLR and it is used as a platform to convert the Eurocontrol's SO6 Data in a format directly readable by AirTOp and other internal DLR software tool chains. The information from SO6 is then exported into separate files compatible with AirTOp containing the following information: flight plan, aircraft, routings, waypoints and airports.

Figure 2 Implementation of the aircraft formation flight in AirTOp

2.3 Aircraft formation flight (AFF)

In order to be able to perform the first simulation, we have implemented the AFF in the fast simulation tool. The AFF actually represents an aircraft model which was especially designed by RWTH Aachen [4, 5]. It contains the performance data of the following aircraft in the formation. For that purpose, a flight mission tool from the multidisciplinary integrated conceptual aircraft design optimization (MICADO) platform has been used. The mission tool has employed the conditions for more realistic operation conditions. In particular, the lift to drag ratio ***L/D*** has been considered as a function of true airspeed (***TAS***), flight altitude (***h***) and the current aircraft mass (***m***) which is updated by the fuel consumption in previous mission segment. Similarly, the specific fuel consumption (***SFC***) varies with ***TAS***, ***h*** and the engine thrust (***T***) that is determined by the current aerodynamic drag. The total flight mission is discretized into sufficiently small mission segments that are analyzed by using Newton's laws of motion, where the aircraft can be considered as a mass point. The power equilibrium needs to be fulfilled, i.e. the net power of thrust and drag transforms to the potential and kinetic energy changes. Within the mission calculations, an iterative process is employed to reflect the changes of variables in each mission segment. The aerodynamic polar and engine performance parameters are interpolated for the full flight mission usage, which, as mentioned earlier, are dependent on flight Mach number, flight altitude [3].

For this presenting study, the mission tool employs the pre-defined mission profiles, which are derived from the (AirTop) simulations, i.e. optimal mission profiles for aircraft in solo, in formation flight. The fuel consumption of aircraft in formation flight is then estimated by utilizing different aerodynamic polars for formation leading/trailing aircraft with given rendezvous point and split-up point. (ref 4, 5)

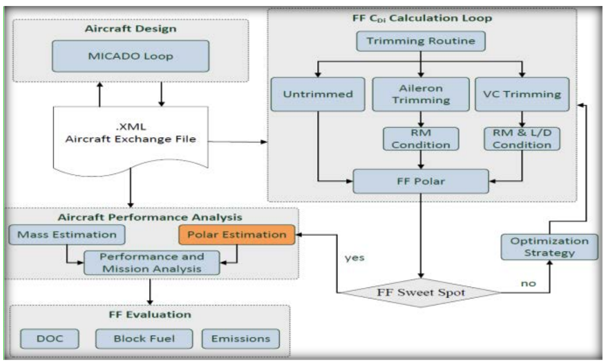

Figure 3: The overall process of aircraft formation flight modelling at the ILR, RWTH Aachen

The purpose of this simulation scenario is to establish the benefit in fuel consumption savings from the formation flights in long haul flights, as well as to test the possibility of such simulations in AirTOp.

3. OPERATIONAL SCENARIOS AND SIMULATION

The first part of the study, as mentioned above, begins with an implementation of an aircraft formation flight in our fast time simulation tool. The purpose of this implementation is to test the capabilities of the simulation tool itself. Since this is a novel approach in modelling formation flights with the help of fast-time simulation, several tests and adjustments were needed, before creating and integrating the unmanned freight formation scenarios in the same simulation environment.

As we have learned above, the benefit of such formation flights are so far noteworthy only for long haul flights. Therefore, the first part of the study has been performed with two flights in formation over the North Atlantic.

In the second part of the study, several operational scenarios are created in order to simulate and investigate the benefit of implementation of unmanned freight operations in the European ATM system. The freight formation also consists of long haul flights.

To begin with any further description of the operational scenarios, we first elaborate on the type and importance of the air traffic network and then continue with a short description of the implementation of the AFF in the fast time simulation tool and end with the description of the operational scenarios for the unmanned freight formation.

3.1 Air traffic network

The air traffic network consists of specific routes, which could be categorized in terms of distance, connections, airline or usage. Therefore, we can distinguish between short, medium or long-haul routes (distance); direct, feeder or city-pair routes (connections); low cost, network carrier or charter (airline): and number of legs flown and efficiency (usage).

In the context of formation flight only a specific set of routes could be addressed to use the proposed benefits: long haul flights. A classic sample could be the intercontinental connection between Europe and US. These transatlantic connections [7] are used by aircraft between FL290 and FL410. The NAT are designed to provide a uni-directional, minimum time route by taking the advantage of wind conditions (minimize head wind, maximize tail wind) and consist of specific oceanic entry and exit points. The NAT traffic points out alternating westbound and eastbound flows. The westbound flow departs in Europe in the morning and the eastbound flow departs in North America in the evening. The corresponding daytime and nighttime structure is published by Shanwick and Gander Oceanic Transition Area respectively [7].

Areas of interest in our study are not only the NAT tracks, but also other long haul flights which depart/arrive in the European ATM. Therefore, the unmanned freight formation flight represents a long-haul flight with departure from Europe and arrival in Africa. Introducing new type of operations in saturated and complex airspace like the European can be a big challenge and one of the main points of investigation in this paper.

3.2 Flight formation in AirTOp with AFF model

For the purpose of the first part of this research several scenarios were designed and then implemented in a fast time simulation suite. The idea behind these scenarios is to evaluate the potential fuel consumption reduction from flying a formation in the North Atlantic Region, but also to test the capabilities of the simulation suite for operations like this. As already seen in [9] study for aircraft route optimization for formation flight were already carried out. Hereby, [9] concentrates on the fuel and cost benefits of the formation configuration in commercial airline operations and it deepens its research and focus in the area of optimization of different long haul formations and the benefits of such flying but those missions that have flight and airport delays are not considered.

In our simulations we set the focus on the formation and enable for the aircraft to join the formation whether there is delay or not. The idea behind that is to tackle the question of potential impact that the formation might have on the departing airports, as well as on the increment of controller workload on one side and the economic potential on the other side. Each scenario consists of two aircraft in formation. The leading aircraft is represented by A330 and the following aircraft is represented by the AFF aircraft.

3.3 Variations of the unmanned freight formation scenarios

The assumption in the second part of the study is that an aid supply transport with 45 tons of freight is carried from Germany to Eastern / Central Africa. The distance to be flown is around 3,000 NM. The newly added freight flights for the purpose of simplification and better comparability of the simulation are flying the great circle. Same as in the first part of the study, the fast-time simulation tool AirTOp is used to create and execute the simulation scenarios.

Description of the scenario S0, S1, S2and S3

S0 represents the baseline simulation scenario which parameters are later used for comparison. This scenario contains the original flightplan with an assumption that there is no disruption in the system and there are no additional flights or formation.

In scenario S1 the entire cargo is collected and transported with a single, conventionally manned Boeing 777-F. The disadvantage in this type of transportation is that it has to be carried out at a hub airport in East Africa and later on redistributed to the regions in need. This of course has an impact on the costs as well as the logistics. The cruising flight level is FL350 with a speed of Mach 0.84.

In scenario S2 the freight is transported in three unmanned aircraft each carrying 15 tons, according to the departure airports. For this purpose three turboprop airplanes LM-100J (C-130J) are used. They provide an optimal profile with regard to the required weight/range and have been hypothetically converted for unmanned operation in remotely piloted aircraft (RPA). In contrast to the B777-F from S1, these aircraft offer the possibility of dropping the freight in the target area without the need to land on a hub airport. Also in this case it is assumed that this type of operation exists with the unmanned aircraft.

The difference to S1 can also be noticed in the cruising level of the aircraft as well as the speed. Because of the performance data of the turboprop aircraft, the flight time is significantly increased, but this is not a big factor for the unmanned flight because this deficiency is compensated by the much better ecologically efficiency of the flight.FL290 is used as the respective travel flight altitude (Mach 0.58).

In S3, the three RPAs from S2 join together in a formation for most of the flight. It is important to mention that in this scenario the formation is represented by a single flight, which requires higher separation with the other traffic. All three aircraft were previously simulated separately so that the departure times are coordinated and the formation can be formed without problems and without delays, similar to our first test scenario with the AFF in the North Atlantic formation.

Although fast-time simulation uses a sophisticated model to recreate environment as close as possible to reality, there are several entities that are expected to be different. For example, no weather impact was taken into account. At this point of the study also the potential effects on the airports (e.g. delay or capacity issues) were not considered. Since in this simulation we investigated aid supply transportation that has a priority status, no additional safety separation was considered for the formation flight (Table 1).

Table 1: Separations in the simulation

to / from	Formation	Single flight
Formation	7 NM	6 NM
Single flight	6 NM	5 NM

4. RESULTS

The results, same as the definition of the scenarios distinguish two parts: a) flight formation with the AFF model, and b) results on the integration of unmanned freight transportation in the European air traffic management system.

4.1 Fuel burn results of the flight formation in AirTOp with the AFF

Chart 1 gives us an overview of the preliminary results and post-processing analysis of the simulations output for this section. It presents the fuel burn calculations for both aircraft of the formation in duration of the whole length of the flight. As expected the leading aircraft (the A330 model aircraft) does not change any of the values for the fuel burn and it has a constant consumption of 37,235.8kg. However, regarding the fuel consumption values for the following aircraft of the formation are exponentially decreasing, meaning that there is a reduction of the fuel consumption for the following aircraft in each scenario in the range of 13, 9%-15, 5%.

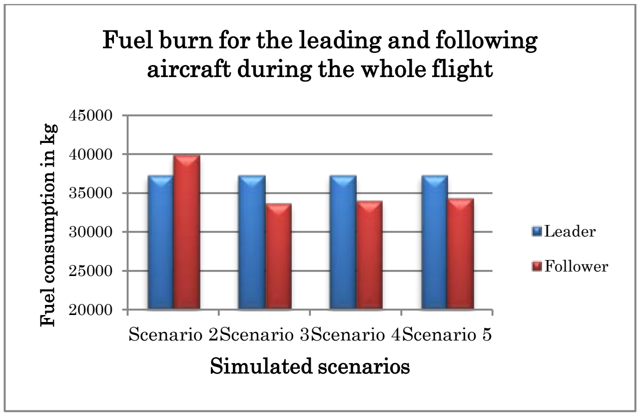

Chart 1Fuel burn calculations

These are sole preliminary results and they considered single parameter in the post processing analysis and that is the fuel consumption. However, the results from the simulations and the potential economic and environmental benefits of the formation were considered as a very good fundament for the further analysis in the unmanned freight formation scenarios.

4.2 Results of the unmanned freight formation scenarios

As it was already mentioned above, the simulation of unmanned freight scenarios is a very challenging task and therefore required many assumptions. One of those assumptions we made at the beginning while defining the scenarios included the dismissal of any additional separation (which in normal cases would exist) due to the prioritization that the aid transportation has. The character of the unmanned flight of the aircraft does not play any relevant role in the effect on the partial evaluation. The parameters which are being evaluated from the simulations include: total distance flown, potential conflicts and air traffic controller taskload. All of these parameters are a side-product of the simulation, since we already implemented several evaluation capabilities into the AirTOp environemt in prior projects [2].

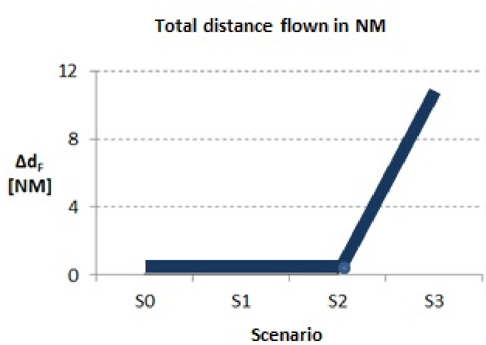

Chart 2 Total distance flown for the scenarios S0, S1, S2 and S3 [2]

Chart 2 shows the results for the foremost investigated parameter and that is the difference of the total distance flown of all imported flights in the individual scenarios. The only notable difference occurs in S3 and it is measured with 10.4 NM. This is caused by a difference in the flight time of 2m and 20s.

The second investigated parameter was the number of potential conflicts that are caused by the newly imported flights in comparison to the scenario S0. The results have shown only one conflict for S1 and five conflicts in S3, as for S2 there are no additional conflicts.

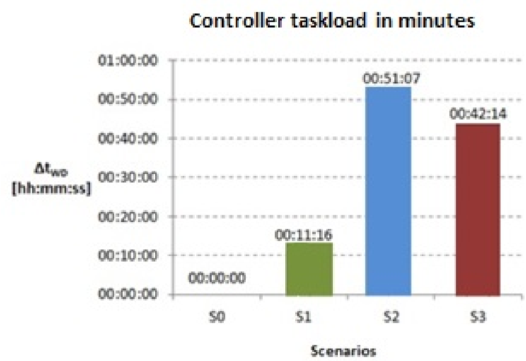

Chart 3 Controller taskload calculated (min) [2]

Chart 3 provides an overview of the results of the last measured parameter controller taskload. There is an increased taskload in all three scenarios compared to the baseline scenario S0. In S1 there is a slight increment of the taskload of 11m 16s and S3 has an increased taskload of 42m 14s. This could be explained with the fact that these two scenarios had an increased number of potential conflicts in comparison to S0, which means that the air traffic controller has spent additional time with monitoring and conflict resolution tasks.

S2 on the other hand has an increased taskload of 51m 07s which is exceptionally strong taking into account the fact that in this scenario there were no additional conflicts. Consequently, it must be assumed that the additional monitoring times for the individually flying RPA in S2 have a greater influence on the total load time than the isolated conflicts in S3.

As a conclusion, according to this result, it could be argued that a continuously higher monitoring time has a greater share of the total taskload time than the time required for the solution of occasional conflicts. However, the load time in S3 increases with respect to S1, which in turn can be attributed to the increased number of conflicts.

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