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National Aerospace Laboratory NLR

NLR-TP-2002-057

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An operational concept for Gate-to-Gate 4D flight planning

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This report is based on a presentation to be held on FAA-Eurocontrol Workshop "The Impact of ATM/CNS Evolution on Avionics and Ground System Architectures", Toulouse, June 2002.

Customer:	National Aerospace Laboratory NLR
Working Plan number:	L.1.A.1
Owner:	National Aerospace Laboratory NLR
Division:	Air Transport
Distribution:	Unlimited
Classification title:	Unclassified
	March 2002

Summary

One of the most urgent problems of ATM is to reduce delays and to improve the punctuality of air traffic arriving at congested hub-airports. Layered planning with refinement and convergence in time and space, as proposed by EATMP [*European ATM Programme*], could give the required support for better use of these scarce resources. Refined Flow Management, a concept to support gate-to-gate 4D flight planning, could be one of the most significantly contributing elements to an enhanced layered planning system. Success of such a concept should take into account the interests and competencies of all actors participating in the applicable operations, while the necessary information needs to be made available to enable them to act as expected and committed. The most essential conditions for a feasible and short-term implementation of this 4D planning concept, are:

- The system should be beneficial towards the main requirement from operators to improve punctuality and should be flexible enough at the same time to be able to cope with unexpected events.
- The system, supporting a 4D planning concept, should be robust and manageable.
- Present-day roles and competencies of ATC, AOC [*Aircraft Operations Centre*], pilots and the CFMU [*Central Flow Management Unit*], tasked to perform Flow and Capacity Management at an ECAC-wide scale, are to be respected.
- The impact on tactical operations and on executive control services should be minimal so that the impact on safety can be minimal as well.

4D capability at an airborne level is under development now and can be expected to become mature technology within a few years. However, it is less clear how to develop an operational concept for ATM on the ground that provides the complementary functionality required to support air-ground integrated 4D planning and control. A concept for 4D gate-to-gate flight planning is presented here which aims at offering significant benefits, but which does not incorporate safety-critical aspects of the use of guidance support by the aircraft's 4D FMS [*Flight Management System*].

It is considered that the most significant benefits from 4D can be obtained when the Airline's AOC is able to plan an RTA [*Required Time of Arrival*], and when the CFMU (in the European context) can perform a process of Refined Flow Management to provide ensured capacity with sufficient accuracy (a few minutes) for a punctual and undisturbed arrival. Downlinked 4D trajectories, to be stored in a data repository, will provide the information necessary to perform Refined Flow Management. The required reliability of this flow management process is ensured by regularly updating trajectory predictions produced by the aircraft's 4D FMS. The pre-departure exchange of planning information and the accurately determined departure time

constraints, imposed by the CFMU, are the means to obtain benefits. The effect should be a regulation of arrival traffic flows at congested destinations and the avoidance of bunching effects. The starting conditions of the Arrival Management process will be improved, but the process itself is considered as a local process just as today, performed by local ATC, following the usual procedures and using downlinked 4D trajectory prediction data in the best case as reliable planning data. Furthermore, there will be an incentive for Airline Operators to contribute as much as possible to Refined Flow Management and to keep the planning of their flights up-to-date and reliable, when flights arriving in time will be prioritised by ATC.

Different projects within the Framework programmes of the EU are stimulating the development and validation of 4D capability such as AFAS, MA-AFAS and Gate-to-Gate. NLR will support the development of an operational concept, based on the principles described above, and aims at validating parts of this concept by their participation in these projects.
This validation process will be performed with a focus on:

- Enhanced punctuality by coherent and consistent planning,
- Improved flight efficiency and reduced flight duration by Refined Flow Management,
- More effective use of available capacity by improved regulation of arrival flows as result of Refined Flow Management,
- A potential (limited) increase of declared capacity as result of enhanced stability of flows of arrival traffic due to flow regulation.

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1 Introduction

Layered planning can be considered as the heart of the EATMP [*European ATM Programme*]. An operational concept for ATM comprises a planning concept, which is convergent in space and time. It reaches from a highly strategic level, with planned flow and capacity management half a year before the flight, up to tactical control actions, planned with a required precision of e.g. 10 seconds in order to be able to maintain the separation of flights in their sequence on Final Approach. Planning a flight ultimately always means making a 4D planning, and it is the interest of the Airline Operator to accomplish a planning which meets his RTA [*Required Time of Arrival*] before departure, ensuring a timely and undisturbed arrival at destination. The idea of the presented concept is that ATM providers can be enabled to ensure the capacity for a timely and undisturbed arrival when they receive a predicted trajectory from the aircraft which can be flown and which will be flown. The ATM providers can apply these predicted trajectories to perform a process of Refined Flow Management, which aims at reaching an accuracy of a few minutes for the difference between the planned and realised arrival time at destination.

The way to develop a 4D FMS [*Flight Management System*] for the aircraft and to provide the Airline Operator with the software to make accurate 4D predictions for a gate-to-gate planning of a flight is a comprehensible problem that can be solved. Yet, it is less clear how it will be possible to allow the ATM providers on the ground to collect and exchange 4D trajectory predictions, and to perform the process that ensures the capacity for a timely and undisturbed arrival. It is proposed here to create and maintain a centralised or distributed database with downlinked 4D trajectories for Europe which could be managed e.g. by the CFMU [*Central Flow Management Unit*]. In addition, it is proposed that the CFMU will perform a process of Refined Flow Management resulting in pre-departure imposed departure constraints, while the database is updated regularly by making use of in-flight 4D trajectory predictions downlinked by the aircraft.

The status of development of 4D capabilities at an airborne level is described, followed by a brief overview of aims, objectives and requirements for the ATM capabilities on the ground. An outline of the most relevant features of an operational concept is described in this paper that meets the aim to allow ATM on the ground for provision of 4D services in a complementary and satisfactory way. The expected benefit for ATM is that improved punctuality can be ensured to the Airline Operators.

2 Development of 4D capabilities for the aircraft

From a high level perspective, the development of adequate 4D capabilities comprises the implementation of a 4D FMS in the aircraft with advanced functionality to support 4D planning of a flight and to perform monitoring, guidance and control to realise this planning. The operational requirements are mainly asking for a 4D prediction capability to predict one flight, gate-to-gate, with the potential to optimise the planning towards the punctuality requirement to meet a planned RTA with certain accuracy and in balance with other requirements, such as operational costs, and in particular fuel.

Although still complex enough, the task to develop 4D capability for the aircraft seems sufficiently comprehensible and sufficiently simple with regard to technological, institutional and organisational aspects to assume that 4D capability at an airborne level can be brought to maturity within a few years. In technological respect major parts of the required capabilities are available in present FMSs. Accurate monitoring, guidance and control can be provided when there is evidence about the benefits to follow a predicted trajectory and to meet a predicted time by making corrective actions at the cost of less than optimal flight performance. A present-day advanced FMS is able to predict a trajectory, which, in general, can be flown with high precision, efficiently, safely and cost-efficiently. What is missing yet is the real 4D capability to optimise towards an RTA, which meets imposed ATM constraints and which is in balance with other operational factors such as fuel costs. To solve this problem, aircraft need to be equipped with a 4D FMS, and improved capability must be implemented for the planning of one flight, gate-to-gate. Although this is a highly complex technical problem indeed, it is still relatively simple in other aspects. The reason is that there are industries to develop and to build a 4D FMS and 4D equipped aircraft and there are operators to buy on the condition that the aimed benefits are achievable for a profitable exploitation of their flights.

Delays are considered the main deficiency of quality of service to the passengers, indeed. Operators may be willing to pay for 4D capability in future aircraft if this diminishes their problems with delays and with the consequences of delays for their exploitation. However, the success of use of 4D capability in the aircraft will be dependent on the way that airborne 4D operations can be embedded in an ATM concept for planning, monitoring, guidance and control on the ground. This really is a weak point in the development and introduction of a 4D FMS, and we therefore have to look at the new and advanced capabilities on the ground, required to follow the development in the aircraft (Figure 1)

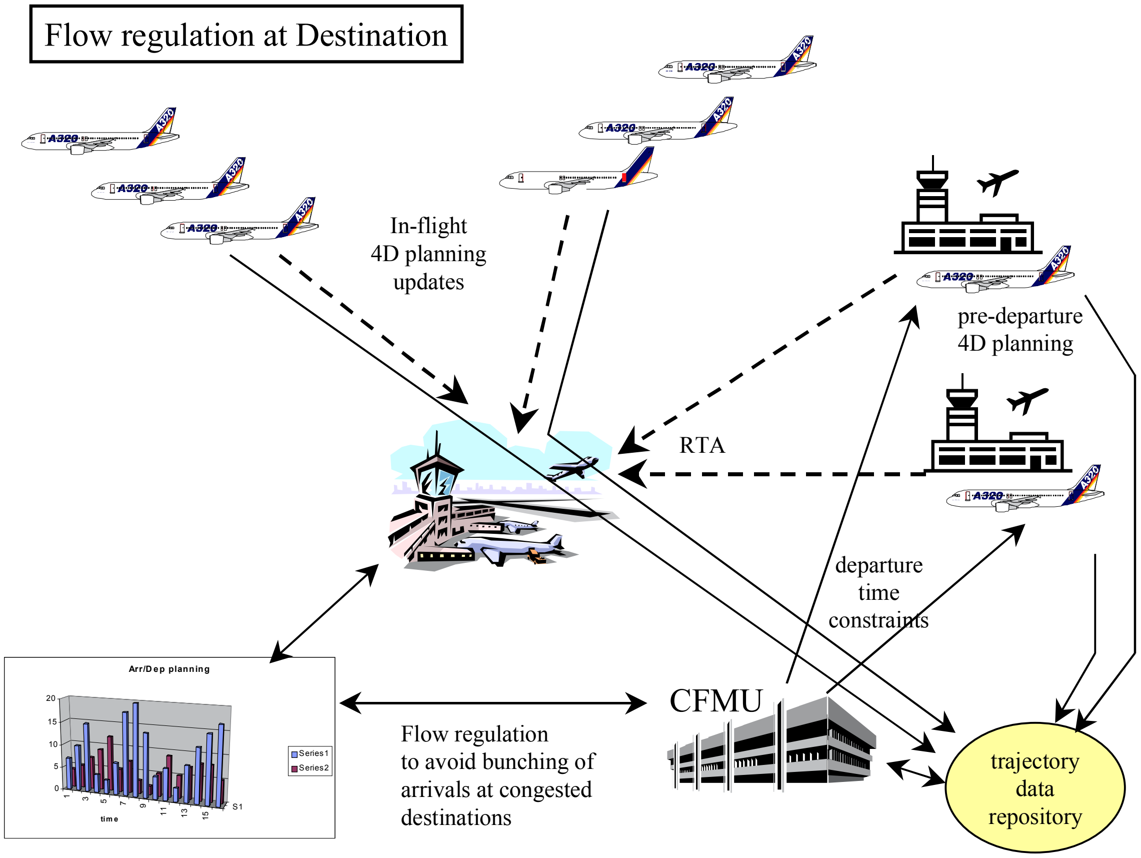

Figure 1 - Flow regulation at destination by Refined Flow Management of CFMU

3 Aims, objectives and requirements for beneficial use of 4D on the ground

Punctuality is definitely one of the major points which have to be improved in ATM and this qualifier is directly dependent on capacity, use of airspace, use of runways, and on planning, monitoring (surveillance) and guidance (navigation) capabilities. The first question is: Is it possible for the operator to plan an RTA for a flight and to realise it with sufficient accuracy, given the traffic conditions and the potential of ATM to plan and control air traffic?
The next question is: What is the sufficient accuracy and how well is the operator able to plan his RTA? Then the following question: What is required from ground ATM to be able to adopt this RTA and to provide ATM services to realise an ATA [*Actual Time of Arrival*], as close to the RTA as required and as permitted by safety, capacity, environmental and efficiency conditions (e.g. acceptable costs of service provision)?

Fact is that commercial air traffic is characterised, fortunately, by precocious and detailed scheduling and planning, required simply for a cost-beneficial exploitation of extremely costly resources. The operators are able to determine the RTA for the broad majority of flights long in advance and are able to plan and to commit in most cases to an RTD [*Require Time of Departure*], a planned take-off time, well enough to realise this RTA. Nevertheless, operators also fail to miss their scheduled departures frequently and for many reasons. In those cases operators often ask the CFMU for new slots or for slot extensions at present. Also for future modes of operations it can be expected that planning facilities will be required offering operators the flexibility to adapt their planning at any moment. Typically, this flexibility will be a convergent flexibility. The closer one gets to the actual realisation of the planning the smaller the time corrections will be in size. Even in-flight corrections on the planning will not always be avoidable and the way corrections are executed will depend on flight conditions and flight performance costs.

The operators require punctual ATM service provision enabling them to realise their RTA, and at the same time taking into account the required flexibility. But what is the required accuracy for a punctual arrival? At present, many operators are considering a flight as undelayed, if the delay is less than 10 minutes. Given the flight time and the overall travelling time, 10 minutes seems to be a reasonable punctuality figure for the passengers as well. Possibly, somewhat stricter constraints could be imposed due to tight planning on transit conditions or on turn-around flights. So there also might be a flight dependable aspect and it could be that a somewhat stricter criterion for punctuality would allow the operator to handle a more profitable exploitation schedule. Concluding, it can be stated that the operator-imposed accuracy yields a requirement to meet the planned RTA with an accuracy of several minutes (e.g. 5 min.) and not with an accuracy of seconds.

The strongest timing requirements are imposed when the aircraft approaches its destination airport with a flying distance of less than 30 to 40 minutes left, and comes under control of an ATC centre tasked to control the arrival at the airport. Assuming congested arrival conditions, it is the objective of ATC to make best use of scarce capacity, in particular the runway capacity, in an efficient and safe way. An accuracy of 10 to 20 seconds is required at Final Approach in order to preserve a dense traffic sequence, while maintaining the obliged separation at the same time.

Making use of the 4D prediction capability and of the 4D guidance and control capability of the FMS in the aircraft may possibly lead to an enhanced tactical control process during the arrival phase in the future. Strictly speaking, however, it is not a requirement to be able to meet the RTA. There is, without doubt, potential to improve the tactical control process in the arrival phase, but this is not the essential point to ensure an undisturbed arrival at a congested airport. ATC is able to maintain the separation and to control the traffic, albeit possibly not with an hourly landing capacity which meets a theoretical maximum. A really essential requirement to enable ATC to ensure a timely and cost-efficient arrival is, that approaching air traffic arrives in a smooth and regular flow, good enough to fully deploy the available runway capacity and to avoid holding manoeuvres. However, if the flow of traffic is so regular and so continuous that the available capacity is fully deployed, there are few options left. Improvement of the tactical control process may be beneficial, but the potential for increase of capacity is modest and an increase in the order of 1 to 2 aircraft per hour is already ambitious in this respect.

The last option then is the unavoidable last one: to accept delays and to absorb delays, either as holding manoeuvres in-flight or, preferably, before take-off at departure. It is the author's opinion that there is more to win by optimising efficient use of available landing capacity than by increasing the hourly landing capacity, and there are sufficient figures to make this a plausible assumption. The benefits from efficient use of capacity may come from fine-tuning the demand, and to avoid any waist of capacity by unbalanced arriving flows.

As a conclusion, it can be stated that accurate and reliable flow regulation is the best way to support and to ensure the realisation of an RTA as close as possible to the scheduled arrival time. However, it is not excluded that enhanced 4D guidance may ultimately contribute to an increase of capacity and, in this way, will contribute to enhanced punctuality.

A refinement of flow regulation imposes high accuracy requirements on the Flow Management process. In Europe, this process presently is performed by the CFMU. Flow Management is performed using the flight specifications of ICAO flightplans submitted by AOCs and making very basic assumptions about flight performance characteristics. Moreover, there is no feed-back from in-flight data and realised actual departure times, and it is not sure that actual traffic flows will correspond with planned flows, because slot extensions are not excluded. At present, the tolerance for slot assignments is: -5 min. and +10 min.

A system of flow regulation, enabling ensured RTAs, is required to be able to manage the traffic flows with a resolution of a few minutes at most. This should be sufficient to cope with bunching effects during Arrival Management, because corrective control actions during this process have a maximum scope of roughly this size. In addition, the planning of traffic flows should be made in correspondence with actual flows. This requires regular updating and actualisation of the planning and a process which performs the guidance on this planning. If 4D planning data downlinked by the aircraft is used for flow regulation and if the 4D guidance capability of the aircraft is used to provide guidance for flight execution, then ATM Flow Management on the ground can be enabled to meet the requirements for a Refined Flow Management process. It is this solution which is investigated in more detail with respect to feasibility, realism and implementation.

An important requirement for operational implementation of a concept of Refined Flow Management is that a system, supporting this concept, can be developed and implemented within a timeframe of a few years and that this system is able to support all participating actors involved. Because of the need for a short and efficient development programme, it is also important, that the system can be implemented and can be brought to operation with all respect for institutional and organisational rights, tasks and competencies. Furthermore, ATM ground support should cover a European (ECAC) scale in order to control a coherent area of traffic wherein about 80% to 90% of the flights will have both their departure and their destination. Finally, the current operations of the CFMU are taken as an accepted and consistent way of providing Flow and Capacity Management services, albeit at present with insufficient reliability and accuracy to cope with the requirements for future 4D operations.

4 Overview of R&D within EATMS to meet the requirements for 4D operations

The last 10 years there were several projects and programmes that aimed at contributing to R&D in support of development and validation of 4D concepts. A brief discussion may highlight their positioning in relation to the Operational Concept, presented in this paper.

A large programme with a very wide scope was PHARE [*Programme for Harmonised ATM Research in Eurocontrol*], lead by Eurocontrol. The PHARE programme aimed at investigating a long-term advanced 4D layered planning concept. This concept had a focus on 4D planning and control from departure until arrival. As such, it was missing the gate-to-gate Refined Flow Management process, presented here, but the in-flight 4D procedures were assumed to make use of the same supportive technology of an airborne 4D FMS and an air-ground datalink, exchanging trajectories. The PHARE concept was risky for operational implementation due to its impact on the ATC tasks and procedures of planner and executive controller [Ref.4].

At present, several projects are addressing parts of the technology or concepts which were already investigated in PHARE. Some projects in the Framework programmes of the EU are stimulating the development and validation of 4D capability such as AFAS, MA-AFAS and Gate-to-Gate. The AFAS and MA-AFAS projects are aiming at developing a 4D FMS. Their focus is to address the airborne aspects of a concept for air-ground integration, as well as the development of datalink procedures for 4D data exchanges between air and ground. These procedures are taken as a starting point for the Operational Concept, presented here.

There are several projects, conducted by Eurocontrol, to implement new and advanced functionality for the operations of the CFMU. A central point of these projects is to improve the slot allocation algorithm and to investigate dynamic slot allocation. The flexibility for slot allocation asks for improved interactive access for Airline Operators to the planning of traffic flows. CARAT [*Computer Aided Route Allocation Tool*], assuming to support this enhanced air situational awareness, is under development and would allow AOC to receive the appropriate information on the planned traffic situation in Europe and to interactively perform the planning of its flights. The functionality supported by CARAT is also considered as essential for the concept, described here [Ref. 5].

Another Eurocontrol conducted project performed a study on the feasibility to create a more or less centralised data repository of predicted trajectories. This project, EFDAS [*European logical Flight Data Server*] investigated a global design of several alternatives for implementation [Ref. 6]. Typically different from what is presented here, is that the aim of the EFDAS database is to support in-flight planning and control of air traffic, and that its contents should be determined not only by AOCs, delivering initially their planned trajectories, but also by European ATC centres, storing trajectories, planned and predicted by them. Contrary to this, the data repository, proposed in this paper, contains trajectories that are generated only by the Airline Operator and the aircraft's FMS as the principle owners of the trajectory data. Another difference is that the implementation required for Refined Flow Management is less demanding from the point of view of complexity of implementation, and that the applicability of the trajectories is indeed restricted mainly to flow management. However, the EFDAS database was supposed to be used also for flight planning and, thus, for conflict resolution, and that requires active control on trajectories and the capability to apply data fusion. This scenario should be considered as a following and also a more critical step in the development of a data repository of 4D trajectories.

In the next section, the conditions to manage and to use such a data repository are explained in more detail.

5 Refined Flow Management, a feasible way to meet the requirements for 4D on the ground

It was concluded previously that the most significant benefits of 4D operations are expected from pre-departure planning. However, these benefits are dependent on sufficient functionality on the ground to perform a flow and capacity management process ensuring an undisturbed RTA at destination. The CFMU is expected to be able to perform Refined Flow Management to accomplish sufficient accurate regulation of traffic flows which allows ATC at destination to perform Arrival Management on air traffic, delivered with an improved equalised distribution over time. The CFMU will receive pre-departure and in-flight trajectory information, and its Refined Flow Management process will result in imposed departure time constraints, issued as fine-tuned departure slots for flow regulation, en-route and at destination.

A data repository with stored and regularly updated in-flight trajectory prediction information will be the enabling facility. Such a data repository can be implemented as a centralised database, managed e.g. by the CFMU, but a more distributed concept could be considered very

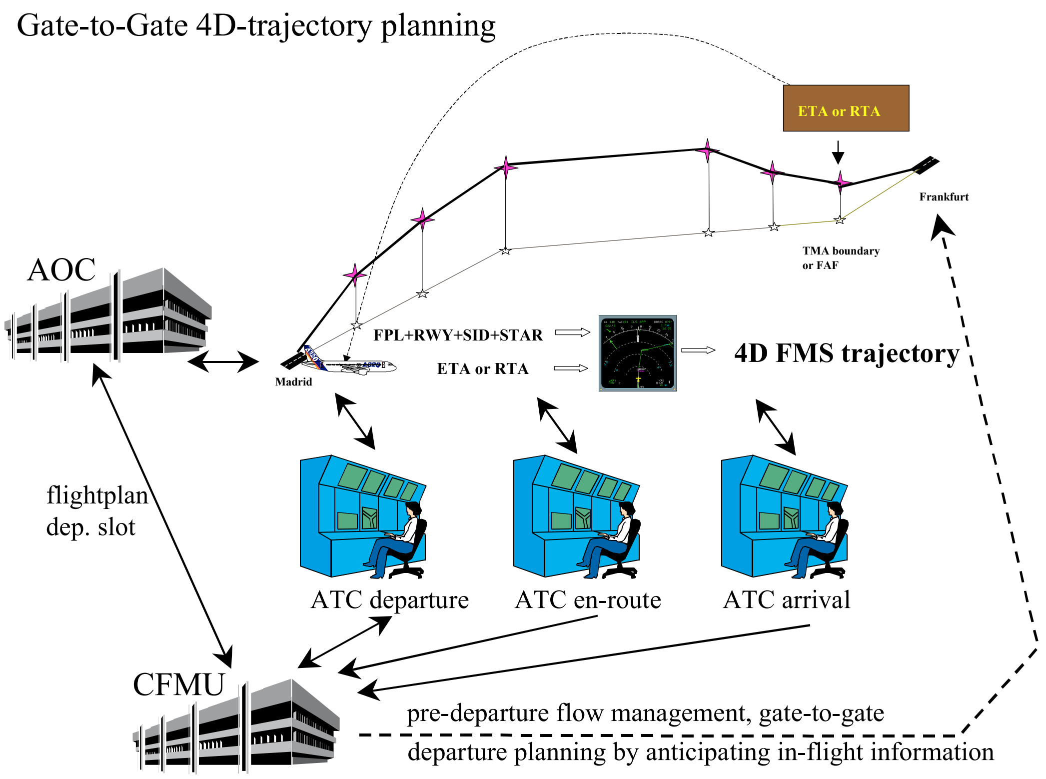

Figure 2 - 4D planning of a flight before departure

likely just as well. Implementation of such a data repository is feasible, because the function can be performed passively by simply accepting planned 4D trajectories. The flow management activities of the CFMU would not change the trajectories, but would merely impose the required departure time constraints and would therefore result in a time-shift only. (Figure 2)

The process of Tactical Flow Management is assumed to be maintained as at present. This makes sense, because not all the data required for a 4D planning process will be available from some hours up to a day before departure, and the AOC particularly needs an assigned departure slot to allow it to plan a departure (take-off) time. Tactical Flow Management will also be performed by CFMU on ICAO flightplans, submitted and managed by AOC, just as is the case today.

AOC receives an assigned departure slot from CFMU roughly two hours before departure (off-blocks) and determines a 4D trajectory prediction with a planned take-off time within the assigned slot and with a take-off window sufficient to meet a planned RTA in an efficient way. The prediction will be based on an expected and/or preferred departure runway, SID, approach path, and arrival runway, to be assigned yet. AOC is assumed to have access to the expected traffic flows, enabling it to select and determine a feasible 4D planning. Information on planned traffic flows can be obtained via access to the traffic flow data repository, as available already at present or under development with enhanced performance characteristics [Ref. 5]. The planned 4D trajectory is sent to CFMU, ATC at departure, and the crew, when boarding the aircraft.

The received trajectories will be incorporated in the data repository, representing the actual status of expected traffic flows over Europe and the planning for the coming hours. Given these traffic flows, CFMU may impose delays on not yet departed flights, when arrival flows at destination are exceeding their declared capacity. Imposed departure time constraints are sent to ATC at departure and ATC will give priority to honour these constraints. The constraints, imposed by CFMU, can be considered as the penalties accepted to obtain optimised flow regulation of arriving traffic at congested destination airports.

When ATC at departure receives a trajectory prediction from AOC, and later on from the pilot, then this trajectory is incorporated in a Departure Management process. Departure Management will take into account: CFMU imposed constraints, planned and preferred off-blocks and take-off times, and available capacity. The departure sequencing will result in a planning, including planned take-off time, runway assignment and SID for each flight.

The crew, starting their flight preparation activities, will receive from AOC a flightplan, a departure slot, its initial trajectory planning and weather info. The crew will initialise their 4D FMS, and will receive from ATC, after Initial Contact, a planned departure time (off-blocks and take-off), an assigned runway and SID [*Standard Instrument Departure*]. The crew, with support of their FMS, generates a 4D trajectory prediction which will be downlinked to ATC at departure and to AOC. ATC will forward this trajectory to be stored in the data repository, and without further delays or flightplan changes it is this trajectory that will be used to guide the departure flight phase.

ATC will issue the departure clearance, and the Airport and ATC will provide the services for push-back, ground movements and take-off. It is essential that the actual take-off time (ATD, [*Actual Time of Departure*]) accurately meets the planned take-off time (ETD, [*Estimated Time of Departure*]), e.g. with an accuracy in the order of magnitude of 1 to 2 minutes, in order to make the previously accurate planning meaningful. Therefore, it is the task of ATC to monitor compliance of actual operations with the planning. After take-off, the ATD can be downlinked to ATC and forwarded to be stored in the data repository to update the 4D planning with a time dimension, which finally meets the aimed level of confidence. In-flight and up to the landing, the 4D trajectory prediction can be revised and updated by the pilot whenever necessary. This may be required after a significant deviation, after change of control at sector or centre level, and after each initiative for a flightplan change. Updates of trajectory predictions will be downlinked to ATC and stored in the data repository. ATC, en-route and at destination, will be able to make use of this information for planning purposes, e.g. to update sector inbound and sector outbound lists, but not to play a role in the executive control process. The CFMU will use this information to update the status of information about actual and forecast flows of traffic to enhance the quality of their refined flow management activities.

The 4D trajectory prediction will be available to ATC when they start their process of Arrival Management. However, the main benefits are already provided, when the described concept succeeds in delivering the aircraft with sufficient regularity to enable ATC to cope with the demand and to allow an undisturbed arrival at its destination airport for each punctually arriving flight. The 4D prediction data will not play a particular role during the executive process in the approach flight phases, except that an accurately predicted landing time for a nominal approach path may help controllers in decision making.

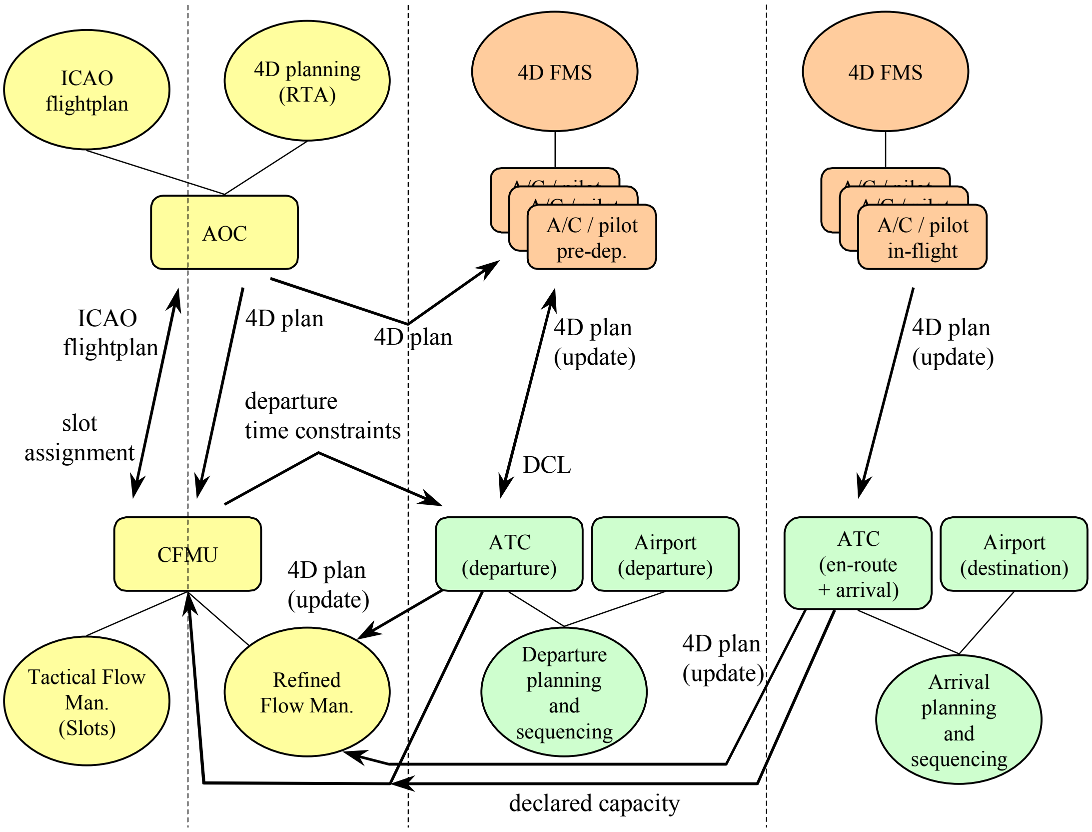

Figure 3 - Scheme for collaboration in 4D flight planning between actors involved in different flight phases

6 Some implementation aspects

Now that the principles of the concept have been discussed, in this section the attention will be focused on some implementation aspects and some consequences for operations. The description will consider operational implications for the different actors involved in the process of Refined Flow Management. Flight preparation and execution activities will be looked at in four different phases:

- The pre-departure flight phase, Tactical Flow Management
- The pre-departure flight phase, Refined Flow Management
- The departure flight phase
- The en-route and arrival flight phases

Figure 3 gives an illustration of the sequence of these four phases of activities, the actors involved, and the related activities with respect to Flow Management.

A general requirement aspect concerns the necessary communication services and the information processing capabilities. 4D trajectories are generated by AOCs and by the 4D FMS of the aircraft. If AOC and FMS are not yet capable to make full 4D predictions, including optimisation towards time constraints, they may be capable at least, to predict the trajectory to be flown. This will be sufficient to operate the concept as a first instance of implementation. The other actors involved, CFMU and ATC centres, need sufficient processing power to receive the trajectories, to validate acceptance, to store, and to distribute these trajectories. The need for manipulation, however, is very limited. Validation of 4D trajectories may comprise e.g. checks of compliance with the ICAO flightplan and with the previously assigned departure slot.

Datalink applications for support of air-ground data exchanges are specified or under development. Specifications for traditional ATC-related data communication services are specified by ODIAC [Ref. 7]. In addition, trajectory exchange services are specified and/or under development by ODIAC (COTRAC service) and, among others, by the AFAS project [Ref. 8]. These services are covering the exchange of trajectory information between aircraft and ATC. In addition, similar services are required to exchange trajectory information between AOC and aircraft, AOC and CFMU, as well as between ATC and CFMU. The first of these communication links is currently implemented using ACARS via VHF or VDL as offered by the major ATS providers, and might be realised in the future using the ATN as successor of present networks. The other communication links are instantiated at present by ADEXP ground-ground services. In the future there might be extensions or upgrades of these services on the ATN, which are required in order to be able to cope with exchange of trajectory information.

The minimum amount of trajectory exchange processes in the pre-departure and departure flight phases will encompass three exchanges:

- One initial 4D planning data exchange by AOC communicated to CFMU to allow Refined Flow Management and communicated to the aircraft to allow the pilot to initialise his FMS. This 4D planning has to be made available after reception of the slot assignment, about two hours before departure, and before flight preparation of the crew, about one hour before departure.
- One 4D planning data exchange, initiated by the pilot, after reception from ATC of a planned runway assignment, SID, and ETD. This trajectory planning overrules earlier planning by AOC and includes ATC departure planning. It is communicated before receiving the departure clearance.
- One 4D planning data exchange directly after take-off. This data exchange gives the 4D trajectory planning the level of confidence of a trajectory prediction that is subject to navigation, guidance and control by a flying aircraft.

More trajectory exchange processes are required during these departure flight phases when the planning is subject to flightplan changes and/or delays, and iterations have to be anticipated in those cases. The high-level transaction sequences are illustrated in Figure 4. The results of the

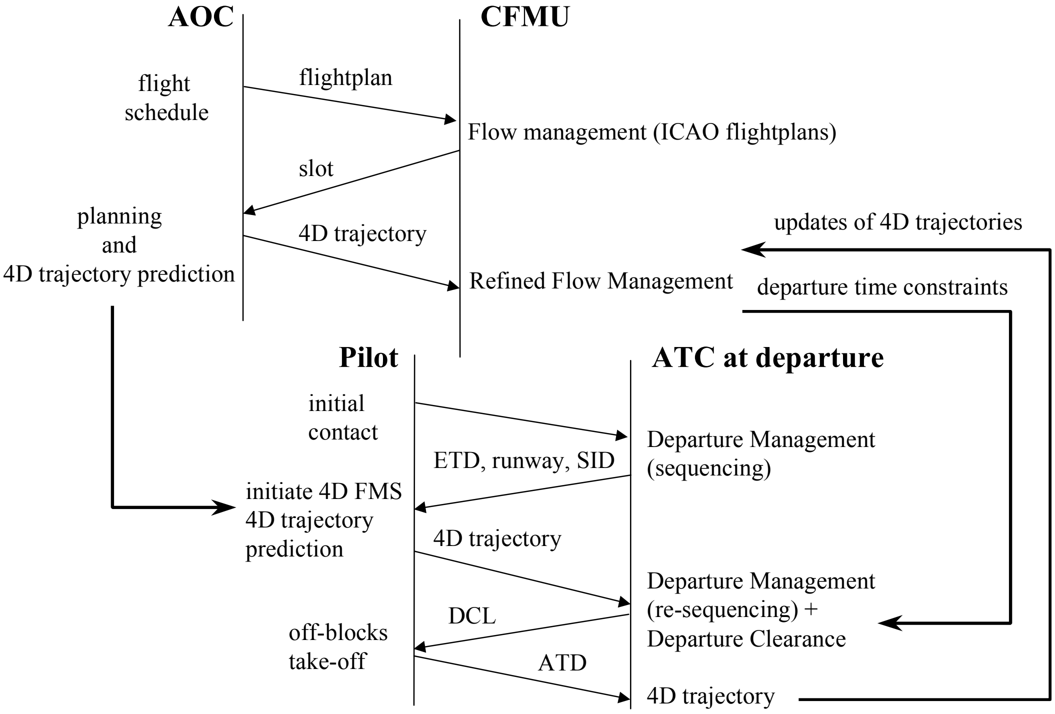

Figure 4 - High-level transaction scheme for the exchange of 4D planning information in the pre-departure and departure flight phases.

exchanges of 4D planning information are the departure time constraints, imposed by CFMU and communicated to ATC to regulate departures to congested destinations.

Furthermore, in-flight trajectory planning exchanges are required to maintain consistency between the 4D trajectory planning updated and flown by the aircraft on the one side, and the planning data used by CFMU to determine the need to regulate departures of not yet departed flights on the other side. The update frequency of trajectory planning information can be modest, i.e. one or two trajectory exchanges for crossing an FIR with a flight time of 10 to 20 minutes.

The implementation of these services will have consequences for the operations of the actors involved. Consequences for each of them will be discussed briefly now.

AOC is expected to have the capabilities to make a 4D prediction, i.e. to have available knowledge about models, performance data and weather information. Possibly, more than at present, AOC has to be able to select the appropriate routing and must therefore have access to the traffic forecast conditions. Predicted traffic conditions can be visualised mainly in 2D by presenting traffic flows through sectors and the associated levels of saturation of these flows. This requires (passive) interactive access to the flight data repository [Ref. 5].

Another consequence of 4D planning in an early stage is that possibly more information than at present has to be available about estimated ground movement timing, about planned use of runways and about associated use of SIDs and STARs. The use of SIDs and STARs can be considered initially as Operator’s preferences, but, of course, these preferences can be overruled by ATC’s decision making during Departure Management and Arrival Management.

The operations of CFMU affect all actors involved in the proposed concept. Refined Flow Management encompasses a new process in addition to traditional Tactical Flow Management. The amount of data involved in flow management with 4D predictions is a multiple of the amount used in traditional flow management with flightplan data, and the frequency of status updating and data exchange is considerably higher. Moreover, the processing of updates of flow regulation constraints will have to occur frequently and close to the actual departure times. Altogether, this will impose high response and throughput requirements on CFMU operations and the related data communications.

The Refined Flow Management process itself requires completeness and consistency with the applicable ICAO flightplans, but CFMU will not be responsible for the quality of predictions. The Airline Operators will be responsible and their commitment will be ensured by a commitment of ATC to an undisturbed and undelayed flight when flight execution proceeds in conformance with the 4D planning. The Airline Operators will have to monitor the timely updating of their planning.

ATC and the Airport, responsible for ATM operations and dependent activities around the airport, are facing higher precision requirements with respect to planning and execution of departure operations. In addition, they have to cope with the departure time constraints, imposed by CFMU. Altogether, there is a need to improve Departure Management with planning tools and with CDM applications in order to meet the required accuracy of the planning of departures [Ref. 2 and 3].
Another aspect in which ATC can support the working of the concept is the improvement of the planning regarding available runway configurations and the distribution of this planning information to involved actors in ATM. In this way AOCs are able to anticipate their preferences on planned use of Airport resources.
Operations of ATC en-route are hardly affected by the proposed concept, but ATC of the arrival sectors are expected to receive the ultimate benefits of the concept. Indeed, ATC at arrival may experience a smoothed supply of arrival traffic, and when optimised flow regulation proofs its added value, ATC will be able to raise the declared capacity.

The pilot has to cope with an extended 4D planning process that has to be tuned, when necessary, to keep track with a traditionally controlled process of guidance and control in co-ordination with ATC. Re-planning and sending planning updates will have to occur during the en-route flight phases as a new and extra activity, but this activity looses its need and relevance during the arrival flight phases.

7 Critical issues

It is necessary to look for critical aspects in an operational concept which deeply affects present-day operations and which affects also the co-ordinated operations of several actors at once. The aim is that the presented solution is appropriate to ensure integrity and consistency of operations, as well as sufficient robustness. A set of critical issues can be discussed briefly:

- *Adherence to natural or present roles and tasks*: New tasks should not exceed the natural interest of an actor and his scope of control. The latter means e.g. that strategic flight planning has to be accomplished by AOC, because they follow the operations of their fleet and are aware of dependencies exceeding the scope of the individual flight, while CFMU addresses the flow management with a European scope of control. In-flight updates of 4D planning information have to be exchanged between pilot and ATC, because they will be the direct users of such information.

- *Take into account mixed traffic situations with different levels of equipment with and without 4D functionality and D/L services*:
  - Executive control services are not affected by the presented concept, and an important reason is that the quality of executive control services is very sensitive for mixed mode operations with different services accomplished by different procedures. This is avoided because the executive ATCO is never directly involved in the use of exchanged information.
  - It is important for integrity reasons that the flight data repository will be complete and will also be up-to-date for non-equipped flights and for long-haul flights approaching the ECAC airspace. A simple and generic trajectory prediction model can be sufficient to allow e.g. the CFMU to complete missing information, albeit not with optimal modelling quality.
- *Integrity of the flight data repository and quality of predictions*:
  - Completeness can be ensured by generating trajectory predictions for missing flights.
  - Regular updating can be ensured by allowing ATC to update at least the predictions with actual FIR entry and FIR exit times, thus ensuring convergence in time also for non-equipped flights.
  - The quality of data is not very critical for the consistency of predictions. Some basic checks on plausibility may be required, but in general, there is no need to require consistency in applied modelling and data, as trajectories are not manipulated. The only ground-initiated action takes place in the pre-departure flight phase. It is a time shifting by CFMU, but this is not critical with respect to the applicable modelling.
- *Quality of Service*: The quality of the data is best served by giving priority to flights that meet their predicted arrival time and that deserve adequate service provision. A just-in-time arrival at the start of the Arrival Management process deserves a timely and undisturbed arrival at the gate. It is in the interest of the operators to take care of an optimal quality of their trajectory predictions and for timely updating them.
- *Workload*: The presented concept is not critical for extra workload. If workload is required it is due to extra activities in the pre-departure flight phase. However, there is no extra effort required during the en-route and arrival flight phases, and there is no effort required due to extra co-ordination. Most of the datalink exchanges and the communication with CFMU can be implemented as an interactive automation process without extra co-ordination between different actors.
- *Imposed time constraints*: Constraints are imposed only on not yet departed flights, because there is evidence for the benefits. In-flight penalties are avoided, because there is no unambiguous way to determine how to cope with an imposed delay. However, if applicable, problems for in-flight delays can be solved by voice communication between pilot and ATC and between pilot and AOC.

8 Conclusions

A successful way to generate 4D trajectory planning information and to exchange this information between the different actors of ATM is the basic functionality which determines the performance quality of all other applicable ATM planning and control processes. Detailed 4D planning information, that is used also to execute the flight, will help to improve the effectiveness of ATM and to provide air traffic services in a safe, efficient and expeditious way. In that sense, it is firmly believed that consistent planning information will contribute to enhanced control services, merely because it will be available, and because all actors will automatically focus their activities to meet the same planned targets.

The described concept avoids inducing involvement with any executive control activity, because that can be considered as a direct risk for bringing the concept into operation. Nevertheless, there is potential to extend the concept for a further integration between air and ground in the future. One option is to allow ATC to make use of the guidance capability of the 4D FMS to control part of the flight during the en-route and arrival flight phases. Another option is to allow pilot and AOC to re-plan their flight en-route when this is deemed necessary.

The described concept focuses on the strategic planning gate-to-gate and the involvement of a process of Refined Flow Management in 4D gate-to-gate flight planning, because this is the essential condition for being able to receive the major benefits from 4D flight planning. When there is ensured capacity for a timely and undisturbed arrival, and when this is ensured before departure, then the concept meets its main objective: to improve punctuality and efficiency.

9 Abbreviations

ACARS - Aircraft Communication Addressing and Reporting System
ADEXP - ATS Data Exchange Presentation
AFAS - Aircraft in the Future Air Traffic Management System
AOC - Aircraft Operations Centre
ATA - Actual Time of Arrival
ATD - Actual Time of Departure
ATN - Aeronautical Telecommunication Network
CARAT - Computer Aided Route Allocation
CFMU - Central Flow Management Unit
COTRAC - Common Trajectory Co-ordination Tool
EATMP - European ATM Programme
EFDAS - European logical Flight Data Server

ETD - Estimated Time of Departure
FIR - Flight Information Region
FMS - Flight Management System
ICAO - International Civil Aviation Organisation
ODIAC - Operational Development of Integrated Air/Ground Communications and surveillance
OSED - Operational Service and Environment Definition
PHARE - Programme for Harmonised ATM Research in Eurocontrol
RTA - Required Time of Arrival
RTD - Require Time of Departure
SID - Standard Instrument Departure

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