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MANAGEMENT RESEARCH
IN EUROCONTROL

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# Trajectory Negotiation in a Multi-sector Environment

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# FOREWORD

The Objective of the Programme for Harmonised ATM Research in EUROCONTROL (PHARE) is to:

*" organise co-ordinate and conduct on a collaborative basis, experiments and trials aiming at proving and demonstrating the feasibility and merits of a future air ground integrated air traffic management system in all phases of flight."*

The integration of the air and the ground elements of the ATM System involves amongst other things the use of datalink to pass trajectory information. This information is **not** passed as pseudo-R/T commands as with Controller Pilot Data Link Control (CPDLC). Instead there is an exchange of inter-process messages and data-objects between the airborne and ground based sub-systems that allow these sub-systems to inter-operate successfully as one integrated ATM System. The information exchanged ensures that both the air and the ground have one common view of the aircraft's intentions precisely described in terms of a 4 dimensional trajectory[1].

This document describes the methods that may be used for the 'negotiation' of trajectories between the air and the ground. The aircraft operator's requirement is taken to be the negotiation of the most optimal or preferred trajectory[2] whereas the responsibility of the 'ground' or ATC sub-system is to ensure the safe separation of the aircraft flying the trajectories and the optimal sequencing, from the system viewpoint, of those aircraft that are departures and arrivals.

There are many ways that trajectories may be negotiated between the air and ground. The methods put forward in this paper describe, in the main, those used by the PHARE project as developed for the third and final demonstration of the programme (PHARE Demonstration 3 or PD/3). However, there are aspects of trajectory negotiation that were not included in PD/3, such as linkages between ATC Centres. Where this is the case they are mentioned but it is noted that this was not an aspect used in PD/3.

This paper was originally written as an internal working paper to stimulate and form a basis for discussion on trajectory negotiation. The paper has been refined and now forms the basis for dissemination of methods of trajectory negotiation as an output from PHARE. For specific definition of aspects of the Trajectory Negotiation Applications the PHARE documents defining the Experimental FMS, the ground Negotiation Manager and the PHARE ATN should be read together with the PHARE Data Link Control Requirements Definitions (DLCRDs).

Within PHARE the terms '4D Contracted Trajectory' and 'Contract Tube' are used for the 4D trajectory agreed with the ground sub-systems and the deviation tube around that trajectory. The contract is not immutable and may be altered at any time. However, this usage carries unfortunate semantic links to other more inflexible methods of using 4D trajectories. In particular in the US the term '4D Contract' was used to denote a firm and unchangeable contract to fly a trajectory that was negotiated before flight. This semantic difference has produced an unintentional

1 More precisely the aircraft intentions are described by an object that will return the details of the 4 dimensional trajectory on request.
2 These are not necessarily the same.

language barrier to the understanding of the PHARE philosophy. In consequence, throughout this paper, the PHARE term ‘Contracted Trajectory’ has been replaced by the now more commonly accepted ‘agreed 4D intent’. The term ‘Contract Tube’ has been replaced by ‘allowed deviation tube’.

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# EXECUTIVE SUMMARY

In the PHARE Philosophy the airspace is a known trajectory environment. Those aircraft with AFMS generate their trajectories and datalink them to the ground. Other aircraft have trajectories generated for them in the ground system by 'proxy' software. Thus mixed capability aircraft may be catered for.

The procedures for flying and controlling with trajectories are extensions of existing procedures based on flight plans. They are more explicit and accurate but are intuitive. Trajectories are passed between the air and the ground as data objects and displayed and modified graphically. This ensures intuitive and easy understanding of the information with an increase in accuracy and reduction in potential errors. Control by trajectory should therefore be inherently safer than current control methods.

Once generated the trajectories are sequenced and any conflicts are automatically detected by ground based software. 'Problem solver' software tools are used by controllers to deconflict trajectories. The constraints put on the trajectories for deconfliction and sequencing are then datalinked to the aircraft which then regenerate trajectories that meet the constraints in the most optimum way. The new trajectory is then datalinked to the ground system. If the new trajectory meets the constraints the ground system issues the parameters of a deviation tube around the trajectory within which the aircraft is expected to fly[3]. If the crew accept the trajectory on the AFMS the aircraft will now fly that trajectory and the ground system receives an ACCEPT which indicates that the trajectory has been entered into the AFMS. The Ground system then also activates the trajectory. In this way both the air and the ground are consistent and are using the air generated trajectory. This process is called Trajectory Negotiation.

Trajectory Negotiation always follows a very similar sequence regardless of the stage of flight and may be instigated either by the air or by the ground. On the ground the current Tactical Controller normally monitors the aircraft progress along the trajectory previously planned by the sector Planning Controller. The next sector Planning Controller will at the same time be planning the aircraft, if necessary, through the next sector. A Multi-Sector Planner will be monitoring the workload of sectors 10 to 30 minutes in the future and Arrival Manager software will have sequenced the aircraft to an arrival runway and may resequence the approach if required. Negotiation Manager software in the ground system applies rules to ensure that the aircraft does not receive complex and conflicting negotiations from the ground systems.

Unlike current systems, in which there are repeated R/T contacts and 're-clearances' as the aircraft crosses sector boundaries, in a negotiated 'gate-to-gate' trajectory environment, it is possible for an aircraft to transit many sectors without any controller contact, intervention or negotiation. Consequently, in PHARE, due to concerns that the aircrew could lose awareness of the current control sector, a system message is issued from the ground system to the aircraft each time control of the aircraft is assumed by a Tactical Controller. The AHMI then displays the extent of that Tactical Controller's control of the flight as a different coloured highlight on the agreed trajectory.

[3] This deviation tube allows the aircraft to recover to the trajectory smoothly and gives a small margin for guidance errors.

The Ground System design should be based on a consistent distributed Flight Database that allows near real time transaction processing. The view of the system from the aircraft and from the control positions then remains the same regardless of sector or centre boundary crossing.

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# 1. INTRODUCTION

1.1 The handling of trajectory negotiation has to be consistent and simple to understand for both controllers and pilots. There should not be any extra work-load on controllers or aircrews neither should there be repeated re-negotiations from the ground or R/T advisories to data-link equipped aircraft modifying the negotiated trajectories. Previously, various complex rule based methods have been suggested for controller to pilot datalink, based to a large degree on automation of manual procedures. For example it has been suggested that the arrival management sequencing time constraints should be sent as text ‘advisory messages’ to the upstream sectors replicating an Arrival Planner telephoning the upstream sectors. Similarly, approaches to datalink rather than make an analysis of the functions required have merely tended to replicate R/T messages as data messages as in CPDLC.

1.2 If the intention of the current R/T process is analysed it can be seen that the controller is attempting to gain a complete understanding of the intentions of the aircraft in order to be able to deconflict that aircraft from other traffic. Due to the limitations on the information that can be passed accurately on R/T, the types of constraint are limited and indeed the process tends towards a restrictive control of the aircraft to limit the variables the controller has to visualise mentally. This process inevitably leads to a regime in which aircraft receive less than optimal routings. Removal of the limitations of the communications medium allows the controller the freedom to plan and deconflict further ahead whilst allowing the aircraft more freedom to fly closer to its preferred trajectory.

1.3 The approach taken in PHARE is to use an information link that transmits objects bearing little or no relation to current R/T. Both the pilot and controllers are presented with graphical representations of the trajectory being negotiated and may edit the trajectory graphically. This 'communication by pictures' is intuitive and can pass information rapidly, accurately and succinctly between the air and the ground. The concomitant reduction in errors and misunderstandings ensures that control by trajectory is inherently safer than control by R/T.

1.4 It is possible to simplify the entire Trajectory Negotiation process by taking advantage of extensions of the existing ATM system procedures, behaviour and rules. This has the advantage that the procedure will be consistent and follow familiar concepts. Most importantly the negotiation of trajectories will be unaffected from the controller point of view with no new ATC rules being required. However, to take full advantage of the new capabilities each operational rule or procedure should be examined for relevance in the known trajectory environment. Those procedures that were instituted due to the limitations of the previous system can be varied or discarded. When this is done not only can the controllers’ tasks be simplified, but considerable advantages can accrue to the operators of equipped aircraft and the environment.

1.5 <u>Definition of Terms</u>

Some important terms need to be defined:

<u>a. Trajectory</u>. The precise description of the flight path of an aircraft as a 4 dimensional continuum from take-off point on the departure runway (or from present position in flight) to touchdown on the arrival runway.

<u>b. Optimal Trajectory</u>. A trajectory which, if flown, would result in the most efficient use of the aircraft resources and minimised environmental impact.

c. Constraint. For the purposes of Trajectory Negotiation a Constraint is the altering of the optimal trajectory by the imposition by either the ground control system[4] or the pilot on the optimal trajectory for the aircraft of:

i. a geographic position to be overflown (2D Constraint);

ii. an altitude to reach/maintain at a 2D point (Altitude or 3D Constraint); or,

iii. a time to arrive at a 2D point (time or 4D Constraint).

d. Direct Route. A direct route is a straight line, or more correctly a great circle route, between 2 points. It has no concept of altitude nor of any ‘intelligence’ in the routing to avoid dense traffic areas for example. It can also be defined as a route that has been constrained in 2D to be a straight line between end points

e. Free Route. A Free Route is a route that has been chosen by the aircraft between 2 points. It may be the same as the direct route or it may be less direct. It may even follow known ground navigation aids. It can also be defined as a route with no 2D constraints imposed by the ground system.

f. User Preferred Trajectory (UPT). A UPT is a free route, defined by the Aircraft Operating Company (AOC), where the aircraft may also choose its own flight profile. This is likely to be an optimal trajectory modified to meet AOC business requirements external to the simple flying of the aircraft[5]. It may also be defined as route and profile between end points unconstrained by the ground system.

g. Control Responsibility. Control Responsibility is the responsibility of a Tactical Controller (TC) to ensure that an aircraft remains safely deconflicted, receives an expeditious and orderly route and profile. In the PHARE environment this entails monitoring the flight of the aircraft and ensuring that it follows the planned trajectory.

h. Planning Responsibility. Planning Responsibility is the responsibility of a Planning Controller (PC) to assess the trajectory of an aircraft through the controller’s sector, prior to its entry to the sector, and if necessary apply and negotiate constraints to the trajectory to ensure that the aircraft will be safely deconflicted, and will receive an expeditious and orderly route and profile through the sector[6].

i. Controlling Sector. The Controlling Sector is the sector of the TC who currently has the aircraft under control. This sector has R/T control of the aircraft and has Control Responsibility for it. Only one controller may have Control Responsibility for an aircraft.

j. Planning Sector. The Planning Sector is usually the sector subsequent to the Controlling Sector in the flight. The PC of the Planning Sector has Planning Responsibility for the aircraft. It is possible, although not ideal, to have 2 or more sectors with planning responsibility where an aircraft trajectory has a short transit time in a sector.

k. Multi-Sector Planning Area. A Multi-Sector Planning Area (MSA) is a combination of adjacent sectors usually organised around traffic flows. A Multi-Sector Planner controller (MSP) has authority to modify trajectories in the MSA with the intention of reducing the complexity of the traffic and the traffic loading on each of the Planning Sectors within the MSA. The MSP normally plans between 30 minutes and 10 minutes in advance of a flight penetrating the MSA. The MSP does not have direct Planning

4 A constraint may be inserted by procedures such as SID or STAR, or by Letter-Of-Agreement as well as at flight time by a controller or pilot. In all cases imposition of a constraint deoptimises the optimal trajectory. Therefore each constraint should be seen as having an adverse cost impact.

5 These business requirements are currently unknown to the controller and may include such things as expedition to meet complex timetabling for hub operations, airport stand (un)availability or even special handling for ‘high value’ passengers.

6 There may be instances, due to uncertainty of some conflicting trajectories (for example those of departing aircraft not yet airborne), in which the final deconfliction decisions have to be taken by the Tactical Controller.

Authority and negotiation with the aircraft is indirect with MSP constraints being added to the next PC negotiation.

l. Agreed 4D Intent. The 4D trajectory that an aircraft has agreed by negotiation with the Planning Controller of the Planning Sector or previous Sector Planning Controllers is the ‘agreed 4D intent’. The trajectory will be from the aircraft departure point or current position to its destination. The implications of this agreement are:

i. Aircraft. The aircraft SHALL follow the agreed trajectory to its destination unless a change to the intent is negotiated and agreed, or the aircraft has an emergency that requires immediate deviation from the trajectory, or there is a tactical intervention by R/T from the Tactical Controller. In either case a new 4D intent should be negotiated as soon as possible.

ii. Tactical Controller (TC). The TC with Control Responsibility SHALL ensure that the agreed 4D intent remains conflict free in the TC’s sector. Re-negotiating the trajectory or intervening using R/T only for deconfliction.

iii. Planning Controller (PC). The PC with Planning Responsibility is the planning controller in the sector after the current controlling sector[7]. The PC SHALL assess the agreed 4D intent for conflicts in the sector(s) after the Controlling Sector, if necessary re-negotiating a trajectory with the aircraft that ensures, as a minimum, that it is conflict free in the PC's sector. This planning SHALL be completed as early as possible before the aircraft leaves the current Controlling Sector for the PC's sector.

iv. Loss of Contact Procedures. Should the aircraft lose contact with the ground for whatever reason it SHALL continue to fly the agreed 4D intent to destination (as in (i) above ) and the controllers for the sectors penetrated SHALL ensure that other aircraft are de-conflicted from the 4D intent. (This is a more accurate version of current ICAO Loss of R/T procedures.)

[7] It is normally the case that there is only one PC with Planning Authority. However, when a flight passes briefly through a sector it may be that 2 or more PCs have Planning Authority. Normally such occurrences would result in one or more sectors being 'skipped' by controller-controller coordination and the Planning Authority being given to a single PC.

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## 2. PURPOSE OF PAPER

2.1 The purpose of this paper is to define and elaborate the datalink based trajectory negotiation procedures in a multi-sector, multi-centre environment for both the air and the ground participants in an integrated ATM environment.

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## 3. TRAJECTORY GENERATION AND MANGEMENT OF CONSTRAINTS

3.1 In the PHARE airspace concept **all** aircraft have trajectories generated by the ATM System. Those aircraft with AFMS will generate their own trajectory and datalink it to the ground flight database; those without an AFMS will have a trajectory generated by a ground sub-system acting as their 'proxy'[8]. An aircraft flies its 'Active' trajectory which is the 4D Intent agreed with the ground [See section 6 below] guided either by its AFMS or by the controller issuing R/T commands. There may be other trajectories or 'Alternate' trajectories generated either by the aircraft or the ground system for modelling purposes or negotiation.

3.2 For any aircraft there will be a current Controlling Sector, a ‘next sector’ or Planning Sector planning the aircraft, a subsequent Multi-Sector 'area' and an ‘arrival manager’ TMA Sector generating sequencing and time constraints. It is undesirable and confusing for both aircrew and controllers for these controllers to independently start negotiations with an aircraft. An aircraft crew set up a dialogue with ‘the ground’ as it would be unreasonable to expect the aircraft to address negotiation to particular sectors[9]. For the controller there may be many aircraft to negotiate with. The TC will negotiate solely with aircraft currently under control in the sector. The Sector PC will negotiate solely[10] with aircraft in the preceding sector. The MSP will define transit plans solely for aircraft more than 10 minutes flight from the MSP boundary. (Note: the MSP can **not** have either control or planning responsibility for an aircraft.)

3.3 The term ‘Negotiate’ needs to be defined. A controller wishing to modify the trajectory of an aircraft will first access the trajectory and its constraints in the Flight DataBase (FDB). The trajectory details are accessed by selecting the aircraft, or its trajectory, on a graphical Plan View Display (PVD). The trajectory is then displayed graphically in both plan and elevation views allowing the controller to see the constraints and their effect. The constraints in the FDB will be all the currently input constraints. The controller can then modify the trajectory by adding, deleting or altering constraints within the sector(s) in which the controller is allowed to modify trajectories this modelling creates alternate trajectories. The controller will then use the system to transmit all the trajectory *constraints* to the aircraft, not the ground modelled alternate trajectory. The aircraft Advanced Flight Management System (AFMS)[11] will then generate an optimal trajectory for the entire flight from the aircraft current position, as modified by the uplinked constraints, and display the generated trajectory in plan view or elevation view to the pilot. The pilot may accept the trajectory or modify it and counter propose a trajectory to the controller. Normally it is only the controller with Planning Authority[12] who would carry out the negotiation and Planning Authority is assigned when the aircraft is within 10 minutes of the sector boundary. Negotiation is carried out through the Negotiation Manager software tool[13] of the TC with Control Responsibility.

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8 Aircraft with 4D FMS and datalink do have advantages over lesser equipped aircraft, but there is no requirement for all aircraft to upgrade avionics or to use 4D FMS or datalink.

9 In a Flexible Use Airspace environment keeping track of sector boundaries should not be an issue for aircrew.

10 It may be that a PC negotiates for some reason with an aircraft actually within his sector. However, a PC negotiating with an aircraft in the sector can be considered to be acting on behalf of the TC.

11 The PHARE AFMS is known as the Experimental FMS (EFMS)

12 It is possible that the sector design and the aircraft trajectory give a brief transit time in a particular sector. In this case, use of a simplistic 10 minute rule would lead to overlapping planning authority. In PHARE this was allowed with co-ordination and mediation of the negotiation by the software tool called the Negotiation Manager.

13 This may be a 'logical' Negotiation Manager. The system architecture may consist of one or many negotiation managers.

3.4 Negotiations are controlled by a ground sub-system software tool the Negotiation Manager, which arbitrates between controllers initiating negotiations with aircraft. It ensures that urgent interventions from Tactical Controllers pre-empt less urgent Planning Controller negotiations and long term Multi-Sector Planning . The software enforces the correct dialogue protocols and alerts controllers to co-ordination requirements between sectors. To reduce controller workload, if a downlinked trajectory meets the controller's uplinked constraints, or, in the case of an unsolicited downlink, the trajectory has not been significantly changed, and there is no new conflict caused in the current or subsequent sectors, then the Negotiation Manager software will accept the downlinked trajectory on the controller's behalf.

# 4. MESSAGE AND NEGOTIATION SEQUENCE DETAIL

4.1 During any flight the actions and messages sequences tabulated below may be sent and received.

| Time | Originator | Recipient | Action or Message Sequence | Result |
|---|---|---|---|---|
| 2 hours or more before Take-off [14] | Aircraft operating Company (AoC) | CFMU | File Flight Plan | 'Corrected' Flight Plan returned and transmitted, Slot(s) allocated to flight |
| 30 to 40 minutes prior to Take-off[14] | CFMU | ATC Flight Data processing Systems | Initial Flight Plan Processing ‘trigger’ | Ground Systems produce nominal flight trajectory |
| 30 to 40 minutes prior to Take-off | ATC Flight Data processing Systems | AoC | Departure Manager and Arrival Manager assign runway | Nominal Sequence and SID/STAR allocated. |
| 20 minutes prior to Take-off | Aircraft AFMS | ATC Flight Data processing Systems | Start-up Log on to Context Management | ATC Flight Data processing Systems Initiate Meteo Uplink to Aircraft |
| 20 minutes prior to Take-off[14] | Aircraft AFMS | ATC Flight Data processing Systems - for Departure PC | Downlink of User Preferred Trajectory (UPT) based on SID/STAR and Meteo | ATC Evaluate UPT and agree 4D Intent following negotiation if required. |
| 5 to 20 minutes prior to take-off (before push back) | Aircraft AFMS | ATC Flight Data processing Systems - for Departure PC and Ground Controller | Push-Back / Off-Blocks re-negotiate UPT if required | Revised 4D Intent negotiated with departure PC, precise departure time allocated, slot opened in arrival stream by Arrival and Departure Management software, if mixed-mode runway |
| At Take-Off | Aircraft AFMS | ATC Flight Data processing Systems | DAP on state change to ‘airborne’ re-negotiate UPT if required | Revised 4D Intent negotiated - With Departure TC and/or ETMA PC |
| At any time when aircraft airborne | PC or TC | Aircraft AFMS | Deconfliction - constraints to edit UPT | Revised 4D Intent negotiated |
| At any time when aircraft airborne | Aircraft AFMS | PC or TC | Request from pilot for re-route | Revised 4D Intent negotiated |

[14] Or before entry into the ‘known trajectory airspace’.

4.2 Although Trajectory Negotiation follows a standard sequence there may be reasons either in the aircraft or on the ground for truncating the sequence or changing the initiator of the negotiation. There are 4 potential variants of the Trajectory Negotiation sequence. These are:

a. Standard Negotiation.
b. Pre-empted Standard Negotiation
c. Formalised Clearance
d. Missed Approach Negotiation.

4.3 <u>Standard Negotiation</u>

This is the standard Trajectory Negotiation Sequence. All the other Trajectory Negotiation Sequences are variants of this standard.

| Seq.# | Operation |
|---|---|
| 1. | Aircraft downlinks 4D UPT to Ground |
| 2. | Ground checks trajectory and adds constraints for deconfliction or arrival sequencing if required. If no constraints required go-to seq# 7. |
| 3. | Ground uplinks edit constraints to aircraft - this may be the full constraint list if required. |
| 4. | Aircraft inserts ground constraints and regenerates UPT to meet the constraints if possible. New UPT displayed to pilot for approval. |
| 5. | If pilot approves UPT downlinked to Ground with indication of non-compliance with constraints where necessary. If pilot does not approve - amend UPT - go-to seq# 1. |
| 6. | Ground checks downlinked trajectory. If conflicts go-to seq#2. |
| 7. | Ground uplinks Deviation Tube parameters or indication to use ‘standard’ parameters. |
| 8. | Trajectory displayed to pilot for approval with indication of ground ‘clearance’. |
| 9. | Pilot Activates Trajectory in FMS which also issues ‘4D Intent ACCEPT’ to the Ground. |
| 10. | Ground enters Trajectory of 4D Intent into FDB on receipt of 4D Intent ACCEPT. |

## 4.4 Pre-empted Standard Negotiation

An aircraft may leave the Agreed 4D Intent trajectory for reasons such as an R/T direction from the TC or for exceptions such as to avoid weather or perhaps TCAS RA. In these cases the aircraft has already altered the flown trajectory and negotiation has been pre-empted. However, it is important to ensure that the actual trajectory being flown is entered into the Ground FDB as otherwise no deconfliction or replanning can be carried out.

| Seq.# | Operation |
|---|---|
| 1. | Pilot Activates Trajectory causing AFMS to downlink 4D UPT to Ground with indicator showing ‘pre-emption’ |
| 2. | Ground enters Trajectory into FDB, since this is the trajectory the aircraft is actually flying. |
| 3. | Ground checks trajectory and adds constraints for deconfliction if required. If no constraints required go-to seq# 8. |
| 4. | Ground uplinks edit constraints to aircraft - this may be the full constraint list if required. |
| 5. | Aircraft inserts ground constraints and regenerates UPT to meet the constraints if possible. |
| 6. | UPT downlinked to Ground with indication of non-compliance with constraints where necessary. |
| 7. | Ground checks downlinked trajectory. If conflicts go-to seq#2. |
| 8. | Ground uplinks Deviation Tube parameters or indication to use ‘standard’ parameters. |
| 9. | Trajectory displayed to pilot for approval with indication of ground ‘clearance’. |
| 10. | Pilot Activates Trajectory causing AFMS ‘4D Intent ACCEPT’ to be issued to the Ground. |
| 11. | Ground enters Agreed 4D Intent into FDB. |

### 4.5 Formalised Clearance

The TC, or, in exceptional circumstances, the PC may wish to direct an aircraft with no delay or with no negotiation. In this case a Formalised Clearance would be issued. In both cases an Agreed 4D Intent already exists in the FDB and in the AFMS.

| Seq.# | Operation |
|---|---|
| 1. | Ground uplinks edit constraints to aircraft - this may be the full constraint list if required - with 'Formalised Clearance Flag' |
| 2. | Aircraft inserts ground constraints and regenerates Trajectory to meet the constraints as closely as possible. |
| 3. | Aircraft downlinks 4D intent trajectory to the ground. |
| 4. | Pilot Activates Trajectory causing AFMS '4D Intent ACCEPT' to be issued to the Ground. |
| 5. | Aircraft flies within standard Deviation Tube parameters. |

### 4.6 Missed Approach Negotiation

In the case of a Missed Approach Procedure (MAP) the aircraft will fly the procedure and not delay while a Trajectory is negotiated. The MAP for each approach is, in any case, a published procedure. The aircraft can also be assumed to require re-sequencing for another approach. The sequence is very similar to the Pre-emptive Trajectory Negotiation.

| Seq.# | Operation |
|---|---|
| 1. | Pilot Activates Missed Approach causing AFMS to downlink 4D Missed Approach Trajectory to Ground with indicator showing 'Missed Approach' |
| 2 | Ground enters Trajectory into FDB, since this is the trajectory the aircraft is actually flying. |
| 3. | Ground checks trajectory and adds constraints for deconfliction if required and for arrival sequencing. If no constraints required go-to seq# 6. |
| 4. | Ground uplinks edit constraints to aircraft - this may be the full constraint list if required. |
| 5. | Aircraft inserts ground constraints and regenerates UPT to meet the constraints if possible. |
| 6. | UPT downlinked to Ground with indication of non-compliance with constraints where necessary. |
| 7. | Ground checks downlinked trajectory. If conflicts go-to seq#2. |
| 8. | Ground uplinks Deviation Tube parameters or indication to use 'standard' parameters. |
| 9. | Trajectory displayed to pilot for approval with indication of ground 'clearance'. |
| 10. | Pilot Activates Trajectory causing AFMS '4D Intent ACCEPT' to be issued to the Ground. |
| 11. | Ground enters Agreed 4D Intent into FDB. |

## 5. SECTOR VIEW OF NEGOTIATION

5.1 At any one time the following control positions may have a requirement to negotiate trajectory constraints with an aircraft:

a. The Tactical Controller - with Control Responsibility.
b. The Planning Controller - with Planning Responsibility.

5.2 At any one time the following control positions may have a requirement to have their trajectory constraints included in negotiations with an aircraft:

a. The Multi-Sector Planner of Down-Stream Multi-Sector.
b. The Arrival Manager and Arrival Sector Planner.

5.3 <u>Tactical controller - with Control Responsibility</u>

5.3.1 TC directions to the aircraft will normally require immediate action. Therefore, any Trajectory Negotiation by the TC will be in the form of a Formalised Clearance unless sufficient time exists for a full negotiation sequence. The Formalised Clearance could be indicated by the AHMI in a similar way to a TCAS RA. Emergency control action would still be taken using R/T but would be followed with either Pre-empted trajectory negotiation from the aircraft or by negotiation from the TC using a trajectory editing tool. If the TC starts a dialogue with an aircraft that is already in negotiation with the planner controller with Planning Responsibility then the planner controller dialogue will be aborted (See below). If a TC carries out a negotiation, all the current constraints in and from the down-stream sectors will be added to the negotiation. This ensures that the aircraft trajectory will be the optimum to meet *all* the flight constraints and that all TC actions are ‘closed loop’ with a fully Agreed 4D Intent as the outcome. TC negotiations are carried out through the Negotiation Manager of the TC’s sector.

5.4 <u>Planning Controller with Planning Responsibility</u>

5.4.1 The PC of the sector following the Current Control Sector is expected to start planning a flight when it is within 10 minutes of the sector boundary. There is no need to set hard rules on the time of planning. It is important, however, that sequential planning is adhered to wherever possible. That is, a planner should not start deconflicting an aircraft trajectory until the previous planner has finished. Any modification of the aircraft trajectory should be limited to within the PC’s sector and subsequent sectors. (A PC would be expected to avoid causing conflicts within the boundary area or ‘Area of Common Interest’ in the subsequent sector.) If conflicts are caused in the subsequent sector within a parameter time from the boundary, the Negotiation Manager software would show that controller-controller co-ordination was required. Planning responsibility is not explicitly ‘handed over’ the Negotiation Manager software mediates between planners.

5.4.2 If it is necessary to modify a flight such that entry conditions into the PC’s sector are changed beyond certain acceptable parameters then that has to be co-ordinated with the preceding sector TC who would be expected to negotiate this trajectory modification. This is current controller practice. When the PC carries out a negotiation all the current constraints in the preceding and down-stream sectors will be added to the negotiation. This ensures that the aircraft trajectory is the optimum to meet all the flight constraints. All PC negotiations are carried out through the Negotiation Manager of the sector of the TC with Control Responsibility - the Current Controlling Sector. However, it should be emphasised that there is no need for the PC to take any action on every trajectory. Thus, an aircraft without conflicts during a flight should not have any re-negotiations for the entire flight, apart perhaps from the addition of the Arrival Manager sequencing constraints.

## 5.5 Multi-Sector Planner of Down-Stream Multi-Sector

5.5.1 The task of the MSP is to ensure that the workload of the sectors in the MSP area is within reasonable limits[15]. The Multi-Sector Planner (MSP) will start assessing flights when they are between 40 and 10 minutes from the multi-sector boundary and will normally take action on groups of flights[16]. The MSP should, if possible, not alter the trajectory of aircraft in preceding multi-sectors. If such action was required then it would be done by co-ordination[17]. However, as the flights are still more than 10 minutes away from the first sector in the MSP's multi-sector area the planner controller of that first sector would be unaware of an alteration made by the MSP or from a down-stream MSP. Therefore the MSPs will normally only need to negotiate changes with preceding sectors if the flight trajectory is being altered in the flight's current sector or the sector with Planning Responsibility. The same parameterised rules apply for trajectory changes and negotiation [See 7.4.2 above]. Any trajectory constraints produced by the MSP will be stored in the FDB and will be included in the next negotiation for that aircraft. Note that an MSP never engages in direct trajectory negotiation. MSP constraints exist to achieve workload balancing between sectors or to reduce the complexity of traffic patterns rather than explicit deconfliction of trajectories, although this may be their effect. The sector planner may simply over-ride an MSP constraint by editing or deleting it. The MSP does not require notification that this has happened.

5.5.2 The MSP will be acting so far in advance of present time that there are limitations on the constraints that the MSP can apply. This limitation avoids redundant constraints being applied to flights. If the MSP uses simple modifications then there is less probability that modifications subsequently introduced by PCs will interfere. Therefore, if an MSP wishes to impose a level constraint it should be done with caution. The MSP should not apply time constraints as these cannot be applied to groups of aircraft and can rapidly be superseded by minor control actions from sectors or by departure delays and arrival sequencing. Thus, the trajectory editing of the MSP should ideally be limited to imposition of 3D constraints to transit plans to reduce the complexity in the MSP sectors.

## 5.6 Departure Manager Sequencing

5.6.1 The Departure Manager software will receive a new trajectory as soon as it is in the FDB. The Departure Manager software will then check that the departure is from 'its' airport and if so will sequence the departure of the flight based on the initial trajectory time that has originated from the flight plan. When the aircraft is ready for push back, the Departure Manager software will identify a suitable slot at least normal taxi time from the gate to the holding point in the future that separates the departing aircraft trajectories from themselves and from the arriving aircraft. If the runway is mixed mode the Departure Manager software will request the Arrival Manager software to insert a departure slot for the aircraft again sufficient time in the future for taxi to the holding point and also for insertion of a slot in the arrival stream18. The Departure Manager software will pass the precise tack-off time to the ground controller and to the aircraft as a time constraint. The aircraft will then regenerate a trajectory based on the allocated departure time and datalink it to the ground.

5.6.2 The Departure PC is responsible for overseeing the sequencing produced by the Departure Manager software. If necessary varying the sequencing or the runway and

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[15] Note that the MSP assesses workload *not* number of aircraft. A sector may have a low workload with many aircraft in stream crossing it whilst another may be overloaded with 3 or 4 aircraft with complex and conflicting requirements.

[16] Due to limitations in PD/3 the MSP only edited flights singly.

[17] Where airspace design requires 'Buffer Areas' or 'Areas of Common Interest' may be agreed where such co-ordination is deemed unnecessary.

[18] The time in the future will normally mean that the call for push back will result in a departure slot 10 minutes or more in the future. But that slot is precise and the aircraft is expected to be ready at the holding point at the slot time. This may be a matter for Advanced Ground Control Systems.

SID choices. If the Departure Manager software is unable to deconflict departing trajectories with other traffic, the Departure PC will carry out deconfliction or alter the suggested departure parameters to clear the conflict. In doing this the Departure PC will work closely with the Arrival PC (see below). The Departure PC, in co-ordination with the Arrival PC may alter take off rates and thus in multi-mode runway operation will influence arrival rates.

### 5.7 Arrival Manager Sequencing

5.7.1 The Arrival Manager software will receive a new trajectory as soon as it is in the FDB. The Arrival Manager software will check that the flight is to 'its' airport and if so it will sequence the flight. The ground Trajectory Predictor modelling the flight will use all the existing constraints on the trajectory and include any new constraints inserted by the Arrival Manager software to meet the sequencing requirements. The output of the sequencing will be new trajectory constraints that will be stored in the FDB and will be included in the next negotiation for that aircraft. Each time the aircraft trajectory is updated throughout its flight the arrival sequence is re-examined and modified as necessary causing new time constraints to be applied. If the Arrival Manager Sequenced Time of Arrival (STA) and ETA are more than a parameter separated then the Arrival Manager constraints are immediately negotiated. This ensures that the aircraft trajectory is modified early to take account of changes in arrival sequence. However, it limits the repeated re-negotiation of minor changes. At a parameter time before Top of Descent the arrival sequence is frozen and only action by the Arrival Sector Planner can instigate a sequence change. As soon as the aircraft is within the TMA Arrival Manager constraints are handled as formalised clearances.

5.7.2 The Arrival PC is responsible for overseeing the sequencing, runway choices and runway loadings produced by the Arrival Manager software. If necessary varying the sequencing or the runway and STAR choices. In the case of conflicts within the Terminal Area the Arrival PC will carry out deconfliction or alter the suggested sequencing or STAR to clear the conflict. In doing this the Arrival PC will work closely with the Departure PC.

### 5.8 Negotiation Sequence

The negotiation sequence can be looked at from the viewpoint of the PC with Planning Responsibility. Normally, it is the PC with Planning Responsibility who would be using datalink to negotiate with the aircraft. When the PC starts modelling the aircraft trajectory the constraints from other sectors, MSP or Arrival Manager, will be included and therefore will also be sent to the aircraft when the trajectory is negotiated. To ensure that MSP or Arrival Manager constraints are negotiated even if none of the PCs take action, the Negotiation Manager software monitors them and forces a negotiation in sufficient time prior to the MSP or ETMA sectors. It therefore follows that no action to initiate negotiation need be taken by downstream MSP or Arrival controllers as the planning controller with Planning Responsibility will automatically include all constraints from them in any negotiation.

### 5.9 GHMI Indications

5.9.1 A planner may decide that there is no reason for any negotiation with an aircraft. However, whenever there are un-negotiated constraints on a trajectory the Negotiation Manager of the PC should raise a GHMI event to flag the flight data block of the flight with an indication that there is an outstanding negotiation for the flight. The controller would be able to use the GHMI to view the effect of the proposed change and then the negotiation would be carried out in the normal way. The same indication of negotiation requirement could be used to alert the TC with Control Responsibility if there are new constraints required on an aircraft trajectory in the current sector. A similar indication would be required to show the TC/PC that the aircraft had downlinked a new trajectory that changed the trajectory outside the automatic acceptance parameters or caused a conflict and therefore started a negotiation sequence. A GHMI flag indicating un-negotiated constraints or changes will be displayed to the PC with Planning Authority. The GHMI would also indicate the current progress of negotiation such as uplink or downlink in progress.

5.10 Aircraft Viewpoint

5.10.1 From the aircraft viewpoint there is ***always*** an Agreed 4D Intent. The Agreed 4D Intent held by the aircraft is also held in the ground ATM system. For non-datalink equipped aircraft, the Agreed 4D Intent is still in place, but it is only held in the ground ATM system. The initially Agreed 4D Intent is negotiated before pushback and taxi and the trajectory is only 'killed' when the aircraft lands at the destination. The Agreed 4D Intent will be all the way to touchdown (or system boundary). It is *expected* that the 4D Intent will need to be re-negotiated, especially on events such as pushback clearance and possibly immediately after take-off, when the times of the trajectory will or may alter from those previously negotiated. However, when the aircraft is airborne, there is no need to re-negotiate before each sector boundary. Renegotiation should only occur if there are conflicts The number of conflicts has been shown to be considerably reduced in an environment with aircraft flying user preferred trajectories [19].

5.10.2 It is the ground ATC system's responsibility to avoid constraining Agreed 4D Intents unless really necessary as every constraint added to the UPT will not only increase the airline costs and increase route complexity for both the aircrew and the controllers, but also increase their workloads. The use of whole flight trajectories should give a coherent view that allows the AFMS to optimise the flight profile avoiding, for example, expedition followed by delays. More importantly, should anything go wrong a 'whole flight' Agreed 4D Intent exists which the aircraft can follow with safety as the ground would know the Agreed 4D Intent that is being flown. It also follows that there is no requirement for specific 'clearance' at sector boundaries as the whole route agreed 4D Intent exists and the planner of the sector being entered has already agreed the 4D Intent with the aircraft. However, as noted above, to ensure that the aircraft keeps a picture of the current status of control, it will receive 2 ground system originated messages to be displayed to the pilot. Firstly, there will be a 'Frequency Change' message providing the next sector R/T frequency that will be issued when the 'giving' TC indicates on the GHMI that handover should commence, or automatically when the Negotiation Manager software initiates silent handover. When the 'receiving' TC 'Assumes' the aircraft, another system message is issued from the ground system to the aircraft. The AHMI then displays the extent of the new Tactical Controller's control of the flight as a different coloured highlight on the agreed trajectory. The routine R/T check-in and check-off should not be required[20].

5.10.3 The aircrew of an aircraft that is flying on or close to its UPT is unlikely to require to change its trajectory by any great amount as each change is likely to impact the operating cost. However, the crew may downlink a new trajectory proposal at any time. If the change is within the parameters set to indicate changes of importance to the current TC or the planning PC and if the proposed trajectory is not in conflict with another trajectory within the current and next sector, then the system will automatically accept the proposal. In other cases the ground system will alert the affected controller(s) for their acceptance or counter proposal.

[19] This was modelled as part of a PD/1+ exercise when conflicts reduced by more than 50%.

[20] This is a matter of some debate. The routine check-in/check-out at each sector boundary can block a channel and be a considerable workload. At the same time there will always be a wish to confirm that the R/T channel is working as it is the system of last resort. It is probable that the use of digital radio running over the datalink may obviate the need for these checks as the system will ensure the connection is continually good.

5.10.4 The Airborne HMI (AHMI) of the AFMS shows the crew the current trajectory in both plan and elevation views. When the ground sends constraints to the aircraft the AHMI will display the trajectory that it generated to meet those constraints to the pilot. The pilot may edit the trajectory before the downlink. All the detail of the trajectory including ownership of the constraints is available to the AHMI. If the pilot imposes a constraint then that is shown to the controller by the GHMI.

## 5.11 Impact on Controller Roles

5.11.1 It is not the intention of this paper to enlarge on the impact on controller roles of a datalinked integration of air and ground sub-systems into a single ATM System. However, what is clear is that the PC will be planning ahead of the aircraft penetration of the sector prompted by Conflict Probe software and using a constraint editor to modify trajectories. Therefore, it is conceivable that the PC task could be carried out without live radar using only a trajectory display. Ideally, all conflicts within a sector will be solved by the sector PC although there may be occasions due to uncertainty perhaps of departures that the TC may need to take action. In most instances, the TC task will become that of monitoring trajectories and issuing system advisories to guide non-equipped aircraft along their trajectories and intervention for any exception handling. The TC will be aided in the task by monitoring software that will alert to any deviations from the planned trajectories.

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## 6. SYSTEM SUPPORT

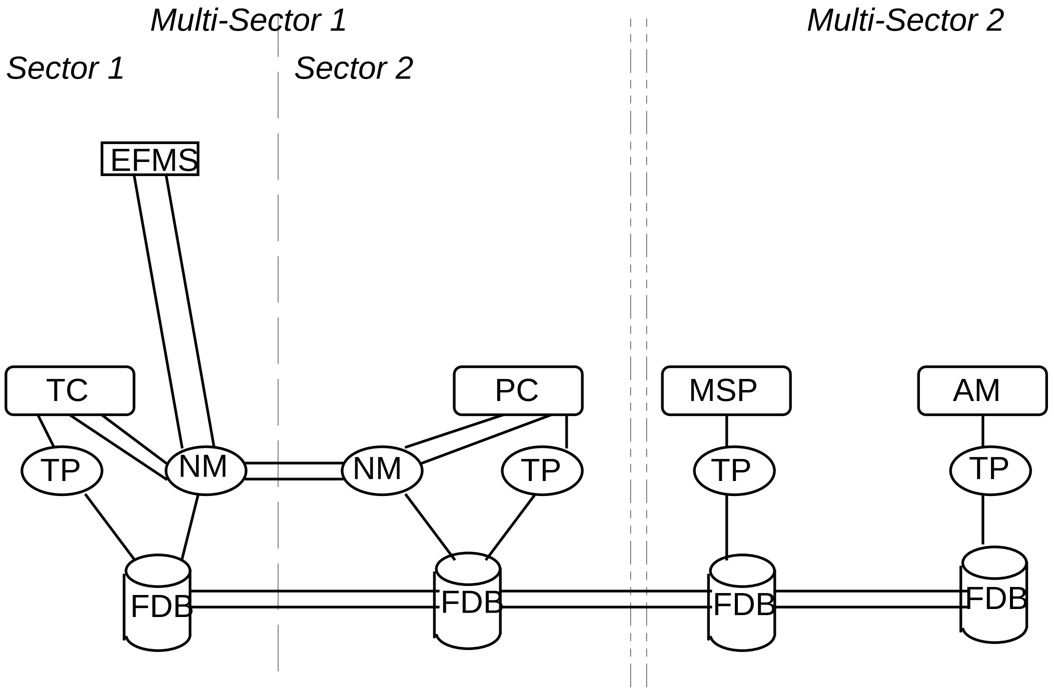


Figure 1

Note: EFMS = Experimental FMS; TP = Trajectory Predictor software; NM = Negotiation Manager software; FDB = Flight Data Base; AM = Arrival Manager software. This diagram shows a 'logical' architecture.

### 6.1 ATM System Architecture

The constraints in the FDB are provided by the controllers using the editing facilities of the Trajectory Predictor usually via another tool such as the Problem Solver or the Arrival Manager. The FDBs at every centre are interlinked to ensure that a consistent distributed database is retained. The PC with Planning Responsibility in Sector 2 communicates with the aircraft through the Negotiation Manager in Sector 1, which controls the dialogue via the Negotiation Manager in Sector 2. Should the TC in Sector 1 wish to negotiate the Negotiation Manager in Sector 1 is used and any negotiation from the PC in Sector 2 is aborted. Nevertheless, the constraints from Sector 2 would be picked up by the TC's negotiation. Use of the architecture above ensures that the centre boundaries are transparent to the controllers.[21]

### 6.2 Ground HMI

The Ground HMI (GHMI) shall flag the radar display labels (flight data blocks) in some way to show that there were outstanding constraints to be negotiated, that negotiation was in progress and also the status of the negotiation process. The GHMI indications should normally only be shown to the Planning Controller with Planning Responsibility unless the constraints affect the flight within the current sector. The flag should be raised as a result of an event from the Negotiation Manager of the TC with Control Responsibility and/or the PC with Planning Responsibility. If the MSP has edited the trajectory with a constraint and the constraint is not negotiated within a parameter time,

[21] PHARE PD/3 was not run as an interlinked, multi-centre demonstration. Therefore, this architecture was not trialled.

the Negotiation Manager will initiate a negotiation. If an MSP negotiation would cause a significant change of trajectory within the current or planning sector then the Negotiation Manager software shall instigate co-ordination between the MSP and the affected sector(s).

### 6.3 Flight DataBase

The Trajectory stored in the FDB should hold information indicating the origin of any constraints. Thus, it would be possible for a controller to see which controller imposed a constraint or if the constraint was a pilot imposed constraint. The FDB at each centre will need to ensure that trajectories and constraints are correctly propagated to the FDBs of other centres[22]. In this way, each 'what if' modelling and every negotiation would always be based on the correct data. This requirement should be met by the system(s) at each centre transparently to the Trajectory Predictor and the Negotiation Manager. The temporal differences between the operation of the MSP, PCs and TCs should mean that locking requirements on the FDB are minimised.

[22] The FDB should be considered as a single distributed FDB. Secure distributed databases are common practice in many other fields of Information Systems.

## 7. SUMMARY

7.1 An aircraft is always under the control of one sector while being planned by the subsequent sector. The Control and Planning Responsibilities are simply handed on as the flight progresses. Agreed 4D Intents exist for every aircraft, are always for the whole flight, and include all the constraints in the FDB. The Trajectory Negotiation with an aircraft follows a standard form that may be truncated for certain exception handling. Constraints from MSPs and Arrival Managers are not negotiated directly but are included in the next negotiation for the flight or automatically negotiated by the Negotiation Manager software.

7.2 By using the operation of the system and current control rules, it is possible to avoid complexities in the trajectory negotiation process such as passing textual advisories between sectors. By using all the downstream constraints each time there is a negotiation, the trajectory negotiation process will automatically provide the optimum trajectory for the constraint set that exists. This is done without loading controllers with extra procedures and messages. It also provides the Aircraft with a consistent approach to negotiation and a safe, whole flight 4D Intent.

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# Glossary{tc "Glossary" \f C \l 1}

| | |
|---|---|
| AFMS | Advanced Flight Management System - the FMS required for an aircraft to be able to fly as a 4D&datalink aircraft in EATMS airspace. |
| AHMI | Airborne HMI |
| AoC | Aircraft Operating Company |
| ATC | Air Traffic Control |
| ATM | Air Traffic Management |
| CFMU | Central Flow Management Unit |
| DAP | Downlink of Aircraft Parameters |
| EFMS | Experimental FMS - a research version of the AFMS. |
| EOBT | Estimated Off Blocks Time |
| ETA | Estimated Time of Arrival |
| ETMA | Extended Terminal Manoeuvring Area |
| FDB | Flight Database |
| FMS | Flight Management System |
| GHMI | Ground HMI |
| HMI | Human Machine Interface |
| MAP | Missed Approach Procedure |
| MSA | Multi Sector Planning Area |
| MSP | Multi-Sector Planner |
| PATs | PHARE Advanced Tool(s) |
| PHARE | Programme for Harmonised ATM Research in Eurocontrol |
| PC | Planning Controller |
| RA | Resolution Advisory |
| SID | Standard Instrument Departure |
| STAR | Standard Arrival Route |
| TC | Tactical Controller |
| TCAS | Traffic Conflict Alerting System |
| TMA | Terminal Control Area |
| UPT | User Preferred Trajectory |

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