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PHARE

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PHARE : Air-Ground Data Exchange Study, S3

EUROCONTROL

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Glossary of terms

Flight identification :

this is an identification of a flight which will have the following properties:

-it will be unique in such a way that no ambiguity with other flights can occur.
-the ground system will use this identification as an entry point to the data which it manages with respect to the aircraft (i.e. when it needs to access information which it manages about the flight, it will select it from amongst other information using this flight identification).
-it may be equal to the aircraft addressing identification (see below).

Aircraft addressing identification :

this is an identification of the addressing information of an aircraft, which will be unique for each aircraft. A data link application for which communications have to be carried out, will need this aircraft identification to get addressing information from a directory service (see below). To prevent frequent updates of the directory, the addressing identification of an aircraft will have to be fixed for that aircraft.

Directory :

A system which can provide among others presentation addresses to its users, who need this information in order to be able to communicate (comparable to a phone book, only more dynamic, since users are frequently connected to and disconnected from the communication network).

Technical log-in :

A number of technical procedures performed in relation to a certain flight, which are necessary to end in a state in which:

-one or more sub networks are available for communications;
-it is known to both the ground system and the aircraft which data link applications will be available;
-it is known to both the ground system and the aircraft what the (presentation) addresses are of the ground and airborne parts of these applications;
-applications can therefore be used to exchange data for their users.

Trajectory :

list of 4D trajectory points, latitude and longitude in WGS 84 ellipsoid format, altitude as barometric altitude and time in UTC, with the maximum distance between the points depending on the flight phase. Between these points linear interpolation will be used for the straight segments. A more complex description would be required if the aircraft is expected to control to an up linked trajectory.

Constraints :

the instructions used to modify a trajectory.

Tube :

list of points (which can only be copies of trajectory points), with windows attached to them. Each point that appears in the tube will be represented by the time co-ordinate of the corresponding trajectory point. The windows attached to this point can either be specified completely or as predefined windows.

reference to a known position:

this is the name of a defined 2-dimensional position which is known both on the ground and on board aircraft. It comprises up to 5 characters, e.g. 'LEKKO'.

co-ordinates of a position:

these are the lateral and longitudinal co-ordinates of a certain position. They are assumed to have the accuracy as defined by ARINC 429, i.e. they have a resolution of approx. 0.000172 degrees and therefore a total data size of 29 bits (14 for latitude and 15 for longitude).

QNH:

Barometric pressure at see level extrapolated from a pressure observed locally at ground level and assuming an International Standard Atmosphere (ISA). The QNH is given to the aircraft prior to landing. When the aircraft is on the ground his altimeter indicates the altitude above sea level.

PHARE area:

A geographical area (i.e. western Europe) where the ATM system runs a full set of PHARE Advanced Tools (PATs).

Air System :

The aircraft equipped with a full capability Experimental Flight Management System.

Ground system:

The ground component of the ATM system running within the PHARE area.

1 Introduction

In the PHARE ATM/ATC environment, where computers will be distributed on the ground and in the air, one basic requirement is the ability to exchange data in real time between machines.

Within the PHARE project an initial study was executed by NLR to identify several air-ground data link applications.

However the evaluation of the message sizes required within these applications and the data flows necessary for real time operation have not been dealt with as these aspect were not considered to be within the scope of that task.

The main purpose of this study is to provide an initial estimation of the **user** data flows and of the message sizes required in two basic situations.

- The dialogue required before an aircraft enters a Advanced ATM area in order to establish consistent data bases on the ground and in the air. Two cases will be considered : before take off and an entry in flight. Also a short estimation will be made of the amount of data required to up link meteo data for the update of the on-board data base.

- The establishment of a 4D contract between an aircraft equipped with an EFMS and a ground ATM/ATC computer running PHARE Advanced Tools (PATs). To establish this contract several kind of message have to be exchanged between air and ground prior to an agreement. The two possibilities which will be presented in this paper are quite similar, e.g. they will be exchanging messages which often contain similar data, but the ATC philosophy behind is slightly different. These approaches are called the Full Negotiation process (FN) and the Formalised Clearances process (FC).

Several assumptions and shortcuts have been taken in order to come to figures in this study and therefore the results which are provided in this document should be considered as a first estimation and will require refinement using some type of simulation exercises.

2 The environment

The environment, hereafter referred to as the PHARE environment, of the tasks to be performed within this report is the following :

In the air: Aircraft are equipped with a Flight Management System (FMS) with a level of functionality similar to the EFMS and full bi-directional data link capabilities. As such they are able to compute four dimensional trajectories matching different sets of constraints coming from the ground ATM/ATC centres. The FMS is able to fly within a volume of airspace specified by the ground ATM system.

Data link: One or several data link sub networks exist. (e.g. Mode S, VHF, Satellites, ...)

On the ground: ATM/ATC centres are equipped with a full set of PHARE Advanced Tools and as such are able to provide the aircraft with a set of constraints or trajectories to be flown which guarantees the ATC controller a conflict free path for the aircraft's under contract.

3 Air-ground dialogue at system entry.

3.1 Introduction

This section aims to define the dialogue which takes place prior to takeoff or when the a/c is transferred from a traditional (non PHARE) ATC centre or sector to an ATC centre where PATs are available.

This dialogue is required in order to log the aircraft into the system. It is foreseen that this dialogue will take place only once. Information will be transferred between sectors/centres once the aircraft has entered the advanced ATM system.

When the aircraft enters in flight from a non PHARE area it could become possible that the information concerning the ATM/ATC situation stored in the air computer is obsolete. When this situation occurs we could consider two approaches to solve the problem :

- An additional dialogue is added in the entry section to cover the update of the airborne data base with ground data.

- The update of the airborne data base will be done through the dialogues required for establishing a 4 D contract. This will probably add some iterations to the first attempt to establish a contract.

3.2 Definition of the system entry application.

Reference 1 identified a number of applications which will be necessary to exchange data between the ground system and systems on board aircraft in a future 4D ATM environment. Since the ground system is considered to be the core of the ATM system, this constraint is especially relevant for systems on board aircraft. In order to make it possible for an aircraft to enter the ATM system a special application will be necessary. This application is called the System Entry Application (SEA).

Before a given flight enters the ATM system, information about this flight will be present in both the ground system and in the aircraft which will carry out the flight.

This information is the result of the (coordinated) pre-flight planning by the ATM system and the operator of the flight. At system entry only limited information will therefore have to be exchanged by means of air ground data exchange. The purpose of the system entry application could therefore be defined as:

> "The purpose of the System Entry Application will be to exchange those data at the entry of a flight into the PHARE environment which are not yet commonly known by the partners involved, but which are necessary for the operation of the flight within the system. These data exchanges will only concern air ground data exchanges. (no ground-ground data exchange will be considered)"

The scenario in which this application will be used is the following:

Before the start of a flight the future system management function in the aircraft will control the activation of the various on-board systems. A number of these systems will contain data link applications. One or more sub networks will be made available for data link communications.For the data link applications to be able to communicate, addressing information has to be available. For this purpose, directory information will be present on board the aircraft as well as on the ground. All the addressing information which will be necessary during the flight may however not be present in both parts of the system. During a technical log-in procedure, the air and ground management system will arrange, inter alia, that relevant addressing information is exchanged.

Once the technical log-in has been completed the ground system and the airborne system will be able to communicate. The ground system will however have to relate information obtained by means of data link communications to the information which it manages with respect to this flight. For this purpose the SEA will be necessary. The information which will have to be exchanged for this purpose, will consist of a unique flight identification and a unique aircraft addressing identification. This will be further elaborated.

In the next section a dialogue will be identified which can be used to exchange the information for this SEA.

3.3 Dialogue description.

From the description in the previous section it can be concluded that the exchanges for the System Entry Application will be very simple. System management on-board the aircraft will initiate the exchanges. It will do this by sending the necessary information to the ground system. Because of the essential nature of the information, a "confirm" by the ground system will also be part of the dialogue. This confirm will indicate whether the identification has been successful or not. If not, it will be indicated why. Three primary reasons for an unsuccessful identification can be expected:

1) The flight identification parameter can not be related to any information about the flight in the ground system. In this case the following situations are possible:

    - the flight identification in the identification message is not correct;
    - the flight identification which is contained in the information about the flight in the ground system is not correct;
    - information related to this flight is not present in the ground system.

    In each of these cases, the system entry can only partially be carried out. This means that a new set of information will have to be created in the ground system, which will be related to the aircraft identification. Use of other applications, like the strategic (re-)negotiation application, will subsequently be required to get other necessary information from the aircraft.

2) The aircraft identification could not be related to addressing information of any known aircraft. This can only happen if the aircraft identification in the identification message is corrupted during transfer. Re transmission of this message will then be necessary.

3) Neither the aircraft identification parameter nor the flight identification parameter can be matched with the relevant information in the ground system. This also has to be a result of a corrupted identification message. In this case, re transmission will also be necessary.

3.4 Message contents

Three types of messages can be exchanged during the SEA dialogue. These messages will have the following contents:

Type 1: The request for identification message:

- From an operational point of view this message does not contain user information. It is meant to indicate to the airborne end-user that identification is requested.
- Encoded user data: 0 bits

Type 2: The identification message will contain:

- a unique flight identification consisting of up to 7 characters. This identification will be necessary to make the link to the correct information about this flight in the ground system. It will have to be the same flight identification which was present in the filed flight plan for this flight. It should be noted that in the flight plan the aircraft registration may be used as flight identification. If this is the case for a certain flight, the flight identification and the aircraft identification may be the same.
- Encoded user data: max. 42 bits (using encoding rules which result in a minimum amount of encoded data, like e.g. the EFMS encoding rules)
- a unique aircraft identification. This identification will be necessary to make the link to the aircraft addressing information. Since this identification will be part of the titles of the application processes which are present in the airborne system, and since the application protocol allows for the transfer of these titles as protocol information of a message, this aircraft identification will not be included in the identification message as user data.
- Encoded user data: 0 bits

Type 3 : The identification confirm message:

- a result indication: It is meant to indicate to the airborne end-user whether the identification was successful or not and if not, what the reason was. As described above three reasons are possible in case of an unsuccessful

system entry. Together with the successful entry this means four possible values, so two bits will be necessary to encode the possible values.
- Encoded user data: 2 bits.

3.5 Examples

3.5.1 General

Previously a first description has been given of the use of the system entry application. In this chapter the use of the SEA is elaborated by means of four examples. The different situations in these examples do not immediately affect the application itself but more the constraints which are imposed on its use.

3.5.2 System entry before take-off within the PHARE area

The SEA will most frequently be used by aircraft before take-off within the PHARE area. In such a case it is assumed that one or more communications sub networks will be available while the aircraft is still on the ground. This means that sufficient time will be available to perform the technical log-in (a.o. directory information exchange, which may take some time depending on the capacity of the sub network) and the system entry exchange. The procedure for the system entry will then be that an aircraft, after having performed the technical log-in will initiate the system entry by means of an identification message. Assuming that the identification is successful the ground end user will respond with an identification confirm message. This will conclude the system entry. The exchanged user data will be up to 42 bits from the aircraft to the ground system and 2 bits from the ground system back to the aircraft.

3.5.3 In-flight system entry from outside the PHARE area

Another use of the system entry application is foreseen for aircraft entering the PHARE area whilst in flight. Information on such flights will sometimes be available within the ATM system as a result of ground-ground communications. In this case the same procedure as described in the previous example will be followed. However, for others it will be required that additional information is exchanged before the aircraft actually enters the PHARE area, the technical log-in and the system entry will have to be initiated some time before this point (this time has to be determined by research). It will have to be taken into account that mobile sub networks are expected to have a smaller capacity than those available for aircraft entering the system before take-off, as described in the previous section.

3.5.4 In-flight system entry from within the PHARE area

At some airfields within the PHARE area it may not be possible to have a data link communications sub network available before take-off. In such a case data link communications can only start once a mobile sub network connection becomes available. The mobile sub network capacity may result in the technical log-in taking an extended period. Once the technical log-in has been completed the basic system entry procedure as described above will be initiated by the aircraft.

3.5.5 The system entry initiated by the ground system

It can not be excluded that on rare occasions an error occurs within the ground system which causes the loss of the link between the information about this flight and the aircraft identification. In such a case, the aircraft will not be aware of this fact. The ground system will therefore have to initiate a new system entry of the aircraft. It will do so by sending a request for identification message to the aircraft. The aircraft will respond by sending an identification message, and the procedure will be concluded by the identification confirm message which is subsequently sent by the ground system to the aircraft. Since the request for identification message contains no user data, the total amount of user data exchanged in this situation is the same as in the normal aircraft initiated system entry (Note: although no user data is exchanged for the request for identification message the total overhead will be increased).

4. The Meteo exchange application.

This section sets out a basis for the estimation of the data requirements for the up link met data. The down link of met data as observed by the aircraft and sent to the ground for the update of short term meteo forecasts in not considered in this paper.

4.1. General

As described earlier it will frequently happen that aircraft will enter the PHARE area from outside. In such cases information exchanges will be necessary before a trajectory negotiation takes place. Such exchanges will aim at providing the aircraft with sufficient and up to date information for it to be able to generate an accurate trajectory. One type of information which is needed for this by the aircraft consists of meteorological information which is given along the defined route of the aircraft.

It is assumed that when an aircraft enters the PHARE area from outside it will have acquired some meteo information with respect to the area in which the flight will take place. This will have happened at the departure airport, and the information may have been updated during the flight. This information will however not comprise detailed meteo information but more general meteorological information, like regional wind, temperature and pressure information (METAR, TAF), which will be of use to the pilot but which will not be usable by the FMS. When entering the advanced ATM area, the aircraft will therefore need more detailed meteorological information in order for its FMS to be able to accurately perform its trajectory calculations. The minimum information which it will need for this is the route meteo. This consists of meteo information only for points on the trajectory the aircraft intends to fly. Even though route meteo may represent the minimum with respect to the amount of data necessary to calculate a trajectory once, it may not be the minimum if a complete flight is taken into account, since every trajectory change will require additional meteo information to be exchanged. Furthermore it will require quite detailed trajectory information on the ground on the basis on which the relevant meteo information can be selected and up linked.

In the PHARE area, the ground system will gather meteorological information from a wide variety of sources, including 'live' meteo from aircraft operating in the flying in defined airspace. The ground system is therefore expected to have the capabilities to give accurate predictions of the meteorological situation throughout the advanced PHARE area.

4.2. Dialogue description

The general meteo information up-link dialogue is a simple request-reply type of dialogue. It is initiated by the airborne end user, by sending a message requesting for meteo information. This message may need to define the aircraft route for which the meteo data is requested. The route description will consist of a series of points along the trajectory which will be of a density sufficient to allow the aircraft to reconstruct the meteo for intermediate points. By default, if ATC has the route and not the aircraft profile, vertical profiles of meteo data will have to be up-linked (NOTE:

the assumption has been made that the ground end user will be able to decide for which part of the trajectory it will have to up-link the meteo information). The ground end user will respond to the request by sending the applicable meteo information to the aircraft. This will conclude the dialogue.

4.3. User data description

4.3.1. General

In the previous section it is described that two types of messages will be exchanged in a general meteo information up-link dialogue of the meteo exchange application. These are the meteo request message and the meteo response message. The contents of especially the latter message is highly dependent on what type of meteo information will be necessary for the aircraft. Since the meteo information is given for distinct route points which will have a distinct 4D definition (time as well as position), calculations of meteo parameter values for intermediate points will have to be made on-board the aircraft itself. These calculations will comprise interpolations with respect to position which will imply a time interpolation. For a simple linear interpolation with respect to position the parameter values for at least two locations in space have to be given.

Descriptions of the foreseen contents of the messages of the general meteo information up-link dialogue are given in the following sections.

4.3.2 The meteo request message

Based on the descriptions above, the following assessment has been made of the possible contents of the meteo request message:

Meteo request message :

- header : Aircraft identification (24 bits) + Message type code (3 bits)
- default :
  - . no information will be present because the agreed trajectory is known by the ground system
- optional:
  - . 2 or more points along the intended trajectory, each consisting of:
    - - a time reference,
    - - an altitude (= pressure) and
    - - a 2D position identification which in turn consists of either:
      - . a reference to a known position or
      - . the co-ordinates of a position.

4.3.3 The meteo response message

The following description of the contents of the meteo response message has been made by trying to optimise the data description to minimise the number of bits required.

Meteo response message :

header : Aircraft identification (24 bits) + Message type code (3 bits)
meteo data, consisting of :
. a 2D reference position identification consisting of:
- a reference to a known position or
- the co-ordinates of the position
and
. a list of one or more points which are combinations of:
- a list of meteo info blocks, each of which in turn consist of:
. a location identification consisting of:
- the relative position along route of the point,
- QNH
- a list of one or more meteo points each consisting of:
- a relative altitude (= pressure),
- a related temperature,
- a related wind speed and
- a related wind direction.

NOTES:

- This data description allows for a flexible definition of the meteo point resolution. The point spacing is defined within the description. This allows the ground system to determine an optimum spacing to ensure that the interpolation errors are kept within defined limits. This spacing will vary along the route according to meteo conditions (fronts etc) and aircraft altitude changes.

- This description aligns the meteo with the 4D route description. If the trajectory is not known by ATC then the number of pressure levels for which information will need to be sent for points in the climb and decent will need to be based upon the range of potential trajectories for the type of aircraft concerned. If the aircraft trajectory is known then data related to only one or two pressure levels need be sent.

4.4 Estimation of amount of user data

4.4.1 General

On the basis of the description of the user data in the previous sections only a very preliminary estimation of the real amount of the user data can be given. This estimation is based on efficient encoding of the data (e.g. using the encoding rules used by the EFMS). The uncertainty in these estimations lies in the number of trajectory points in the meteo request message and the point density in the meteo response message.

4.4.2 Estimated message size of the meteo request message

The following estimation is made of the user data size of the meteo request message:

aircraft identification + message type 27 bits
default user data: none -> size: 0 bits
optional data:each point: a reference to a known position: 13 bits or the co-ordinates of a point: 29 bits
an altitude : 14 bits
a time reference: 14 bits

total : either 27 bits if no data
27 + 41 or 57 bits for each point

The number of points necessary to describe the airspace for which meteo information is requested will depend on the structure of the airspace, the defined airways, and the algorithm used by the ground system to determine which meteo information has to be sent. Based on the assumption that the up linked meteo will be related to the intended trajectory, in most cases there will be no need for the aircraft to define the points for which the meteo is requested. If ATC have the trajectory, the aircraft's full 4D profile is available to the ground system and can be used as the basis for data up link. If however ATC have only the route information (for example prior to trajectory negotiation), it will reduce the data exchange requirements if the aircraft was to define a data set which will allow the ground system to calculate a very approximate version of the aircraft's expected profile. In such circumstances approximately 6 points will be sufficient to describe the trajectory for which meteo is requested.

Thus whilst a minimum data down link is simply a meteo request without further data, the request could require a data exchange of up to 342 bits (this is only user data). It should be noted that the default option to request meteo related to the trajectory according to flight plan is assumed to occur most of the time, whereas giving a description by means of a series of points along the intended trajectory is assumed to occur only occasionally. These assumptions need to be verified. In either case the ground system will use ground trajectory prediction routines to determine the trajectory for which meteo information is requested.

4.4.3 Estimated message size of the meteo response message

As can be seen in section 4.3.3 the meteo response message is expected to consist of basic definition information which is independent of the number of points in the message (but which reduces the information necessary to describe each point) and of information specific to each point.

Definition Information

The basic meteo definition information is built up of the following elements:

aircraft identification + message type code: 27 bits
a reference position, consisting of either:

a reference to a known position:	13 bits
or the co-ordinates of a position:	29 bits

The total amount of data definition information is therefore either 40 or 56 bits.

Meteo Data Block

The basic unit of information for meteo data is a meteo data block. It consists of the following items:

the relative co-ordinates with respect to the route. It is assumed that up to 32 positions along the route will be sufficient to define the route meteo points:

- relative distance: 12 bits (4096 NM resolution 1 NM)
- QNH 6 bits

for this relative position a list of one or more meteo points consisting of:

- Relative altitude (pressure level)	:	7 bits (64,000 ft resln 1000ft)
- temperature deviation from ISA	:	6 bits (range ±32, resln 1 deg C)
- the related wind speed	:	9 bits (range 512, resln 1kt)
- the related wind direction	:	8 bits (range 360, step 1.4 degs)

Thus for each given position the meteo data will consist of;

Position and QNH = 18 bits
Meteo data = 30 bits * number of Flight Levels for which data is provided.

Assuming that data associated with two altitudes per point is provided for climb and descent phases this leads to 18+60 bits per point in climb or descent and 18+30 bits per point in cruise..

A full meteo data up link will consist of:

Basic position information = 13 or 29 bits

plus

78 bits per meteo point in climb or descent.
48 bits per meteo point in cruise.
The number of points required per route will be dependant upon the length of route and actual meteo conditions. However, in order to provide an initial estimate the following is proposed for the average European flight of 1.5 hours:

Climb - duration 20 minutes climb to 30,000 ft. Data every 5,000 ft= 6 points

Descent - as climb. Data every 5,000 ft = 6 points required
Cruise - 50 minutes. Data every 5 minutes = 10 points

Total number of data points is 22

Total data requirements become

Header	56 bits maximum
Data	1416 bits

4.5 Conclusions

From the data above it can be concluded that the meteo up link for an average route would require in the order of 1,500 bits of user data. This could be reduced by data compression techniques and the format proposed is still subject to further optimisation.

Assuming Mode S data transfer this up link would require two data blocks and potentially two radar sweeps for the complete up link.

The frequency of meteo updates will determine the total data requirements per flight.

5 The establishment of a 4D Air-Ground contract

5.1 Introduction

In a PHARE environment the EFMS equipped aircraft have the possibility of flying within a tube (volume of airspace) agreed with the ground. Sometimes to come to this agreed airspace a "negotiation process" has to take place because ATC requirements in the ground system will not always be able to allow the aircraft to fly it's preferred trajectory.

The two techniques which will be described in this section should be looked at as being quite similar and complementary. Both use similar messages and the difference is more in the philosophy behind them than in the message exchange process. It should also be noted that both approaches allow allocation of airspace around the aircraft's preferred trajectory, provided this is acceptable to ATC.

The Full Negotiation (FN) is a process where the ground system specifies the constraints and the air system provides a trajectory which matches them in order to come to a contract.

The Formalised Clearances (FC) is a process where the ground system tells the air system within which volume of airspace it has to fly. This volume of airspace could have been defined with or without the help of a trajectory down linked by the air system.

It is quite important to note that these two techniques are not very different in terms of dialogue required nor in the messages types and contents. However from the ATC point of view there is a difference: with the FN the air and ground computer systems try to arrive to an agreement and with the FC approach the ground system tells the aircraft where it has to fly while maintaining the possibility of taking into account the aircraft's desires by using an on board computed trajectory that was previously down linked to the ground.

This short study will only try to estimate the required data flows per flight. No estimation of the time required for the different set of exchanges will be done as this will need simulation exercises where the sub network(s) used will have to be modelled.

5.2 Full Negotiation process (FN)

The concept of Full Negotiation has been described in several documents within PHARE. The work presented here intends to take into consideration inputs from EFMS project, as well as FN prototype developed in CENA.

Mainly the documents with references [1] and [3 to 11] have been taken into account:

5.2.1 Detailed description

As Full Negotiation is thoroughly described in documents mentioned above, we only note here the main features of this concept :

The aim of the negotiation is to reach an agreement between an airborne system and the ground ATM system, regarding the space of manoeuvre the aircraft will be allowed to fly along the nominal trajectory. The result of the negotiation is an agreed tube, elaborated by the ground system, around the agreed trajectory, the latter being elaborated by the airborne system on the basis of requested flight plan and possible constraints imposed by the ground system.

Main hypothesis :

- In the dialogue, the Ground System is seen as a unique entity by the Airborne System. This means that necessary negotiation and coordination between ATC sectors or facilities are managed via Ground / Ground communications and are not considered in this study which is dedicated to Air / Ground data exchange.

- The agreement resulting from the negotiation is valid for at least the next 20 minutes period of flight; a periodic negotiation would normally take place in the order of every 20 minutes to elaborate a new contract.

5.2.2 Dialogue description

5.2.2.1 Basic dialogue

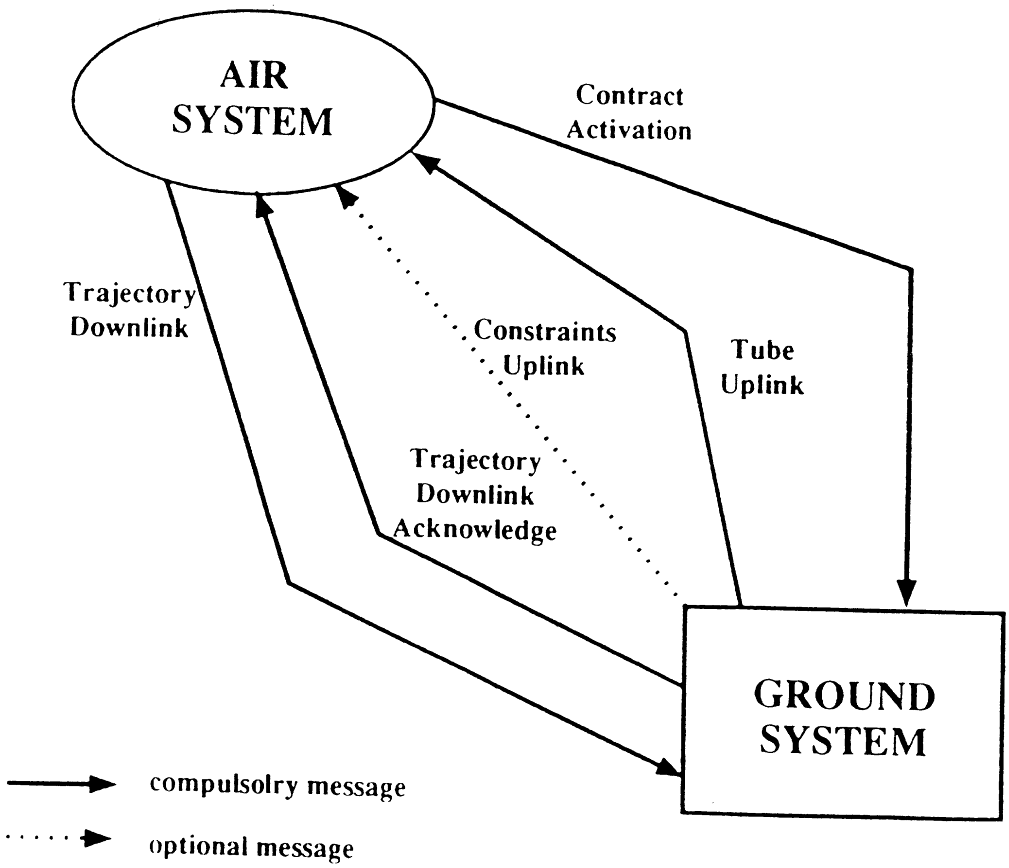

Figure 1 : Full Negotiation basic dialogue

According to this scheme the negotiation dialogue develops in the following way :

1 Aircraft down links requested trajectory : Trajectory Down link

2 Two possibilities :
2.a - Ground system up links constraints : Constraints Up link. In this case the dialogue re-starts at point 1 (see Notes).

2.b- Ground system agrees the trajectory and up links the tube : Tube Up link; In this case the agreement is achieved.

3 Aircraft closes the negotiation by sending the Contract Activation.

Notes :

- It is important that negotiation should start with the down link of the Aircraft trajectory as this provides the Ground System with the most accurate prediction of the trajectory the pilot would ideally like to follow on this particular flight.
- When constraints are up linked, the new down link trajectory should comply with the constraints unless it is unfeasible; but this should be a rare event as ATC will have set the

constraints using a generic aircraft model. On the few occasions that the trajectory cannot meet the constraints, then the trajectory closest to meeting the constraints should be down linked together with indications of where it fails to meet them.
- On rare occasions again, ATC may issue another constraint list even if the down linked trajectory comply with the first list. This can happen when something significant has changed after the first list was up linked.
- In TNP/MAGIC (Mock-up for Air Ground Integration Concept) project, pilot may reject ground constraints once if it is a re-negotiation on ATC's request, three times if it is an initial negotiation or a re-negotiation on pilot's request. Moreover there is a global time-out on the whole dialogue. These parameters will be evaluated and tuned accordingly.

As the contract is sought for a limited period of time (20 minutes or so), it might be envisaged to limit the down linked trajectories to the same time scale. Nevertheless, as down linked trajectory is an input to improve ground system prediction data, the complete trajectory, or at least one hour projection trajectory, should be down linked. For the continuation of the study, we assume that the complete trajectory is down linked.

On the other hand, constraints and tube description are limited to the time scale of the contract , e.g. 20 minutes starting at a point taking into account the expected average time for the negotiation itself. This period is the valid length of the tube at the end of the negotiation.

5.2.2.2 Initial negotiation

For the initial negotiation the whole dialogue as described earlier takes place and is initiated by the airborne system prior the entry into the PHARE area. For the continuation of the study we assume that initial negotiation takes place between 5 and 10 minutes prior the aircraft enters the ATM area. The following messages are exchanged :

- Trajectory down link (starting at the entry of the ATM area)
- Constraints Up link (if necessary)
- Constrained Trajectory Down link (if constraints were up linked)
- Tube Up link
- Contract Activation Down link

5.2.2.3 Contract extension (periodic negotiation)

Contract extension will probably be achieved without trajectory down link. It may be necessary to initiate a negotiation in time to avoid the situation where the aircraft reaches the end of the contracted tube without any new activated contract. The following description stands as a proposition based upon EFMS proposals :

5.2.2.4 Re-Negotiation on pilot's request

A re-negotiation may be initiated any time by the pilot and the dialogue is the same as periodic negotiation mentioned above :

- Trajectory down link (starting at the point of divergence from the previous trajectory)
- Constraints Up link (if necessary)
- Constrained Trajectory Down link (if constraints were up linked)
- Tube Up link
- Contract Activation Down link

5.2.2.5 Re-Negotiation on ATC's request

When ATC needs to change the contract to impose new constraints, it starts a re-negotiation dialogue :

- Constraints Up link
- Constrained Trajectory Down link
- Tube Up link
- Contract Activation Down link

5.2.2.6 Tube infringement

The contract is no longer valid as soon as the tube is infringed by the aircraft. This event may occur for two reasons:

- ATC issues a tactical clearance,
- For any reason, the aircraft has been unable to either to remain in the tube, or to negotiate a new contract prior it exits the tube.

When this situation occurs, the aircraft is considered to be in a tactical status. To go back the contractual status a dialogue of the type "initial negotiation dialogue" must take place.

5.2.3 Message Contents

In this scenario of full negotiation, the basic messages may be of three kinds : trajectories, constraints and tubes. The description of their content is given in the Appendix.

Besides those basic messages, which contain DATA, other messages are defined in the protocol, which do not contain any data but whose purpose is to make the dialogue reliable:

- Trajectory Down link Acknowledgement : up linked by the ground on the reception of a Trajectory Down link message.
- Contract Activation : closes the negotiation.

5.3 Formalised Clearances (FC)

The concept of Formalised Clearances has been relatively unexplored within PHARE. The work presented here takes into consideration the full negotiation process and the corridor approach of CAA/ DRA(M) to extend the original Formalised Clearance work.

Mainly the following documents have been taken into account: Ref. [1], [4-7] and [10]

5.3.1 Detailed Description

The aim of a formalised clearance is for the ground ATM system to provide an airborne system with the manoeuvre space within which the aircraft will be allowed to fly.
Whenever possible this manoeuvre space will be around an aircraft generated trajectory. The result of this process is that the ground system sends the aircraft the information required to define a tube.

Main hypotheses:

- In the dialogue, the Ground System is seen as a unique entity by the Airborne System. This means that necessary negotiation and coordination between ATC sectors or facilities are managed via Ground / Ground communications and are not considered in this study which is dedicated to Air / Ground data exchange.

- The agreement resulting from the formalised clearance is valid for the maximum period that the ground system can provide and a new formalised clearance should be sent before the previous clearance expires.

5.3.2 Dialogue Description

5.3.2.1 Basic Dialogue

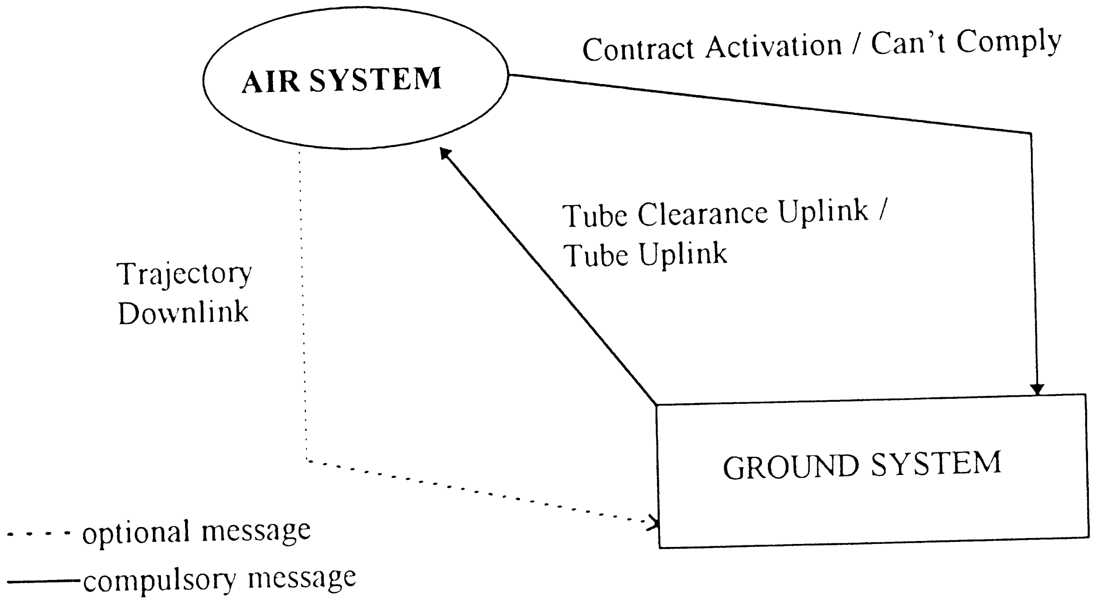

Figure 2 : Formalised Clearances basic dialogue

Notes:

Although formalised clearances can work without a Trajectory Down link, it is highly desirable that this takes place. Also FC has been shown without a Trajectory Down link Acknowledgement. This is not significantly different from FN, but suggests that acknowledgements may sometimes be handled by lower ISO communication layers in both FN and FC.

According to this scheme the dialogue develops in the following way:

1. Aircraft has the option to down link its requested trajectory : Trajectory Down link.

2. Two Possibilities for ensuring the aircraft has a tube

2.a. Air system has sent the ground system a trajectory and the ground system agrees with it. The ground system then up links the manoeuvre space allowed around this trajectory : Tube Up link. Agreement has been achieved.

2.b. If the air system has not sent the ground system a trajectory, or the ground system cannot accept the aircraft's trajectory or the aircraft sends a cannot comply message (see 3b) then the ground system up links all the information required to define a tube i.e. the 4-D path the tube follows and the manoeuvre space allowed : Tube Clearance Up link.

3. Two possible actions occur when the aircraft receives a tube:

3.a. Aircraft closes the communication by sending the Contract Activation.

3.b. The aircraft cannot comply with the tube and sends a "Cannott Comply" message to the ground system which includes brief information on where and why the aircraft cannot comply. The dialogue goes back to step 2b.

4. Aircraft has the option to down link its revised trajectory : Trajectory Down link.

It is desirable if this communication takes place.

Notes :

The simplest situation, where the aircraft sends a trajectory, ATC accepts it and sends back a tube, is identical in both FC and FN.

After Contract Activation, if the ground system has sent a Tube Clearance Up link (which implies a change in the aircraft's future trajectory), it is desirable for the aircraft to down link its requested trajectory to the ground from the point where the Tube Clearance Up link finished. This Trajectory Down link message from the aircraft should not contradict the previous Tube Clearance Up link message from the ground. Such a down link can then be used as step 1 for the next dialogue.

One possible change to the dialogue is to down link the entire trajectory so that ATC knows how the aircraft intends to fly through the tube, thus assisting the monitoring task. This possibility is not considered further in this document even though it is highly desirable that such communication takes place.

A practical way of implementing a Tube Clearance Up link is to send a 4-D path in space, defined in the same way as a Trajectory Down link, together with tolerances around it, defined in the same way as a Tube Up link. For the remainder of this report it is assumed that this is the mechanism for sending Tube Clearance Up links.

There is an assumption that the ground system will on nearly all occasions provide a future tube for the aircraft that can be flown. Given a sufficiently large tube this will be possible and step 3b of the protocol will rarely be required. However, there is a need to determine the minimum size of tube which the ground system can allocate while meeting this criterion, and to calculate its effect on capacity and aircraft efficiency compared with a FN tube.

Step 3b is defined just to contain information on where and why the aircraft could not comply. This will be the 4D point where the aircraft leaves the tube and defines the cause of the failure (height, time).

The question "As the contract is sought for a limited period of time, should down linked trajectories be limited to that time scale or not?" applies both to full negotiation and formalised clearances.

To simplify comparison between the two styles of data exchange this section shall use assumptions equivalent to those of section 4.2, namely that the complete trajectory is always down linked from the point where trajectory up links finish (this seems reasonable especially as new trajectories might be efficiently described as minor changes to previous trajectories and therefore require minimal bandwidth to transmit), but that tube descriptions are limited to the time scale of the sought contract.

5.3.2.2 Initial negotiation

For the initial negotiation, the whole dialogue described earlier takes place. This is initiated by the airborne system at a point some distance or time, decided by an appropriate set of rules, prior to the entry into the ATM area. In the case that the airborne system does not initiate the dialogue soon after the required point, the ground system has the option of directly sending a Tube Clearance Up link. For compatibility with section 4.2 analysis, for the rest of the study it is assumed that initial negotiation takes place between 5 and 10 minutes prior to the aircraft entering the ATM area and that the aircraft always sends a trajectory down link. The following messages are exchanged:

- Trajectory Down link (starting at the entry of the ATM area)
- Tube Up link / Tube Clearance Up link
- Contract Activation Down link / "Cannot Comply" Down link
- Trajectory Down link (only if a Tube Clearance Up link was used)

5.3.2.3 Contract extension

Contract extension should take place often enough to avoid the situation where the aircraft reaches the end of the contracted tube without any new activated contract.

The contract extension is normally initiated by the ground system when some distance or time X, decided by an appropriate set of rules, prior to the expiry of the existing contract. The parameter X will have to be adjusted to take into account the maximum duration of the contract extension dialogue. For the continuation of the study I assume that contract extension takes place between 5 and 10 minutes prior to the aircraft reaching the end of the previously cleared tube.

Contract extension develops in the following way:

- Tube Up link / Tube Clearance Up link

- Contract Activation Down link / "Cannot Comply" Down link

- Trajectory Down link (only if a Tube Clearance Up link was used and after a Contract Activation Down link is sent.)

It is also possible for the aircraft to initiate contract extension following the protocol of a new negotiation on the pilot's request.

5.3.2.4 New negotiation on pilot's request

A new negotiation may be initiated at any time by the pilot and the dialogue is the same as contract extension. In this case it is essential that an initial trajectory down link comes from the aircraft in order to trigger the new negotiation.

- Trajectory Down link

- Tube Up link / Tube Clearance Up link

- Contract Activation Down link / "Cannot Comply' Down link

- Trajectory Down link (only if a Tube clearance Up link was used)

With this dialogue, both for formalised clearances and for full negotiation, there may be a need for the aircraft to indicate the importance of the request. For example, an aircraft requesting a minor change to the route may be trying to avoid bad weather or just improving the flight efficiency. This should affect the priority that ATC gives to complying with the request. Similarly requests for re-routing to different airports may need to be given higher priority than requests to optimise flight levels. Finally, this mechanism can be used by the aircraft to prompt the ground for a contract extension although this should not be necessary as contact extensions should be provided automatically.

5.3.2.5 New negotiation on ATC's request

When ATC needs to change the contract to impose new constraints, it starts a new dialogue :

- Tube Clearance Up link

- Contract Activation Down link / "Cannot Comply" Down link

- Trajectory Down link

5.3.2.6 Breaking the contract

The contract is no longer valid as soon as either of the following events occur:

- ATC issues a tactical clearance

  The aircraft exits the tube for any reason (e.g. has been unable to negotiate a new contract prior to exiting the tube).

In both cases, the aircraft is then considered to be in a tactical status. In order to regain the contractual status a dialogue of any one of the previously described types must take place.

5.3.3 Message Contents

In this scenario of formalised clearances, the basic messages may be of three kinds: trajectory down link, a tube up link or a tube clearance up link. The following description of message contents is based on ref [8] :

- "Cannot Comply" Down link : down linked by the aircraft when it is unable to fly a tube described by the ground. The reason for the non compliance and the position where the aircraft would break out of the tube will be sent to the ground.

- Trajectory Down link : list of 4D trajectory points, latitude and longitude in WGS 84 ellipsoid format, altitude as barometric altitude and time in UTC, with the maximum distance between the points depending upon the flight phase. Between these points linear interpolation will be used for the straight segments.

- Tube Up link : list of points (which can only be copies of trajectory points), with windows associated with them. Each point that appears in the tube will be represented by the time co-ordinate of the corresponding trajectory point. The windows associated with this point can either be specified completely or specified as predefined windows.

- Tube Clearance Up link : list of any 4-D points with windows associated with them. The window associated with a point can either be specified completely or specified as a predefined window. This has the effect that the tube does not have to follow a previously defined trajectory. However, one way of sending a tube clearance is to send a trajectory up link and tube up link together to the aircraft.

Besides these basic messages, which contain DATA, other messages are defined in the protocol, which do not contain any data but whose purpose is to make the dialogue reliable:

- Contract Activation : closes the dialogue.

6 Brief comparison of the protocols

The previous chapters describing the full negotiation and formalised clearance protocols have restricted themselves to details of how the communications will operate. This chapter compares the protocols and examines some of their implications on ATC and aircraft operations.

The formalised clearance approach is similar to the full negotiation approach except that in the event of the ground system not accepting an aircraft trajectory request both the position and size of the tube are sent up from the ground, rather than constraints and the aircraft sends acceptance to the ground before (ideally) sending another trajectory to the ground.

The other difference between FN and FC is that in the latter it is not essential for the aircraft to down link a trajectory to the ground system, although it is highly desirable.

The effects of these differences are noted below.

6.1 Human interactions with the two protocols

Controllers may have several active dialogues with aircraft at the same time. When the ground system cannot accept the aircraft's trajectory, the full negotiation protocol requires more separate messages to be passed before contract activation is reached although the total data amount that has to be passed is the same for both. Therefore the time between assessing the need to change the trajectory and closing down negotiation is likely to be longer for full negotiation. Hence in a multi-tasking situation controllers are likely to have open dialogues with more aircraft than with the formalised clearance protocol and this will influence the functionality of support tools that will need to be available to the controller.

Both FC and FN are expected to provide long conflict free clearances. This will require a shift of controller activity from tactical to longer term strategic resolutions. FN explicitly takes into account the wishes of the aircraft, as calculated by the FMS. This is also true of FC when the Tube Clearance Uplink is around a Trajectory Downlink. This consideration of aircraft requirements may be a second new item introduced into ATC working practice, depending upon the precise interface designed for receiving and checking details of Trajectory Downlinks.

6.2 The implications of not passing constraints

In the FC approach there is no longer the need for the ground system to check that the aircraft has generated a trajectory that is compatible with the ground system's expectation of the trajectory the aircraft will generate.

Since no constraints need to be passed in the FC approach there is a change in the time at which the bandwidth is needed for the protocol compared with full negotiation.

Note: The clearance data in the up link FC requires more details than for FN, whereas FC does not need a trajectory down link

However, extra airspace may be required when sending tube clearance up links to aircraft rather than constraints:

1. Will the tube defined for formalised clearances be bigger or smaller than the constraints used in full negotiation?

For both FC and FN the size of tube will be set so that aircraft will, with a very high probability, be able to follow it. However, ATC can allocate a larger airspace (temporarily) using constraints for FN, than they can allocate (permanently) using tubes for FC, because the FN protocol allows the agreed tube to shrink below the size of constraints, but FC allows no negotiation in the allocation of airspace. This ability of FN should allow the generation of more efficient trajectories.

2. Will the tube defined for formalised clearances be bigger or smaller than the tube used in full negotiation?

Under most circumstances the two tubes could be the same size because, assuming the ground system has a prediction model which can take into account airframe/engine characteristics of each aircraft, the aircraft should be able to use the EFMS to keep within the defined tube.

One exception to this is when the aircraft is close to the edge of its acceptable performance envelope. In this situation ATC will need to allow a larger margin for error, corresponding to the difference in accuracy of the ground based and airborne based trajectory prediction systems. (Extra bandwidth could be used for down linking suitable information to keep the additional airspace to a minimum. However, this is not defined within the FC dialogue).

The poorer performance of ground based trajectory prediction, compared to airborne prediction, is likely to produce less efficient tubes. However, the costs to the aircraft of this inefficiency should be compared with the costs to the aircraft of performing the avoiding manoeuvre requested by ATC.

In summary, the tubes provided by FC will be larger and/or less efficient than those provided by FN.

6.3 The implications of not requiring down linked trajectories

Another difference between FN and FC is that in the latter it is not essential for the aircraft to down link a trajectory to the ground system, although it is highly desirable.

In airspace where substantial manoeuvring and ATC changes are likely (e.g. in the TMA) this could save some bandwidth. (It would require development of the FC protocol to include a simple mechanism for switching trajectory passing by the aircraft on and off).
However, this would result in less efficient aircraft operation, and therefore might only be appropriate when communications limits are being reached.

In cases where the aircraft's datalink transmitter fails, the protocol is simple enough on the down link transmissions to allow their completion by other means - e.g. R/T.

In any other case where the aircraft system cannot send/has not sent a trajectory to the ground system, the protocol can still be made to work.

On the other hand, flight path monitoring, performed either by the ATC controller or by computer assistance software, is likely to be less sensitive when the actual trajectory the aircraft is going to fly is not known. The availability or otherwise of the actual trajectory to be flown by an aircraft could be of significance in the application of deviation alerts and in the final separation that has to be applied by ATC between adjacent tubes.

6.4 Ways in which negotiation and formalised clearances could be harmonised.

The ground sends the EFMS a tube clearance up link as a trajectory and tube.

EFMS could interpret this to be a form of constraints list sent to the aircraft within which the aircraft has to fly. Provided the aircraft can fly within the constraints, then contract activation is given in response. Later, if appropriate, the aircraft could send a trajectory from the end of the ground generated trajectory. This overcomes nearly all of the problems identified above.

This is an easy solution to implement because most of the components for its operation are in place in the EFMS or planned on the ground system.

Alternatively the ground system could send constraints to the aircraft for a limited period of the flight and set a flag saying that they are to be used in a formalised clearance mode. This is a slightly more complex situation for the ground system to implement, but the relevant ground interpretation routines may be simple compared with what is required in the aircraft for the case described above. Also, depending upon the modelling on the ground, fewer constraints may be required and this may reduce the communication costs on the up link.

Both of the schemes suggested above would benefit from augmenting the EFMS protocol to:

1. allow constraints to be given to the aircraft even when no trajectory has been received from the aircraft.

2. allow the ground system to turn off trajectory transmissions from the aircraft.

3. ensure the EFMS can handle up linked constraints and tubes in a compatible manner

6.5 The Transition from Formalised Clearances to Full Negotiation

Since the previous section suggested that it is possible to harmonise the Formalised Clearance approach within the EFMS framework, it also becomes possible to consider a gradual transition between FC and FN:

1. Formalised clearances might be used as an initial phase of implementation because the sequence of operations is closer to current ATC working practice.

2. As computer support for the extended TMA becomes more prevalent, time constraints will be available to automatic systems and controllers. As a first step towards full negotiation these constraints could be sent to the aircraft, either manually (with the assistance of software and datalink) or automatically. This effectively would provide the ground with an improved trajectory from the aircraft.

3. As ATC improves to know further in advance more of the restrictions it will place on aircraft, improved trajectories can be obtained more frequently.

4. Negotiation with aircraft is allowed, but it might be limited at first to just one dimension e.g. controllers use formalised clearances for the 3-D tube of the aircraft, but precise timings are negotiated.

5. The dimensions negotiated by the planner are expanded to full 4D negotiation. However, formalised clearances may remain available for handling shorter-term strategic situations, particularly in the TMA, assuming they can be handled more quickly by the controller.

6.5 Conclusions

Formalised Clearances should allow the ground system to rapidly have agreement with aircraft about the airspace they will fly within. Full Negotiation has an extra step: the ground system obtains aircraft preferred trajectories whenever manoeuvres are suggested by ATC. This should allow more efficient aircraft operations than Formalised Clearances.

It should be possible to provide both protocols in a harmonised system and if required, this could allow the gradual transition from formalised clearances to the more efficient full negotiation. Nevertheless, formalised clearances may remain available for handling more tactical situations, particularly in the TMA.

7 Data link scenario for FC and FN.

7.1 Introduction

This section describes a future air traffic scenario, estimates the likely effectiveness of data compression techniques and from this information derives the user data flows required per aircraft both for the Formalised Clearance air-ground protocol and the Full Negotiation protocol.

For ease of comparison it is assumed that with both protocols the aircraft will always down link its remaining trajectory from the point where trajectory up links finish. This leads to a potential overestimation of the required bandwidth.

7.2 Method

The ground system designer will need to know the number of bits per aircraft per second in the regions of most densely populated airspace, so that adequate communications equipment can be installed to meet the expected demands.

The overall method chosen for making this estimate is to sum the following expected costs where the term cost in this instance relates directly to data requirements:

1. Getting the initial trajectory from an aircraft
2. Aircraft requesting changes to their trajectory (but on the same route).
3. Aircraft requesting changes to their trajectory (with a change of route).
4. Up linking the tube.
5. Manoeuvring aircraft
6. Aircraft deviating from their trajectory.

These costs can be estimated as follows:

7.2.1 Initial Trajectory Cost

The initial trajectory cost is the number of bits that need to be sent on the air ground datalink per hour to describe a typical aircraft trajectory prior to the aircraft entering the PHARE airspace. I.e. it describes a trajectory from PHARE area entry to exit (probably start of flight to finish). Two cases need to be considered:

1. initial trajectory available in ground system
2. initial trajectory available only from air

In case 1, there may be no air-ground cost if the aircraft filed its trajectory before take-off or because an adjacent centre sent details of the aircraft's trajectory. In case 2, the full trajectory cost is incurred. Therefore it is necessary to estimate the relative proportion of case 2 to case 1 to allow the following calculation to take place:

Initial trajectory cost = % of cases initial trajectory unavailable on ground * cost of trajectory

7.2.2 Aircraft Profile Change Cost

When new information is available to the aircraft, it may wish to recompute its trajectory prediction to improve likely flight efficiency when following a tube around the trajectory. This is likely to change only the vertical profile and timings of the trajectory.

Profile Change Cost = rate of trajectory changes * average cost of changes.

7.2.3 Aircraft Route Change Cost

There are likely to be occasions when aircraft have to re-route, perhaps because of flow control or bad weather. In such situations substantially more information is likely to be changed in the trajectories sent to the ground system.

Route Change Cost = rate of route changes * average cost of changes.

7.2.4 Tube Up link Cost

Whenever the contract with an aircraft is to be extended a tube up link will be sent.

cost of tube up links = rate of tube up link * (cost of header + number of points * cost per point)

Here the rate of tube up links is just 1 / (time between tube up links when not manoeuvring).

7.2.5 Manoeuvring Cost

manoeuvring cost = rate of manoeuvring * (fixed cost + number of points * cost per point)

Here the term manoeuvre refers to changing the trajectory of the aircraft from its desired trajectory. Rate of manoeuvring refers to the probability that the trajectory will be changed in any one situation when the tube is being extended. Fixed cost is the overhead of sending any transmission to the aircraft. I.e. the header size. Points are the individual points (constraints) that must be given to the aircraft to describe the manoeuvre.

7.2.6 Aircraft Deviation Cost

The proportion of aircraft deviating should be low (say less than 5%) so that the majority of controller workload is not concerned directly with handling deviations. However, there may be a larger effect upon the datalink traffic because complete renegotiation may be required.

This renegotiation may just be in times or altitudes but could potentially affect routes. As in sections 7.2.2 and 7.2.3 above route changes are handled differently from altitude or time changes.

Route Deviation Cost = rate of route deviations * average cost of route deviations

Profile Deviation Cost = rate of other deviations * average cost of other deviations

7.3 Scenario

This section estimates some of the figures required by section 7.2. In particular, operational assumptions have been made to provide full information for the size of a given datalink message. It should be noted that altitude and time changes have been handled separately from route changes, because improved efficiency is likely by making these changes independent for datalink transmissions.

7.3.1 Initial trajectory scenario

It is assumed that there exists a core region which corresponds roughly to Western Europe and which has a well developed ATC infrastructure. All flights taking off within this area are assumed to have sent their trajectories to the ground system using a ground based data-link. Using CENA estimates, on a busy day, about 45% of traffic flying in this region takes off outside the region (from EUROCONTROL Central Route Charges Office data) .

For the purpose of this study it is assumed that this percentage will not change substantially in the future therefore in 45% of cases, the initial trajectory will be unavailable on the ground.

7.3.2 Aircraft Profile Change Scenario

In the current EFMS the trajectory is recalculated several times during flight. These times correspond approximately to lift off, top of climb, any cruise time constraint, top of descent, TMA entry and twice to define path stretching in the TMA. Only the latter two trajectories will require route changes. All the other updates will merely be to the vertical profile.

Another source of trajectory changes will be when new meteo forecasts are sent to aircraft. These changes might be made hourly, in which case the aircraft will on average recalculate its vertical profile about twice in each 80 minutes trajectory.

7.3.3 Aircraft Route Change Scenario

The proportion of aircraft that are likely to request a re-routing once airborne is likely to be very low, perhaps just some of the traffic with oceanic clearances. As an estimate, only 2 % of aircraft will request such dynamic re-routing.

Therefore the expected frequency of messages is 0.02 trajectory messages per 100 minutes (assuming 80 minutes average flights). In these cases it is assumed that a complete new trajectory will need to be sent to the ground.

In the arrival TMA, the aircraft is likely to request its preferred path stretching manoeuvre to meet its requested landing slot. This is estimated to happen twice in each TMA. First, when the aircraft receives its requested landing slot and secondly when ATC has caused the aircraft's trajectory in the TMA to be changed.

7.3.4 Tube Up link Scenario

Typically, future ATC scenarios talk of conflict free planning for 20 minutes ahead, without discussing how often planning is performed. To make this more precise, assume that sector transit times are 20 minutes on average and that conflict free planning / negotiation across a sector starts when the aircraft is in the middle of the previous sector. In this case, planning takes place once every 20 minutes (once per sector) for an average duration of 30 minutes.

Therefore three tube up link messages occur per aircraft every hour. In the densest airspace the tubes themselves are likely to be of constant size, namely the minimum that the EFMS is capable of efficiently sustaining. This size may change between flight phases and possibly close to some (occasional) situations that might be almost conflicts. This latter type of situation should only rarely occur, say once per tube up link.

To summarise, on average 4 up link messages will be sent per aircraft every 80 minutes, with about 5 standard tube sizes and one non standard tube size within each message.

7.3.5 Manoeuvring Scenario

The proportion of aircraft manoeuvred vertically by ATC before the TMA was estimated by an ATC controller to be between 10 and 30% in today's ATC system. The proportion of minor lateral changes is also estimated to be between 10 and 30%. Fast time simulations have shown that as a rule of thumb, when traffic increases by X%, the proportion of aircraft needing to be manoeuvred increases by 2*X%, assuming the same system organisation. Fortunately, system improvements may ameliorate the situation.

For a situation with doubles today's traffic, this factor seems sufficiently uncertain, that a range of values needs to be tried. The minimum value in the case of vertical manoeuvres is 10% of aircraft and the maximum value 120% of aircraft (i.e. each aircraft manoeuvred vertically 1.2 times on average). Similar figures can be applied in the lateral case. Fewer resolutions are likely to take place by temporal control because of the limited manoeuvrability of aircraft in this dimension. Given the large uncertainties expressed in the proportion of lateral and vertical manoeuvres, temporal control will not be considered separately, but assumed to be covered by the allowances made for these other values.

Within the TMA it can be assumed that 100% of aircraft will be manoeuvred laterally, vertically and in time when being metered and sequenced into a busy airport.

The average extent of each manoeuvre is estimated to be two changes to the trajectory. For example, a level off and restart climb would count as two changes. Flying a parallel route and then resuming own navigation would require up to three changes depending upon implementation.

The rate of manoeuvring is one complex manoeuvre (in the TMA) and between 10% and 120% with a two point manoeuvre vertically and the same proportion of aircraft manoeuvred laterally per 80 minute flight.

Since this is considered to be the most unreliable estimate in the scenario, if a more accurate bandwidth estimate is required, better figures need to be found for the frequency of aircraft manoeuvres.

7.3.6 Aircraft Deviation Scenario

It is assumed that 5% of aircraft will deviate from their trajectory during their flights (EFMS documents talk in terms of 95% confidence limits) and it is estimated that it will not be especially complex to manoeuvre aircraft back into a safe tube. Therefore the expected cost of deviations per aircraft is 5% * cost of a complete negotiation for half of the trajectory length. It is assumed that this will be split evenly between lateral and other manoeuvres.

7.4 Data Requirements

This section estimates the size of datalink messages, to provide the information required by section 7.2. The format of trajectory messages is assumed to be substantially different from that used in EFMS phase 1 to allow for likely improvements of efficiency. The EFMS Phase 1 data communication was formulated to simplify the communication requirements. However, as now defined in the EFMS Phase 1b URD, the route editing allows significant reduction in data transfer requirements and this will be assumed in the following calculations.

The assumed format is outlined in the appendix. Although general indications of the improvements are given, precise format descriptions are inappropriate at this stage and will be derived as part of the EFMS and PD 1/PD 2 developments.

7.4.1 Header Sizes

The likely header size will be calculated as follows

Table 1: messages common fields

field name	field size
Aircraft_ID	24 bits
ATC_centre_code	24 bits
Message_type_indicator	3 bits
TOTAL header	51 bits

7.4.2 Initial Trajectory Data

In a future system the description of a trajectory point can be made more efficient in several ways. First, the named points could be more efficiently allocated using a numbering system. At worst 20 bits could allow 1,000,000 points to be defined. If these points are further divided into regions (perhaps corresponding to ATC centres) 10 bits might refer to the region and 10 bits to the waypoint/facility within the region. In this case the region need only be sent when the aircraft changes region. The details of further optimisation are not considered here. For example, making the coding of the next waypoint dependent on the last one would allow nearby points to have efficient coding. However, from this perspective, it is assumed that typically only 11 bits will be required for identifying known points; 1 bit to show that the points are from the same region and 10 bits to identify the point.

For non named points, the use of positions relative to the last point, rather than absolute positions should reduce the necessary information. For example, a flag could be used to indicate whether the next position is an absolute position or within +/- 1 degree of the last reported position. In congested airspace, where the highest density communications requirement will exist, the positions are likely to be within 1 degree. With this scheme, most of the time a latitude will require 14 bits and a longitude 15 bits (including 1 bit each for the flag).

Some specialised manoeuvres, such as path stretching in the TMA may require specialised descriptions for the trajectory. Their precise definition has not been considered in this document, but allowance has been made for describing some parts of a trajectory in this way. It is assumed that these manoeuvres have the same amount of data as a named point. The data cost of this is one extra bit for each trajectory point - to indicate whether a point is a special (path stretch) manoeuvre or not. This is in addition to a one bit requirement showing whether a point is named or not.

Table 2 summarises the discussions above:

Table 2:

lateral point type	data size
named_point	13 bits
unnamed_point (small lat./ long. change)	31 bits
unnamed_point (full lat./ long. change)	47 bits
path_stretch_point	13 bits

By making time relative to the last point (say within 8 minutes) would require only 9 bits (plus one for a flag to use absolute time if necessary) compared with 17 bits in the current EFMS protocol.

By completely decoupling the altitude profile from the route, altitude changes are kept independent of route changes, so promoting efficient changes of profile. Also, only the bare number of points required for a profile need to be given, rather than an altitude at every route point. Additionally, altitudes would only have to be quoted at 1000 ft resolution provided that time information was passed with each altitude point. With this scheme, altitudes between 0 and 63000 ft could be encoded with 6 bits of information (plus one bit to indicate whether or not the EFMS phase 1 definition of 14 bits should be used).

Assume that:

1. trajectories last 80 minutes on average
2. that lateral points are needed once per two minutes in climb or descent and once per 5 minutes in en-route
3. that vertical points are required only once per two minutes in climb or descent.
4. that climb and descent phases each last 20 minutes

The data requirements for the initial trajectory then becomes:

51 (header) + 5 bits (message number) + 7 bits (lateral points count) +28 * (length of lateral point) + 7 (vertical point count) + 20 * (length of one vertical point) =

70+ 28 * (13 bits (all named points initially) +10 bits (time)) + 20 * (vert. point.) =

70 + 28 *23 + 20 * (7 bits +10 bits) = 1054 bits, i.e about 132 bytes.

However, some allowance needs to be made for positions that require the full number of data bits for their description. Assuming 20% of lateral and vertical cases will require this, then an extra 6 * 10 bits will be required laterally (for ATC centre changes) and 4 * 8 bits vertically (for long time periods between points) bringing the total requirement to

1146 bits (143 bytes).

Thus the simple data compression scheme outlined above might obtain about 47% saving in datalink traffic for initial trajectories compared with the EFMS scheme.

7.4.3 Profile Change Data

On most occasions when the EFMS sends an updated trajectory only the vertical profile will have changed and the time at each of the route points.

This will require two trajectory editing commands to be sent which extends the header length by 2 * 3 (to describe two editing commands) + 2 * 7 (command start) + 2 * 7 (command end) = 2 * 17 bits from 51 bits to 85 bits. The trajectory number will also have to be referred to, requiring another 5 bits, making a total of 90 bits.

Using the assumptions on the spacing of lateral and vertical points described above, the data required to change the lateral and vertical timings will need 28 lateral points and 20 vertical points at take-off. The data required will be

Lift Off: 90 + 28 points * (10 bits per point) + 20 points * (10 bits per point) + 4 * 8 (for describing more detailed vertical points) = 602 bits

Similar calculations can be used for top of climb, mid cruise points, top of descent and the metering fix:

Top of climb: 18 lateral points will be required and 10 vertical points:

90 + 18 *10 + 10 *10 + 2 * 8 = 386 bits

Cruise constraint point / typical met. point (mid cruise): 90 + 14 *10 + 10 *10 + 2 * 8 = 346

Top of descent: 90 + 10 *10 + 10 *10 +2 * 8 = 306

TMA metering fix (half way through descent): 90 + 5 *10 + 5 *10 + 1 * 8 = 198

Note that using a coding that changed time relative to the previously used point might allow fewer than 10 bits to be used for each point. Nevertheless, these figures compare very favourably with the figure of 2160 bits (270 bytes) estimated for the Phase 1 EFMS protocol.

In a typical flight, one of each of these message types will be required, with the exception of the mid cruise updates, of which 3 are expected. This gives an expected quantity of data to be

602 + 386 + 3 * 346 + 306 + 198 = 2530 bits.

7.4.4 Route Change Data

The route changes from the EFMS are likely to happen close to the arrival runway. With the use of standard manoeuvring procedures, this should require the equivalent of about 5 route points and associated profile to be defined perhaps with three editing commands (delete one point, add 5 extra points, change vertical profile). I.e.

51 (header) + 5 (trajectory number) + 51 (for three editing commands) + 5 * (47 bits for a full unnamed point) + 5 * (10 bits for change in plan times) + 5 * (10 bits for change in profile times) = 442 bits

These changes are expected twice per flight giving a data content of 884 bits.

7.4.5 Tube Up link Data

Since standard tube sizes are likely to be used on most occasions, a reasonable range of sizes may be required, possibly with lateral, along route and vertical tolerances separately defined. Allowing 7 values in each dimension requires 9 bits to define a standard tube point. One of the options in each dimension could be to use a non standard value. In this case an extra few bits will be required to cover the range of possible values - say 9 bits. (This might allow +/ - 5120 ft in 10 ft increments vertically, +/ - 5.12 NM laterally in 0.01 NM increments and + / - 512 seconds in 1 second increments in along track timing.

However, each point needs a start time. This will require an extra 10 bits per point.

Assuming 5 normal size and one special size point per tube up link, the required data is

51 + 5 (trajectory number) + 7 (no of lateral sizes) + 7 (no of vertical sizes) + 7 (no of temporal sizes) + 5 * (9 tube size + 10 time) + (18 special size +10 time) = 200 bits

In addition to the tube up link a contract activation message will need to be sent. This will just be the size of a header i.e. 51 bits.

This total of 251 bits will need to be sent 5 or 6 times per typical flight with a total data cost of 1506 bits.

7.4.6 Manoeuvring Data

When an aircraft is manoeuvred the Full Negotiation and Formalised Clearance approaches need to be considered separately.

7.4.6.1 Full Negotiation

Constraints

Typically only 1, 2 or 3 constraints will need to be sent to the aircraft to add to its current constraint list in order to ensure that a safe manoeuvre is sent down in the trajectory. The information carried in each constraint will be equivalent to a trajectory point and a tube point. Each constraint window might contain

31 bits (unnamed point) + 9 bits "window size" = 40 bits

assuming that a typical manoeuvre requires 2 constraints the average size of constraints messages will be

51 (header) + 5 (constraints list number) + 17 (for an editing command) + 2 * 40 (constraint window) = 153 bits

Trajectory

In many occasions only a few trajectory points near the constraints will need to be changed. Assuming that trajectories are all described in relative terms (i.e. the relative position and time from the previous point) then trajectory changes can be described just as a set of editing commands to the previous trajectory. In this case the cost of the trajectory will be just the cost of the editing commands plus the data for the new trajectory points. The editing may require about 6 bits to identify a position in the original trajectory and an extra 2 bits to identify an editing command (e.g. insert, delete, overwrite) for each trajectory change.

The constraints given may change just the profile, or both route and profile. Also there is a big difference, depending upon whether or not the aircraft attempts to make up lost time. If the aircraft does not attempt to keep to its original times, then no further information needs to be sent. However, if the constraint times are kept, then there is a need to completely re-send the route and profile timing information.

Note also that for each lateral constraint, two trajectory segments are required, specifying a straight section and a turn.

For changes in the profile with no time constraints: two new profile points will be added and some of the route timings from the first new point will need to change (This is estimated to be just 2 points, provided the aircraft does not permanently change level) . The data required is estimated to be:

51 (header) + 5 (trajectory number) + 17 (editing information) + 2 * (7 bits altitude +10 bits timing) + 17 (editing information) + 2 * (10 bits timing) = 144 bits

For changes in the route with no time constraints: four new route points may be added and some of the vertical timings from the first new point will need to change (this is estimated to be just two points). The data required will typically be

51 + 5 (trajectory number) + (17 bits editing information) + 4 * (47 bits lateral + 10 bits timing) + (17 bits editing information) + 2 * (7 bits altitude +10 bits timing) = 352 bits

For changes in the profile with time constraints: two new profile points will be added and all of the route timings from the first new point will need to change (This is estimated to be 10 points) . The data required is estimated to be:

51 + 5 + 17 (editing information) + 2 * (7 bits altitude +10 bits timing) + 17 (editing information to change profile) + 10 * 10 (altitude timings) + 17 (editing information to change route times) + 16 * 10 (route timings) = 401 bits

For changes in the route with time constraints: four new route points may be added and all of the vertical timings from the first new point will need to change (this is estimated to be 10 points). The data required will typically be

51 + 5 + 17 (editing information to change route) +4 * (47 bits lateral point +10 bits timing) + 17 (editing information to change profile) + 10 * 10 (altitude timings) + 17 (editing information to change route times) + 16 * 10 (route timings) = 595 bits

Taking a naive view that each of these types of trajectory changes is equally likely, then the average trajectory cost is 373 bits.

Tube Up link

The tube up link will be a normal tube up link, i.e.

200 bits.

Assume that a constraints, a trajectory, a tube and an extra header message (to confirm tube activation) are required. i.e. only one iteration is required between air and ground. Then the average number of bits needed for each manoeuvre in the full negotiation protocol is

153 + 373 + 200 + 51 bits = 777 bits

6.4.6.2 Formalized Clearances

Sending the trajectory and tube information up together in one message is equivalent to sending a trajectory down and tube message up separately, but with a saving of a header and trajectory number i.e. 56 bits.

Assume that a trajectory, a tube and an extra header message (to confirm tube activation) is required. I.e. that the aircraft can successfully accept the ground's proposal. Then the average number of bits needed for each manoeuvre in the formalised clearance protocol is

373 + 200 - 56 + 51 bits = 568 bits

7.4.7 Deviation Data

As stated in section 7.3.6 the data required for the Deviation Scenario is equivalent to that for an average manoeuvre, as described in section 7.4.6 above.

7.5 Bandwidth Estimates

The overall bandwidth costs of the different protocols is obtained by weighting the cost of individual data messages by their frequency as stated in the scenario.

7.5.1 Full Negotiation

The total expected costs for FN on a typical flight of 80 minutes are as follows:

45% * initial trajectory cost of 1146 bits = 516 bits

Profile updates: 2530 bits

Route updates 884 bits

tube up link costs 1506 bits

Manoeuvring Costs (lower estimate) 110% * 777 bits = 855 bits

Manoeuvring Costs (upper estimate) 220% * 777 bits = 1710 bits

Therefore the total costs are estimated to be between 6291 bits and 7146 bits. Taking the higher figure, the bandwidth required in a typical flight of 80 minutes is about 90 bits per minute or about 1.5 bits per second on average.

7.5.2 Formalised Clearances

The total expected costs for FC on a typical flight of 80 minutes are as follows:

45% * initial trajectory cost of 1146 bits = 516 bits

Profile updates: 2530 bits

Route updates 884 bits

tube up link costs 1506 bits

Manoeuvring Costs (lower estimate) 110% * 568 bits = 625 bits

Manoeuvring Costs (upper estimate) 220% * 568 bits = 1250 bits

Therefore total costs are estimated to be between 6061 bits and 6686 bits. Taking the higher figure, the bandwidth required in a typical flight of 80 minutes is about 84 bits per minute or about 1.4 bits per second on average.

This assumes that a final revised trajectory is not down linked, although, as noted in section 5.3.2.2 subparagraph 4 that the final down link of trajectory would be desirable to aid ATC trajectory monitoring.

7.6 Conclusion

The estimated 6% difference in bandwidth requirements between Formalised Clearances and Full Negotiation is quite small and does not by itself justify the choice of one scheme over the other. This difference would be reduced in the finally agreed trajectory is down linked from the aircraft. The reason for this small difference is that essentially the two scenarios require the exchange of the same data. The main difference between the two does not consist in the actual data requirements but rather in the points in time at which the data is required to be transferred.

8. Conclusions.

As described in this document there is no significant difference in terms of data flows between the Full Negotiation and the Formalised Clearances approach if both could establish a contract with only one trial.

This is why the two techniques should not be seen as mutually exclusive but complementary.

The FC approach probably requires slightly less sophistication from the ground system in terms of ATM functions and its ATC philosophy where the ground decides unilaterally where the aircraft is going to fly. Also it may be more understandable to present day controllers, because the controllers will have to adjust trajectories, with computer help, and a trajectory should be an object familiar to them.

However the drawback of the FC is that it limits the aircraft's capabilities to optimise its flight. Also the ground system will need a sophisticated trajectory prediction and control tool that ensures, in nearly all situations, the establishment of a contract with a single up link of the ground computed trajectory and associated tube. This is a basic requirement for the future ATM system.

The FN process has the advantage of making full use of the capabilities of on board flight optimisation. This technique will require from the ground system the functionality to establish a contract through a computer to computer dialogue, with human interaction possible, and a way to present to the controller what is going on and what are the results.

It is not required that the ground system uses a sophisticated trajectory prediction and control tool. However as the number of dialogues should be kept to a minimum it will most probably be necessary to have a ground based trajectory predictor of a level of sophistication similar to the one required for the FC. Thus the computed constraints could be honoured by the air system without requiring further changes.

At this stage of refinement it is not possible to decide how the ATC implementation of these two approaches will be done. An environment should be envisaged where both techniques are used in order to use the best out of each one.

The bandwidth limitations and the delays involved in an air ground data exchange will persist for some time. When there is time to establish a contract using the FN approach (thereby making optimum use of the airborne flight optimisation possibilities) this technique should be used. However, in situations where time is limited, within heavy loaded airspace, the FC approach should be used: it is hopefully be less consuming in time and has a marginally lower data link channel bandwidth.

This complementarity is supported by the expectation that the FN will have the highest chances to be applied during cruise and en-route descent. It will allow the airborne system to optimise during the phases of flight which are the most suitable for flight cost reduction. The FC will be applied in areas where the density of traffic is such that the ground system has to decide unilaterally on where the aircraft's are going to fly. These areas should be a limited part of the whole flight, minimising the use of a less efficient technique.

It is also relevant to compare the amount of data required to up-link meteo data with the expected amount required for establishing a 4D contract. A short calculation gives a raw data flow of approximately 1.5 to 2 bits per aircraft and per second for the contract negotiation process and 25 % of this for airborne meteo data base.

Finally it is necessary to list some areas which have not been examined in this study:

- the down link of meteo data observed by the aircraft as this aspect was not considered part of this study.

- time required for the exchanges of data defined within this document have not been calculated since these will depend upon the chosen communication method.

- the study has not dealt with the problem of errors or interrupted transmissions and the percentage of messages or incomplete dialogues which will need to be sent again.

- the integration of air and ground requires an Aeronautical Telecommunications Network (ATN) with two unusual characteristics for computer networks: dynamic reconfiguration and mobile nodes. This will require the development of protocols which will decrease the throughput available for user data. The impact of this protocol on the theoretical data flows of air ground links has not been investigated within this study.

Consequently this document is a primary identification of user data flow requirements for an experimental future ATC system where ATM functions will be distributed in the air and on the ground.

9 References

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[4] The Communication Requirements Documents (CRDs) for EFMS Phase 1, Version 1.0 - NLR/VG/BO/EFC1 - February 4 1992

[5] Specification of the Communication Objects between Air and Ground for EFMS Phase 1, Revision B - NLR CR 91124 L - June 15 1992

[6] Transfer syntax for the Communication Objects between Air and Ground for EFMS Phase 1, Revision A - NLR CR 91414 L - June 15 1992

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[8] EFMS Phase 1 - Air Ground Communications, Version 1.0 - EUROCONTROL/DOC 92-20-14 - July 24 1992

[9] Architectural Design Document, Version 3 Draft 1, CENA/N92167/17 September 92

[10] Formalised Clearances: An Alternative Philosophy for Air Ground Negotiation - DRA File reference RAD/902/15/4.0 - April 15 1992

[11] Esser: NLR TR 93249 L "The impact of the SSR Mode S data link within the ATN on air/ground information exchanges."

Appendix.

A.1 Appendix 1: Approximate Data Format for Trajectories, Tubes and Constraints.

Note on syntax :

<a>*	repeated copies of <a>
<a>	a is defined in more detail
[a | b]	choice of either a or b
<a> <b>	both a and b

<Trajectory> = <trajectory_header>
<plan_waypoint_count> <plan_waypoint>*
<vert_waypoint_count> <vertical_waypoint>

<trajectory_header> = <header> <trajectory_message_number>

<header> = aircraft ID
ATC centre ID
<message type>

<trajectory_message_number> = <message_number>

<message_number> = 0 <= integer <= 31

<message_type> = (000) trajectory down link
(001) trajectory and tube up link
(010) constraints up link
(011) tube up link
(100) contract activation down link
(101) edit trajectory (may be up link or down link)
(110) edit constraints up link
(111) for other message types

<plan_waypoint_count> = [<more_points_flag =0 > 0 <= integer <=63 |
<more_points_flag = 1> 0 <= integer <= 1023]

<plan_waypoint> = [<point_type = named> <named_point> <delta_time> |
<point_type = unnamed> <unnamed_point> <delta_time> |
<point_type = path_stretching> <path_stretch_manoeuvre>]

<path_stretch_manoeuvre> = as defined for EFMS phase 1.

<named_point> = [<current_centre_flag = 1> <waypoint_number> |
<current_centre_flag = 0><centre_number><waypoint_number>]

<waypoint_number> = 0 <= integer < = 1023

<centre_number> = 0 <= integer < = 1023

<unnamed_point> = <delta_latitude> <delta_longitude>

<delta_latitude> = [<large_lat_change_flag = 1> <full_latitude> |
<large_lat_change_flag = 0> <small latitude>]

<full_latitude> = 21 bits

<small_latitude> = 13 bits

<delta_longitude> = [<large_long_change_flag = 1> <full_longitude> |
<large_long_change_flag = 0> <small longitude>]

<full_longitude> = 22 bits

<small_longitude> = 14 bits

<delta_time> = [<large_time_change_flag = 1> <full_time> |
<large_time_change_flag = 0> <small_time>]

<full_time> = 17 bits (from 0 to 2 **17 seconds)

<small_time> =8 bits (from 0 to 2 **9 seconds)

<vert_waypoint_count> = <plan_waypoint_count>

<vert_waypoint> = [<large_vert_change_flag = 1> <full_vertical><delta_time> |
<large_vert_change_flag = 0> <small_vertical> <delta_time>]

<full_vertical> = <altitude_type> <altitude> (as defined for EFMS phase 1)

<small_vertical> = 0 <= integer * 1000 ft <= 63000

Note that standard turn radii will be assumed between lateral waypoints.

<edit_trajectory> = <trajectory_header>
<number_of_edits>
[
<edit_type = delete_plan_points> <start_point> <end_point> |
<edit_type = add_plan_points> <start_point> <point_count>
<plan_waypoint>*|
<edit_type = delete_vert_points> <start_point> <end_point> |

<edit_type = add_vert_points> <start_point> <point_count>
<vert_waypoint>* |
<edit_type = change_plan_times> <start_point> <point_count>
<delta_time> * |
<edit_type = change_vert_times> <start_point> <point_count>
<delta_time> *
] *

<start_point>
<point_count> = <plan_waypoint_count>
<end_point>

<number_of_edits> = 0 <= integer <= 8

<tube> = <tube_header>
<lateral_tube>
<vertical_tube>
<temporal_tube>

<tube_header> = <header> <tube_message_number>

<tube_message_number> = <message_number>

<lateral_tube> = <lateral_count> (<lateral_size> <time>)*

<lateral_size> = (000) - (110) pre-defined size in nm.
(111) <full_lateral_size>

<full_lateral_size> = 0 <= integer * 0.01 nm <= 5.11

<vertical_tube> = <vertical_count> (<vertical_size> <time>)*

<vertical_size> = (000) - (110) pre-defined size in ft.
(111) <full_vertical_size>

<full_vertical_size> = 0 <= integer * 10 ft <= 5120

<temporal_tube> = <temporal_count> (<temporal_size> <time>)*

<temporal_size> = (000) - (110) pre-defined size in seconds.
(111) <full_temporal_size>

<full_temporal_size> = 0 <= integer * 1 second <= 511

<lateral_count>

<vertical_count> = 0 <= integer <= 15
<temporal_count>

<constraints> = <constraints_header>
<constraint_count>
<constraint> *

<constraints_header> =<header> <constraints_message_number>

<constraints_message_number> = <message_number>

<constraint_count> = <plan_waypoint_count>

<constraint> = [
<plan_waypoint> |
<vert_waypoint> |
<plan_waypoint> <vert_waypoint>
]
[<lateral_size_flag = 1> <lateral_size> | <lateral_size_flag = 0>]
[<vert_size_flag = 1> <vert_size> | <vert_size_flag = 0>]
[<temporal_size_flag = 1> <temporal_size> |
<temporal_size_flag = 0>]

A constraint can be considered as being a trajectory point and a tolerance

<edit_constraints> = <constraints_header>
[<edit_type = delete> <start_point> <end_point> |
<edit_type = insert> <start_point> <point_count> <constraint>*]

A.2 Appendix 2 : Traffic statistics.

We consider the proportion of each category of flight in the european traffic. The figures available for France in september 1992 show the following repartition :

- overflights : 36%
- departing : 18%
- arriving : 18%
- domestic : 26%

On the other hand Eurocontrol provides figures for the "CRCO 90" region (includes : Belgium, Luxembourg, UK, Germany, France, Holland, Ireland, Switzerland, Austria, Spain, Portugal, the Azores, the Canaries, Greece, Turkey, Malta). Average values for the year 1991 are :

- overflights : 2%
- departing : 13%
- arriving : 13%
- domestic : 72%

As CRCO 90 region is very large it may be sensible to consider in this study, intermediate figures to correspond with the core region where Air-Ground integration would be first implemented.:

- overflights : 20%
- departing : 15%
- arriving : 15%
- domestic : 50%