A CONCEPTUAL MODEL OF A FUTURE INTEGRATED ATM SYSTEM

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A Conceptual Model of a Future Integrated ATM System

1. Introduction

An Action Group within the CARTEUR organisation has been in existence since the end of 1984 with the aim of identifying the functional and operational objectives which should be in a future integrated Air Traffic Management System to take advantage of the capabilities of flight management systems.

The Action Group has members from DLR, formerly DFVLR (Federal Republic of Germany), NLR (Netherlands), RAE and RSRE (United Kingdom) and an invited member from the Eurocontrol Agency.

The need for such an integrated system arose from the pressures for change caused by increased traffic flow and the simultaneous need for best possible economy of operation; the need to maintain or even improve levels of safety can, of course, be taken for granted in the air transport industry.

Roughly in parallel with the activities of this Group, several authorities have also produced concept descriptions of a new system. Examples are:

- the Advanced En-Route Automation (AERA) system concept of the FAA,
- the Future ATS system concept description of Eurocontrol, and
- the ATM section of the fourth report of the ICAO FANS Committee.

Because these programmes have been concurrent, there has been interchange of information and ideas and therefore these concepts have considerable commonality with the ideas presented in this conceptual model. They give, however, only the basic principles; more detailed descriptions are therefore required. This report tries to contribute to the refinement process. The paper also emphasises the need for a common and well-organised international approach. Also just beginning is the definition of the Common Medium Term Plan (CMTP) of Eurocontrol.

Because the volume of airspace is basically fixed and, for all practical purposes, so are the number of runways, increased traffic inevitably implies reduced average separations. Most current systems, both air and ground, rely
heavily on human estimation of future aircraft position and in particular that of the air traffic controller to estimate future aircraft relative position so that separation can be maintained. Whilst humans can become very skilled at such estimation, a high mental workload and considerable uncertainty are involved in this process. The consequence of this uncertainty is that for most airspace the actual aircraft separations are substantially greater than the allowed minimum separations. This estimation workload is, of course, additional to that of communicating decisions and information between ground positions and air-to-ground. Thus, achieved capacity is limited in most cases by human workload in estimating, communicating and executing plans.

It is widely accepted that computer assistance is required to assist in these tasks, indeed on the air side it is virtually unthinkable to have a new aircraft without a flight management or area navigation computer already installed. Even when comparable technology is available and deployed on the ground side, the full potential of computer assistance will not be realised unless ground and air components operate together in an integrated fashion to their mutual benefit, i.e a partnership.

In 1986, the Group published A Future Air Traffic Management Scenario (Ref 1) which contained its ideas on the influences for change, the constraints and an outline description of how a future integrated ATM system could work.

The Group accepted that there was a need for a further paper which would be more detailed whilst recognising that there are as yet many unanswered questions. As a result the Conceptual Model was devised which was seen as a working paper which reflected the current ideas of the Group but was also regarded as capable of being developed to include future ideas and results as they became available.

The aim of the Conceptual Model is to:

(a) Encourage and guide ATM research and development especially in areas where long lead times are needed.

(b) Assist National and International Authorities in planning systems for the 1990s and beyond.

(c) Allow users and operators to understand how the benefits of greater traffic capacity and closer to optimum operation of aircraft would be achieved.
It is important to stress the urgency of starting on this long term process.

The remainder of this paper presents a summary of the ATM Scenario and goes on to present the Conceptual Model under four major headings.

(i) Operational Needs and Problems.

(ii) The concept of strategic time based ATM based on tubes in space.

(iii) Enabling technologies and technological problems.

(iv) The benefits.

It has to be accepted that validation and quantification of benefits have yet to be achieved, but this would not be possible within the remaining lifetime of the present Action Group.

2. A Future ATM Scenario

The complete scenario has already been widely published but the main points can be summarised as follows:

Present day ATM is seen as less than optimal and needing:

1. Improved information flows both air-ground and ground-ground to support more advanced architectures.

2. To adopt more sophisticated computer based algorithms within ATC to assist in prediction, optimisation and monitoring, together with the man-machine interfaces to allow their efficient use.

3. Improved en route, intersection and TMA capacity through exploitation of accurate navigation in 3 and 4 dimensions.

4. Strategic planning and improved short and long term conflict prediction to allow the adoption and execution of efficient profiles.

There are, of course, constraints on changing the ATM system. Some of these can be listed as:
(i) Safety must be maintained at least equal to present levels.

(ii) Change must be evolutionary – i.e. take place in small, well defined steps, even into the distant future. In the early stages of change, this will imply compatibility with currently existing systems.

(iii) The system must be capable of working with a wide variation of traffic densities, aircraft types, avionic sophistication etc. There should be no discontinuous changes in procedures to cope with peak levels of demand.

(iv) The system must continue to operate following random disturbances, e.g. emergencies, errors in forecasting.

(v) Pilots and Air Traffic Controllers must be kept 'in the loop' to effectively manage and monitor the ATM process.

(vi) Penalties on specific aircraft types or operators should be minimised and not be unreasonable.

The most important section of the scenario outlines a concept of operation that meets the criteria described, but has some very significant changes from current operations. The elements are:

(i) The exploitation of improved navigation by suitably equipped aircraft, to increase capacity and availability of optimum flight levels.

(ii) Ground based, real time, database to provide short-term high accuracy forecasts of meteorological conditions (notably wind speed and direction, air temperature, icing index) in three dimensions, within the geographical areas of interest. Such a database would be updated by aircraft observations.

(iii) Earliest possible dialogue between aircraft and ATC to establish a flight's preferred four-dimensional profile, for forecast meteorological conditions etc. It is likely that such technology will be applied first to the approach task, and finally in the very long term, to achieve ramp-to-ramp clearance.
(iv) ATC performs 'collective optimisation' to resolve conflicts between individual preferred profiles and seeks to achieve maximum capacity at minimum cost. This would require information to be given to ATC on the cost sensitivities of an aircraft's profile. The rules for such 'collective optimisation' would require careful design. The profile, once agreed, would not normally be changed.

(v) ATC clearances take the form of a rigorously defined four-dimensional tube in space. The dimensions of the tube must be established with respect to:

(a) Traffic density – in heavy traffic, more compact tubes would be required to eliminate conflicts. In lighter traffic larger tubes would give more freedom to absorb errors cost effectively, e.g. in meteorological forecasts.

(b) The aircraft equipment fit – a poorly equipped aircraft would not have the capability to navigate within a narrow tube. This implies that poorly equipped aircraft limit system capacity. Incentives should be built in to encourage upgrading of avionic equipment.

Such a clearance could be imagined as a 3-dimensional bubble moving in such a way that its position and dimensions are specified functions of time. Note that the ATC function has become that of ensuring that these four-dimensional tubes remain separate.

(vi) Well equipped aircraft would be capable of complying with the clearance unaided. Poorly equipped aircraft might require assistance, particularly in terminal areas where the constraints would be more stringent.

(vii) Communication between aircraft and ATC to update air/ground databases, alter optimisation objectives or revise ATC clearances. Three distinct levels of communication can be distinguished.

(a) Background level – automatic exchange of information between air and ground computers, without direct human intervention, e.g. meteorological data, aircraft data to aid ground tracking etc.
(b) Strategic level - human initiated exchange of relevant strategic information, e.g. ATC planning, ATC strategic clearances.

(c) Tactical level - exchange of information requiring short term response, or where party channel is essential to enhance situation awareness of other aircraft, e.g. ATC tactical instructions.

Data link offers the most appropriate mechanism for background and strategic communication. For some time voice R/T would be likely to remain the primary channel for all tactical transactions, but later on it could not be excluded that data link would become the primary channel; voice R/T could also serve as a redundant back up for strategic data link exchanges.

3. The Conceptual Model

3.1 Operational Needs and Problems

When the Group was formed, the driving influences of providing increased system capacity and improved operating efficiency were equally weighted.

Estimates of traffic increase at that time were typified by those published by the Eurocontrol Future ATS System Concept Working Group which assumed there would be a flight movement growth rate of 2.4% annually from 1985 to the year 2000 within the Eurocontrol area. This would imply a growth of about 42% over the 1985-2000 period and a doubling by the year 2014 if the growth rate was sustained.

More recent trends have shown annual traffic growth to be far in excess of 2.4%, with traffic demand now expected to double before the year 2000.

The emphasis of National authorities and researchers has consequently changed with the need to provide more system capacity as the main aim.

It is believed that developments of current ATC philosophy cannot meet anything like these future demands and a radically new approach is needed. One such approach is here proposed which will significantly improve airspace utilisation and will allow nearer to optimum operation of aircraft.
It is worth noting here the parametric study result derived by Magill (Ref 2) of RSRE which was based on earlier Eurocontrol simulations and assumptions that controller communications would be improved and that computer tools for conflict alert, conflict prediction and track deviation monitoring would be available. Given this starting point he estimated that the maximum improvement in en route capacity would be about 75% and would then be again limited by controller workload.

There are regions within Europe where the limitations are due to different causes, for example in South East England the main limitation on growth is seen as runway capacity and all measures so far proposed only add 56% to runway movements, (Ref 3).

3.2 The Proposed Concept

3.2.1 Strategic ATM as an Extension of Planning

The scenario description in Section 2 introduced the concept of strategic control based on complex aircraft trajectories that had been agreed in a negotiation process between individual aircraft and the ATC system.

The ICAO FANS Committee as part of their studies produced the following definitions of strategic and tactical phases.

**Strategic phase**: time frame in which it is possible to resolve potential conflicts which, due to the nature of the ATM environment, should not be left to a tactical phase and whereby an alternative near optimum flightpath will be offered.

**Tactical phase**: latest time frame in which ATC can still intervene to resolve possible conflicts in the optimum path.

**Short term phase**: time frame in which ATC must intervene to resolve conflicts, whereby it is likely that optimum flightpaths will be disturbed.

The Group felt that it was useful to regard the strategic ATM process as a planning process within a range of timescales from months to minutes ahead of the flight operation.
Scheduling and route orientation committees work about 6 months ahead to achieve a balance between demand and capacity.

A flow structuring process occurs (perhaps one day ahead) when flight plans are known. This would enable an ATC unit to forecast the number of aircraft to be expected in, say, the next hour. Thus the ATC system could make a provisional allocation of trajectory tubes in a manner similar to today's slot allocations. The allocation would be provisional because although some aircraft would be in flight, others would not yet have taken off and precise timing of these would be very difficult.

The next phase would begin about 30 minutes ahead of the aircraft arrival within the region of interest, at which time the majority of aircraft seeking allocations would be in flight.

The 4D FMS equipped aircraft would propose a trajectory which can be regarded as a very precise flight plan. The trajectory sought would be expected to lie in the range between minimum time and minimum cost trajectories, bids outside this range may well be queried by ATC. For non-4D equipped aircraft, the company flight profile and independent position estimates could be used by ATC to allocate a trajectory.

Thus conflict free tubes could be allocated to all aircraft and these would not be expected to be disturbed in the normal course of events. However, there would still be flexibility to allow for diversions, missed approaches and emergencies.

The final phase would commence about 15 minutes ahead of arrival, tubes would be regarded as frozen for all but emergencies. Non-emergency cases, for example a missed approach, would be accommodated by inserting aircraft in the previous phase (i.e. 30 to 15 minutes before arrival).

The ATC system would be expected to optimise the traffic flow; for the foreseeable future the emphasis would probably be on achieving maximum capacity without undue penalty on economy.

It is unlikely that such a strategic system could become operational in anything but an evolutionary manner. It is expected that such time based systems would initially be used in the TMA for arriving aircraft, then the en route phase and finally for aircraft in the take-off and departure phase.
3.2.2 Trajectory Negotiation

The active role played by an aircraft in proposing and negotiating a trajectory is a significant extension of current practice. It is thought to be an essential part of the process of achieving a balance between capacity and economy of operation. In addition, it gives ATC a precise understanding of the capability and status of the airborne equipment and a firm basis for monitoring the flightpath during the execution phase.

The routine exchange of data during the flight gives ATC access to data on the atmospheric conditions that an aircraft is experiencing which, when combined with conventional weather forecast data, improves the quality of the weather input to the prediction processes in air and ground computers.

3.2.3 Description of Trajectories as Tubes in Space

In essence a 4D trajectory could be described as a line through 4D space. For practical reasons tolerances must be introduced and so the line becomes a tube. It can be imagined as a bubble moving through a tube such that its position as a function of time is known. It could also be regarded as an extension of today's separation standards which are defined in vertical, horizontal and longitudinal directions.

The bubble would have internal structure composed of three concentric regions. From the inside, these regions reflect the performance of aircraft navigation, ATC surveillance and any correction manoeuvre should an aircraft stray outside its agreed trajectory.

The three regions are defined as follows:

- manoeuvre space is the inner region. The aircraft is authorised to optimise its own trajectory within this space, subject only to remaining within this space. The minimum dimensions of manoeuvre space are determined by the aircraft's navigation accuracy.

- detection space, which surrounds manoeuvre space. It is there to allow the ATC surveillance process to detect that an aircraft has left its manoeuvre space. The minimum dimensions of detection space are determined by the accuracy of the surveillance system.
- intervention space, which surrounds detection space. This is the space necessary for an aircraft which has left its assigned manoeuvre space and penetrated detection space to be directed back into manoeuvre space. It is the responsibility of ATC to maintain separation between the intervention space associated with each aircraft.

3.2.4 The Trajectory Execution, Surveillance and Monitoring process

Following the trajectory negotiation process, aircraft equipped with a 4D capability would execute the trajectory and would be expected to stay entirely within the normal manoeuvre space described in the previous section. For non 4D equipped aircraft the guidance function would be performed by ATC.

The surveillance and monitoring function of ATC under normal conditions would operate at several levels.

(a) Monitoring that each participating aircraft remains within its assigned tube.

Corrective action would be needed if an aircraft appeared to be deviating from its assigned trajectory, i.e. was entering the detection space described in 3.2.3.

Action would also be required if, for any reason, a trajectory modification had to be issued.

(b) Ensuring that no other aircraft infringes an assigned tube.

(c) A short term independent conflict probe.

The information source for these ATC functions would be radar or Automatic Dependent Surveillance (ADS) and other data where available.

In addition, it is possible that aircraft will be equipped with an Airborne Collision Avoidance System (ACAS) to provide a final last ditch defence.
3.3 Enabling Technologies and Technological Problems

This section covers some basic technologies that would be needed in a future integrated ATM system. It describes what is known and what has yet to be determined.

3.3.1 ATC Prediction of Aircraft Trajectory

This function is needed for the trajectory negotiation process for well-equipped aircraft and is the means by which trajectories are calculated for poorly or non-equipped aircraft.

It would comprise algorithms hosted in ATC computers that would calculate a broadly optimal 4D trajectory from aircraft current position to the destination point. Included in this function must be conflict prediction and resolution, i.e. a resulting trajectory must remain adequately separated from all previously allocated trajectories. This function would be expected to operate at least 15 minutes ahead of trajectory execution.

(a) Present situation

Prediction algorithms used in today's operational ATC computers have been developed in an open loop system without feedback. Due to the inaccuracy of the input data, their prediction accuracy is limited. They use a simple representation of the aircraft performance producing horizontal and vertical speed values, based on the speed as specified in the flight plan and long-term wind forecasts. Corrections of the basic data or of the prediction result are sometimes made using radar derived ground speed or overflight-times over a reporting point. Up to about 40 different aircraft performance classes are used within certain systems. The flexibility of the trajectory calculation is often further limited by the need to define the start and end of a flight segment by known (predefined) route points.

The prediction accuracy which has been measured (Ref 4) for a prediction horizon of 10-15 mins on established routes is in the order of:

+/- 50 sec (standard deviation) or about 10% of aircraft with a deviation of more than 1 minute for cruising flight;
+/− 80 sec (standard deviation) or about 40% of aircraft with a deviation of more than 1 minute, 5% of aircraft with a deviation of more than 3 mins for arrival flights.

In the present ATS environment some, although limited, improvements seem possible by the following measures:

- a better description of the flight plan (e.g. by using company or FMS flight plans instead of ICAO flight plans), by systematic input to the computer of any flightpath changes (e.g. direct routings) and a less constraining representation of the ATS environment (e.g. by using any points in the airspace rather than just named beacons). This will mainly improve flexibility.

- better or more frequently updated wind forecasts. This will also improve accuracy.

(b) Future Situation

On the other side, evaluations of arriving flights made with 4D FMS equipped experimental aircraft applying speed control or path stretching indicate an achievable accuracy of delivery time at a particular aim point, (e.g. at a gate or metering fix) with a standard deviation in the order of 5 secs (maximum deviation smaller than 8 secs). This can be achieved using the presently available accuracy of wind forecasts, updated by the wind measured on board (Ref 7). These evaluations have concentrated on the determination of precise arrival times. For position accuracy, known figures for good 3D FMS can be assumed.

This precision of track-keeping is achieved by closing the loop between the trajectory prediction/extrapolation function and the actual position determination/navigation function, i.e. by the generation of corrective instructions to the autopilot.

The utilisation of similar and fully compatible algorithms in ground based trajectory prediction and guidance systems applied to non 4D equipped aircraft should produce comparable results of about 10 secs standard deviation if a number of conditions can be satisfied. These include in particular the requirements -
- to close the presently open aircraft-controller loop. For this purpose, the system calculates a realistic 4D trajectory which is then allocated by the controller. He does this by guiding ('vectoring') the aircraft by a series of speed, heading and altitude instructions along the allocated trajectory. The actually flown trajectory is continuously compared with the allocated one and corrected by new instructions if a deviation is detected (Ref 8). Voice communication or a digital air-ground data link can be used for the transmission of instructions.

- to improve knowledge of prevailing winds and of the actual aircraft state vector such as speed, rate of climb and descent and bank angle. The existence of a digital air-ground data link is considered essential for this improvement.

A combination of real-time validation of individual algorithms and overall system simulations in a mixed environment (4D FMS and non-equipped aircraft, no data link) have shown the viability of such an approach (Refs 11 & 12). The situation will further improve when, in perhaps 10 years time, basically all aircraft will be at least RNAV equipped and a data link will exist.

3.3.2 ATC Surveillance and Trajectory Monitoring

These ATC functions are used in the trajectory execution phase.

For well equipped aircraft the required ATC function is to detect any departure of the aircraft from the manoeuvre space of its agreed trajectory and institute corrective action. Trajectory modification or reassignment must also be possible. It must also detect and correct any infringements of an assigned trajectory by other aircraft.

For non-equipped aircraft, trajectory execution would be achieved by an ATC guidance process very similar to current practice. The guidance would be based on computer calculated predictions and advisories, as described in 3.3.1.

Separate from this function would be an independent short term trajectory deviation and conflict prediction function.
The achievable accuracy of the surveillance function determines the minimum size of detection space in the moving bubble.

Available sensors are radar over much of continental airspace and ADS over oceanic or low density continental airspace. The availability of the data link function makes supplementary data from the aircraft available. Examples of such data are avionic system status, intention and tracking support parameters.

3.3.3 The Controller-Computer Interface

The relative roles of controller and his computer tools have yet to be satisfactorily defined, see Section 3.3.8. What is clear is that the controller must remain in overall charge of the situation and to achieve this must be able to appreciate the relationships between many complex trajectories, must be able to engage in 'what if' dialogues with his computer system, must be able to access easily all required subsidiary data and must be able to issue instructions to the computer for transmission to aircraft over a data link.

It is expected that conventional voice links will also be needed to cope with poorly equipped aircraft, failure cases and emergency actions.

There is, however, considerable scope for progressive implementation of computer assistance to humans. It is vital that this combination of humans and computer assistance should be correctly designed. Current belief (Ref 5) is that the controller should remain the central, active, decision making component of the ATC system, with the computer aids providing advice and assistance while performing many of the routine tasks automatically.

The main implication of this belief is that the design of future systems must be 'controller centred'. This involves making explicit what functions are required of the human, and then designing a job and an environment that maximises the controller's abilities and motivation. In broadest terms, important controller characteristics include:

- an ability for flexible decision making, producing new and appropriate responses to unanticipated system states and emergency conditions;
- a broad pattern recognition ability, particularly in the anticipation of problem situations;

- detailed knowledge of a wide range of ATC-related procedures, practices, aircraft characteristics, typical traffic patterns, problems, etc.

Two further aspects of importance relate to confidence, where it remains true that in safety critical systems the users tend to be more prepared to invest their confidence in skilled human operators than in unsupervised computers, and to accountability, where it is preferable that a human operator rather than a remote software engineer should be accountable for real-time events.

An important step in improving the interface between controllers and their computer aids is the extensive use of 'electronic' flight strips with appropriate input devices. This permits the evolution of an accurate central database containing all information relevant to ATM. When this has been achieved the second major step can occur, in which many system improvements can be effected and substantial modifications to controller roles and practices can be contemplated. In particular, the emphasis of ATM will shift towards more strategic than tactical control. The role of the controller may simultaneously evolve to one of evaluating the merits of computer proposed solutions, while the automatic systems take over the majority of routine monitoring tasks. Implicit in this is the need to provide the controller with appropriate displays and interactive devices so that he may readily retain total awareness of the complete situation and be in a position to respond effectively to all eventualities. Only by providing the appropriate aids for the controller can his capacity and that of the system be maximised.

The software must be designed very carefully, such that its outputs are always reasonable and understandable even in abnormal situations. Redundancy in hardware and software should be built in to ensure system integrity. The controller will only have confidence in the system and be able to rely on its performance if it operates without failure and without interruptions, especially in heavy traffic or emergency situations when the stress on the controller would be too high when the computer is not operating correctly.
Finally, the need for adequate planning for change is of paramount importance. Then the changes alluded to above can take place in a smooth, evolutionary sequence with incremental benefits at all stages.

Experiments are under way to explore the characteristics of colour displays, 3D displays, direct voice input and other techniques.

3.3.4 Airborne Optimum Profile Prediction and Negotiation

This is a major change from the current Flight Management System capabilities; at present these can calculate optimum climb, cruise and descent strategies based on aircraft parameters and simple atmospheric data. However, these are not linked to geographical or other constraints.

What will be needed in the future ATM system is the capability to generate an economically optimum trajectory in 2, 3 or 4D between the route start and finish points that will meet all aircraft limitations, take account of all known ATC procedures and limitations (e.g. height constraints, entry gates, defined SIDS and STARS) and of meteorological conditions.

Further, the function must support the trajectory negotiation process with ATC, assessing the impact of any ATC imposed changes. Finally it must generate the most economic trajectory through all agreed constraints to provide the basis for controlling the aircraft to remain within the manoeuvre space portion of the agreed trajectory.

3.3.5 Airborne Execution of Agreed Trajectory

Current operational FMSs navigate and control aircraft along 3D routes with a precision dominated by the navigation accuracy.

Several experimental algorithms exist for 4D control of aircraft that achieve time control to one or several constraint points, usually at the end of the route.

Given a route and points defined in space and time, then two basic methods of control are available, that of adjusting aircraft speed, or adjusting path length whilst maintaining constant speed; of course both can be used together. The choice between these two methods is driven largely by the phase of flight
and the amount of time adjustment required. The most economical form of time control is undoubtedly speed control in cruise flight as, for example, deviations about cruise speed produce only a minor penalty in fuel burn. To exploit this, early notification of arrival time is necessary. However, in later phases of flight there is little time remaining and thus the amount of time adjustment possible is small, made more critical because the more demanding aircraft configuration that results when flaps and landing gear are deployed allows only very small speed changes. In this case the obvious method of adjustment is to alter the path length, which can in general only be done by inserting extra path length and then varying that extra path length. Examples of path stretching are race track shaped holding patterns, variable length U patterns (a trombone) or varying the turn point in a standard path, for example, a variable turn onto the base leg before the final approach.

An example of a speed control 4D system was developed by RAE (Ref 6) over the period 1982 to 1986 based on earlier work by NASA. The system typically operates from the high altitude cruise down to an end of descent point defined in four dimensions at a height of about 4000 feet. The lateral path is defined as usual by a series of waypoints.

The algorithm initially integrates the equation of motion up the descent path, using a flight idle aircraft model and interpolated or known wind data. This allows the top of descent point to be calculated and subsequently the cruise speed to this point. On engagement, the system continually compares actual and predicted position, refines the wind and speed error models and recomputes the trajectory to meet the end point constraint. Flight tests have shown the arrival time error to be about 4 seconds (one standard deviation) under a wide, but not exhaustive, range of wind conditions.

An example of a path control system has been developed at DLR (Ref 7), providing 4-D guidance from a Metering Fix to the Gate. The 4D-guidance concept is similar to usual radar vector guidance techniques of air traffic control. It is characterised by a sequence of flight sections with commanded constant values for indicated airspeed, heading and altitude. Since the time of arrival is controlled by altering the length of the lateral path via a delay fan and holding patterns, if necessary, airspeed and altitude can be chosen independently, e.g. with respect to minimum fuel consumption. The algorithms, utilized to plan the time accurate flight path and to monitor the expected time of arrival error at the fix point (the Gate), take into account suitable wind models updated by actual wind data measured onboard.
The 4D-NAV mode was extensively flight tested on two different types of aircraft (HFH 320 (Ref 7), Boeing B 737 (Ref 8)). A total of 58 fully automatic 4D-approaches has been performed in 1983 and 1987. About 50 different test configurations have verified the performance of the 4D-guidance algorithms. 18 approaches ended up with an arrival time error of less than 1 second. For a total of 51 approaches the time error was less than 5 seconds. Despite very different wind situations during the test flights (calm winds, varying wind directions, wind speeds up to 80 kts at FL 150) the arrival time error has never exceeded a value of 8 seconds.

Future ATM systems will require multiple or continuous constraints with defined tolerances. Typically a number of 4-dimensional windows will be defined and the aircraft required to pass through them in succession. The logical extension of this is to require the aircraft to remain within a continuously defined 'tube' in space. The aircraft is free to optimise its own route within the constraints and the task of ATC becomes that of allocating tubes which do not intersect when viewed in 4 dimensions.

The research needed to achieve this state can be defined as follows:

(i) Develop 4D algorithms capable of satisfying multiple window or continuous tube constraints in a smooth, cost optimal manner.

(ii) Combine speed and path control strategies to provide a continuous range of abilities from cruise level down to the final approach and possibly even to runway threshold.

(iii) Determine the sensitivity functions of 4D navigation so that the trade-offs between time precision, system running cost and input data quality are understood.

(iv) Define the 4D navigation performance that is needed to satisfy the developing ATM concepts and that will meet future capacity and economy of operation requirements.

The dimensions of the manoeuvre region of the tube is dependent on a reasonable balance between small tube sizes to achieve maximum capacity and the larger sizes needed to achieve relaxed and economical control where traffic demand allows.
3.3.6 The Pilot Computer Interface

As for the ground controller, the pilot must remain in charge of his aircraft and all the systems within it, but he will need much more sophisticated computer support than he has at present. Almost certainly the techniques of Artificial Intelligence will have a part in facilitating the dialogue between man and machine. Also necessary will be improved interfaces such as touch screens, rollerball/cursor techniques and direct voice input. There will also need to be improved displays and display formats to allow 3 and 4D trajectories to be displayed and understood.

These interfaces, together with the trajectory prediction capability described in Section 3.3.4, must be capable of supporting the dialogue with the ATC system.

3.3.7 The Definition of Trajectories in Space

It is clear that the definition of the trajectory must be precise and clear to both parties involved in the negotiation, execution and monitoring process and yet must be capable of economic description over a limited bandwidth data link.

It is probable that the trajectory description would be based on a series of waypoints specified in space and time together with the associated tolerances. The trajectory would be derived by interpolation between these waypoints probably by a combination of straight segments and circular arcs. The interpolation process must also include turn definitions as past experience shows that individual manufacturer interpretations of airway turns leads to the largest spreads observed in current precision RNAV operation.

In the vertical plane there would need to be a waypoint associated with the start and finish of any level change; for large changes intermediate waypoints at perhaps 5000 ft intervals would be appropriate so that the difference between actual trajectory and linear interpolation remains small.

In the longitudinal direction, waypoints about 50 n miles apart would be adequate for en route or low density segments where the required 4D precision is of the order 30 seconds. For the TMA and busy sectors the time precision
required might be close to the current technology limit of 5 seconds. In these regions waypoint density would need to be higher to achieve the necessary interpolation confidence, perhaps about 100 seconds of flight time apart.

The absolute minimum size of tube manoeuvre space will be determined by 4 dimensional navigation accuracy; best current navigational accuracies are about 0.025 n miles lateral, 100 ft vertical and 3-5 seconds time, all to one standard deviation. The minimum manoeuvre 'bubble' should be significantly larger to allow for flight technical error, atmospheric turbulence, and meteorological errors and to allow for trajectory optimisation.

3.3.8 The Role of Man in a Future ATM System

The members of the Action Group, in common with most researchers in the ATM field, believe that for the foreseeable future there will not be computer replacements for the pilots and air traffic controllers in charge of their respective portions of the system. There is considerable scope for computer assistance to humans, which should take account of the relative abilities of man and machine. The human can react flexibly and effectively to new or unforeseen situations, the computer is potentially good at planning, numerical predictions and routine tasks such as monitoring. The man can also cope with technical failures in the necessarily rare event that they occur. As the total system moves towards greater automation and sophistication with greater emphasis on strategic rather than tactical control, the role of humans also necessarily changes to one of interacting with computer proposed solutions to create acceptable trajectories and then, with the computer, monitoring progress against these predictions. This change introduces major problems in producing user interfaces such as novel displays and formats to portray three-dimensional and four-dimensional trajectories in an understandable form and raises potential problems of retaining motivation and arousal to cope with rare unexpected events.

Undoubtedly this is one of the major areas of uncertainty in attempting to define the future ATM system. Whereas most purely technological issues can be addressed in reasonably straightforward research, no progress has yet been made in this area beyond stating the problems.
3.3.9 Improved Meteorological Data

There is considerable scope for improvement in capacity by reducing separation distances. These separations are dependent on the degree of uncertainty of current and future aircraft position. One of the large remaining uncertainties in predicting future aircraft position is the state of the atmosphere ahead of the aircraft, the most important parameter is the wind vector but others such as temperature are also important. It seems unlikely that simple extensions to current weather forecasting techniques can provide the accuracy and detail that is needed for, say, precision four-dimensional descents. What does appear possible is to use the aircraft themselves as probes. Suitably equipped aircraft can determine wind and other data and send this as a report over a data link to a central location where the aircraft-derived data can be combined with more conventional forecasts to produce a detailed local 'nowcast' for dissemination to later aircraft.

The status of current forecasting can perhaps be illustrated by reference to the work of the UK Meteorological Office.

An analysis of the accuracy of wind predictions at FL390 as given by the UK Met Office Global Forecast Model (Ref 9) gave an rms vector wind error of 13 knots in 1986. More detail is given in Ref 10 which shows that in January 1985 the rms vector wind error varied from about 10 knots at FL050 to a maximum of about 17 knots around FL300.

There are many factors that contribute to these forecast errors. Firstly, the coarseness of the spatial grid used in the numerical computations (approximately 150 km in Europe latitudes) limits the spatial frequency of the smallest features that can be modelled. Secondly, the ability of the computations to model the physics of fine-scale atmospheric processes is also limited. Thirdly, forecasts are often made many hours ahead of the time when aircraft need the information, based on observations on which the forecasts are based may give poor coverage of some parts of the volume modelled.

Efforts are being continually made to improve the situation. As increased computing power becomes available so the mesh-size of the model can be reduced and the modelling of the physical processes improved. Reference (9) shows how the rms vector wind error has been reduced from about 16 knots in 1983 to 13
knots in 1986. Future planned increases in the computing power available to the Meteorological Office should ensure that this trend continues. In the future, when the Mode S and Satellite digital data links are fully implemented, the greatly increased volume of aircraft meteorological reports should also contribute significantly to the accuracy of forecasts.

It is not yet certain, however, whether the upper air wind information required by aircraft is best derived from enhanced, conventional forecasts, or whether a better service might be obtained from a dedicated, statistical 'now-casting' model, custom designed to make optimum use of down-linked aircraft reports. One of the early applications of experimental data links will be to investigate this approach, as well as to provide extra met reports for use in conventional forecast models. Two early objectives of this research must be to assess the accuracy that might be achieved by the 'now-casting' approach and to estimate the accuracy that may be needed by aircraft and ATM systems in the future.

3.3.10 Data Communication and the Data Link

It is now widely accepted that computers will play an increasingly important role, both air and ground, in providing advice and assistance to controllers and pilots. It is also important to regard ATM as a partnership between air and ground seeking to achieve more efficient operation. In such a partnership communication has a very important role to play; only when the operational and functional objectives of this integration process have been identified and defined, can the information flow be estimated.

An example of the type of exchange envisaged is the trajectory negotiation described in Section 3.2.2

Two likely candidates for the data link medium can be identified, the data link offered by Mode S surveillance radar and satellite based systems.

The data link, whichever system is implemented, must be regarded as a limited resource to be shared between all aircraft and the ATM functions. A significant step will be to estimate the information exchange capacity needed for each data link ATM function.
International agreement is needed for the application and formats of data links. Obtaining this agreement will not be a trivial task.

3.4 The Benefits and the Costs

The air transport industry is very cost conscious. System improvements that have been anticipated here and elsewhere will only be implemented if traffic demands cannot be satisfied in another way or if it is cost effective to adopt them. Necessary steps in the process are to examine the technical possibilities for improvement and to assess the contributions that such technology can make to capacity increase or cost reduction. In parallel with this technical evaluation should be an assessment of the cost of implementation.

The process is essentially iterative; broad scale cost benefit studies should indicate promising areas for further technical and financial studies. The Group has so far been unable to address this issue and perhaps is not qualified for this type of study. However, it is clear that the early broad studies indicated above should be started very soon to provide the guidance and momentum for implementation.

3.5 Definition of an Evolutionary Route to the Future ATM System

There are clearly very major differences between today's systems of ATC and the future integrated ATM system outlined in this document. Indeed, the earliest date at which a system of the type described could be operational is thought to be about the year 2010.

The reasons for this slow timescale are that the air transport system is very large scale and international and has major investment in equipment and aircraft which can be expected to remain in operation for many years.

In addition, each step has to be evolutionary, be capable of operating with earlier equipment and ideally be cost-effective in its own right.

It is perhaps logical to break the evolutionary plan down into areas as follows:
(i) Widespread use within ATC of sophisticated computer assistance for data handling and short term planning, conflict prediction and resolution.

Some advantage could be taken at this stage of aircraft systems such as RNAV and FMSs.

(ii) Introduction of data link to improve data exchange. This would benefit ATC surveillance and handling, improve ATC understanding of aircraft route intentions, and improve short term weather forecasting. This would, in turn, improve conflict prediction, reduce controller workload and provide some increase in capacity.

(iii) Introduction of strategic control based on the concepts outlined in this paper.

Timescales of these eras might be (i) up to 10 years, (ii) 10 to 15 years, (iii) 15 to 20 years. Implementation decisions must be taken very soon to meet these timescales.

4. Concluding Remarks

It is hoped that this paper, by virtue of wide circulation, will stimulate debate and feedback to the ATM research community.
References

1. Interim Report of GAREUR Action Group FM (AG)03
Integration of Flight Management and Air Traffic Management
Systems [TP 025] incorporating a Future ATM Scenario [TP 024]
Published as RAE Tech Memo FS(B)666, April 1987.

2. Some Ways of Increasing the Traffic Capacity of En-Route Air Space.
S A N Magill. RSRE Annual Review of Programme of Research into

3. The Challenge Facing Air Traffic Management in 2000 AD.
R D Hunter and P Brooker.

4. The Application of Trajectory Prediction Algorithms for Planning
Purposes in the Netherlands ATC-System.
J N P Beers, T B Dalm, J M Ten Have and H Visscher.
NLR Tech Memo. NLR MP 87031 U.

5. Keeping the Controller in the Loop - the ATCO's Role in Future Systems.
A Jackson, RSRE Annual Review of Programme of Research into ATC Systems.

N W Witt
RAE Tech Memo (about to be published).

7. Algorithms for the Automatic 4-Dimensional Guidance of Aircraft
Taking into Account the Current Wind Situation.
Lechner, W.

Seminar on "Future Scenario of a TMA. Frankfurt 2010"
V Adam.


10. Meteorological Forecasting for Aviation.
D A Forrester. Article 19, RSRE Annual Review of Programme of

11. Time Scheduling of a Mix of 4D-Equipped and Unequipped Aircraft.
Tobias, L.
NASA, TM 84327, 1983.

12. Simulation of a Future Terminal Maneuving Area Scenario.
Adam V, Gerling W, Hurrass K, Klostermann E, Schick F.
NOVEL FUNCTIONAL REQUIREMENTS FOR A FUTURE FLIGHT MANAGEMENT SYSTEM

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NOVEL FUNCTIONAL REQUIREMENTS FOR A FUTURE FLIGHT MANAGEMENT SYSTEM

1 INTRODUCTION

An Action Group within the CARTEUR organisation has been in existence since the end of 1984 with the aim of identifying the functional and operational objectives which should be in a future integrated Air Traffic Management System to take advantage of the capabilities of flight management systems.

The Action Group has members from DFVLR (Federal Republic of Germany), NLR (Netherlands), RAE and RSRE (United Kingdom) and an invited member from the Eurocontrol Agency.

The major force acting for change towards an integrated ATM system in which the air and ground components actively cooperate is the rising traffic demand and the simultaneous need for the best possible economy of operation. Current systems, both air and ground, rely heavily on human estimation of future aircraft position and in particular that of the air traffic controller to estimate future aircraft relative position so that safety can be maintained. Whilst humans can become very skilled at such estimation, a high mental workload and considerable uncertainty are involved in this process. The consequence of this uncertainty is that for most aircraft the actual aircraft separations are substantially greater than the allowed minimum separations. This estimation workload is, of course, additional to that of communicating decisions and information between ground positions and air-to-ground. Thus, achieved capacity is limited in most cases by human workload in estimating, communicating and executing plans.

It is widely accepted that computer assistance is required to assist in these tasks, indeed on the air side it is virtually unthinkable to have a new aircraft without a flight management or area navigation computer already installed. Even when comparable technology is available and deployed on the ground side, the full potential of computer assistance will not be realised unless ground and air components operate together in an integrated fashion to their mutual benefit, i.e. a partnership.

In 1986, the Group published A Future Air Traffic Management Scenario which contained its ideas on the influences for change, the constraints and an outline description of how a future integrated ATM system could work.
The Group accepted that there was a need for a further paper which would be more detailed whilst recognising that there are, as yet, many unanswered questions. As a result, the Conceptual Model was devised which was seen as a working paper which reflected the current ideas of the Group but was also regarded as capable of being developed to include future ideas and results as they become available.

The aim of the Conceptual Model is to:

(a) Guide ATM research and development.

(b) Assist National Authorities in planning systems for the 1990s and beyond.

(c) Allow users and operators to understand how the benefits of greater traffic capacity and closer to optimum operation of aircraft would be achieved.

This Conceptual Model pointed out the requirement for many functions that are not available in currently operational FMSs; as a consequence the Group thought that it would be useful to produce a short working paper that would stimulate discussion of these new features.

The remainder of this paper summarises the ATM concepts, the new functions that a future FMS should have to operate in the new ATM system, a description of 4D or time based trajectories and the outline of an Experimental FMS defined as a research tool by European experimenters.

2. THE ATM CONCEPT

A full description of the Group's proposed concepts for a future ATM system is given in the Scenario (Ref 1) and the Conceptual Model (Ref 2) and only a brief summary of the principal features is given here:

(a) The system would be integrated, in that air and ground components would be in active partnership.

(b) Computer assistance would be extensively used both air and ground, but man would remain in charge.
(c) Greater capacity and economy would be achieved through the use of precision 4D (or time based) navigation.

(d) The system would be strategic rather than tactical with aircraft trajectories defined a few tens of minutes ahead.

(e) These trajectories would be defined in a process of negotiation between air and ground with allowed tolerances which reflected traffic demands and avionic capability.

(f) Within these tolerances, individual aircraft would have complete freedom to optimise their flight profile.

(g) Aircraft equipped to a lower standard would also be accommodated, but would create a greater workload for the ATC function and probably consume more airspace.

3 THE NEW FUNCTIONS THAT THE FMS MUST SUPPORT

The FMS must provide interfaces to:

(a) The remainder of an aircraft's avionic systems.

(b) A data communication network which incorporates one or more air/ground data links.

(c) Appropriate input and output devices to the pilot.

These interfaces are needed to support the following functions:

(a) Optimum trajectory construction under multiple constraints for submission to the pilot and to ATC.

(b) A trajectory negotiation process between an aircraft and the relevant ATC centre by exchange of data with the ground system.

(c) Execution of a resulting agreed trajectory via the Flight Guidance System.
(d) Monitoring of the trajectory execution process to detect and warn of deviations.

(e) Exchange of data with the ground system -

(i) To help create better weather data bases on the ground and in turn receive improved weather data.

(ii) To make available to ATC data on aircraft status, intention and flight tracking parameters.

The process of trajectory negotiation can be expressed in diagrammatic form as in Fig 1. Following the trajectory proposal by the aircraft, the ATC system will seek to allocate a trajectory which entails minimum global cost and is as close as possible to the trajectory proposed. It is important to realise that this trajectory negotiation process may be iterative.

A more detailed description of the process and the associated functions will be found in Ref 2, bound with this document.

To achieve these exchanges, international agreement would have to be reached on the data standards and coordinate systems to be employed.

4. 4D TRAJECTORY DESCRIPTION

In essence a 4D trajectory could be described as a line through 4D space. For practical reasons tolerances must be introduced and so the line becomes a tube. It can be imagined as a bubble moving through a tube such that its position as a function of time is known. It could also be regarded as an extension of today's separation standards which are defined in vertical, horizontal and longitudinal directions.

The bubble would have internal structure composed of three concentric regions. From the inside, these regions reflect the performance of aircraft navigation, ATC surveillance and any correction manoeuvre should an aircraft stray outside its agreed trajectory.
The three regions are defined as follows:

- manoeuvre space is the inner region. The aircraft is authorised to optimise its own trajectory within this space, subject only to remaining within this space. The minimum dimensions of manoeuvre space are determined by the aircraft's navigation accuracy.

- detection space, which surrounds manoeuvre space. It is there to allow the ATC surveillance process to detect that an aircraft has left its manoeuvre space. The minimum dimensions of detection space are determined by the accuracy of the surveillance system.

- intervention space, which surrounds detection space. This is the space necessary for an aircraft which has left its assigned manoeuvre space and penetrated detection space to be directed back into manoeuvre space. It is the responsibility of ATC to maintain separation between the intervention space associated with each aircraft.

5 A CONCEPTUAL MODEL FOR AN EXPERIMENTAL FLIGHT MANAGEMENT SYSTEM

As part of European collaborative effort to carry out research into future ATM systems, an Experimental Flight Management System has been defined as a necessary research tool.

This tool was defined so as to provide maximum flexibility for research purposes and was not intended to be a model for any commercial system. Nevertheless some of the ideas outlined might be useful in future commercial systems. A full description is available in Ref 3; the following is a summary of that paper.

The EFMS will not require the complexity and integrity of full commercial equipment; indeed, for use with purely ground based simulation, many elements of such equipment are entirely superfluous (e.g navigation, sensor management etc). However, two issues are crucial. Firstly, researchers must, in the light of their experiments, be able to develop and modify algorithms incorporated in the EFMS. Secondly, complementary research activities will need to exchange the products of their work (in the form of algorithms and/or software modules, such that they could be incorporated in each others' experiments with minimal effort.
The above requirements point strongly to the need for a structured and modular EFMS design. The document lays the foundation of such a design, by describing a conceptual model of an EFMS, consisting of a network of interacting 'functional elements'. It defines a minimum subset of 'information objects', providing communication between the elements, that is considered essential to support ATM research. It is believed that this approach will offer the flexibility to accommodate most foreseen experiments, while also providing sufficient structure to achieve compatibility between cooperating research groups.

The relationship between the functional elements and their lines of communication are shown in Figure 2.

The model includes only the minimum subset of functional elements and information objects that are considered strictly necessary to provide functionality essential for ATM research. Furthermore, both general architecture and definition of the information objects are, as far as possible, non-specific to particular ATM concepts, profile types, or guidance algorithms. These have been deliberate policies, so as not to constrain research activities unnecessarily, and also to allow maximum possible freedom for the physical realisation of the Conceptual Model.

The term information object was coined to represent classes of information. Three kinds of information object were defined, namely:

(i) Classes of information produced by a single element which are then broadcast at regular intervals for use by other functional elements. Seven types of broadcast object were distinguished, some examples are the aircraft state vector, the list of active trajectory constraints and the predicted flight profile.

(ii) Dialogue information objects exchanged between cooperating elements, this class was sub-divided into:

(a) Management information objects, of which only two were defined, associated with editing and activating the list of constraints.
(b) Database information objects, of which ten were defined. Examples include query ATM data, query weather data update, temporary ATM data, update weather data.

References


Fig 1. The trajectory Negotiation Process
Fig 2. EFMS Functional Elements
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