INTEGRATION OF FLIGHT MANAGEMENT AND AIR TRAFFIC MANAGEMENT SYSTEMS

SUMMARY

This Memorandum is the Interim Report of GARTEUR Action Group FM AG03. This Group considers the Integration of Flight Management and Air Traffic Management systems. The Report introduces the Group's task, the relevant research programmes in NLR (Netherlands), DFVLR (West Germany) and RAE/RSRE (UK). It identifies the need for an ATM Scenario and the areas needing further research. The Report is concluded by a description of the proposed programme for the Group's second year's work. The ATM Scenario document (GARTEUR TP 024) provided earlier by the Group has been included as an Appendix for reference.

GARTEUR TP 024 and TP 025 prepared under the auspices of the Responsibilities for Flight Mechanics of the Group for Aeronautical Research and Technology in Europe.

Departmental Reference No: 666

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1987
## LIST OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
</tr>
<tr>
<td>2</td>
<td>THE NATIONAL PROGRAMMES IN THE RESEARCH ESTABLISHMENTS</td>
</tr>
<tr>
<td>2.1</td>
<td>The nature of ATM research</td>
</tr>
<tr>
<td>2.2</td>
<td>The NLR programme</td>
</tr>
<tr>
<td>2.3</td>
<td>The DFVLR programme</td>
</tr>
<tr>
<td>2.4</td>
<td>The RAE/RSRE programme</td>
</tr>
<tr>
<td>2.4.1</td>
<td>The RSRE programme</td>
</tr>
<tr>
<td>2.4.2</td>
<td>The RAE programme</td>
</tr>
<tr>
<td>3</td>
<td>NEED FOR AN ATM SCENARIO</td>
</tr>
<tr>
<td>4</td>
<td>SIGNIFICANT GAPS IN KNOWLEDGE OR RESEARCH</td>
</tr>
<tr>
<td>4.1</td>
<td>Air/ground integration and division of responsibility</td>
</tr>
<tr>
<td>4.2</td>
<td>Data communication and the data link</td>
</tr>
<tr>
<td>4.3</td>
<td>Improved meteorological data</td>
</tr>
<tr>
<td>4.4</td>
<td>The man in the loop</td>
</tr>
<tr>
<td>4.5</td>
<td>The benefits and the costs</td>
</tr>
<tr>
<td>5</td>
<td>GROUP ACTIVITIES FOR ITS SECOND YEAR</td>
</tr>
<tr>
<td>Appendix</td>
<td>Membership of GARTEUR Group FM AG03</td>
</tr>
<tr>
<td>Enclosure</td>
<td>A FUTURE AIR TRAFFIC MANAGEMENT SCENARIO</td>
</tr>
</tbody>
</table>

Report documentation page
1 INTRODUCTION

Discussions in GARTEUR committees and elsewhere over the past few years have highlighted the research and development work being carried out in many countries with a view to improving the Air Traffic Control (ATC) system; these researches all point to the increased use of computer automation in future ATC systems. At the same time commercial pressures are increasingly forcing the adoption of digital avionic systems in all major civil aircraft; the resulting capabilities of enhanced navigation, performance management and precision of flight have been so significant in saving fuel and other costs that the use of such systems has spread to older and smaller aircraft. It has been realised that the maximum benefit will only be obtained from this investment in ground and airborne systems when both are integrated together into a future total Air Traffic Management (ATM) System.

A proposal to form a GARTEUR Action Group to study the integration of Flight Management and Air Traffic Management Systems was developed by staff from NLR (Netherlands), DFVLR (Federal Republic of Germany) and RAE (United Kingdom) and finally approved by the Executive Committee and Council of GARTEUR in mid 1984. This Action Group FM AG03 has members drawn from the above three establishments plus an invited member from RSRE (United Kingdom). The chair is currently held by the UK.

Working from the basis of the current national programmes, the Action Group will identify the functional and operational objectives which should be incorporated in an overall Air Traffic Management system to take full advantage of the developing flight management systems and to identify the fields in which research is required, as such the feasibility of a future ATM system can be explored. A further goal is to propose a future cooperative programme which might involve the research aircraft of the three nations combined with one or more representative simulations of the future ATC systems, to explore the problems generated and the potential advantages to be gained by the combination of advanced avionics and ground systems in a busy, complex ATC environment.

The Action Group has had four meetings in the period November 1984 to November 1985; this has produced detailed descriptions of the ATM related research programmes in NLR, DFVLR and RAE/RSRE and a discussion Paper entitled a Future Air Traffic Management Scenario.
The programme for the second year will seek to define the areas of research needed to move towards future ATM systems and to identify areas where the research establishments can usefully collaborate.

2 THE NATIONAL PROGRAMMES IN THE RESEARCH ESTABLISHMENTS

2.1 The nature of ATM research

There are relevant research programmes in the research establishments of the Netherlands, the Federal Republic of Germany and the United Kingdom. Although obviously there are differences between the programmes they have in common the premise that increasingly sophisticated avionics will provide three-dimensional (3-D) and four-dimensional (4-D) navigation of great accuracy and correspondingly precise trajectory control and that Air Traffic Control must evolve to cope with the anticipated growth in air traffic and customer demands for increased cost efficiency.

Because the civil air transport industry is international and governed by international rules and procedures and because investment cycles are long and expensive, improvements tend to be slowly implemented over many years. This in turn means that virtually all research in the ATM area is very long term research, indeed it is probably that many of the concepts being worked on now will not be in operational use until after the turn of the century.

2.2 The NLR programme

In the Netherlands the National Aerospace Laboratory, NLR, is engaged in ATC and avionics research. NLR operates two research aircraft (a Swearingen Metro II and and Beechcraft Queen Air) as well as a moving base research flight simulator.

Facilities

There are plans to equip the Metro with the following systems:

- Navstar GPS.
- Microwave Landing System (MLS).
- Inertial Reference System (IRS).
- Programmable Electronic Flight Instrument System (EFIS).
- Programmable Flight Management System (FMS).
- Programmable Flight Control Computer (FCC).
- Side-stick controller.
- Interface with digital data link.
- Digital VOR, DME, ADC.
- Digital data recorder.

Where possible ARINC 700 series equipment will be used. Some of the equipment is already installed in the METRO or available at NLR, e.g. a GPS receiver. A programmable EFIS has recently been ordered. A position determination system developed by NLR based on multiple-DME may be used as a reference system. Plans are to use a ROLM computer, of which NLR employs several for flight test purposes, to incorporate the FMS and FCC functions. An initial avionics capability for the Metro based on EFIS with standard avionics systems is scheduled for mid 1987.

The research flight simulator will also be equipped with EFIS in 1986.

For the investigation of the operation of aircraft fitted with modern avionic systems in coordination with ATC, it is planned to employ a digital data link between the Metro and an ATC research simulator that NLR will develop and equip over the next 3 or 4 years.

The research programme

NLR's flight test activities will include research in the areas of:

- establishing MLS procedures for straight-in and segmented approaches,
- use of Navstar GPS as a navigation and approach aid,
- Four-dimensional (4-D) guidance and control,
- conventional and unconventional displays with the EFIS,
- coordination between aircraft and ATC,
- digital flight control,
- flight safety.

The flight simulator is used for research related to advanced aircraft control systems, handling qualities, human factors, MLS and ATC. Furthermore, NLR carries out studies, together with the Dutch Civil Aviation Department, for the definition of present and future ATC systems. Emphasis has been laid on aircraft trajectory prediction, planning conflict search, radar data processing and also on future ATC system concepts.

2.3 The DFVLR programme

In the Federal Republic of Germany the German Aerospace Research Establishment, DFVLR, is engaged in long term research programmes on integrated
air traffic and flight management associated with relevant avionics and aircraft technologies. Particular consideration is given to the role of the human operator in increasingly automated guidance and control systems.

Facilities

The Advanced Technologies Testing Aircraft System (ATTAS) Aircraft.

By fall of 1985 DFVLR had taken delivery of their new ATTAS VFW 614 research aircraft. ATTAS will be used for fundamental research activities in aircraft technology, flight mechanics and flight control, avionics and operational procedures. This aircraft carries an experimental fly-by-wire system, powerful computers and an extensive fit of various sensors which are all accessible to the user via standard interfaces. A comprehensive ground rig offers all hardware and software components needed to test and flight-qualify experimental equipment.

ATTAS will carry a removable single-seat experimental cockpit in the rear cabin called the Airborne Experimental Cockpit (AEC). The AEC is designed to interface with the fly-by-wire flight control system and the sensor system of the ATTAS aircraft. A four-screen EFIS consisting of flexibly programmable standard A310 hardware is used to realize advanced information concepts for the aircrew.

Initially the AEC will give the ability to pilot the ATTAS aircraft be means of a side-stick controller, command control modes, and autopilot modes. Implementation, flight certification and qualification for experimental use are expected to be finished during 1987. A subsequent upgrading would include an experimental FMS in conjunction with refined displays and intelligent speech understanding.

The Air Traffic Management and Operations Simulator (ATMOS).

ATMOS is a fully operational simulation complex intended to investigate in real time complex present and future ATM scenarios. The general set-up is centred around a comprehensive and versatile ATC simulation which provides for a realistic representation of air traffic operations at two controller workstations. Optionally the simulation may include a moving base flight simulator and finally the ATTAS aircraft in flight to realise a closed-loop ATM scenario with real controllers and aircrew. ATMOS offers standard interfaces to integrate user hardware and software. Until the end of 1986 ATMOS will host the COMPAS project. Future work will deal with intelligent controller/link
communication and the simulation of new Communication, Navigation and Surveillance (CNS) concepts in the framework of the ICAO FANS committee on Future Air Navigation Systems.

The research programme:

- Four-dimensional (4-D) guidance.

Flight-proven hardware and software will be expanded to accommodate more economic flight profiles aiming at improved matching of the TMA and en-route flight phases. On-board flight planning will rely on enhanced wind filtering in the horizontal and vertical plane. Cooperative interfacing with the ATM system and flexible reaction to its planning needs are the prime concern of this four-dimensional (4-D) guidance approach.

- Pilot's workstation.

One major focus of research is the optimization of aircrew workstation functions, design and procedures. Future work will concentrate on integrated ATM-compatible FMS layout and improved operator/system interfaces. In addition a comprehensive set of tools for human factors related overall system performance assessment is being continuously expanded and refined.

- Computer-aided Air Traffic Management (COMPAS).

Currently an extensive experimental programme involving DFVLR and BFS (German Federal Administration for Air Traffic Services) has been carried out to study operational and controller related implications of computer-aided planning procedures taking the Frankfurt/M TMA inbound traffic as an example. The philosophy of COMPAS (Computer-Orientated Metering Planning and Advisory System) provides for an adequate sharing of tasks between computer-based overall planning capability and controllers' professional skills to fine-tune system performance. An extension of the system concept to higher levels of Air Traffic and Flight Management including mode S datalink communication is under consideration. Detailed results will be available by end of 1986.

- The data link man/machine interface.

Special attention is being devoted to operationally crucial aspects of future air/ground communication. Studies are envisage to improve man/machine interaction in aircrew and ATC workstations by natural language conversation with Artificial Intelligence (AI) based components
in Air Traffic and Flight Management. Intelligent speech understanding will play a major role to enhance speed, reliability and efficiency in air/ground data exchange via mode S or satellite digital datalinks.

The activities described all serve the prime aim of improving ATM efficiency by increased automation and to ensure the adequate involvement of the human operator in emerging new technologies and procedures.

2.4 The RAE/RSRE programme

In the UK work on ATM is divided between two research establishments, RSRE Malvern where ATC research is carried out and RAE Bedford which concentrates on avionic aspects.

2.4.1 The RSRE programme

The ATC related work at the Royal Signals and Radar Establishment, (RSRE) is funded by the UK Civil Aviation Authority and is concentrated entirely in one division.

Facilities

Facilities available include an ATC simulation on a Dec VAX 780 with several controller positions, an experimental mode S radar station, data link terminals and other computing facilities. In addition, the division can call upon the software and hardware expertise elsewhere in the establishment.

The research programme

SSR research:

Work has gone on for many years to identify factors which degrade ground based radar performance and seeks to develop solutions to these problems. Recent developments include monopulse radar operation, the use of shaped elevation polar diagrams and the use of diffraction fences.

Mode S radar research:

The division has been active in this area since ADSEL/DABS were first defined. An experimental mode S radar station has been developed and based at RSRE, it will be joined to a second station situated at Gatwick Airport in 1987. The programme seeks to develop and evaluate all the hardware and software techniques that will be needed for a mode S based surveillance system.
Radar data processing:

An activity that investigates the options available for radar data processing and tracking with special emphasis on multiple radar networks.

Data link research:

This group investigates the technological and systems aspects of the use of air-ground data links. There is obviously special emphasis on the data link function provided by mode S radar for use in a future air traffic management system. An experimental mode S data link network is being constructed in conjunction with RAE Bedford and the CAA.

ATC system research:

This group carries out research into the management of air traffic operations and how computer assistance can be implemented. A special target will be the implementation of such techniques into the London ATC Centre by 1995. The research relies heavily on the use of system modelling and the ATC simulator to assess new techniques and system components and especially the interface between the controller and the computer aids.

Software engineering:

Involves the development of software tools and techniques to achieve software of high integrity and high reliability.

ACAS:

This activity studies the operation of Airborne Collision Avoidance Systems (ACAS) and also the operational implications of such systems with special reference to UK airspace.

IKBS and DVI:

There is a low level of activity examining possible applications of Intelligent Knowledge Based Systems (IKBS) and Direct Voice Input (DVI) systems in a future computer aided ATM system.

Satellites:

There is also a low level of activity examining the roles that satellite based systems might have in future.
2.4.2 The RAE programme

Facilities

The ATM work at the Royal Aircraft Establishment, RAE is centred on a BAC 1-11 jet aircraft equipped as a flying laboratory. The aircraft is fitted with an EFIS based on 8 inch square colour CRT displays, an experimental FMS, an automatic speech recogniser for Direct Voice Input studies, a versatile experimental autopilot, general computing and a comprehensive range of navigation aids. The aircraft is supported by a ground development rig and normal computing and laboratory support.

The research programme

Product development support:

The nature of the aircraft allows the testing, development and even the demonstration of products or systems from UK industry to be readily accommodated.

Control law development:

A small group pursues the development of improved control laws that exploit modern computing hardware and should lead to better control and/or lower operating cost. Developments are tested in flight in the experimental versatile autopilot.

The man-machine interface:

Modern flight decks have probably reduced the pilot workload to a point where further reduction would bring no benefit. However in the advanced ATC scenarios of the future the flight paths, constraints and communications will be more complex. This part of the programme examines what can be done using colour CRT displays and novel input techniques such as DVI, roller-ball driven cursors and touch screen displays to improve this interface.

Air traffic management:

This topic includes improved two-dimensional (2-D) and three-dimensional (3-D) navigation, four-dimensional (4-D) navigation, data link integration and exploitation and the integration of air and ground systems to act as prototypes of future ATM systems. An important goal is to link the BAC 1-11 to one of the RSRE simulations via a data link to demonstrate the necessary capabilities and explore the problems of such control.
These activities are supported by cost benefit studies undertaken by a nearby university, the Cranfield Institute of Technology.

3 NEED FOR AN ATM SCENARIO

During the Action Group's discussions, it has become clear that although each establishment had firm views on aspects of a future system, each had concentrated on its own areas of specialisation. It seems therefore that it would be helpful to pool ideas on what driving forces and limitations would play a part in shaping a future ATM system and to develop some broad system-based but realistic views of how such a system might operate. It was felt that a future ATM scenario should be defined in order to provide a framework to help assess the benefits of the integration of Flight Management and Air Traffic Control systems.

It was the view of the Action Group that the ATM scenario might be of wider interest and so the agreement of the GARTEUR Executive Committee has been sought to circulate it as a discussion Paper; for the is reason the scenario has bee produced as a short self-contained Annex to this interim Report but has its own GARTEUR TP (TP 024) number to allow wider circulation.

4 SIGNIFICANT GAPS IN KNOWLEDGE OR RESEARCH

It is clear that most of the current researches are concentrating on isolated items of technology, such at ATC algorithms, data link development and four-dimensional (4-D) navigation capability; there is, however, a class of problems that only emerge when complete or partial systems are constructed from individual items. On the whole these large scale system issues are not yet being addressed. Some such issues are:

(i) How should the functions of planning, monitoring and control be partitioned between air and ground.

(ii) How should the data link function be used.

(iii) How to improve meteorological data to support these operations.

(iv) How to keep the man-in-the-loop adequately involved, informed and motivated.

(v) What overall improvements in capacity and cost benefit can be realised and at what cost.

The following sections discuss these topics in more detail.
4.1 Air/ground integration and division of responsibility

Discussion of this issue is always complicated by the background from which it is viewed, the air traffic controller tends to the view that the ground system is the ideal location to make all decisions. The avionics researchers emphasise the current level of sophistication seen in modern aircraft will continue to increase and should be exploited to enhance overall efficiency. It should be possible, however, to write down some overall ground rules that could be agreed by both communities. Some of these are:

(a) The best model of the aircraft's performance, its costs and capabilities will reside in the aircraft's computers. One may deduce that the aircraft should propose a trajectory and possibly bid for a time slot.

(b) The only viable model of the overall ATC situation is in the ATC system and its computers, therefore the ground based system should retain the overall adjudication, safety and optimisation functions. It must allocate slot times and trajectories and arbitrate between conflicting requirements.

(c) Air and ground system should agree on the description of a partial or complete trajectory to ensure that it is practical and safe, which the aircraft must then execute.

(d) The ground system should provide a monitoring function against significant deviations from these agreed trajectories.

(e) Provision must be made for modification of this trajectory to cope with unexpected events.

Within these guidelines there is considerable choice in the degree of automation, the division between air and ground computation, how to describe trajectories, how to navigate and control and how large separation distances need to be.

4.2 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 4.1.

Two likely candidates for the data link medium can be identified, the data link offered by mode S surveillance radar and later on, 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.

4.3 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 (4-D) 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. Parameters to be determined are the accuracy and resolution needed for trajectory prediction as well as the likely accuracy to be achieved by the above technique.

4.4 The man in the loop

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 prediction 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 monitoring progress against these predictions. This change introduces major problems in producing user interfaces such as novel displays and formats to portray three-dimensional (3-D) and four-dimensional (4-D) trajectories in an understandable form and raises potential problems of retaining motivation and arousal to cope with rare unexpected events.

4.5 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 do so. 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.

It is beyond the capacity of the present Action Group to do more than indicate some of the technical gains to be made, but the need for such broad scale cost benefit studies should not be forgotten.

5 GROUP ACTIVITIES FOR ITS SECOND YEAR

The Group was of the opinion that it was still too early to define detailed collaboration programmes directly addressed to the problem areas described in section 4. Instead it felt that there was a need to continue the system approach (as exemplified by the ATM scenario) that has been adopted so far.

The Group therefore felt that it was important to further discuss the ideas described in the ATM scenario and in this Report as widely as possible in the international community. This process should ensure that only viable philosophies and concepts survive.

Also recognised was the need to convince the ATC authorities when necessary that a shift to an increasingly automated strategic ATM system is justified. Part of the performance analysis effort must be aimed at this demonstration.

It was agreed that the following three point plan be adopted:
(a) The advanced ideas and concepts described in the future ATM scenario and in this Report should be discussed as widely as possible in the international ATC community. This process should converge on a widely accepted ATM concept.

Action Group members are already represented on/or have an input to:

ICAO
- FANS committee and some of its sub groups.
- SICASP

Eurocontrol - Mode S Data Link Working Group
- The Advanced Radar Control for the year 2000 programme (ARC 2000)


(b) To develop from the ideas so far described an increasingly detailed conceptual mode of an ATM solution. This would be expected to develop into a test bench on which to assess system performance data as it became available. This process would be expected to reveal any flaws that are contained in the concept and lead to their correction.

(c) Using performance data obtained from the many existing ATM research programmes and the model described above, assess the operational benefits that can result.

(d) By iterating steps (b) and (c) a sound ATM concept should emerge together with a good indication of system sensitivities and benefits.

Issues which should be addressed in this process are the further exploitation of air-ground integration and function assignment, the role of the data link and the achievable benefits of improved met forecasting. This process is unlikely to address the issue of implementation cost.

It would therefore seem appropriate to press others to attempt the broad system cost benefit studies which will eventually provide the justification for the adoption of the advanced systems that are currently being developed.

To achieve this and produce the Action Group's final Report by mid 1987 will need considerable effort and it is expected that the Group will need to hold 4 two day meetings.
It is therefore likely that the Group will have to dwell on broad issues for several meetings and that plans for future collaboration will still be defined in very broad terms. Detailed design of subsequent experiments will have to be attempted after the demise of this Group.
Appendix

MEMBERSHIP OF GARTEUR ACTION GROUP FM AG03

P. England (Chairman), RAE (Bedford) United Kingdom
P. Humphrey, RSRE United Kingdom
J. Thomas, DFVLR, Federal Republic of Germany
T. Hagenberg, NLR Netherlands
T. Dalm, NLR Netherlands
A FUTURE AIR TRAFFIC MANAGEMENT SCENARIO

A discussion Paper produced by GARTEUR Action Group FM AG03

March 1986

GARTEUR TP 024 prepared under the auspices of the Responsables for Flight Mechanics of the Group for Aeronautical Research and Technology in Europe.
# LIST OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTRODUCTION</td>
<td>3</td>
</tr>
<tr>
<td>2. ATM DEFINITION</td>
<td>3</td>
</tr>
<tr>
<td>3. ATM CHARACTERISTIC PARAMETERS</td>
<td>3</td>
</tr>
<tr>
<td>4. ATM OBJECTIVES</td>
<td>3</td>
</tr>
<tr>
<td>5. CHARACTERISTICS OF PRESENT DAY ATM</td>
<td>4</td>
</tr>
<tr>
<td>6. BROAD DIRECTION OF CHANGE</td>
<td>4</td>
</tr>
<tr>
<td>7. CONSTRAINTS AND CONDITIONS ON CHANGE</td>
<td>5</td>
</tr>
<tr>
<td>8. SOME SIGNIFICANT DEVELOPMENTS</td>
<td>5</td>
</tr>
<tr>
<td>9. ELEMENTS OF A FUTURE SCENARIO</td>
<td>6</td>
</tr>
<tr>
<td>10. SUGGESTIONS FOR FURTHER STUDY</td>
<td>7</td>
</tr>
<tr>
<td>11. ORGANISATIONS ACTIVE IN THE DEVELOPING ATM SCENE</td>
<td>8</td>
</tr>
<tr>
<td>Annex 1 Membership of GARTEUR Action Group FM AG03</td>
<td>9</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

This short discussion document has been produced by the members of GARTEUR Action Group FM AG03. The Group has members from NLR, DFVLR, RAE and RSRE; their task is to examine the necessary future integration of FMS and ATM systems. It was felt that a future ATM Scenario should be defined in order to provide a framework to help assess the benefits of the integration of Flight Management and Air Traffic Control Systems. This scenario was seen as an essential foundation to the work of the Action Group and the individual research programmes on data links, ATC systems and FMS being carried out in the national research establishments. It may contribute to useful discussion in the wider international debate taking place on future ATM systems.

2 ATM DEFINITION

Air Traffic Management is the term used to describe the total system, ground and air, needed to ensure the safe and efficient movement of aircraft, in all phases of operation. It covers airborne equipment (such as Flight Management Systems), the Air Traffic Control (ATC) systems, and in particular the procedures to integrate the two.

3 ATM CHARACTERISTIC PARAMETERS

An ATM scenario may be characterised by the following set of quantifiable parameters:

(i) Traffic load, and mix of aircraft types and avionic capabilities, as a function of time.

(ii) Airspace Architecture (including air routes and airports).


(iv) Information Services. (Current examples at ATIS, VOLMET, FIS etc.)

(v) Air Traffic Control Services.

(vi) Cooperation and Integration of Air and Ground Systems.

4 ATM OBJECTIVES

Air Traffic Management must aim to achieve:

(1) Maintenance or improvement of established safety levels.

(ii) Efficiency - important elements of which are:

(a) Cost of implementation (both air and ground).
(b) Direct operating costs (including time and fuel cost).

(c) Capacity (airspace and runway).

But note that different operators and authorities would place different priorities on these aspects of efficiency.

(iii) Ability to meet individual user requirements.

These elements are inter-related and the relationships may well be very complex, but as an example, reduced direct operating costs could result from greater ability to achieve individually optimised flight profiles, achieved in turn through investment in greater capability (both in the air and on the ground).

5 CHARACTERISTICS OF PRESENT DAY ATM

Present day control of aircraft is not seen as being 'optimal' in the widest sense of efficiency. Without proper measures this lack of efficiency will increase in the future because of predicted growth in air traffic. In particular:

(i) The information flow within and between ATC organisations and the aircraft under their control is insufficient to support improvements.

(ii) ATC needs more sophisticated algorithms for prediction and optimisation.

(iii) Despite long term planning, ATC often relies on tactical intervention to resolve conflicts. Hence only limited accommodation of strategically optimised flight profiles is achieved.

(iv) The capability of airborne equipment in the fields of planning and optimisation has outstripped that of the ground system to support it. Operators are pressing to be able to more fully exploit such capabilities.

(v) Route structures are inflexible, based as they are on the location of navigation aids. Increasingly direct routings are allowed in quiet conditions.

6 BROAD DIRECTION OF CHANGE

(i) Improved handling and transfer of information between operators, aircraft and ATC centres.

(ii) Provision of facilities on the ground to assist in prediction, optimisation and monitoring, together with effective man-machine communication.
(iii) Resolution of conflicts more strategically, over longer time horizons.
(iv) Improved en-route capacity through exploitation of more accurate three-dimensional (3-D) navigation, and use of longitudinal (i.e., time) navigation and control to increase capacity of junctions and terminal areas.
(v) Improved accommodation of a flight's preferred profile in all phases of flight, based on company objectives.

7 CONSTRAINTS AND CONDITIONS ON CHANGE

These guidelines for change should be observed:

(1) Must maintain safety 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 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 not be unreasonable.

8 SOME SIGNIFICANT DEVELOPMENTS

A number of new capabilities and systems are evolving, and will undoubtedly form components of ATM in the future. Examples include:

(i) Improved ATC algorithms to aid sequencing, conflict prediction and resolution.
(ii) FMS algorithms to provide multiple constraint four-dimensional (4-D) navigation, which are fuel and cost efficient.
(iii) Developments in man-machine communication, such as displays and novel interaction devices.
(iv) Improved communication/navigation/surveillance systems (eg mode S SSR, MLS).

(v) Developments in satellite technology, potentially providing universal communication/navigation capabilities.

9 ELEMENTS OF A FUTURE SCENARIO

(i) 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, then the departure problem 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. This would required 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.

(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 cost-effectively absorb errors, eg 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.

(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 are apparent:

(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.

10 SUGGESTIONS FOR FURTHER STUDY

(i) A collaborative demonstration of principle would required more specific description of a number of aspects of the scenario than has occurred so far. In particular:

(a) Broad description of FMS and ATC functions to participate in this scenario.

(b) Minimum set of parameters to describe aircraft's cost sensitivities for collective optimisation.

(c) 'Rules' for collective optimisation.

A major force towards change in the ATM system must be the end users, responding to demonstrable cost benefits. An important goal must therefore be the study of cost-benefit implications of the proposed methodology. Such analysis needs to be applied in the context of the total concept to produce meaningful results, although this should include cost sensitivities of more specific components, e.g. provision of improved meteorological forecasts. However, this is a complex issue, and is possibly outside the scope of this Group.
ORGANISATIONS ACTIVE IN THE DEVELOPING ATM SCENE

(i) ICAO
   - FANS Committee.
   - SICASP.

(ii) Eurocontrol
     - ATC Systems Concept Group.
     Data Link Working Group.
     Navigation and Separation Panel.

(iii) Euro CAE
     - MNPS Group.

(iv) ARINC
     - Developing future airborne system architectures.

(v) NASA/FAA
    - Working on a wide spectrum of air and ground capabilities
      eg National Airspace Plan, ATOPS program.

(vi) RTCA SC 155
     - Developing the future CNS.
Appendix

MEMBERSHIP OF GARETEUR ACTION GROUP FM AG03

P. England (Chairman), RAE (Bedford) United Kingdom
P. Humphrey (invited member), RSRE United Kingdom
J. Thomas, DFVLR, Federal Republic of Germany
T. Hagenberg, NLR Netherlands
T. Dalm, NLR Netherlands
Integration of flight management and air traffic management systems

Air traffic management. Flight management. Air traffic control.

This Memorandum is the Interim Report of GARTEUR Action Group FM AG03. This Group considers the Integration of Flight Management and Air Traffic Management systems. The Report introduces the Group's task, the relevant research programmes in NLR (Netherlands), DFVLR (West Germany) and RAE/RSRE (UK). It identifies the need for an ATM Scenario and the areas needing further research. The Report is concluded by a description of the proposed programme for the Group's second year's work. The ATM Scenario document provided earlier by the Group has been included as an Appendix for reference.