AGARD-R-811

# AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

**AGARD REPORT 811**

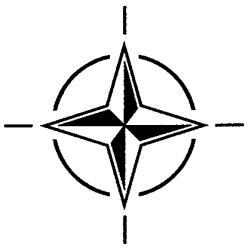
# Twenty-five Years of Contributions to Air Traffic Handling (Research, Development, Operations and History): a Bibliography

(Vingt-cinq années de contributions au contrôle du trafic aérien (recherches, développement, opérations et historique): une bibliographie)

Edited by
**Dr. André BENOÎT**

*This Report has been sponsored by the Mission Systems Panel of AGARD.*





**NORTH ATLANTIC TREATY ORGANIZATION**

Published February 1996

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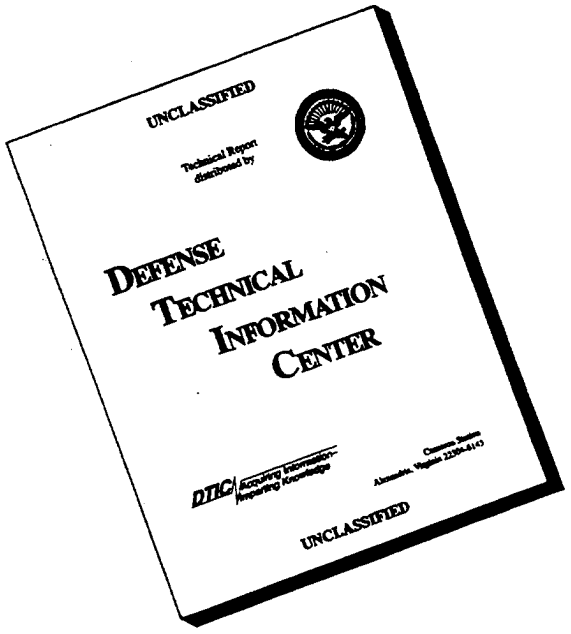


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# Twenty-five Years of Contributions to Air Traffic Handling (Research, Development, Operations and History): a Bibliography

(Vingt-cinq années de contributions au contrôle du trafic aérien (recherches, développement, opérations et historique): une bibliographie)

Edited by

**Dr. André BENOÎT**
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This Report has been sponsored by the Mission Systems Panel of AGARD.



North Atlantic Treaty Organization
*Organisation du Traité de l'Atlantique Nord*

# The Mission of AGARD

According to its Charter, the mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;
- Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Exchange of scientific and technical information;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.



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# Twenty-five years of Contributions to Air Traffic Handling (Research, Development, Operations and History): a Bibliography

## (AGARD R-811)

# Executive Summary


The Air Traffic Control Community has appreciated the quality and value of the forum offered by AGARD and continuously supported the related activities. "... *No conferences or organizations, and that includes those in the US, have equalled these AGARD meetings in bringing together the world's leaders in ATC research and in providing a venue for presenting original research papers of the highest technical quality. Unlike other ATC meetings I could name, here the tradition is technical depth, not superficial round table discussions by managers...*".*

The contributions of AGARD to the Handling of Air Traffic have been essentially generated by the Guidance and Control Panel, which since 1970 has sponsored five symposia (Edinburgh, Scotland, 1972; Cambridge, Mass. USA, 1975; Copenhagen, Denmark, 1979; Brussels, Belgium, June 1986; Berlin, Germany, October 1993), one specialists meeting (Lisbon, Portugal, 1982), one specialist mission (Rome, Italy, 1980), and three AGARDographs (1975, 1990, 1994) totalling twelve volumes, addressing most of the areas of this complex but challenging field.

Automatic generation of control advisories remains a key issue and the question "*The air traffic controller facing automation: conflict or co-operation*?" is still — even more than ever — very pertinent. Similar remarks apply to other issues raised 25 years ago, both for major concepts and subsystems options.

The material available in these AGARD volumes covers most of the developments undertaken during this period, pursued or abandoned, and through the associated bibliographies they connect the reader with the entire Air Traffic Control Community.

For such reasons and some others, it was thought beneficial to assemble in some *thesaurus-index form*, the summaries of all presentations recorded in the AGARD Guidance and Control forum on the Handling of Air Traffic, together with a detailed subject index, a list of the authors, other contributors and GCP Panel Officers.

To illustrate the evolution of the overall programme of work over this period, the prefaces to these 12 volumes have been reproduced in facsimile and attached in an annex.


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* *Dr. Heinz Erzberger, Aircraft Guidance and Navigation Branch, NASA Ames Research, USA.*
**"Machine Intelligence in Air Traffic Management"**, *Berlin, Germany, 14 May 1993.*

# Vingt-cinq années de contributions au contrôle du trafic aérien (recherches, développement, opérations et historique): une bibliographie

## (AGARD R-811)

# Synthèse

La communauté du contrôle du trafic aérien a apprécié la qualité et la valeur du forum offert par le Groupe consultatif pour la recherche et le développement aérospatiaux, AGARD. Cette communauté a toujours encouragé les activités proposées par ce groupe consultatif. «... *Aucune conférence ou organisation, y compris celles des États-Unis, n'a atteint le niveau des réunions AGARD, celles-ci ayant contribué à réunir en un même lieu les meilleurs experts mondiaux dans le domaine de la recherche ATC, offrant à chacun l'opportunité de présenter des publications de recherche originales, de grande qualité technique. Au contraire d'autres réunions ATC que je pourrais citer, ici la tradition est de s'attacher à la recherche technique approfondie et à ne pas se limiter à des tours de table superficiels réalisés par des gestionnaires ...*».

Ces contributions à la gestion du trafic aérien sont essentiellement l'œuvre de la *Commission guidage et pilotage*, qui, depuis 1970, a organisé cinq symposia (Édimbourg, Écosse, 1972; Cambridge, Massachusetts, USA, 1975; Copenhague, Danemark, 1979; Bruxelles, Belgique, 1986; Berlin, Allemagne, 1993); une réunion de spécialistes (Lisbonne, Portugal, 1982); une mission pour spécialistes (Rome, Italie, 1980); trois AGARDographies (1975, 1990 et 1994), constituant douze volumes traitant de la plupart des aspects de ce domaine complexe mais stimulant qu'est le traitement du trafic aérien.

L'automatisation de la génération des instructions de contrôle demeure un domaine de recherche quasiment fondamentale et la question «*le contrôleur du trafic aérien face à l'automatisation: conflit ou coopération*?» reste — plus que jamais — d'actualité. Il en est de même pour bien d'autres problèmes soulevés au cours de ces vingt-cinq années, qu'il s'agisse d'options secondaires portant sur des sous-systèmes ou même du choix de concepts majeurs.

Les informations disponibles dans les publications AGARD couvrent la plupart des développements entrepris durant cette période, qu'ils fussent abandonnés, poursuivis ou devenus opérationnels. De plus, au travers des bibliographies présentées, les publications AGARD établissent un lien entre le lecteur et pratiquement l'ensemble de la communauté de recherche et de développement du contrôle du trafic aérien.

C'est pour ces diverses raisons qu'il nous sembla bénéfique de réunir dans cet ouvrage la grande majorité des présentations enregistrées dans les réunions de la Commission guidage et pilotage et consacrées à la gestion du trafic aérien. Cet ensemble est complété par un index analytique et une liste des contributeurs: auteurs, autres responsables et représentants de la Commission guidage et pilotage.

Afin d'illustrer l'évolution générale des programmes proposés au cours de cette période, les préfaces de ces 12 volumes ont été reproduites en fac-similé et jointes en annexes.

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* *Dr. Heinz Erzberger, Aircraft Guidance and Navigation Branch, NASA Ames Research, USA.*
«**L'intelligence artificielle dans la gestion du trafic aérien**», *Berlin, Allemagne, 14 mai 1993.*

# Contents

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**ACKNOWLEDGEMENT/REMERCIEMENTS**

The Programme Director wishes to express his appreciation to the Mission Systems Panel for the publication of this Report.

*Le Directeur du programme tient à remercier la Commission missions et systèmes pour la publication de ce rapport.*

# Contributions of the
# Guidance and Control Panel
# to the
# Handling of Air Traffic

Over the past 25 years, the Guidance and Control Panel (GCP) of the Advisory Group for Aerospace Research and Development (AGARD) to the North Atlantic Treaty Organization (NATO) has devoted part of its activities to cover multiple facets of Air Traffic Handling (ATH) ranging from 20-year long term conceptual design to 20-second short term collision avoidance.

The scope of the work undertaken was broad and included scientific, technical, technological and procedural developments, in the numerous fields concerned with the improvement of communication, navigation, surveillance, aircraft operation, the human role in the overall on-line control loop and ... automation.

In 1970, Professor Cornelius Leondes visualising the constraints which Air Traffic Control (ATC) might impose on Air Transport and on the development of aviation in general, requested an advisory paper* to outline the need for the Panel to focus attention on such a large scale system which could certainly benefit from the professional and international potential of the navigation, guidance and control community duly represented in AGARD. After some discussions addressing such issues as civil versus military, system versus components, the Guidance and Control Panel then proposed a whole symposium entirely devoted to the subject of air traffic control. The proposal was endorsed by the Board of the National Delegates and the symposium was hosted by the National Delegation of the United Kingdom.

In the Welcome Address delivered by Norman Coles, British National Delegate, at the opening ceremony of this Guidance and Control Panel Symposium entitled **Air Traffic Control Systems** and held in Edinburgh, Scotland, U.K., in June 1972, he stated the following problems and challenges "... *we in the United Kingdom have yet perhaps to experience some of the most acute congestion in the ATC field which is arising on the American Continent. Nevertheless, on occasions we experience stacking times equal or greater than the associated flight time! To quote from the A.T. Advisory Committee, in 1969, "Air traffic in is crisis. The crisis now manifest at a few high density hubs is the direct result of the failure of airports and Air Traffic Control capacity to keep up with the growth of American Aviation*".

The encouragements received at the time from the **Air Traffic Control Community** were tremendous. Both civil and military components were represented at the Symposium. Major General A.R. Shiely, Jr. from the United States of America and George Trow, Director Operations at EUROCONTROL, European Organisation for the Safety of Air Navigation, delivered the two papers of the keynote session.

Contributions originated from a wide variety of horizons, including Government Administrations and other Institutes, Research and Academic Institutions, national and international Associations and numerous companies deeply involved in these matters.

Among the Government, Academic and Research & Development Institutions and other Associations presenting an original contribution, we can mention - for the sake of illustration only - the Department of Transportation, the Office of Secretary of Defense, the Federal Aviation Administration, the United States Air Force, the US Army - Electronics Command and navigation/control systems - the National Aeronautics and Space Administration and the Massachuset Institute of Technology (United States of America), the Defence and Civil Institute of Environmental Medicine (Canada), the Civil Aviation Authority, the Royal Air Force - Institute of Aviation Medicine - and the Royal Aircraft Establishment (United Kingdom), the Centre d'Expérimentation de la Navigation Aérienne, le Service Technique de la Navigation Aérienne et l'Office National d'Études et de Recherches Aérospatiales (France) and the Rijksluchtvaartdienst and the Nationaal Lucht-en-Ruimtevaart Laboratorium (The Netherlands).

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* **"Air Traffic Control Planning Considerations"**,
*A. Benoît and R.H.G. Martin*
*Paper presented to the Guidance and Control Panel of AGARD,*
*NATO MAS HQs, Brussels, Belgium, 31st August 1970.*

The Symposium also received contributions from a wide variety of companies, among which were : A/S Informasjonskontroll (Norway), Ferranti Limited (U.K.), Honeywell Inc. (USA), IBM-Italia (Italy), ITT Gilfillan (USA), Litton Systems Inc. (USA), RCA (USA), Singer-Kearfott Division (USA), Standard Elektrik Lorentz AG, (Germany), Systems Control Inc. (USA), The Aerospace Corporation (USA), The Mitre Corporation (USA), Thomson-CSF (France), TRW (USA), Wilcox Electric Inc. (USA) etc.

The GCP Symposium on Air Traffic Control was definitely a great success and quoting again from N. Coles' Welcome Address "*the subject has attracted a record attendance for any AGARD meeting in the United Kingdom, and I understand that it may well be an all time record for any AGARD panel meeting.*"

Isn't it surprising that problems and essential issues as presented 25 years ago still remain to be solved or are still present-day concerns ? It is of great interest and very instructive to go back and read the initial proposals for the development of systems such as approach and landing, near-terminal area optimal sequencing, airborne collision avoidance and the calls for reduction of separation standards. It is also of great relevance to compare the plans then made ten-to-twenty-year ahead with the subsequent actual achievements.

Some superficial conclusion of such a comparison may generate appreciable disappointment. Indeed, still today, delays, even if spent on the ground - engine on or not -, may remain greater than flight durations. In Western Europe where an appreciable number of air connections between main cities are of the order of one hour or even less, the air transport will definitely be challenged by high speed trains.

In contrast, if attention is focused on the overall picture which results as an overview of the assembly of the various modules concerned, the Air Traffic Control appears in its true nature: a large scale system, extremely complex, non-linear by essence, discreet and rapidly stochastic. In face of automation, this system is unique: the human role is essential, the controller is sovereign and, furthermore, her/his way of generating guidance directives is difficult to apprehend for translation in engineering terms.

From there, results a series of constraints inherent to the limitations of the human potential and the human behaviour; examples of such constraints include sectorisation and ... social disputes. On the other hand new emerging technologies indicate other possible ways ahead, in particular the potential offered by the "*autonomous aircraft*" idea as introduced in the free "*flight initiative*" of the FAA.

This situation being known, it was clear that AGARD could offer a remarkable podium for exchanges of views in this important and difficult field which is wide open for studies, applied research and innovations.

After this symposium, the Guidance and Control Panel pursued its activities in Air Traffic Handling and a series of symposia and AGARDographs followed as listed in the next section.

Now, if we follow the evolution of the work undertaken and presented over this 25-year period, we can notice an appreciable progress in a number of directions, including automation and, most important, co-operation between all concerned, of which, in Europe, the Programme for Harmonization of Air Traffic Management Research in Europe (PHARE) and the European Air Traffic Control Harmonization and Integration Programme (EATCHIP) are valuable examples.

This is perhaps the reason which lead us to assemble in a single manual the summaries of all the papers which were published in the AGARD Conference Proceedings and in the AGARDographs devoted to Air Traffic Control and Air Traffic Management over the last 25-year period.

We hope that this compilation will contribute to assist the new generation of developers, offering them a wide scope of what has been suggested in the past, what has been accomplished, what has been a failure, what should and could now be done with the new technologies available and ... we offer our best wishes for the success of their efforts.

# Summary of 25 Years of Activities of the Guidance and Control Panel in the Handling of Air Traffic

The Guidance and Control Panel's contributions listed below cover in particular, the air and ground components considered as parts of a single system, the methods, techniques and technologies applicable to or usable for the management of the flows of aircraft and the control of individual flights, the integration of control phases over extended areas, the 4-D guidance of aircraft in critical conditions, the ever-increasing level of automation, the introduction of machine intelligence and its impact on the essential role of the human acting on-line in the control loop.

## Panel Officers

## Activities

# GUIDANCE AND CONTROL PANEL OFFICERS

## 1965 - 1994

***Chairmen*** :

| | | |
|---|---|---|
| WRIGLEY W. | US | 1965 - 1969 |
| ROBINSON H.G.R. | UK | 1969 |
| LEONDES C.T. | US | 1969 - 1972 |
| SORG H. | Germany | 1972 - 1974 |
| BENOÎT A. | Belgium | 1974 - 1976 |
| OSTGAARD M.A. | US | 1976 - 1978 |
| KANT P. | Netherlands | 1978 - 1980 |
| HOWELL G.C. | UK | 1980 - 1982 |
| VAUGHN R.S. | US | 1982 - 1984 |
| ONKEN R.C. | Germany | 1984 - 1986 |
| PEEBLES K.A. | Canada | 1986 - 1988 |
| van den BROEK P. Ph. | Netherlands | 1988 - 1990 |
| STEAR E.B. | US | 1990 - 1992 |
| LEEK S. | UK | 1992 - 1994 |

***Deputy Chairmen*** :

| | | |
|---|---|---|
| FRAEIJS DE VEUBEKE B. | Belgium | 1965 - 1968 |
| ROBINSON H.G.R. | UK | 1968 - 1969 |
| LEONDES C.T. | US | 1969 |
| SORG H. | Germany | 1970 - 1972 |
| BENOÎT A. | Belgium | 1972 - 1974 |
| SUGERMAN I.R. | US | 1974 - 1976 |
| KANT P. | Netherlands | 1976 - 1978 |
| HOWELL G.C. | UK | 1978 - 1980 |
| VAUGHN R.S. | US | 1980 - 1982 |
| ONKEN R.C. | Germany | 1982 - 1984 |
| PEEBLES K.A. | Canada | 1984 - 1986 |
| van den BROEK P. Ph. | Netherlands | 1986 - 1988 |
| STEAR E.B. | US | 1988 - 1990 |
| LEEK S. | UK | 1990 - 1992 |
| RAMAGE | US | 1992 - 1994 |

***Executives*** :

| | | |
|---|---|---|
| READDY F.J. | US | 1965 |
| STUDABAKER W.A. | US | 1966 - 1969 |
| MOUNT C.D. | US | 1969 - 1972 |
| TAILLE A.L. | France | 1972 - 1975 |
| CAVENEL M.H. | France | 1975 - 1978 |
| de CHASSEY J.C. | France | 1978 - 1980 |
| HELIOT B.M. | France | 1980 - 1985 |
| CARRE P. | France | 1985 - 1986 |
| ROCHER A. | France | 1986 - 1988 |
| MOUHAMAD M. | France | 1988 - 1994 |
| FORTABAT P. | France | 1994 |

**AIR TRAFFIC CONTROL SYSTEMS**
Guidance and Control Panel Symposium, Edinburgh, Scotland, 26-29 June 1972.
AGARD-CP-105, April 1973.

**A SURVEY OF MODERN AIR TRAFFIC CONTROL**
AGARDograph AG-209, Vols. I and II, July 1975.

**PLANS AND DEVELOPMENTS FOR AIR TRAFFIC SYSTEMS**
Guidance and Control Panel Symposium, Cambridge, Mass., USA, 20-23 May 1975.
AGARD-CP-188, February 1976.

**AIR TRAFFIC MANAGEMENT :**
**Civil/Military Systems and Technologies**
Guidance and Control Panel Symposium, Copenhagen, Denmark, 9-12 October 1979.
AGARD-CP-273, February 1980.

**AIR TRAFFIC CONTROL IN FACE OF**
**USERS' DEMAND AND ECONOMY CONSTRAINTS**
Guidance and Control Symposium, Lisbon, Portugal, 15 October 1982.
AGARD-CP-340, February 1983.

**EFFICIENT CONDUCT OF INDIVIDUAL FLIGHTS AND AIR TRAFFIC** or
**"An Optimum Utilisation of Modern Technology**
(Guidance, control, navigation, surveillance and processing facilities)
**for the Overall Benefit of Civil and Military Airspace Users"**
Guidance and Control Symposium, Brussels, Belgium, 10-13 June 1986.
AGARD-CP-410, December 1986.

**AIRCRAFT TRAJECTORIES :**
**Computation - Prediction - Control**
AGARDograph AG-301, Vols. 1 (March 1990), 2 and 3 (May 1990) :

Vol. 1
- **FUNDAMENTALS**
- **FLIGHT IN CRITICAL ATMOSPHERIC CONDITIONS**
- **IMPACT OF NEW ON-BOARD TECHNOLOGIES ON**
- **AIRCRAFT OPERATION**

Vol. 2
- **AIR TRAFFIC HANDLING**
- **GROUND-BASED GUIDANCE OF AIRCRAFT**

Vol. 3
- **ABSTRACTS**
- **BIBLIOGRAPHY**
- **CONTRIBUTORS**

**MACHINE INTELLIGENCE IN AIR TRAFFIC MANAGEMENT**
Guidance and Control Panel Symposium, Berlin, Germany, 11-14 May 1993.
AGARD-CP-538, October 1993.

**ON-LINE HANDLING OF AIR TRAFFIC :**
**Management - Guidance - Control**
AGARDograph AG-321, November 1994.

**25 YEARS OF CONTRIBUTIONS to AIR TRAFFIC HANDLING**
**Research - Development - Operations - History**
**A BIBLIOGRAPHY**
AGARDograph 339, November 1995 (This volume).

**Acknowledgement**

The AGARD Aerospace Database* has been used and has proved to be very useful for the compilation of this Bibliography.

**Disclaimer**

The views expressed in the papers presented in this document are those of their authors. They do not necessarily reflect the policies of the Institutions to which they belong.

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# AGARD-CP-105

**published 1973**

# AIR TRAFFIC CONTROL SYSTEMS
# (The volume contains 33 papers)

**Guidance and Control Panel Symposium of AGARD
held in Edinburgh, Scotland, 26-29 June 1972**

**André Benoit, Program Chairman and Editor**

**Title:** **Status and trends in military air traffic control systems**

**Reference:** AGARD-CP-105 - paper 01

**Author:** SHIELY, A. R., JR.

**Abstract:** The status and trends in military air traffic control systems are discussed. The air navigation facilities operated by U.S. Military Forces are described. The mission of the Air Defense Control System is explained. The development of automated air control systems, airborne search radar, and integrated communication, navigation, and identification systems is reported.

**Title:** **Air traffic control in the Eurocontrol area**

**Reference:** AGARD-CP-105 - paper 02

**Author:** TROW, G. H.

**Abstract:** The organization and operation of the Eurocontrol area air traffic control system are discussed. The member nations comprising the organization are identified. The accomplishments of the organization are presented. The problems peculiar to European flights because of national sovereignty are analyzed. The development of an improved system of air traffic control is reported. Maps of the Eurocontrol area of operation are included.

**Title:** **Decisions for the 70's**

**Reference:** AGARD-CP-105 - paper 03

**Author:** SHANK, R. J.

**Abstract:** The nature of the air traffic control system and procedures during the 1970's are almost completely determined by decisions made during the past twenty years. A brief review of this already-determined baseline system and its operation is included, and a set of objectives for the future and guiding principles will provide a background for the major decisions now confronting the world air traffic control community. The important proposed changes or improvements in the areas of surveillance, navigation, communications, collision avoidance, and instrument landing are examined, and the major issues for decision are proposed.

**Title:** **ATC automation, present and future**

**Reference:** AGARD-CP-105 - paper 04

**Author:** SCHOLTEN, C. G. H.

**Abstract:** A number of design principles in which future air traffic control systems should differ from present systems in order to cope with increased air traffic demands are discussed. The principles are that available air space and airports should be used in as flexible a manner as possible by using computers and that improved data links between ground and air will be required for pilot-computer communication. The need for a back up system in the event of complete computer failure to allow controllers to clear existing traffic safely is proposed.

**Title:** **Automation of air traffic control in Italy, Rome Control Area**

**Reference:** AGARD-CP-105 - paper 05

**Author:** MARTUCCI, C.
TINCANI, B.

**Abstract:** The physical structure and operative unit organization of the Rome, Italy air traffic control system are discussed. The automation of the system is described to include the functions and capabilities. The phases in which the automated system is being implemented are reported. Diagrams of the system components and network to show the operation of the system are provided.

**Title:** **The SAVVAN: Means for inspection by VOR and DME**
**Le savvan, moyen d'inspection des vor et des dme**

**Reference:** AGARD-CP-105 - paper 06

**Author:** MONTEL, G.

**Abstract:** An evaluation is presented of the effectiveness of the SAVVAN (automatic system for vertification of navigation aids in flight) in locating and controlling high altitude aircraft. The system responds to signals from VOR and DME onboard the aircraft. Signals are registered on a magnetic band where they are processed according to a pre-established computer program. Along with the magnetic band, the system has logic elements and 12 receivers.

**Title:** **Status and trends in civil air traffic control systems**

**Reference:** AGARD-CP-105 - paper 07

**Author:** LUNDQUIST, G. E.

**Abstract:** The status and trends on civil air traffic control systems are discussed. The use of automation programs to increase air traffic control safety by providing the air traffic controller with better information on which to base decisions is examined. The development of a network of computers, displays, and communications which will process, store, and distribute instrument flight rules is reported. The operation of the system is described by illustrations and block diagrams.

**Title:** **Area navigation: Cost versus operational benefits**

**Reference:** AGARD-CP-105 - paper 08

**Author:** AMACKER, J. Z.

**Abstract:** Cost, complexity, and cockpit workload were compared for seven potential area navigation system configurations. Cockpit workload was found to be minimum for the very simple and most sophisticated systems. However, the sensitivity of the cost parameter is such that it increases dramatically with system complexity with relatively little gain in operational benefit. A detailed study of the Mark 1, Mark 13, and ATA Operations Committee requirements document discerned that almost all required operational functions could be accomplished with minimum systems.

**Title:** **Airborne area navigation equipment**

**Reference:** AGARD-CP-105 - paper 09

**Author:** BRIDGE, C. S.
HOLM, R. J.

**Abstract:** A broad base of area navigation equipment, manufacturers and users exists. Types of equipment extend from simple adaptation of VOR to triple inertial systems with multiple radio position inputs and digital computer processing. Air transport equipment is grouped into Mark I, Mark II and Mark 13 systems which are described. Area navigation systems are based upon, or augmented by, air data, VOR, Doppler, inertial, Loran A/C, Omega, and satellite. Demonstrations and performance in recent flight tests show state-of-the-art for area navigation systems with consideration of projected requirements. Examples of enroute navigation, vertical navigation, terminal area and landing are shown. Controls, pictorial displays, automatic data entry and data link are discussed.

**Title:** **An ATC/surveillance modeling approach for specifying lane separation standards**

**Reference:** AGARD-CP-105 - paper 10

**Author:** SORENSEN, J.
STEPNER, D. E.
TYLER, J. S.

**Abstract:** The reduction in separation standards for both domestic and oceanic air routes because of increased travel demand is discussed. The overall problem of relating lane separations to safety for different navigation systems, surveillance systems, and air traffic control procedures are considered. A model is described which has the same general input/output format as the Reich model that has been used for specifying North Atlantic route separations. Numerical results are presented to show the impact of inertial navigation systems and satellite surveillance on the separation standards and safety for the North Atlantic route structure.

**Title:** **Analysis of terminal ATC system operations**

**Reference:** AGARD-CP-105 - paper 11

**Author:** NOLL, R. B.
SIMPSON, R. W.
ZVARA, J.

**Abstract:** The effects of automation in terminal air traffic control are analyzed with respect to the impact of the automation on the controller. The present air traffic control system based on radar information and manual techniques is discussed and compared with an advanced system which uses a computer to generate alphanumeric radar displays and automated features. A typical control operation is presented to demonstrate controller activity in both the present and an advanced system. ARTS I is used to represent the advanced air traffic control system. The principal features of ARTS I are described and the interface of the controller with the computer and the display equipment is discussed.

**Title:** **An analytic study of near terminal area optimal sequencing and flow control techniques**

**Reference:** AGARD-CP-105 - paper 12

**Author:** HOGGE, J. E.
PARK, S. K.
STRAETER, T. A.

**Abstract:** Optimal flow control and sequencing of air traffic operations in the near terminal area are discussed. The near terminal area model is based on the assumptions that the aircraft enter the terminal area along precisely controlled approach paths and that the aircraft are segregated according to their near terminal area performance. Mathematical models are developed to support the optimal path generation, sequencing, and conflict resolution problems.

**Title:** **A real world situation display for all weather landing**

**Reference:** AGARD-CP-105 - paper 13

**Author:** BURKE, E. J.
BURROUGHS, K.
DECELLES, J. L.

**Abstract:** A flight data display for use in aircraft approach and landing under all conditions of visibility is described. The device provides airborne self-contained glide path guidance for use in visual flight conditions. In its most sophisticated form it provides total information for manual landing, or monitoring automatic landing and roll-out during reduced visibility. It is stated that the heads-up display symbology similar to that described is urgently required for see-to-land approaches and will be essential for pilot acceptance of automatic landings in actual nonvisual conditions.

**Title:** **The influence of the future landing guidance system on integration of short take-off and landing and conventional air traffic at a major airport**

**Reference:** AGARD-CP-105 - paper 14

**Author:** HUGHES, N. H.

**Abstract:** Some of the benefits to air traffic control which may result from deploying landing guidance systems are identified. The characteristics of short takeoff and landing aircraft intercept of the instrument landing system localizer and final approach path are studied and the final approach geometry is established. STOL approach sequencing requirements are defined and sequencing geometry suggested. The ability of nonvisual approach and landing guidance systems to ease air traffic control problems is discussed. Avionics developments which are required to allow aircraft to take advantage of future landing guidance systems are described.

**Title:** **US Army air traffic management now through 1980**

**Reference:** AGARD-CP-105 - paper 15

**Author:** DANIELS, T. E.
GROSSMAN, C.

**Abstract:** The requirements of an air traffic management system which will be capable of providing for the safe operation of large numbers of aircraft under instrument meteorological conditions (IMC), and thus afford the commander maximum utilization of hare combat capability within reasonable constraints of money and equipment, a totally integrated ground and airborne system, are discussed. The requirements are based upon the assumption that the Army will continue to exploit and expand the air mobility concept in the future. In order to accrue the maximum benefits from such a concept the field commander must be afforded the means to effectively use his aircraft with minimum constraints. The absence of such a system currently precludes effective field exploitation of Army aircraft under adverse weather and visibility conditions, and furthermore precludes the onset of operations until weather predictions give reasonable assurance of resupply/evacuation.

**Title:** **Functional design of Microwave Landing System (MLS) airborne equipment as influenced by ground equipment configuration and aircraft type**

**Reference:** AGARD-CP-105 - paper 16

**Author:** CARLSON, D. N.
SEACORD, C. L.

**Abstract:** A description of a proposed microwave landing system (MLS) is presented, with particular emphasis on the functional design requirements of the airborne equipment. This system has the potential of meeting the expanded, more precise, and more complex needs generated by a growing aircraft population consisting of both conventional and unconventional (V/STOL) types. A modular approach to both ground and airborne equipment is identified as a means of achieving desired flexibility and low cost required for a truly universal system serving the full spectrum of user aircraft and aircraft types. Elements of the ground system are identified and their influence on the nature of the transmitted signal is described.

**Title:** **The performance of the Doppler microwave landing system in a multipath environment**

**Reference:** AGARD-CP-105 - paper 17

**Author:** ROSIEN, R. A.
SANDERS, L. L.

**Abstract:** The success of the Doppler microwave landing system in meeting the multipath challenge is described. Techniques, which can be used to eliminate the effects of multipath are described. The various multipath sources are listed together with the specific requirements for each. Performance data is given which has been gathered from three sources: (1) computer simulation; (2) laboratory tests of an equipment model; and (3) field tests on two experimental Doppler systems. The data indicates that the Doppler MLS, utilizing the simplest form of signal processing, namely, a filter and zero crossing counter, may be adequate under limited accuracy and siting conditions. For performance in heavy multipath, some form of narrowband device will probably have to be employed in order to satisfy the accuracy and minimum coverage angle requirements.

**Title:** **Landing guidance system: Hermes**

**Reference:** AGARD-CP-105 - paper 18

**Author:** HOLME, N.

**Abstract:** The basic principles of the landing guidance system Hermes are described. The system is based on the establishment and detection of a coded pattern of gamma radiation from radioactive sources. This principle offers a remarkable combination of high accuracy, extreme reliability and low cost, especially when applied to the final approach and runway for conventional/short takeoff and landing operations. The ground installation is purely mechanical, with no moving parts. All information is air-derived.

**Title:** **A forward area homing and landing guidance concept for military aircraft**

**Reference:** AGARD-CP-105 - paper 19

**Author:** HUNTER, I. M.

**Abstract:** The characteristics of a forward area homing and landing guidance concept for military aircraft are discussed. The relative advantages of air-derived and ground-derived concepts are compared. It is concluded that a pure air-derived system cannot meet the military requirements. The development of a hybrid solution is proposed.

**Title:** **The potential of a system of satellites as a part of an air traffic control system**

**Reference:** AGARD-CP-105 - paper 20

**Author:** DIAMOND, P. M.

**Abstract:** The air traffic control (ATC) performance potential of satellite systems utilized in a data acquisition and communications role within a continental United States (CONUS) ATC system is discussed. The unique properties of satellite-based relays provide the only viable means of achieving complete coverage to ground level of the entire airspace, coupled with uniform and highly accurate surveillance position fixing. Position determination, identification, flow control, and collision avoidance functions can be implemented through the use of regional centralization of ground computation, resulting in important benefits to the utilization of the airspace and adaptability of the ATC system. It is shown that the concept of intermittent positive control (IPC) requires aircraft speed/acceleration restrictions and leads to the requirement for surveillance accuracies of 100 to 200 ft within the densely populated regions of airspace expected in the 1980s. A class of satellite systems is described which offers the requisite performance for both commercial carriers and general aviation with low anticipated costs of aircraft equipment.

**Title:** **TAM-TAM system**
**systeme TAM-TAM**

**Reference:** AGARD-CP-105 - paper 21

**Author:** LOUET, J.

**Abstract:** The TAM-TAM (automatic transmission of messages of air traffic by multiplex) system as a possible data link in air-ground-air transmission during oceanic, continental, and terminal control area flight, is discussed. Problems encountered and solutions to those problems are included.

**Title:** **Derivation of a wide area position location capability using a synchronized time division multiple access communication system**

**Reference:** AGARD-CP-105 - paper 22

**Author:** DEMARINES, V. A.
THOMPSON, R. L.

**Abstract:** A concept for the use of a high bandwidth time division communications system to provide a ground based, wide area, position location system is presented. General principles upon which the system is based and a discussion of computational techniques employed are covered. A discussion of system behavior as a function of systematic and random errors caused by individual element position uncertainty and geometric effects is included. Control mechanisms required to produce stable and reliable performance are also described. Results of a computer simulation are presented to provide estimates of capability under various conditions and to establish the system performance envelope.

**Title:** **SECANT: A solution to the problem of mid-air collisions**

**Reference:** AGARD-CP-105 - paper 23

**Author:** PARSONS, J. L.

**Abstract:** The principal characteristics of SECANT, a system for the separation and control of aircraft using non-synchronous Techniques are described. This cooperative, transponding collision-avoidance system, designed to be compatible within the entire aviation community, is capable of accommodating the dense air traffic anticipated for the 1980s and beyond. It makes available to the pilot evasion or escape maneuvers in any direction - vertical, horizontal, or a combination. SECANT helps the pilot to avoid mid-air collisions by transmitting probes and receiving replies with a 1 microsecond pulse at 1000 pulses per second on 24 different frequencies. Various discriminants are used to eliminate undesired signals, and the false alarm rate is near zero.

**Title:** **A French collision: Avoidance systems of time-frequency type. Critical analysis of test results**

**Reference:** AGARD-CP-105 - paper 24

**Author:** MOREAU, R.

**Abstract:** Performance tests of a system for air traffic control and collision avoidance are discussed. The system is described and the method of operation is outlined. The precision obtained is analyzed and compared with established standards. Modifications of the signal format are examined. Problems raised by the introduction of the new air traffic control system are reported.

**Title:** **Human factors problems in conflict detection and resolution**

**Reference:** AGARD-CP-105 - paper 25

**Author:** HOPKIN, V. D.

**Abstract:** Conflict detection and resolution as human factors problems in air traffic control are discussed. It is contended that this assumption is probably incorrect, primarily because of the large differences in urgency, information, procedures and facilities in various phases of flight. The controller's responses depend on the confidence he has in the data available to him, and on his knowledge of how accurate it is likely to be. Automated aids may not be properly used if they include no indication of the accuracy, quality and comprehensiveness of the data on which automated computations are being made. Relevant research methods for human factors studies on conflict detection and resolution are indicated.

**Title:** **Problems involved in ATC automation**

**Reference:** AGARD-CP-105 - paper 27

**Author:** STODDART, D. L.

**Abstract:** The two major problems involved in A.T.C. automation, suitable man-machine interfaces and system reliability, are considered. These problems are placed in perspective by examining the need for automation and by considering the information required by the controller, and how this should be displayed. Suggested man-machine interfaces are examined, including synthetic plan displays, tabular displays, touchwires, keyboards, rolling balls and light pens. The operational and technical advantages and disadvantages of these devices are discussed. The problem of reliability is introduced and the need for fail safe systems explained. Various methods of achieving reliability are considered, including triplicated hardware, and systems having preferred and reconfigured functional organization. The implications of these systems are discussed and a system design suggested.

**Title:** **The man-computer interface problem in terminal automation**

**Reference:** AGARD-CP-105 - paper 28

**Author:** INNES, L. G.

**Abstract:** The main concern in the several large air traffic control automation programs which have been implemented has been the provision of information to the controller in a more accurate and more easily assimilable form. The aim was, if not to reduce the controller's workload, to at least keep it within acceptable limits. Experience with these systems to date is reviewed, and the conclusion reached that in few instances has this aim been achieved. Without adequate isolation of the controller from the requirement to continually interact with the computer, workload is inevitably increased to an unacceptable degree, due to the additional tasks imposed on the controller by the demands of the automated aspects of the system. The development of the Canadian Forces automated terminal control concept involved evaluation of several methods of simplified man-computer interaction, carried out within constraints imposed by limited available manpower in the controller trade, and limited funding for the program. A solution has been developed which appears to adequately act as a compromise between these conflicting requirements.

**Title:** **Intergration of communication functions, navigation, identification, and traffic control Intergration des fonctions de communication, de navigation, d'identification et de controle de trafic**

**Reference:** AGARD-CP-105 - paper 29

**Author:** MILOSEVIC, L.
MOLLIE, P.

**Abstract:** The economic aspects of replacing separate aircraft landing and anticollision equipment with an integrated time-frequency system are discussed in detail. A comparison was also made of the relative cost value of replacing equipment mounted on the aircraft.

**Title:** **Satellite considerations in future air traffic control systems**

**Reference:** AGARD-CP-105 - paper 30

**Author:** FINDLEY, D. E.

**Abstract:** A program for improving the air traffic control system of the United States is discussed. The program is involved with deployment and implementation of major improvements for certain enroute and terminal area air traffic control functions. Development efforts are proposed for the following subjects: (1) traffic surveillance; (2) conflict prediction; (3) resolution and avoidance; (4) landing guidance; and (5) automation of air traffic control functions. The background for the formulation of a concept of the air traffic control system for the 1980 time period and beyond is considered. Emphasis is placed on the use of artificial satellites to meet the air traffic demands.

**Title:** **Conceptual analysis of ICNI systems**

**Reference:** AGARD-CP-105 - paper 31

**Author:** CRAIGIE, J. H.

**Abstract:** The development of an improved communications, navigation, and identification (ICNI) system for command and control, air traffic control, and mission execution is discussed. The program is mainly directed toward the requirements of four major Air Force Commands. The special requirements for each type of Air Force mission are analyzed to show the variations required in the proposed system.

**Title:** **A practical design of an ICNI system**

**Reference:** AGARD-CP-105 - paper 32

**Author:** ELLINGSON, C. E.

**Abstract:** The key factors which have resulted in the proliferation of communications, navigation, and identification equipment in aircraft are discussed. The advantages of interconnective communications capability and common position location capability in reducing complexity of the system while improving operational capability are examined. A specific candidate communication system is proposed and its capabilities are analyzed.

**Title:** **Integrity of ICNI systems**

**Reference:** AGARD-CP-105 - paper 33

**Author:** LINDEN, R. L.

**Abstract:** An analysis of integrated communications, navigation, and identification systems for aircraft operation is presented. Advances in electronics, solid state devices, logic circuits, and discrete function modules are described to show application to systems integration. The anticipated improvements in operational capability through system integration are analyzed.

# AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1

**published 1975**

# A SURVEY OF MODERN AIR TRAFFIC CONTROL. Volume 1 (The volume contains 18 papers)

**André Benoit, Program Director and Editor**

**Title:** **Principles of air traffic control**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 01

**Author:** RATCLIFFE, S.

**Abstract:** Air traffic control techniques are discussed along with the principles of traffic flow. Other topics discussed include: flight operations, terminal control, and organizational problems in an ATC sector.

**Title:** **ATC concepts**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 02

**Author:** NEUMANN, H.

**Abstract:** Ground based ATC procedures are discussed in terms of manual, electronic and structural air traffic control.

**Title:** **Principal ATC components**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 03

**Author:** FRIEDRICH, H. G.

**Abstract:** Functional descriptions are presented of ATC components. The systems described include navigation, surveillance, communications, and control centers.

**Title:** **The controller versus automation**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 04

**Author:** HOPKIN, V. D.

**Abstract:** The relation of the controller to automation in air traffic control is discussed in terms of human factors engineering. Concepts discussed include: task changes and automation, workload, quality of navigation aid, training, potentially incompatible aims, effects of automation on task design, and automation and communication.

**Title:** **The future position of the controller**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 05

**Author:** BRAUSER, K.
SEIFERT, R.

**Abstract:** The problem of automation of ATC systems was shown to be a very complex task, concerning three different control loops with different characteristics but using the same data source. The different control loops were defined as executive (radar) control with the tasks of tactical intervention; planning control, with the tasks of procedural planning; and flow control. It was found that the human responsibility for air traffic safety cannot be delegated, but that there are many human activities which can be defined as black box actions performed more efficiently by computers. The resulting system is characterized as a highly effective human control system with an optimum amount of automatic devices to perform routine tasks as well as an effective decision aid with good on-line characteristics.

**Title:** **The psychologist's view of human factors in air traffic control**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 06

**Author:** HOPKIN, V. D.

**Abstract:** The role of human factors in air traffic control depends on the stage at which it is first applied. The psychologist's contribution is most effective early in the system evolution, when he can forestall problems as well as cure them. In studying air traffic control systems, ideally the psychologist uses system and job analysis, which he can both conduct and interpret. Aspects of the man-machine interface, such as displays, controls and communications, are optimized in relation to the efficiency and well-being of the men. His knowledge of differences between men is applied to recruitment, selection, training and screening. The effects of ageing and of experience are predicted from known progressive changes within each individual. Knowledge of the capabilities and tolerances of the man is used to solve problems of work-rest cycles, stress and workload. To solve these problems, the psychologist uses orthodox methods and specially devised techniques for assessing and measuring the man at work.

**Title:** **Medical problems relating to air traffic control personnel**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 07

**Author:** EVRARD, E.

**Abstract:** The protection of air traffic control personnel was studied. The following points were examined: (1) working conditions in the air traffic control services, flight information services and alerting services; (2) psychophysiological factors determining the efficiency of air traffic control systems; (3) occupational pathology of air traffic controllers, covering the problem of the danger of emission of X-rays by the cathode-ray tubes in the display screens, visual pathology, auditory pathology, and pathology caused by nervous tension; and (4) protection of air traffic control personnel.

**Title:** **The International Federation of Air Traffic Controllers Associations (IFATCA)**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 08

**Author:** HARRISON, T. H.

**Abstract:** The IFATCA history is presented. The aims of the federation are discussed along with the annual conferences, and standing committees.

**Title:** **Principles of automation in air traffic control**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 09

**Author:** RATCLIFFE, S.

**Abstract:** The automation of ATC by reducing the data for processing by digital computer techniques was studied. Hardware and software reliability are discussed along with men and machines in ATC. Data sources for automated systems, and the use of computers in decision making are also discussed.

**Title:** **Data processing for ATC**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 10

**Author:** NEUMANN, H.

**Abstract:** There are two main objectives of data processing for air traffic control: first, support of tactical control by the provision of a sophisticated display of the air traffic situation and by the application of procedures of real-time conflict detection and solution; second, avoidance of air traffic congestion as well as reduction and balancing of the load of both the planning and the executive controller by automatic filtering of conflicts and by hierarchical structuring of planning and control functions. Features and criteria of functions termed flow planning, flow control and flight progress planning and control to achieve the second objective with the application of electronic data processing are considered.

**Title:** **Automation in air traffic control systems**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 11

**Author:** KHAMBATA, A. J.

**Abstract:** Controlling the ever-increasing number of aircraft movements in an orderly and safe manner in the nation's airspace is becoming a problem. The historical evolution is traced of Air Traffic Control (ATC) since before World War II. It also discusses the current ATC problems. The National Airspace System (NAS) design concept is presented, and the progress made in implementing it in the enroute area is described. The progress of automation in the terminal areas include systems such as the unique Common IFR Room at New York, one of the world's most congested metropolitan terminal areas, and the recently installed ARTS III System at O'Hare Field in Chicago, which is considered the world's busiest air terminal. Several other areas of automation, such as collision avoidance, which impact the ATC system, are also discussed.

**Title:** **Conflict and collision avoidance systems**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 12

**Author:** MOREAU, R.

**Abstract:** Greater flight safety dispite the growth in traffic by improved air traffic control was investigated. The means of ensuring greater safety for successive phases of a flight from takeoff to landing, airborne collision avoidance systems (CAS), and ATC/CAS compatibility are discussed.

**Title:** **Conflict alert and intermittent positive control for ground based collision avoidance**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 13

**Author:** CULHANE, L. G.
HOROWITZ, B. M.

**Abstract:** Analytical, simulation and experimental results are presented which were obtained in the process of designing and progressing toward the implementation of ground-based collision avoidance systems for air traffic control. Selective subsystem performance criteria established as part of the design process are also presented. Different, but compatible system concepts are discussed. For situations involving IFR aircraft, a conflict alert capability will provide the controller with a displayed alert of impending situations of separation being less than minimums. An Intermittent Positive Control (IPC) function, utilizing data link and improved surveillance, provides an automated collision avoidance capability for VFR/VFB and VFR/IFR aircraft pairs, and provides an independent backup to the ATC system for IFR aircraft pairs. In addition, IPC includes pilot warning indications (PWI) for informing pilots of the location of proximate aircraft.

**Title:** **Air traffic flow control**
**Major operational problems in controlling air traffic from a central facility**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 14

**Author:** BELLANTONI, J. F.
PERIE, M. E.
WOLF, I. G.

**Abstract:** The major operational problems in controlling the general flow of the nation's air traffic from a central facility are described, and some of the approaches that may be taken to help automate their solutions are outlined. The discussions are based on operational experience at the FAA's Air Traffic Control Systems Command Center and on the present prototype computer programs, developed by the Transportation Systems Center, that provide data processing support to the controllers at that facility. The operational problems, giving the history, present procedural techniques and constraints, data sources, and control strategies available are described. Some of the pitfalls in solving the operational problem. Various approaches to automating flow control such as quantifying the objectives and developing algorithms to assist the controllers are discussed.

**Title:** **Local and regional flow metering and control**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 15

**Author:** RATNER, R. S.
SCHMIDT, D. K.
WONG, P. J.

**Abstract:** The safety and efficiency requirements for improving air traffic control were studied. Current sequencing and spacing operations in terminal areas are described along with local flow operations.

**Title:** **Application of modern control theory to scheduling and path-stretching maneuvers of aircraft in the near terminal area**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 16

**Author:** ATHANS, M.

**Abstract:** A design concept is presented for the dynamic control of aircraft in the near terminal area. An arbitrary set of nominal air routes, with possible multiple merging points, all leading to a single runway is considered. The system allows for the automated determination of acceleration/deceleration of aircraft along the nominal air routes, as well as for the automated determination of path-stretching delay maneuvers. In addition to normal operating conditions the system accomodates variable commanded separations over the outer marker (to allow for takeoffs between successive landings); and emergency conditions (in the sense that an aircraft is given partial or complete priority for landing). The system design is based upon the combination of three distinct optimal control problems: (1) a standard linear-quadratic problem, (2) a parameter optimization problem, and (3) a minimum-time rendezvous problem. Simulation results involving twelve aircraft under both normal and emergency conditions are presented.

**Title:** **Aircraft trajectory prediction data for ATC purposes**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 17

**Author:** BENOIT, ANDRE
EVERS, E.

**Abstract:** A method is presented for assembling the aircraft trajectory data in a compact form which indicates the quality of the aircraft characteristic data produced. The main aspects are outlined of an EROCOA aircraft performance handbook which is being prepared. The method covers all phases of the flight with the exception of the takeoff and initial acceleration, final deceleration and landing. Climb, acceleration and deceleration at cruising level, cruise and descent are considered equally and data are assembled in order to compute the trajectory components during any of these phases. The data produced cover a fleet of over one hundred aircraft versions including sixty different aircraft types, namely most of the current commercial aircraft operating in Western Europe and manufactured in Europe of North America and a sample of aircraft specifically designed for military purposes.

**Title:** **Navigation performance requirements for reducing route centerline spacing**

**Reference:** AGARD-AG-209-VOL-1 / AGARDOGRAPH-209-VOL-1 - paper 18

**Author:** BRAFF, R.

**Abstract:** Several different studies have looked into the question of what can be done in the ATC system to enable the current route centerline spacing standard to be safely reduced. These studies include that of Boeing, The Royal Aircraft Establishment (RAE), Autonetics and MITRE. These four approaches to the problem of reducing route centerline spacing are summerized, and the results derived from each are compared.

AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2

published 1975

# A SURVEY OF MODERN AIR TRAFFIC CONTROL. Volume 2
# A discussion of navigation aids, inertial navigation, and instrument landing systems
# (The volume contains 16 papers)

André Benoit, Program Director and Editor

**Title:** Principles of radiolocation

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 19

**Author:** CRONE, W.
PEUKER, G.

**Abstract:** The basic principles of radio location are reviewed from the physical point of view; these include travel time, propagation time difference, phase difference, and amplitude. Properties of electromagnetic waves are summarized, and methods for error reduction are described with reference to errors generated by multipath propagation and reflection by obstacles.

**Title:** Long distance aids (Omega, Loran)

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 20

**Author:** STANNER, W.

**Abstract:** The ground-based long distance aids Omega and LORAN provide the user with position data by using the hyperbolic principle. Characteristics and equipment for the Omega, LORAN-A and LORAN-C systems are discussed.

**Title:** Medium distance aids (VHF omnidirectional radio beacons)

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 21

**Author:** HOEFGEN, G.

**Abstract:** VHF omnidirectional radio range (VOR) is a radio aid for aircraft guidance; it is an omnidirectional radio beacon providing the angle between aircraft and North, seen from the ground station. The VOR ground station radiates an azimuth-dependent signal which is analyzed as the bearing information by the aircraft receiver. The pilot guides the aircraft along the course selected with the aid of constant azimuth indication. The range is of the order of 100 to 150 nm.

**Title:** **Distance measuring methods**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 22

**Author:** BOEHM, M.

**Abstract:** The distance-measuring methods employing electromagnetic waves make use of the velocity of light; the path covered by a light or radio signal can be determined, if the transit time is known, from a formula. Round-trip and one-way distance measuring systems are described; the round-trip systems operate with responding transmitters (or with passive reflectors as in the case of radar or radio altimeters), and the responding transmitter will retransmit the received signal with an exactly defined delay. In the case of one-way distance-measuring systems, identical and extremely accurate time standards are used in both the transmitter and the receiver locations. Airborne and ground station equipment is discussed.

**Title:** **Tacan**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 23

**Author:** BOEHM, M.

**Abstract:** Tactical air navigation (TACAN), a radio position-fixing method for military short and medium range aviation, is described. Each ground station currently provides azimuth or 'theta' values to any number of aircraft and distance or 'rho' values to maximum 120 aircraft at the same time. Both types of values are either directly displayed or are inputs for a navigation computer. Operational principles, airborne equipment, and TACAN ground stations are described in detail.

**Title:** **Inertial navigation and air traffic control**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 24

**Author:** MCKINLAY, W. H.

**Abstract:** The history of the development of navigation within air traffic control systems is traced briefly, and the requirements for effective navigation and flight path control are discussed. They are related to the adoption of inertial navigation and to the possible future extention of its use. Typical airborne system configurations are described together with the facilities provided by them. Reference is made to systems for both civil and military aircraft. The principles of inertial navigation are described with a review of the standards of accuracy and reliability being achieved, and the technology involved.

**Title:** **Landing guidance systems**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 25

**Author:** BRADY, F. B.

**Abstract:** The evolution of aircraft landing guidance technology is reviewed, from rudimentary nondirectional beacons and markers in the 1920's through the development and installation of the current standard instrument landing system (ILS) and the microwave landing systems (MLS) proposed for future world standardization. The major milestones in landing guidance system development are depicted. Design considerations for MLS are discussed in detail.

**Title:** **Digital radar data processing for enroute air traffic control**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 26

**Author:** VARELA, J. A.

**Abstract:** Digital radar data processing (RDP) in operation in twenty air route traffic control centers (ARTCCs) in the contiguous states are discussed. The system was extensively tested, its performance measured, and standards established for system performance. The functions of primary and secondary surveillance radar target detection, and the processing of target data in the central computer at the ARTCC are described. The latter includes filtering the data, conversion to common coordinates, correlation with automatic tracks, track smoothing and prediction in several modes, and measurement of data quality in real time. Data on measured system performance are given, and a short description of current efforts to improve system performance is included.

**Title:** **Display techniques for air traffic control systems**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 27

**Author:** JENYNS, R.

**Abstract:** The cathode ray tube is discussed which fulfills requirements for dynamic data displays in air traffic control systems. The basic principles of the cathode ray tube are described together with some recent developments which help to keep it in the forefront of display technology. Advanced techniques which emerged from research and development laboratories offer advantages not found with the cathode ray tube. The most promising of these techniques, which may find applications in air traffic control systems, are discussed together with their characteristics and relative merits.

**Title:** **Use of computer in air traffic control**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 28

**Author:** KIRSTETTER, B.
MAIGNAN, G.
VACHIERY, V.

**Abstract:** The characteristics and applications of computers in air traffic control, are discussed, mainly based on experience in the upper airspace. After a short summary of the different applications, the general characteristics of hardware and software architecture are discussed. This includes a description of multiprocessor and multicomputer systems with their specific ATC oriented peripherals, real-time operating systems, programming techniques, data base, and reliability aspects and the associated problems of recovery management. The principles of data transmission in air traffic control systems are included. Radar data processing deals mainly with mono- and multi-radar tracking aspects. A summary of the different functions is given which can presently be provided by a flight data processing system.

**Title:** **General aspects of data flow**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 29

**Author:** NEUMANN, H.

**Abstract:** Regarding complex systems such as air traffic control, data acquisition and data processing are performed through cooperation of man with machine. Indispensable dialog usually is accomplished by output of machine's results via teletypes, lineprinters, plotters, or luminous data displays and by input of man's acquired data, results, and decisions via functional keys, keyboards, and touch displays. A block diagram of data flow in air traffic control is presented. Manual data input is combined with data acquisition; data output is differentiated with respect to the receiver (pilot and controller). The diagram, as seen from a general point of view, represents implicitly all possible concepts of air traffic control executed on-ground, including even the concept of manual control, which leaves time-consuming tasks of data acquisition and preprocessing as well as all crucial tasks of intrinsic data processing to controllers.

**Title:** **Some trends in hardware concepts for ATC computer**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 30

**Author:** NITTNER, W.

**Abstract:** Four main requirements are discussed for hardware-structures resulting from applications such as radar data tracking, conflict detection and resolution, long-term flight plan coordination and flow control, flight progress adjustment, recording, and statistics application programs: reliability and safety, storage capacity and processing power, time behavior, and hardware-software-integration and software related features. Technologies and important features of computer structures are outlined.

**Title:** **The satellite as an aid to air traffic control**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 31

**Author:** MCDONALD, K. D.

**Abstract:** The capabilities and potential are discussed of satellite-based systems for navigation and air traffic control (ATC). The utility of satellite systems was extended from communications, surface navigation, and geodetic applications into air and space, and to other functional areas such as position surveillance for air traffic control, precise time and time transfer, international maritime and aeronautical position location and reporting services, and collision avoidance. A summary is presented of the basic principles upon which the satellite systems operate, along with an indication of their advantages and potential, a brief review of the historical developments, and a description of the system concepts and characteristics of selected satellite-based ATC systems.

**Title:** **Eurocontrol data processing systems**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 32

**Author:** KIRSTETTER, B.
MAIGNAN, G.
VACHIERY, V.

**Abstract:** The air traffic control data processing systems MADAP and KARLDAP, are designed for combined flight data and radar data processing. A description is given of the functions and hardware and software structure of the systems with special consideration to reliability, programming, and implementation aspects. The radar data processing system SHANDAP is also described.

**Title:** **The Netherlands ATC automation program**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 33

**Author:** SMIT, J. S.

**Abstract:** A historical summary is presented of air traffic control radar data processing systems in use in the Netherlands. Operational characteristics and specifications are included.

**Title:** **Overview of US air traffic control system**

**Reference:** AGARD-AG-209-VOL-2 / AGARDOGRAPH-209-VOL-2 - paper 34

**Author:** KIRSHNER, H. J.

**Abstract:** A brief overview is presented of the technical features of the systems used in U.S. air traffic control centers. Emphasis is placed on the recently modernized en route and terminal control systems.

AGARD-CP-188

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# PLANS AND DEVELOPMENTS FOR AIR TRAFFIC SYSTEMS (The volume contains 40 papers)

Guidance and Control Panel Symposium of AGARD
held in Cambridge, Mass., USA, 20-23 May 1975

André Benoit and David Israël, Program Chairmen and Editors

**Title:** **Studies of automatic navigation systems to improve utilization of controlled airspace**

**Reference:** AGARD-CP-188 - paper 01

**Author:** RAWLINGS, R.
WATLING, K.

**Abstract:** It is shown that the use of improved navigation in controlled airspace in the future could produce useful savings in time and money within a short time. This conclusion is based on the optimum use of VOR/DME and will rely, from the start, on allowing reduced lateral and longitudinal separations by the provision of accurate statistically predictable performances. Certain en-route applications are possible which provide the means of assessing, at an early stage, the effectiveness of the improved systems and which provide the means of assessing, at an early stage, the effectiveness of the improved systems and which allow the development of more ambitious systems for the busy TMAs in the future.

**Title:** **Four-D navigation in terminal zones: An automatic control problem speed control for aircraft approach spacing**

**Reference:** AGARD-CP-188 - paper 02

**Author:** PELEGRIN, M.

**Abstract:** It is shown that, if a velocity profile is imposed upon the plane and controlled along a selected approach path, it is possible to limit the deviation from the computed arrival time of the plane at the ILS entry gate. Two simulation programs, a fast time one and one in real time, determine and control the optimum 4-D trajectory. The first results show that the accuracy of the simulation need not be very great; thus, the extra computing ground capacity is fairly limited. It can also be shown that an accurate descent trajectory is no problem for an aircraft equipped with an automatic throttle command. Moreover, a head-up display that gives the optimum glide slope angle allows a very accurate control of the plane along its longitudinal axis.

**Title:** **Strategic control of terminal area traffic**

**Reference:** AGARD-CP-188 - paper 03

**Author:** ERWIN, R. L.

**Abstract:** An advanced method of controlling air traffic in high density terminal areas is reported. In this concept the air traffic control system defines four dimensional tracks for all arrivals that will derandomize and space the traffic for landing on the runway. The aircraft use four dimensional navigation and guidance equipment to fly the assigned paths. The advantages that result from a strategic control system using airborne four dimensional navigation and guidance equipment are presented; the resulting benefits of increased capacity and reduced fuel consumption are discussed. The logic used by the air traffic control authority to strategically control arrivals is described. This logic determines the sequence for handling the aircraft, establishes the time schedule for use of the runway by each flight, and calculates the four dimensional path to be assigned to each aircraft, recognizing the aeroperformance capabilities of the individual flight. The performance of the algorithm is demonstrated by the results of a fast time simulation of strategic control as applied to arriving traffic for Los Angeles International (LAX) Airport.

**Title:** **ATC concepts with extensive utilization of automatic data processing**

**Reference:** AGARD-CP-188 - paper 04

**Author:** NEUMANN, H.

**Abstract:** Alternative concepts of electronic data processing supported ATC are outlined and technical and procedural problems are specified in each case. Emphasis is on conceivable planning functions and logical relations with air traffic control functions leading to semi-automatic air traffic control. There are two main effects of such an ATC concept utilizing automatic data processing extensively: (1) expedition of the air traffic flow and reduction of the load of both the planning and the radar controller, because automatic filtering of conflicts will be achieved; and (2) optimum balancing of the load, because automatic allocation of flights to controllers will permit more continuous control and guidance within joint control sectors.

**Title:** **OMEGA: A system whose time has come considering military aircraft navigation**

**Reference:** AGARD-CP-188 - paper 05

**Author:** BERAN, J. F.
BORTZ, J. E., SR.

**Abstract:** The United States Air Force program to equip approximately 700 airlift aircraft with Omega navigation equipment is described. The program structure emphasizes obtaining low cost automatic equipment satisfying enroute air navigation performance requirements. Required equipment characteristics are identified and the structure of the equipment acquisition program is outlined. Several important Omega technology issues are discussed from a user's perspective. The paper concludes with a summary of the results of an Air Force flight test program designed to evaluate the important technology options now available in Omega navigation equipment.

**Title:** **A survey of primary radars for air traffic systems**

**Reference:** AGARD-CP-188 - paper 07

**Author:** MILNE, K.

**Abstract:** Application areas for primary radars in air traffic systems are reviewed. Problems facing the designers of such radars are outlined. Minimization of ground clutter, precipitation clutter and angle echoes figure high on the list of desiderata, combined with the needs for adequate data rate and high equipment reliability. Approaches to the solutions of these problems are surveyed and examples given of current practice. Future trends in primary radars are discussed in the light of recent advances in automation and in signal processing techniques. Improvements in the immediate future are likely to be evolutionary in nature, aimed at making the performance of today's radars compatible with more automated control systems.

**Title:** **ATCRBS improvement program**
**improved antenna design for monopulse radar**

**Reference:** AGARD-CP-188 - paper 08

**Author:** NATCHIPOLSKY, M.

**Abstract:** The Air Traffic Control Radar Beacon System (ATCRBS) experiences a number of problems such as false, broken, fading, missed and garbled targets. Although many factors contribute to the degradation of ATCRBS performance, most problems can be attributed to poor interrogator/receiver antennas, the difficulty of interrogator management, inadequate reply target detection and processing criteria or airborne transponder performance. A major development effort has been directed at improved interrogator antenna designs because the present FAA ATCRBS antenna is responsible for many of the system problems. Planned development efforts for improved ATCRBS reply processing and target detection are based on utilization of the improved antenna performance and sum difference pattern capability for monopulse processing.

**Title:** **ADSEL/DABS: A selective address secondary surveillance radar**
**digital surveillance radar system**

**Reference:** AGARD-CP-188 - paper 09

**Author:** BOWES, R. C.
DROUILHET, P. R.
STEVENS, M. C.
WEISS, H. G.

**Abstract:** ADSEL/DABS (Address Selection/Discrete Address Beacon System) is a selectively addressed secondary radar system which is an extension of present day ATCRBS/SSR. The system provides the usual surveillance data, identity, height and position and in addition a data link communication facility is available on both the ground to air and air to ground channels. The system is entirely compatible with present day ATCRBS/SSR and introduction can take place over an extended period. A modified transponder is required in the aircraft which operates on both normal ATCRBS/SSR and ADSEL/DABS. The new ground stations can provide surveillance of aircraft fitted with existing ATCRBS/SSR transponders as well as handling those with selective address transponders on board. An overall description of the system is given together with details of the message formats and modulation techniques adopted.

**Title:** **LEA microwave approach and landing system**

**Reference:** AGARD-CP-188 - paper 10

**Author:** NICOLI, R.

**Abstract:** The system operates in time sharing for terminal area navigation and landing or runway taxiing aids. In addition to the over 100 aircrafts that the system is capable of assisting in the landing phase, it can provide TMA navigation aid to several hundreds aircrafts inside a 30 n.m. radius area. The system utilizes a simple airborne equipment, while the ground equipment can be implemented at various degrees of sophistication, according to the airport size and traffic. Aircraft position data and identification are simultaneously available onboard and on the ground so that TMA and ATC are simplified. On the ground, ATC personnel have available data of all aircraft in TMA, landing or taxiing in the runways, complete with the aircraft indentification codes. The pilot has available onboard-- on standard cockpit instruments--the accurate position data of the aircraft in relation to the airport for TMA and to runway for landing. The ATC operator who monitors the aircraft situation on a scope gives ground-to-air instructions for TMA to the pilots and emergency communications for landing.

**Title:** **MATCALS: Expansion of capacity for expeditionary airfields**

**Reference:** AGARD-CP-188 - paper 11

**Author:** WILZ, R. R.

**Abstract:** The Marine Air Traffic Control and Landing System (MATCALS) is being implemented to upgrade and automate the ATC and all weather landing control capabilities of Marine Air Traffic Control Units (MATCU). The overall role of Marine Corps aviation is reviewed, and the crucial role and operational functions of the MATCU as a supporting element are described. An overview is presented of the MATCALS implementation program, the system as a whole, and the advanced capabilities which MATCALS will provide. Specific functional capabilities for air traffic management and control are indicated, and the technical approach toward implementing these functions is described. The MATCALS landing control capabilities and functions are then described, with emphasis on the operational advantages realized with an automated ground derived system. Finally, the impact of MATCALS on overall Marine aviation effectiveness is summarized. This summary emphasizes the quantitative factors by which MATCALS will increase the maximum rate of air firepower delivery through increased traffic handling capacity at expeditionary airfields.

**Title:** **Advanced ATC automation: The role of the human in a fully automated system**

**Reference:** AGARD-CP-188 - paper 12

**Author:** RUCKER, R. A.

**Abstract:** An overview is presented of one approach to formulating and evaluating an experimental model which automates routine en route sector traffic control. Basic design concepts are identified, and the automated control tasks performed by the Front Royal sector model, a digital computer simulation, are discussed. The paper then focuses on the anticipated roles and responsibilities of the journeyman air traffic controller in such an environment and how en route sector position designs may further evolve as a result. The purpose is to explore some long range implications and potentials from the perspective of the air traffic controller.

**Title:** **The provision and use of information on air traffic control displays**

**Reference:** AGARD-CP-188 - paper 13

**Author:** HOPKIN, V. D.

**Abstract:** Several kinds of mismatch can occur at the man machine interface in air traffic control systems. One, often overlooked, concerns the provision of certain essential information in a form which is unusable. The traditional reliance on the man's strengths of adaptability and flexibility in order to match man and machine in the system is thwarted if he cannot use the information presented to him. Changes from qualitative to quantitative information, incomplete automation, and the apparent retention of decision making roles which in fact have been greatly modified, all pose problems of ensuring that the displayed information has been adapted successfully.

**Title:** **Automation of local flow control and metering operations in the enroute/transistion environment**

**Reference:** AGARD-CP-188 - paper 14

**Author:** RATNER, R. S.

**Abstract:** Local flow control procedures are described that are used when a sector of the enroute/transition airspace becomes saturated, in terms of the workload or control capacity of the sector control team. The procedures are generally implemented according to prespecified plans, and take the form of restrictions on the permissible in-trail inter-aircraft separation for traffic flows upstream of the impacted sector. The desirability of enhancing this process of local flow control is discussed. A concept, termed planning control, for enhancing local flow control operations through automation, is described. The concept is based on prediction of prospective traffic levels on routes and in sectors within an air route traffic control center, using the on-line traffic data base of the NAS Enroute Stage A system. Appropriate flow control restrictions, are instituted whenever control workload in a sector exceeds a standard level.

**Title:** **The optimisation of traffic flow around a network**

**Reference:** AGARD-CP-188 - paper 15

**Author:** ATTWOOLL, V. W.

**Abstract:** The use of flow control is considered for air routes subject to saturation. Alterations to intended flight times at the planning stage penalize the operator, but so do the delays from congestion which occur if such alterations are not made. Hence there is an optimum balance which can be expressed as a planning target flow rate on a given route. For a network of routes subject to constraints, similar considerations lead to an optimum planned distribution of traffic flow around the system. The assessment of this optimum can become complex and is best handled by computer optimization techniques. The use of such techniques may become inevitable when the increasing complexity of route systems and constraints makes it impracticable for the unaided human brain to approach an optimum traffic distribution. Our study is illustrated by examples of traffic conditions at the England/France boundary.

**Title:** **The introduction of accurate aircraft trajectory predictions in air traffic control**

**Reference:** AGARD-CP-188 - paper 16

**Author:** BENOIT, ANDRE
STOREY, J.
SWIERSTRA, SIP

**Abstract:** A family of methods is proposed for predicting the trajectory of an aircraft of which a limited past history is known from radar observations at the time the prediction is produced as well as the intentions available from flight plan data. The approach is particularly designed to accommodate climbing and descending traffic and, in consequence, the paper concentrates on the vertical component of the trajectory prediction.

**Title:** **Interactive conflict resolution in air traffic control computerized flight path simulation**

**Reference:** AGARD-CP-188 - paper 17

**Author:** BALL, R. G.
LLOYD, R. B.
ORD, G.

**Abstract:** Aircraft of the major operators are becoming more and more capable of flying trajectories well defined in space and time. Such trajectories offer distinct advantages to operators and could also offer advantages to controllers for planning conflict free situations in the tactical phase of control. However, in order to use them, it is necessary for controllers to be able to visualize the trajectories further into the future, and in greater detail, than they can at present. A technique is outlined for improving the controller's visualization ability by using computer assistance to provide a predictive display. The technique is capable of being extended to help the controller with conflict detection and resolution. An important feature of the extension is that it allows the controller to conduct a dialogue with the computer enabling him to try out various options, the outcome of each of these being displayed so that he can assess the consequences of any action. The paper also discusses how the computer can assist with monitoring that aircraft remain on trajectories which are conflict free.

**Title:** **Intermittent positive control: A ground-based collision avoidance system**

**Reference:** AGARD-CP-188 - paper 18

**Author:** BEUSCH, J. U.
HOROWITZ, B. M.
MCFARLAND, A. L.
PERIE, M. E.
SENNE, K. D.

**Abstract:** Intermittent Positive Control (IPC) is a totally automated ground based collision avoidance system. It functions by taking positive control of Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) aircraft on an as needed basis to avoid hazardous encounters. By also providing pilots with continuous information on the location of nearly aircraft, it results in safety in controlled, mixed, and uncontrolled airspace, among all users (air carrier, general aviation and military) in both IFR and VFR flight, while maintaining the freedom of action associated with VFR flight. To receive IPC service an aircraft must carry a Discrete Address Beacon System (DABS) transponder and an IPC display. The transponder, in addition to its beacon function, receives digital messages from the ground and presents them on the IPC display. The ground portion of the IPC system consists of the DABS sensor and an IPC computer.

**Title:** **Integrated navigation system: Multifunction digital ground-air-ground communications system**

**Reference:** AGARD-CP-188 - paper 19

**Author:** MILOSEVIC, L.

**Abstract:** The multifunction integrated navigation system is designed in an homogeneous manner for radio navigation aid functions. It carries out navigation, surveillance with identification, anticollision, data transmission and voice communications functions. It is compatible with either direct ground to air transmission links or indirect satellite transmission links. It significantly simplifies aircraft equipment. It features modular extensible design and it is practically a non-saturable system. Two overall views of the system utilization are either with enroute T/R ground stations or using satellites to cover the enroute space.

**Title:** **Future ATC technology improvements and the impact on airport capacity**

**Reference:** AGARD-CP-188 - paper 20

**Author:** HARRIS, R. M.

**Abstract:** The United States is presently in its third generation of air traffic control systems and technology. This third generation system is the first nationwide application of modern computer based technology to the management of traffic in the national airspace system. Twenty NAS Stage A enroute installations are now in place at the domestic air route traffic control centers. In addition, 61 automated radar terminal systems are now installed and operational in the major terminal areas. Linkages between these enroute and terminal facilities are presently being established and verified. Upon completion of the installation and testing the U.S.A. will have operational a large scale, semi-automated capability to provide highly improved ATC services for domestic medium, high altitude, and terminal airspace.

**Title:** **Secondary radar for ground movement control**

**Reference:** AGARD-CP-188 - paper 21

**Author:** GRIFFITHS, H. N.

**Abstract:** A method of using secondary radar for ground movement identification is outlined which could have sufficient positioned accuracy to label a high definition primary radar display of airfield ground movements. An experimental ground movement secondary radar installation at an airfield site is described and the results of trials are discussed. Methods for improving the performance of the basic system are indicated and possible future developments are suggested.

**Title:** **ATCRBS trilateration, the advanced airport surface traffic control sensor**

**Reference:** AGARD-CP-188 - paper 22

**Author:** HAGEROTT, R. E.
MORONEY, M. J.
OGRADY, J. W.

**Abstract:** The requirements of an advanced Airport Surface Traffic Control (ASTC) system have been developed and the technology identified for the sensor part of the system. Employing Air Traffic Control Radar Beacon System (ATCRBS) replies from aircraft transponders and trilateration receivers for accurate position location and vehicle identification, the sensor system satisfies the performance and readiness requirements of intermediate (1980) goal systems. The advanced ATCRBS trilateration sensor for ASTC has been analytically established and a brassboard system is being fabricated to provide empirical validation.

**Title:** **The CORAIL surveillance system for airport runways**
**systeme corail de surveillance de pistes d'aeroport**

**Reference:** AGARD-CP-188 - paper 23

**Author:** FAYSSE, J. M.
PLOTTIN, G. G.

**Abstract:** The prototype CORAIL radar installed on the Paris Orly airport runway and originally intended only for automatic runway surveillance under conditions of poor visibility has proven itself to be a powerful facility for controlling runway and approach corridor movements in real time, making it possible to increase the frequency of aircraft landings and takeoffs, even in clear water, whilst maintaining a high level of safety.

**Title:** **Predictive techniques for wake vortex avoidance**

**Reference:** AGARD-CP-188 - paper 24

**Author:** HALLOCK, J. N.
SPITZER, E. A.
WOOD, W. D.

**Abstract:** Aircraft wake vortices represent a major impediment to increasing runway capacity. Separation criteria are conservative most of the time and thus traffic unnecessarily delayed by always adhering to the present inflexible regulations. Systems which employ vortex tracking sensors and/or meteorological sensors to determine safe reduced spacings are being designed. Any wake vortex avoidance strategy relies upon the ability to predict vortex transport and decay. The paper discusses vortex behavior, preliminary predictive models based upon the tracking of vortices from over 24,000 landing aircraft, and systems and their implementation to provide the capability of using adaptive separations.

**Title:** **US/UK vortex monitoring program at Heathrow Airport for aircraft approach spacing**

**Reference:** AGARD-CP-188 - paper 25

**Author:** GOLDSTONE, L.
HALLOCK, J. N.

**Abstract:** Vortices shed from aircraft landing are being recorded and analyzed and their motion correlated with ambient meteorological conditions. It is shown that if the crosswind component measured near the runway threshold exceeds five knots, vortices linger near the extended runway centerline for a time in excess of one minute for less than 0.5 percent of the landings. This small percentage is almost entirely due to vortices from the heavy wide body jets -- the B747, DC-10 and L-1011.

**Title:** **Fog dispersal at airports, the state of the art and future trends**

**Reference:** AGARD-CP-188 - paper 26

**Author:** BALDUS, W.
MELEWICZ, F. V.
POCRNJA, A.
RUPPERT, K.
SOWAR, J. F.
WENZEL, H.

**Abstract:** Cold fog is being dispersed routinely by airborne seeding with dry ice and results show a favorable benefit to cost ratio. Also ground based systems of liquid propane dispensers are used operationally for cold fog dispersal. Warm fog dispersal being more difficult has become operational at two airports of Paris. Improved prospects of economic warm fog dissipation are offered by a new heat pump system with favorable thermodynamic properties which result in an essentially lowered requirement. The artificial visibility improvement by fog dispersal systems is considered a valuable aid for safe aircraft operation under all weather conditions.

**Title:** **United States program to ICAO for a new non-visual approach and landing system**

**Reference:** AGARD-CP-188 - paper 27

**Author:** DELBALZO, J. M.
JONES, S. R.

**Abstract:** The microwave landing system is a precision approach and landing guidance system designed to meet the needs of all types of aircraft, civil and military, throughout the world through at least the balance of this century. It is an air derived data system, i.e., ground stations will generate coded signals which will enable an airborne receiver/processor unit to derive precise azimuth angle, elevation angle, and range data, which are suitable for display to the pilot or for use by an automatic flight control system. Inherent in the MLS design is the incorporation of a ground-to-air data link which will provide runway identification, condition of runway, operational status of the MLS, and weather information. An important element in the concept is that of performance modularity wherein a range of equipment configurations, both ground based and airborne, would be responsive to the operational requirements and economic considerations of each category of user.

**Title:** **Doppler MLS**

**Reference:** AGARD-CP-188 - paper 28

**Author:** BENJAMIN, J.

**Abstract:** This paper briefly describes the reasons why the UK does not subscribe to the FAA-MLS technique selection and reviews the state of the UK programme.

**Title:** **Instrument landing system performance prediction**

**Reference:** AGARD-CP-188 - paper 29

**Author:** CHIN, G.
JORDAN, L.
KAHN, D.
MORIN, S.

**Abstract:** A physics model based on electromagnetic scattering theory has been developed for predicting comparative Instrument Landing System (ILS) localizer and glide slope antennas array performance and course structure degradation resulting from a change to an airport environment. The theoretical predictions of the localizer model were compared with flight test data from Syracuse-Hancock airport. The agreement was good. The glide slope model has been used to predict and compare the perfromance of three image type antennas: The null reference sideband reference and capture effect antennas for non flat terrain configurations. It was found that acceptable course results often could be found with only one type of glide slope antenna without performing a major terrain regrading.

**Title:** **Measurements of runway visual range**

**Reference:** AGARD-CP-188 - paper 30

**Author:** STAGE, I. A. C.

**Abstract:** This review of the measurement of runway visual range returns to the basic recommendation of the International Civil Aviation Organization as the basis of a fundamental appraisal of the instrumentation and system requirements. The definition of the operational requirement contains an assessment of the instrumentation task and stresses the need for representativeness in the measurement. The processes of selecting and developing the instrumentation techniques using supporting data processing are shown to provide superior system performance. Results from evaluation trails demonstrate the superior performance of an automated runway visual range system over the observer in providing operationally useful data. In conclusion, the paper discusses future requirements and instrumentation techniques for supplementary visibility assessment.

**Title:** **Independent landing monitors/survey report**

**Reference:** AGARD-CP-188 - paper 31

**Author:** TINSLEY, G.

**Abstract:** Continued interest over a number of years in independent landing monitor systems has resulted in proposals for widely varying techniques and devices to give the pilot a check on the primary instrument landing system and an assurance that the approach and landing is proceeding safely. An independent assessment that an approach is progressing safely may be essential for operator acceptance of approach guidance based on a single electronic signal. Current related developments are summarized to include concept, technical characteristics, and development status. For programs presently undergoing testing, a brief summary of test results is included.

**Title:** **Computer assisted approach sequencing**

**Reference:** AGARD-CP-188 - paper 32

**Author:** BONNY, J. M.

**Abstract:** An experimental prototype system is described that is being developed on behalf of the civil aviation authority, to investigate the feasibility of providing computer assistance in the approach sequencing task at Heathrow airport.

**Title:** **Advanced air traffic management system study**

**Reference:** AGARD-CP-188 - paper 33

**Author:** RECK, R. H.

**Abstract:** Plans for the advanced air traffic management system for the late 1980's and beyond are summarized. The plans are presented in the framework of an evolutionary system concept of traffic management building upon the upgraded third generation air traffic control system, and designed to meet the projected demands for service, safety, and flexibility in a cost effective manner. The advanced air traffic management system concept is characterized by the use of satellite to supplement ground equipment for aircraft surveillance, navigation, and communication over the United States and nearby oceanic regions; strategic flight planning and control for flight in dense traffic regions; centralization of the control system; and a high level of automation. A program of research and development is described to provide the information needed for planning future system developments.

**Title:** **Future air traffic control systems, a preliminary study**

**Reference:** AGARD-CP-188 - paper 34

**Author:** ATC SYSTEMS COMMITTEE, LONDON

**Abstract:** The results of this study particularly emphasize the vital importance both of the place of man in the system, and of the environmental factors affecting the efficiency of the air traffic controller and the pilot, especially in the context of increasing automation. It is firmly believed that future planning will not be successful unless these two user professions are closely involved in it. A predominantly directive method of air traffic control rather than a totally permissive one is evisioned for the future. Furthermore, predictable penalties associated with a pre-planned traffic flow are to be preferred to the chance penalties associated with a random distribution of traffic. At the same time it is imperative to reduce all possible penalties associated with the system to an acceptable minimum.

**Title:** **Applications of the airborne traffic situation display in air traffic control**

**Reference:** AGARD-CP-188 - paper 35

**Author:** CONNELLY, M. E.

**Abstract:** The potential usefulness of displaying traffic and map information in an aircraft cockpit and the effects that the availability of such information would have on ATC procedures and capacities are evaluated. These tests indicate that the ATSD is a valuable aid to the pilot in executing the following basic functions: conflict detection and resolution, conforming to airspace structures, precise spacing in trail, merging, sequencing, monitoring runway occupancy, backup procedures after an ATC failure, approach to one of two closely spaced parallel runways operating independently, and taxiing on the airport surface. A simulation study of a terminal area metering and spacing system in which computer generated commands were transmitted directly to the pilots showed that the introduction of the ATSD eliminated all violations of spacing minimums and cut the dispersion of arrival times at the runway threshold in half. When the ATC generated metering and spacing schedule was made available to the pilots and their flight instruments modified to assist them in executing a 4DRNAV approach corresponding to the schedule, the dispersion of arrival time errors at the runway threshold was reduced to less than three seconds.

**Title:** **A new system architecture for ATC automation**

**Reference:** AGARD-CP-188 - paper 36

**Author:** HAMBURGER, P. E.

**Abstract:** Automation of the National Airspace System (NAS) is well underway with both enroute and terminal control centers successfully converted to automation. These systems are based on interfacing radar outputs to high resolution displays through one or more large scale computers which provide a variety of automation functions, the most important of which are tracking controlled aircraft and formating alphanumeric data blocks for the associated aircraft. Recent studies for air traffic control systems outside the United States have shown that for applications with less concentrated traffic, a system architecture in which numerous minicomputers share the processing task, has significant advantages in cost, reliability and modularity. By being modular, the number of minicomputers required can be tailored to the size of the air traffic control center, and the computer program size can be tailored to the functional complexity warranted by the country's size, traffic level, and sophistication desired. In designing such systems, minicomputers are assigned to functions in one of two ways: either functions are subdivided and minicomputers are assigned to each subfunction, or a function performed in a similar way many times is subdivided so that several minicomputers perform the function once, or at most a few times.

**Title:** **CONUS aeronautical radionavigation by satellite**

**Reference:** AGARD-CP-188 - paper 37

**Author:** STIGLITZ, I. G.

**Abstract:** A variety of satellite system concepts have been promulgated as solutions to the CONUS ATC problems. By categorizing these, it is possible to draw some generally valid observations about the characteristics of each of them. By selecting system architectures, representative of each category, key technical aspect of systems within each category can be explored. Critical aspects illuminated include avionics complexity, required number of satellites, system vulnerability, capacity, required ground processing, and accuracy.

**Title:** **Aeronautical satellite system (AEROSAT)**

**Reference:** AGARD-CP-188 - paper 38

**Author:** RUDEN, J.
THOMAS, J.

**Abstract:** An experimental aeronautical satellite program is being undertaken on an international basis to provide a satellite system and to evaluate the ability of such a system to meet future air traffic control requirements over oceanic regions. The reasons for undertaking such a program are outlined. The system itself is described and the principal parameters, which will be evaluated to assess performance and establish standards for any future satellite system, are discussed.

**Title:** **Measurements of the control capacity of ATC system**

**Reference:** AGARD-CP-188 - paper 39

**Author:** BRAUSER, K.

**Abstract:** Three methods of measuring the executive control load and control capacity have been developed and applied: (1) the measurement of the total time consumption of all executive control tasks generated by all a/c movements occurring in the area of jurisdiction of the executive controller; The time saturation condition indicates that the executive control load is approximating the saturation, i.e. the control capacity; (2) the measurement of a well defined partial work load which has been proved to be average constant part of the total workload, this partial work load being the R.T. channel load; and (3) controller questionnaires on estimates of their control capacity.

**Title:** **A measuring rod for ATC systems, the index of orderliness**

**Reference:** AGARD-CP-188 - paper 40

**Author:** GENT, H.

**Abstract:** The index of orderliness is considered as a measuring rod for ATC systems which gives a numerical estimate of system performance at any moment of time. Its calculation requires a basis for conflict prediction and a threat weighting formula. The index is then defined as a weighted count of future conflicts. The index of orderliness/time curves produced by a collision avoidance system simulation is discussed. It is shown that such curves contain valuable information on the response time of the system. This time structure is displayed via calculation of the autocorrelation function of an index of orderliness graph. The relation of the Index to a complete ATC system viewed as a hierarchy of control loops is presented and shown to be close. Finally it is suggested that indices of orderliness can be used to give a quantitative measure of the style of an ATC system, as well as of its performance.

AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018

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# AIR TRAFFIC MANAGEMENT
## Civil/Military System and Technologies conference
## (The volume contains 29 papers)

**Guidance and Control Panel Symposium of AGARD held in Copenhagen, Denmark, 9-12 October 1979**

**André Benoit and C. T. Elliott, Program Chairmen and Editors**

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**Title:** **Air traffic in NATO Europe: Its characteristics and its needs**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 01

**Author:** PEDDER, I. M.

**Abstract:** The needs and characteristics of air traffic in NATO Europe are reviewed. The divergent requirements and particular problems of airspace users are described and it is concluded that efficient use of the airspace can only be achieved through cooperation between the civil and military authorities. Areas where research and development would be fruitful are listed.

**Title:** **Air Traffic Management. The problem of evolving new concepts.**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 02

**Author:** FRECKLETON, S.

**Abstract:** Article not available at time of publication.

**Title:** **Remote display of processed radar and flight plan data at air defence stations for identification purposes.**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 03

**Author:** WOODS, M. A.

**Abstract:** Classified

**Title:** **The UK Air Traffic Services / Air Defence Interface.**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 04

**Author:** BENNETT, J. W.
USHER, R.A.

**Abstract:** Classified

**Title:** **Helicopter air traffic management systems with civil/military interoperability**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 05

**Author:** SAGANOWICH, J. T.

**Abstract:** In order to achieve significant near-term improvement in the Army's air traffic management capability, several configurations of 'very lightweight air traffic management equipment' (VLATME) were developed. Based upon totally compatible use of today's common civil/military system ATCRBS (air traffic control radar beacon system). Concurrently with the VLATME development, helicopter instrument landing technology work over the past few years has revealed that the key to solving this problem lies in the ability to perform deceleration of the aircraft on instruments, along the approach path, so as to bring the aircraft to a hover a few feet above the intended landing point. The decelerated instrument approach means that helicopter spacings will have to be much smaller than those encountered in fixed wing practice if reasonable flow rates are to be realized. Because of the potential garbling problem in conventional ATCRBS with closely spaced aircraft, a system which integrates the ground and airborne equipments of a scanning beam microwave landing system with the airborne transponder while preserving interoperability was also developed and successfully tested.

**Title:** **A study for development of methods for air traffic management**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 06

**Author:** BERTONI, G.
BONIVENTO, C.
PARDINI, S.
PETRIOLI, R.

**Abstract:** Models and methods for optimal air traffic management were studied as part of the multi-year project 'Navigation aids and air traffic control' funded by the Italian National Research Council (CNR). The scope of the study on the context of CNR project is reviewed. The software structure, its main characteristics and possible utilizations in the planning and management of air traffic system is discussed. Finally, a description is given of more relevant used models and algorithms.

**Title:** **System, airspace, and capacity requirements for future ATC-systems**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 07

**Author:** OCH, G.
SEIFERT, R.

**Abstract:** Based on control capacity measurements of various air traffic control (ATC) systems, a theory of control capacity was developed. The theory of control capacity allows comprehensive knowledge to be gained concerning the relationship and interdependence of the following: (1) The airspace configuration (including the present separation requirements), the traffic structure and the resulting conflict probability. (2) The airspace capacity, the control capacity of the ATC control positions (functional units) and their dependence on air traffic structure and the technical ATC system features and capabilities. Using the theory of control capacity, systems of different technical structure were then assessed. Outdated, present day's, and future ATC systems are compared, showing the effect certain technical components and/or system functions have on system capacity.

**Title:** **Air traffic control automation: Its impact and use in the selection and screening of air traffic controllers**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 08

**Author:** BOONE, J. O.

**Abstract:** The impact of automation in air traffic control on personnel screening is discussed. The mathematical and technical aspects as they are currently being developed are focused upon.

**Title:** **Data link: The key to improvements in civil/military air traffic management?**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 09

**Author:** COX, M. E.

**Abstract:** Experimental work which is being undertaken both to explore how an air/ground data link might be exploited for future air traffic control purposes and to determine its possible capacity requirements is described. Details of the form and functions of experimental equipment built to investigate what is believed to be the major problem area influencing communications improvements, the pilot/link interface, are given. Details are also given of studies investigating the possible use of the link in transferring aircraft, derived data both to yield improvements in the precision of meteorological forecast data and to enhance the performance of radar-based tracking and conflict-alerting systems. Capacity requirements and the feasibility of realizing a link for these purposes within the next two decades are discussed.

**Title:** **Midair conflicts and their potential avoidance by progressive implementation of automation**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 10

**Author:** WEBER, O.

**Abstract:** Actual midair conflicts between civil and military aircraft in German airspace where at least one of the airplanes involved was flying under visual flight rules were analyzed. Operational, environmental and human factors, which contributed to the accidents, and the limits of the 'see and avoid' concept for collision avoidance are discussed. Some shortcomings of the present air traffic control system are mentioned. Taking the actual midair conflicts and some simulated three dimensional flights as examples, the improvement of collision avoidance by progressive implementation of advanced techniques is discussed. The lead time to the potential conflict or to a circular zone of protection, the distance at the closest approach and some other thresholds, estimated by means of a ground-based radar system or an airborne electronic collision avoidance system, are used as main criteria for an automatic conflict alert. Potential advantages of a data link to detect sudden manoeuvres in time are mentioned.

**Title:** **Determination of the safety in a North Atlantic organized track system with reduced lateral separation**
**statistical tests**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 11

**Author:** MOEK, G.
TRAAS, C. R.

**Abstract:** Collision risk modelling as related to the reduction of lateral separation from 120 NM to 60 NM at any fixed level in the North Atlantic Organized Track System is considered. Requirements on the navigation performance are described which aircraft must be able to meet if this reduction would be implemented. Two statistical tests are derived which can be applied to the measured number of navigation errors to determine whether the actual navigation performance is such that the system with 60 NM lateral separation meets a target level of safety. The first test which belongs to the standard equipment of the NAT/SPG for judging the safety of the track system is based on one random model for all navigation errors. The second test is applicable for the case different types of navigation errors can be distinguished and modelled separately. The different contribution of each type of error to the total risk is taken into account by the use of weighting factors. This test, however, is still in discussion in the North Atlantic Systems Planning Group.

**Title:** **US Army users outlook on air traffic management**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 12

**Author:** KREPS, L. P.
MALONEY, W. H.

**Abstract:** The need for air traffic control, not only in support of its fixed base peace-time mission, but also its tactical mission is recognized by the U.S. Army. Air traffic management as it existed during the Vietnam era of the 1960's and as it evolved during the 1970's is described. The European scenario literally dictates doctrine for hostile operations in a mid-intensity environment. What is happening and planned from an ATC viewpoint in support of U.S. Army/Europe (USAREUR) is discussed including the future potential of a global positioning system.

**Title:** **The development and test of a tactical self-contained landing system landing military helicopters when the safe corridor is unknown**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 13

**Author:** SHUPE, N. K.

**Abstract:** The existence of a digital symbol generator (DSG) whose basic function is to compute and display the augmenting symbolic data necessary to operate a helicopter in the NOE environment via a FLIR presentation of the contact world, and a digitally-generated topographic map display (DMG) is sufficient justification to consider adaptation of the DSG and DMG equipments to the reversionary function of providing IMC terrain-following and tactical landing capabilities. The control/display architecture necessary to use a radar altimeter to control the elevation flight path of the aircraft and a Doppler radar to control the deceleration of the aircraft is presented. The assumed precision navigation system provides the Northing/Easting aircraft position: (1) to permit the aircraft to be steered along the prescribed ground track to the landing zone; (2) to provide a starting point for interrogation of the DMG terrain elevation data for purposes of generating anticipation for the TF system; and (3) to act in concert with the velocity output of the Doppler radar for purposes of following a preprogrammed deceleration profile to the landing zone. A multi-phase simulation and flight-test program to assess the performance of the complete system in the NOE environment are described.

**Title:** **Very lightweight air traffic management system using an electronic scan antenna**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 14

**Author:** SHAGENA, J. L., JR.
WOODALL, P. J.

**Abstract:** An electronically scanned antenna with all solid-state interrogator, complemented by a multi-microprocessor driver tactical interactive display, provides a full alphanumeric PPI air traffic management system. This system utilizes the standard Mark X/XII ACTRBS/IFF airborne transponder to provide position information on all targets (up to 100) and tracked range, azimuth, and altitude (via mode C) on up to 13 targets. The two key features of this system are the electronically steered matrix-fed cylindrical array and the microprocessor based intelligent controller. The controller performs search and active track, minimizing interrogator PRF (64-198.5/Sec) and electromagnetic interference. The antenna and R/T are physically integrated into a single assembly to minimize set-up time and maximize reliability.

**Title:** **Technical and operational factors concerning the licensing and introduction of a new microwave landing system for category 2**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 15

**Author:** BRAMMER, K. G.
KRICKE, K. D.

**Abstract:** For the new aircraft Tornado and Alpha-Jet, the landing system SETAC is now being prepared for category 2 service at the assigned air bases in Germany. As soon as this system's technical capabilities are to be exploited to the full extent for operational use, all relevant rules and regulations applicable for ILS category 2 operations must be exhaustively expanded and supplemented. This concerns concepts for infrastructural measures, such as extension of obstacle clearance limits to the whole area of coverage, calibration and testing of the total radio field, modifications of the approach light pattern, additional training and licensing of ATC staff and pilots etc. In order to reduce this extensive task to a short-term solution, a stagewise procedure of system introduction is outlined. The concept is to utilize SETAC equipment with all the corresponding advantages regarding installation, but to retain in the first stage as closely as possible all regulations, flight procedures and instrumentation pertaining to ILS approach and landing.

**Title:** **The integration of area navigation and the microwave landing system**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 16

**Author:** RICH, P. M.
RICHARDSON, D. W.

**Abstract:** The RNAV and MILS are non-competitive complementary navigation/landing systems that, working together, can markedly enhance the safety and efficiency of terminal area operation while at the same time impacting the overall concept of terminal airspace management. Primarily, these systems afford the opportunity, which has been debated so vigorously for many years, of converting to a distributed management philosophy of ATC system design and operation in which much of the navigation function is transferred from the radar vectors issued by the ground controller to the flight crew, aided by increasingly available, low cost, multifunction avionics systems. Some activities on the part of the United States Federal Aviation Administration to develop and integrate these complementary capabilities into the terminal area airspace system are examined.

**Title:** **SINTAC-C TMA: Application of SINTAC-C in the terminal area, during landing and ground taxiing**
**integrated navigation, traffic control, collision avoidance and communication system**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 17

**Author:** HETYEI, J.
MILOSEVIC, L.

**Abstract:** An integrated navigation, traffic control, collision avoidance and communication system is described which can control between 200 and 1000 aircraft according to the number of runways (or airports) included in terminal area. During final approach and landing, the system controls 16 aircraft, the maximum which can be considered in the MLS beam, with a 30 second landing rate. According to the required control capacity, the system uses one, two or three time-shared nets for all the functions and for all the in flight and ground phases. The navigation transmission rates are very high (32-16 Hz) thus ensuring a practically continuous navigation function. The surveillance and synchronization frequency depend on the area: a maximum of 4 seconds in the terminal area and a 1 second maximum at landing time. Three types of SINTAC ground stations are considered: (1) SINTAC-TMA: 100-150 km range covering the TMA area with three or four stations; (2) SINTAC-landing: located at the far-end of the runway (precision DME), range and antenna beam aperture same as MLS; and (3) SINTAC-ground taxiing: airport area coverage by three stations: station range: 5 to 10 km.

**Title:** **Evolution and transition of today's military landing system to compatibility with present and future civil military systems**
**multimode receivers and the marine remote area approach landing system**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 18

**Author:** SHAPIRO, A. J.

**Abstract:** The operational need for a single avionics system to operate with the present instrument landing system, the future ICAO approved microwave landing system and the Marine remote area approach landing system (MRAALS), is discussed. The operational solution developed in response to a U.S. Navy/Marine requirement is a multimode receiver that is capable of operating with any of the systems mentioned above. The evolutionary process involved in progressing from a single to a multiple mode system capability is reviewed with emphasis on the technological advances leading to a most cost and volume effective solution.

**Title:** **Introduction on LORADS and ASDE**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 19

**Author:** PRIEBEE, E. C.

**Abstract:** A long range radar and display system (LORADS) and airport surface detection equipment (ASDE) are described. A panoramic view of both systems, its functional and operational requirements, and the system architecture of both the hardware and software are given.

**Title:** **Air Track. An ATC Multiradar Tracking System based on the track combination method.**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 20

**Author:** LIEBELT, G. A.
SEELS, W.

**Abstract:** Classified

**Title:** **PDME as a core of common military and and civil radio en route navigation and landing aids.**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 21

**Author:** BOEHM, M.

**Abstract:** Classified

**Title:** **Applications of microprocessors in air traffic**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 22

**Author:** STODDART, D. L.

**Abstract:** The use of microprocessors in air traffic control (ATC) systems is examined. The characteristics of microprocessors are compared with those of mini and main frame computers to identify the most suitable role of the microprocessor in ATC Systems. The application of microprocessors for system functions such as Data Link Management, Display Console Management and Format Converters is discussed. To emphasize the impact of microprocessors on system design a conventional display system is compared with one using microprocessors where this device is built into the overall design of the display system with consequent saving in display generation hardware. The design is extended so that the display microprocessor becomes the central element in display console management. The F100L microprocessor is described in some detail and used as model to define the capability of a microprocessor.

**Title:** **Precision navigation for air traffic management**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 23

**Author:** RATCLIFFE, S.

**Abstract:** The problems that would arise if airspace users had the use of NAVSTAR or some other much better position-fixing aid than at present, and the uses that air traffic control (ATC) could or could not make of this capability are examined. There would be formidable transitional problems in the vertical plane, because NAVSTAR measures height from the Earth's center whereas current altimeters measure atmosphere pressure. In either vertical or horizontal planes much work would be necessary to prove that the separation standards can be reduced at all. The changes that might be possible in the ATC system should appreciable reductions in separation standards prove possible are discussed. NAVSTAR might form the basis of a collision avoidance system based on either the broadcast coordinates of each aircraft or on a time frequency basis using NAVSTAR as the time reference. The latter scheme would offer protection of a fully equipped aircraft against threat that could not afford the expense of a NAVSTAR fit.

**Title:** **JTIDS: An integrated communications navigation and identification system, and its potential for air traffic management**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 24

**Author:** NEUMAN, D. D.

**Abstract:** The integrated data communications, voice communications, navigation, and identification features of the Joint Tactical Information Distribution System (JTIDS) are described with emphasis on those features applicable to air traffic management. The JTIDS system architecture simultaneously provides data at the ground centers and in the cockpit. Airspace control and advisory data are made available to all aircraft to permit subscribers to be aware of, and comment upon, directions provided to others. Network control techniques are discussed which support civil air traffic management applications. These techniques provide for the apportionment of capacity among subscribers in such a manner as to allow all subscribers access to all data in their area of interest without real time network management. The potential exists for a substantial reduction in the avionics boxes aboard aircraft. A JTIDS like system can simultaneously provide the data for airspace management and control, collision avoidance, area navigation, air-to-air coordination, cooperative surveillance, cockpit situation display, airport surface traffic control, and possibly instrument landing. The transition from the existing air traffic management system to a JTIDS like system is also addressed. Austere terminal designs appear to be possible at a cost that is affordable for general aviation.

**Title:** **Synchronisation, Measurement of the distance and position determination in the SINTAC.**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 25

**Author:** CHARAVIT, J.C.
LAURENT, P.
MILOSEVIC, LJ.

**Abstract:** Classified

**Title:** **Discrete address beacon system air traffic control**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 26

**Author:** HOGKINS, P. D.

**Abstract:** A discrete address beacon system (DABS) to provide upgraded air traffic control radar beacon system (ATCRBS) surveillance is discussed. The DABS concept provide improved air traffic control automation service and ground based automatic traffic advisory and resolution service through its integral high capacity digital air ground data link. The compatibility of DABS with ATCRBS, interrogation concepts, and the computer processing subsystem are specifically discussed and current testing and evaluations of the system are reviewed.

**Title:** **ADSEL: Selective address SSR, performance of the evaluation station air traffic control**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 27

**Author:** BONNY, J. M.
BOWES, R. C.
NICHOLS, T. B.

**Abstract:** A selectively addressed radar system (ADSEL) designed to overcome the 'garble' problem of the current secondary surveillance radar (SSR) system and provide a data link facility is discussed. The system requires aircraft to carry a transponder which includes the selective address mode of operation and a ground station with monopulse direction finding system plus data processing facilities. In particular the evaluation trials that have been carried out are reviewed and the results of a large number of aircraft flights are given. The main aim of the trials is to assess the accuracy with which the position of an aircraft can be measured, the performance of the communication links, and to optimise the operating rules. A detailed analysis is given of the performance of the SSR and ADSEL system when monitoring two aircraft flying close together such that their transponder replies were 'garbling'.

**Title:** **Surveillance performance measurements of the SSR mode of the discrete address beacon system**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 28

**Author:** DROUILHET, P. R.
ORLANDO, V. A.

**Abstract:** The field measurements, taken to evaluate the surveillance performance of the Discrete Address Beacon System (DABS), are described. Simultaneous measurements made by transportable measurements facilities and the existing ground stations provided the opportunity for a side-by-side comparison of DABS off-boresite monopulse and conventional surveillance measurement performance. The results indicate that both range and azimuth accuracies of the DABS design are four times better than those provided by current terminal secondary surveillance radar (SSR) equipment. Blip/scan ratio for monopulse SSR is 98% or better, and remains high in crossing track situations where the performance of existing equipment is observed to degrade. Significantly, this improvement in SSR performance was accomplished with 1/4 the pulse repetition frequency of the present equipments.

**Title:** **Effectiveness of advanced fuel-conservative procedures in the transitional ATC environment**

**Reference:** AGARD-CP-273 / ISBN-92-835-1347-9 / AD-A087018 - paper 29

**Author:** OBRIEN, P. J.
TOBIAS, L.

**Abstract:** The real time simulation (involving both the pilot and the air traffic controller) of fuel conservative approaches, profile descents, and four dimensional area navigation to assess the effectiveness of the procedures is discussed. Generally, results indicate some difficulties with the procedures tested in a mixed traffic environment and point to the need for computer assistance for effective implementation of candidate procedures.

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# AIR TRAFFIC CONTROL IN FACE OF USERS' DEMAND AND ECONOMY CONSTRAINTS
## (The volume contains 12 papers)

Guidance and Control Symposium of AGARD
held in Lisbon, Portugal, 15 October 1982

André Benoit, Program Chairman and Editor

**Title:** **Present situation and requirements.**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 01

**Author:** GAYRARD, M.

**Abstract:** Overview Paper

**Title:** **A UK NATS view of the air traffic management requirements in the next decade**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 02

**Author:** HEMMING, P. H.

**Abstract:** The main categories of user demand in United Kingdom airspace at present and the Air Traffic Management infrastructure currently provided are discussed. Aspects of NATS plans for improvement and modernization of air traffic control and the relationship of these plans to improved economy and fuel conservation are outlined. The main focus of these plans is related to development of ATC capability in the London and South East England area, therefore the redevelopment of the London Air Traffic Control Centre is described in the context of the theme of the Special Session. The relationship applicable to the United Kingdom between financial policy, implementation plans and the cost to system user is discussed in view of the constraints it places on the ability of the ATC system to meet commercial demand for the most economic service.

**Title:** **Fuel conservation and economy constraints**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 03

**Author:** BARBER, D.
MORRALL, J. C.

**Abstract:** Fuel conservation in civil aviation may be achieved by increasing the efficiency of the aircraft themselves, by operating the aircraft more efficiently, and by providing them with a more efficient air traffic environment. Three aspects are discussed briefly, and possible improvements in the air traffic management environment are examined in more detail. Finally, attention is drawn to the Research and Development program needed to achieve fuel conservation by improved air traffic management.

**Title:** **The airline facing the present crisis**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 04

**Author:** WAGENMAKERS, J. H.

**Abstract:** The impact of the drastic fuel price increase on airline operations is briefly discussed. Some measures that are being taken to contain the economic effect are reviewed. In particular air traffic control (ATC) criteria and military constraints are highlighted, which are known to have a direct influence on fuel burn. This is illustrated with examples and furthermore a specific comment is made in relation to the Portuguese ATC environment.

**Title:** **Military requirements**
**LES BESOINS MILITAIRES**
**fuel economy, air traffic control, and defense budgets**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 05

**Author:** DEDONCKER, J.

**Abstract:** In view of the constraints affecting the military user, it is beneficial to question how much traffic control can contribute to solving actual problems which border largely on the matter of fuel costs. An outline of progress related to approval of the defense budget in member countries of the Atlantic Alliance illustrates how difficult it is in western demoncracies to obtain, in this crisis period, the credits needed to carry out the collective defense programs which were elaborated by NATO in consultation with member countries of the Alliance and approved by governmental authorities. Concrete results, obtained in recent years through the coordination of civilian and military partners responsible for space management provide a glimpse of models of action capable of contributing to a form of economy of costly fuel. These gains seem ridiculous when the question of means needed to realize a deliberately agreed upon policy is raised in all its seriousness.

**Title:** **Air traffic services in Portugal**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 06

**Author:** CARVALHO, J. F.

**Abstract:** The Portuguese area of responsibility for the provision of Air Traffic Services; and the organization of services and authorities are described. An overview is given of development projects, for the Lisboa and Santa Maria FIR's, their objectives basic concepts, and implementation dates.

**Title:** **Air traffic services in Portugal: Civil-military coordination aspects**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 07

**Author:** ROCHA, L. G.

**Abstract:** The provision in Portugal of Air Traffic Services in civil and military aircraft and concurrent procedures is discussed. This assessment is based on a strictly military point of view having in account either its requirements or national and international involvements. All over the world the users of the airspace as well of the Air Traffic Control Systems are basically the General Aviation, Air Carriers with their trunk, regional and short haul categories and the military aviation. The effect that military activity has on ATC Systems is extremely inconstant depending on either air space structure or Air Traffic Services organization at each country.

**Title:** **Potential developments and applications.**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 08

**Author:** RICCIARDELLI, S.

**Abstract:** Overview Paper

**Title:** **Overview of United States program for modernizing air traffic control and airway facilities**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 09

**Author:** DROUILHET, P. R.
WEDAN, R. W.

**Abstract:** The Federal Aviation Administration (FAA) recently completed a comprehensive plan for moderning the United States (U.S.) Air Traffic Control and Airways Facilities over the period from now to the year 2000. An overview of this plan is provided and description of some of the recent technological developments that provide the foundation for significant improvements to the system are discussed. These improvements include a new discrete address surveillance and data communications system, an airborne collision avoidance system that operates independently from the ground based air traffic control system, the replacement of the air traffic control computer facilities with modern equipment, the inclusion of a higher level of automation to aid the controllers and to provide greater freedom of severe precision landing aids using microwave equipment, and enhanced dissemination of severe weather information to controllers and pilots. Other innovations are also planned in order to meet an increasing demand for air traffic control services but without incurring a proportionate increase in the cost of providing these services.

**Title:** **Management and planning concepts**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 10

**Author:** RATCLIFFE, S.

**Abstract:** The processes used for management and control of air traffic are outlined. Some congestion in airspace or at airports is inevitable, the further ahead this congestion is foreseen, the more economically it can be resolved. A limit is set by the accuracy with which the future can be predicted. Existing ATC systems necessarily use human controllers, who often significantly outnumber the aircraft under their control. It is not easy to see how this situation might be improved. Control tasks must be divided up between numerous controllers who, at busy times, cannot discuss each others problems in any detail. Controllers therefore solve only subsets of the total problem, and their solutions are significantly less efficient than theory indicates is possible. The extent to which 'automation' might make possible cheaper or more efficient ATC is safety considerations and difficult 'human factors' problems.

**Title:** **Dynamic control of inbound flights for minimum cost operation**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 11

**Author:** BENOIT, ANDRE
SWIERSTRA, SIP

**Abstract:** The Zone of Convergence (ZOC) concept is proposed as an essential short term Air Traffic Control contribution to the economics of air transport. It is established that, when considering traffic inbound to a medium to high density terminal, this approach could reduce fuel consumption by some ten to thirty percent, this value being referred to the total fuel burn in an extended area including and surrounding main terminal and extending over some 100, ideally 300, nautical miles. The selection of profiles tailored to the operators' criteria, whether constrained by ATC or not, is discussed in some detail. The compatibility of the techniques proposed with online operations is found to be satisfactory. This conclusion results from test conducted using ATC simulation facilities, airline flight simulators, and online exercises involving regular scheduled flights.

**Title:** **Investigations on four-dimensional guidance in the TMA**

**Reference:** AD-A127146 / ISBN-92-835-0326 / AGARD-CP-340 - paper 12

**Author:** ADAM, V.
LECHNER, W.

**Abstract:** The four dimensional (4D) guidance of aircraft in the terminal area (TMA) allows for precise control of the minimum separation and thus efficient use of the available approach capacity of the respective airport. A concept for the 4D guidance of transport aircraft was developed and a corresponding control mode was integrated in an automatic flight control system for transport aircraft. The 4D mode is based on usual radar vector guidance technique of air traffic control and, therefore, is characterized by a succession of flight sections with constant values for indicated airspeed, heading and descent rate. The time of arrival is controlled by altering the path via a delay fan. The algorithm for the calculation of the commanded 4D flightpath takes into account suitable wind models updated by actual wind data. The 4D mode is described and first flight test results are discussed.

AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150

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# EFFICIENT CONDUCT OF INDIVIDUAL FLIGHTS AND AIR TRAFFIC
## Optimum Utilization of Modern Technology for the Overall Benefit of Civil and Military Airspace Users
## (The volume contains 25 papers)

**Guidance and Control Symposium of AGARD held in Brussels, Belgium, 10-13 June 1986**

**André Benoit, Program Chairman and Editor**

**Title:** The selection of future civil air navigation systems

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 1.1

**Author:** CAREL, OLIVIER

**Abstract:** The International Civil Aviation Organization has established a special committee (FANS) responsible for assessing Future Air Navigation Systems. This report describes the creation of this committee and gives a detailed summary of its principle meeting, FANS-2, held in April 1985. Recent work of the committee is also discussed. Automatic dependent surveillance (ADS) and required navigation performance capability (RNPC) concepts are addressed. Finally, the rapid evaluation of aeronautic mobile communications by satellite is discussed.

**Title:** FANS - A U.S. perspective

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 1.2

**Author:** PORITZKY, S.B.

**Abstract:**

**Title:** **Air navigation services and aircraft around the year 2000**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 1.3

**Author:** VACHIERY, V.

**Abstract:** The Air Traffic Services (ATS) System for 2000 and beyond shall have to cope with the constantly increasing traffic demand. It shall take wholly into account the methods by which the aircraft are conducted, and, in particular the ability to adhere accurately to a predefined profile. Since 1980 a working party of the EUROCONTROL Agency has been in charge of the development of a future system concept and the formulation of a corresponding research program. The objectives, the difficulties, the main principles and the characteristics associated with the development and implementation of the future ATS concept are reviewed. The necessity for close consultation between aircraft manufacturers, avionics manufacturers, aircraft operators and the authorities responsible for air traffic management is discussed.

**Title:** **GPS: Overview and present status**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 2.1

**Author:** HARTL, PH.
SCHOELLER, W.
THIEL, K.-H.

**Abstract:** Due to various reasons the interest in the practical use of the Global Positioning System (GPS) has considerably increased during the last two years. The test phase has demonstrated its outstanding performance. With the differential method the relative accuracies achieve values that open its use even for the precision approach of aircraft landing. The development of new techniques also allows 3-dimensional attitude measurement and angular rate determination. Diverse civilian groups will use GPS in the future; in particular motor car drivers, geodesists, civil engineers etc. The present state of development and various practical applications are discussed.

**Title:** **Inertial-GPS: A marriage of reason, an analysis**
**INERTIE-GPS: UN MARIAGE DE RAISON - A L'ESSAI**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 2.2

**Author:** CAPIT, B.
LLORET, P.

**Abstract:** The coupling of inertial navigation methods with the Global Positioning System (GPS) is examined. The characteristics of various types of inertial systems are reviewed and past attempts at inertial/radionavigation hybridizations including those with multi- and VOR-DME (VHF omnidirectional range - distance measuring equipment), Transit, OMEGA, ILS (instrument landing systems), and altitude correlation are discussed. The possible configurations for an inertial/GPS systems, given the type (classical platform and strap-down) and classes of inertial designs and the number of GPS channels utilized, are defined and performance characteristics are outlined for each. Simulation and in-flight studies of prototype systems are discussed. Signal properties and Kalman filtering are addressed. Finally, perspectives on the continuing development of inertial/GPS hybrid systems are offered.

**Title:** **GPS as the sole means navigation system in US Navy Aircraft.**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 2.3

**Author:** LOWENSTEIN, G.
PHANOS, J.
RISH, E. R

**Abstract:** Paper not available at time of printing.

**Title:** **Communication, Navigation and Surveillance services for the aviation industry using satellite technology**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 2.4

**Author:** PICKENS, R. A.

**Abstract:** A general historical survey of Communication, Navigation, and Surveillance (CNS) services for the aviation industry using satellite technology is given. Aeronautical Radio, Inc's (ARINC) air-ground communications services, which consist of VHF voice and data transfer services, and HF voice communications are discussed. ARINC's implementation of an integrated satellite system and companion integrated avionics to provide air traffic control, company operational control, navigation capability for enroute operations, and support for cooperative operations is discussed.

**Title:** **Possible contributions from the SSR mode S data link to the conduct of efficient aircraft operations**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 2.5

**Author:** COX, M. E.

**Abstract:** The paper entitled Data Link - The Key to Improvements in Civil Military Air Traffic Management, presented at the Guidance and Control Panel (GCP) Symposium, Copenhagen, in October 1979, outlined a number of potential applications of a data link, then known as ADSEL/DABS, and referred to a number of feasibility studies that were being conducted in respect of these applications. Since that date the two systems (ADSEL/DABS) have led to the emergence of secondary surveillance radar (SSR) Mode S which is now being standardized for international use. Here, a brief description is given of the Mode S data link characteristics. A number of the applications proposed in 1979 are recalled and the results of studies conducted subsequently on such topics as the controller/pilot interfaces with the link and machine/machine data interchanges and their possible benefits to air traffic control (ATC) are given. Plans are discussed for more extensive data link evaluations. The initial steps that could be taken in progressing from today's situation towards a system of control employing a high level of automation are proposed.

**Title:** **Space-based multifunction radar systems: Future tool for civilian and military surveillance**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 3.1

**Author:** GALATI, G.
LOSQUADRO, G.

**Abstract:** Space-based surveillance systems, including primary radar (SBR) and secondary surveillance radar (SBSR) are of interest for both air traffic control and the air defence. The relevant state of the art, surveillance system architectures with special reference to the European scenario and future work are discussed. Multifunction space-based surveillance for European applications, synthetic aperture radar for remote sensing and system options and tradeoffs are discussed.

**Title:** **Monopulse secondary radar: Practical realization and achievement. Mode S: The radar of tomorrow**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 3.2

**Author:** DELILLE, FRANCOIS

**Abstract:** There can be no doubt that Mode S will be part of tomorrow's Air Traffic Control (ATC) radar. Its assets in terms of air traffic surveillance and data link are noted. Fundamental characteristics are its compatibility with existing secondary surveillance radar's (SSR), selective interrogation and monopulse reception. The monopulse SSR is a landmark in the transition towards Mode S; it contributes several major improvements, without requiring onboard transponders to be changed. Choices made in the implementation of the system are discussed, in particular as regards the antenna, transmitter, reception and processing techniques. Through these options, full Mode S compatibility is maintained. Practical results have turned out to be conclusive, and so the system was taken into production and already many stations are operational round the world. The Mode S extension which has to be added to the monopulse radar is also described, and it is being operated at Orly as part of an experimental development program.

**Title:** **A practical example of Moving Target Detection (MTD) processing for an air traffic control radar with weather channel**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 3.3

**Author:** BRUNO, CHRISTINE

**Abstract:** Air Traffic Control (ATC) radar processing of the Moving Target Detector (MTD) type is described. It comprises an independent processing channel called weather channel, which supplies meteorological data. The MTD processing technique is aimed at improving the detection of useful targets in the midst of clutter. The algorithms employed are detailed, as well as the performance to be expected, in particular the improvement in the radar picture presented to the operator. The processing system is made up of programmable processors, of which the architecture and other main features are described, as is the radar station remote monitoring and maintenance system. Finally, results obtained in experiments are given.

**Title:** **Microwave Landing System (MLS) area navigation: Computed centerline experiments and system accuracy analysis in an RF environment**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 4.1

**Author:** BILLMANN, BARRY R.
REMER, JAMES H.

**Abstract:** By definition of the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPS) the Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS) will supplant the existing Instrument Landing System (ILS) as the recognized international standard as early as 1995. Among numerous other advantages, the MLS provides the ability to determine the aircraft's position in three dimensional space over a large coverage volume in the airport terminal area. The use of this capability to navigate and execute approaches throughout this volume of coverage results from the application of a technique known as Microwave Landing System Area Navigation (MLS RNAV). Applications of MLS RNAV can be as simple as executing approaches offset from but parallel to the MLS 0 azimuth or as complex as multi-segment and curved path approaches. MLS RNAV is particularly adaptable to helicopter operations. It allows approaches to heliports located away from the main instrumented runway. In order to assess and further develop the potential capabilities of MLS RNAV, the FAA Technical Center has undertaken the task of performing analytical studies, as well as the development of a prototype MLS RNAV system. Applications of this system to helicopter operations are particularly being emphasized. The unique feature of this work is that besides the onboard data acquisition systems, an independent source of position information was, at times, available for comparison. The source was independent position tracking in t

**Title:** **MLS: Its technical features and operational capabilities**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 4.2

**Author:** SEIFERT, R.

**Abstract:** Taking into account present developments in guidance and control automation in the airplane cockpit as well as in Air Traffic Control (ATC) systems, the following aspects of the Instrument Landing System/Microwave Landing System (ILS/MLS) are analyzed and presented: (1) the complexity of MLS approach procedures and function allocation to ATC and aircraft; (2) cockpit automation and presentation of MLS approach information; and (3) aspects of all weather approach and landing with military aircraft.

**Title:** **Advanced ATC: An aircraft perspective**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 4.3

**Author:** CREDEUR, LEONARD
HOWELL, WILLIAM E.
SPITZER, CARY R.
WILLIAMS, DAVID H.

**Abstract:** The principal operational improvements desired by commercial aircraft operators in the United States are efficient aircraft operations and delay reductions at the major terminals. Efforts underway within the Advanced Transport Operating Systems Program at the Langley Research Center to provide a technology basis for reducing delay while improving aircraft efficiency are discussed. The principal thrust is the development of time-based traffic control concepts which could be used within the framework of the upgraded National Airspace System and which would allow conventionally equipped aircraft to operate in a manner compatible with advanced aircraft.

**Title:** **Strategic control to improve efficiency of air traffic management**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 5.1

**Author:** BIANCO, LUCIO

**Abstract:** The strategic control concept, intended as a new management philosophy that can improve efficiency of Air Traffic Control (ATC) systems, is discussed. After having introduced a classification of the different ATC functions based on a multilevel scheme, strategic control is decomposed in a hierarchy of sub-functions. Subsequently, the on-line strategic control of flights is considered and the mathematical aspects of this problem are illustrated. Then the structure of a real time solution algorithm, proposed in a previous work, and a possible scheme of route-time profile generation are reported. Finally, computational efficiency of the proposed approach is discussed.

**Title:** **A time-based concept for terminal-area traffic management**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 5.2

**Author:** ERZBERGER, HEINZ
TOBIAS, L.

**Abstract:** An automated air-traffic-management concept that has the potential for significantly increasing the efficiency of traffic flows in high-density terminal areas is discussed. The concept's implementation depends on techniques for controlling the landing time of all aircraft entering the terminal area, both those that are equipped with on-board four-dimensional (4D) guidance systems as well as those aircraft types that are conventionally equipped. The two major ground-based elements of the system are a scheduler which assigns conflict-free landing times and a profile descent advisor. Landing time provided by the scheduler is uplinked to equipped aircraft and translated into the appropriate 4D trajectory by the-board flight-management system. The controller issues descent advisories to unequipped aircraft to help them achieve the assigned landing times. Air traffic control simulations have established that the concept provides an efficient method for controlling various mixes of 4D-equipped and unequipped, as well as low- and high-performance, aircraft. Piloted simulations of profiles flown with the aid of advisories have verified the ability to meet specified descent times with prescribed accuracy.

**Title:** **Philosophy of applying automation to air traffic control**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 5.3

**Author:** PAGE, LELAND F.

**Abstract:** The objectives of the U.S. program for applying automation to air traffic control systems, progress thus far, and plans for the future are discussed. Since the time in 1958 when computers were first used to print flight strips in the United States at a small number of air traffic control (ATC) centers, it has been a continuing objective to capitalize on the rapidly evolving computer technologies to improve the ATC system. Specific objectives have been to apply computers and the associated automation functions to: improve safety of ATC operations; increase the efficiency of traffic management; and increase the productivity of ATC controllers.

**Title:** **Computer assisted arrival sequencing and scheduling with the COMPAS system**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 5.4

**Author:** VOELCKERS, U.

**Abstract:** The Computer Oriented Metering Planning and Advisory System (COMPAS) developed at the DFVLR-Institute for Flight Guidance was tested and evaluated at the institute's air traffic simulation facility, using traffic scenarios of Frankfurt airport with up to 52 aircraft movements simultaneously. The operational objectives of the COMPAS-system are, with regard to Frankfurt airport, to achieve the best possible usage of the available but limited runway landing capacity, to avoid unnecessary delays and to apply economic approach profiles whenever possible. The planning functions which today are still carried out by human controllers will be transferred to a computer. It generates a comprehensive plan for a best overall arrival sequence and schedule. The execution of this plan, however, intentionally remains the task of the human controllers. They are provided with all data necessary to control the approaching aircraft. The systems concept, the dynamic planning algorithms as well as the operational concept for computer assistance and the man-machine interface are presented. Some preliminary results of the experiments and evaluation are reported.

**Title:** **Next generation of control techniques in advanced TMA**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 5.5

**Author:** BENOIT, ANDRE
DEWISPELAERE, RENE
SWIERSTRA, SIP

**Abstract:** It is very likely that any future concept to be used for the safe and efficient conduct of air traffic (in terms of expedition, economy and capacity) will exhibit two essential, closely interrelated components. Firstly, the on-line management of air traffic over a large area - from a Zone of Convergence type to a continental coverage - will generate the landing and departure times for each aircraft entering the area, while at the same time defining the essential characteristics of the relevant flight paths. Secondly, an operational control procedure will be required to conduct each individual flight accurately throughout the area, that is to say, in the case of a Zone of Convergence, from entry to touchdown, in agreement with the air traffic management directives and in line with operational practice (onboard and on the ground). The essential operational features of a control procedure suitable to meet the above constraints while ensuring a 10-second accuracy for the time of arrival as predicted initially at entry into the zone (and possibly amended subsequently), for current air carriers in present R/T or future D/L communications environments are outlined.

**Title:** **Exploiting the capabilities of flight management systems in solving the airport arrival problem**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 6.1

**Author:** MEREDITH, J. F.

**Abstract:** Increasingly Flon present day passenger aircraft (737-300, 757, 767, A310, A300-600). Avionic update programs which incorporate Flight Management Computers are in hand for 747 and MD 80 and new aircraft programs A320, MD 11, 7J7, A330 and A340 are or are likely to include Flight Management Computing as standard fit. As these aircraft come to dominate the traffic entering and leaving major airports there is potentially a new level of information and of control available to the air traffic controllers whose task it is to schedule the aircraft flow into and out of the terminal area. This information flow and the consequent control actions should enable the traffic to be handled in a manner to minimize delay, thus enhancing the available traffic handling capacity of an airport.

**Title:** **Application of flight performance advisory systems to US Navy aircraft**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 6.2

**Author:** CARSON, R. C., JR.
COWLES, L. J.
FRIEDMAN, M. J.

**Abstract:** The U.S. Navy, in its Aircraft Energy Conservation Research and Development Program, is currently investigating various methods for improving the fuel efficiency of existing and future Navy aircraft. Fuel saving concepts under development include an aircraft integrated flight performance advisory system, a pre-flight mission planning program utilizing a desk type computer and an aircraft performance advisory system using an HP-41 CV hand-held calculator. The integrated flight performance advisory system for the F/A-18, the A-7E, and the S-3 are described in detail by reviewing the displayed outputs to the pilots and describing the required inputs and their sources. Features of each aircraft system are described in accordance with the development status of the program. The preflight mission planning program utilizing an HP-9845 desktop computer is described for the P-3C aircraft. The approach to weather, takeoff and cruise are described by specifying the input and output data. Sample displays are also shown. The hand-held HP-41 CV calculator utilized for flight performance predictions is described for the P-3C. All the calculator functions are described for the takeoff and cruise flight modes of this aircraft. The operational status of these three programs and plans for other Navy aircraft are also specified.

**Title:** **Design criteria for multi-loop flight control systems**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 6.4

**Author:** SCHAENZER, G.

**Abstract:** The problems of design criteria and architecture of multiloop flight control systems for a realized system to achieve precise flight path guidance, safe and economic control of the aerodynamic flow (airspeed, angle of attack and lift coefficient control) and passenger comfort are discussed. Joint root locus and quality criteria design are presented. The structure of the presented multiloop flight control system consists of nonlinear open loop control for flight performance and flight management; superposed quasilinear state vector feedback; and six control surfaces (aileron, rudder, elevator, trim, throttle, direct lift/drag control).

**Title:** **Some experiences in integrating avionic systems on the civil flight deck**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 6.5

**Author:** COOKE, N.
ENGLAND, P.
HARLOW, R.

**Abstract:** Some of the work carried out in the Civil Avionics Research program at the Royal Aircraft Establishment, Bedford is described. After a discussion of some of the factors that are leading to a future Air Traffic Management system, the activities in navigation, flight management, displays and novel human input techniques are reviewed. The progress made and some of the lessons learned are also described. A view of how a future air traffic management system might operate is given.

**Title:** **Semi-automatic cross-checking between different copies of the same flight plan**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 7.2

**Author:** RATCLIFFE, S.

**Abstract:** A flight-plan usually exists in several different forms in the aircraft flight management system: as hard copy on the flight-deck, in one or more Air Traffic Control/(ATC) data processors, and distributed over flight-progress strips (or their electronic equivalents) in one or more control centers. Any discrepancies between various versions of the plan are potentially hazardous. Given that the flight plan is already stored, for one reason or another, in at least one computer, it is proposed that each computer should also be used to generate a check word which can easily and rapidly be compared with that stored as hard-copy or in some other machine. The check word might consist of four alpha characters which can easily be remembered and passed by voice. Possible algorithms for generating check-words are discussed. The results of some laboratory trials of a prototype system are given.

**Title:** **The application of intelligent knowledge based systems to air traffic control**

**Reference:** AGARD-CP-410 / ISBN-92-835-0403-8 / AD-A182150 - paper 7.3

**Author:** DEAN, G. C.
JACKSON, A.
NICOL, W. S.
STRETTON, W. A.

**Abstract:** The need to explore the approach of Intelligent Knowledge Based Systems (IKBS) towards meeting the pressures for change in future air traffic control systems is discussed. The discussion includes the role of automation in air traffic control (ATC) and the suitability of IKBS within a shared approach between controller and machine. Areas selected to provide practical experience of IKBS applied to ATC include air traffic flow management and conflict resolution and training. Finally, guideline concepts for the introduction of a new technology to ATC are outlined.

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# AIRCRAFT TRAJECTORIES: COMPUTATION, PREDICTION, CONTROL. Volume 1.

## Part 1: Fundamentals.
## Part 2: Flight in critical atmospheric conditions.
## Part 3: Impact of new on-board technologies on aircraft operation
## (The volume contains 10 papers)

André Benoit, Program Director and Editor

**Title:** Introduction to the study of aircraft trajectories.

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 01

**Author:** HAUS, F.

**Abstract:** General outline of the problem

**Title:** Optimal trajectories of aircraft and spacecraft

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 02

**Author:** MIELE, A.

**Abstract:** Work done on algorithms for the numerical solutions of optimal control problems and their application to the computation of optimal flight trajectories of aircraft and spacecraft is summarized. General considerations on calculus of variations, optimal control, numerical algorithms, and applications of these algorithms to real-world problems are presented. The sequential gradient-restoration algorithm (SGRA) is examined for the numerical solution of optimal control problems of the Bolza type. Both the primal formulation and the dual formulation are discussed. Aircraft trajectories, in particular, the application of the dual sequential gradient-restoration algorithm (DSGRA) to the determination of optimal flight trajectories in the presence of windshear are described. Both take-off trajectories and abort landing trajectories are discussed. Take-off trajectories are optimized by minimizing the peak deviation of the absolute path inclination from a reference value. Abort landing trajectories are optimized by minimizing the peak drop of altitude from a reference value. Abort landing trajectories are optimized by minimizing the peak drop of altitude from a reference value. The survival capability of an aircraft in a severe windshear is discussed, and the optimal trajectories are found to be superior to both constant pitch trajectories and maximum angle of attack trajectories. Spacecraft trajectories, in particular, the application of the primal sequential gradient-restoration algorithm (PSGRA) to the determination of

**Title:** **Comparison of a mathematical one-point model and a multi-point model of aircraft motion in moving air**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 03

**Author:** BROCKHAUS, R.

**Abstract:** The steadily growing capacity of computers favors increasingly exact simulation of even complex processes. On the other hand, parameter identification and state estimation require much more precise models than are generally used for the design of feedback systems. A multi-point model of the aircraft motion is proposed in which the different coupling effects between the two sub-processes, aircraft and air flow, can be modeled with much higher accuracy than is obtained by using the ordinary one-point model, where all the force, moment, and velocity vectors are referred to the aircraft center of gravity. The modeling of the effects of aircraft rotation, wing down-wash, wind gradients, and other unstationary effects should be greatly improved by a multi-point approach, provided that the aerodynamic effects on the aircraft components can be described appropriately. The nonlinear equations of the total process are set up for the one-point and multi-point models and compiled into block diagrams, from which the physical background of the interrelations between air and aircraft motion can be seen very clearly. The possible improvement in model quality and the additional computer capacity needed are estimated by comparing the two approaches.

**Title:** **Computation of sub-optimal real-time guidance laws for combat aircraft trajectories**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 04

**Author:** HUYNH, HUU THANH

**Abstract:** An application of singular perturbation theory (SPT) for the computation of real-time control laws for Combat Aircraft trajectories is presented. The principle of SPT is first briefly reviewed for solving a multiple-time scale differential equations, then its application to optimization of nonlinear systems is presented. The main drawbacks and difficulties which were encountered in the computation of real-time control laws for Aircraft trajectories are described, then various techniques are also pointed out in order to overcome with these problems. Basing of this SPT, real-time guidance law, of closed-loop type, was developed for minimum time to climb in a vertical plane and three-dimensional interception for a combat Aircraft. The performances of these suboptimal guidance laws were then compared, in numerical simulation using a typical Aircraft model, with optimal control laws, of open-loop type, provided by an iterative numerical algorithm, using a generalized projected gradient technique. A better than 1 percent accuracy was obtained for the performance index (time-to-climb) for vertical climb trajectories. The real-time guidance laws are slightly less accurate for interception trajectories. The suboptimal guidance laws can fulfill final conditions on altitude or/and flight path angle and remain valid for a large flight envelope domain. Their computation times are very small and are compatible with real-time an board computer applications.

**Title:** **Critical aspects of trajectory prediction: Flight in non-uniform wind**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 05

**Author:** ETKIN, BERNARD
ETKIN, DAVID ALEXANDER

**Abstract:** The genesis of natural wind is described from a meteorological standpoint. Its influence on aircraft trajectories is discussed with reference to steady winds, turbulence, and wind shear. The main problems exist when flight is close to the ground, during landing, take-off, or terrain following. A model for analysis and simulation is presented consisting of four components - dynamics, kinematics and transformations, aerodynamics, and wind. The axis systems chosen are well suited to simulation of landing and take-off.

**Title:** **Effect of wind and wind variation on aircraft flight-paths**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 06

**Author:** HAHN, K.-U.
HEINTSCH, T.
KAUFMANN, B.
SCHAENZER, G.
SWOLINSKY, M.

**Abstract:** Wind shear accidents during landing and approach could generally be avoided by using modern flight control systems. The problem is to inform the pilot by an adequate wind shear warning display, that he can understand the reaction of the control system. Wind shear is particularly dangerous if it occurs in a height of approximately 80 to 120 m, where the attention of the cockpit crew is affected by getting view contact to the ground. Wind shear during take-off and go-around is a pure flight performance problem. Pilots should avoid a take-off into a thunderstorm. In moderate downbursts a practicable escape maneuver is to maintain the flight level at a low height to pass the core of the downburst before starting the climb. This procedure can also be applied on the go-around.

**Title:** **Aircraft flight in wind-shear**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 07

**Author:** MCLEAN, D.

**Abstract:** A brief account of wind-shear and some representations is given before discussing the effects of wind-shear on aircraft motion. A procedure for estimating the vertical and horizontal velocity components of a wind-shear microburst, based on observer theory is developed, and a brief discussion of flying in wind-shear concludes the paper.

**Title:** **How to fly windshear**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 08

**Author:** CAMUS, PAUL

**Abstract:** Aviation safety history is a long fight against severe environmental constaint. Modern aircraft are able to face safely most of them but one still remains a potential killer, that is what is generally described as a windshear situation. What can be done, necessarily fall either in how to timely detect such a situation in order to avoid it or/and what tools could be given to the crew to better escape should they are trapped in. Latest state of build-in equipment, 3-D Navigation, electronic displays and flight control, provide now all necessary tools to develop an efficient in-board detection and protection system. Such a system will be described altogether with a review of some fundamental criteria to be considered when assessing their efficiency.

**Title:** **Wind models for flight simulation**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 09

**Author:** HAHN, K.-U.
HEINTSCH, T.
KAUFMANN, B.
SCHAENZER, G.
SWOLINSKY, M.

**Abstract:** Wind shear, downdraft, and turbulence can endanger takeoff and landing approach. The effects of wind results in a modified dynamic response of the aircraft as well as in flight performance variation. In each case flight path deviation can occur, more or less controlled by the pilot. For the analysis of the aircraft behavior in a changing wind field, a mathematical model of the aircraft is used including the wind effects. It can be said, that gusts and turbulence will have more influence on the pilot workload and reaction to this short scale wind disturbances. Large scale wind variations can produce significant flight path safety problems. An important aspect for the flight safety is the energy situation of an aircraft affected by wind. Therefore this was chosen as a useful criterion for the determination of the influences of the wind and wind variation.

**Title:** **Aircraft trajectory: Prediction and control in the air transport flight management computer systems**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 10

**Author:** HOWELLS, PETER J.

**Abstract:** The declining cost of computing power and memory has enabled avionic manufacturers to develop sophisticated airborne computing systems. One of the most complex aircraft systems on modern air transport aircraft is the Flight Management Computer System (FMCS). The FMCS has reduced pilot workload by taking over the more mundane but complex functions, such as calculating the most economical speed, and, together with improvements in cockpit displays and monitoring systems, has allowed the transition from the three to two crew airline cockpit. The FMCS can compute the most economical path from one airport to another and then fly the aircraft along that path. To achieve this the computer must be able to select the most economical speed schedules for each phase of flight, then predict the complex vertical and horizontal profile that the aircraft would fly and, when connected to the aircraft's autopilot, control the aircraft along that three dimensional flight path. The forth dimension of time can also be selected as a control criteria, and the FMCS will compute the speed schedules and flight path based on a required time of a arrival at a selected point along the flight plan. In addition to reducing pilot workload, air traffic control efficiency is increased because the airborne navigation data base can be used to select and accurately fly published arrival and departure procedures without supervision from the ground controllers. The algorithms used for the Smiths Industries 737 FMCS prediction and control functions ar

**Title:** **Impact of new technology on operational interface: From design aims to flight evaluation and measurement**

**Reference:** AGARD-AG-301-VOL-1-PT-1-3 / ISBN-92-835-0547-6 / AD-A223568 - paper 11

**Author:** BLOMBERG, R. D.
FOUILLOT, J. P.
MONTEIL, C.
SPEYER, J. J.

**Abstract:** Since the early 1980s Airbus Industrie has conducted a progressive research program investigating the ergonomic, physiological, and psychological factors affecting flight crew in their working environment, and progressively refining the data acquisition and analysis techniques. This self-imposed commitment to a dedicated appreciation of man-machine aspects was met in two ways: informally, by stringent application of human engineering principles, although in short supply in as far as their explicit formulation is concerned; and formally, by continuous development of statistical methods and engineering experiments, concentrating on pilot questionnaires, performance evaluations and workload models. A statistical workload calculation model highlights the link that enables correlation of pilot performance parameters with estimates on the impact of new technology on the operational interface. The purpose is to review the space between initial design aims and subsequent flight evaluation and measurement. A practical review is presented of the operational objectives and technological modules that marked the outgrowth of the Airbus family of commercial aircraft.

AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265

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# AIRCRAFT TRAJECTORIES: COMPUTATION, PREDICTION, CONTROL. Volume 2: Air traffic handling and ground-based guidance of aircraft.

## Part 4: Air traffic handling.
## Part 5: Guidance of aircraft in a time-based constrained environment.
## Part 6: Surveillance.
## Part 7: Meteorological forecasts.
## Part 8: Aircraft operation in air traffic handling simulation
## (The volume contains 27 papers)

André Benoit, Program Director and Editor

**Title:** Optimum on-line handling of air traffic over Western Europe

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 12

**Author:** BENOIT, ANDRE
SWIERSTRA, SIP

**Abstract:** For today's airlines, Western Europe is not very large and the flights they make within it do not last very long. Consequently it should be possible within such an area as Western Europe to arrange Air Traffic Control (ATC) clearances and instructions so that any flight will, from departure clearance to touch-down be conducted in accordance with airline policy and without the changes to route and profile due to short term planning which are so disruptive to air traffic. An approach is recommended for the on-line handling of air traffic over such an area, covering in particular the integration of control phases from departure to destination. This leads to a central on-line optimal definition of departure/arrival sequences and essential characteristics of all flights, and a series of regional units to implement the relevant proposals/directives. This should provide the optimum integration of adjacent Zones of Convergence in which the time and altitude at which aircraft enter and leave each Zone are precisely controlled and are affected by the traffic conditions in their corresponding space/time sphere of influence. As a prerequisite to the above, a system is proposed for the purpose of accurately predicting and controlling the 4-D trajectory of an aircraft over any part of a flight, and in particular that part which extends from entry into until exit from the airspace of a given control center.

**Title:** **The EUROCONTROL future ATS system concept and the programme of studies, tests, and trials**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 13

**Author:** VACHIERY, V.

**Abstract:** The era of parallel, uncoordinated development of ground systems and guidance, navigation and communications avionics is at an end. The pursuit of optimum economic operating conditions, coupled with the need to handle an increasing volume of traffic, demand that those responsible for Air Traffic Management apply solutions that easily combine available ground and air technologies. Cooperation between pilot and controller actions constitutes one of the keystones of the future systems. It is possible to increase the capacity and efficiency of air traffic management, while at the same time maintaining essential safety requirements, only by making more use of automation for control planning functions. It is considered that increased automation cannot provide real advantages, however, unless the accuracy of aircraft trajectory prediction is greatly improved. This was made clear in the description of the Future ATS Concept drawn up by EUROCONTROL. The Concept is presented in broad outline. Its implementation will call for a number of studies and trials, and a rundown is given of EUROCONTROL's program. The program places great emphasis on analysis of the conditions that need to be met to enable ground systems in future to have available facilities for the acquisition and exploitation of aircraft state vector parameters. The key aspects of the program are: (1) Improvement of the surveillance system; (2) Improvement of Air/Ground communications (Automatic data link); (3) Increased automation; and (4) Improvement of evalu

**Title:** **Prediction of aircraft trajectories**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 14

**Author:** RATCLIFFE, S.

**Abstract:** Air traffic management, in designing route structures, drawing up rules for flight in various types of airspace, and in framing the instructions for air traffic controllers, are concerned with predicting the behavior, often on worst case assumptions, of each class of traffic with which they may have to deal. The problems are examined of on-line trajectory prediction to a time-horizon perhaps a little longer than the estimated time of the flight or as short as a few tens of seconds, the object being to predict and avoid collision with terrain or with another aircraft, and to ensure that any in-flight delays due to traffic congestion along the route are absorbed as economically as possible. Military aircraft are concerned with the avoidance of anti-aircraft missiles and in intercepting airborne targets. This latter problem may, very loosely, be regarded as collision avoidance in reverse, and is briefly discussed, as is the problem of terrain-following by high performance low flying military aircraft. The conclusion draws attention to areas where further R and D would seen desirable.

**Title:** **Aircraft dynamics for air traffic control**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 15

**Author:** WILLEMS, P.-Y.

**Abstract:** The equations of motion of airplanes in the context of Air Traffic Control (ATC) are discussed. The basic laws of mechanics are examined together with a mathematical model of mechanical systems which is suitable for airborne systems; the generally accepted (but often implicit) assumptions of usual models are pointed out. A simplified description of the main dynamical effects (gravity and aerodynamical interactions) are given together with a complete kinematical description of the system. The coherence with ISO norms (ISO - 1985) are respected as far as possible; some dynamical short commings of these norms are mentioned.

**Title:** **The application of trajectory prediction algorithms for planning purposes in the Netherlands ATC-system**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 16

**Author:** BEERS, J. N. P.
DALM, T. B.
TENHAVE, J. M.
VISSCHER, H.

**Abstract:** The Netherlands ATC-environment, the basic set-up of the trajectory prediction module, improvements realized, and the performance figures are presented. Applications of the trajectory prediction results in the system are listed, including data distribution rules, presentation of estimated times of arrival, boundary estimates, and, in particular, long term detection of conflicts for overflying aircraft, planning of inbound traffic for Schiphol airport, and planning of departure times for an efficient engine start-up procedure.

**Title:** **Generation of aircraft trajectories for on-line operation: Methods, techniques, and tools**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 17

**Author:** BENOIT, ANDRE
SWIERSTRA, SIP

**Abstract:** An appreciable amount of work has been conducted at the EUROCONTROL Agency's Engineering Directorate in the division engaged in the Study of Long Term Air Traffic Control (ATC) System Requirements in order to generate accurate aircraft trajectory predictions for use in both ATC on-line operation and real time simulations in current and realistic conditions, human interfaces included. The basic approach developed for two distinct classes of application are outlined: (1) the on-line generation of predictions for use in actual operation and, accessorily, real time ATC simulations; and (2) the introduction of realistic aircraft response and motion into ATC simulations, with pilot/auto-pilot interfaces included.

**Title:** **Optimization models and techniques to improve air traffic management**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 18

**Author:** BIANCO, LUCIO

**Abstract:** A survey of earlier works is given with particular emphasis on optimization models and solution techniques. First, a multilevel model of the different ATC functions is proposed. Then, attention is devoted to the on-line control functions (flow control, on-line strategic control of flights and aircraft sequencing in the terminal area); for each problem, an optimization model is established and a solution technique is illustrated. The numerical behavior is also discussed.

**Title:** **The high-resolution graphic display:**
**A possible man/machine interface for a computer assisted ATC management system**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 19

**Author:** GARCIA-AVELLO, CARLOS

**Abstract:** An application is described of high resolution graphic display in the field of management and control of air traffic in an extended area including a major terminal, the radius of the area being liable to vary from 150 to 300 nm. Reference is made to air traffic management and 4-D guidance techniques for individual aircraft in a Zone of Convergence (ZOC) in the knowledge that the graphic display techniques are applicable virtually to all systems affording the controller assistance at the decision making level. For the purpose of presenting data to the controller, a graphic rectangular display is employed having a resolution of 1280 by 1024 points, capable of displaying 16 colors. A circular display similar to most existing radar scopes could of course be used if it had equivalent resolution and color characteristics. The management directives and orders for guidance are presented to the operator, area manager or controller of an individual sector as part of the set of data displayed on the radar surveillance and control scope without the use of additional special tabular displays.

**Title:** **The 4-D control of current air carriers in the present environment: Objectives, status, and plans**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 20

**Author:** BENOIT, ANDRE

**Abstract:** The accurate control of the time of arrival of aircraft will play an essential role in the efficient conduct of air traffic in terms of both economy and capacity. A technique was developed to select efficiently and control accurately each aircraft trajectory inbound to medium to high density traffic airports. The selection is made in terms of the overall traffic on the basis of the airline or pilot-preferred criterion, either cost, consumption or time, and the subsequent control is made in a ground/air co-operative manner, using whenever applicable speed and/or track corrections. The 4-D control is studied along with individual trajectories as applicable to current air carriers in the present environment directly adaptable to future automated air/ground digital communications. The overall control loop was simulated in an environment representing in particular the Belgian airspace configuration, using various flight simulators in conjunction with airline pilots and air traffic controllers. The results obtained to date make it possible to envisage on-line tests in the near future, aiming at a 10-second accuracy at the runway threshold for current commercial aircraft.

**Title:** **Four dimensional navigation in air traffic with 4-D navigation aircraft**
**NAVIGATION 4-D EN CIRCULATION AERIENNE**
**AIRCRAFT 4-D NAVIGATION**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 21

**Author:** IMBERT, NICOLE
PELEGRIN, M.

**Abstract:** Bearing in mind that the waiting times before landing are always increasing while the maximum landing rates are not reached, the monitoring of one more parameter during the approach is suggested. This is, in fact, two speed corrections and one heading correction (Nav. 4D, 3 space dimension + time). The first problem to be solved is the choice of the mathematical model to be used to simulate a plane. A model as complete as possible (in fact of the 18th order) was the starting point and it was degraded until a criterion was no longer satisfied. This criterion was a measurement of the error between the complete model and the degraded model along a reference trajectory (Roissy approach) of 54 km extension. It was assumed that the error due to the use of a simpler model should not reach + or - 320 m at the ILS entry beacon. A 6th order model was declared acceptable. After a number of simulations it was shown that corrections must arise after the entrance in the zone of convergence (ZOC) during the flight at constant level (speed correction) in the middle of the descent flown at constant indicated speed, (speed correction) and during the last leg before the ILS capture (heading correction). By a management method using a mathematical model on a fast time basis, an optimal time of arrival at the ILS entrance beacon can be determined, corresponding to an easy to fly trajectory. A model of the atmosphere must be used and it was checked that the robustness of the method (3 corrections) with regard to this model is correc

**Title:** **On the automation of future ATC centres in the light of the concept of the "Zone of Convergence".**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 22

**Author:** ATTWOOL, V.

**Abstract:** The paper describes the Zone of Convergence concept briefly and its potential benefits.

**Title:** **The control of inbound flights**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 23

**Author:** BENOIT, ANDRE
SWIERSTRA, SIP

**Abstract:** The basic principles are described of the method to guide aircraft accurately down to the runway in a time-of-arrival constrained environment. The method is designed to be used in a Zone of Convergence context or in any similar advanced Air Traffic Control (ATC) system characterized by the integration of control phases over an extended area on the one hand and true computer assistance to the air traffic controller on the other, i.e., assistance provided at the decision making level through the automatic generation of guidance advisories. The method includes two closely coupled basic components, namely, a predictor, which computes a trajectory once initial conditions and plans are known, and a profile manager, which adapts the plans to meet the time constraint and generates the guidance directives on the basis of present position, actual surveillance information, aircraft operation and route constraints.

**Title:** **Guidance concepts for time-based flight operations**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 24

**Author:** VICROY, DAN D.

**Abstract:** Airport congestion and the associated delays are severe in today's airspace system and are expected to increase. NASA and the FAA is investigating various methods of alleviating this problem through new technology and operational procedures. One concept for improving airspace productivity is time-based control of aircraft. Research to date has focused primarily on the development of time-based flight management systems and Air Traffic Control operational procedures. Flight operations may, however, require special onboard guidance in order to satisfy the Air Traffic Control imposed time constraints. The results are presented of a simulation study aimed at evaluating several time-based guidance concepts in terms of tracking performance, pilot workload, and subjective preference. The guidance concepts tested varied in complexity from simple digital time-error feedback to an advanced time-referenced-energy guidance scheme.

**Title:** **The 4-D descent trajectory generation techniques under realistic operating conditions**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 25

**Author:** KNOX, CHARLES E.
WILLIAMS, DAVID H.

**Abstract:** NASA-Langley has been conducting and sponsoring research in airborne energy management for a number of years. During the course of this research, two fundamental techniques for the generation of 4D (fixed time) descent trajectories have emerged as viable candidates for advanced flight management systems. The first technique utilizes speed schedules of constant Mach number transitioning to constant calibrated airspeed chosen empirically to produce minimum fuel usage. The second technique computes cost optimized speed schedules of variable airspeed developed through application of optimal control theory. Both techniques have been found to produce reasonable and flyable descent trajectories. The formulation of the algorithms for each technique is evaluated and their suitability for operations in realistic conditions is discussed. Operational factors considered include: airplace speed, thrust, and altitude rate constaints; wind, temperature, and pressure variations; Air Traffic Control altitude, speed, and time constaints; and pilot interface and guidance considerations. Time flexibility, fuel usage, and airborne computational requirements were the primary performance measures.

**Title:** **Expert systems for the generation of thermal area arrival paths for civil transport**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 26

**Author:** SIMPSON, R. W.

**Abstract:** Efficiencies can be gained from dynamic scheduling of the takeoff and landing operations for the system of runways at a major civil airport. It is then necessary to be able to generate a conflict-free set of flight paths which implements this schedule, and which can be easily changed. For landing arrival aircraft, these flight paths start at a known time, point and speed in the descent towards the airport, and end at a reduced speed and time at the outer marker of the final approach to the assigned runway where desired in-trail separations must be achieved. To generate sets of conflict-free arrival paths, an expert systems computer program finds and selects a path feasible within the performance limits of each aircraft from a set of patterns which are easily understandable by the human controller. This technique is easily adaptable to the geometric characteristics of different terminal areas and runway configurations, and easily accepts rules and procedural limitations which can be specified and implemented by ATC controllers themselves, as desired.

**Title:** **A description and evaluation of TIMER: A time-based terminal flow-control concept**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 27

**Author:** CAPRON, WILLIAM R.
CREDEUR, LEONARD

**Abstract:** A description of a time-based ATC concept called TIMER (Traffic Intelligence for the Management of Efficient Runway-scheduling) and the results of a fast time and real time computer evaluation are presented. The concept was designed to improve the efficiency of extended terminal area operations (en route approach, transition, and terminal flight to the runway). TIMER integrates en route metering, fuel efficient cruise and profile descents, terminal sequencing and spacing together with computer-generated controller aids, in order to fully use runway capacity and improve efficiency of delay absorption. The concept, by using simplified aircraft models, accommodates both 4-D and non 4-D equipped aircraft and is designed for integration into the manual, voice linked ATC system in an evolutionary manner and still be able to accommodate proposed system upgrade features such as data link and further ground automation. Fast time and real time computer simulation results identify and show the effects and interactions of such key variables as horizon of control, metering fix and final approach delivery time errors, aircraft separation requirements, delay discounting, wind, flight technical error, and knowledge of aircraft final approach speed. The current ATC system has a runway interarrival-error standard deviation of approx. 26 seconds. Simulation results indicate that, with computer aiding, the runway interarrival-error standard deviation for non 4-D equipped traffic can be reduced to the region of 8 to 12 seconds if e

**Title:** **Use of 4-D RNAV in time-based en route arrival metering**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 28

**Author:** ERWIN, R. L.
IZUMI, K. H.

**Abstract:** Arrival metering in en route airspace can match the demand rate to the airport acceptance rate. Air traffic control (ATC) is evolving time-based control techniques to facilitate en route arrival metering. This allows fuel savings by using speed reduction to absorb delay. The logic for en route arrival metering: (1) estimates the undelayed landing time of each arrival; (2) assigns the earliest available landing time; and (3) controls each arrival to its terminal area arrival (feeder) fix according to the common schedule developed for all arrivals. The airplane flight management system (FMS), used along with the ATC computer as part of a distributed data processing system, can define a minimum fuel cruise and descent flight profile which is consistent with ATC constraints. A study of four-dimensional area navigation (4D RNAV) operational requirements for use in en route arrival metering has determined the functions and time-guidance accuracies needed for ATC compatible operations. A 4D RNAV capability is most easily achieved by wrapping a time navigation capability around a 3D FMS. Concepts for controlling a mix of 4D RNAV equipped and unequipped aircraft in a time-based en route arrival metering system have been the subject of on-going analyses and simulations by NASA-Ames. The use of 4D RNAV in en route arrival metering operations can save the operator fuel, reduce both pilot and controller workload, and reduce terminal airspace congestion.

**Title:** **Air traffic management and aircraft guidance in a zone of convergence**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 29

**Author:** BENOIT, ANDRE
SWIERSTRA, SIP

**Abstract:** The basic principles of air traffic management and guidance of individual aircraft in a Zone of Convergence (ZOC) have been presented in previous papers at successive stages in the development of the project. These principles are summarized as is their applicability to the actual operational environment, compatibility with present technology and direct adaptability to future developments, the quality of the interfaces involving the air traffic controller and the aircraft crew and the resultant benefits to the community in terms of economy, use of available capacity and safety.

**Title:** **Ground-based 4-D guidance of flights in strong wind**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 30

**Author:** BENOIT, ANDRE
SWIERSTRA, SIP

**Abstract:** In strong wind, groundspeed may vary appreciably during a turn, just as for example in the case of a landing after a U-turn preceding the localizer intercept. Such conditions are critical for maximum use of the runway, and render human estimation of aircraft motion extremely difficult. The tests are summarized which were conducted using a ground-based 4D guidance program, developed to assist the air traffic controller in maintaining the predicted landing time sequence with an accuracy better than 10 seconds for each arrival.

**Title:** **A piloted simulator evaluation of a ground-based 4-D descent advisor algorithm**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 31

**Author:** DAVIS, THOMAS J.
ERZBERGER, HEINZ
GREEN, STEVEN

**Abstract:** A ground-based, four dimensional (4D) descent-advisor algorithm is under development at NASA-Ames. The algorithm combines detailed aerodynamic, propulsive, and atmospheric models with an efficient numerical integration scheme to generate 4D descent advisories. The ability is investigated of the 4D descent advisor algorithm to provide adequate control of arrival time for aircraft not equipped with on-board 4D guidance systems. A piloted simulation was conducted to determine the precision with which the descent advisor could predict the 4D trajectories of typical straight-in descents flown by airline pilots under different wind conditions. The effects of errors in the estimation of wind and initial aircraft weight were also studied. A description of the descent advisor as well as the result of the simulation studies are presented.

**Title:** **The air traffic controller facing automation: Conflict or cooperation**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 32

**Author:** BENOIT, ANDRE
DEWISPELAERE, RENE
SWIERSTRA, SIP

**Abstract:** Today, developments in ground-based and on-board computers, navigation and digital air/ground/air communications make it possible to envision, for tomorrow, extensive automation of the overall air traffic control process, always provided that reliability, safety and responsibilities can be absolutely covered in all possible eventualities, however remote. Accordingly, before tomorrow, an appreciable amount of traffic will cross our skies and be handled by air traffic controllers without the support of advanced automated tools. Nevertheless, at the same time, the potential of automation will continue to increase. This subject is discussed in the light of the experience gained during the development of an approach to the definition, assessment and testing in an operational environment of a procedure suitable for guiding aircraft along 4-D trajectories illustrative of the next system generation of ATC. The essential aspects are examined of the computer/controller/pilot/aircraft chain of dialogues, placing the emphasis on the interface between the computer and the controller, the intelligent interpretation of the surveillance information by the computer, the definition, generation, and relay of guidance directives to the pilot and finally, the use of navigation aids. The integration of the ground-based 4-D guidance and control system messages on a standard ATC radar display is shown, illustrating this for the guidance of flights conducted by SABENA crews operating B-737 and DC-10 aircraft.

**Title:** **Aircraft trajectory reconstitution on the basis of multi-radar plot information**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 33

**Author:** VAN DER KRAAN, P.

**Abstract:** A short description of the various techniques in use for the establishment of aircraft reference trajectories is presented. Then a description of the principles and operation of the EUROCONTROL program MURATREC (Multi-Radar Trajectory Reconstitution) follows, covering in particular: (1) estimation of systematic radar errors; (2) curve fitting by the use of B-splines and dynamically adaptable spline steps; (3) accuracy of the reconstructed positional information; and (4) reconstitution of altitude, accelerations and speed. Applications of the MURATREC program are outlined, including application for the analysis of radar plot and track accuracy (examples) and possible applications for incident investigations, on-line alignment of multi-radar information and simulation of aircraft trajectories in a given radar environment.

**Title:** **Bayesian multi-sensor tracking for advanced air traffic control systems**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 34

**Author:** BLOM, H. A. P.
HOGENDOORN, R. A.
VANSCHAIK, F. J.

**Abstract:** An overview is given of a Bayesian tracking system for a multi-sensor environment. The main modules perform track initiation, track continuation and systematic error estimation, respectively. The track continuation module plays for Air Traffic Control the most important role. It consists of a combination of those approximate Bayesian methods that proved to be the most efficient for the main problems of track continuation: Extended-Kalman filtering for nonlinear dynamics, Probabilistic Data Association for unassociated measurements and Interacting-Multiple-Model filtering for sudden maneuvers. Comparisons of this new tracking system with alpha-beta Kalman based and state-of-the-art tracking systems show its superiority for application to Air Traffic Control surveillance. It provides better track continuity, more accurate expectations of position and velocity and more complete additional information in the form of probabilities of modes of flight (turning, accelerating and straight modes) and consistent estimates of its own accuracy. With this track information, advanced Air Traffic Control systems may better cope with the many uncertainties that are inherent to air traffic.

**Title:** **The use of downlinked measurements to track civil aircraft**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 35

**Author:** LEFAS, C. C.

**Abstract:** The use is described of measurements made on board civil aircraft to improve tracking accuracy in air traffic control (ATC) systems. The measurements are transmitted to the ground station via the Secondary Surveillance Radar (SSR) mode S data link. First the widely used alpha-beta filter and the first order Kalman filter are reviewed. Next the problem of maneuver handling is described and it is established that significant SBN-92-835-0562-X / AD- improvements, in terms of tracking accuracy, are expected when tracking maneuvering aircraft. The shape of maneuvers is examined using recordings made on board civil aircraft during normal scheduled services. The on-board measurements considered are roll angle, heading, and true air speed (TAS). Roll angle and the rate of change of heading are theoretically equivalent, since they are related though aircraft velocity. Maneuver tracking filters using either roll angle or heading are described and compared. It is shown that the filter using heading provides a better performance in the event of missing replies, since changes of heading are eventually detected. Both filters cannot track longitudinally accelerating targets. Next the use of velocity measurements, derived from TAS and heading, is considered. A filter is described that is capable of estimating the wind speed in the vicinity of the aircraft. The same filter provides satisfactory tracking accuracy during maneuvers and can handle longitudinal accelerations. Under monoradar coverage, where the data rate and accuracy are fairly constant, t

**Title:** **Contribution of the satellite techniques to the surveillance of air traffic**
**L'APPORT DES TECHNIQUES SATELLITAIRES A LA SURVEILLANCE DE LA NAVIGATION AERIENNE**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 36

**Author:** CAREL, OLIVIER

**Abstract:** The International Civil Aviation Organization asked a special committee FANS (Future Air Navigation Systems) to study satellite system implementation for communication navigation and surveillance applications. This committee recently issued its final report. FANS work is presented and the consequences are analyzed of satellite system implementation in case of the surveillance of air traffic. The most important element will be Automatic Dependent Surveillance (ADS) which implies the automatic air to ground return transmission of various airborne measured parameters, i.e., mainly aircraft position as supplied by the aircraft navigation equipments. This concept allows a much more efficient air traffic control in every area lacking a ground infrastructure. In continents areas with heavy air traffic, satellites will not substitute the secondary surveillance radar. The new techniques however will allow a flexible design of the ground infrastructure.

**Title:** **Developments to enhance meteorological forecasting for air traffic services**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 37

**Author:** COX, M. E.
FORRESTER, D. A.

**Abstract:** In the future, the quality of the meteorological data available for use both in ground-based systems and on aircraft will become even more important as ATC strives to handle increasing volumes of traffic in the most efficient manner. An indication of the effect of errors in meteorological data on the precision of predictions of aircraft trajectories is discussed and the variability of wind and temperature is examined, showing the influence of location, altitude and season, in the European area. An outline of present-day forecasting methods follows (the data used and accuracies achieved are included). Potential sources of improvements are then discussed with the emphasis being placed on the use of aircraft-derived data (details are given of the accuracy of such data, possible methods of recovery, and their application within the Meteorological Services). The impact is described of turbulence on both the safety of air traffic and the accuracy of flight profile predictions (possible methods of providing aircraft with the means for the automatic reporting of turbulence are included). Some experimental work either performed or being planned in the European area is also described, aimed at improving the quality of the meteorological data made available for ATS purposes as a result of using data recovered from aircraft through both satellite and ground-based (Mode S SSR) systems.

**Title:** **Integration of aircraft capability in air traffic handling simulations**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 38

**Author:** BENOIT, ANDRE
DELNATTE, YVES
SWIERSTRA, SIP

**Abstract:** The incorporation of airline/aircrew/aircraft specific procedures and performances into simulations and air traffic handling operations is a prerequisite for the next generation of management and control techniques. This matter is analyzed in the light of the shortcomings inherent in the present situation, in order to meet operators' demands in terms of capacity and efficiency. A practical approach is then proposed which includes the operators (aircrew/aircraft/avionics) in the overall ground/air/ground control loop at development, assessment, validation, and real time simulation levels. As an illustration of the potential offered, this approach is used to assess a ground/air coordinated 4-D guidance technique, and the results are summarized.

**Title:** **Simulation of automated approach procedures considering dynamic flight operations**

**Reference:** AGARD-AG-301-VOL-2-PT-4-8 / ISBN-92-835-0562-X / AD-A225265 - paper 39

**Author:** FRICKE, MANFRED
HOERMANN, ANDREAS

**Abstract:** During peak hours almost all major commercial airports operate close to their capacity limits. Moreover, the traffic demand often exceeds the offered capacities leading to more or less stringent restrictions in slot allocation. The purpose of the fast-time air traffic simulations, was to analyze and assess the performance and the practicability of automated time-based approach concepts, currently developed to optimize the terminal area air traffic process with respect to safety, capacity and economy. The developed program system TASIMD (Terminal Area SIMulation considering the aircraft Dynamics) simulates flight operations of arriving aircraft within a terminal area during a specific time interval. TASIMD models all major elements of a TMA scenario related to the control and operations of automated approach procedures on the ground and in the air (e.g., surveillance, control procedures, aircraft dynamics, flight guidance). The aircraft fly along 4D-trajectories, described by a horizontal profile, an altitude profile and a speed profile to integrate the time element, considering influences on the path following accuracy in space and time. Sources of error impact are: entry fix time deviation, navigation, wind, airspeed error and profile management algorithm error. Errors are modeled in Monte-Carlo technique. Two types of automated approach procedures were developed and analyzed: a variable path speed control concept (VPSC) and a fixed path speed control concept (FPSC). Both concepts presume a shared air/ground r

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# AIRCRAFT TRAJECTORIES: COMPUTATION, PREDICTION, CONTROL. Volume 3.

## Part 9: Book of abstracts.
## Part 10: Bibliography.
## Part 11: List of contributors

André Benoit, Program Director and Editor

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# MACHINE INTELLIGENCE IN AIR TRAFFIC MANAGEMENT
# L'INTELLIGENCE ARTIFICIELLE DANS LA GESTION DU TRAFFIC AERIEN
# (The volume contains 31 papers)

Guidance and Control Panel Symposium of AGARD
held in Berlin, Germany, 11-14 May 1993

André Benoit, Program Chairman and Editor

**Title:** **A functional definition of Air Traffic Management process.**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 01

**Author:** SIMPSON, R. W.

**Abstract:** Paper not available at time of printing

**Title:** **Advances in development capabilities for intelligent air traffic management systems**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 02

**Author:** FEARNSIDES, JOHN J.
LEVIN, KERRY M.

**Abstract:** Visual presentation is a major source of information for air traffic control. Significant advances in computers, display technology, and the tools used by developers of intelligent air traffic management (ATM) systems pose challenges for the development of computer-human interfaces (CHI's) associated with the new automation. The CHI must be designed to be both usable and suitable. This paper reviews three capabilities available to developers of intelligent ATM systems: case-based reasoning system design, rule-based system design, and individually tailored CHI. It recommends that any intelligent ATM system be examined early in its development cycle in a laboratory environment, where it can be tested in concert with other elements of the ATM system.

**Title:** **Intelligent systems for air space control and management**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 03

**Author:** BOWEN, DAVID
HLIBOWICKI, ANDRZEJ

**Abstract:** Complete automation of an air traffic control system requires the identification of functions and their allocation to a distributed system, part of which is on the ground and part of which flies. The evolution of current systems appears to be taking place with ill-defined visions of what the final system will or should look like. In some cases this fuzzy view of the future is purposely carried because of the implications of proposing a view which antagonizes various groups or associations representing those already engaged in the process. Yet, each step along the way implies explicitly or implicitly some final target system. As each year goes by, we move toward a system which may be a long way from what is really desirable in the next century. It seems reasonable that some versions of the ideal future system should be understood within the community. At least one of these options should be what is technically feasible. From this, an acceptable system can be negotiated. The first step in this process is to determine the desired functionality without regard to any other factors. From this, technical feasibility can be determined and/or predicted; and finally, the allocation of the functions to humans or machines can be debated. The management of a dense cluttered air space requires a set of skills and capabilities on the part of an air traffic control team which, in some of their functions, cannot be represented algorithmically. Successful automated air traffic management systems will necessarily emulate the intu

**Title:** **Use of advanced technologies in ATM (air traffic management) domain**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 04

**Author:** BONNARD, M.
PLANCHON, P.

**Abstract:** The CENA is in charge of studies related to Air Traffic Management and therefore to some of the communication, navigation, and surveillance means. The work is carried out to support French and European ATC (air traffic control) in an international cooperation. It encompasses studies and experimental development aiming at operational implementation within the CAUTRA 5 program. The different CENA projects are integrated in an experimental simulator frame named ADER. This test-bed will support one of the demonstrations within PHARE, a joint European experimental program. The CENA organization is based upon a technical directorate in charge of the horizontal projects as previously described and 10 divisions located either at Athis-Mons (near Paris) or in Toulouse. One of these divisions, called COA (Control Organization and Automation), deals mainly with studies aiming at providing ATM (air traffic management) operators with helpful decision tools, using advanced methods and technologies. In this paper, it can be found a short description of COA division activities and a more precise analysis of one of the projects, called GOETHE, aiming to provide ATFM (Air Traffic Flow Management) regulators with a more user-friendly tool.

**Title:** **Air traffic management as principled negotiation between intelligent agents**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 05

**Author:** STENGEL, ROBERT
WANGERMANN, JOHN

**Abstract:** The major challenge facing the world's aircraft/airspace system (AAS) today is the need to provide increased capacity, whilst reducing delays, increasing the efficiency of flight operations, and improving safety. Technologies are emerging that should improve the performance of the system, but which could also introduce uncertainty, disputes, and inefficiency if not properly implemented. The aim of our research is to apply techniques from intelligent control theory and decision-making theory to define an Intelligent Aircraft/Airspace System (IAAS) for the year 2025. The IAAS would make effective use of the technical capabilities of all parts of the system to meet the demand for increased capacity with improved performance.

**Title:** **Use of GPS in automated air traffic control**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 06

**Author:** HEGELS, HERMANN F.
HOEKSTRA, WILLEM E.

**Abstract:** The Global Positioning System NAVSTAR is rapidly becoming the world standard for navigation and timing. Although primarily designed to be a military system, the civil user community is expanding at a breathtaking pace. After an introduction to the general GPS policies and the technical fundamentals this paper presents an idea on how to use GPS NAVSTAR to improve Air Traffic Control. Existing selective identification features will form the key to a GPS-based position, velocity, and acceleration message. Higher update rates and the vastly improved information on each aircraft will provide the input for a flight plan correlation function enabling an automatic air traffic monitoring and control far beyond current standards.

**Title:** **Ground independent landing system**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 07

**Author:** BRAUN, HANS MARTIN
HARTL, PH.

**Abstract:** Air traffic in Central Europe is dramatically increasing today. There are some indications that present upgrades of the air traffic control system might not be efficient and that planned upgrades will not be realized in time due to budgetary restrictions. One key element in air traffic control is a precise navigation of the aircraft during landing, the most critical part of the flight. It is presently performed by use of the instrument landing system ILS and in some areas already by the microwave landing system MLS. The latter provides a very high navigation performance and allows a high landing sequence under all weather conditions. However, it requires extensive ground equipment at the airports and hence, only a few airports in Central Europe are equipped with it today. This paper presents the results of a study on a new microwave landing system with a spaceborne radar transmitter and airborne radar receivers. Based on this bistatic radar system, navigation in landing phase could also be performed independently from weather conditions. However, it does not require any active equipment at the landing site. Even taxi way guidance could be performed with this system. It is called 'Ground Independent Landing System' (GILS).

**Title:** **GPS/GNSS for ATM**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 08

**Author:** BANTLE, GERHARD
JACOB, THOMAS
MEYER-HILBERG, JOCHEN
ROESCH, WINIFRED
SCHMIDT, HORST
WIPPICH, HEINZ-GEORG

**Abstract:** The actual implemented Air Traffic Control (ATC) systems have radar coverage gaps on the Northern Atlantic and Trans-Siberian Routes as well as in the Pacific area. This situation results in insufficient air traffic surveillance information in the corresponding control sectors and larger separation between aircraft on these routes to ensure safe operation. Unfortunately, this procedure reduces the capacity and limits air traffic flow. These problems can be overcome by the worldwide use of the high accurate position data from Global Navigation Satellite Systems (GNSS) such as the U.S. Global Positioning System (GPS) and the Russian Global Navigation System (GLONASS) aboard the aircraft as proposed by the ICAO-FANS plan. In combination with the Automatic Dependent Surveillance (ADS) function as specified by ARINC 745, the onboard computed position and flight path data is transmitted to the Aeronautical Telecommunication Network (ATN) for further use by ATM and ATC. Based on these principles, Deutsche Aerospace AG, Airborne Systems Division has developed a demonstrator. This system integrates the precise (Differential) GNSS information with the data from an Inertial Measurement Unit (e.g. AHRS) aboard the demonstrator aircraft to fulfill the accuracy and consistency/integrity requirements during all phases of flight. This system integration has been done to ensure integrity of GNSS position information during satellite outages or satellite masking, e.g. during turns. For demonstrating ADS-functionality, the onboar

**Title:** **ACCS Surveillance Exploratory Prototype (ASEP)**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 09

**Author:** GAEBLER, K.

**Abstract:** The increasing sophistication of surveillance systems, both civilian and military, has generated a great deal of interest in techniques of multi-target tracking and sensor integration. To help SHAPE and the NATO Air Command and Control System (ACCS) Management Agency (NACMA) to specify and implement the ACCS surveillance subsystem, in particular in the areas of data fusion and identification, the SHAPE Technical Center (STC) is currently developing an ACCS Surveillance Exploratory Prototype (ASEP) as an element of its new integrated testbed. The purpose of the ASEP is to demonstrate the feasibility and operational benefits of future air picture generation systems. The significant difference between this advanced system and currently available systems is that ASEP will provide better tracking continuity, more accurate estimates of track positions, velocity, acceleration, and additional information on targets. The provision of this information on air targets is also of great importance for civil ATC systems, especially in view of growing requirements for ATC planning, conflict alert and conflict resolution. The use of multiple sensors and sources requires the fusion of different types of data, including sensor reports containing measured attributes such as the target type and other target features. Since advanced fusion algorithms are using kinematic data as well as attribute data for the identification process, the majority of all air targets can be identified automatically. This paper gives an overview of the f

**Title:** **Contributions of DLR to air traffic capacity enhancement within a terminal area**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 10

**Author:** BROKOF, U.
DIPPE, D.
SCHUBERT, M.
VOELCKERS, U.

**Abstract:** Enhancement of air traffic capacity within the TMA cannot be achieved easily. Single solutions and improvements of technical equipment, procedures and standards, with automation support for human operators in isolated areas, e.g. for the management of the airport, airspace and Air Traffic Control very often will only yield marginal capacity increases. Whether it is: new concrete (runways, taxiways, aprons), reduced separation minima, or advanced ATM functions, all these measures will only result in significant capacity increases, if they are designed, developed and implemented in a comprehensive, combined effort, making use of set of complementary measures and functions in a well structured, optimized architecture and implementation strategy. This comprehensive approach is especially true for high density TMA's/airports, operating close to capacity limits, where any capacity enhancement measure will directly affect and/or require capacity related issues in other areas. Based upon the specific needs of the Frankfurt airport and TMA, DLR is working on a variety of tools and functions, which--combined and implemented in a well designed strategy plan--can yield significant capacity increases without the construction of new runways. Three candidate systems--under development or even already in operation--which mutually depend on and complement one another will be presented as examples of an even larger capacity enhancement plan for the TMA.

**Title:** **Design of Center-TRACON Automation System**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 11

**Author:** DAVIS, THOMAS J.
ERZBERGER, HEINZ
GREEN, STEVEN

**Abstract:** A system for the automated management and control of terminal area traffic, referred to as the Center-TRACON Automation System (CTAS), is being developed at NASA Ames Research Center. In a cooperative program, NASA and FAA have efforts underway to install and evaluate the system at the Denver area and Dallas/Ft. Worth area air traffic control facilities. This paper will review CTAS architecture, and automation functions as well as the integration of CTAS into the existing operational system. CTAS consists of three types of integrated tools that provide computer-generated advisories for both en-route and terminal area controllers to guide them in managing and controlling arrival traffic efficiently. One tool, the Traffic Management Advisor (TMA), generates runway assignments, landing sequences and landing times for all arriving aircraft, including those originating from nearby feeder airports. TMA also assists in runway configuration control and flow management. Another tool, the Descent Advisor (DA), generates clearances for the en-route controllers handling arrival flows to metering gates. The DA's clearances ensure fuel-efficient and conflict free descents to the metering gates at specified crossing times. In the terminal area, the Final Approach Spacing Tool (FAST) provides heading and speed advisories that help controllers produce an accurately spaced flow of aircraft on the final approach course. Data bases consisting of several hundred aircraft performance models, airline preferred operational procedures,

**Title:** **Simulation of fully automated air traffic control concepts**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 12

**Author:** DENBRAVEN, WIM
VANDENBOS, HANS

**Abstract:** In order to be able to investigate various aspects of the complex Air Traffic Control (ATC) system of the future, a real-time ATC simulation facility has been constructed at NLR. The ATC automation environment of this simulator is provided by CTAS, the Center/TRACON Automation System, developed by the NASA Ames Research Center. For the simulation of air traffic, radar observations, and data link, the NLR ATC Research Simulator (NARSIM) is used. The facility can be used at various levels of automation, ranging from conventional, 'manual' ATC to fully automatic control. For the latter, CTAS has been extended with various decision and control algorithms, dealing with tasks normally executed by the air traffic controller. In a set of real-time simulation experiments different concepts of fully automated ATC are investigated, characterized by various combinations of control functions and different levels of air-ground interaction. Furthermore, the effect of different levels of aircraft navigation performance is studied. The traffic samples are based on single-runway IFR operations for Schiphol Airport, with the traffic mix and distribution based on predictions for the year 2000. The Dutch airspace is simulated with one overall area control sector, controlling traffic from all directions to the three arrival gates, and one Schiphol approach sector, merging the aircraft from these gates into a properly spaced sequence on final approach. For the analysis of the simulations, methods are under development to present over

**Title:** **"Fast Tracking" Automation Technology into the Terminal Air Traffic System.**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 13

**Author:** FRIESENHAHN, C. R.

**Abstract:** Paper not available at time of printing

**Title:** **Decision Making Aids (DMA) in on-line ATC systems**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 14

**Author:** BENOIT, ANDRE
POMERET, JEAN-MARC
SWIERSTRA, SIP

**Abstract:** This paper covers the potential of Decision Making Aids to be implemented before the year 2000 and, within the time frame considered, covers all of the aspects of automated assistance, based on flight path prediction and monitoring, which help air traffic controllers to establish and assess the predicted traffic situation more efficiently. Problem detection, problem minimization, and 'best next clearance' advisories will permit the reduction of the controller's mental workload without decreasing the level of safety or the controller's situational awareness.

**Title:** **Cognitive approach to specifications on air traffic controllers' decision assistance systems□Une approche cognitive pour la specification d'aides a la decision pour les controleurs aeriens**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 15

**Author:** LEROUX, MARCEL

**Abstract:** The central problem of this investigation is the creation of an Air Traffic Control System (ATC) involving both man and machine. The present document reports on two examples which typify the man-machine relationships in systems which are partly automated. In one case, the part played by the machine is detrimental to man's involvement; in the other case, man and machine work together for better results. The manner in which this second approach was used during the development of the CENA's ERATO project is described.

**Title:** **Considerations on graphical user interfaces for intelligent ATM support systems**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 16

**Author:** BEYER, R.

**Abstract:** Considerations on the design of graphical user interfaces (GUI's) for air traffic controllers are presented in the context of a European Air Traffic Management System (EATMS). The fundamental issues discussed include the following: air traffic controller tasks; human information processing and mental models; and automation strategies with respect to the GUI design. The more specific issues of GUI design which are also discussed include the following: GUI programming environments and standards; development tools; design principles and human factors/human engineering standards; and usability testing. Conclusions are drawn regarding the current background of GUI design with respect to an EATMS and necessary future developments.

**Title:** **Interactive analysis and planning tools for air traffic and airspace management**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 17

**Author:** MAHLICH, S. E.

**Abstract:** Since 1989, the Institute for Flight Guidance of the German Aerospace Research Establishment (DLR) has been developing prototypes of interactive tools in close cooperation with the German Air Navigation Services (DFS) in order to achieve gradual improvements in the efficiency and productivity of the air traffic control system. The paper briefly describes the potential of a selection of analysis and planning tools that have been developed in this framework. After an introduction into the 'planning world' of tactical and strategical air traffic planning, the objectives and potentials of four tools will be demonstrated as applied to real traffic scenarios and actual problems of the current ATM system.

**Title:** **DAISY: A decision aid for an air situation interpretation system**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 18

**Author:** ALLOUCHE, R.
BICHAT, N.
BORIES, A.

**Abstract:** Due to increases in air traffic volume and the evolution of operational missions, Alcatel ISR has been awarded a contract to analyze the requirements of military air traffic controllers, especially in the area of the air situation interpretation and the implementation of a mock-up. DAISY is aimed at providing controllers with a decision aid for an air situation interpretation system. In this context, interpretation stands for all the rules and combined information which give an operational meaning to the air situation. Abnormal situations are highlighted, a diagnosis is given, and a proposal is made for decision. After a requirements analysis is conducted, both by experts and controllers during six months, a twelve-month technical feasibility study was led by Alcatel ISR, and a mock-up was developed dealing with typical interpretation scenario such as trajectory prediction.

**Title:** **DLR's ATM demonstration programme**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 19

**Author:** ADAM, V.
KLOSTERMANN, E.
SCHUBERT, M.

**Abstract:** The Institute for Flight Guidance of DLR is involved in medium and long term research and development of concepts, procedures, functions, and components for a future integrated Air Traffic Management System. The medium term work concentrates on improvements concerning the capacity of Frankfurt airport. This paper describes a planned demonstration program which is designed to prove concepts and tools developed by the Institute in cooperation with the German ATC Authority (DFS) and the operator of Frankfurt airport (FAG) as well as with PHARE. The aim of these experiments is to demonstrate the feasibility and merits of integration of onboard avionics with advanced ATC systems on the ground. For this purpose an Air Traffic Management Demonstrator System will be employed, which comprises an air segment and a ground segment connected via an automatic data link and voice communication. The demonstration program will be performed in several phases comprising simulation runs in an air traffic simulator as well as flight tests with a real aircraft.

**Title:** **Advanced air traffic control and flight management system concepts**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 20

**Author:** SCHULTZ, ROBERT L.

**Abstract:** A time-based air traffic control (ATC) system where vehicles are sequenced on desired time of arrival (TOA) has been proposed as one way that might help increase airport capacity. This paper evaluates three time-based ATC system concepts: (1) ground based (computing trajectories on the ground), (2) aircraft based (computing trajectories on the aircraft), and (3) ground and air based (generating parametrized velocity and acceleration profiles on the aircraft and transmitting them to the ground where trajectories are recomputed). The parameters compared are amount of database, complexity of communications, computational requirements, autonomy of aircraft, and similarity to current procedures. The ground-and-air-based approach using parametrized profiles has the best potential for providing a high-landing-rate ATC system with minimal processing and communications requirements. In this approach, ATC assigns time slots at the metering fix based on desired time of arrival (TOA) and range-TOA windows generated on the aircraft. The aircraft sends a simple set of parametrized deceleration and velocity profiles to the ground. The ground processor uses these profiles to generate trajectories and identify conflicts. The ground processor resolves conflicts by examining nearby trajectories using both the sets of parametrized deceleration and velocity profiles and the range-TOA windows. The new horizontal plan and the new profile parameters are sent to the aircraft, where the aircraft flight management system (FMS) regenerate

**Title:** **Opportunities for integrating the aircraft FMS, aeronautical operational control centers, and future air traffic management systems in oceanic airspace**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 21

**Author:** BLAKE, BILL
MILLER, CLYDE
MILLER, JOSEPH
SORENSEN, J.

**Abstract:** Rapid technological changes are taking place in the aviation system user facilities - both on the aircraft flight deck and at the aeronautical operational control (AOC), or flight dispatch centers. On the flight deck, the flight management system (FMS) is bringing capability for precise three-dimensional guidance, flight path optimization, and speed control to meet required time-of-arrival (RTA) constraints at key route waypoints. This is enhanced by the precision global navigation satellite system (GNSS), use of digital datalink for communications, and automatic dependent surveillance (ADS). At AOC facilities, advancements in flight planning, flight following, weather information and datalink allow the dispatcher greater flight operations management capability over the airline fleet. This is especially significant for oceanic airspace operations. In parallel, the oceanic air traffic management (ATM) system is undergoing an evolution in automation that will enhance the overall aviation system productivity. Much of the information that each of the three system components - flight deck/FMS, AOC, and ATM - have would be very useful to the other two components for flight efficiency and overall productivity enhancements. Worldwide datalink technology will provide a universal and reliable data communication capability between these components to allow this information sharing. This paper discusses the opportunity to integrate the functions of the FMS, AOC, and ATM computers by exploiting the capabilities of worldwide

**Title:** **Profile negotiation: An air/ground automation integration concept for managing arrival traffic**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 22

**Author:** ARBUCKLE, P. DOUGLAS
DENBRAVEN, WIM
GREEN, STEVEN
WILLIAMS, DAVID H.

**Abstract:** NASA Ames Research Center and NASA Langley Research Center conducted a joint simulation study to evaluate a profile negotiation process (PNP) between a time-based air traffic control ATC system and an airplane equipped with a four dimensional flight management system (4D FMS). Prototype procedures were developed to support the functional implementation of this process. The PNP was designed to provide an arrival trajectory solution that satisfies the separation requirements of ATC while remaining as close as possible to the airplane's preferred trajectory. The Transport Systems Research Vehicle cockpit simulator was linked in real-time to the Center/TRACON Automation System (CTAS) for the experiment. Approximately 30 hours of simulation testing were conducted over a three week period. Active airline pilot crews and active Center controller teams participated as test subjects. Results from the experiment indicate the potential for successful incorporation of airplane preferred arrival trajectories in the CTAS automation environment. Controllers were able to consistently and effectively negotiate nominally conflict-free trajectories with pilots flying a 4D-FMS-equipped airplane. The negotiated trajectories were substantially closer to the airplane's preference than would have otherwise been possible without the PNP. Airplane fuel savings relative to baseline CTAS were achieved in the test scenarios. The datalink procedures and clearances developed for this experiment, while providing the necessary functionality, w

**Title:** **Air-ground integration of the ATM system in PHARE**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 23

**Author:** HUNTER, R. D.
KIRSTETTER, B.

**Abstract:** This paper provides a general introduction into the Programme of Harmonised Air Traffic Management Research in EUROCONTROL (PHARE). It describes the objectives of the research program and addresses the benefits of the integration of the automated systems onboard the aircraft with those of the ATC systems on the ground using a digital air-ground data link. The assumptions on the expected infrastructure and environment are explained and the possible automation and air-ground negotiation strategies discussed. Finally descriptions of the experimental facilities available or under development and of the planned experiments are provided.

**Title:** **Experimental flight management system**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 24

**Author:** ADAM, V.
INGLE, G.
RAWLINGS, R.

**Abstract:** The paper reviews the requirements for an Experimental Flight Management System (EFMS) and the methods adopted for its development. The functionality is described and the future application of the system is summarized.

**Title:** **The PHARE advanced tools**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 25

**Author:** BLOM, H. A. P.
DEAN, GARFIELD
LEGUILLOU, MARC
PETRE, ERIC
VOELCKERS, U.

**Abstract:** The Programme for Harmonisation of ATM Research in Eurocontrol (PHARE) has undertaken to perform the required research work necessary for the introduction of advanced ATM. Within this PHARE framework, it is the task of the PHARE Advanced Tools (PAT's) group to develop the appropriate automation and communication tools to support the air traffic controller. Although the principles for computation, prediction and control of air traffic trajectories are well developed, the various future ATM scenarios reflect different views on the way automation and communication technology can best be applied. The consequence of this is that PHARE research has to be directed towards multiple ATM scenarios, and that the PAT's to be developed should be applicable to automation and communication under different ATM scenarios. The paper gives an overview of the approach taken by the PAT's group in facing this challenge.

**Title:** **The Common Modular Simulator (CMS): An architecture test bed for future advanced ATM systems**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 26

**Author:** VELTEN, J. R.

**Abstract:** The Common Modular Simulator (CMS) project is part of the Program for Harmonized ATM Research in Eurocontrol (PHARE). The main objective of this project is to provide a common integration environment which shall allow the creation of a homogeneous infrastructure in order to facilitate and harmonize the development as well as the evolution of ATM simulators in the different research establishments. To meet such an ambitious objective, CMS partners have adopted a system architecture based on a client-server model with active servers providing event subscription and event notification mechanisms. The main advantages of such client-server models are to offer a very modular system architecture and to provide, through the associated application programming interface (API), a very powerful mechanism of abstraction. This leads to a very flexible, evolutive, open, scalable and adaptable system. CMS will offer an architecture test bed for future advanced ATM systems. As a consequence, this project should be of great benefit to many other ATM projects.

**Title:** **ARC2000: Automatic radar control**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 27

**Author:** FRON, XAVIER
MAUDRY, BERNARD
NICOLAON, JEAN-PIERRE
TUMELIN, JEAN-CLAUDE

**Abstract:** The 'Studies, Tests, and Applied Research' (STAR) program of the EUROCONTROL Agency is addressing several implementation timescales for air traffic management (ATM) systems and procedures. ARC2000 (automatic radar control 2000) is presently the major long-term component of the STAR program, for implementation beyond 2015. ARC2000 is addressing the enroute ATC capacity issue, which is severe in Europe, by investigating the limit case where both major constraints, workload and sectorization, are eliminated. It is often easier to solve a complex problem by first looking at the limit case. ARC2000 could not be implemented as such, but should provide precious information with respect to feasible levels of automation in the long term. There are also significant by-products which will speed up shorter term research. Indeed, ARC2000 provides a 20-30 minute conflict-free planning which is a key feature of the European Air Traffic Management System (EATMS) concept.

**Title:** **Automatic control steps for aircraft taxi guidance**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 28

**Author:** MOEHLENKAMP, KLAUS
SCHAENZER, GUNTHER

**Abstract:** Modern high precision navigation systems based on satellite and inertial navigation provide a positioning accuracy that has never been achieved before, for aircraft enroute as well as during approach and on the airfield. By using such combined accurate positioning systems it is possible to guide aircraft on the ground and to perform automatic taxiing, which further increases the safety of ground operations. Whenever high precision terrestrial navigation is needed, common aeronautical navigation displays are not able to provide the information, which easily can be combined with the pilot's view from the cockpit, to deliver the necessary guidance aid. A flexible map display is desired to be shown in the cockpit. The new taxi guidance system GINaS, presented in this paper, is based on an integrated navigation system (DGPS/INS) and a digital map using only the standard display and navigation hardware of modern commercial aircraft. The system was successfully tested in one of our testbeds, a van. This van can be driven automatically by the system as well as by the pilot using the information of the digital map and a drive-director. The accuracy reaches submeter level.

**Title:** **Airside ground movements surveillance**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 29

**Author:** CLARK, A. N.
CORRALL, D. R.
HILL, A. G.

**Abstract:** In the modern world there is an increasing need for surveillance, and a consequent need for automatic or semi-automatic methods for processing dynamic input data and presenting it in a form which is useful to the end user. This paper outlines advanced knowledge-based techniques for monitoring such data. The techniques have been applied to airport ground traffic applications and demonstrated in particular on data from actual turn-round scenarios for stand area servicing of an aircraft as observed by a single camera. Results are output in real-time as a status report by an integrated system which is designed to handle the vagaries of real data in respect to incompleteness and uncertainty. The new techniques developed can also be applied to other ground movements surveillance applications which have multiple sensor inputs of the same or different modalities.

**Title:** **A novel near-range radar network for airport surface control**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 30

**Author:** BETHKE, K.-H.
ROEDE, B.
SCHNEIDER, M.
SCHROTH, A.

**Abstract:** This contribution describes a radar network for airport surface movement guidance and control. The network comprises several low power radar stations which are organized in modules of four stations each. All antennas are staring and illuminating the area continuously. Moving objects are localized by range profile measurements and a subsequent multilateration. Each module runs autonomously. The module computer at the master station calculates the multilaterations and controls the communication with three slave stations. The measured data from these stations are transferred via the radar transmitters to the master station, while the multilateration and imaging results are sent via data cables to the central computer. There, the information from all modules will be merged and tracks will be constructed; furthermore, a classification process on the basis of the images will be executed.

**Title:** **Development of precision runway monitor system for increasing capacity of parallel runway operations**

**Reference:** AGARD-CP-538 / AD-A275680 / ISBN-92-835-0724-X - paper 31

**Author:** WONG, GENE A.

**Abstract:** This paper describes the results of a research program to investigate the use of advanced radar, display systems, and controller alert automation aid to increase capacity at airports with closely spaced parallel runways. Analysis has indicated that the runway spacing could be reduced without adversely affecting capacity if a surveillance radar of higher update and accuracy and a high resolution color display system with controller alert automation aid are used. This paper first describes a research program to demonstrate the feasibility of using a precision runway monitor (PRM) system for conducting independent simultaneous approaches to parallel runways spaced at less than 3400 ft (1035 m) apart. A PRM system consists of an improved radar system that provides high azimuth and range accuracy and higher data rates than the current terminal airport surveillance radar (ASR), a processing system that monitors all approaches and generates controller alerts when an aircraft appears to be blundering, and a high resolution color display. Two airports were selected to serve as the demonstration and test facilities of the PRM system. This paper describes the key elements of the demonstration program including test criteria and scenarios, controller and pilot/aircraft response times, and risk analysis. Results of the demonstration program on the feasibility of the 3400 ft runway spacing standards using PRM are presented. Recommendations on radar update rate, accuracy, and display requirements for the PRM system are summar

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# ON-LINE HANDLING OF AIR TRAFFIC MANAGEMENT - GUIDANCE - CONTROL

André Benoit, Program Director and Editor

**Title:** GENERAL INTRODUCTION
MANAGEMENT - GUIDANCE - CONTROL

**Reference:** AGARD-AG-321 - GI

**Author:** BENOIT, ANDRE

**Abstract:** General Introduction:
In 1983, we were invited by the Associazone Elettrotecnica e Elettronica Italiana to deliver a lecture dealing with some particular aspects of "air traffic management" in a seminar devoted to "air navigation aids" . The terms "air navigation aids" will probably suggest an idea rather clear in the mind of the reader i.e. any facility which permits or facilitates navigation, guidance and possibly air traffic control, this latter in terms of guidance directive generation. By contrast, the expression "air traffic management" which in general covers an adequate organisation of the traffic is rather new and it may require some additional qualification if ambiguities are to be avoided. Accordingly, this general introduction will outline what should currently be understood by these terms as well as their relationship in the context of this general presentation.

**Title:** THE AIR TRANSPORT SYSTEM

**Reference:** AGARD-AG-321 - Paper 01 / ISBN : 92-835-0758-4

**Author:** PELEGRIN, M.

**Abstract:** After the recall of the expected rate of growth for the 10 to 15 next years, the typical profile of a commercial flight is presented as a succession of 10 phases (plus a de-routing one in case of impossibility to land at destination). The first one is the ground motions of the plane, including the acceleration on the runway, the last one is .also the ground motions, after touch down ; this phase includes the braking on the runway ; it could be automatically controlled.
Such a profile is not an optimum one, though it does not depart from it in some phases (climb phases, though ATC constraints degrade the optimum ; cruise phase, though an ascending cruise would be better).
In a real flight, guidance control, due to aircraft interferences, modifies heavily the optimum profile ; thence compromises should be looked for. The present safety level must be kept at the same level or improved ; no degradation is acceptable even in spite of the traffic rate of growth. It should be kept in mind that 53 % of the fatal accidents occur during the last phases of the flight from "initial approach" to "landing".

**Title:** THE AIR TRAFFIC COMPLEXITY

**Reference:** AGARD-AG-321 - Paper 02 / ISBN : 92-835-0758-4

**Author:** PELEGRIN, M.

**Abstract:** In this paper the environment - at the largest meaning of the word - is described and its implications on this type of transportation system.
The cruise phase of a plane is in the vicinity of the tropopause, a border between the troposphere and the stratosphere. Air motions are quite different in these two spaces : in the lower one (troposphere) convexion, which implies vertical motions of air masses, prevails, in the upper one horizontal motions prevail.
The structure of an aircraft is constrained by the effects of air turbulence (troposphere) ; the secondary effects of chemical pollution seem more serious when planes fly inside the stratosphere. In the troposphere other dangerous phenomena, such as lightning, icing, downbursts occur frequently. Correct prevision and detection of the probability of occurrence of such phenomena along the route of the plane is mandatory.
Final approach is a critical phase : high density of aircraft on major airports, approach speed limited to 1.2 or 1.3 Vstall, vertical speed at touch down limited to 4 or
5 m/s, position and orientation of the plane within restricted tolerances.
In the take-off phase, engine failure during acceleration should be detected immediately and clear indication should be given to the pilot (go on or abandon take-off).
Man is still in the loop - and probably will stay in it for a long time - vocal communications are still used, as they were 30 years ago - language ambiguities may cause accidents.

**Title:** TRAFFIC EVOLUTION

**Reference:** AGARD-AG-321 - Paper 03 / ISBN : 92-835-0758-4

**Author:** PELEGRIN, M.

**Abstract:** This short paper analyses some data issued by expert concerning the rate of growth of air traffic passengers (min 4,5 % /year) freight (min 8 % year) and the probable evolution of the air fleet structure.
Ecological constraints (noise reduction, chemical pollution) could only be stronger and stronger. Airport extensions will be limited by ecological and economical constraints. On the technological side, the second generation of supersonic aircraft has a low probability of quick development while large capacity aircraft (400-600 passengers) may enter commercial service within 10 years.
At last, the actual trends concerning the transfer of short haul (400-500 km) to trains will certainely go on, mainly in Europe.

**Title:** ELECTRONIC AIDS TO CONTROLLERS

**Reference:** AGARD-AG-321 - Paper 04 / ISBN : 92-835-0758-4

**Author:** PELEGRIN, M.

**Abstract:** The guidance of IFR flights and the aid to VFR flights remain in the controller responsibility. Electronic aids are already in use : the Dutch ASA system (Schipal), the German COMPAS system (Frankfurt), the French MAESTRO system (Orly and Roissy) ; other systems are in developm ent or at the experiment phase the EUROCONTROL ZOC project, the UK PACTAS system the TAAS, CTAS and TIMER systems in the US.
Most major airports operate two parallel runways at the same time ; modification of the separation distances between planes in final approach phase would be revised soon, probably.
The electronic aid for final approach and landing in bad meteorological conditions is the ILS (which in CAT3 version allows automatic landing).
The MLS won't be implemented widely. The GPS for the navigation and the D-GPS (Differential GPS) for final approach phase, are developed extensively.
Monopulse radars with MODE-S capability will be implemented in Europe and in USA around 1998.
At last the T-CAS (Traffic alert Collision Avoidance System) already in operation in the Stage II will be replaced by T-CAS IV before the end of the century ; this stage will allow lateral maneuvers.

**Title:** ARRIVALS MANAGEMENT SYSTEMS
**TIME BASED AIR TRAFFIC CONTROL IN AN EXTENDED TERMINAL AREA**
**- A Survey of such systems -**

**Reference:** AGARD-AG-321 - Paper 05 / ISBN : 92-835-0758-4

**Author:** PETRE, ERIC

**Abstract:** This paper presents a critical review of several on-line helps to solve the traffic flow harmonisation/optimisation problem, mainly concerning Terminal Air Traffic Management. It firstly describes the various solutions proposed by several organisations/research centres and endeavour to identify the comparative benefits or limitations in each case. The criteria used range from accuracy of Trajectory Prediction components (procurement of Estimated Time of Arrival), to System-Controller relationship, via fairness, security and capacity arguments for sequencing strategies. It finally identifies opportunities to efficiently integrate controller skills into a more automated environment, taking advantages of both kind of resources (man & machine), without putting penalty or restriction on the controller.

**Title:** DECISION MAKING AIDS
DESIGN OF DECISION MAKING AIDS FOR ATC SYSTEMS

**Reference:** AGARD-AG-321 - Paper 06 / ISBN : 92-835-0758-4

**Author:** SWIERSTRA, SIP

**Abstract:** The traffic capacity of an Air Traffic Control sector is often limited by the available throughput of the air-ground communication channel and/or the limitations of the human controller team. The next generation of ATC systems, covered by the EATCHIP Phase III Workprogramme, aims to, inter alia, increase sector capacity by improving air-ground and ground-ground communication capabilities and introducing "task sharing" between humans and machines. The thus "extended controller team" constitutes an optimum symbiosis between human and machine capabilities.

An operational concept has been developed to achieve the user requirements. It is essential that efficient "resource management" is introduced to optimise the performance of the extended controller team to define at any time: "Who (humans or machines) does what, when and how". Consequently the automated functions cannot be designed in isolation, but must be developed as a consistent suite of tools supporting each other's functionality. Moreover, as in the aircraft cockpit, task sharing between humans and machines will have an impact on controller training and preparation for contingencies.

Trajectory prediction and conflict risk analysis are the technical prerequisites for Decision Making Aids. Different methodologies are analysed in terms of required infrastructure, ATC efficiency and impact on flight operating costs. Their impact on working rules and procedures is discussed.

**Title:** **A LOOK FURTHER INTO THE FUTURE :**
**OPTIMISATION DE L'ENSEMBLE DES TRAJECTOIRES**
**- deux phases du developpement -**

**Reference:** AGARD-AG-321 - Paper 07 / ISBN : 92-835-0758-4

**Author:** BENOIT, ANDRE
GARCIA-AVELLO, CARLOS
SWIERSTRA, SIP

**Abstract:** Lors de son allocution de bienvenue aux participants de la Conférence AGARD tenue en juin 1972 à Edimbourg (Ecosse) sur le contrôle de la circulation aérienne (désigné habituellement par l'acronyme ATC, Air Trafic Control), N. Coles, Directeur adjoint, "Establishments and Research" faisait la déclaration suivante : "... Au Royaume-Uni, il se pourrait que nous ayons un jour à faire face à certains des plus sérieux encombrements que connaît le continent américain. Toujours est-il que nous enregistrons parfois des temps de "stacking" égaux ou supérieurs aux temps de vol correspondants !"

En mai 1993, la Commission Guidage et Contrôle organise un symposium consacré au rôle que l'intelligence artificielle pourrait jouer dans la gestion du trafic. Dans le discours liminaire exposant le thème de la conférence, G. Maignan reprend cette citation, la développe, expose la complexité du contrôle aérien et trace les grandes lignes d'une automatisation globale, dont un de ses collaborateurs présentera un projet allant dans ce sens au cours de la même réunion.

Jusqu'à très récemment, les développeurs les mieux placés, voire les plus téméraires, ne prévoyaient point avant 15 ou 20 ans le remplacement du contrôleur humain par une combinaison de matériels/logiciels comme c'est le cas depuis plusieurs années déjà dans certains transports terrestres, tels les métros municipaux.

Aujourd'hui, qu'en est-il ? Des efforts considérables sont entrepris par l'ensemble des administrations concernées, mais il faudra sans doute attendre encore longtemps pour en ressentir les effets bénéfiques. Témoin, cette expérience récente vécue et confirmée par plusieurs autres du même genre. Au départ de Bruxelles, à destination de Lisbonne, tout s'annonce bien, l'avion décolle avec un retard sur l'horaire affiché de l'ordre de 5 à 10 minutes. Après quelque 40 minu-tes de vol, l'hôtesse invite les passagers à admirer la ville de Londres par les hublots de droite. Sommes-nous détournés ? Que non. A son initiative, le commandant de bord choisit cette route - particulièrement coûteuse pour la compagnie, nous confiera-t-il plus tard - plutôt que d'attendre pendant 80 (quatre-vingts) minutes, le créneau de décollage autorisé par le contrôle pour pouvoir suivre une route normale.

Ceci montre bien la disparité entre les limitations de capacité transmises par le gestionnaire des flux de trafic au contrôleur humain et le potentiel d'une gestion en-ligne dans laquelle les passages de chaque avion aux points critiques seraient contrôlés par ordinateur à quelques secondes près.

Aussi, entre la situation actuelle et le lointain futur où gestion en-ligne, guidage et pilotage fonctionneront en mode automatique, il y a place, nous semble-t-il, pour des systèmes de transition, compatibles avec les habitudes et techniques opérationnelles d'aujourd'hui, mais directement adaptables aux nouvelles technologies, telles les communications numériques automatiques, le positionnement via satellites et le pilotage optimisé par le gestionnaire de bord ou par le gestionnaire central de la compagnie couplé au gestionnaire de trafic basé au sol et très précis dans le continuum spatio-temporel.

**Title:** INTERNATIONAL AIR TRAFFIC HANDLING COOPERATION

**Reference:** AGARD-AG-321 - Paper 07A / ISBN : 92-835-0758-4

**Author:** BENOIT, ANDRE

**Abstract:** The Decision Making Aids programme (DMA), a direct extension of the Zone of Convergence project (ZOC), remains as a short term concept, an intermediate step towards the efficient integration of air traffic control over all flight phases for all flights. It is a ground-based approach that is consistent with the effort undertaken by aircraft manufacturers and operators aimed at making efficient use of auto pilots and more specifically airborne flight management control and guidance systems. These will allow aircraft to determine and fly trajectories meeting airline criteria duly adapted to the numerous constraints resulting from the overall air traffic situation.

**Title:** TOWARDS GLOBAL OPTIMIZATION FOR AIR TRAFFIC MANAGEMENT

**Reference:** AGARD-AG-321 - Paper 08 / ISBN : 92-835-0758-4

**Author:** PELEGRIN, M.

**Abstract:** Aircraft are highly sophisticated machines. If the plane were alone in the sky, a fully automatic flight would be possible. How to manage the ability of performing a flight and the traffic flow ? Only a global optimization of traffic from take-off to landing would comply with the traffic growth.
An optimization process implies a precise definition of the boundary of the system to be optimized, the knowledge of the behaviour of the system a criterion, which is a quantity (called generalized cost), to be minimized by adjusting the control parameters of the system.
A global optimization of the air traffic, in real time, implies the abandonment of the sector concept as it stands today.
It can be formulated as follow :
In a first step the system is divided into sub systems for simplification. For the "cruise sub system", the criterion is : minimized the total penalization of the whole fleet inside the boundary (North West Europe for example). The individual penalization is derived from the flight envelope of the plane ; by agreement, it must be the same for all airline operators for each type of aircraft. Exceptional re-quotation of the penalization figures may be requested by an operator to compensate for a delay at take-off, for example. The traffic evolves and stays optimum until an "event" occurs ; 5 types of events are defined. Then a new pattern (speed change, new FL...)...leading to a global minimum cost is computed. The other sub-systems (climb, descent...) are processed in a similar way.
It is mentioned that "comfort requirents (for piloting and for passengers) are taken into consideration ; they must lead to accept slightly higher global penalization factor.
The difficulties of the problem are clearly mentioned ; this paper claims only for giving a possible way of studying the problem.

**Title:** SYSTEMS EVALUATION FACILITIES :
A SIMULATION ENVIRONMENT FOR PROTO-TYPING AND EVALUATION OF ATM CONCEPTS

**Reference:** AGARD-AG-321 - Paper 09 / ISBN : 92-835-0758-4

**Author:** GARCIA-AVELLO, CARLOS

**Abstract:** As existing simulation facilities lacked the level of realism and flexibility to support ATC tool research in an integrated UAC/ACC/TMA Air Traffic Control environment, the STANS facility (Reference 1) has been designed to support the development and demonstration of advanced ATC tools used in the next generation of operational ATC systems. The general structure of STANS allows the quick proto-typing of ATC tools and eases their evaluation in different ATC environments through easily adaptable system characteristics.

In its most condensed form the complete STANS simulation facility is set up on a single desk top workstation thus bringing the power of an advanced simulation facility to the direct working environment of the ATC system designer without the need of early planning of evaluation exercises. However the systematic application of a client/server architecture ensures that the hardware configuration can be easily adapted to the required extent of the simulation exercises. This provides the capacity for large scale real-time ATC simulations using the same software modules thus enabling a smooth transition from the research environment to pre-operational evaluation.

This wide range of possibilities and the flexibility of the STANS systems will be demonstrated in the section where we describe the experiments/evaluations for which this systems has been and is currently used.

**Title:** SYSTEMS EVALUATION FACILITIES :
AN ORIGINAL MAN/MACHINE INTERFACE TO HANDLE MUTLI-AIRCRAFT PILOTING IN SIMULATIONS

**Reference:** AGARD-AG-321 - Paper 09A / ISBN : 92-835-0758-4

**Author:** LEMAITRE, JACQUES

**Abstract:** In order to satisfy large-scale ATC simulation requirements, a flight simulation facility has been developed by the engineering Directorate of EUROCONTROL. The main component is the ACCESS flight simulator.
This paper describes another component of this flight simulation facility: the SIGMA pseudo-pilot position (System for Input and Generation of Messages for ACCESS).
In an ATC system, the controllers send ATC directives via radio telephone communication channels (R/T) to the pseudo pilots who convert them into a form understandable by the flight simulation module. Interaction with the automatic flight procedures can be realized in several ways: manual operation which involves one operator per aircraft, or operation by "pseudo-pilots" whose task it is to communicate the ATC directives received to the flight simulation module for several aircraft.
The SIGMA position includes two main components: an input device which consists of a standard of-the-shelf graphical digitizing tablet and the data display sharing the identification of the aircraft presently under control and their flight/message status. Contrary to many present software facilities using pull-down menus, one main criterion has steered the design of the command entry position: A passive and stable layout is considerably faster and less tiring than successive screens through menu selection.

**Title:** **THE AIRPORT OF THE FUTURE**

**Reference:** AGARD-AG-321 - Paper 10 / ISBN : 92-835-0758-4

**Author:** PELEGRIN, M.

**Abstract:** Will the airport be the major bottleneck of the air traffic growth ? Here again it is claimed that only a global approach may solve the problem. First the airport system is defined : it includes the control of the descent, the landing, the ground movements, the passengers walk inside the buildings, the connections to town ; the ground motions of plane, take-off and initial climb.

The highest rate of landings and take-offs could be reached only if the interactions between all factors concerning the flight and the ground movements are considered as a whole, for example, the determination of the TOD (Top Of Descent), the detection and tracking of the wing vortices of all the planes which are in a given vicinity, the evaluation of the intensity of meteorological phenomena along the predicted route, data concerning "curved approaches" in the final approach phase, automatic control of ground movements, automatic baggage control, de-icing prior to take-off...

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# Annex

## Facsimile reprints of the prefaces of the AGARDographs (AG) and Conference Proceedings (CP)

# PREFACE [1]

The contribution of AGARD, and in particular the contribution of the Avionics and Guidance and Control Panels, to the field of Air Traffic Control is certainly appreciable. Indeed, during the last decade quite a number of AGARD documents have been published on phenomena or techniques directly relevant to the control of air traffic.

As examples the following can be mentioned – wave propagation, Kalman filtering, flight test instrumentation, airborne equipment, guidance and control displays, navigation equipment, radar techniques, man-radar interface, etc. In addition, special contributions have been devoted to particular subjects in the field of air traffic control. Among those subjects which have been given special attention, it is worth noting automatic approach and landing, collision avoidance, radar and automation, traffic flow in terminal areas, and advanced navigation techniques including possible use of Earth satellites.

Nevertheless, all these papers are scattered over the whole of AGARD's literature and this is, in fact, the first time that a complete AGARD Symposium is entirely devoted to air traffic control. It is an effort to update existing publications and bring together the various component parts so that these can be discussed within the context of the overall ATC system.

Initially, the meeting was planned to extend over a three-day period. The interest raised by the announcement of the Symposium and the response of the ATC world to the Call-for-Papers were such that a four-day meeting certainly appeared more appropriate. Without going into detail, it might be of general interest to indicate some of the main features of this particular response. Ninety-six papers originating from eight different NATO countries were submitted for possible presentation at the meeting. Apart from the keynote addresses and the contributions to the session devoted to integrated communication, navigation and identification which were called for by AGARD invitation, only twenty-five papers could be retained within the program scope limitations. As a result seventy-one proposals could not be included although each abstract appeared to summarize an interesting piece of work.

As can be seen from the Table of Contents, the symposium is structured along the following main lines: control concepts, automation, area and en-route navigation, terminal navigation and control, landing guidance, surveillance, communications, collision avoidance, human aspects and, following a request of NATO Headquarters, a special session devoted to integrated communication, navigation and identification.

As a matter of fact, when organizing the symposium, it was decided as a general policy to place the emphasis on new techniques, new approaches, future aspects and conceptual developments as opposed, for instance, to detailed descriptions of equipments. This might explain why the program contains little on radars although the proposals received would provide enough material for at least a full-day meeting on secondary radars and related techniques.

Subjects related to overall ATC concept-description, implementation, development and, to a certain extent, automation have been grouped into a first session. This is because we would like to see all the articles presented at the meeting as constituting an entity, each element being placed in its right context and its expected contribution to the overall improvement in air traffic control being clearly indicated. We thought that the subject grouped in Session I would contribute to generating discussions towards this objective.

Dr A.Benoit, *Program Chairman*
Eurocontrol
Brussels, Belgium

[1] *Facsimile reprint, AGARD-CP-105, 1973.*

# PREFACE [2]

With the encouragement and the scientific support of the air traffic control world, the Guidance and Control Panel of AGARD has made provision within its field of activities for offering a podium to the ATC specialists who wish to present and propound their views. It is hoped that this will constitute a valuable source of information on all the aspects of this fascinating field.

A major step towards these objectives was the planning in 1970 of the first AGARD symposium entirely devoted to air traffic control. Following the call for papers, about one hundred articles were submitted to the Program Committee. The symposium took place in June 1972 in Edinburgh, Scotland, and set a record attendance for all AGARD Panel meetings.

This meeting and the proceedings published subsequently – the proceedings of the Edinburgh meeting were issued by AGARD under the reference "Conference Proceedings CP-105" – constitute an excellent update of information on specific projects. Nevertheless, it clearly appeared that there was a need for a general survey of modern concepts and techniques used in, or applicable to, the control of the air traffic. In an attempt to fill this gap, the Guidance and Control Panel initiated the present work and divided it into five main Parts, as given below.

The first Part describes the **General Organisation of Air Traffic Control**. The principles of ATC are outlined, the principal components are presented and possible concepts are discussed.

The second Part is devoted to the **Human Factors in ATC**. This, in view of the progressive implementation of automation, was considered an important subject and it is discussed in some length. Indeed, the position of a man responsible for the proper conduct of control, while surrounded by automated or semi-automated elements, can be a very debatable topic. Although the different aspects of such a subject can hardly be separated, an attempt was made to cover separately the interaction between the human controller and the machine, the views of the psychologist and the medical aspects. In addition, there is a brief outline of the International Association which groups most of the associations of air traffic controllers.

The third Part is entitled, perhaps too ambitiously, **Automation of Control Procedures**. It covers the main techniques associated with the implementation of automation and is divided into five main sections. A first section, entitled *Principles and Applications of Automation* covers the general principles of automation and automatic data processing and illustrates the introduction of automation in ATC systems. The second section covers the *Conflict and Collision Avoidance Systems*. The first paper places the emphasis on an on-board collision avoidance system and on its potential compatability with the conventional ground based control. The second paper describes the ground based collision avoidance systems developed in the United States, namely the En-Route Conflict Alert, now in operation, and the Intermittent Positive Control which is being developed by the Federal Aviation Administration. The third section comprising three papers, is devoted to *Flow Control*. The first paper states the problems and presents the possible and recommended approaches to a solution; the second deals with local and regional flow metering and control; the third paper shows how modern control theory can be applied to scheduling and path stretching manoeuvers of aircraft near the terminal area. The fourth section is devoted to *Aircraft Trajectory Prediction*. The paper presented shows the development of a method of predicting accurate aircraft trajectories for ATC purposes. The emphasis is placed on the constitution of an aircraft performance handbook including detailed data, in a compact form, of climb, cruise and descent for individual aircraft. The fourth section constitutes a critical survey of various studies which have been conducted in order to produce a safe approach to the reduction of *Route Centerline Spacing*.

Part four describes some of the main **Technical Aids to Air Traffic Control**. It is not intended to cover all possible aids in this limited document, but a selection of topics has been made with a view to complementing existing literature. The Part has been divided into seven main sections dealing respectively with *Ground Based Navigation Aids*, *Self-Contained Navigation Aids* which for coordination reasons was limited to the relation between inertial navigation and air traffic control, *Landing Guidance Systems* including categorization of landing conditions, technology, ICAO Instrument landing system and the microwave landing system, *Surveillance* more specifically the digital radar data processing for en-route air traffic control, *Visual Display* techniques, *Computer and Processing Facilities* including the software and hardware aspects and, finally, a section is devoted to the *Use of Satellite for ATC Purposes*. Other topics, such as secondary surveillance radar and communications, especially digital communications (data link) which have not been covered should certainly be included in an overview of air traffic control; it is intended to cover these topics in a subsequent document specifically devoted to surveillance and communications.

Finally, the fifth and last Part describes **Operational Air Traffic Control Systems**. The systems which have been chosen for this illustration exhibit a relatively high degree of automation and include European as well as North American examples.

To conclude, it is believed that this document constitutes a valuable overview of modern techniques used in air traffic control. Because of space limitations, some aspects have been left out – such as the position of the pilot in

the ATC loop for instance – but it is the intention of the Guidance and Control Panel to complete this work in the near future.

It is hoped that this AGARDograph will help those who are joining the ATC world to look at the landscape of this wide field from a good vantage point and that it will also assist those who are currently involved in a particular area to keep abreast with the development made in connected areas.

Dr A Benoît
Program Chairman
EUROCONTROL
Brussels, Belgium

[2] *Facsimile reprint, AGARD-AG-209, Volume I and II, 1975.*

# PREFACE [3]

The fascinating field of Air Traffic Control is extremely broad and wide open to basic and applied research: most fundamental disciplines of science, applied science, engineering, psychology and medicine have potential contributions to make to the development of the control of the air traffic for both the civil and military users.

One intrinsic difficulty in realizing an efficient control of the air traffic lies in its historical development, during which the increase of traffic density has not always been followed by a parallel adjustment of the handling capacity, leading in certain circumstances to appreciable traffic delays and economic penalties.

It appears essential that all concerned with ATC be aware of current development undertaken in all related areas by the National Administrations – civil and military – universities, research institutions and industry, in order to improve the understanding of each others requirements and constraints and, as a result, contribute efficiently to a necessary cooperation between users, operators, system designers and equipment manufacturers.

In an attempt to promote such a cooperation at the international level, the Guidance and Control Panel of AGARD has established a general program for the exchange of information. This started with the symposium held in Edinburgh in 1972 entitled "Air Traffic Control Systems" (Ref. CP 105). Subsequently, a general review of the various aspects and techniques of the ATC was published under the title "A Survey of Modern Air Traffic Control" (Ref. AG-209).

The objective of the present symposium is to give some fair indication of the trends of the overall motion of the ATC field: it is hoped that the selected title "Plans and Developments of Air Traffic Systems" will reflect the contents of the presentations and subsequent discussions.

If the implementation of this program has been possible, it is due to the positive response of all the institutions involved or interested in Air Traffic or in its control:

To all the contributors, the Guidance and Control Panel of AGARD would wish to express its sincere appreciation.

Dr A.BENOIT
Chairman
Guidance and Control Panel

[3] *Facsimile reprint, AGARD-CP-188, 1976.*

# FOREWORD [4]

In the evolution of Air Traffic Control certain important phases can be identified. Until recently, these phases were usually characterized by the advent of a particular technical or technological development.

A first phase which roughly covered the period 1930--1950 was characterized by manual operation, visual surveillance, time separation of aircraft, the use of radio for communication and low frequency aids for navigation. A second phase which extended, say, from the late 1950's until about 1970 was essentially characterized by the introduction and extensive use of two techniques: radar, both primary and secondary, for surveillance and VOR/DME for navigation. Then, from the late 1960's onwards, the introduction of the computer in to ATC opens a new era: flight plans and radar data processing, synthetic data displays and digital communications. In some systems, automation is already providing systematic back-up for the controller and this phase of automation is only just starting.

In the early 1970's, a new and completely different phase started in parallel and is continuing. It is a phase not related to any particular technological developments but one born of concern, concern shown by both the users of the airspace and the authorities responsible for the ATC services for economy and concern expressed by the community regarding the conservation of natural resources, in general, and the impact which further development of aviation can have on ecology, in particular.

In this era, demands and constraints issued from various sources are no longer simple and may even contain some degree of contradiction. Consequently, present overall requirements for aviation operation have reached a high level of complexity. As a result, the management and control of air traffic as expressed in terms of modern control theory, have become a large multicriteria system. In this system, safety remains the basic constraint whilst expedition will progressively result from a wider economic criterion which will also ensure the maximum use of available capacity. This is to be reflected at each stage of the planning, management or actual control of the air traffic and related services. In particular, a prerequisite to any subsequent investigation, consists in clearly defining the "control variables" to be associated with each hierarchical control/management loop, each loop being characterised by a particular "look ahead" period of time, ranging from, say, twenty years for major orientations to some thirty seconds for pilot actions following collision avoidance directives or commands.

Further, in the NATO environment, there are strong recommendations for considering air traffic control as a joint civil/military system, the emphasis being placed on the compatibility, the coordination and complementary aspects of both civil and military components. A valuable effort is presently being made in Europe towards such objectives and it is probably therefore appropriate to openly debate the various views on the challenges which result from such requirements.

In the past, the civil air traffic systems have largely benefited from the results of military research and development programs in the fields of surveillance, navigation, communications and automation. Today, military effort is greater than ever: it is expected that several programs or technological developments which have been initiated will have an appreciable impact on the future orientation of air traffic systems. These include a wide range of subjects such as the global positioning system, the automatic distribution of information, the integration of various functions, the use of digital communications between the air and the ground.

In conclusion, from whatever angle we look at air traffic today, one leading directive appears, printed in capital letters: ECONOMY. On the civil side, it characterizes the new procedures and practices, and is demonstrated by a general policy on fuel conservation. Similarly, civil/military cooperation should be enhanced and the possible future applications of present military developments duly investigated to this end. Thus, it appeared timely and appropriate to initiate this symposium as part of the programme of activities of the Guidance and Control Panel of AGARD.

Dr A.BENOIT
Programme Chairman

[4] *Facsimile reprint, AGARD-CP-273, 1980.*

# PREFACE [5]

Before the 1973 crisis, safe expedition of traffic was certainly the essential concern of both the users and the Air Traffic Control Authorities. The operators aimed generally to fly close to maximum allowable speed, the consumption incidence on the operating cost remaining within reasonable limits. In fact, the price of fuel was kept practically constant from 1900 to 1973; in actual terms it even decreased over extended periods. Then the tide turned: in less than ten years, fuel prices have increased tenfold. Now that fuel has become the highest "single item" (at least 50 percent) in air transport operating cost, this has had a direct influence on the policies and economy of aviation resulting in the operations criteria being revised accordingly.

On all sides, appreciable efforts are being made or requested to attenuate the impact of the escalation of fuel prices on operating costs. The present situation renders critical the airlines' economy and even threatens their existence. Given that the military allocations are limited, the question of how airspace should be shared can be a crucial subject during discussions of the civil/military coordination aspects.

From a different point of view, automation and/or supporting techniques offer broad scope for the consideration of concepts hardly conceivable some twenty years ago. From avionics, flight mechanics, guidance and control to data processing and communications developments, it is certain that advanced technology is available today to enable an entire flight to be conducted in a completely automatic mode. At the same time some small aircraft will proceed with minimum onboard equipment in accordance with visual flight rules. Between these two extremes, the existing fleet operates to rules specified by ground-based authorities (control, environment, . . .).

Faced with a host of contradictory requirements, offered a wide range of new techniques and automated aids, can or should Air Traffic Control revise its attitude, rules and current conduct of the control of aircraft? The answer is a resounding "YES". Critical surveys of the various sources of fuel savings involving manufacturers, operators, air traffic authorities etc. and ranging from day-to-day maintenance to the design of new powerplants, clearly indicate that potential contributions of Air Traffic Control to the economy of air transportation are considerable; this is probably the most substantial contribution which can and will be made in the next ten years.

In Western Europe, more specifically in the region covered by the EUROCONTROL Route Charges System, the excess cost of flights (actual as against ideal) is estimated to be at least equivalent to two million tons of fuel per year, one million for the excess route lengths and one million for the use of non-optimum trajectories in the present air-route network.

It is believed, and in some cases established, that the expected benefits which would result from the measures proposed would easily compensate for the investment required. The Air Traffic Authorities conscious of these facts have taken local measures to ease the situation. National and International Administrations have published exhaustive lists of possible contributions to the reduction of fuel consumption and precise recommendations have reached international assemblies. However, the process of reviewing control standards and procedures is progressing at an extremely slow pace, indeed, the conception and acceptance of advanced aids requires the build-up of a high level of confidence both on the ground and in the air. In the United States, the Federal Aviation Administration has defined a plan to modernise the present system while providing a framework for the future National Airspace System. This appears to be the first time that Air Traffic Control is, as a whole, being considered as a large-scale system, i.e. the control operation resulting from the objectives, needs and multiple functions which may be developed using modern science, engineering and technology.

The Guidance and Control Panel of AGARD is closely associated with the developments made or applicable in the field of air traffic (see for instance "Air Traffic Control Systems" CP-105, 1972; "Plans and Developments for Air Traffic Systems" CP-188, 1975; "A review of Modern Air Traffic Control", Vols. 1 and 2, AG-209, 1975, "Air Traffic Management, Civil/Military Systems and Technologies" CP-273, 1979). At this stage, it was reasonable to attempt to produce a state-of-the-art review, inviting the Military and the Civil Operators, the Air Traffic Control Authorities, the Research Institutions and Specialised Consultants to express their concerns and requirements, to show their contributions or expose their plans and, above all, to exchange objective views on a subject affecting all concerned with aviation in general and air transport in particular.

The opportunity for such an event was offered by the initiative of the Portuguese National Delegation to AGARD, inviting the Guidance and Control Panel to organise a special one-day session to review the present situation in face of the users' requirements, economic constraints and developments in technology. The materials available in the NATO countries could readily be brought to an open forum thanks to the exceptional response of all Authorities and Institutions concerned.

We would like to express our sincere appreciation to all the Authors and Session Chairmen who agreed to share their knowledge and experience for the benefit of the whole community.

We are grateful to the Portuguese National Delegation to AGARD for suggesting and hosting this Conference. In particular, we would like to thank Eng. Antonio Alves-Vieira and his colleagues for the coordination of the meeting conducted in an efficient and most pleasant manner.

Dr André Benoit
Program Chairman
Guidance and Control Panel

[5] *Facsimile reprint, AGARD CP-340, 1983.*

# PREFACE [6]

*This Symposium marks a step forward in the progress made by the Guidance and Control Panel of the Advisory Group for Aerospace Research and Development (GCP/AGARD) towards providing a forum for those responsible for the selection of technological options suitable for meeting the air traffic control and management challenges of the future.*

*The computer has already been of great service to the air traffic controller. It has relieved him of a series of mainly logistical tasks, enabling him to concentrate his attention on the safe conduct of navigation.*

*We have now reached a stage where we can look forward to the development of a ground-based computer capable of talking direct to an onboard computer to guide aircraft safely from departure to destination with a level of safety as high as that achieved today and with near maximum efficiency in terms of economics and capacity.*

*The use of satellites for highly accurate surveillance, navigation that is virtually independent of local facilities, and reliable communications with aircraft anywhere in the sky over the planet, together with the tremendous power of the next generation of computers or, more generally, processing facilities suitable for taking guidance decisions in the most complex configurations, tend to confirm that the above expectation is no longer a mere dream. Clearly, it is not our intention to suggest that both stations (ground-based and onboard) will operate without human intervention. But does the presence of either one person (the pilot) or two persons (the pilot and the controller) necessarily prevent the overall control system from operating automatically? In other words, what level of automation do we envisage and, regardless of present legislation, what role may we expect the human to play in the ground/air/ground control loop?*

*The density of air traffic continues to grow, but the available capacity seems unlikely to keep pace. As a result, the complexity of air traffic management and control will increase and the computer will have to take guidance decisions. In the initial phase it will offer them to the human controller who will then decide whether or not to implement them. If the computer proves itself to be reliable, the controller will begin to accept its guidance systematically. The consequences are easy to predict. A second phase will follow, in which the computer will simply present what it intends to send to the unit(s) concerned (either adjacent centre(s) and/or aircraft) and request their agreement. This procedure could in due course become no more than a courteous formality. At that stage, what role will the human controller play?*

*It is in an attempt to answer this question that this Symposium will investigate the latest perspectives on a number of fundamental issues by examining the possibilities offered by new technologies. Particular attention will be focused on the use of more powerful data processing facilities, the introduction of satellites for integrated navigation communications and surveillance and the potential role of automatic two-way air/ground data links. The fields covered will include advanced surveillance radar, advanced landing systems, the management of air traffic (particularly in extended terminal areas), the potential and limitations of automation, including the possible applications of intelligent knowledge based systems, and new onboard equipment that will clearly necessitate a fresh look at the relationship between air traffic control and individual aircraft.*

Dr. André Benoît
Symposium Chairman

[6] *Facsimile reprint, AGARD-CP-410, 1986.*

# Preface [7]

The determination of the motion of aircraft exhibits a very great number of facets and this is required in a wide range of applications. It is accordingly our intention to limit the scope of this manual to specific aspects related to the computation, prediction and control of trajectories, and guidance of flights.

Within this framework, the work will be structured around two main themes: on the one hand the fundamentals of the computation of a trajectory in terms of present knowledge and technologies and, on the other, the handling of air traffic, implying the availability of methods and techniques to compute on-line the future paths of a large number of aircraft and the possibility of guiding their flights safely and efficiently in dense traffic, and even, in congested areas.

These two themes are developed in two separate volumes, numbered 1 and 2 respectively. A third volume will include the book of abstracts, an extensive bibliography and the list of contributors, including affiliations and professional addresses; these last two parts being complemented by adequate indexes.

This first volume has been divided into three parts, namely:

**Part I** Fundamentals
**Part II** Flight in Critical Atmospheric Conditions
**Part III** Impact of New On-Board Technologies on Aircraft Operation

Parts I and II actually constitute a single entity: the reader will note that the structure of the contributions presented reflects the tight coupling between the subjects covered, mainly optimum trajectories/non-linear models/flight in non-uniform wind. This results from the inherent nature of this work; each individual contribution tending to be autonomous, although placing the emphasis on a particular topic.

After an introduction illustrating relationships between the elements affecting the motion of an aircraft, the emphasis is placed on determination of optimal trajectories and the computation of flight paths in the presence of wind variations. Several applications are treated, including the derivation of optimal trajectories for the take-off phase, the determination of control laws — optimal and non-optimal — to fly aircraft in the presence of windshear and the generation of directives relating to military interceptions. Further, models are proposed to account realistically for wind and wind variations in flight simulations.

Part III affords a picture of the impact of new on-board technologies on aircraft operation. It is made up of two contributions. The first one presents the use of on-board computers to improve efficiency in air transport, while the second treats the difficult subject of the role of man in the face of increasing automation in the cockpit, and the resulting effect on the conduct of the flight.

Dr André Benoit
Programme Director and Editor
Guidance and Control Panel

[7] *Facsimile reprint, AGARD-AG-301, Volume 1, 1990.*

# Preface [8]

Irrespective of the complexity of the traffic situation or the navigation potential of the aircraft, the control of air traffic is at present carried out by the human controllers. Clearly, assistance from modern technology is available, but for the conduct of ancillary tasks, never at the decision level. In contrast, pilots rely on automatic guidance, especially in the most critical phases of flight. Further, the present trends in aircraft operations make it realistic to envisage the planning of a complete flight, or an appreciable part thereof, with little subsequent intervention from the pilot.

Accordingly, the present handling of air traffic exhibits the following paradoxical characteristics.

On the one hand, the captain responsible for the safe conduct of the flight — several hundred human lives involved, his own included — will be able to plan a 4-D trajectory and execute this plan with a high degree of accuracy, trusting the on-board computerized navigation, guidance and control equipment.

On the other hand, the air traffic handling organization cuts the flight into slices and distributes the control tasks to the controllers of the relevant units, each phase being controlled practically independently of what has happened previously and regardless of what the subsequent unit will do. For example, a straight 45-minute Brussels to London flight may comprise up to 5 different control phases, not to mention sectorization, aerodrome/tower and taxi control.

This situation must and will change, under the influence of several essential factors acting in the same direction, which include the requirements covering an increased use of the available capacity, more consideration for the economy of flight operations and adequate adaptation of air traffic handling practice to the individual aircraft's 2-D, 3-D or 4-D navigation capability.

The Zone of Convergence (ZOC) concept constitutes an initial step in an attempt to meet these requirements. It aims at integrating on-line the handling of air traffic over an extended area including and surrounding a main Terminal Manoeuvring Area (TMA) and possibly secondary airports. In Europe, the concept was initially developed at the European Organisation for the Safety of Air Navigation, EUROCONTROL, in co-operation with air traffic control units, research institutions and several airlines of the Organisation's Member States. Subsequently, specific versions designed for immediate operational use were initiated by several national authorities.

The French approach, known under the acronym MAESTRO, constitutes a remarkable step in the evolution of the Air Traffic Control (ATC) automation process. With the assistance of the computer assessing the aircraft's range of manoeuvrability, a team of 3 duly selected en-route (2) and approach (1) controllers working in close co-operation, "pre-regulate" the inbound traffic while en-route, ensuring a properly scheduled set of deliveries at the entries (geographical fixes, some 50 nm from the runways) into the TMA. As a result, the approach controllers know that the problem of bringing the aircraft down to the runway without the systematic use of "stacking" has a solution. Further, they also know that one of their colleagues was involved in the negotiation of the solution. When this volume is printed, MAESTRO will in principle be in operation in the North Control Centre of France, for the traffic inbound to Orly. It will be most interesting to follow the evolution of this essential co-operation, namely the controller and his computerized assistant.

The second volume of the treatise on Aircraft Trajectories is mainly devoted to methods, procedures, techniques and technologies considered for the benefit of air traffic handling.

The emphasis is placed on some preliminary aspects relating to the computerized decision assistance to be provided to the air traffic controller for the determination and control of future events, such as the allocation of landing time slots, avoidance of conflicts — otherwise certain to happen — or any other critical situation. Special attention is given to the regulation of traffic and the guidance of flights in a time-of-arrival constrained environment.

The main parts of the volume cover successively, general requirements and European prospects, on-line use of aircraft trajectory prediction, including fundamentals, applications, ground-based guidance of aircraft, radar tracking, the potential role of the satellite for surveillance, the impact of the quality of meteorological forecasts and specific consideration of air traffic handling simulations.

André Benoit
Programme Director and Editor
Guidance and Control Panel

[8] *Facsimile reprint, AGARD-AG-301, Volume 2 , 1990.*

# Introduction [9]

Le troisième volume de l'AGARDographie consacrée au calcul, à prévision et au suivi des trajectoires d'aéronefs se subdivise en trois parties:

(a) un **recueil des résumés** des contributions — le texte intégral sera normalement disponible au moment de la mise sous presse de ce volume;

(b) un importante **bibliographie** comprenant les coordonnées de la plupart des documents cités par les auteurs des contributions réunies dans le présent ouvrage, et complétée par un index organisé par année. Cet index donne par ordere alphabétique, la liste des auteurs cités dans la bibliographie et pour chacun d'eux, les dates et le nombre de publications mentionnées;

(c) **la liste des auteurs des contributions** présentée selon l'ordre alphabétique de leurs pays d'origine, avec le nom et l'adresse de leur entreprise ou de leur organisation. Cette liste comprend également un index alphabétique des auteurs presicant la nature et les références de leurs contributions.

* * *

This third volume of the AGARDograph devoted to the **Computation, Prediction and Control of Aircraft Trajectories** includes three main parts, namely

(a) a **Book of Abstracts** limited to those for which the complete paper or at least an adequate executive summary was available at the date of publication;

(b) an extensive **Bibliography** which incorporates in particular, most of the references cited by the authors of the contributions to this work. It is completed by an index of authors' names giving for each year a list, in alphabetical order, of the names of authors referred to in the bibliography; for each author, it gives the year of publication and each year the number of publications listed.

(c) the **List of Contributors**, ordered by countries alphabetically, with applications and professional addresses; this being completed by an index of the contributors' names giving in particular, the type of contribution and whenever applicable, the reference of the paper contributed.

André Benoît
Directeur du programme
Membre de la Commission Guidage et Pilotage

[9] *Facsimile reprint, AGARD-AG-301, Volume 3 , 1990.*

# Preface [10]

Airspace congestion is a reality and, whatever the causes, the resulting problems are known only too well. And yet, **demand continues to grow.** Forecasting experts agree that traffic densities will double in 10 to 15 years time. Others envisage, in the slightly longer term, the bringing into service of supersonic aircraft cruising at Mach 3 and even hypersonic speeds.

In today's chain of control it is the **human** link, i.e. the controller, who is **sovereign.** He is in a sense an artist dealing with situations on a case-by-case basis, drawing on his talent, intuition, experience and judgement. These are all inputs which are difficult for him to get across to us and which are hard for us to put in a form which can be expressed mathematically.

The **arrival of state-of-the-art technologies** has opened up new visions revealing ways of rolling back the present day limitations of the ATC system, namely the restricted runway or en route capacity and the rapid saturation of the human controller's ability to handle increasing situation complexity. Thanks to this **technological potential,** we are now able to envisage the acquisition, enhancement and exploitation of knowledge bases together with the use of **automated digital data links** for one-way or two-way ground-air data exchange which would then be able to extend far beyond current applications and encompass an extremely wide range of information.

In order to transit to a new and efficient system in which there is **harmonious integration of modern technologies and human abilities,** close cooperation between the ground component designers and those responsible for the air component is essential. More particularly, the ATC system designers must ensure that there is **efficient collaboration involving controllers, who alone are capable of transferring their art, albeit only in part, to highly automated decision making aids.**

This **twofold cooperation** should be emphasised: firstly, between the **ground and air** components: secondly, cooperation between those setting up and using the ATC system: **controllers, pilots, psycho-metricians, engineers** and . . . **passengers.**

Over the past 20 years, the Guidance and Control Panel of the Advisory Group for Aerospace Research & Development, AGARD-GCP has devoted part of its activities to the fascinating field known historically as **Air Traffic Control,** covering both civil and military domains (see Activities of GCP in ATC, page v). This vast discipline includes a variety of control loops each being characterized by a specific look-ahead time.

This Symposium, namely the 56th Symposium organized by the Guidance and Control Panel of AGARD, intended to place the emphasis on the potential use of **"Machine Intelligence"** in the overall control loop covering all sub-loops — management, flow management, control, guidance, conflict alert and collision avoidance — and assessing the benefits which should or might result for the aviation community — designers and users. Clearly, this programme was ambitious and challenging: the response of Air Traffic Control confirmed the interest of the subject and the hopes placed in advanced technologies, in particular machine intelligence.

And, basic questions to be addressed include:

- Will Machine Intelligence solve the present difficulties of Air Traffic Handling? Have we any other choice?
- How do we evolve from the present state to a possible future fully automatic system?

From the Keynote Address, till the final Round Table Discussion, the proceedings of the meeting show the **overall effort being made by the ATC world** to meet an increasing demand, the **sense of cooperation** now existing among the ATC communities and the **results already achieved,** in various areas, through the development and implementation of automated aids.

André Benoit
Symposium Chairman
Guidance and Control Panel

[10] *Facsimile reprint, AGARD-CP-538, 1993.*

# Preface [11]

It is quite evident that, if traffic increases as it is expected to, Air Traffic Management concepts which are used at present should soon become obsolete. Full automation is not feasible today. Nevertheless it is conceivable and research - studies and experiments - has been undertaken in this direction[1].

These points were recognized many years ago. In addition, the fact that political boundaries existed, preventing the integration of control over an extended area covering several States, led to the development of the Zone of Convergence concepts, realizing the integration of en-route and approach control over a region including essentially a main terminal manoeuvering area, TMA, and possibly several secondary airports, and extending anisotropically as far as possible - e.g. 100 nm or even up to 300 nm - away from the converging or critical point, e.g. the runways system centre point.

Presently, several systems aiming at a local efficient management of arrival flights are in operation, in implementation and/or in further development. A critical survey of such systems has been made recently[2], and it is clear that the present trends confirm the adequacy of the above first step undertaken to provide the human controller with advisories generated automatically by the computer.

The next step is clearly the integration of control over a series of such Zones of Convergence or extended terminal manoeuvering areas. To illustrate what is meant, consider a region including several major terminals such as Amsterdam, Brussels, Frankfurt, London and Paris, and the area around each terminal as in the Zone of Convergence concept, now schematized by as many circles whose radii extend as appropriate, to 150 - 250 nm. The total area encircled in this example constitutes a major part of Western Europe.

Clearly, the traffic seen and to be controlled on-line in such a total area includes flights conducted entirely inside this area (regional and Western European traffic), flights originating or terminating outside the area (connecting with the rest of the world) and flights whose origin and destination are both located outside (over-flights). Different sets of control variables apply to each of these different categories of traffic. For instance, initial conditions are imposed for the traffic originating outside, while departure time sequences could be included among them - within reasonable ranges depending on the efficiency of pre-organization units - for the traffic originating inside, whatever the internal or external destinations.

How should we approach the on-line control of the entire traffic in such an extended area in conformity with the numerous and varied severe demands covering, in particular :

- increase of air transport both in volume and diversity;
- conservation of natural resources and deference to the environment;
- national/international economy restrictions;
- general and specific airspace users' requirements.

A main distinction is made between the efforts conducted by all Administrations and Institutions concerned with developing the off-line aspects characterized by different timescales, on the one hand, and the on-line conduct or management of the traffic, including the guidance of each individual flight, on the other hand. The work covered in the off-line category includes special programmes on the increase - or improved use - of capacity (such as construction of additional runways, simultaneous use of parallel runways, reduction, even temporarily, of restricted areas, air traffic flow management), and, in particular, the main project undertaken by the European Organisation for the Safety of Air Navigation, EUROCONTROL, in conjunction with the European Civil Aviation Conference, ECAC, namely the European Air Traffic Control Harmonization and Integration Programme, EATCHIP[3].

[1] *"Towards a Global Air Traffic Management System", G. Maignan.*
*Keynote Address, AGARD Guidance and Control Panel 56th Symposium, 11-14 May 1993, Berlin, Germany.*

[2] *"Time Based Air Traffic Control in an Extended Terminal Area - A survey of such systems", E. Petre.*
*Doc. EUROCONTROL 912009, June 1991.*

[3] *"The EUROCONTROL / ECAC view. The EATCHIP programme", W. Philipp.*
*Paper presented at the International Forum: Congestion in the Skies:*
*The Challenges for the 21st Century, 27-28 January 1994, Paris, France.*

The on-line control of air traffic - globally optimized - over such an area, including several major TMAs, follows and should exploit the results of the previous efforts, the last step having been achieved by the prediction of traffic prepared by a Central Flow Management Unit. Without efficient on-line traffic management and control of individual aircraft, the capital which should result from the preceding developments might be appreciably reduced, if not completely lost.

Accordingly, laying down a programme to specify the characteristics of the on-line component of traffic management and guidance of individual flights in the future European environment has become a necessity. This concern does not really constitute a new idea. The subject was presented and discussed at several workshops or seminars[4]. Even if in many respects, it remains a medium to long term objective, it is nevertheless essential to identify the processes which will require the application or development of mathematical methods or algorithmic techniques. These are, a priori, complex due to the stochastic character of the phenomena themselves and the amount of data to be processed on-line - thus in real time - at a high repetition rate.

Except for the airspace users' operational requirements, the essential demands mentioned above - environment, national resources, developments versus economy restrictions - will appear fairly well defined within perfectly quantified constraints.

There still remain the airline demands and the overall economy requirements of the Community - in a widely acceptable sense as outlined below. As a consequence, the on-line control problem becomes more precise and can be stated in applied mathematical terms. For each aircraft entering the area concerned, this amounts to defining the relevant 4-D trajectory and possibly amending the trajectories of a series of aircraft already flying in the same area.

The relevant determination of the trajectories of all aircraft involved amounts to a complex optimization problem whose essential characteristics include :

- definition of multi-criteria, based essentially on flight economy, i.e. combining cost, time and consumption of all flights concerned. Indeed, it can be shown that the minimum general cost, in case of saturation, tends to correspond to a maximum use of the available capacity;
- accurate specification of the control variables, such as sequences of arrival times for all aircraft with destinations in the controlled area, possible sequences of departure times for all flights originating in the controlled area, and for all aircraft, speed profile control in the vertical plane with some possible adjustments in the horizontal one;
- taking account of all the constraints placed on the system by all additional demands (geographic restrictions, noise abatement procedures, etc.);
- operation on-line - thus in real time - with machine/machine, human/machine and human/human interactions.

The problem is highly complex: it covers a large scale system; it is non-linear, discreet and discontinuous ; as already said, it is stochastic on a very short term basis and involves a set of voluminous data bases, some to be consulted on-line at a high frequency rate. The advisories generated by the computer should be adaptable to the technology available - for instance, Radio-Telephone or Data-Link communications environments - and easily understood by the human controller who will remain sovereign in the control loop. It is to be noted that the computer/controller/pilot interface presently developed in the ZOC/DMA system is directly applicable and has proved to be fully compatible with present and a fortiori future aircraft operation, as shown by the results from a substantial series of tests conducted to date[5] [6].

[4] *"On-line Management and Control of Air Traffic", A. Benoît.*
*"Flow Control of Congested Networks", NATO ASI Series,*
*Series F, Vol. 38, Springer-Verlag, Berlin, Heidelberg 1987. Also Doc. EUROCONTROL 872005, April 1987.*

[5] *"The Air Traffic Controller Facing Automation : Conflict or Co-Operation",*
*A. Benoît , S. Swierstra and R. De Wispelaere.*
*Paper presented at the Conference D3 - Data Dissemination and Display, NAV 87, Royal Institute of Navigation, London, United Kingdom, 29, 30 September - 1 October 1987. Also Doc. EUROCONTROL 872008, July 1987.*

[6] *"A report on flight trials to demonstrate a Mode S data-link in an ATS environment",*
*M. E. Cox, S. Swierstra et al.*
*EUROCONTROL-CAA Mode S Data Link, October 1991.*

At the present stage of the European ATC/ATM development, it should be possible to proceed with such an integration of air traffic handling - with on-line management and control, departure and arrival sequences as essential parts of the control variables - and it is now opportune to initiate the basic developments required to meet such a stimulating challenge.

The initial purpose of this presentation was to outline the general environment in which should be made the selection, assessment and running - in real time - of optimization techniques suitable for conducting on-line an efficient global and optimized management of air traffic over Western Europe.

The criteria of the system should cover overall flight economy and maximum use of available capacity, en-route and in TMAs. Control variables should include individual aircraft flight profiles in both vertical and horizontal planes and, whenever appropriate, times of arrival and, ultimately, times of departure within acceptable limits. The numerous, varied and sometimes contradictory constraints expressed by the various communities involved should be treated in a flexible manner.

The optimization methods presently available to approach such a problem are essentially based on numerical techniques - branch-and-bound, genetic algorithms, for instance - and relatively complex to implement in the on-line ATC/ATM environment. Nevertheless, they should be considered even it is felt that they may be successfully replaced by rather simple strategies as introduced previously in the optimized management of traffic in the Zone of Convergence approach[7].

It is clear that such a work programme calls for competencies not necessarily available in present Air Traffic Services institutions. Already - see the EATCHIP programme, for instance - the increase in complexity of air traffic handling calls for an increase in staff, with members specialized in a variety of disciplines. As a result, young colleagues joining Air Traffic Control advanced project teams may be highly competent in their specific field, be it information theory, optimization techniques, automated data communications etc., but, at the same time lacking a basic knowledge of the Air Traffic Control background and the associated constraints.

For those new to the Air Traffic Control Research and Development community, this AGARDograph should offer, on the one hand, a precise idea of a particular long term system objective and, on the other hand, a broad view of the present situation and actual limitations.

After a **General Introduction** and a short note on **The Air Transport System** (Chapter 1), some aspects of the **Air Traffic Complexity** is presented (Chapter 2). The trends of the **Traffic Evolution** are then outlined (Chapter 3), this presentation being based essentially on the information published regularly by the International Civil Aviation Organization (ICAO).

In line with the educational textbook character of this AGARDograph, Chapter 4 is devoted to the **Electronic Aids to Controllers** presently available at the control center. Chapter 4 constitutes an introduction to the subject, it summarizes the essential technological supports currently available, while the aids to assist the human controller at the decision making level as presently developed at the Engineering Directorate[8] of the European Organisation for the Safety of Air Navigation are described in a separate and subsequent section, entitled **Decision Making Aids** (Chapter 6).

Besides Conflict Alert - also referred to as Safety Net - systems, the first steps undertaken to develop aids were related to the terminal area extended to cover an appreciably wider area than the current - or in some places, the former - 25 nm extent. A substantial coverage of the subject, including a critical review of the systems developed, is made under the title "**Arrivals Management Systems**" (Chapter 5).

From where we stand today, it is worth to dare "**A Look Further into the Future**" (Chapter 7). Some 20 years ago, the Federal Aviation Administration had already initiated a programme of work aiming at automating if only partly, most of the en-route filed regular traffic. It appeared to us that such a programme was never perceived as fully realistic, partly due to some lack of understanding between the developers and the potential users. In terms of automation, the conduct of air traffic control constitutes a complex large scale system; its full automation remains a great challenge (See Note[1], page iii) and it will not be treated here. Instead, we shall limit this presentation to an outline of two transitional steps, one extending from the on-line management of arrival traffic, the other applying simultaneously to a series of main terminals as suggested at the beginning of this

[7] *"Air Traffic Handling and Ground-Based Guidance of Aircraft", AGARDograph N° 301, "Aircraft Trajectories : Computation - Prediction - Control", Vol. II, AGARD, Neuilly-sur-Seine, France, May 1990.*

[8] *Now the Directorate of Eatchip Development.*

Preface. Then, in chapter 8, some emphasis is placed on several general aspects of this last approach, under the title **Towards Global Optimization.**

The initial assessment and, subsequently, the thorough validation of advanced on-line ATM concepts implying an accurate 4-D control of each aircraft trajectory, require simulation facilities suitable to reproduce in particular, the behaviour of the pilot/aircraft system in a highly realistic manner. It appeared that classic experimental units did not contain such resources. Accordingly, complementary facilities were developed to supply the lacking components, an example of which is presented in chapter 9 under the title **Systems Evaluation Facilities.**

The advanced ATM concepts rarely integrate the ground movements from gate to brake-release and from touch-down to gate. The reason is simply the complexity of the entire system. At some future stage, these components should nevertheless be integrated in a global management system. The last chapter of this book suggests some guidelines to look at the **The Airport of the Future** (Chapter 10). This important subject will be treated further in an open forum[9] and it is hoped that precise practical recommendations will result.

In concluding this foreword, we wish to welcome the young graduates joining this fascinating field known historically as Air Traffic Control and fully open to innovation, science application and technological development.

André Benoît
Programme Director
Guidance and Control Panel

[9] *Académie Nationale de l'Air et de l'Espace, ANAE, Toulouse, France, Programme d'activités 1995.*

[11] *Facsimile reprint, AGARD-AG-321, 1994.*

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**14. Abstract**

Over 25 years, the Guidance and Control Panel of the Advisory Group for Aerospace Research and Development to the North Atlantic Treaty Organization has devoted part of its activities to the fascinating field known historically as **Air Traffic Control**, covering also **Air Traffic Management**, and more generally **Air Traffic Handling**.

This Report provides a list of the summaries of the papers which were presented at the symposia and included in the AGARDographs devoted to this wide and most challenging subject, covering essentially,

**Air Traffic Control Systems** (1972)
**A Survey of Modern Air Traffic Control,** Vols. I and II (1975)
**Plans and Developments for Air Traffic Systems** (1975)
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