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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARDograph No.301

Aircraft Trajectories Computation—Prediction—Control

(La Trajectoire de l'Avion
Calcul—Prédiction—Contrôle)

Volume 3

NORTH ATLANTIC TREATY ORGANIZATION

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Volume 3

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

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Aircraft Trajectories Computation—Prediction—Control

(La Trajectoire de l'Avion
Calcul—Prédiction—Contrôle)

VOLUME 3

Part IX Book of Abstracts
Part X Bibliography
Part XI List of Contributors

Edited by

André Benoît
Programme Director

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Introduction

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 ci és 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.

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La Commission Guidage et Pilotage tient à remercier tous les auteurs et coordonnateurs qui contribuèrent à la réalisation et la publication de cette AGARDographie.

Activities in Air Traffic Handling

Over the past 20 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.

The 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 such as in the Zone of Convergence type concepts, the 4-D guidance of aircraft in critical conditions, the ever-increasing level of automation and its impact on the essential role of the human acting on-line in the control loop.

AIR TRAFFIC CONTROL SYSTEMS
Guidance and Control 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., United States
20—23 May 1975.
AGARD-CP-188, February 1976.

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Guidance and Control 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 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, 2 and 3:
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FLIGHT IN CRITICAL ATMOSPHERIC CONDITIONS
IMPACT OF NEW ON-BOARD TECHNOLOGIES ON AIRCRAFT OPERATION
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C - NON-LINEAR MODELS OF AIRCRAFT

A - GENERAL OUTLINE OF THE PROBLEM

Reference 1F

INTRODUCTION A L'ETUDE DES TRAJECTOIRES D'AVION

Schéma général des problèmes posés

par

Frédéric Haus

Professeur Emérite aux universités de Gand et de Liège

RESUME

La détermination d'une trajectoire d'avion comporte un nombre élevé d'opérations. Dans cet article, nous essayons de classer celles-ci et de les répartir en 12 groupes.

Reference 1E

INTRODUCTION TO THE STUDY OF AIRCRAFT TRAJECTORIES

General Outline of the Problem

by

Frédéric Haus

Emeritus Professor Universities of Gand and Liège

ABSTRACT

The determination of the trajectory of an aircraft comprises a large number of operations. In this paper, an attempt is made to classify these into 12 groups.

B - COMPUTATION OF OPTIMAL TRAJECTORIES

Reference 2

OPTIMAL TRAJECTORIES OF AIRCRAFT AND SPACECRAFT

by

A. Miele

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SUMMARY

This paper summarises some of the work done by the Aero-Astronautics Group of Rice University on algorithms for the numerical solutions of optimal control problems and their application to the computation of optimal flight trajectories of aircraft and spacecraft.

Part 1 deals with general considerations on calculus of variations, optimal control, numerical algorithms, and applications of these algorithms to real-world problems.

Part 2 deals with the sequential gradient-restoration algorithm (SGRA) for the numerical solution of optimal control problems of the Bolza type. Both the primal formulation and the dual formulation are discussed.

Part 3 deals with 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. Both take-off trajectories and abort landing trajectories are discussed. Take-off trajectories are optimised by minimising the peak deviation of the absolute path inclination 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.

Parts 4 and 5 deal with spacecraft trajectories, in particular, the application of the primal sequential gradient-restoration algorithm (PSGRA) to the determination of optimal flight trajectories for aeroassisted orbital transfer. Both the coplanar case (problem without plane change, Part 4) and the noncoplanar case (problem with plane change, Part 5) are discussed within the frame of three problems; minimisation of the total characteristic velocity; minimisation of the time integral of the square of the path inclination; and minimisation of the peak heating rate. The solution of the second problem is called nearly-grazing solution, and its merits are pointed out as a useful engineering compromise between energy requirements and aerodynamics heating requirements.

Part 6 presents the conclusions. The references are given in Part 7.

C - NON-LINEAR MODELS OF AIRCRAFT

Reference 3 **COMPARISON OF A MATHEMATICAL ONE-POINT MODEL AND A MULTI-POINT MODEL OF AIRCRAFT MOTION IN MOVING AIR**

by

R. Brockhaus

Technische Universität Braunschweig

SUMMARY

The steady growing capacity of computers favours 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. In this paper, therefore, 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 modelled 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 centre of gravity. The modelling 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 (wing, fuselage, tail) 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.

Reference 4 **DETERMINATION DES LOIS DE GUIDAGE QUASI-OPTIMALES EN TEMPS REEL**

POUR

DES TRAJECTOIRES D'AVIONS DE COMBAT

par

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RESUME

Cet article présente une application de la théorie des systèmes multi-échelles de temps au contrôle en temps réel des trajectoires d'avions de combat.

Après avoir rappelé les principes de la théorie des perturbations singulières dans la résolution des systèmes différentiels multi-échelles de temps, son application à l'optimisation des systèmes non-linéaires est présentée. Les principales difficultés rencontrées dans la détermination des lois de guidage "temps réel" sont ensuite mentionnées, puis différentes techniques utilisées pour les résoudre sont indiquées.

Des lois de guidage "temps réel" en boucle fermée sont ensuite développées pour différents types de trajectoires d'avions de combat: montée en temps minimum, interception dans un plan horizontal, dans un plan vertical et dans l'espace tridimensionnel. Les performances fournies par ces lois sont ensuite évaluées en simulation numérique sur un modèle d'avion type, par comparaison avec les lois optimales en boucle ouverte obtenues par un algorithme numérique de gradient projeté, sans approximation de type multi-échelles de temps.

Reference 4

COMPUTATION OF SUB-OPTIMAL REAL-TIME GUIDANCE LAWS FOR COMBAT AIRCRAFT TRAJECTORIES

by

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SUMMARY

This chapter presents an application of singular perturbation theory (SPT) for the computation of real-time control laws for Combat Aircraft trajectories.

The principle of SPT is first briefly reviewed for solving a multiple-time scale differential equations, then its application to optimization of non-linear systems is presented. The main drawbacks and difficulties which have been 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 laws, of closed-loop type, have been developed for minimum time to climb in a vertical plane and three-dimensional interception for a combat Aircraft. The performances of these sub-optimal guidance laws have been 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 % accuracy has been 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 sub-optimal 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.

PART II - FLIGHT IN CRITICAL ATMOSPHERIC CONDITIONS

A - GENESIS OF WIND AND INFLUENCE ON AIRPLANE TRAJECTORIES

B - FLIGHT CONTROL IN WIND SHEAR

C - FLIGHT SIMULATION

PART II-A - GENESIS OF WIND AND INFLUENCE ON AIRPLANE TRAJECTORIES

Reference 5

CRITICAL ASPECTS OF TRAJECTORY PREDICTION:

FLIGHT IN NON-UNIFORM WIND

by

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and

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SUMMARY

The genesis of natural wind is described from a meteorological standpoint. Its influence on airplane 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.

Reference 6

EFFECT OF WIND AND WIND VARIATION ON AIRCRAFT FLIGHT - PATHS

by

Hahn, K.-U.; Heintsch. T.; Kaufmann, B.
Schänzer, G.; Swolinsky, M.

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SUMMARY

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 80m - 120m, 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 manoeuvre 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.

PART II-B - FLIGHT CONTROL IN WINDSHEAR

Reference 7

AIRCRAFT FLIGHT IN WINDSHEAR

by

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SUMMARY

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.

Reference 8

HOW TO FLY WINDSHEAR

by

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SUMMARY

Aviation safety history is a long fight against severe environmental constraint. Modern aircraft are able to face safely most of them but one still remain 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 on-board detection and protection system. Such system will be described altogether with a review of some fundamental criteria to be considered when assessing their efficiency.

PART II-C - FLIGHT SIMULATION

Reference 9

WIND MODELS FOR FLIGHT SIMULATION

by

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Schänzer, G.; Swolinsky, M

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Technical University of Braunschweig,
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SUMMARY

Wind shear, downdraft and turbulence can endanger take-off and landing approach. The effects of wind result 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's behaviour in 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's work load and his reaction to this short scale wind disturbances. Large scale wind variations can produce significant flight paths respectively safety problems. An important aspect for the flight safety is the energy situation of an aircraft affected by wind. Therefore this is chosen as a useful criterion for the determination of the influences of the wind and wind variation.

PART III - IMPACT OF NEW ON-BOARD TECHNOLOGIES ON AIRCRAFT OPERATION

A - FLIGHT MANAGEMENT IN AIR TRANSPORT

B - CREW/AUTOMATION INTERFACE

PART III-A - FLIGHT MANAGEMENT IN AIR TRANSPORT

Reference 10

AIRCRAFT TRAJECTORY - PREDICTION AND CONTROL IN THE AIR TRANSPORT FLIGHT MANAGEMENT COMPUTER SYSTEM

by

Peter J. Howells

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Grand Rapids, Michigan, USA

SUMMARY

The declining cost of computing power and memory has enabled avionic manufacturers to develop sophisticated airborne computing systems. These systems can predict and control the airplane along complex three and four dimensional flight plans. The most complex airplane system on modern air transport airplanes is the Flight Management Computer System (FMCS) which has reduced pilot workload by taking over the mundane but complex functions - such as navigation - and enabled the transition from the three to two crew airline cockpit. This paper describes the algorithms used in prediction and control and identifies the difficulties and requirements for successful implementation.

PART III-B - CREW/AUTOMATION INTERFACE

Reference 11

IMPACT OF NEW TECHNOLOGY ON OPERATIONAL INTERFACE : FROM DESIGN AIMS TO FLIGHT EVALUATION AND MEASUREMENT

by

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SUMMARY

Since the early 1980's Airbus Industrie has conducted a progressive research programme 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,

- Formally, by continuous development of statistical methods and engineering experiments, concentrating on pilot questionnaires, performance evaluations and workload models.

The purpose of this paper is to review the span between initial design aims and subsequent flight evaluation and measurement with regard to that aspect of the Airbus programme. Much of our work appears to be relevant to the topic of this Agardograph since air traffic control will not be modernized without improvements in aircraft trajectory control studies. A statistical workload calculation model will for instance highlight the link that permits a correlation of pilot performance (and hence aircraft trajectory) parameters with estimates of the impact of new technology on the operational interface.

Except for the general recommendations of Fitts, Wanner, Nagel, Wiener and Curry, few fundamental design guidelines appear to be available in the scientific field of human factors. A practical review is presented of the operational objectives and technological modules that marked the outgrowth of the Airbus family of commercial aircraft. Progressively integrated, several waves of innovations engineered an evolutionary process that brought to bear growing functionality at the operational interface. The emerging role of the pilot is becoming more that of a systems monitor than that of a controls handler, devoting himself to overall intelligence functions which new technology features were precisely aimed to support. Several contemporary human factors views are mentioned in the paper suggesting that the pilot be brought back into a more active role to avoid automation- or design-induced errors. What has been achieved with the early 1980's A310/A300-600 cockpit however is, in our view, still in the vicinity of the Wiener and Curry philosophy on automation and cockpit design. In the step that was to be taken in the latter 1980's A320/A330/A340 design aims have moreover been intended to cover even more error- tolerance or- protection against incidents of the Wanner scheme.

Reviewing aircrew comments on design aims and achievements from flight evaluation became a practice in the early 1980's when soliciting crewmember opinions received considerable impetus. Conclusions are presented from questionnaire surveys on new technology aircraft conducted successively by Airbus Industrie, Wiener, Curry and Lufthansa. Commonly criticized on most new aircraft types are the autopilot/autothrottle interactions and the FMS whose training definitely needs more emphasis on basic know-how and practice. It appears that crews want automation even further developed to improve system integration and crew interface, with no significant fear for the possibilities of errors or potential loss of flying skill. But what also seems to be requested is intuitive design allowing the pilot to understand more straightforwardly the automation systems at work and to monitor more easily their performance, limits and crew errors.

Measuring the impact of new technology on the operational interface could precisely help setting up this human factors capability. Which in turn should eventually influence on design guidelines and specifications.

The success of the questionnaire technique prompted Airbus Industrie to use it again for its Fly-by-wire proof-of-concept experiment on the A300 testbed. The unanimous enthusiasm of airline & authority pilots for the fly-by-wire/sidestick combination was also confirmed by the fact that, as a group, they did not feel uncomfortable with the idea of being primarily responsible for the management of system interfaces rather than the direct operation of their aircraft. It would appear from these studies that older technology aircraft can more often be discredited on the basis of human factor principles than new ones. It is however with the coming of the latter that more emphasis was gradually put on human factors by all those concerned, manufacturers, airworthiness authorities, pilots and airlines. Even more systematic efforts on man-machine interface analysis were put in the wake of the crew complement question which triggered the development of several evaluation methods. One of these, the Performance Criteria Methodology, was developed to statistically investigate the impact of new technology features such as the EFIS, the FMS and Fly-by-Wire/Sidestick. A brief review is given of engineering experiments' results for the first two to conclude on the contribution of this equipment towards improving smoothness of performance and alleviating workload. The advantages of a FbW system over conventional controls are operationally demonstrated with the third experiment. Performing analysis of variance on basic flight parameter measures allows again to demonstrate marked smoothness and stability improvements, flight efficiency, reduced task- and workload.

Our previous research suggested that workload ratings collected in minimum crew certification campaigns might be modelled using data extraneous to the pilot (aircraft flight performance parameters and flight status measures) and data intraneous to the pilot (heart rate variability measures). The aim was to achieve an objective analysis of an until-then subjective process (workload rating) which had received too little scientific attention. A computer model was evolved from the A310-200 certification process, which indeed conformed well with the subjective data. Certification of the A310-300, a generally similar but sufficient different aircraft, provided a further check on the degree of objectivity attained, helped to simplify the model's formulation. As part of the development program for the A320, the A300 FbW flying testbed had numerous visiting pilots involved in extensive demonstrations as well as special manoeuvres such as simulated engine failure at take-off and a demonstration of the inherent stall protection of the control system. The model was again successfully applied to these flights in order to determine if it could cope with the new control system and the unusual profiles. Finally, the very first flight of the A320 also had both pilots equiped with heart rate monitoring equipment so as to test the model. Cleared for experimental use, the Airbus Workload Model was then used in January 1988 for the A320 Minimum Crew Certification to generate second-by-second estimates of pilots' subjectively estimated workload. The purpose of this demonstration was to provide a range of low to high workload situations by means of 12 scenarios which provided varying flying problems. In all, 48 simulated line flights, which involved different levels of automation, were flown. Crew errors were also recorded and classified according to their severity and awareness. As a tool to investigate the impact of new technology, the Airbus Workload Model presents a novel opportunity to study workload and its relationship to both errors and automation. The findings are descriptive in nature because the certification data base was not constructed to support research on these issues. But they suggest that there is a relationship between the severity and type of error and workload, and that automation and workload are inversely related.

PART IV - AIR TRAFFIC HANDLING

A - REQUIREMENT : INTEGRATION OF CONTROL PHASES
B - PROSPECT : A FUTURE EUROPEAN AIR TRAFFIC SYSTEM CONCEPT
C - ON-LINE PREDICTION OF AIRCRAFT TRAJECTORIES
D - AIR TRAFFIC MANAGEMENT

PART IV-A - REQUIREMENT : INTEGRATION OF CONTROL PHASES

Reference 12E **OPTIMUM ON-LINE HANDLING OF AIR TRAFFIC OVER WESTERN EUROPE**

by

André Benoît and Sip Swierstra

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SUMMARY

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 (defined for simplicity as the non-oceanic area covered by the EUROCONTROL route charges system) to arrange ATC clearances and instructions so that any flight will, from departure clearance to touch-down (including therefore departure and arrival routes, standard or otherwise), 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.

The present paper recommends an approach 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) a central on-line optimal definition of departure/arrival sequences and essential characteristics of all flights and (b) 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 hereby 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 centre.

Reference 12F **REGULATION TEMPS REEL OPTIMALE DU TRAFIC AERIEN EN EUROPE OCCIDENTALE**

par

André Benoît et Sip Swierstra

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SOMMAIRE

Pour les compagnies aériennes, l'Europe occidentale est devenue un espace bien exigu et les vols y sont de courte durée. Pour plus de commodité, nous entendons ici par "Europe occidentale" la région desservie par le système EUROCONTROL de redevances de route ; à une telle échelle, il devrait être possible de délivrer les autorisations et les instructions de contrôle de telle manière que tout vol, depuis son départ jusqu'au point de prise de contact avec la piste d'atterrissage (c'est-à-dire pour la totalité de l'itinéraire, ce qui inclut notamment les routes d'arrivée, normalisées ou non) puisse être exécuté en conformité de la politique générale décidée par sa compagnie et sans subir les déroutements et modifications de profil de vol qu'impose la planification à court terme et qui perturbent tant la fluidité du trafic aérien.

Le présent exposé vise à recommander une méthode pour la régulation des vols en temps réel pour l'ensemble de cette région, en particulier l'intégration des différentes phases de contrôle depuis le départ jusqu'à l'arrivée. A cette fin, il faut que les séquences d'arrivée et les séquences de départ, ainsi que les principales caractéristiques de tous les vols en cause soient définies au mieux, en direct et à partir d'un point central, et que soient mis en place une série d'organismes régionaux chargés de veiller à l'application des propositions ou directives de régulation. Un tel système optimiserait l'intégration de zones de convergence adjacentes pour lesquelles les heures et les altitudes à l'entrée deviendraient - tout comme les instants d'atterrissage dans une zone unique - subordonnées aux conditions de trafic prévalant dans l'ensemble d'une telle région étendue.

Dans un premier temps, le système de calcul, de prédiction et de contrôle de la trajectoire dans les quatre dimensions mis au point pour la zone de convergence est étendu à l'ensemble du vol depuis son entrée - éventuellement un décollage - jusqu'à sa sortie - éventuellement un atterrissage - de la région de contrôle étendue ainsi constituée, l'ensemble de l'espace aérien concerné relevant d'un centre de gestion déterminé.

PART IV-B - PROSPECT : A FUTURE EUROPEAN AIR TRAFFIC SYSTEM CONCEPT

Reference 13E

THE EUROCONTROL FUTURE ATS SYSTEM CONCEPT

and

THE PROGRAMME OF STUDIES, TESTS AND TRIALS

by

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SUMMARY

The era of parallel, uncoordinated development of ground systems and guidance, navigation and communications avionics is at an end. The pursuite 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 harmoniously combine available ground and air technologies. Close cooperation between pilot and controller actions constitutes one of the keystones of the future systems.

It will be possible to increase the capacity and efficiency of air traffic management, while at the same time maintaining essential safety requirements, only by making more intensive 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 substantially improved.

This was made quite clear in the description of the Future ATS Concept drawn up by the EUROCONTROL Organisation. The Concept, the principles of, which were approved by the EUROCONTROL Commission of Ministers in July 1987, will be presented in broad outline.

Its implementation will call for a number of studies and trials, and a rundown will be given of EUROCONTROL's programme. Furthermore, the idea of a Harmonised Programme of Research for ATM (PHARE) is developed.

As will be seen, the EUROCONTROL's programme places considerable 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 programme are :

- Improvement of the surveillance system (Mode S).
- Improvement of Air/Ground communications (Automatic data link).
- Increased automation.
- Improvement of evaluation methods by recourse to a realistic representation of the airborne side.

Reference 13F

LE CONCEPT DU FUTUR SYSTEME ATS EUROCONTROL

et

LE PROGRAMME D'ETUDES, ESSAIS ET EXPERIMENTATIONS

par

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RESUME

L'ère des développements parallèles et non concertés des systèmes au sol et de l'avionique de guidage, de navigation et de communications est révolue. La recherche de conditions d'exploitation économique optimales d'une part, et la nécessité de faire face à un trafic croissant d'autre part, imposent aux responsables de la Gestion du Trafic Aérien des solutions qui marient harmonieusement les technologies disponibles au sol et à bord. Une concertation étroite entre le pilote et le contrôleur constitue une des clefs de voûte des systèmes futurs.

Accroître la capacité et l'efficacité de la gestion du trafic tout en respectant les impératifs de sécurité, n'est possible que par un recours plus intensif à l'automatisation dans les fonctions de planification du contrôle. Il est considéré que l'automatisation ne peut apporter un bénéfice réel que si la précision dans la prédiction de la trajectoire de l'avion est fortement améliorée.

Cet aspect a bien été mis en lumière dans la description du concept ATS futur élaboré par l'Organisation EUROCONTROL. Ce concept, approuvé sur le plan des principes par la Commission des Ministres d'EUROCONTROL en juillet 1987 sera présenté dans ses grandes lignes.

Sa mise en oeuvre implique un certain nombre d'études et expérimentations. Le programme d'EUROCONTROL sera passé en revue. Par ailleur l'idee d'un Programme harmonisé de recherche "ATM" (PHARE) est évoqué.

On verra que le programme d'EUROCONTROL fait une large place à l'analyse des conditions à réunir pour que les systèmes au sol puissent disposer dans l'avenir des moyens permettant d'acquérir et d'exploiter les paramètres du vecteur d'état de l'avion.

Les points clefs du programme sont:

- L'amélioration du système de surveillance (Mode S).
- L'amélioration des communications Air-sol (Liaison automatique de données).
- L'augmentation de l'automatisation.
- L'amélioration des méthodes d'évaluation en faisant appel à une représentation réaliste de la partie "air".

PART IV-C - ON-LINE PREDICTION OF AIRCRAFT TRAJECTORIES

(I) GENERAL DISCUSSION

(II) FUNDAMENTALS

(III) APPLICATIONS

Reference 14

PREDICTION OF AIRCRAFT TRAJECTORIES

by

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SUMMARY

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 behaviour, often on "worst-case" assumptions, of each class of traffic with which they may have to deal. The present paper will concentrate on the problems 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 will be briefly discussed in what follows, as will the problem of terrain-following by high performance low-flying military aircraft. The conclusion will draw attention to areas where further R & D would seem desirable.

Reference 15

AIRCRAFT DYNAMICS FOR AIR TRAFFIC CONTROL

by

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SUMMARY

This paper presents the equations of motion of airplanes with special emphasis on the kinematical description of the trajectory. The various concepts introduced in ISO norms are presented from a dynamical point of view. The equations are obtained in a form which can easily be implemented in a simulation programme. Furthermore, various approximations are presented together with their implications on the dynamics, and the limitations of their application.

Reference 16 **THE APPLICATION OF TRAJECTORY PREDICTION ALGORITHMS FOR PLANNING PURPOSES IN THE NETHERLANDS ATC-SYSTEM**

by

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SUMMARY

The paper first describes briefly some relevant aspects of the Netherlands ATC-environment, it then gives the basic set-up of the trajectory prediction module, the improvements that have been realised so far and the performance figures. Furthermore it lists the applications of the trajectory prediction results in the system. Some of these applications such as data distribution rules, presentation of Estimated Times of Arrival (ETA's), Boundary Estimates etc. are only briefly mentioned. Others are given more attention; among these are: 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.

Reference 17 **GENERATION OF AIRCRAFT TRAJECTORIES FOR ON-LINE OPERATION**
Methods - Techniques - Tools

by

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SUMMARY

An appreciable amount of work has been conducted within the Engineering Directorate of the Agency in the division responsible for the Study of Long-Term ATC System Requirements, in order to generate accurate aircraft trajectory predictions for use in both ATC real-time simulations and on-line operation, in current and most realistic conditions, human interfaces included.

This paper will outline two basic approaches developed for two distinct classes of application : on the one hand, the on-line generation of predictions for use in actual operation and accessorily for real-time ATC simulations, on the other the introduction of realistic response and motion of aircraft in ATC simulations with pilot/auto-pilot interfaces included.

PART IV-D - AIR TRAFFIC MANAGEMENT

(I) OPTIMISATION : MODELS AND TECHNIQUES
(II) MAN/COMPUTER INTERFACE

Reference 18

OPTIMISATION MODELS AND TECHNIQUES TO IMPROVE AIR TRAFFIC MANAGEMENT

by

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SUMMARY

In this paper a survey of earlier works of our is given with particular emphasis on optimisation models and solution techniques. Firstly, in section 2, a multilevel model of the different ATC functions is proposed. Then, in the successive sections 3, 4 and 5 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 optimisation model is established and a solution technique is illustrated. The numerical behaviour is also discussed.

Reference 19

THE HIGH-RESOLUTION GRAPHIC DISPLAY :
A possible man/machine interface for a computer assisted ATC management system.

by

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SUMMARY

This article describes an application 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 we employ a graphic rectangular display 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 colour 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.

RESUME

Cette communication traite d'une application des écrans graphiques à haute résolution dans le domaine de la gestion et du contrôle du trafic aérien dans une vaste zone comprenant un aéroport important, le rayon de cette zone variant de 150 à 300 miles nautiques.

Les aspects de la gestion du trafic aérien et les techniques de guidage et de contrôle 4D pour chaque avion sont ici appliquées dans une Zone de Convergence. (concept ZOC) Il faut cependant garder à l'esprit que les techniques graphuques employées peuvent être appliquées à tous les sytèmes apportant une aide au contrôleur au niveau décisionel.

L'écran choisi pour la presentation des données au contrôleur est de forme rectangulaire, a une résolution de 1280 par 1024 points et peut presenter 16 couleurs. Un écran de forme circulaire similaire à la plus part des écrans radar actuellement en service peut evidemment être employé pourvu qu'il ait une résolution et des possibilités de couleur semblables.

Les directives de gestion du trafic et de conduite des vols sont présentées à l'operateur, qui peut être le gestionnaire de la zone ou le contrôleur d'un secteur, sur l'écran radar même intégrées dans l'étiquette de l'avion : cette approche ne nécessite aucun écran tabulaire supplementaire.

PART V - GUIDANCE OF AIRCRAFT IN A TIME-BASED CONSTRAINED ENVIRONMENT

A - CONTEXT - OBJECTIVES - PLANS

B - GENERAL DISCUSSION

C - GUIDANCE AND CONTROL : PRINCIPLES AND CONCEPTS

D - CONDUCT OF AIR TRAFFIC CONTROL IN A ZONE OF CONVERGENCE

E - GROUND-BASED 4-D GUIDANCE OF AIRCRAFT IN MOVING ATMOSPHERE

F - THE COMPUTER/CONTROLLER/PILOT DIALOGS

PART V-A - CONTEXT - OBJECTIVES - PLANS

Reference 20E **4-D CONTROL OF CURRENT AIR CARRIERS IN THE PRESENT ENVIRONMENT**

Objectives - Status - Plans

by

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SUMMARY

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 has been 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. This paper concentrates on the 4-dimensional control of individual trajectories as applicable to current air carriers in the present environment, and directly adaptable to future automated air/ground digital communications.

The overall control loop has been 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.

Reference 20F **REGULATION 4-D DANS L'INFRASTRUCTURE ACTUELLE**

Point de la situation et objectifs à atteindre

par

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SOMMAIRE

Le contrôle précis de l'heure d'arrivée des vols sera un élément essentiel de la régulation efficace du trafic aérien au double plan de l'économie du transport et de la capacité de prise en charge. Une technique a été mise au point pour déterminer efficacement et contrôler avec précision les trajectoires d'arrivée aux aéroports de moyenne à forte activité.

Le sélection des trajectoires porte sur l'ensemble du trafic en fonction du critère que retiennent les compagnies ou les pilotes, à savoir coût, consommation de carburant ou temps de vol; le contrôle intervient ensuite, avec les éléments "sol" et "air" opérant en synthèse et les corrections de "vitesse et/ou de "route" appliquées chaque fois que cela est possible. Le présent exposé s'attache au contrôle 4-D de chaque trajectoire applicable aux avions de transport actuels utilisant l'infrastructure existante, lequel est directement adaptable aux communications air-sol numérisées de demain.

L'ensemble de la boucle de contrôle a fait l'objet de simulations en un environnement représentant en particulier la configuration de l'espace aérien belge, avec utilisation de divers simulateurs de vol et conjointement avec des pilotes de ligne et des contrôleurs de la circulation aérienne. Sur la base des résultats enregistrés à ce jour, on pourrait envisager dans un proche avenir des essais "on line" qui permettraient d'obtenir une précision de 10 secondes au seuil de piste pour les avions commerciaux actuels.

Reference 21

NAVIGATION 4-D EN CIRCULATION AERIENNE

par

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SOMMAIRE

Historique et Principe de la Navigation 4-D

Partant de la constatation que les délais d'attente avant atterrissage sont croissants alors que les cadences maximales possibles ne sont pas atteintes, on a proposé d'introduire une consigne supplémentaire lors de la procédure d'approche consistant en 2 corrections de vitesse et une correction de cap (Nav. 4-D, D pour dimension).

Le premier problème à résoudre fut le choix du modèle mathématique à adopter pour simuler l'avion. La méthode utilisée consistait à partir d'un modèle "le plus complet" (on est parti d'un modèle du 18e ordre) et à le dégrader jusqu'à ce qu'un critère ne soit plus satisfait. Ce critère consistait à mesurer l'erreur entre le modèle complet et le modèle dégradé sur une trajectoire de référence (approche Roissy) longue de 54 km. On admettait que l'erreur apportée par le modèle dégradé ne devait pas atteindre ± 320 m à la balise d'entrée de l'ILS. Un modèle de 6e ordre convenait.

Après un certain nombre de simulations il a été montré que les corrections devaient se placer après l'entrée dans la zone de contrôle (zone de convergence) sur le vol à niveau constant (correction de vitesse), au milieu de la descente effectuée à vitesse indiquée constante (correction de vitesse) et dans la dernière branche avant l'interception de l'ILS (correction de cap).

Par une méthode d'ordonnancement on peut, grâce à l'utilisation du modèle utilisé en temps accéléré, affecter un instant de passage optimal à la balise d'entrée de l'ILS, en vérifiant qu'une telle trajectoire peut être obtenue par un "pilotage aisé" (termes qui seront définis dans l'article). Bien entendu, un modèle de l'atmosphère doit être utilisé; on a vérifié que la sensibilité de la méthode proposée par rapport à ce modèle n'était pas critique. On a également vérifié que l'erreur sur le passage à la balise due à l'incertitude sur la masse de l'avion à sa prise en compte n'était pas critique.

Résultats de simulation et mesures en vol

On a comparé par simulation les dispersions des instants de passage à la balise sans correction et avec correction. Pour ce faire le pilote était simulé par les erreurs qu'il introduisait dans le pilotage (erreurs définies stochastiquement par rapport à la "procédure compagnie"); les corrections étaient calculées par l'erreur constatée aux 3 points indiqués précédemment et étaient quantifiées (corrections non inférieures à 5 kts) puis retardées pour tenir compte des délais de transmission.

Sur un lot de 200 simulations on a constaté une division par 3 de l'erreur quadratique moyenne des instants de passage à la balise lorsque les corrections étaient envoyées à l'équipage (9 s au lieu de 27 s), toutes autres conditions étant égales par ailleurs.

Grâce à la collaboration de la compagnie Air Inter, 4 expérimentations en vols réguliers ont été faites. les corrections étaient données à bord, grâce à des tables pré-établies et à l'aide du contrôle sol pour les positions exactes de l'avion. Après analyse des résultats et corrections dues au vent, les résultats obtenus par simulation ont été confirmés.

Le NASA/Langley a de son côté repris la même méthode (deux corrections de vitesse et une de cap) et a procédé à des simulations (approche Denver, Colorado; avion B737) qui ont confirmé nos premiers résultats (un rapport commun NASA/CERT a été publié).

Perspective pour un ordonnancement temps réel

Dès leur origine nos études ont été suivies par EUROCONTROL et sur contrats de cet organisme nous avons pu étudier des procédures optimales de descentes pour des avions réels (B727; B737, DC10, Caravelles 12, A300) en tenant compte des contraintes réelles d'aéroport (Bruxelles, Londres, Francfort). Les lois de descente devaient minimiser le temps total de circulation des avions et la consommation totale de carburant dans la zone de convergence. La prise en compte d'un nouvel avion dans la zone, oblige à reprendre l'ordonnancement et les instants de passage à la balise. Les algorithmes proposés sont décrits.

Avenir

Les études initiales dates de 1975-77 ; elles restent valables aujourd'hui et des expérimentations du trafic réel sur des algorithmes mis au point par EUROCONTROL (voisins de ceux proposés) vont avoir lieu prochainement à Bruxelles.

Cependant le développement des FMS conduit à poser le problème en de nouveaux termes : il y a mélange de 2 catégories d'appareil. Le "pilotage aisé" mentionné au paragraphe 1 sera confirmé pour les avions non munis de FMS. Par contre ceux munis de FMS pourront recevoir une seule information, celle du passage à l'heure à la balise après calcul par le "contrôle sol" (ATC). Le FMS, possédant un modèle de l'avion, doit pouvoir retrouver la solution indiquée par le sol. Mais la solution peut ne pas être unique, aussi est-il nécessaire d'assurer la conformité des 2 trajectoires (celle calculée au sol et celle restituée par le FMS) par l'envoi de paramètres supplémentaires.

L'usage d'une transmission automatique air-sol sol-air s'impose.

PART V-B - GENERAL DISCUSSION

Reference 22 **ON THE AUTOMATION OF FUTURE ATC CENTRES IN THE LIGHT OF THE CONCEPT OF THE "ZONE OF CONVERGENCE"**

by

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INTRODUCTION

Describes the Zone of Convergence concept briefly and its potential benefits.

ASPECTS OF SOFTWARE AT ATC CENTRES

Automated assistance will be required by ATC controllers engaged in sequencing arrivals in a Z.O.C. Important sub-routines are the aircraft performance model and the Conflict Detection process.

The Aircraft Performance Model

This is a model to predict the 4D profile of an aircraft for a given pilot (or autopilot) inputs. Once the model is developed, it is a trivial problem to enhance it so as to answer the reverse question : what pilot input is necessary to achieve a desired profile, specifically to achieve a stated gate time. The output from this process forms the basis of the ATC instructions given to the pilot.

Conflict Detection and Resolution

Having estimated the arrival profiles of a number of aircraft which give the correct sequence at the "gate", they should be further checked for infringement of separation standards along their length. Where such conflict exists, the corresponding profile must be modified to remove the conflict and still, hopefully, achieve the correct time at the gate.

INPUTS REQUIRED FOR THE SEQUENCING PROCESS

The basic aerodynamic or performance information on each type of aircraft must be obtained from the manufacturers, hopefully, in a standard format, for insertion into the aircraft performance model. Other, more transient inputs are :

Meteorological

Up-to-date wind, and perhaps temperature information covering the "playing area". Direct measurement from aircraft is preferred - forecasts may not be accurate enough.

Information on the Aircraft's Intentions

Flight Plan information, suitably updated, intended flight levels, speeds, way-points etc.

METHODS OF COMMUNICATION

These include both air to ground and controller to computer (man-machine interface or MMI)

Air to Ground

It is desirable for reduction in both workload and RT loading that, as much as practicable, communication air to ground should be by data-link (Mode S or satellite). The order of implementation of data-link facilities is likely to be: first ground data held in store (VOLMET etc) ground to air, then ambient meteorological data air to ground, then data on the current state of the aircraft (content of Flight Management Systems) air to ground and finally executive ATC instructions ground to air.

MMI

Possible modes of rapid insertion of updated information to the computer include Direct Voice Input as well as more conventional means.

SUMMARY AND CONCLUSIONS

This would include comments on the potential benefits and likely time-scales of the projects considered. Attention would be drawn to the need for developments to proceed in step with each other and to the need for proper validation before operational service.

PART V-C - GUIDANCE AND CONTROL : PRINCIPLES AND CONCEPTS

Reference 23E

THE CONTROL OF INBOUND FLIGHTS
Principles

by

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SUMMARY

This paper describes the basic principles of the method developed to guide aircraft accurately down to the runway in a time-of-arrival constrained environment. The method is to be used in a Zone of Convergence context or in any similar advanced ATC system characterized by the integration of control phases over an extended area on the one hand and a true "computer assistance" to the air traffic controller on the other, that is to say an assistance given at the decision level through the automatic generation of guidance directives.

The method includes two basic components closely coupled, namely a "predictor" which computes a trajectory once initial conditions and plans are known and a "controller" 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.

Reference 23F

LE GUIDAGE DES VOLS A L'ARRIVEE
Principes généraux

par

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SOMMAIRE

Cet article décrit les principes fondamentaux de la méthode mise au point pour le guidage précis des avions jusqu'aux pistes dans le cas où les temps d'atterrissage sont imposés. Cette technique de guidage sera utilisée dans un contexte ATC du genre Zone de Convergence à savoir un système caractérisé par l'intégration des phases de contrôle sur une distance relativement importante d'une part, et par une véritable assistance au contrôleur de la circulation aérienne d'autre part, cette assistance au niveau décisionnel comportant la génération automatique des directives de guidage.

La méthode de guidage proposée comprend deux fonctions fondamentales étroitement couplées ; l'une, la fonction "prédiction", calculant la trajectoire future sur la base des conditions initiales et plans actuels, l'autre, la fonction "guidage", déterminant les ordres de guidage sur la base de la position actuelle - données provenant du système de surveillance -, des procédures de conduite du vol propres à l'avion et des contraintes de route

Reference 24

GUIDANCE CONCEPTS FOR TIME-BASED FLIGHT OPERATIONS

by

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SUMMARY

Airport congestion and the associated delays are severe in today's airspace system and are expected to increase. The National Aeronautics and Space Administration in conjunction with the Federal Aviation Administration, 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. This paper presents the results 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.

Reference 25

4D DESCENT TRAJECTORY GENERATION TECHNIQUES UNDER REALISTIC OPERATING CONDITIONS

by

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SUMMARY

The NASA Langley Research Centre 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 utilises speed schedules of constant Mach number transitioning to constant calibrated airspeed chosen empirically to produce minimum fuel usage. The second technique computes cost optimised speed schedules of variable airspeed developed through application of optimal control theory. Both techniques have been found to produce reasonable and flyable descent trajectories. This paper evaluates the formulation of the algorithms for each technique and discusses their suitability for operations in realistic conditions. Operational factors considered include: airplane speed, thrust, and altitude rate constraints; wind, temperature, and pressure variations; Air Traffic Control altitude, speed, and time constraints; and pilot interface and guidance considerations. Time flexibility, fuel usage, and airborne computational requirements were the primary performance measures.

PART V-D - CONDUCT OF AIR TRAFFIC CONTROL IN A ZONE OF CONVERGENCE

Reference 26 EXPERT SYSTEMS FOR THE GENERATION OF TERMINAL AREA ARRIVAL PATHS FOR CIVIL TRANSPORT

by

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SUMMARY

There are efficiencies to be gained from scheduling 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 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" approach 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 is subject to rules and procedural limitations which can be easily specified and implemented by ATC controllers themselves, as desired.

The patterns always include a downwind, base, and intercept legs of varying lengths and locations, prior to merging with a "bubble" representing the scheduled position and speed of the arrival aircraft. Arriving aircraft are expected to conform to the early parts of the assigned arrival paths with a known accuracy which ensures safe separations. However, on the downwind and base legs, radar tracking of position, speed and direction is used to dynamically issue commands to turn to base and intercept legs, and to reduce to final approach speed on the intercept leg. The expert system ensures that patterns are selected with a sufficient number of radar scans to ensure steady-state tracking by the primitive straight-line trackers used in current ATC surveillance systems.

Reference 27 A DESCRIPTION AND EVALUATION OF "TIMER" -- A TIME-BASED TERMINAL FLOW-CONTROL CONCEPT

by

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and

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SUMMARY

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 approximately 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 expected-final-approach speed is known; however, the reduction is only in the region of 16 to 20 seconds if expected-final-approach speed is unknown. Another major finding is that en route metering fix delivery-error standard deviation should be kept to less than a number somewhere between 35 to 45 seconds to achieve full runway capacity. This requirement implies the need for either airborne automation or assistance to the controller since the current manual performance in today's en route metering environment is in the order of 1.5 minutes.

Reference 28

USE OF 4D RNAV IN TIME-BASED EN ROUTE ARRIVAL METERING

by

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SUMMARY

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 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. Special investigations have evaluated the use of clean-idle Mach/CAS, constant flight path angle Mach/CAS, and fuel optimal cruise/descent arrival profiles individually and in combination. Significant differences in these descent strategies only appear at high arrival rates.

A 4D RNAV capability is most easily achieved by "wrapping" a time-navigation capability around a 3D FMS. It is estimated that fifty percent of U.S. jet transports will have been delivered with a full 3D FMS by 1995 without any special effort to implement 4D RNAV ATC operations. Inclusion of systems such as performance management systems as candidates for 4D RNAV will bring this estimate well above fifty percent.

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 the National Aeronautics and Space Administration (NASA) Ames Research Centre. Meanwhile, Boeing on contract to NASA Langley Research Centre, used a fast-time simulation to show that even with a small percentage of equipped aircraft, the 4D RNAV user could expect a 4D RNAV clearance a high percentage of the time.

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. Eventually, the extension of 4D RNAV to the runway and 4D RNAV departures can increase airport capacity. ATC operational units have shown enthusiasm toward aircraft capable of precisely achieving assigned fix times. The key issue remains of how to get the jet transport fleet to equip so that 4D RNAV operations can grow.

Reference 29

AIR TRAFFIC MANAGEMENT AND AIRCRAFT GUIDANCE IN A ZONE OF CONVERGENCE

by

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SUMMARY

The basic principles of the air traffic management and the guidance of individual aircraft in a Zone of Convergence have been presented by the authors in previous papers at successive stages in the development of the project (1980, 1982, 1984, 1986). The subject is dealt with in general terms by V. Attwool in Section 5.2.

The purpose of this paper is to summarise these principles and to discuss the level of 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 for the community in terms of economy, use of available capacity and safety.

PART V-E - GROUND-BASED 4-D GUIDANCE OF AIRCRAFT IN MOVING ATMOSPHERE

Reference 30

GROUND BASED 4-D GUIDANCE OF FLIGHTS IN STRONG WIND

by

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ABSTRACT

In strong wind, the ground speed may vary appreciably over a turn as is the case for landing after a U-turn preceeding the localiser intercept. Such conditions are critical for maximum use of the runway and human estimation of aircraft motion then becomes extremely difficult.

This paper summarises the tests 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.

Reference 31

A PILOTED SIMULATOR EVALUATION OF A GROUND-BASED 4D DESCENT ADVISOR ALGORITHM

by

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SUMMARY

A ground-based, four-dimensional (4D) descent-advisor algorithm has been developed that combines detailed aerodynamic, propulsive, and atmospheric models with an efficient numerical integration scheme to generate fuel-efficient descent advisories. This paper investigates the ability of the algorithm to provide advisories for controlling arrival time of aircraft not equipped with on-board 4D guidance systems. A piloted simulation was conducted to determine the precision with which the algorithm predicts the trajectories of typical straight-in descents flown by airline pilots under different wind conditions. The effects of errors in the estimation of winds and initial aircraft weight were also evaluated. A description of the algorithm as well as the results of the piloted simulation are presented.

PART V-F - THE COMPUTER/CONTROLLER/PILOT DIALOGS

Reference 32E

THE AIR TRAFFIC CONTROLLER FACING AUTOMATION: CONFLICT OR CO-OPERATION

by

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and

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SUMMARY

Today, developments in ground-based and on-board computers, navigation and digital air/ground/air communications make it possible to envisage 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.

Its inherent benefits for the overall community may be refused and lost for a long period; in contrast, it may contribute to the production of more sophisticated and powerful tools and assist the controller in achieving a degree of efficiency which he could never have dreamed of before. What is it which will tip the scales in favour of one or the other option?

This subject will be 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 paper will cover the essential aspects of the computer/controller/pilot/aircraft chain of dialogues, placing the emphasis on the connivance between the computer and the controller, the intelligent interpretation of the surveillance information by the computer, the definition and generation of guidance directives, their relay to the pilot and finally, the use of navigation aide.

The paper concludes by showing the integration of the ground-based 4-D guidance and control system messages on a standard ATC radar display, illustrating this for the guidance of flights conducted by SABENA crews operating B-737 and DC-10 aircraft.

Reference 32F **LE CONTROLEUR DE LA CIRCULATION AERIENNE ET L'AUTOMATISATION :**

CONFLIT D'INTERETS OU CONVERGENCE ?

par

André Benoît et Sip Swierstra

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SOMMAIRE

Les progrès réalisés dans le domaine de l'ordinatique aéronautique (qu'il s'agisse de l'infrastructure au sol ou de l'élément embarqué), des systèmes de navigation et des télécommunications numérique air-sol-air nous autorisent à imaginer pour "demain" un processus de contrôle de la circulation aérienne hautement automatisé pour autant que dans toutes les éventualités - même dans les moins probables - la fiabilité, la sécurité et la stricte délimitation des responsabilités soient totalement garanties.

Mais bien avant cela, nos cieux auront été traversés d'innombrables vols que les contrôleurs de la circulation aérienne auront pourtant dû prendre en charge sans l'aide de ces techniques de pointe. Entre-temps, toutefois, les possibilités qu'offre l'automatisation ne cesseront de croître.

On pourrait certes vouloir se passer des avantages intrinsèques qu'elle présente pour toute la communauté aéronautique, mais on en perdrait alors le bénéfice pour longtemps; à l'opposé, on peut en tirer parti pour l'élaboration de moyens plus perfectionnées et plus puissants et aider ainsi le contrôleur à atteindre un niveau d'efficacité dépassant tout ce qu'il aurait pu concevoir.

Quel est donc l'élément qui déterminera le choix de l'une ou l'autre option?

Tel est précisement le problème que nous nous proposons d'aborder ici, à la lumière de l'expérience acquise dans la mise au point, l'évaluation et la mise à l'épreuve, en conditions réelles d'exploitation, d'une procédure qui permet de guider les aéronefs sur des trajectoires quadridimensionnelles et qui est représentative de la prochaine génération de systèmes ATC. Nous décrirons par ailleurs les principaux aspects des maillons calculateur/contrôleur/pilote/aéronef constitutifs de la chaîne du dialogue (en nous attachant particulièrement à l'alliance ordinateur-contrôleur), l'interprétation intelligence, par l'ordinateur, des informations destinées à la surveillance, la définition et la production de directives de guidage, la transmission de celles-ci au pilote et, enfin, l'emploi des aides à la navigation.

Dans la conclusion, nous montrons comment on intègre les messages du système sol de guidage et de contrôle quadridimensionnels au dispositif sur les écrans standard de visualisation radar dont sont dotés les services ATC; les exemples choisis pour les besoins de la démonstration sont des vols exécutés par des équipages de la SABENA sur B-737 et DC-10.

PART VI - SURVEILLANCE

A - RADAR TRACKING

B - SATELLITE TECHNIQUES

PART VI-A - RADAR TRACKING

Reference 33

AIRCRAFT TRAJECTORY RECONSTITUTION

on the basis of

MULTI-RADAR PLOT INFORMATION

by

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SUMMARY

A short description of the various techniques in use for the establishment of aircraft reference trajectories is presented. Then adescription of the principles and operation of the EUROCONTROL program MURATREC (Multi-Radar Trajectory Reconstitution) follows, covering in particular :

- estimation of systematic radar errors ;
- curve fitting by the use of B-splines and dynamically adaptable spline steps ;
- accuracy of the reconstructed positional information ;
- reconstitution of altitude, accelerations and speed.

Applications of the Muratrec program are outlined, including (a) application for the analysis of radar plot and track accuracy (examples) and (b) possible applications for incident investigations, on-ligne alignment of multi-radar information and simulation of aircraft trajectories in a given radar environment.

Reference 34

BAYESIAN MULTI-SENSOR TRACKING FOR ADVANCED AIR TRAFFIC CONTROL SYSTEMS

by

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SUMMARY

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 non-linear dynamics, Probabilistic Data Association for unassociated measurements and Interacting-Multiple-Model filtering for sudden manoeuvres.
Comparisons of this new tracking system with α-β, 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 wit. the many uncertainties that are inherent to air traffic.

The results in this paper were obtained partly under contract with the Dutch Organization of Civil Aviation (RLD).

Reference 35 **THE USE OF DOWNLINKED MEASUREMENTS TO TRACK CIVIL AIRCRAFT**

by

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SUMMARY

This paper describes the use 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 SSR mode S data link.

First the widely used α-β filter and the first order Kalman filter are reviewed. Next the problem of maneuver handling is described and it is established that significant improvements, in terms of tracking accuracy, are expected when t.. cking 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, the filters reduce to a particulalry simple form, that may be regarded as an enhanced α-β filter.

The performance of the filters is evaluated using data recorded during normal scheduled services.

PART VI-B - SATELLITE TECHNIQUES

Reference 36

L'APPORT DES TECHNIQUES SATELLITAIRES A LA SURVEILLANCE DE LA NAVIGATION AERIENNE

par

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RESUMÉ

La mise en oeuvre des satellites pour les communications, navigation et surveillance de l'aviation a été étudiée et a commencé à être planifiée par l'Organisation de l'Aviation Civile Internationale qui a créé le comité spécial Future Air Navigation Système (FANS) à cet effet. Ce comité vient de rendre son rapport final. La note présente ses travaux et analyse les conséquences de l'introduction des satellites dans le cas particulier de la surveillance du trafic. L'élément le plus important sera la "surveillance dépendante automatique" (ADS) qui consiste en une retransmission automatique de l'avion vers le sol de divers paramètres mesurés à bord, principalement sa position telle qui fournie par les moyens de navigation de l'appareil. Ce système permettra un contrôle bien plus efficace dans les zones sans infrastructure sol. Dans les zones continentales à fort trafic, les satellites ne substituent pas au radar secondaire, cependant les nouvelles techniques permettront plus de souplesse dans la conception de l'infrastructure.

Reference 36

CONTRIBUTION OF THE SATELLITE TECHNIQUES TO THE SURVEILLANCE OF AIR TRAFFIC

by

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SUMMARY

The International Civil Aviation Organisation asked a special committee FANS (Future Air Navigation Systems) to study satellite system implementation for communication navigation and surveillance applications. This committee issued recently its final report. The paper presents FANS work and analyses the consequences of satellite system implementation upon 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 is to allow 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.

PART VII - METEOROLOGICAL FORECASTS

IMPACT OF FORECASTS QUALITY ON TRAJECTORY PREDICTION

Reference 37

DEVELOPMENTS TO ENHANCE METEOROLOGICAL FORECASTING FOR AIR TRAFFIC SERVICES

by

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SUMMARY

In the future, the quality of the meteorological data available for use both in ground-based systems and on the aircraft will become even more important as ATC strives to handle increasing volumes of traffic in the most efficient manner.This paper, which deals primarily with European work, commences with an indication of the effect of errors in meteorological data on the precision of predictions of aircraft trajectories and then discusses the variability of wind and temperature, 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. A further short section describes the impact 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.The final section of the paper describes some of the experimental work either performed or being planned in the European area, aimed at improving the quality of the meteorological data available for ATS purposes as a result of using data recovered from aircraft through both satellite and ground-based (Mode S SSR) systems.

PART VIII - AIRCRAFT OPERATION IN AIR TRAFFIC HANDLING SIMULATION

A - REALISTIC OPERATION AND MOTION OF AIRCRAFT
B - FLIGHT OPERATIONS WITHIN A TERMINAL AREA

PART VIII-A - REALISTIC OPERATION AND MOTION OF AIRCRAFT

Reference 38

INTEGRATION OF AIRCRAFT CAPABILITY in AIR TRAFFIC HANDLING SIMULATIONS

by

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SUMMARY

Incorporation of airline/aircrew/aircraft specific procedures and performances in simulations and operations of air traffic handling is a prerequisite for the next generation of management and control techniques. This matter is analysed in the light of the shortcomings inherent to the present situation to meet operators demand in terms of capacity and efficiency.

A practical approach is then proposed to include the operators (aircrew/aircraft/avionics) in the overall ground/air/ground control loop at the development, assessment, validation and real-time simulation levels.

As an illustration of the potential offered, this approach is followed to assess a ground/air coordinated 4-D guidance technique, and the results obtained are presented.

PART VIII-B - FLIGHT OPERATIONS WITHIN A TERMINAL AREA

Reference 39

SIMULATION OF AUTOMATED APPROACH PROCEDURES CONSIDERING DYNAMIC FLIGHT OPERATIONS

by

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SUMMARY

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.

Purpose of the fast-time air traffic simulations performed at the Technical University of Berlin, was to analyze and assess the performance and the practicability of automated time-based approach concepts, currently being 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 specified 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 responsibility for profile control.

Being a typical representative of an airport with capacity problems the terminal scenario of Frankfurt/FRG has been taken as data base for the developed simplified model TMA. The layout of the different scenarios (e.g. configuration with navigation systems) was chosen on the basis of requirements for future terminal navigation previously derived from results of a simplified macroscopic Monte-Carlo simulation. TASIMD is written in FORTRAN and kept as general as possible to allow similar investigations for almost any future terminal scenario.

Generally, the analysis indicated the practicability of applying automated terminal procedures based on a shared air/ground responsibility. In order to adapt such concepts to a real environment, however, many details as e.g. emergency procedures or procedures for aircraft with less sophisticated equipment, have to be considered. The analysis of such questions which would require real time simulations in cooperation with pilots and controllers, however, goes beyond the scope of TASIMD.

PART X

Bibliography

A — Glossary
B — Reference
C — Index

PART X-A - GLOSSARY

GLOSSARY

This glossary lists the abbreviations currently used for the names of institutions and the titles of journals and reports frequently cited in the bibliography.

AFNOR	Association française de normalisation Tour EUROPE, CEDEX 7, F - 92080 Paris
AGARD	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organisation, 7, rue Ancelle, 92200 Neuilly-sur-Seine, France
AIAA J	Journal of American Institute of Aeronautics and Astronautics, 1290 Avenue of the Americas, New York, NY-10019, USA
DFVLR	Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, Flughafen, Institut für Flugmechanik, 3300 Braunschweig, R.F.A.
EUROCONTROL	European Organisation for the Safety of Air Navigation, 72, rue de la Loi, B-1040 Bruxelles
FAA	Federal Aviation Administration, Washington, DC-20-590, USA
FFA	Flygtekniska Försöksanstalten The Aeronautical Research Institute of Sweden, Stockolm
IEEE	Institute of Electrical and Electronics Engineers, New York
JA	Journal of Aircraft
JAS	Journal of the Aeronautics Sciences
JGC	Journal of Guidance; Journal of Guidance and Control; Journal of Guidance, Control and Dynamics
JSR	Journal of Spacecraft and Rockets
MIT	Massachusetts Institute of Technology, Cambridge
NASA	National Aeronautics and Space Administration Washington, DC-20-546, USA
NLR	National Aerospace Laboratory, P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
RAE	Royal Aircraft Establishment, Farnborough, England
SAE	Society of Automative Engineers, Warrendale, PA, USA
UTIAS	Institute for Aerospace Studies University of Toronto, 4925, Dufferin Street, Downsview, Ont. Canada, M3H 5T6

Subjects

(ACP)	Aircraft Performance Evaluation
(ATM)	Atmospheric and Meteorologic Sciences (see also (WND))
(CST)	Computer Simulation / Prediction Techniques
(EMY)	Economy Aspects / Fuel Savings / Noise
(FOP)	Flight Optimization
(GEN)	General Considerations
(HSC)	Handling, Stability and Control
(LDG)	Approach and Landing / Miscellaneous
(MEQ)	Flight Mechanics / Equations of Motion
(NCG)	Navigation Control and Guidance
(RFI)	Research Facilities and Instrumentation
(RRP)	Rules, Regulations and Procedures
(SIM)	Simulation, Flight simulators
(TCS)	Traffic Control Systems / Strategies
(WND)	Wind Impact on Aircraft Motion (see also (ATM))

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B I B L I O G R A P H Y

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INDEX OF CONTRIBUTORS' NAMES

This index presents in alphabetical order the names of the authors of contributions to this AGARDograph. For each author, it gives the reference of the paper (Ref.) and the affiliation as listed in Part XI-A (Loc.).

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Computation
Prediction
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Abstracts
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AGARDograph No.301 Volume 3
Advisory Group for Aerospace Research and Development, NATO
AIRCRAFT TRAJECTORIES: COMPUTATION — PREDICTION — CONTROL. VOLUME 3
Edited by André Benoit
Published May 1990
158 pages

This volume — part of a set of three — is composed of a short introduction, a Book of Abstracts of the 39 papers included in the overall work, an extensive Bibliography which incorporates, in particular, most of the references cited by the 56 authors and co-authors, and a List of Contributors ordered by countries alphabetically.

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