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RNAV APPLICATION IN TERMINAL AIRSPACE

- AN ATC OPERATIONAL PERSPECTIVE -

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THIS DOCUMENT IS FOR INFORMATION PURPOSES ONLY AND DOES NOT SET RULES FOR TERMINAL AIRSPACE RNAV DEVELOPMENT AND/OR IMPLEMENTATION
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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

FOREWORD

This document constitutes a second effort at examining the application of RNAV in Terminal Airspace from an ATC perspective. Since its first edition in February 1998, more research, information and experience has been acquired so as to make this second edition more comprehensive.

As with its predecessor, the aim of this document is to examine, **from an ATC perspective**, the application of Area Navigation (RNAV) within Terminal Airspace. Because airspace design, associated procedures and operations are usually location specific and therefore depend on local requirements, this document does not attempt to provide a universal blueprint for application in Terminal Airspaces Europe-wide. Consequently, this document is intended primarily for use by ATS providers and would be of particular relevance to personnel involved in:

Airspace Policy, design, planning and organisation;

PANS-RAC Procedure Specialists

Air Traffic Controllers

Controller Training establishments

For ease of reading, the structure of this document is briefly detailed below:

PART I – Provides a high-level, general view on RNAV application in Terminal Airspace. The starting point is background and historical information on RNAV application, and this is followed by an explanation of what RNAV is – and what it is not. The benefits along with the potential impact of possible disadvantages are then assessed and the areas in which RNAV would find application in Terminal Airspace and ATC techniques are then listed. This Part of the document is finalised by noting that very ATC specific issues pertaining to RNAV application in Terminal Airspaces do exist – thus providing a lead in to Part II.

PART II – deals with the specific as opposed to general. The issues so addressed are grouped under the headings of *Human Factors, Legal Issues, PANS-RAC* and, to a lesser extent, *Harmonisation* and *Controller Training.* With some States already introducing their own RNAV operations (such as GPS-based procedures), it is important that, where possible, common standards are utilised throughout Europe.

PART III - draws conclusions from both Parts I and II.

Note: Whilst this document focuses almost entirely on RNAV application in an Approach **Radar** environment, it should be remembered that RNAV certainly also has applicability in the procedural environment.

PART 1 - A GENERAL VIEW

1.1 INTRODUCTION

Departure, Arrival, Approach and Missed Approach Procedures are designed to ensure the safe operation of aircraft, which are flown in accordance with the published requirements of the particular procedure. Up to now, these procedures have been based on the use of terrestrial source navigation aids (navaids) such as VORs, DMEs and NDBs, the availability and siting of which have frequently dictated procedure design parameters. In addition to producing less than optimum routeing in many instances, the given accuracy of the primary aid, VOR, is ± 5 ° (ICAO Annex 10), required large amounts of airspace being used by the actual tracks flown using this type of facility. The current procedures also assume that aircraft will be navigated by reference to primary instrument displays alone. Over the last 20 years or so, a growing percentage of the total aircraft fleet has been equipped with increasingly sophisticated Area Navigation equipment (RNAV). These aircraft, whilst still using inputs from existing navaids, are no longer constrained to use such aids in the traditional manner.

During the last 20 years, there has been a dramatic increase in the percentage of aircraft equipped with RNAV capability. These aircraft routinely fly conventional procedures (SIDS, STARS and Enroute) using RNAV navigation. Until recently, RNAV procedures had not been used in a systematic manner in Terminal Airspace[1]. As they are introduced, aircraft navigation performance (and ability to comply with controller instructions) should continue at the present levels or be improved (with properly designed RNAV procedures). The enhanced navigational accuracy and flexibility that RNAV capability affords may yield benefits when combined with well designed RNAV procedures and/or RNAV optimised control techniques. These gains may be achieved by:

- The airspace user (through improved operating techniques)
- The airspace designer (by optimising instrument approach and like procedures).
- The Air Traffic Management (ATM) service provider (through a more efficient operation of the ATM system using preferred flight paths and a potential increase in controller traffic handling capacity)
- The airport operators (by increased runway capacity and the improvement in community relations brought about by the containment or reduction of impact on the environment)

Until the first issue of this document, there was no overall concept to describe how RNAV Procedures could be employed in Terminal Airspace and what these consequent benefits would be. In addition, there are many issues which need to be addressed and analysed in the RNAV procedure development and implementation process in this airspace. Clearly, the transition to RNAV procedures is not going to be carried out in one large step.

[1]EUROCONTROL: ***Terminal Airspace Design, Guidelines for an Operational Methodology,*** *Doc. ASM.ET.1.ST06.* (Ed. 1.0, June 1998): **Terminal airspace** is a non-ICAO generic term used in this document. It describes airspace surrounding an airport within which air traffic services are provided. It encompasses all the various terminology currently used throughout the ECAC region. [Explanatory note: This term is aimed at including TMA, CTA, CTR, SRZ, ATZ airspace classification or any other nomenclature used to describe the airspace around an airport].

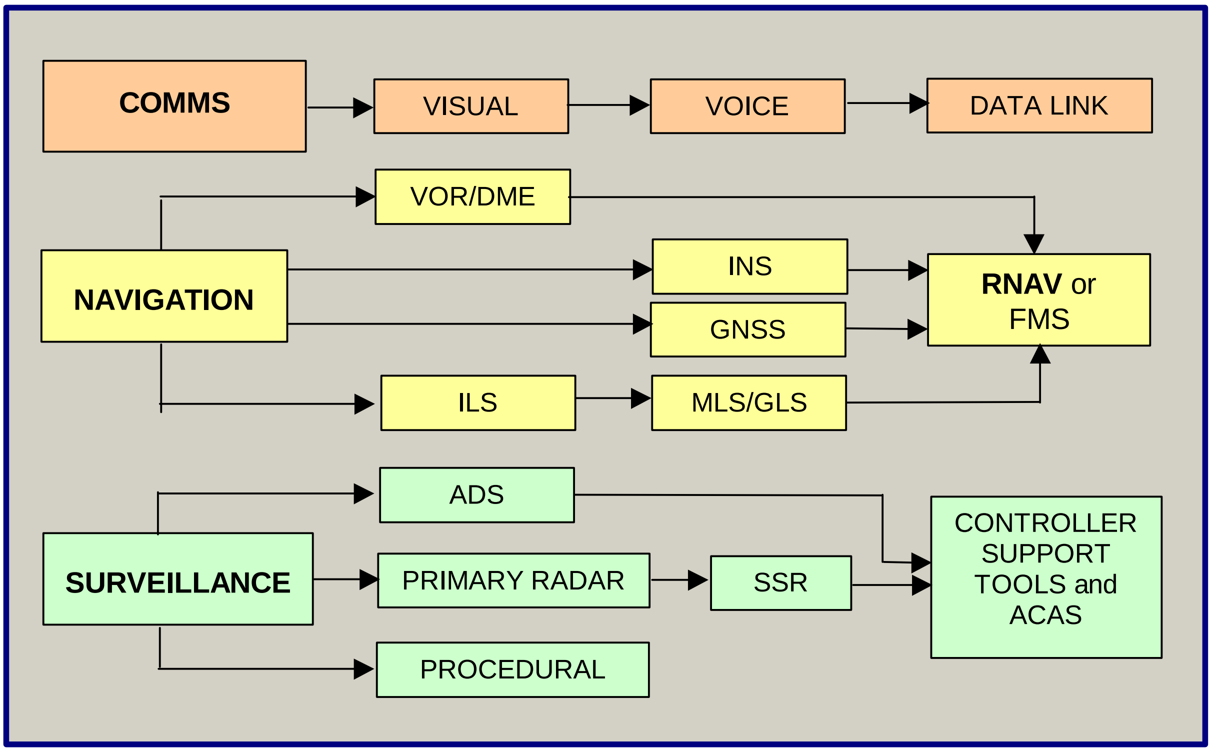
Implementation arrangements should ensure that both RNAV and conventionally equipped aircraft can be accommodated without significant penalty for either group. This may well be the most difficult balance to achieve, especially during the early phases of the transition when RNAV procedures are in the minority.

That the ATC system will adapt to change is inevitable. It has done so each time that controllers have been provided with the products of technological development. Controllers made the switch from Primary to Secondary Surveillance Radar and before that, they changed from Procedural control to the Radar control. The shift from procedural to radar control was momentous, allowing controllers to see their traffic and later, with SSR, obtain continuous aircraft identification.

New technology (see Figure 1-A) often results in controllers being able to handle more air traffic. Radar's introduction, for example, made it possible for traffic separation criteria to be reduced and controllers became able to provide navigational guidance to aircraft in the form of radar vectors. Very quickly, this became an accepted means of separating, sequencing and expediting the air traffic flow. As air traffic increased, this tactical use of radar became more fully exploited and in Europe's cluttered Terminal Areas of today, radar is extensively used by the controller as a tactical tool to expedite air traffic flows.

The significance of extending RNAV's application to Terminal Airspace is that the controller now has more tactical controlling aids available to him than previously, and the shift of emphasis to [pilot] self-navigation may have the result that Approach controllers might be able to reduce the frequency of their tactical intervention in the control of air traffic.

Figure 1-A: Changing Technology for the Controller



But what is area navigation or RNAV? This part of the document attempts to answer this and other more general questions. It examines the capabilities of current RNAV equipment, describes the operational tasks facing Air Traffic Control (ATC) in Terminal Airspace, and then correlates the capabilities of RNAV equipment with these ATC tasks. The possible benefits and potential disadvantages to ATC operations and controllers are then listed. It should be noted, however, that this list is not exhaustive and other specific benefits or disadvantages at particular locations may arise.

1.2 WHAT IS AREA NAVIGATION?

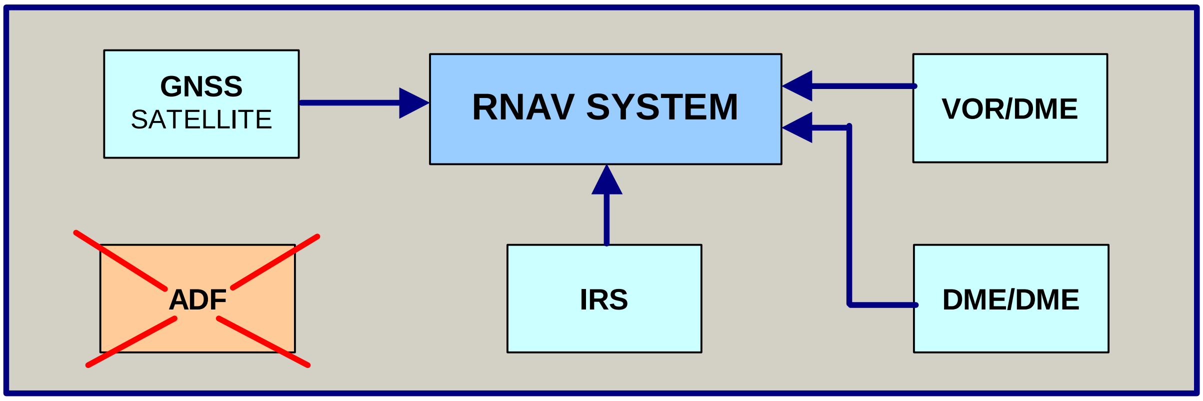
ICAO defines RNAV as: 'A method of navigation which permits aircraft operation on any desired flight path within the coverage of the station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.'[2]

An RNAV system can be viewed as a computer model which 'draws' a picture of the world and allows the placement of an aircraft's position on this 'model' world. In order to accurately place or locate the aircraft's position on this world model, the RNAV system automatically accepts inputs from various sources. These can be ground-based, satellite or airborne navigation aids or systems e.g. VOR, DME, GPS – see Figure 1-B. 3D position information can be obtained by , for example, use of four or more satellites. Importantly, the quality of the available Navaid structure will directly impact on the accuracy of the Nav solution. Thus a patchy Navaid environment might result in inconsistent navigation accuracy. Thus RNAV's 'challenge' can be said to be the accurate placement of the aircraft on its world model. However, the high quality of navigation based on RNAV is currently demonstrated world-wide by the large number of aircraft operating using RNAV on conventional routes.

1.2.1 RNAV Routes and Profiles

Not only is the RNAV system capable of locating the aircraft's position in its model world, but it also has the ability to compute distances along and across track – a feature that is particularly significant to the controller. This particular facility makes it possible for aircraft to 'self-navigate' along complex routes whose reporting points or significant points[3], need not be based on ground-navaids. An RNAV route is defined by a series of waypoints which may be a runway threshold, navaid location or a co-ordinate position.

Figure 1-B: Inputs to RNAV



The routeing element of RNAV, when translated to the approach environment, means that the first way-point[4] of an inbound RNAV route could be located at Terminal Airspace entry[5]

[2] ICAO***: Rules of the Air & ATS*, Doc. 4444-RAC/501** (13th Edition - 1996; Amendment 2, 1998) Definitions.
[3] ICAO: ***Air Traffic Services***, ***Annex 11*** (11th Ed.,1997) Appendix 2 & 3.
[4] A 'way-point' is a fix (which also may be a reporting point) that does not necessarily coincide with the location of a ground-based navigation aid. A way-point's location is determined by navigation source(s) referred to in the preceding paragraph.
[5] At a point which is part of the en-route structure.

and the last located at the Missed Approach Waypoint (MAWP) – see Figure 1-C. Over and above this, an altitude and airspeed requirement can be allocated to specific way-points

along an arrival/approach route – thus enabling the aircraft's self-navigation ability in the vertical plane and with speed control as well.

1.2.2 Navigation Accuracy (B-RNAV and P-RNAV) Dimensions

RNAV (aircraft) position information quality is dependent on two critical elements:

- The accuracy of the input sources to the RNAV system
- The navigation database being used by the RNAV equipment.

As regards input sources to the RNAV equipment, the accuracy provided by ADF is not sufficient for RNAV use. Similarly, position information provided by RNAV obtained from double DME will normally, depending on range from the facility, be more accurate than position information obtained from a combination of VOR/DME.

The navigation database is RNAV's second critical element. It contains latitude and longitude co-ordinate information[6] data on each way-point contained in the database. Data base service providers obtain this information from each State's Aeronautical Information Service (AIS), and then provide, update and maintain the databases used by the various RNAV systems.[7] Whilst the source information of actual data can be translated between the various databases furnished by the different providers, each RNAV system needs its database to be 'tailor-made' for its particular use which may also have specific needs of the end user imposed on it. Thus, although the 'pure' data might be the same, its interpretation and application by the different types of RNAV equipment may be different. Moreover, the way in which SIDs, STARs and Approaches are interpreted and coded may not be uniform. These differences, together with the possibility of data errors at source are the starting point of potential discrepancies and errors creeping into the application of RNAV. Controllers may have to deal with such errors, for example, when observing slightly different tracks being flown by several RNAV-equipped aircraft.

Of considerable importance to the controller is the navigation accuracy that can be expected from the RNAV equipment. B(asic)-RNAV defines European RNAV operations in the en route phase which satisfy a required track keeping accuracy of ± 5NM for at least 95% of the flight time. This level of navigation accuracy can be achieved by conventional navigation techniques based on VOR/DME.[8] P(recision)-RNAV on the other hand refers to a track keeping accuracy of 1NM or less. Although the parameters for Terminal Airspace operation have not yet been defined, it is likely that at least a minimum accuracy similar to or better than P-RNAV will be required in Terminal Airspaces.

Additionally, the extent to which the RNAV equipment is capable of being used is also important to the controller. For example, RNAV may be operated in 2-D (lateral plane only), 3D (which includes the vertical element), and 4D – time, which presupposes a common time base, data link communications, and fully automated sequencing managers for both Arrivals and Departures.

[6] These must conform to WGS84 standards.
[7] For example, Racal, Jeppesen etc; A 28-day cycle is usually required for database coding activity including any subsequent changes and notification.
[8] With various conditions.

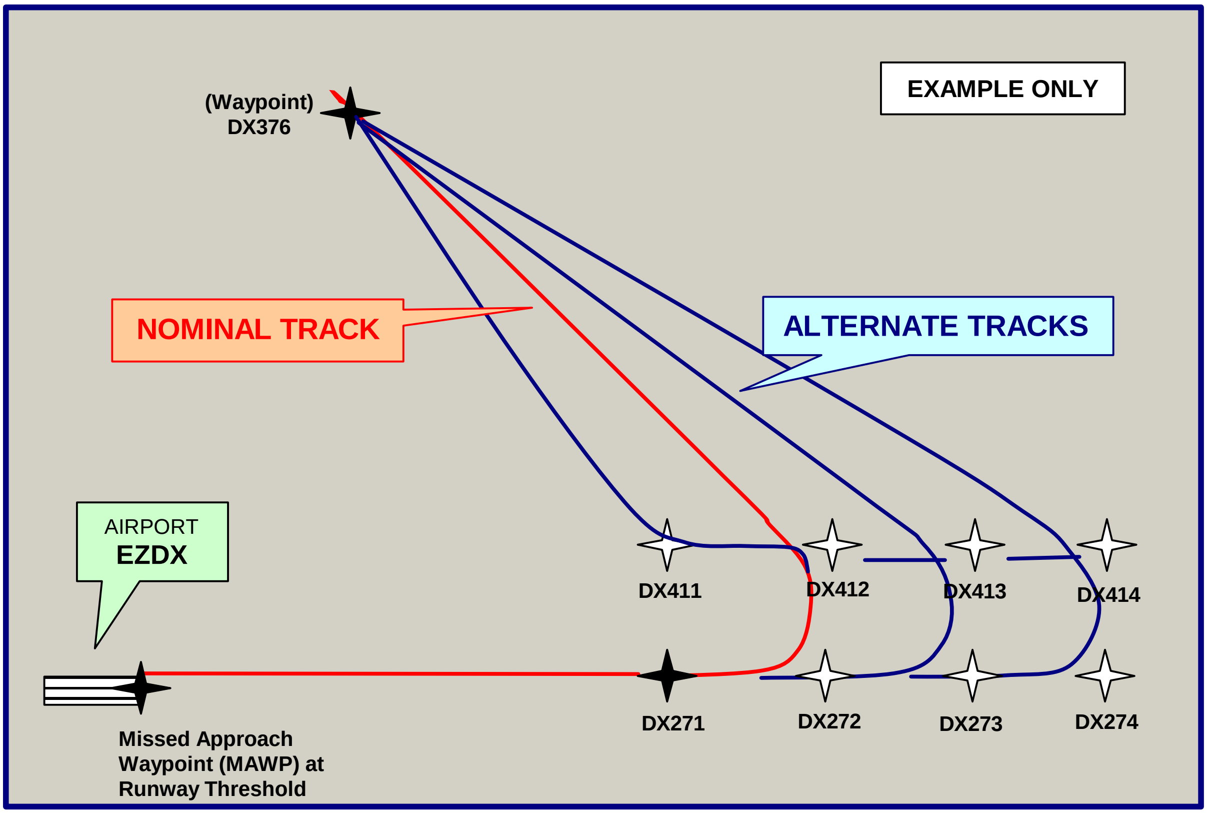
1.2.3 Using RNAV Procedures in Terminal Airspace

The facilities provided by RNAV, as described above, potentially translate into interesting possibilities for the Approach Radar Controller. Routes can be designed inside a Terminal Airspace along tracks which replicate existing vectoring patterns used by radar controllers.

Where traditionally only one arrival track might have linked a Terminal Airspace entry fix and a point on the down-wind or base-leg, several tracks can be designed from entry fix, fanning out towards various positions on the down-wind (or base-leg), giving coarse sequencing options. Arrival and departure tracks can potentially be separated laterally or vertically, although the separation criteria for Terminal Airspace still require redefinition.

Where currently, aircraft may be vectored while descending on a long downwind (with vector changes for different winds and drift with different aircraft speeds), RNAV permits direct tracking between two fixes with no heading adjustments.

Figure 1-C : Example of RNAV Routes inside Terminal Airspace



Potentially, the reduction of RTF workload and a more hands-off approach means a possible capacity enhancement in the Terminal Airspace (see also paras. 4 & 5). This may in turn require a review of ATC staffing levels, controller functions and airspace sectorisation. Appropriate continuation training on the re-defined tasks and education initiatives may be ways of easing the introduction of RNAV procedures.

1.2.4 The Flight Management System (FMS)

The interchangeable use of the terms RNAV and Flight Management System is common place and sometimes inaccurate. In an attempt to discourage this erroneous fusion of terms and any confusion which may arise as a result of this, a description of FMS is provided followed by a comparison between FMS and RNAV.

The FMS is an integrated system consisting of airborne sensor, receiver and computer with both navigation and aircraft performance databases. It provides performance and RNAV guidance to a display and automatic flight control system The FMS can be said to have four main functions viz.

- Navigation

  The navigation function in the FMS equates to the RNAV functionality. Usually multi-sensored, inputs can be accepted from various sources such as GPS, DME, VOR, ILS and IRS and some models can correct for IRS errors. Usually, FMS allows for high-accuracy navigation, and can provide for the detection and isolation of ‘faulty’ navigation information.

- Flight Planning

  Pre-defined company routes and lateral off-set routes can be flown using this function. The flight crew can create way-points and flight plan intersections can be obtained from a reference fix. e.g. radial and distance from fix. The possibility may exist for routeing from abeam a way-point direct to another point – a convenient feature if the aircraft is tactically re-routed by ATC. Wind data is retained and used in the flight planning calculations.

- Trajectory Prediction

  This facility allows for the rapid re-computation of trajectories for flight plan changes. Terrain obstacle avoidance may be provided. Some FMS can provided fully integrated navigation on both lateral and the vertical plane.

- Aircraft Performance Management

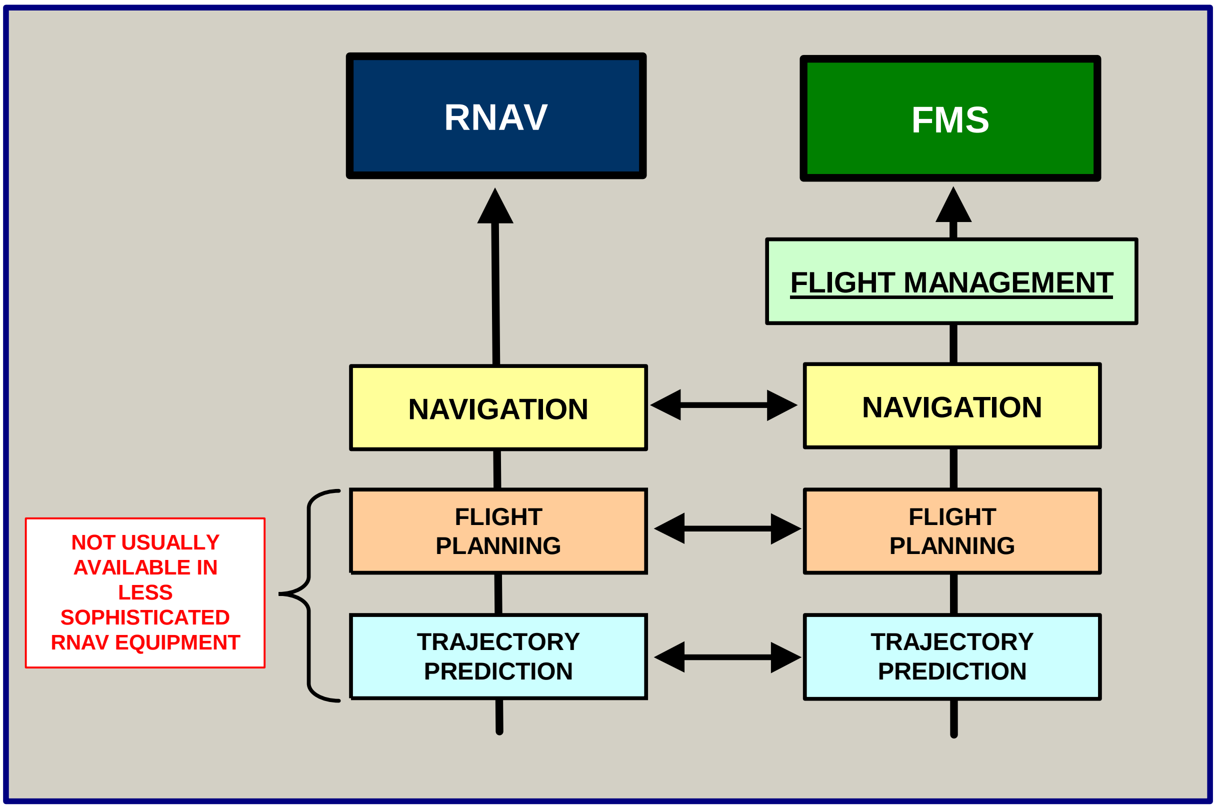
  The FMS’s flight management capability makes it possible to manage the way the aircraft is operated. Computers are able to compute, select and manage the flight as regards the most economically beneficial speed, rate of climb and turn. Safety is catered for – some Flight Management Computers, when coupled to the auto-pilot, will not let an aircraft stall, for example – and optimum economic performance becomes possible. The benefits envisaged could result in increased traffic.

1.2.5 Contrasting RNAV and FMS

An FMS is an RNAV system but an RNAV system is not necessarily an FMS. Thus in terms of providing assistance in aircraft performance, the FMS offers more to the pilot than RNAV does. An RNAV system is fundamentally a navigation system that does not include an aircraft performance component. The navigation function in most FMS equipment meets the B-RNAV requirement and is expected to comply with the more demanding P-RNAV conditions.

Controllers should expect slight variations in achieved tracks, both in the turn and on straight legs by a stream of aircraft carrying out the same RNAV procedure. This issue is being addressed in various forums which cover matters such as aircraft certification and the requirement for a set navigation performance accuracy. However, track dispersion will be significantly less than when flying conventional navigation techniques. Figure 1-D illustrates the difference between FMS and RNAV, showing the flight management element of the FMS that RNAV does not share. Thus, the terms RNAV and FMS should not be casually interchanged.

Figure 1-D : Distinguishing RNAV and FMS



1.2.6 Standardisation Issues

RNAV systems are manufactured by various companies that aim to tailor make their equipment for their customers. (Here, the customer is usually the aircraft manufacturer, such as Airbus Industrie, which can in turn request special features to meet the needs of the end-user). Whilst some standardisation does exist in the data provided in the navigation databases used by the equipment, uniformity does not necessarily exist as to the way in which this data is interpreted. **Likewise, the computer 'logic' used (or algorithm) by one system does not necessarily correspond to another. Potentially, the end result is that one 'desired' track may be flown or navigated slightly differently by different equipment. It is appropriate to point out, however, that such differences are not always caused by the technology itself but may be influenced by the way in which it is operated.**

It is worth remembering that differences in (aircraft navigation) performance are not simply explained by the fact that there are various RNAV systems on the market. Data-bases servicing the equipment may also differ, as may the algorithms used by the various systems. Moreover, not all flight decks represent the navigation data in the same way.

Last but not least, controllers have to deal with a host of different aircraft performances as affected by atmospheric conditions viz. outside air temperature, pressure etc., see Figure 1-E.

Figure 1-E : Multiple Equipment Mix

This diagram shows an example where one aircraft type could have two different FMS fits or be equipped solely with RNAV. In addition, the operator could buy the database from three different providers, giving a potential nine different equipment fit options for that type of aircraft alone. It should be noted, however, that this is a fairly extreme example and that the multiple equipment mix exists already without significant adverse impact to today's operations.

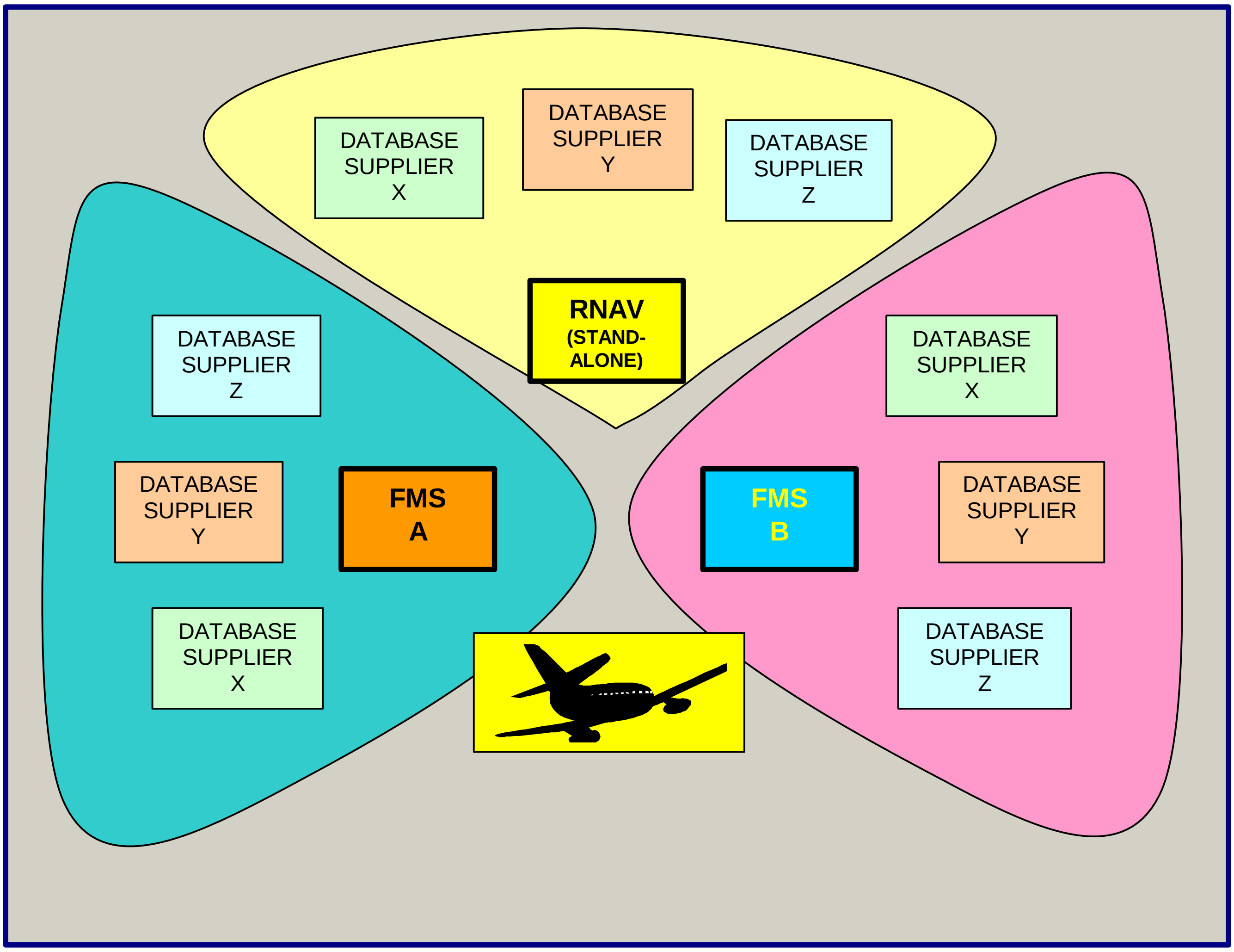


Figure 1-F : Multiple Navigation Capabilities

NAVIGATION CAPABILITY	LOWEST DENOMINATOR STAND-ALONE RNAV SYSTEM	ADVANCED STAND-ALONE RNAV SYSTEM	OLD-STYLE FMS	NEW GENERATION FMS
L-NAV (lateral (2-D) navigation)	YES	YES	YES	YES

V-NAV (vertical navigation)	UNLIKELY	LIKELY	PROBABLY	YES

1.3 APPROACH TASKS AND RNAV

The objectives of an ATC Service include the provision of safe, orderly and expeditious flows of air traffic within the airspace for which it is responsible. In regard to each of the elements mentioned, the type of airspace and the nature of the air traffic dictates the extent and complexity of the task to be carried out.

Within the Terminal Airspace, as elsewhere, the ATC objectives can be summed up using two keywords: Responsibility for separating and sequencing air traffic.

RNAV cannot separate or sequence air traffic. At best, RNAV equipment can be viewed as an airborne tool which facilitates the pilot's navigation tasks, and whose benefits can be exploited by controllers.
A Terminal Airspace structure (see footnote 1, page 2) exists in the vicinity of one or more airports and is designed to facilitate the orderly and efficient transition of aircraft to and from the airport runway(s) and the connecting en-route airspace structure. Within this airspace, the ATM system is required to handle both arrival and departure traffic and, whilst each task is different in the demand it makes upon the ATM system, it is related to the others. An understanding of the demand on ATC of each task and its inter-relationship is useful when considering potential applications of RNAV in Terminal Airspace.

1.3.1 Departure Tasks[9].

To meet the overriding safety objectives, ATC must achieve three departure tasks, namely:

Task 1	Separating departures from each other (Table I – Annex C)
Task 2	Separating departures from arrivals (Table II – Annex C)
Task 3	Integrating departures efficiently into the en-route system

Note: Task 3 achieves the integration of traffic into the en-route system and should not normally impose a major demand on the Terminal Airspace system as integration is usually the responsibility of the en-route controller. There is therefore no table associated with this application.

Task 1 is the least complex with regard to airspace utilisation. Initial separation is achieved through pre-departure planning and, because departing traffic is moving from a zone of convergence (the airport) to an area of greater volume, the task is made easier. Slow-moving or slow-climbing departures ahead of higher performance aircraft can cause problems, but well-proven methods have evolved to remedy these. These solutions include:

[9] All Tables Associated with ***Departure Tasks*** are to be found at Annex C

- Sequencing of departure order.
- Separate SIDs for aircraft of differing performance.
- Radar vectoring (to achieve standard separation).
- Use of speed control/speed tables.

Task 2 is based on the strategic de-confliction of SIDs and STARs and/or by the use of radar-aided intervention. When these procedures have been designed effectively, workload on pilots and controllers alike should be reduced in comparison with a system which has no comparable established procedures.

1.3.2 Arrival Tasks[10].

The arrival tasks of ATC are, in general, very work-intensive, especially in busy Terminal Airspace. In many locations, peak demand exceeds maximum runway capacity and, as a consequence, there is considerable pressure on the ATM system to achieve best possible runway utilisation rates. However, safety cannot be compromised and the tasks imposed upon ATC when handling arrival traffic are as follows:

Task 4	Arrivals must be separated adequately from other arrivals (Table III –Annex C)
Task 5	Arrivals must be separated adequately from departures

Task 4 is a demanding task as aircraft are flying from a large volume of airspace into a zone of convergence with a diminishing volume of airspace.

Note: Task 5 is similar to Task 2 (Departures) and is less work-intensive than Task 4, especially when strategically de-conflicted SIDs and STARs are being used. As this task is synonymous with Task 2 (Table II) there is no need to replicate the techniques in the form of a table.

Task 6	Arrivals must be integrated safely into an efficient landing sequence (Table IV – Annex C)

Task 6 (Table V – Annex C) requires the safe integration of arrival traffic into an orderly and efficient landing sequence and is probably the most demanding task that ATC carries out in Terminal Airspace. It requires sequencing of each flight, using radar vectoring, into a precise position at a precise time to achieve the maximum possible runway throughput. The task becomes more refined and critical as each aircraft reaches final approach. Some units employ Arrival Manager computer software to support the work of the arrival controllers by providing decision-making and sequence formation assistance to achieve optimum runway capacity levels. Whilst controllers quite consistently use their expertise to achieve maximum available runway capacity, the Arrival Manager can reduce the controller(s)' workload and helps ensure that the sequencing order is maintained efficiently.

[10] All Tasks associated with **Arrivals** are to be found at Annex D

1.4 POTENTIAL BENEFITS OF RNAV

The economic, environmental and political advantages to be gained by the employment of RNAV systems and procedures are well documented (and outside the direct scope of this paper). ATC may too reap some benefit from the use of RNAV in Terminal Airspace. Some of these benefits are listed below.

1.4.1 ATC Benefits

Listed below are some of the potential advantages to ATC which may follow the implementation of RNAV in Terminal Airspace:

- Amendment to controller techniques i.e. less radar vectoring may potentially increase capacity and traffic handling capacity.
- An increase in the time available for problem-solving (e.g. conflict resolution) - this advantage has safety as well as workload benefit implications.
- A reduction in the amount of monitoring required to ensure aircraft maintain track or assigned levels/altitudes.
- By instructing aircraft to track to a specific RNAV way-point, instead of radar vectoring (heading), any change in wind conditions or direction will have little effect on controller decision-making and workload.
- There should be a reduction in controller/pilot RTF loading when aircraft are instructed to use RNAV transitions rather than vectoring.
- Track repeatability/assurance is an asset for ATC particularly on inter-sector transfers. Much more certainty exists on where the traffic will be presented when flying, for example, on an RNAV STAR.

1.4.2 Non-ATC Orientated Benefits

In addition to ATC-specific benefits, there is great potential for some or all of the following to be provided by RNAV implementation:

- Economic

Reduced track miles - reduced fuel costs in addition to those already achieved in the en-route phase.
Improved Take Off Payload (TOPL) leading to increased overall payload.
Improved energy management in the arrival and departure phases.
Improved track-keeping leading to containment of noise signature and consequent fines.
Possible reduction in number of ground-based navaids (reduced installation and maintenance costs)
Potential increase in runway capacity rates.

- Environmental

Better track-keeping which concentrates noise and visual impact into smaller areas.
Constrained noise signature patterns.
Flexibility in route design to reduce sensitive area noise intrusion.
Reduction in fuel consumption and consequent reduction in fuel pollution, particularly if continuous descent approaches are possible from top of descent.
Better infrastructure planning.

Staying higher for longer through the use of V-NAV will possibly mean that fewer people will be covered by the noise footprint.

- Political

Increased goodwill with local authorities and neighbours.
Release of non-utilised airspace for other users.

1.5 POSSIBLE DISADVANTAGES OF RNAV

Whilst it is recognised that there are potential gains to be made from the implementation of RNAV procedures in Terminal Airspace, there are likewise important issues, which if not addressed appropriately, could prove to be serious disadvantages to ATC service providers and controllers – see Part II. A few of these topics are listed below:

Application of inappropriately designed RNAV procedures, could lead to some loss of flexibility for ATC. Any implementation of RNAV needs to combine its inherent advantages with the best, well tried and contemporaneous ATC techniques if the aims of increasing traffic handling capacity, maintaining safe practices and prevention of the overloading of controllers are to be achieved. ATC and the operators should be fully involved, from an early stage, in the design process. This is ONE OF THE MOST SIGNIFICANT AND CRITICAL issues with RNAV procedure implementation. A procedure which, from its inception, is not designed to take account of the requirements of ATC service providers is destined to produce frustration and ultimately will not be used.

During the transition phase when mixed-mode (i.e. both RNAV and conventional) procedures are in force, controllers will need to continue to provide efficient and safe integration of the different types of traffic. To assist this process, a possible solution might be the introduction of easy-to-use controller back-up tools (for example, conflict probes).

From a more specific RNAV procedure aspect, controllers might find it difficult to predict the profiles of RNAV-flown turns, making it more difficult to integrate RNAV (and FMS) traffic into the best possible landing sequence. Because of the perceived risk of getting aircraft too close together, there might be a tendency to allow extra separation to ensure standard separation. This would not allow the maximum landing rate to be achieved in all cases. Again, the air traffic controller could be aided by appropriate training and the installation of effective sequencing tools which, whilst not assisting the controller to separate traffic, could provide some sequencing guidance. In real terms, however, suitable training and confidence building in new RNAV procedures is of utmost importance for controllers to develop skills required for handling RNAV traffic.

More reliance may be placed upon speed control as an effective way of separating traffic on RNAV routes. The possibility therefore arises that the potential benefit (to aircraft) of flying 3D profile descents through RNAV application, may be diluted by controllers applying speed control in order to space their traffic.

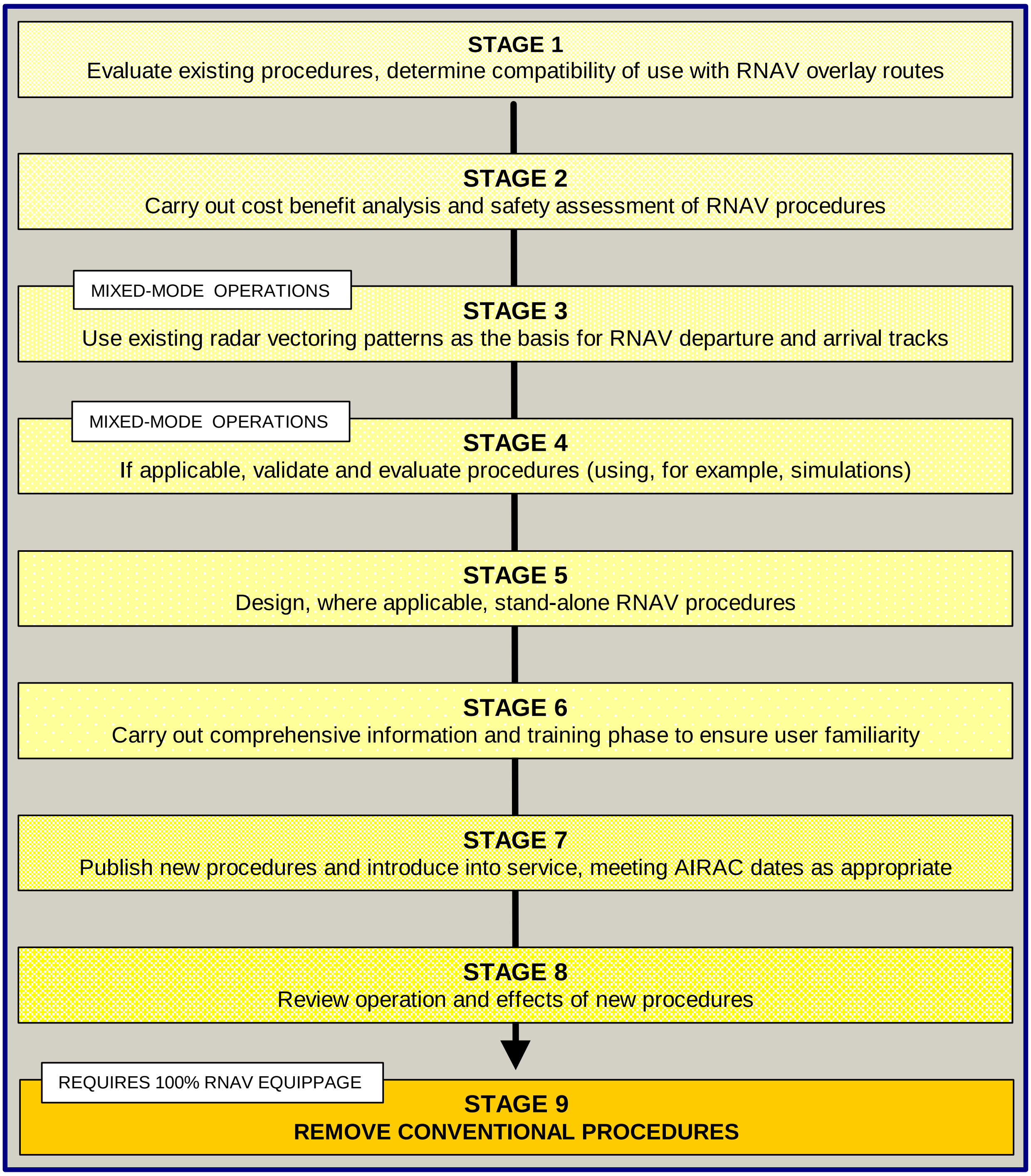
1.6 EFFECT ON ATC TECHNIQUES

Table 5 (Annex E) considers the perceived impact that RNAV capability will have on the application of the specific techniques used by controllers to help achieve the tasks detailed in para. 1.3.

1.7 TRANSITION PLAN

As mentioned in the Introduction to this document (para. 1.1), it would not be practicable to move directly in one step from a conventionally-based system to one based on either RNAV or FMS procedures. Consequently, a transition strategy and plan could be useful in giving guidance to both controllers and airspace users as to how to cope with this mixed-mode situation. The sample transition plan provided below is not meant to be prescriptive or comprehensive, but rather a rough guideline. Other stages can of course be included and amendments to this plan can be made to suit specific requirements or locations.

Figure 1-G: Suggested Transition Plan



PART 2 - SPECIFIC ISSUES

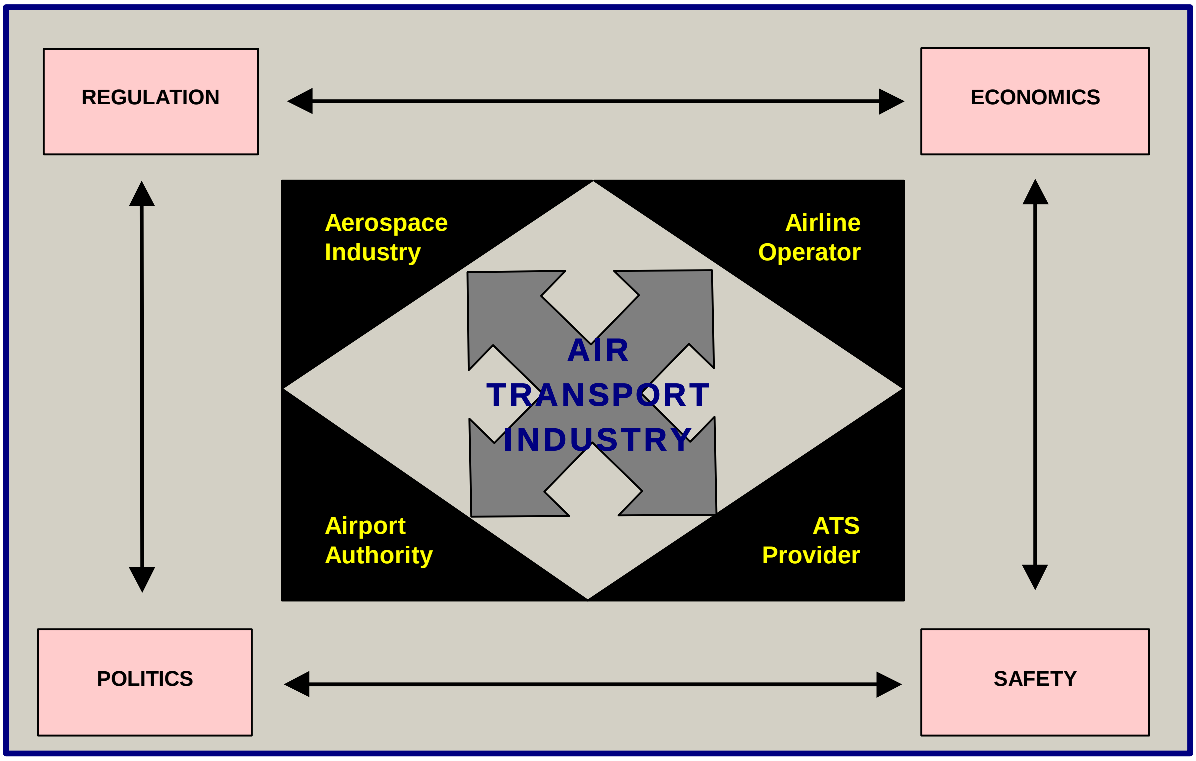
2.1 INTRODUCTION

The application or use of any new technology invariably brings with it both benefits and disadvantages. Tempting though it might be to over-stress either positive or negative – perhaps, so as to support an argument put forward – this part of the document will attempt to objectively identify and discuss those issues which are of specific interest and relevance to the controller.

Exclusively isolating RNAV application issues of relevance to only the air traffic controller, may justifiably draw criticism for two main reasons:

Air traffic control, is but one of the ‘variables’ in the air transport industry equation. (The other ‘variables’ are Airports, Safety and Economics, Regulation, Airline Operators and the Aerospace Industry). As with most equations, a change to one of the variables must affect the overall result. Technological advancements made in one area are likely to have some effect on other areas of the industry. Viewing the air transport industry as this composite whole makes it easy to see that the selection of only one of the variables as point of focus, risks painting an unbalanced picture.

Figure 2-A: Interactions in Air Transport Industry ‘Equation’



Another risk with isolating controller issues on RNAV application has to do with the fact that navigation is not new. Unoriginal though it might be, its relevance lies in the following statement: navigation-related issues which are presently unresolved will, of necessity, reappear in this RNAV discussion. Responsibility for terrain clearance is one such example. The nature of RNAV routes, and the use of way-points for tactical traffic management may thus add more questions to the existing list. As far as this document is concerned, however, the 'repetition' of existing unresolved issues may paint a particularly dark picture for RNAV, which would not be truly representative.

Particularly because of the above point, this part of the document must be read with the following caveat.

Many of the issues raised in this document are not solely confined to the application of RNAV in Terminal airspace. Most issues are also relevant to other areas of ATC. Because of this, issues which gained prominence prior to RNAV application, are marked with the symbol ⌘

Although this edition of the document focuses almost entirely on RNAV application in a Radar Controlled Terminal Airspace, it is essential to state that RNAV can also be applied in a Procedurally Controlled Terminal Airspace.

The issues arising from RNAV Application in Terminal Airspace are grouped under four broad headings:

- Human Factors.
- Legal Issues.
- Operational/PANS-RAC Issues.
- Controller Training/Notification .

Where possible or relevant, conclusions are provided at the end of sections or sub-sections.

2.2 HUMAN FACTORS ISSUES[11]

2.2.1 Introduction

An important aptitude required by controllers is the ability to maintain a three dimensional, ever-changing air-traffic mental picture. Controllers must know the whereabouts of their air traffic, what it can be expected to do and what needs to be done to resolve conflicts. The controller picture can be seen as an integration of various intellectual attributes[12] coupled to skills which are formally taught. Controllers must not only fuse these attributes and skills but also apply them according to regional, national and ICAO regulations (embodied in International Standards and Recommended Practices (SARPs[13])), in order to plan ahead and make decisions to resolve traffic conflicts. The dynamic nature of this air traffic picture makes its continued maintenance one of the most challenging aspects of the controller's job. Loss of the picture is potentially perilous – and most likely to occur during periods of high task demand with excessive time pressures and no chance of relaxation. Its loss can also occur because of premature relaxation following high stress or being faced with the unexpected.

[11] Hopkin, V.David.; ***Human Factors in Air Traffic Control*** (Taylor & Francis Ltd., 1995) - generally.
National Research Council; ***Flight to the Future*** (National Academy of Sciences, 1997) pp. 122, 123, 125, 129, 139-140, 269, 278.

[12] Hopkin; *op.cit.,* pp.58-60. See Also Annex F of this Document.

[13] Found in ICAO Annexes and Documents.

During training, controllers have been conditioned to bear a weighty responsibility for the safety of the air traffic under their control. Controllers know what skills are needed and tasks that should be performed without error. Fear of error is a very real one to the controller. Not many professions provide so little margin for error because a mistake by a controller can, with alarming immediacy, result in many fatalities, not only in the air, but on the ground as well.

2.2.2 Managing Change

From the controller's perspective, RNAV has the potential of substituting not only pilot but also some controller tasks. Controllers' 'traditional' scepticism of new equipment and procedures can be seen as a function of both reliability or effectiveness of the changes (i.e. positive effects on workload, capacity and safety) and controllers' trust in their own abilities. In short, controllers are understandably inclined to be wary of anything that might interfere with the skills needed to perform their tasks. New technology is often perceived as a safety risk – unless and until the contrary is proved.

In an attempt to balance this adverse perspective, it might be opportune to remember that the successful implementation and effects of changes do not happen spontaneously with all changes. Change, whatever its source, can be managed and the management of change occurs at various stages, starting right at the research stage and extending into application and implementation. Historically, changes have been managed each time new technology has been introduced into the ATC arena, if only because neither ICAO or national administrations would willingly expose themselves to the legal liability that could be imputed to them were they to mandate the use of 'unsafe' new equipment or 'hazardous' procedures. Part of the process of managing change that new technology brings with it, has to do with taking cognisance of and addressing the relevant human performance or human factors issues.

2.2.3 Situational Awareness [SA]

The 'Controller Picture' referred to above lies at the focal point of a human-centred air traffic control system. Because of its importance, RNAV-associated aspects which have the potential to impact on this picture are brought under the spot-light and are shown below:

Reduced tactical control due to RNAV

Keeping the air traffic picture is very much an active as opposed to passive process. One of the potential risks of moving towards an automated ATC system concerns possible degradation of the controller picture. The thinking behind this theory is that in transforming controllers into a system (computer) monitors, their controller picture may be diluted.[14] Aviation psychologists[15] argue that some resource-demanding, routine, repetitive controller tasks serve to strengthen human memory and research shows that the human being does not function best in a monitoring role.[16] This opinion supports the view that lack in tactical involvement in the air traffic picture risks making controllers inattentive or might make them lose concentration and/or understanding of the air traffic situation. (This challenge already exists for on-the-job ATC instructors who monitor their trainees).

14 Hopkin; *op.cit.,* pp. 305

15 Hopkin; *op.cit.,*

16 Reason, J.; ***Human Error*** (Cambridge University Press, 1995) pp. 180.

Extending this thesis into RNAV application in Terminal Airspace, where radar vectors are supplanted by self-flown RNAV routes, fears exist that the lack of reinforcement of the air traffic picture will adversely alter the nature of this air traffic picture

Considering this assertion objectively, it is significant to note that some Terminal Airspaces have been using conventional arrival and departure routes instead of radar vectors for some time. Whether or not controllers managing these airspaces have suffered 'picture loss' as a consequence, is debatable. Although accident and incident statistics are not the only safety yardstick, it is noteworthy that, although further research is still needed in this area, this particular 'fear' does not appear to have been realised.

Mixed-Mode Operation

Another factor considered potentially disadvantageous to the controller picture concerns what is known as 'mixed-mode' operation'. This refers to a mix of air traffic where the navigation performance capability of the aircraft is not uniform i.e. some are RNAV equipped whilst some are not.
This mixed mode of operation could be considered to be the most risky because controllers presently have no way of knowing what combination of equipment and flight-displays is available to aircraft under their control. A mix of navigation performance may require a controller to have to radar vector some traffic, allow others full 3D performance and give to others 2D-only aircraft level instructions.

2.2.4 Skill Integrity

Some concerns exist that lack of radar vectoring practice brought about by RNAV application, may, in the long term, result in the dilution of this skill. Realistically however, a full 4D RNAV is likely to only be tendered for operation if the systems on the ground and in the air are failsafe, in which case, loss of radar vectoring skills would carry little risk. History already proves this point where controllers tended to lose their procedural control skills over time with the advent of radar. Today, the multiple back up radar systems make procedural control almost redundant in many parts of Europe. In the interim phase, while RNAV application is under development, this particular issue could be addressed by introducing what is known as Emergency Training in some countries. Under this scheme, controllers' less-used skills are maintained in a simulated environment on a regular basis as a way of ensuring minimal skill loss.

2.2.5 Vigilance/Boredom

Another aspect of the RNAV debate has to do with the other effects transforming the controller into a monitor of tasks – as opposed to the controller actually carrying out the tasks. In non-demanding traffic environments, controllers risk falling prey to boredom and some researchers consider boredom as potentially dangerous. This is because boredom can create its own stress.

Up to the present time, controller 'automation' has managed to keep the human being in the control loop, because automation has concentrated mainly on data gathering without impeding the controller's decision-making and planning roles.

2.2.6 Consolidation

The introduction of new equipment or technology inevitably requires a settling in period during which people and the technology have to come to terms with each other. An excerpt from Air Traffic Control: Human Performance Factors[17] recalls the 'recent days of air-crew coming to grips with the glass cockpit':

"Flight guidance and FMS computer logic often appears to have been programmed by someone who has never flown an aircraft and the 'default modes' on the flight guidance system often work against you in high workload situations without adequate annunciation of their engagement. I do not agree with the 'quiet cockpit' concept, as crew communication is paramount in order that each crew member knows what the other is about to do, rather than what he has done. During non-precision approaches (thankfully rare) the flight guidance system logic and 'default' modes are a positive hindrance.- Anonymous pilot."

Technology is not infallible, and when introducing it into ATC systems, its impact on procedures and on other inter-dependent systems should be examined. Traps aplenty await the unwary or the complacent. This is not to say that the new technology should be avoided but rather that it should be managed, and controllers trained in its use so that maximum overall benefit can be obtained.

2.3 LEGAL ISSUES

The original text of this paragraph has been withdrawn, in order to eliminate any risk of misinterpretation of its content, even though the document is intended as information material and not to form the basis for any rules for implementation.

The legal issues surrounding RNAV operations are both complex and of infinite importance, in particular with regard to responsibility for terrain clearance. Furthermore, it is recognised that the legal issues are of such magnitude that they require much further detailed evaluation and consideration by bodies with the appropriate mandate and expertise before any statements, particularly regarding responsibility, can be republished in this document.

2.4 PANS-RAC ISSUES

2.4.1 Procedures

Separation Principles

No clearance shall be given to execute any manoeuvre that would reduce the spacing between two aircraft to less than the separation minimum applicable in the circumstances.[18] The above quote from ICAO seems to imply that in a full blown RNAV environment which includes profile descents for parallel runway operation, current PANS-RAC procedures might be insufficient. They do not appear to cater for a situation where two aircraft descend on head-on base-legs towards each other without an altitude restriction ensuring

[17] (Ashgate, March 1999) pp.217

[18] Doc. 4444, pp.3-1 para. 1.3

their continuous vertical separation until established on adjacent (staggered) Localiser courses.[19]

[19] ICAO: ***Aerodromes,* Annex 14** (2nd Ed.,1995), pp. 13 & Doc. 4444 pp. 4-6 to 4-9 incl.

Radar Separation and Radar Monitoring

Two main schools of thought exist when it comes to deciding the way in which radar separation is to be applied. Whether or not (self-navigating) RNAV routes could be radar separated in Terminal Airspace, depends on the perspective held:

One theory states that in order for radar separation to be applied, the controller must have the aircraft being radar separated on tactical radar headings.[20] Differently put, both aircraft being radar separated must be 'locked' on radar headings.

The second theory holds the view that radar separation can be applied when a radar Monitoring service is provided. These proponents argue that throughout the world on a daily basis, radar separation is provided between aircraft whose tracks are observed (i.e. radar monitored) by the controller. Under this scheme, ATC steps in to correct significant track deviations to ensure radar Separation. ATC intervention in these cases in usually in the form of a corrective radar vector. Over and above this, PANS-RAC makes provision for radar Separation to be applied between two aircraft where only one of the two aircraft is under Radar Control (and the other is expected to enter the area of radar cover).[21]

Widespread use is already made of the second method in Europe: radar separation is often effected by radar monitoring as opposed to radar vectors e.g. aircraft on Europe's web of ATS routes are not generally on a tactical radar heading.

Altimeter Setting Procedures

In cases where aircraft are given uninterrupted descent on a 3D RNAV arrival route from their cruising level, procedure designers may need to be wary of allocating a way-point level restriction close to Transition Altitude/Level so that vertical profiles are not adversely affected by pressure differences.[22]

2.4.2 General Issues/Questions

Disruption Factor

The extent to which equipment malfunctions, adverse weather, runway changes and other disruptions may or may not unsettle RNAV application in Terminal Airspace would have to be established in assessing the viability of implementing this system.

Wider Application of RNAV

To date, pioneer projects in applying RNAV (based on FMS) in Terminal Airspace developed their application in well controlled environments i.e. selected number of airlines, well briefed aircrew and controllers. Data on the impact of RNAV routeings/procedures is not yet available for situations where the 'environment' is less controlled.

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[20] In the UK, this is a requirement in Terminal Airspaces.

[21] Doc. 4444, pp.6-11 para. 7.3.7

[22] Doc. 4444, pp. 2-8 para. 12 *et seq.*

Radio Procedures

Existing RTF provisions do not cover RNAV application in Terminal Airspace and these would need to be developed at ICAO level. Along with the need for RTF procedures, the nature of the RNAV routes (either SID/STAR or Instrument Approach Procedure) would require a decision to be reached on how these routes are to be described by voice and other communication means. The current procedures applicable to the identification of MLS/RNAV routes in Annex 11 at Appendix 3, may provide a suitable basis for discussion.

Flight Planning

The ICAO EUR region currently uses 'R' on the ATC Flight Plan to denote that an aircraft is RNAV equipped and meets the navigation accuracy of RNP5.[23] No equivalent means exists as regards Repetitive Flight Plans.[24] Although this issue may appear insignificant, it is not a simple to resolve because the ATC Flight Plan is trying to cope with many other 'additional' pieces of information such as 8.33 equipage, RVSM capability, B-RNAV capability and the HMI risks becoming overly complex. Uncertainty also exists as to how best to address the flight planning issue in instances where the RNAV accuracy requirement is not uniform throughout the flight.

RNP Selection

The concept of Required Navigation Performance (RNP) was developed by the ICAO Special Committee on Future Air Navigation Systems (FANS). RNP is a statement of navigation performance accuracy required to be achieved for at least 95% of the time in a designated airspace. It also has associated requirements for integrity, availability and continuity. It was envisaged that RNP could be achieved using the RNAV equipment which was already in widespread use. While this has proved possible to some extent with RNP 10 in the Pacific Region (and which may be extended to cover other Oceanic areas), it has been much more difficult to achieve more demanding RNP values. A new Minimum Aviation System Performance Standard (MASPS) has been developed and it is intended that this will form the basis for future RNP systems.

In the interim, EUROCONTROL has developed an RNAV Standard which addresses many of the requirements of RNP while, at the same time, recognises the continued use of systems which do not meet RNP criteria. The minimum requirements for initial En-Route RNAV applications are specified as Basic RNAV (B-RNAV). The JAA is finalising the minimum requirements for Precision RNAV (P-RNAV). Initial Terminal Area RNAV applications are expected to be covered by the P-RNAV requirements.

Mixed-mode Operations[25]

The implications of mixing RNAV and non-RNAV equipped aircraft in the same airspace has been discussed under the Human Factors issue of Situational Awareness. Procedures, which may include a re-examination of separation standards may need to be put in place to accommodate mixed-mode operation. It is likely that a high aircraft-performance traffic-mix together with mixed-navigation mode operation will require

[23] ICAO***: Regional Supplementary Procedures,* Doc. 7030/4** (4th Edition – 1987 (reprinted 1995)), EUR/RAC-6

[24] This issue is currently being addressed by EUROCONTROL's ATC Procedures Development Sub-Group (APDSG).

[25] In this paper, ***mixed- navigation mode*** refers to traffic mix where not all aircraft are RNAV equipped.

particular attention, particularly in view of the fact that controller workload does increase where a high aircraft-mix is the norm in traffic patterns.

Combination of ACAS RAs and RNAV in Terminal Airspace

Current EUR region ATC procedures as regards Resolution Advisories require ATC not to issue instructions that are contrary to those given by the ACAS RA. Furthermore, it is spelt out that 'Once an aircraft diverts from the current clearance in compliance with an RA, the controller ceases to bear responsibility for separation between that aircraft and other aircraft affected as a direct consequence of the manoeuvre induced by the RA. However when circumstances permit, the controller should endeavour to provide traffic information to aircraft affected by the manoeuvre." Whether this would have any impact on RNAV application in Terminal Airspace will have to be established – see Human Factors, para.2.2.

2.5 HARMONISATION

⌘ To date (September 1999) several operational RNAV or FMS procedures already exist in European Terminal Airspaces (e.g. Frankfurt, Munich, Vienna) with others approaching implementation. In addition, there are schemes in several other European States which are aiming to utilise the techniques applicable to RNAV.

As has become apparent, there is a great impetus in the industry to make progress in achieving significant benefits from the new technology which is becoming increasingly available. Clearly, therefore, it is desirable to achieve some form of commonality and standardisation, both from the ATC and aircraft operators' point of view, during the introduction of RNAV procedures in different Terminal Areas. Such an approach may give the opportunity to reduce any significant differences, and hence potential difficulties for users operating into and out of the various airports. In addition, it might enable the best features of any individual system to be incorporated into new developments, whilst giving the potential to reduce the effects of weaknesses seen in any particular scheme.

Such advances could be based on the various pilot projects being undertaken in the various States and also on the results of simulations which would be able to explore the way forward, examining not only the potential benefits but the possible pitfalls as well.

2.6 CONTROLLER TRAINING/NOTIFICATION

⌘ Discussions under the titles of Human Factors and PANS-RAC make it clear that the use of RNAV procedures may require a change in existing controller practices, should the perceived advantages for the aircraft operators enable controllers to also benefit from reduced workload and increased capacity.

Training would have to be designed to convert controllers to this new ethos, especially in the period when mixed-mode operations (i.e. handling both RNAV and non-RNAV equipped traffic) necessitates employing both current and new controlling techniques. Such 'conversion' would need to address matters other than the mere mechanics of the change in controlling techniques, such as convincing them that this advance would have the benefits advertised, without significant disadvantages.

As the proportion of RNAV-flown procedures increases, then the need for routine controller intervention would probably decrease and further thought would have to be given as to the methods by which controllers would be given practice in the controlling techniques needed should aircraft convert suddenly from RNAV to conventional flying. Such methods could include a requirement to complete a structured and regular simulator programme to practise "worst case" scenarios in order to retain currency.

PART 3 - CONCLUSIONS

This document has sought to examine the background information and the issues surrounding the effects of the implementation of RNAV procedures in Terminal Airspace, largely from an ATC perspective.

The possible advantages and disadvantages of employing RNAV procedures have been high-lighted, with the consequent effect on controller decision-making, workload and controlling techniques. The different emphasis on the various controlling techniques shows RNAV implementation to be an area in which careful thought needs to be applied in order that any benefits gained are not significantly lessened or even outweighed by disadvantages introduced by such implementation.

By the same token, the issues raised under the headings of Human Factors, Legal Issues and the nuts and bolts of operational procedures cannot be left unattended – neither can Harmonisation and Controller training.

All these elements are part of the composite whole on which the successful implementation of RNAV application in Terminal Airspaces rests.

Of paramount importance is the need to keep Controllers in the developmental loop and to educate and inform operational controllers as to what RNAV means to them in an Approach environment. Controllers and ATC service providers must be clear in their own minds as to the responsibilities that each of them have and what actions are required in a given scenario.

The undertaking of a harmonised and structured approach to RNAV procedure implementation cannot be over-emphasised. With the growing number of RNAV developments throughout Europe, there is no time to waste in trying to provide enough knowledge, guidance and ideas to allow the Member States to co-ordinate their efforts to ensure that where RNAV is introduced, it is implemented efficiently and safely, with, where possible, a common and standardised methodology. Therefore, it is vital that all issues, not just benefits but also possible disadvantages, are fully examined so that current practices can be augmented by RNAV-based procedures with as few problems and as many advantages as possible.

RNAV application in Terminal Airspace is an iterative process, and the mixed-mode operational phase is likely to be the most critical. However, the critical issues can be identified, resolved – and managed. This accomplishment could lead ATC into a new age, bringing with it significant improvements to Terminal Airspace air traffic management. Once tried and tested, the introduction of arrival and departure management tools based on 4D principles could be the next step.

ANNEX A

DEFINITIONS

Radar Control:

Term used to indicate that radar-derived information is employed directly in the provision of an air traffic control service.

Radar Monitoring:

The use of radar for the purpose of providing aircraft with information and advice relative to significant deviations from nominal flight path, including deviations from the terms of their air traffic control clearance.[26]

Radar Separation:

The separation used when aircraft position information is derived from radar sources.[27]

Terminal Airspace (TA):

Terminal Airspace is a generic term describing airspace surrounding an airport within which air traffic services are provided. It encompasses all the various terminology currently used throughout the ECAC region.
(Explanatory note: The above is aimed at including TMA, CTA, CTR, SRZ, ATZ airspace classification or any other nomenclature used to describe the airspace around an airport. NB. ICAO does not currently use or define the term 'Terminal Airspace').[28]

N.B. All other definitions cited (italicised) are sourced in ICAO unless otherwise indicated.

ANNEX B

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[26] Doc. 4444, Definitions.
[27] Doc. 4444, Definitions.
[28] EUROCONTROL: ***Terminal Airspace Design,*** **ASM. ET1. ST06** (June 1998)

ANNEX C

DEPARTURE TASKS

Table I : SEPARATING DEPARTURES FROM OTHER DEPARTURES

METHOD	CONVENTIONAL	RNAV
1.1	SEQUENCE DEPARTURE ORDER (e.g. fast aircraft ahead of slow)	Nil effect
	Efficient ground control/taxyway infrastructure	Nil effect
1.2	APPLY DIVERGING RADAR VECTORS AFTER TAKE-OFF TO ENSURE SAFE SEPARATION	More consistent track-keeping
	Potentially high RTF loading – continuous radar monitoring and track correction/co-ordination to deliver to En-Route	Still continuously monitored but reduced track correction needed (less RTF loading/decision-making)
1.3	USE SEPARATE SIDs FOR AIRCRAFT OF DIFFERENT PERFORMANCE	More consistent track-keeping (plus, in 3D or 4D, guaranteed level attainment)
	Reduced RTF loading/co-ordination but continuous monitoring still required. Minimal track adjustment	Confidence in aircraft performance frees time for other tasks (possible increase in traffic handling capacity
1.4	USE SPEED CONTROL TO EFFECT SEPARATION	Nil effect in 2D or 3D, more accurate in FMS/4D application
	Consistently easier judgement of lateral separation	Marginal improvement other than confidence in speed maintenance when FMS-flown

Table II: SEPARATING DEPARTURES FROM ARRIVALS

METHOD	CONVENTIONAL	RNAV
2.1	APPLY RADAR VECTORS TO DECONFLICT FROM ARRIVALS, USING LEVEL/ALT CONSTRAINTS AS NECESSARY - RANDOM PROCEDURE WITH NO SIDs/STARS IN OPERATION	Nil effect
	High workload (RTF, monitoring, co-ordination needed) - low capacity due to multiple tasks	Nil effect
2.2	STRATEGICALLY DESIGNED SIDs WITH STANDING AGREEMENT COORDINATION - USING LEVEL/ALT CONSTRAINTS AS NECESSARY	Track flown consistently (plus level/altitude attainment/maintenance in 3D/4D)
	Lower workload than 2.1 but monitoring task unchanged - more controller capacity due to reduction in RTF/co-ordination. Tactical intervention used when situation dictates	Predictable performance may reduce workload and, although tactical intervention may still be necessary, the extra time available would ease early anticipation of required action

ANNEX D

ARRIVAL TASKS

Table III: SEPARATING ARRIVALS FROM OTHER ARRIVALS

METHOD	CONVENTIONAL	RNAV
4.1	USING STARs PROCEDURALLY WITHOUT RADAR	More consistently accurate STARs flown
	Low traffic capacity	Nil effect
4.2	USING STARs AS A BASIS FOR ARRIVALS BUT EMPLOYING TACTICAL RADAR VECTORING AND/OR LEVEL/ALT CONSTRAINTS TO SEPARATE ARRIVALS EFFICIENTLY FOR DELIVERY TO LANDING SEQUENCER	More consistently accurate STARs flown. Use of tactical waypoints allows a coarse method of sequencing.
	High workload, especially once aircraft tactically removed from STAR - co-ordination/RTF workload high, reduced controller capacity	Confidence in track-keeping maintenance (plus level attainment in 3D/4D) gives initial controller workload benefit. However, once controller intervention occurs then task reverts to conventional until/or aircraft returns to the RNAV procedure
4.3	USING SPEED CONTROL	Marginal advantage if FMS-flown
	By requiring all traffic to fly at the same speed, sequencing is more easily achieved - not necessarily best approach profile for all aircraft	Slight increase in confidence that assigned speed is actually being flown

ANNEX D (cont'd)

Table IV: INTEGRATING ARRIVALS INTO AN EFFICIENT LANDING SEQUENCE

METHOD	CONVENTIONAL	RNAV
6.1	FULL INSTRUMENT APPROACH INCLUDING PROCEDURE TURNS - WITHOUT RADAR	Not applicable
	Reduced capacity, inflexible sequencing (inability to change sequence)	Marginal efficiency improvement as aircraft fly procedures more accurately and consistently
6.2	APPLY RADAR VECTORS TO CREATE BEST POSSIBLE LANDING SEQUENCE WITH THE ABILITY TO INSTANTLY AMEND PLAN TO ACCOMMODATE CHANGING SCENARIO	Use of tactical waypoints may reduce RTF loading
	Highly skilled, labour-intensive with very high workload (RTF, co-ordination). Such techniques are employed on a tactical basis to produce a highly efficient landing sequence which has to optimise available runway capacity	Different decision-making processes involved when integrating RNAV and conventional traffic. Possible reduction in workload when handling RNAV traffic may be offset by difficulty in incorporating conventional traffic into best possible sequence without penalising either type or compromising safety
6.3	USING SPEED CONTROL	Marginal improvement in speed maintenance (if FMS-flown)
	Removes one element of the sequencing equation to make judgement easier. Requires aircraft to fly at compromise speed in the radar pattern.	Eases sequencing decision-making but reduces benefits of full RNAV procedure

ANNEX E

EFFECT OF RNAV ON ATC TECHNIQUES

Table V: EFFECT ON ATC TECHNIQUES

REF.	TECHNIQUE	DESCRIPTION USING CURRENT METHODS	POSSIBLE EFFECT OF APPLICATION OF RNAV
A	ASSIGNMENT OF LEVELS/TERRAIN CLEARANCE	Controller responsible for assigning level which ensures adequate terrain clearance. Monitored by pilot's report/SSR observation	The pilot would be responsible for adhering to the procedure - which would be designed to give terrain clearance. Controller monitors SSR as back-up
B	CHANGING LEVELS	Flight conducted in accordance with published procedure or as instructed by controller. Existing rules for vacating/passing/reaching levels apply	No change unless aircraft 4D FMS equipped to enable time specification
C	EXACT REPORTING POINT	Position defined by existing navigation facility - e.g. VOR/DME fix	Using RNAV defined position should be as accurate
D	SEPARATION BASED ON VOR/DME	Used when both aircraft are using the same on-track facility	RNAV positions should be at least as accurate and should be acceptable
E	GEOGRAPHIC SEPARATION	Based on position reports over different geographical locations which have been specified as being separated horizontally	Provided that the certification of the equipment specifies sufficient accuracy then RNAV information should be acceptable
F	LONGITUDINAL SEPARATION	Various techniques employed to achieve adequate separation which, in general, use time over/at a specific point/facility	As above
G	HOLDING AIRCRAFT	Vertical separation is used unless a deeming arrangement allows lateral separation to be used	RNAV holding should be sufficiently accurate to allow strategic separation of holds laterally
H	RADAR SEPARATION	Horizontal radar separation of 3/5/10NM (according to task/equipment performance)	Nil application for RNAV
I	SPEED CONTROL	By requiring aircraft to fly at the same speed, sequencing is made easier by the removal of one of the variable elements in the decision-making equation	In conjunction with arrival manager tools, controllers can use speed control early in the procedure to improve sequencing. The aircraft are reduced to similar speeds as they join the common path.

ANNEX E (cont'd)

J	CLEARANCE LIMIT	ATC clearance limits specified by aerodrome, reporting point or airspace boundary	RNAV way-point could be used instead of/ in addition to the points currently used
K	EXPECTED APPROACH TIMES (EATs)	EATs are issued according to the traffic situation and are based on the landing rate	RNAV 4D techniques should allow flights to arrive at a very accurate pre-planned time which may reduce the need for delayed EATs and consequent extended holding
L	RADAR IDENTIFICATION (POSITION REPORT)	Specified criteria for the authorised use of position reports for identification purposes	RNAV position should be sufficiently accurate for identification - especially useful in a non-SSR environment
M	VISUAL APPROACH	Controller may be responsible for separation of IFR traffic carrying out a visual approach	RNAV information would be used in the same way as current DME/geographical position information

ANNEX F

ATTRIBUTES OF THE CONTROLLER

Aviation Psychologist, V David HOPKIN states that part of being a controller means having a collection of skills, such as: [29]

- Ability to switch from one topic to the next
- Learning those aspects of the job which are seldom taught in ATC colleges, such as: norms and ethos of ATC; attitude to pilots and colleagues; acceptance as a team member
- Learning those procedures which counter the fallibility of human memory, such as repeats, read-backs and checks
- An ability to process much visual and auditory information which is presented simultaneously
- Problem solving abilities, by making correct decisions the first time around.

Two more items could be added to the above list[30]:

- the urgency element of correct decision making i.e. making decisions speedily
- an ability to re-assess any plan made on an on-going basis.

[29] Hopkin; *op cit., pp*. 50-67.
[30] Pavlicevic, F: *Inadequate Infrastructures, Communication ~ A threat to air safety?* (MSc Thesis, unpublished, 1998)

ANNEX G

NATURE OF RNAV ROUTES IN TERMINAL AIRSPACE

RNAV route = SID or STAR:

What ICAO's ATS Planning Manual[31] provides in its guidelines concerning SIDs or STARs, is of relevance to the hypothesis that an RNAV route is either a SID or STAR.
'
[para. 2.1] Standard Instrument departure routes should link the aerodrome or a specified runway of the aerodrome with a specified significant point at which the en-route phase of flight along a designated ATS route can be commenced.

[para. 2.2] Standard instrument arrival routes should permit transition from the en-route phase to the approach phase by linking a significant point on an ATS route with a point near the aerodrome from which –

A published standard instrument approach procedure can be commenced or;
the final part of a published instrument approach procedure can be carried out; or
a visual approach to a non-instrument runway can be initiated; or
the aerodrome traffic circuit can be joined.

[para. 2.3]

[para. 2.4] Standard instrument departure and arrival routes should be designed so as to permit aircraft to navigate along the routes <u>without radar vectoring</u>. In high-density terminal areas, where complex traffic flows prevail due to the number of aerodromes and runways, radar procedures may be used to vector aircraft to or from a significant point on a published standard departure or arrival route, provided that –

Procedures are published which specify the action to be taken by vectored aircraft in the event of radio-communication failure; and
Adequate ATC procedures are established which ensure the safety of air traffic in the event of radar failure.

[para. 2.5] The routes should identify significant points where

a departure route terminates or an arrival route begins;
the specified track changes;
any level or speed restrictions apply or no longer apply;

[paras. 2.8 to 2.10]

[para. 2.11] Level restrictions, if any, should be expressed in terms of minimum and/or maximum levels at which significant points are to be crossed.

[para. 2.12 – 2.13].

Study of existing FMS-routes currently in use in several European Terminal Airspaces [known as FMS-Transition] suggest that it is not inconceivable to perceive RNAV routes as SIDs and STARs.

31 ICAO: ***ATS Planning Manual,*** Doc. 9426-AN/924 (1st Ed.,1984) pp. I-2-4-6.

ANNEX G (cont'd)

The implications of equating RNAV to a SID/STAR as far as terrain clearance is concerned lies in being able to conclude that ATC would not be responsible for terrain clearance where an aircraft is on an RNAV SID/STAR. Naturally, the question that must be asked is who would bear the responsibility? What responsibility, if any, would be imputed to the FMS database provider, the FMS manufacturer? The pilot?

If one examines the definition of radar vectoring however it could be argued that to equate an RNAV route to a radar vector is stretching the definition beyond its limits.

If any event, were an RNAV route considered to equate to a radar vector, then ICAO is clear on this point. When an IFR is being radar vectored, the controller bears responsibility for terrain clearance.[32]

RNAV Route = Instrument Approach Procedure

ICAO tells us that an instrument approach procedure may have up to five segments[33]: arrival, initial, intermediate, final and missed approach segments, each of which begin and end at designated fixes [or specific points, where fixes are not available]. In discussing the Arrival segment, Doc 8168[34] suggests that Standard Instrument Arrival Routes [STARs] can be established, if there is an operational advantage, to link the en-route phase and the a fix/facility published in association with the instrument approach procedure.

Part of the premise for equating these routes with an instrument approach procedure is to view these routes as being the other side of the radar vectoring coin, discussed above. ICAO[35] provides that 'the initial and intermediate phases of an [instrument] approaches executed under the direction of a radar controller comprise those parts of the approach from the time radar vectoring is initiated for the purse of positioning the aircraft for final approach, until the aircraft is on final approach and:

- established on the final approach path of a pilot-interpreted aid; or
- reports that it is able to complete a visual approach; or
- ready to commence a surveillance radar approach; or
- transferred to the precision radar approach controller.

The RNAV route = Instrument Approach Procedures proponents argue that such routes replace radar vectoring (in overlay forms) and because radar vectoring manages to fuse the initial and intermediate approach phases of the instrument approach (see above) then, the RNAV route must be at least part of an instrument approach if not all of it.

Whatever the premise for this type of argument, we can conclude that if an RNAV route is equated to an instrument approach procedure (and not a radar vector) then ATC is not responsible for terrain clearance.

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[32] see fn. **Error! Bookmark not defined.**
[33] ICAO***: Aircraft Operations,*** Doc. 8168-OPS/611 (4th Ed.,1993) Vol. I Part III pp. 3-1..
[34] at Vol. I Part III pp. 3-13, para 3.2.
[35] Doc. 4444, pp. 6-17 para. 9.3.5.