EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

GUIDELINES FOR THE APPLICATION OF THE ECAC RADAR SEPARATION MINIMA

ASM.ET1.ST18.1000 - REP- 01.00

Edition	:	2.0
Edition Date	:	14 December 98
Status	:	Released Issue

EUROPEAN AIR TRAFFIC CONTROL HARMONISATION AND INTEGRATION PROGRAMME

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title
GUIDELINES FOR THE APPLICATION OF THE ECAC RADAR SEPARATION MINIMA

EWP DELIVERABLE REFERENCE NUMBER	
PROGRAMME REFERENCE INDEX ASM.ET1.ST18.1000 -REP-01.00	**EDITION :** 2.0 **EDITION DATE :** 14 December 1998

Abstract

Applying the ECAC defined radar separation values of 5/10, 3 and 2.5 NM in, respectively, En-route High and Low/Medium ATC complexity areas, in TMAs and on Final Approach Track requires conditions to be met not only in the Domain of Radar Surveillance, but also in various technical and operational Domains. These requirements are correlated with the CIP objectives permitting their fulfilment.

Keywords

Radar	Transfer	Technical
Separation	Safety	Minima
Procedures	Operational	

CONTACT PERSON :	Mr. G De Clercq	**TEL :** 3767		**DIVISION :**	DEI2

DOCUMENT STATUS AND TYPE

STATUS		CATEGORY		CLASSIFICATION	
Working Draft	☐	Executive Task	☑	General Public	☑
Draft	☐	Specialist Task	☐	EATCHIP	☐
Proposed Issue	☐	Lower Layer Task	☐	Restricted	☐
Released Issue	☑				

ELECTRONIC BACKUP

INTERNAL REFERENCE NAME :

HOST SYSTEM	MEDIA	SOFTWARE(S)
Microsoft Windows	Type : Hard disk	
	Media Identification :	

DOCUMENT APPROVAL

The following table identifies all management authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
Radar Separation Minima Task Force Chairman	C.M. Loghides Content of the document reviewed and approved.	
Director EATCHIP Implementation Support	G. Paulson EUROCONTROL Internal review completed. Approved for external co-ordination and review with National Representatives.	
EATCHIP Project Leader	W. Philipp Approved for general release	

DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.A	8 Nov 96	Working Draft resulting from the deliberations of RSMTF/1.	-
0.B	17 Jan 97	Incorporates changes as agreed at RSMTF/2 meeting	All
0.C	21 Mar 97	Incorporates editorial changes, the addition of an executive summary and example methodologies for mono-radar systems and multi-radar tracking systems	All
1.0	11 Apr 97	Incorporates editorial comments. Approved by the RSMTF at RSMTF/3 for presentation to the EATCHIP Liaison Officers for endorsement	All
1.1	30 May 97	Endorsed at the EATCHIP Liaison Officers Meeting No.19 after small editorial changes	All
1.2	22 Dec 97	Proposed issue including radar separation minima in TMA and Final Approach Track	All
1.3	12 Feb 98	Proposed issue including comments received from TF Members upon version 1.2	All
2.0	14 Dec 98	Endorsed by ACG Members	All

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The primary function of Air Traffic Control (ATC) is the provision of safe and expeditious sequencing of traffic, by providing safe horizontal and vertical separation distances between aircraft, which may not be reduced simultaneously. Using lower radar separation values has long been recognised as a beneficial way to improve Air Traffic Control Capacity and Efficiency. Such a reduction is to be done in a careful manner in order to maintain the high level of safety existing in Air Traffic Management.

The implementation of 5NM/10NM radar separation by 1995, without degrading Flight Safety, is a defined objective of "The ECAC Strategy for the 90s". Indeed, the Ministers of Transport, meeting in 1989 specifically identified the harmonisation of radar separation values as an ECAC Objective in the document, signed by the Transport Ministers in Paris on the 24 April 1990, which reads

> ***"En-route radar separation of 5 NM is to be applied throughout high-density areas by 1995 at the latest. Elsewhere, en-route radar separation of 10 NM is to be applied by the same date."***

The horizontal radar separation minimum may, if so prescribed by the appropriate ATS authority, be reduced to 3 NM when radar capabilities at a given location so permit (ICAO, Rules of the Air and Air Traffic Services).

Made aware of the fact that the en-route system is only part of the problem, but that also the way in which traffic is handled within and around airports is contributing to the capacity of the air transport system, the ECAC Ministers decided to start in parallel to the previous programme a separate complementary one for airport and air traffic service interface : APATSI. Meanwhile APATSI ceased to exist as a separate programme and has been absorbed in EATCHIP. However, its major objectives remained unchanged. Amongst these the APATSI programme emphasised the acceptance of the current ICAO Standards and implementation of separation criteria not in excess of the prescribed separation minima : as a minimum,

- ***the reduction of separation on final approach to 2.5 NM***
- ***reduction of centreline spacing for independent IFR parallel operations; and***
- ***reduced diagonal separation for dependent IFR runway operations should be pursued****...".*

This document defines some methods by which all States, in accordance with their ATC complexity levels, can apply the radar separation minima. It shows which performance parameter and Standards, linked to the CIP Objectives and Deliverables in the various Domains, should be implemented before the appropriate ATS authority is able to calculate and measure the whole system performance, in terms of risk of collision per flight hour, and approve 2,5NM/3NM/5NM/10NM radar separation minima.

Several Convergence and Implementation Objectives have to be linked together and simultaneously completed in order to reach the full ECAC Objectives as previously described. Both mono and multi-radar environments are considered when determining the safety, operational and technical criteria to support the authorised application of the radar separation minima within one sector, between two sectors (same ACC), between two sectors (adjacent ACCs), silent handovers (same/adjacent ACC) and in TMA and on Final Approach Track.

The radar separation minimum is the starting point for applying radar separation between any pair, or larger number, of aircraft. According to ICAO rules - *"the radar separation minimum shall be prescribed by the appropriate ATS authority according to the capability of the particular system to accurately identify the aircraft position in relation to the centre of the radar position symbol"* (ICAO Doc 4444 Part VI, Par. 7.4.3). This minimum is therefore to be related to the accuracy to which the radar system is capable of representing the aircraft positions on the display. The document addresses this issue in the **technical assessment paragraphs**.

A radar system is considered to be the combination of a radar sensor(s), radar data processor and radar display.

The nationally authorised minimum radar separation, which is the one which can safely be applied in practice by a particular radar controller, using a particular radar equipment, on a particular day, at a particular time, on a particular sector, under particular traffic conditions and when controlling particular aircraft, can only be assessed by the radar controller himself using the prescribed minimum as a starting point. This is further considered in the paragraphs dealing with **operational assessment**.

Beginning from a given radar separation minimum it is necessary to determine what radar system errors would be acceptable to apply the given radar separation. This is addressed in the **safety assessment** paragraphs.

Seven CIP Objectives - 3.4.1 to 3.4.7 - are specifically concerned with the application of radar separation minima in support of different operational ATC functions. The various CIP objectives are listed below against the relevant objective title and definition.

CIP Objective	TITLE	DEFINITION
3.4.1	Radar Separation within one sector	A radar separation minimum of 5NM/10NM may be applied between aircraft under responsibility of one controller, throughout the area of jurisdiction
3.4.2	Radar separation for verbal transfer between en-route sectors, in the same ACC	A radar separation minimum of 5NM/10NM may be applied at the time of transfer of control between adjacent en-route sectors, in the same ACC, provided that verbal co-ordination is effected between the transferring and accepting controllers
3.4.3	Radar separation for verbal transfer between ACCs	A radar separation minimum of 5NM/10NM may be applied at the time of transfer of control between adjacent ACCs, provided that verbal co-ordination is effected between the transferring and accepting controllers
3.4.4	Silent radar transfer between en-route sectors in the same ACC	A radar separation minimum of 10NM/15NM may be applied between aircraft at the time of transfer of control between en-route sectors in the same ACC, without verbal co-ordination being effected between the transferring and accepting controllers
3.4.5	Silent Radar Transfer between ACCs	A radar separation minimum of 10NM/15NM may be applied between aircraft at the time of transfer of control between adjacent ACCs, without verbal co-ordination being effected between the transferring and accepting controllers
3.4.6	Implement 3 NM Radar separation within High Complexity TMAs	A radar separation of 3 NM should be implemented and may be applied between aircraft throughout the TMA area of jurisdiction. Controllers are permitted to apply this separation minima, taking due notice of relevant safety, technical, operational and other circumstances. When controllers are not physically adjacent, two-way direct, instantaneous controller to controller voice communication facilities are mandatory when the separation is applied between aircraft under the responsibility of different controllers.
3.4.7	Implement 2.5 NM radar separation on Final Approach at Category 1 Airports	A radar separation of 2.5 NM should be implemented and may be applied between succeeding aircraft established on the final approach track within 10 NM of the landing threshold, provided prescribed procedures are respected. The controller is permitted to apply this required separation minima, taking due notice of relevant safety, technical, operational and other circumstances

1. INTRODUCTION

The primary function of Air Traffic Control (ATC) is the provision of safe and expeditious sequencing of traffic, by providing safe horizontal and vertical separation distances between aircraft, which may not be reduced simultaneously. In areas outside the coverage of ATC radar systems, horizontal separation remains a function of time.

Using lower radar separation values has long been recognised as a beneficial way to improve Air Traffic Control Capacity and Efficiency. Such a reduction is to be done in a careful manner in order to maintain the high level of safety existing in Air Traffic Management.

Over the last three decades increasingly advanced radar systems, with constantly improving accuracy in both range and azimuth, have been deployed through most of the areas of high air traffic density in Western Europe. This has allowed the reduction of the horizontal separation standard from the procedural (non-radar) ATC separation of 10 minutes between aircraft at the same level to approximately 3 minutes or 20 - 25 miles between en-route aircraft, when the distance between aircraft is being monitored on radar by the controller, and to 10 miles or less, between aircraft, when the controller has the aircraft under positive radar control.

The implementation of 5NM/10NM radar separation by 1995, without degrading Flight Safety, is a defined objective of “The ECAC Strategy for the 90s”. Indeed, the Ministers of Transport, meeting in 1989 specifically identified the harmonisation of radar separation values as an ECAC Objective in the document, signed by the Transport Ministers in Paris on the 24 April 1990, which reads :

“En-route radar separation of 5 NM is to be applied throughout high-density areas by 1995 at the latest. Elsewhere, en-route radar separation of 10 NM is to be applied by the same date.”

The objective of this Strategy is to achieve the most expeditious flow of traffic commensurate with safety, to reduce delays and improve airspace capacity. It is recognised that many States in the high density areas already apply 5NM en-route radar separation minima and in parts of Germany 4NM is in use.

The en-route system being only part of the problem, the ECAC’s Directors General underlined the synergy effects emanating from incorporating the APATSI programme into the EATCHIP programme. MATSE 5 was presented with a proposal to terminate a separate APATSI programme and absorption of its activities into EATCHIP. The proposal was accepted and EUROCONTROL took on responsibility for its management. In the framework of this document it is judged beneficial to quote one of APATSI’s Major Objectives concerning the implementation of the ICAO Standards with regard to the prescribed separation minima : “ **as a minimum,**

- **the reduction of separation on final approach to 2.5 NM**
- **reduction of spacing between runway centrelines for independent IFR parallel operations; and**

– **reduced diagonal separation for dependent IFR runway operations should be pursued**...".

Paradoxically as sector workload increases a point is reached where controllers are unable to apply "tight" separation, since the sector workload does not permit aircraft flying at, or close to, the radar separation minima, being given the continuous level of attention which safe application of such separation distances demand. This effect, at times of high traffic loading, leads to the use of significantly increased separation distances between aircraft. Individual sector capacity is not determined, solely, by the approved radar separation minima. Additional factors may include the complexity of the airspace structure, consequential routine conflicts between aircraft where standard routes cross or converge, the traffic density and the communications workload.

A distinction must also be made between the radar separation minimum as authorised by the appropriate National ATS authority and the actual separation that is applied by the controller, which is dependent on circumstances at a given time.

To authorise a particular radar separation minimum, within a specific airspace, it is necessary to determine the risk of failure of each sub-system element which contributes to the continuous availability of accurate, displayed radar data, so as to calculate that the risk of collision per flight hour is acceptably low and is equal to, or better than, the Target Level of Safety (TLS) adopted and approved by the appropriate ATS authority.

2. STRUCTURE OF THE DOCUMENT

Section 1, the Introduction, provides the reader with the required background knowledge in respect of the function of Air Traffic Control, the current use of radar separation values and the ECAC Objective to harmonise radar separation values as a means to improve ATC capacity and efficiency.

Section 3 defines the purpose and status of the document and proposes how it is to be used by National Administrations.

Section 4 addresses the scope of the document in respect to the geographical and operational areas of application, the radar environments and the criteria used for radar separation value assessment.

Section 5 identifies the criteria to support 5NM/10NM radar separation minima from respectively, safety, technical and operational perspectives.

Section 6 describes the criteria to support 3 NM radar separation in high complexity TMAs and 2.5 NM on final approach.

Section 7 provides information with respect to communication facility properties.

Section 8 translates the previously identified criteria into applicability tables for both the implementation of 5NM/10NM radar separation minima in the en-route phase of the flight and 3NM/2.5NM in TMAs or the final approach track respectively.

Radar separation in the ECAC area is conducted in accordance with the ICAO regulations and recommendations governing the use of radar, as contained in:

- ICAO PANS RAC Doc. 4444
- ICAO Doc. 7030, EUR SUPPS
- ICAO Doc. 9426, Air Traffic Services planning manual
- EUROCONTROL Standard Document entitled “Radar Surveillance in En-Route and Major TMAs” (in more recent documents the term Major TMA is replaced by High Complexity TMA)

The part of the ECAC and ICAO documents relevant to the utilisation of radar separation have been extracted and copied in **Annex 1** Example methodologies used by States today for mono and multi-radar environments to support a given radar separation minima can be found at **Annex 2,** and the methodologies used for implementing the minimum radar separation in TMAs and on Final Approach tracks is set out in **Annex 3.**

3. PURPOSE OF THE DOCUMENT

During the development and subsequent implementation of the ECAC Objective, as part of EATCHIP, it became apparent that the various associated operational requirements and technical functions are Deliverables identified within the several different EATCHIP Domains and CIP Objectives.

This document will define some methods by which all States with high ATC/TMA complexity levels can apply the agreed radar separation minima. It will show which performance parameters and Standards, linked to the CIP Objectives and Deliverables in the various Domains, should be implemented before the appropriate ATS authority is able to calculate and measure the whole system performance, in terms of risk of collision per flight hour, and approve the appropriate radar separation minima for en-route, TMAs and final approach tracks, respectively. Several Convergence and Implementation Objectives have to be linked together and simultaneously completed in order to reach the full ECAC Objectives as previously described.

In order to establish the linkage between the various CIP objectives, which are to be met for the fulfilment of the ECAC high level Objectives, this document specifies the requirements for the practical application of the prescribed radar separation minima.

National Administrations and EUROCONTROL will use it as a reference document permitting the identification of which CIP objectives, in different Domains, are still on the critical path for the application of the ECAC prescribed radar separation values, thereby enabling planners to define the proper priorities.

It will also provide guidance information for States to facilitate the development of National airspace environments where 5NM/10NM and/or 3NM/2.5NM Air

Traffic Control radar separation minima can be approved by the State's Air Traffic Services (ATS) Authority.

4. SCOPE OF THE DOCUMENT

This document addresses the application of Radar Separation Minima within the ECAC en-route upper and lower airspace and within terminal airspace and on the final approach segment in respect to GAT. OAT and State aircraft are bound to these provisions when operating under ICAO regulations. Both mono and multi-radar environments are considered when determining the safety, operational and technical criteria to support the authorised application of the radar separation minima within one sector, between two sectors (same ACC), between two sectors (adjacent ACCs), silent handovers (same/adjacent ACC) and in TMAs or on final approach segment.

5. CRITERIA FOR ACCURACY OF A RADAR SYSTEM TO SUPPORT 5/10NM SEPARATION MINIMA

An ATS system is a complex entity involving aviation authorities, human resources, management and maintenance of technical resources, operational procedures and safety aspects. This section addresses respectively the safety, technical and operational aspects.

The radar separation minimum is the starting point for applying radar separation between any pair, or larger number, of aircraft. According to ICAO rules - *"the radar separation minimum shall be prescribed by the appropriate ATS authority according to the capability of the particular system to accurately identify the aircraft position in relation to the centre of the radar position symbol"* (ICAO Doc 4444 Part VI, par. 7.4.3). This minimum is therefore to be related to the accuracy to which the radar system is capable of representing the aircraft positions on the display and is considered under section 5.2, the technical assessment. A radar system is considered to be the combination of a radar sensor(s), radar data processor and radar display.

The nationally authorised minimum radar separation, which is the one which can safely be applied in practice by a particular radar controller, using a particular radar equipment, on a particular day, at a particular time, on a particular sector, under particular traffic conditions and when controlling particular aircraft, can only be assessed by the radar controller himself using the prescribed minimum as a starting point. This is further considered in section 5.3, the operational assessment.

Beginning from a given radar separation minimum it is necessary to determine what radar system errors would be acceptable to apply the imposed 5/10 NM as required by the third Operational Objective of the "ECAC Strategy for the 1990s". This is addressed in section 5.1, the safety assessment.

5.1 Safety assessment

The primary function of air traffic control is to provide safe separation between aircraft. This is achieved by implementing minimum horizontal and vertical separations, which must not be simultaneously reduced.

The probability of collision, or loss of separation, between two aircraft is generally attributable to human (aircrew or controller) error. There is a risk of collision, between any pair of aircraft, in every encounter that requires controller intervention and the application of radar separation between those aircraft. However radar separation standards are only applied in the horizontal plane and the minima can only be applied when each aircraft is under positive radar control.

5.1.1 Collision risk

The collision risk is the probability of a mid-air accident in a prescribed volume of airspace for a specified number of flight hours due to loss of planned separation and where one collision is considered to produce two accidents (RGCSP - 1A-5).

Factors contributing to the risk of collision include:

- the circumstances requiring the provision of radar separation,
- airspace structure,
- sector capacity,
- communications system occupancy,
- air traffic controller workload,
- pilot/aircrew workload,
- the actual horizontal distance between aircraft,
- both aircraft being at, or passing through, the same level,
- system function,
- the radar plot position error (volume of uncertainty of the aircraft's position) indicating a correct separation where it is actually negligible.

All potential causes of collision must be identified and, where possible, analysed. To determine the appropriate radar separation minima the analysis is related to the effect of inaccuracies, in the displayed radar data, so as to estimate the risk of collision and to decide whether the risk, for the implementation of a particular radar separation minimum within the radar coverage of a specific radar system, is acceptably safe.

The ICAO Review of the General Concept of Separation Panel (RGCSP) has recommended a TLS of 5×10^{-9} fatal accidents per flight hour per dimension (lateral, longitudinal and vertical) arising from collisions due to any cause for systems planned for implementation after the year 2000 (RGCSP - WG/A -- 5/95). This TLS applies to the risk of collision due to all causes, i.e. technical performance, human error etc.

There is no ICAO RGCSP recommendation as to what proportion of the TLS should apply to the risk of collision, within a radar environment, due to the inaccurate radar data. Previous work (See Attachment B) has arbitrarily used a proportioning factor of 10% of $5x10^{-9}$. This results in a TLS due to inaccurate radar data, of $5x10^{-10}$ fatal accidents per flight hour. This TLS does not apply to other causes of collision risk such as lack of accuracy or timeliness in the radar display.

5.1.2 Collision risk due to radar system inaccuracy

It is possible that errors in the accuracy of the radar data, presented to the controller by the RDP system, may be sufficient to cause loss of separation, or worse. The risk of collision, attributable to the system function, depends upon the:

- accuracy, integrity and availability of the ATC radar system,
- accuracy, integrity and availability of the communications system (A/G-G/G),
- contingency support to the radar and Communications systems, and
- established ATC procedures.

5.2 Technical assessment

This section does not aim for a full description of the intricate relation between radar separation and radar system performance. However it is felt that a common understanding of the technical aspects will contribute consistently to the objectives of the whole document.

5.2.1 General

From a processing point of view, the radar data processing chain is undoubtedly the most complex element of the ATM system. This is due to its many complex constituent elements and also to the important influence of the radar environment, be it mono- or multi- radar environment. Obviously the final accuracy of the displayed position is a function of the performance characteristics of all radar sub - systems.

Classically, the radar chain consists of primary (PR) and secondary surveillance radar (SSR) sensor(s). The PR sensor system performance is mainly a function of the aircraft reflection characteristics, the environment (surrounding terrain, objects, weather conditions, interference, etc.); the antenna characteristics, the characteristics of the transmitter and the receiver and the extractor processing stages. For the SSR performance, the same elements play a role. Due to the so-called “co-operative” nature of this system, the performance of the SSR is, however, not affected by the reflection characteristics of the aircraft, but rather by the characteristics of the on-board transponder and corresponding on-board antenna(s) (including the effect of e.g. the impact of the presence of transponder antenna diversity to avoid antenna screening in case of manoeuvring aircraft, which can be very important in the approach phase of an aircraft). For many sensors, both a PR and an SSR are collocated at one site and a logic is present to produce combined target reports.

The target report produced by a radar site is generally referred to as a plot. The performance of a plot is generally measured in the form of a number of plot performance characteristics, categorised as follows (no full definition of all the following notions is given here) :

Coverage The volume of airspace within which the radar system detects and displays aircraft position plots (irrespective of performance)

Reliability

1. Probability of Correct Plot Detection
2. Probability of Correct Code Validation (for the various SSR modes)
3. Probability of the presence of various categories of false PR and SSR plots (not detailed in this paper)
4. Probability of False SSR Code Validation

Accuracy The characteristics of the deviations of the measured radar positions compared to the real aircraft position.

1. Various categories of position errors are measured (3-dimensional), i.e.:
   - Random Errors
   - Correlated Errors, where the errors in range, azimuth and/or altitude on a correlation in position and/or time (multi-path, partial resolution loss)
   - Systematic Errors (various types of systematic range, azimuth, time-stamp and radar position errors).
2. Possible use of filters
3. Ageing inaccuracy (time past since last update)
4. Errors in the display system

The above general reliability and accuracy performance characteristics could in the case of aircraft in close 2-dimensional proximity be affected considerably by the resolution capabilities of the radar system.

Although having a higher overall accuracy modern monopulse SSR-systems suffer particularly from 2-dimensional aircraft proximity.

Overall measured reliability and accuracy of radar plot information are, therefore, not always representative for situations where a radar separation minimum has to be applied. These characteristics should be considered as a function of the degree of proximity of the aircraft. Of particular importance here are cases of correlated position errors, which have been observed for certain radar stations, where, for aircraft in proximity, the “apparent separation” from the radar plot information is larger than the real separation. This behaviour can, in certain conditions, lead to very dangerous situations, and has in the past been the reason for excluding the use of 5 NM separation minimum for certain radar systems suffering from this problem. Separation minima of 8 NM and preferably 10 NM were then applied.

For a single radar station, the effect of correlated position errors, due to “partial loss of resolution”, is found to have the most crucial impact on the radar separation minimum. Correlated position errors, due to another source of radar problems called “multi-path” (distortion of the radar beam due to the characteristics of the terrain surrounding the radar site), has a very limited effect on the separation applied as it affects adjacent aircraft plots in the same way.

5.2.2 Mono / Multi radar data processing

Most radar chains contain, at centre level, a radar data processing system which includes some form of tracking. The type of tracking applied (mono-radar mosaic, multi-radar tracking based on different merging techniques of mono-radar tracks, real-multi radar tracking techniques based e.g. on so-called variable-update techniques, etc.) is of great importance because of the effect on the accuracy with which the overall radar system presents the aircraft positions to the controller.

The effect of random, correlated and systematic single radar errors on the track accuracy is, therefore, very much dependent on the type and complexity of the tracker (e.g. a logic to assess and eliminate systematic radar errors).

Even though more computing resources and communications links are required in the multi-environment and complicated algorithms are needed to reduce the misalignment errors, it is generally acknowledged that a number of the features which constitute a multi-radar environment render this system more attractive than the mono-environment.

The most widespread advantages are listed hereafter :

- Increased opportunity of detection (higher radar data update rate) in a defined interval of time reduces the probability of losing tracks and improves the following of manoeuvres.
- Improved quality of detected air picture.
- Improved combination technique is obtained when the individual target co-ordinated data are weighted according to their accuracy.
- Quality enhancement by redundancy in the domains of acquisition, distribution and processing of data.
- A properly designed multi-radar tracking system, having sufficient overlapping radar coverage, can overcome resolution loss problems created by individual radars.
- Capability of reconfiguration in case of failure of some sensors leads to improved contingency planning.

The further development of the tracker together with the degree of radar redundancy (multi-radar coverage) will finally determine to what an extent a degradation in plot reliability and/or accuracy affects the accuracy of the track position. The track accuracy is simultaneously affected by the movements of the aircraft. Depending on the amount and changes of the aircraft Mode-of-Flight [1] (MOF) and the types of MOF's, the visualised separation of aircraft may be affected.

5.2.3 Technical Summary

In modern radar chains the extent to which the visualised separation of aircraft represents their real separation is a function of:

- the radar plot reliability and accuracy [2]
- the performance characteristics of the RDPS
- the relative changes in the Mode-of-Flight of the aircraft being tracked.

In other words :

- A multi-radar environment compared to the mono environment improves the performance of the tracking system, due to a higher data renewed rate, which should result in better track accuracy.
- The multi-radar environment is, at least, equal or more accurate than the mono-radar environment.

Several different methodologies are used by States today that are all valid in proving that a radar or a group of radars can support the application of 5NM radar separation minima. An example of a methodology that can be used for a mono-radar system can be found at Annex 1 Attachment A. Examples of methodologies that can be used for a multi-radar tracking system can be found at Attachment B and C.

5.3 Operational Assessment

The radar separation minimum, being a function of the surveillance infrastructure and equipment, is used as the starting point (the basis) to ensure that aircraft, separated by the minimum are at an acceptable low risk of collision. In other words, this minimum, which should never be infringed, is established to overcome the inability of the radar controller to estimate which separation, at any given time, would be required to compensate for technical inaccuracies.

However air traffic controllers always visualise and work with estimated future aircraft positions and therefore can not rely upon the minimum authorised radar separation to maintain the necessary protection parameters between aircraft prior to taking adequate action. Therefore, this absolute minimum does not generally represent the operationally applied radar separation. Even though operational conditions do not allow in some instances the controller to apply

---

1) Mode - of - Flight: An generic term to express how a flight is conducted through all phases of flight e.g. take-off, climbing, straight and level, manoeuvring, descending, landing.

2) The required plot and track performance for applying a 5NM (respectively 10NM) radar separation minimum, are specified in parts 6 and 7 of the proposed EUROCONTROL Standard Document (13 May 1996, reference 006-95) titled "Radar Surveillance in En-Route Airspace and Major TMAs" although this Standard only recommends figures for mono-radar systems.

the absolute minima, having this minima as a target provides the controller with flexibility in the design and conduct of his/her control activities. It is also necessary to consider that as the workload increases within a particular sector, it may be necessary to increase the separation to enable the controller to focus concentration upon the resolution of urgent tactical radar control problems

In applying radar separation the controller considers, consciously or not, many more elements, the majority of which are of a non-technical nature. The applied radar separation is the minimum, approve value plus a buffer of non technical factors, such as:

- airspace management, structure and procedures,
- national procedures and regulations,
- quality and usage of human resources (controllers' perception and expertise, controllers' workload). The amount of traffic which can be safely handled at any given time varies with the capabilities and the skills of the individual controller,
- communication congestion.

The applied radar separation minimum in the "transfer of control"-area (area of common interest) is related to the existence of continuous processed surveillance data, available for both adjacent units. It is recognised that actual radar data processing systems (or better Surveillance Data processing and Distributing systems-SDPD) operate in a "system"-area which is in general larger than the ATS area of jurisdiction. As such overlapping exists between adjacent areas of jurisdiction which, with the help of specially adapted SDPD infrastructure, could result in a "Track continuity" [1)] during the transfer activities.

The fact of disposing of the same processed radar data, authorises the application of a uniform radar separation minimum in both adjacent area of jurisdiction, which is generally smaller than the current applied separation.

Summarising the considerations discussed above, it is acknowledged that:

- applying the minimum authorised radar separation may result in more aircraft at a given flight level, thus optimising the cruising altitudes and as such, increasing capacity;
- the minimum authorised radar separation cannot be applied as a mathematical rule and is very much dependent on variables of an operational nature.

6. CRITERIA FOR ACCURACY OF A RADAR SYSTEM/SENSOR TO SUPPORT 3 NM OR 2.5 NM

By analogy with the previous paragraph the same structure is used; accordingly the following issues are addressed : safety, technical and operational assessments.

[1)] SDPD requirements for inter-system "Track Continuity" are described in the Operational Concept Document for EATCHIP Phase III System Generation OPR.ET1.ST02.1000-OCD-01.00)opr.et1.st02.1000-ocd-01.00)

6.1 SAFETY assessment

The provisions of paragraph 5.1 are as applicable to High complexity TMA radar separation minima as they were in the application of 5 NM radar separation. Therefore the accuracy, integrity and availability of both the radar system and communication system, ATC procedures and contingency provisions shall be such that an acceptable level of safety is guaranteed.

Levels of safety may be specified either qualitatively or quantitatively. Whenever practicable, quantitative safety levels should be derived and maintained for all systems (op.cit. “EATCHIP Safety Policy : Implementation guidance material”, page 52, Par. 7.4)

6.2 TECHNICAL assessment

6.2.1 Radar Separation - 3 NM

States noted that, in essence, the method to assess the radar accuracy for 3 NM radar separation does not differ from the one used for the 5NM/10NM radar separation. The contributions of France and United Kingdom, set out in Annex 3/Attachment A, are an illustration of the methodologies being used to evaluate the radar capabilities.

The EUROCONTROL Standard concerning “Radar surveillance in en-route airspace and major terminal areas” formulates criteria for application of 3 NM radar separation minima in High complexity TMAs, such as

a) Duplicated SSR coverage and single PSR radar, as such assuring continuous availability of radar position information and enabling provision of air traffic services to aircraft unable to respond to SSR interrogations.

b) The coverage within major terminal areas shall extend from the lowest altitudes of the intermediate approach segments for the principle aerodrome concerned. Coverage elsewhere will extend from the minimum levels at which radar services are required to be provided, up to the upper limit of the terminal area.

Note: The coverage requirements below the lowest altitudes of the intermediate approach segments can be met in accordance with the local aerodrome conditions, provided continuity of services for the high complexity TMA is ensured.

c) Provisions shall be made for the continuity of radar coverage in the areas interfacing with en-route airspace

d) The position accuracy of the surveillance radar data available at the control position shall have an error distribution with a root mean square value (RMS) equal to or less than 300 metres for high complexity TMAs.

e) Surveillance information updates shall enable the display updates to be no more than 5 seconds.

f) A maximum of 2 successive updates by extrapolation for position data.

6.2.2 Radar Separation - 2.5 NM

A further reduction of the minimum authorised radar separation to 2.5 NM on the final approach track within 10NM from the landing threshold is subject to stringent requirements. In addition to the operational aspects, extensively reproduced in paragraph 6.3.2, ICAO's Rules of the Air and Air Traffic Service (Annex 11 and Doc 4444) also provides technical guidance.

It is the capability of a radar system or sensor and the distance of the target from the sensor which determine the prescribed radar separation minimum. The following elements shall be taken into consideration when deciding upon the minima :

a) appropriate azimuth and range resolution;

b) updating cycle of radar display of 5 seconds or less;

c) availability of Surface Movement Radar or Surface Movement Guidance and Control System.

It is recognised that the radar separation minimum of 2.5 NM on final approach track can not be completely dissociated from the type of approach, such as : (in-)dependent or segregated approaches on parallel runways, on near-parallel or crossing runway etc. Therefore for the different types of approach, reference is also made to the technical provisions of the referred ICAO document in terms of

- more accurate azimuth accuracy;
- shorter updating period;
- higher resolution display, providing position prediction and deviation alert.

6.3 OPERATIONAL assessment

6.3.1 Reduction of horizontal separation

As stated in the introduction, the appropriate ATS authority is authorised to reduce the radar separation minima. Once that the radar separation minima are established, it is incumbent on ATC to ensure that these minima are not compromised. A reduction of the horizontal separation minima to values such as 3 NM and 2.5 NM, should be carefully evaluated and due notice taken of following factors :

a) Navigation accuracy based upon airborne and ground components;

b) The time interval between position information;

c) Rapid and reliable air-ground communication;

In TMAS, by consistently applying radar separation minima, especially to incoming aircraft on the approach track, controllers can optimise throughput. This sometimes leads to a reduction of the length of time for which peak traffic loading is experienced. In comparison , and sometimes paradoxically, in busy periods in the en-route environment, the controller often tends to increase the radar separation to avoid an unacceptable high workload for the given circumstances

6.3.2 ECAC common radar separation

There is an objective to implement common radar separation minima in the ECAC States as follows :

a) **High complexity TMAs** : 3 NM when radar capabilities at a given location permit; and

b) **Category 1 airport** : 2.5 NM between succeeding aircraft which are established on the same final approach track within 10NM of the landing threshold (Cf. Examples in Annex 3, Attachments B, C and D for Germany/Frankfurt, UK/Heathrow and Austria/Vienna).

Note : Category I airport as used in EATCHIP terminology

This minimum can be applied provided that:

1) the average runway occupancy time of landing aircraft is proven, by means such as data collection and statistical analysis and methods based on a theoretical model, not to exceed 50 seconds (an example of Runway Occupancy Time calculations at Frankfurt Main is set out in Annex 3, Attachment E);
2) braking action is reported as good and runway occupancy times are not adversely affected by runway contaminants such as slush, snow or ice;
3) a radar system with appropriate azimuth and range resolution and an update rate of 5 seconds or less is used in combination with suitable radar displays; and
4) the aerodrome controller is able to observe, visually or by means of surface movement radar (SMR) or a surface movement guidance and control system (SMGCS), the runway-in-use and associated exit and entry taxiways;
5) wake turbulence radar separation minima as per ICAO Doc 4444, 7.4.4 or as may be prescribed by the appropriate ATS authority (e.g. for specific aircraft types), do not apply;
6) aircraft approach speeds are closely monitored by the controller and when necessary adjusted so as to ensure that separation is not reduced below the minimum;
7) aircraft operators and pilots have been made fully aware of the need to exit the runway in an expeditious manner whenever the reduced separation minimum on final approach is applied; and

8) procedures concerning the application of the reduced minimum are published in Aeronautical Information Publication.

7. COMMUNICATION FACILITY PROPERTIES

7.1 General

Although in previous chapters both the operational and technical aspects related to radar separation minima have been discussed, it is felt appropriate to dedicate a separate paragraph to the two-way controller/controller communication properties.

Material related to this issue has been taken from the following documents :

- ICAO documents :
  - Doc 4444/PANS-RAC;
  - Annex 10 - Aeronautical communication, Volume II; and
  - Annex 11 - ATS requirements for Communication;
  - Doc 7030 Regional Supplementary Procedures
- EUROCONTROL documents :
  - Guidelines for the Implementation of the Automatic ATS Voice Communication Network.
- Report of the Sixth ICAO European Mediterranean Regional Air Navigation Meeting.

Attributes for controller-to-controller communication facilities should be common and agreed for use in the whole ECAC area. They have to be defined clearly and unambiguously, so as to avoid any possible confusion. Therefore, in support of applying radar separation minima equal to or more than 3 NM on the one hand and less than 3 NM on the other hand, direct, respectively instantaneous voice communication facilities are required.

It remains however the prerogative of a State to implement alternative solutions of an equal level of safety.

7.2 Definitions and applicability

7.2.1 Direct Controller-Controller Voice Communication (DCCVC):

7.2.1.1 Definition

DCCVC is defined as a two-way direct ground/ground voice communication system which allows for a communication to be established between radar controllers within 2 seconds in 99% of the time, supplemented by the ability to interrupt, if necessary, calls of a less urgent priority using the same channel.

Note : The expression" a communication to be established" should be understood as the setting up of a connection, the activation of a technical circuit, between the calling and the receiving controller. It does not include the content of a message, nor does it require any action by the receiving controller.

7.2.1.2 Applicability DCCVC

Within the scope of the Applicability Tables (Cf. Par. 8), the provisions of DCCVC shall be assigned as a minimum requirement of communications systems needed to support radar transfers employing radar separations of not less than 3 NM.

A direct trunk between two ATS units should have sufficient capacity to ensure that only in exceptional circumstances traffic have to be routed via alternate routes. If a call is switched via the alternate route the signalling sequence should not exceed 5 seconds and an individual SSR code should be used for the transfer of radar identity.

7.2.2 Instantaneous Controller-Controller Voice Communication (ICCVC):

7.2.2.1 Definition

ICCVC is defined as a two-way direct ground/ground voice communication system for non physically adjacent controllers, which allows for a communication to be established between them within 1 seconds or less in 99% of the time.

7.2.2.2 Applicability ICCVC

Within the scope of the Applicability Tables, the provisions of ICCVC shall be assigned as a minimum requirement of communications systems needed to support radar transfers and transfers of control/communication on the final approach track, employing separations of less than 3 NM

It is emphasised that no acceptance delay at the receiving end of the communication system should be authorised. In other words no key activation should need to be initiated in order to accept an incoming call. ICCVC refers, for example, to hot lines or intercom type communication devices, but switching systems compliant with the required time parameters qualify just as well.

7.3 Service availability of commercial circuits

An overall service availability of not less than 99.99 % of the time is required in support of ground/ground voice communications.

8. APPLICABILITY TABLES FOR RADAR SEPARATION MINIMA

Seven CIP Objectives - 3.4.1 to 3.4.7 - are specifically concerned with the application of radar separation minima in support of different operational ATC functions. The various implementation requirements are identified below against the relevant objective.

8.1 CIP Objective 3.4.1. Radar separation within one en-route sector

a) Radar, processing and display systems with performance, quality and availability standards equal to, or better than, the maximum acceptable risk and which permit the ATS authority to approve the use of 5NM, 10NM or any other Radar Separation Minima within the appropriate sector airspace,
b) RTF system with necessary quality, reliability and coverage,
c) Updated flight plan information, including individual SSR code,
d) Established contingency procedures,
e) Some States may require civil/military co-ordination before applying 5NM/10NM radar separation.

8.2 CIP Objective 3.4.2. Radar separation for verbal transfer between en-route sectors in the same ACC

a) radar coverage extending at least 30NM beyond the sector boundary,
b) proven continuation of radar plot, position accuracy across the adjacent sector boundaries,
c) 2 way direct (DCCVC) controller to controller contact with the adjacent sector radar controllers,
d) 8.1 a+b+c+d+e.

8.3 CIP Objective 3.4.3. Radar separation for verbal transfer between ACCs

a) agreed TLS and the approval, by the relevant ATS authorities, of the use of the same Radar Separation Minima (5NM/10NM) within the airspace of the adjoining sectors concerned,
b) Letter of Agreement (LoA) between the adjacent ACCs,
c) 8.1 a+b+c+d+e,
d) 8.2 a+b+c.

8.4 CIP Objective 3.4.4 & 3.4.5. Silent radar transfer between en-route sectors in the same ACC or between ACCs

a) approval of the silent radar transfer procedures and specific RadSepMin, by the relevant Aviation Authority (ies),
b) LoA as 8.3 + direct “Planner” to “Planner” telephone line or OLDI,
c) 8.1 a+b+c+d+e,
d) 8.2 a+b+c.

8.5 CIP Objective 3.4.6. : Implement 3 NM Radar Separation within High Complexity TMAs

a) Radar processing and display systems with performance quality and availability standards at levels equal to or better than those which result in a maximum acceptable level of risk and which permit the ATS authority to approve the use of 3 NM within the appropriate sector airspace,
b) Relevant safety, technical and operational requirements must be conformed to,
c) Depending upon the transfer conditions direct (DCCVC) or instantaneous (ICCVC), two-way controller to controller communication facilities must be provided,
d) 8.1. b+c+d.

8.6 CIP Objective 3.4.7.: Implement 2.5 NM Radar Separation on Final Approach at Category 1 Airport

a) Radar processing and display systems with performance quality and availability standards at levels equal to or better than those which result in a maximum acceptable level of risk and which permit the ATS authority to approve the use of 2.5 NM on the Final approach track;
b) Relevant safety, technical and operational requirements must be conformed to,
c) Instantaneous, two-way direct (ICCVC) controller to controller communication facilities must be provided,
d) 8.1. b+c+d.

ANNEX 1

Selected parts from ECAC AND ICAO DOCUMENTS
(relevant to radar separation)

A.1 Foreword

The following text, copied from the ECAC and ICAO documents, is a necessary background for radar separation issues.

All *quoted* text is in *ITALICS*.

Text voluntarily omitted is marked by (...).

Key words or sentences have been put in bold (at the author's initiative).

A.2 ECAC objectives

A.2.1 High-level objectives

The ECAC Strategy for the 1990s, signed by the Transport Ministers in Paris on the 24 April 1990, adopted six operational objectives :

1. *The air traffic services route network and airspace structure is to be optimised, supported by a widespread application of area navigation from 1993 onwards.*

2. *Comprehensive radar coverage is to be applied throughout the area by 1995 at the latest.*

3. *En-route radar separation of 5 NM is to be applied throughout high-density areas by 1995 at the latest. Elsewhere, en-route radar separation of 10 NM is to be applied by the same date.*

4. *Air traffic control systems are to be progressively integrated, after being harmonised in high-density areas by 1995 at the latest, and elsewhere not later than 1998.*

5. *Automatic data communication between air traffic control centres is to be completed by 1998 at the latest.*

6. *A new high-precision air/ground data link system (Mode S) is to be operational in a central area from 1998 onwards.*

A.2.2 Implementation objectives

To achieve these operational objectives, the ECAC strategy further adopted five implementation objectives.

They are listed below together with the abstracts from the related text deemed relevant to radar separation:

***1**.-**Optimise the provision and the use of the radar surveillance function** by installing new facilities or **sharing radar data**.*

*(...) **Radar positional information constitutes the basic tool for the execution of air traffic control. The capacity of the air traffic control system could be materially increased** by the availability of such data throughout the continental ECAC area, since, in its absence in some sectors, procedural separation has to be applied, with the resultant reduction in capacity. **Continuous radar information throughout the area is therefore essential for optimal use of the radar surveillance function and, in particular, for the generalised application of radar separation**. (...)*

*(...) To support the wider exchange of radar data, **the necessary transmission procedures and networks need to be developed** (...).*

***2**.-Make ATC communications more efficient and extend the exchange of data between ATC computers by applying common specifications and installing new equipment.*

***(...) Reliable and efficient communications are an important element of the global air traffic control system. In particular voice communications constitute a vital tool in the execution of air traffic control, for contact both between controllers (co-ordination actions) and between controllers and pilots (ATC instructions).** (...)*

*(...) **The development of more sophisticated means of communications, whether air/ground or ground/ground, will not, however, change the basic requirement for fast and reliable direct voice communications in the years to come.** (...)*

*(...) **Full R/T coverage (...) An ATC telephone system (...) must be able to provide rapid and high quality communications, which are a necessity.***

***3**.-Improve airspace management by implementing new airspace and route structures, common procedures and adequate system support.*

*(...) **The operational division of airspace should be optimised for the tasks to be performed by the controllers** (...)*

*(...) Particular efforts should be made **to dissociate the limits of the sectors from national boundaries**, whenever this is operationally beneficial. (...)*

***4**.-Harmonise the development and implementation of the various technical components of ATC systems by adopting common standards and specifications.*

*(...) **Data processing constitutes a key element in air traffic control, providing automated assistance to support the work of the controller**. Regarding the prime source of basic data, the two main data processing*

functions are : -flight-plan data processing (FPP) ; -radar-data processing (RDP) .

These two systems be interconnected and make use of common data. The information derived from these two elements is the suitably combined for presentation to the controller.(...)

(...) The future controller operating environment will not only improve the presentation of different types of information to the controller (current traffic information, flight-plan information, etc...) but also provide, through ***suitable man-machine interfaces, specific decision-making aids*** *(conflict prediction, traffic-load estimation, etc.). (...).*

5*.-define guidelines for the selection, training, and licensing of air traffic services staff in ECAC member states.*

(...) ***Human resources and their related activities are a key issue in air traffic services, and are possibly the most important one****. (...).*

(...) Functions within air traffic services have changed and will continue to do so with the advent of new technology. Greater attention needs to be paid to this phenomenon in selection and training policy. (...)

A.3 ICAO Documents

A.3.1 ICAO PANS RAC Doc.4444 (Part VI) :

*(...)****The implementation of procedures is the responsibility of Contracting States; they are applied in actual operations only after, and in so far, States have enforced them.*** *(...)*

*(...)****PANS-RAC (Doc 4444) does not carry the status afforded to Standards adopted by the Council as Annexes to the Convention, and therefore, do not come within the obligation imposed by Article 38 of the Convention to notify differences in the vent of non-implementation****. (...)*

(...)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. (...)

(...)Where the type of separation or minimum used to separate two aircraft cannot be maintained, action shall be taken to ensure that another type of separation or another minimum exists or is established prior to the time when the previously used separation would become insufficient. (...)

*(...)****The use of radar to provide air traffic services shall be limited to specified areas of radar coverage, and shall be subject to such other limitations as have been specified by the appropriate ATS authority****(...)*

(...)The ***number of aircraft*** *simultaneously provided with radar* ***services shall not exceed that which can safely be handled under the prevailing circumstances, taking into account*** *:*

a) *the degree of* ***reliability and availability of the back-up facilities of the radar and the communication system in use****;*

b) ***the capabilities and skill of the controller****;*

c) ***the number of radar positions observed on the radar display*** *within the sector or area of responsibility of the radar controller; and*

d) ***the possibility of a radar equipment failure or other emergency*** *that would eventually require reverting to back-up facilities and/or establishment of non-radar separation. (...)*

(...)To ensure the safe and efficient use of SSR, ***pilots and controllers shall strictly adhere to published operating procedures****. (...)*

*(...)****The radar controller shall be satisfied that the information presented on the radar display(s) is adequate for the functions to be performed.*** *(...)*

(...)A radar unit shall normally communicate with an aircraft on the frequency appropriate to the function to be performed. (...)

(...)Before providing radar services to an aircraft, ***radar identification shall be established. thereafter, radar identification shall be maintained until termination of the radar service****.(...)*

*(...)****Radar separation shall only be applied between identified aircraft when there is reasonable assurance that identification will be maintained****. (...)*

*(...) 7.4.1. Unless otherwise prescribed in accordance with 7.4.2, 7.4.3 or 7.4.4, or Part IV with respect to independent and dependent parallel approaches****, the horizontal radar separation minimum shall be 9.3 km (5.0 NM).***

7.4.2 The radar separation minimum in 7.4.1 may, if so prescribed by the appropriate ATS authority be reduced, but not below ***a)5.6 km (3.0 NM) when radar capabilities at a given location so permit; and b) 4.6 km (2.5 NM) between succeeding aircraft which are established on the same final approach track within 18.5 km (10NM) of the runway end. A reduced separation minimum of 4.6 km (2.5NM) may be applied, provided (....)***

7.4.3 The radar separation minimum or minima to be applied shall be described by the appropriate ATS authority according to the capability of the particular radar system or sensor to accurately identify the aircraft position in relation to the centre of the RPS, PSR blip or SSR response and taking into account factors which may affect the accuracy of the radar -derived information, such as aircraft range from the radar site.

7.4.4 The following wake turbulence radar separation minima shall be applied (...)

(...) ***the transfer of radar control*** *of aircraft between adjacent control positions or between two adjacent ATS units may be effected, provided that (...)*

(...) -when the radar controllers are not physically adjacent, ***two-way direct-speech facilities between them are at all times available which permit communications to be established instantaneously****. Note.-"Instantaneous" refers to communications which effectively provide for immediate access between controllers.*

*(...) -****radio communication with the aircraft*** *is retained by the transferring radar controller until the accepting controller has agreed to assume responsibility for providing the radar services to the aircraft (...)*

Where SSR is being used and controllers are provided with radar displays showing the radar position indication and, in alphanumeric form, the identification and level of the aircraft, transfer of radar control of aircraft between adjacent control positions or between two adjacent ATC units may be effected, provided that (...)

*a)-****updated flight plan information*** *on the aircraft about to be transferred, including the discrete assigned SSR Code, is provided to the accepting controller prior to the transfer;*

*b)-****radar coverage provided*** *to the accepting radar controller is such that the aircraft concerned is shown on the radar display before the transfer is effected and is identified on, but preferably before, receipt of the initial call;*

c)-when controllers are not physically adjacent, ***two-way direct speech facilities****, which permit communications to be established instantaneously, are available between them t all times;*

d)-the transfer point or points and ***all other conditions*** *of application (...)* ***have been made the subject*** *of specific instructions (for intra-centre transfer) or of* ***a specific letter of agreement between two adjacent ATC units****;*

(...)

A.3.2 ICAO Doc.7030, EUR SUPPS :

(...) 6.2 <u>Transfer of radar control without verbal exchange - "silent" radar transfer</u>

Transfer of radar control based on the procedures specified in ICAO Doc 4444 Part VI may be carried out without systematic use of the bi-directional speech facilities available between the adjacent units concerned, provided that :

1) -the ***detailed conditions*** *applicable for the transfer are the subject of a* ***bilateral agreement****; and*

2) -the ***minimum distance*** *between successive aircraft during the period of transfer is agreed as one of the following values :*

*a)-****10 NM when SSR information*** *is used in accordance with the provisions of 7.2.1. 3),* ***provided that an overlapping radar coverage of at least 30 NM between units involved exists; or*** *b)-**5 NM** when the conditions of a) above apply and **both units involved posses electronic aids for immediate recognition of release and acceptance of aircraft under radar transfer**.(...)*

*(...) **SSR-derived information may be used alone for the provision of horizontal separation between aircraft** in the circumstance and under the conditions specified below :*

*1)- (...) SSR response may be used for the separation of **transponder equipped aircraft (...)***

*2)- (...) a)- **reliable SSR coverage** exists within the area;*

*b)-the area is designated as **controlled airspace***

c)-the control of air traffic is vested in one ATC unit unless adequate means of co-ordination exist between all ATC units concerned;

d)-actual operating experience has shown that loss of SSR responses is not occurring at a rate affecting the safety of operations and adequate measures for earliest possible detection of such losses have been developed;

***e)-density and/or complexity of air traffic in the area and provision of navigational guidance allow to revert safely to other forms of separation in case of SSR failure**;*

f)-the aircraft concerned have previously been identified and identification has been maintained;

(...)

*3)- In defined areas where **advanced ATS systems are in operation** and SSR is the main source for the provision to air traffic serves of continuous information on the position of the aircraft, **and where the carriage of** transponders is mandatory, the appropriate ATS authority, after consultation **with operators, may authorise the systematic provision of horizontal and/or vertical separation, based on SSR-derived information, between aircraft which are equipped with correctly functioning transponders,** provided that :*

*a)-**adequate SSR coverage** exists throughout the area wherein this procedure is used, and **reliable operation of this service is assured**;*

*b)-**identification of individual aircraft so separated is maintained by means of discrete codes;***

*c)-adequate primary or **SSR ground equipment backup is provided or, alternatively, in case of SSR failure density and/or complexity of traffic in the area and availability of navigational guidance allow to revert safely to other forms of separation (...)***

A.3.3 ICAO Doc.9426 Air traffic services planning manual

(...) Apart from ***adequate and reliable ground-ground and air-ground communications,*** *an air traffic control (ATC) unit applying conventional control methods has comparatively few requirements for additional means and equipment. (...)*

(...) The major reason for the provision of primary surveillance radar (PSR) at a specific location is that ***traffic density and/or complexity has reached a point where, with the application of conventional non-radar control methods only, it is inevitable that aircraft will encounter unacceptable ATC delays****. (...)*

(...) it is important that the location of such a radar should not be decide in isolation by the State concerned, but be made the subject ***of close co-ordination with neighbouring States****. Particular points in question are :*

a)-the overlap in coverage provided by adjacent radar stations to ***ensure continuity of radar control between adjacent ATC units;***

b)-requirements for ***uniform performance so that compatible methods of radar control, including agreed separation minima, can be applied between such units.(...)***

(...) Therefore, early in the planning process, it will be necessary to establish clear-cut priorities as regards the ***expected operational performance of the radar (...)***

(...) The ***standardisation of civil radars*** *(...)*

(...) ***The planning for the provision of radar should always start with the determination of the operational requirements, followed by the transformation of theses requirements into technical specifications****.(...)*

(...) ***All what has been said above with respect to PSR, also applies to secondary surveillance radar (SSR).(...)***

(...) SSR equipment can range from comparatively simple ground facilities to very complex arrangements, especially when it is integrated into an automatic ATC system to provide composite synthetic displays with alphanumeric data presentation or individual flights. (...)

(...) in those ATC units where SSR has already reached a high degree of development, it has been found that changes to the airspace configuration (ATS routes, routings in terminal control areas (TMAs), reporting points and/or its designation are more difficult (...)

(...) it may be possible to arrive at a situation where all the traffic , operating within a defined portion of the airspace, i.e. at higher altitudes, will be SSR equipped. If such conditions are created and transponder reliability has reached a point where failures are rare, ***it may be feasible to rely on SSR without primary radar. Such an arrangement would present a very appreciable economy in the investments required****.*

It would appear advisable, therefore, to consider the use of SSR alone whenever radar is to be provided in additional portions of airspace, or in those portions where it is already provide and where primary radar equipment will need replacement. (...)

(...) ***Separation is a generic term used to describe action on the part of ATC in order to keep aircraft, operating in the same general area, at such distances from each other that the risk of their colliding with each other is reduced. (...)***

(...) The required separation between aircraft is generally expressed in terms of minima, i.e. in distances which should not be infringed. Minima are further specified in firm values of distance; horizontally in nautical miles (NM) or degrees of angular displacement; vertically (...)

(...) the application of separation to aircraft, based solely on positional information received from pilots via air-ground communications, is generally referred to as ***procedural control****. Control based on radar displayed position information and where the application of horizontal separation is effected by maintaining a specified horizontal distance between radar returns (blips) on a display representing the horizontal position of aircraft in space is called* ***radar control. (...)***

(...) ***There is a significant difference between the separation minima used when applying procedural control methods and those used in radar control*** *.(...)*

(...) In the case of radar control, ***ATC is provided with continuously updated information*** *on the position of aircraft making it possible to use significantly smaller separation minima. However, the minima used under these conditions must also take into account the fact that, from radar alone, little information is provided on the future intentions of aircraft and the reaction time, the initiation of corrective action and its execution by aircraft concerned in case of conflict. In this respect possible delays in communication, reaction time for the pilot and the response time of aircraft depending on their speed and size have to be taken into account in determining the appropriate radar separation minima. (...)*

(...) in any case, ***the determination of the prescribed separation minima is a complex process which needs to take account of numerous factors****, many of which are outside the scope of competence of ATC.* ***Frequently it will be left to the individual controller to determine, based on sound judgement, what separation is adequate for a specific situation.*** *However, once separation minima are established by the competent authority, it is incumbent upon ATC to ensure that the established minima are not infringed upon.(...)*

*(...) In recent years, work on separation minima between aircraft has, to a growing extent, been based on the mathematical-statistical treatment of data collected on the performance of aircraft. This approach was used to develop models from which valid information regarding the likely safety of proposed measures could be derived. While such work has been extremely useful as a supplementary means of arriving at valid conclusions, it is, however****, not a***

***substitute for sound operational judgement**. it therefore appears necessary to approach the issue of mathematical models with caution and to make sure that in each individual case, data collection and their subsequent treatment are likely to yield useful results and not only confirm the obvious. (...)*

(...) The responsibility for navigation is vested within the aircraft. (...)

*(...) In airspaces wherein a high quality of frequently renewed position information is available to the controller, longitudinal separation may be expressed in terms of distance rather than in specified intervals of estimated time over the same point. **The controller's display serves as the means to analyse the available information**. In this case the relevant factors involved are the relative accuracy of position information, the age or currency of the information displayed, the elapsed time between updating of the displays, and a buffer. (...)*

*(...) **The way in which traffic information is presented to the air traffic controller has a significant bearing on the establishment of control procedures and on the amount of time necessary for him to assimilate the situation in which he may be required to act to maintain separation**. it can therefore be said that the more dynamic the display system, the better the chances of successfully reducing separation between aircraft, provided the display changes do not exceed the average human capability for observing and analysing the situation and arriving at a decision.*

*(...) Radar separation minimum is normally that which is prescribed in ICAO Doc 4444 Part VI. However, in the **application of radar separation**, the controller must always be alert to the need to take action on a timely basis when it appears that two aircraft may come closer together than the prescribed minimum.*

***Specific circumstances which may require the application of greater radar separation than the minimum normally prescribed are outlined below** :*

a)-Aircraft relative positions and performance limitations. (...)

b)-Radar technical limitations (...)

c)-Radar coverage (...)

d)-Radar controller limitations

*1)-**Radar controller workload***

*The number of aircraft which can safely be provided with radar separation at the same time is limited and varies with **individual controller proficiency**. A radar controller should therefore take due account of the number of aircraft within his sector of responsibility for which he is providing radar control, his own limitations and the geographical extent of his area of responsibility (i.e. the possible requirement to provide radar separation between aircraft in two or more separate traffic complexes which are some distance apart).*

*2)-**Communications congestion***

*Because the relative positions of aircraft may change rapidly, it is implicit in applying radar separation that a radar controller should be able to communicate promptly with any aircraft under his control. If the communications congestion is such that this cannot be assured, then the radar controller should apply greater radar separation, or, when this is not practicable, terminate radar control. in this respect it should be noted that **of all factors affecting the safe application of radar separation, communications congestion is probably the most important and one on which the radar controller may have little influence.** Congestion is also difficult to predict since, with rapidly changing traffic situations, the communications load can build up to saturation within minutes. (...)*

(...) Regional air navigation agreements providing separation between aircraft with the use of SSR alone (...) should cover the following points :

(...)

*f)-**SSR accuracy** in the affected airspace **should be verifiable by means of appropriate monitoring equipment;***

(...)

*i)**-control of all aircraft** within the affected airspace **should be exercised by a single ATC unit, unless adequate means of co-ordination exist between all ATC units concerned.***

(...)

(...) Provided that the plot extractor can discriminate between separate aircraft targets, this system provides the controller with clearly distinguishable position symbols which do not overlap if they are 9.3 km (5 NM) apart in range or azimuth (whatever the beam width of the radar sensor or range of target from aerial head may be). a basic requirement in the use of radar separation is to ensure that aircraft in close proximity can continue to be resolved as separate targets. On raw video radar displays, this resolution is easily achieved by the controller himself by ensuring that displayed radar blips edges (particularly in azimuth) do not overlap. However, with digital displays the controller cannot see from his display when any two aircraft are getting too close to each other in azimuth to permit the plot extractor to continue to resolve the aircraft as individual plots. It is essential, therefore, to compensate for this deficiency of digital data display systems by increasing the azimuth separation minimum applied to cater for the azimuth resolution capability of the sensor used. In practical terms, this requirement is dependent primarily on the beam width of the sensor and the range of target from the aerial head. It means, in fact, that, for azimuth resolution purposes, for any radar sensor, the 9.3 km (5 NM) separation criterion applied between radar position symbols holds good only up to a calculable range from the radar head. thereafter, the minimum should steadily increase with range from the radar head. (...)

(...) Air traffic control systems need to keep pace with the continuing increase in air traffic which usually increases the controller's workload disproportionately

and causes the ATC system to approach the limits of its capabilities. ***Reducing the size of the airspace assigned to individual controllers in order to alleviate this situation results in an increase in the number of control sectors. The net result is an addition to the number of controllers, and an increase in the required inter-sector co-ordination and transfers of control, workload and complexity in the ATC system. Further subdivision will not increase the system capacity significantly and often does not justify the increased cost****. (...)*

(...) ***automation is justified if further improvement in efficiency is required*** *(...)*

(...) Consideration must be given to the costs associated with :

(...)

c)-computers, displays, sensor interfaces, associated peripherals, spare parts and other equipment;

(...)

h)-training of ATC personnel;

i)-equipment and software maintenance and modifications;

j)-inter-unit communications requirements;

(...) ***Such automation would not change the role of the controller****, although it may give him additional tasks in providing information to the computer. A further stage in automation comprises facilities to take over, or assist in, some of the controller's less complex decision making tasks, without significantly changing the ATC system or the responsibilities of the controller.* ***Extension of the application of automation beyond this stage will undoubtedly necessitate some fundamental changes to ATC procedures and the role of the controller. (...)***

*(...) The application of automation will eventually require new and different tasks to be introduced for controllers****. Controller training to accommodate these changes is most important****, since controllers rely greatly on experience gained with the system through constant exposure to live traffic. If the system, including equipment, changes significantly, a period of retraining is necessary to* ***re-establish confidence and develop experience with the new equipment and procedures****.*

(...) ***The importance for ATS of a reliable and efficient message switching system cannot be overemphasised****.(...)*

(...) ***Voice communications are essential in air traffic control****. (...)*

(...) the communications facilities available to controllers should reflect the ***flexibility and re-configuration capability*** *conferred by ATS data processing systems. (..)*

(...) ***Display of the present traffic situation and of aircraft intentions is required to enable controllers to make effective decisions****. (...)*

ANNEX 2
Attachment A

EXAMPLE METHODOLOGY FOR MONO-RADAR SYSTEMS

CRITERIA FOR ACCURACY OF A RADAR SYSTEM TO SUPPORT 5/10 NM SEPARATION MINIMA (UNITED KINGDOM)

1. INTRODUCTION

1.1 The Research and Development (formerly Chief Scientist) Directorate of the United Kingdom National Air Traffic Services (NATS) made available a study done in July 1994, CS Report 9449, 'Criteria for the Accuracy of a Radar Required to Support a Given Separation Minimum'. This paper summarises the report, and presents the Conclusions and Recommendations of the Report. It does not present the full report.

2. PRESENTATION

2.1 The NATS Study was aimed at devising criteria which could be applied to a routinely measured distribution of radar errors, to determine whether the radar is sufficiently accurate to support a given separation minimum. The parameters used were the required separation minimum and the critical value for the Horizontal Overlap Probability (HOP). The HOP is the probability that two aircraft are displayed to a controller as being correctly separated when they are in fact overlapping. For purposes of this study each aircraft was modelled in plan view as a disk of diameter 61.1 meters. This is a conservative estimate of the average length of an aircraft - it is larger than the average wingspan. Two aircraft are in overlap when their centres are horizontally separated by less than 61.1 meters.

2.2 The separation minimum is considered acceptable when the HOP is less than a critical value which is derived by multiplying the Target Level of Safety (TLS) and the passing frequency in a given airspace, i.e. the number of times two aircraft pass with minimum horizontal and no vertical separation. This allows the HOP to be computed in terms of overlaps per flight hour.

2.3 Based on global standards set by ICAOs Review of the General Concept of Separation Panel (RGCSP), the TLS to be used is $2X10^{-8}$ fatal accidents per flight hour until the year 2000, and $5X10^{-9}$ for an application put in place after 2000. NATS currently allocates 10% of this target of $5X10^{-9}$ fatal accidents per flight hour to the risk of collision due to inaccurate radar. As a result, the TLS currently allocated to accidents caused by inaccurate radar is $5X10^{-10}$ fatal accidents per flight hour. It should be noted that one collision is considered to be two fatal accidents. This TLS considers only the risk of collisions resulting from inaccuracies in radar data. It does not take into account other causes of risk, such as the accuracy and timeliness of the display of radar data, human error, or communications errors.

2.4 In computing the HOP, the study reviewed three sets of assumptions about the way in which errors may combine to cause an overlap situation when they appear to be separated. Eventually the study considered only the more cautious assumption. In this instance, aircraft are assumed to be separated only in azimuth, as viewed by the radar. Since radar inaccuracies are greatest in azimuth, the assumption is very conservative. It depends only on the distribution of azimuth errors of a radar. It is independent of any assumptions about controller judgement, and independent of the observed headings of aircraft.

2.5 Currently in the UK, radar data is recorded simultaneously from the radar to be assessed and from other, overlapping radars. A suite of computer programmes is used to reconstruct the tracks of aircraft and from these, the error at each radar plot is estimated. The distribution of the errors is then plotted, and the HOP is computed on the basis of the distribution. If the HOP is less than the ‘critical value,’ (e.g. $2.5X10^{-10}$ per flight hour), the radar system is considered suitable for the separation minimum to be applied. It should be noted that comparison of simultaneous radar data recordings is not the only acceptable method to determine errors. A comparison between radar data and satellite navigation or other airborne equipment records could be used, for example.

2.5.1 Since ‘gross’ radar errors are rare, a relatively large number of plots need to be recorded in order to record enough errors to have sufficient confidence that the radar performance can be assessed. The UK study consisted of 162,000 recorded plots, of which 48 plots were tail errors. It is stated in the study report that approximately 25 plots in the ‘tail’ of the distribution are sufficient for an assessment. This is expected to require a sample in the order of 50,000 plots for an SSR.

3. CONCLUSIONS OF THE STUDY

3.1 The study recommends criteria to determine whether a radar may support given separation minima, based on measurements of performance. For a separation minimum of 5NM applied to a range of 160NM with en-route traffic, the criteria are:

a) the number of errors with absolute value greater than 0.2^o must be less than 1% and;
b) the tail of the distribution (beyond 0.4^o must have exponential form, or be faster decaying; and
c) the number of errors with absolute value greater than 0.4^o must be less than 0.03%; and
d) the mean value of errors with absolute value greater than 0.4^o must be less than $0.55^{o.}$

3.2 The table below sets out the criteria for a radar to support four possible separation minima. They have been optimised for SSRs operating in combined mode (SSR and PSR).

Criterion	2NM	3NM	5NM	10 NM
Less than 1% of errors may be greater than:	0.08^o	0.12^o	0.20^o	0.40^o
The tail is defined as starting at: Less than 0.03% of errors may be in the tail, and they must have a negative exponential or faster-decaying form.	0.16^o	0.24^o	0.40^o	0.80^o
The mean of errors in the tail (see previous criterion) must be less than:	0.22^o	0.33^o	0.55^o	1.10^o

ANNEX 2
Attachment B

EXAMPLE METHODOLOGY FOR MULTI-RADAR TRACKING SYSTEMS

French methodology for assessing that a multi-radar system can support a given radar separation minima.

1. FOREWORD

This paper deals with the technical aspects of the topic, in relation with the accuracy of the multi-radar system in the horizontal plane, needed for supporting a given separation minima. Operational aspects related to the practical conditions for the application of a given separation minima, such as system availability, contingency considerations, etc ... and all the technical aspects not related to radar are not taken into account in this paper.

2. FRENCH APPROACH

The French approach is pragmatic. It only takes into consideration the 5NM which we are aiming to use. In short, one can say that the French method is a comparative method based on the fact that a 5NM radar separation minima [1)] has already been used in France for several years in the case of mono-radar display. So if sensible comparative means can be found between multi and mono-radar situations, and if multi-radar proves to be as good as or better than mono-radar, then a 5NM radar separation minima can also be applied in the multi-radar case.

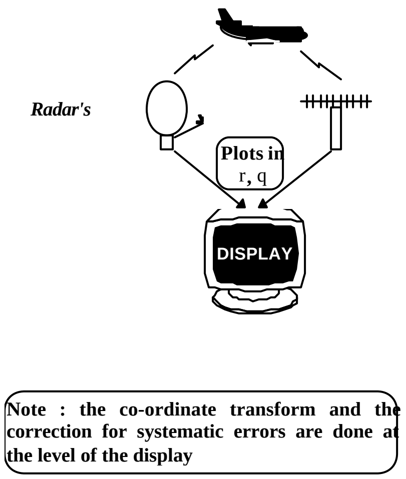
In other words, we do not try to measure a target level of safety for the system. We assume that the target level of safety for the mono-radar situation is acceptable, without being able of measuring it, and we try to compare multi-radar with mono-radar. So the question is : What are the comparative means between mono and multi that we use ?

3. COMPARISON BETWEEN MONO AND MULTI-RADAR SYSTEM

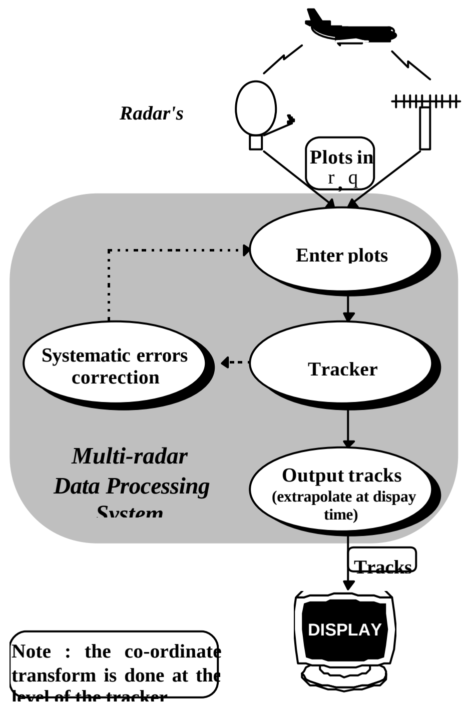
One must remind that the separation minima is applied by the controllers at the level of the radar display. Figure 1 (resp. 2) gives a very simple overview on a mono- (resp. multi-) radar chain.

---

1) In France, in the mono-radar case (both for primary radars and monopulse SSR), the radar separation minima is 3 NM for a range less than 40 NM and 5 NM for greater ranges.



- Figure 1 -



- Figure 2 -

Therefore, the following elements have to be taken into account for a multi-radar system, because they all influence the accuracy in the horizontal plane :

1 the intrinsic accuracy of the multi-radar tracker (including the loop for on line correction of systematic errors).

2 the errors which may exist in the slant range correction in case of poor knowledge of the altitude (because usually, multi-radar positions are displayed in a common plane, using co-ordinate transform with slant range correction). This mainly concerns MRDPS [1)] dedicated to approach control.

3 the loss of precision which results from the extrapolation at the display time.

4 the accuracy proper to the display screen (which depends on the precision of the coding of the distances inside the display, on the pitch of the screen, on the size of the symbols, etc ..., and which vary with the scale).

Some of these elements are common between the multi-radar and the mono-radar situations. Actually, the fourth one (4) impacts the same way for both situations if the same display is used for multi and mono-radar display (this is true in France since analogue display has been abandoned). So the same precautions have to be taken. The very first concerns the precision of the coding : the less significant bit (LSB) of the distances in the display must be equal or smaller than the one used for the broadcast of the tracks (either mono-radar tracks or multi-radar tracks).

[1)] MRDOS : Multi-Radar Data Processing System

Item 3 does not directly concern mono-radar display as usually mono-radar data are displayed in (rho, theta) just as they are sent by the radar [1] (except that they are corrected from the radar systematic errors). However, mono and multi-radar display can be compared. Indeed, both display methods have advantages and drawbacks :

- the direct display used for mono-radar shows the position at the time of detection. So it may not show the positions of close aircraft at the same time. And anyway, the positions are a little obsolete when shown on the display. There is a temporal inaccuracy.

- on the opposite, the extrapolation at the display time used for multi-radar shows the positions which are estimated at the time when the display refreshes the screen. There is a geographical inaccuracy due to the estimation process.

Both inaccuracies are about the same provided a certain quality of the speed vector [2] elaborated by the tracker in case of multi-radar, and provided that the extrapolations are made as short as possible.

This demonstrates that there is a need for evaluating the quality of the whole state vector, not only the position, in relation with separation minima.

Item 2 (co-ordinate transform) has the same influence for mono and multi-radar. Indeed, mono-radar positions are usually sent in (rho, theta) by the radar's but are transformed within the display in the common plane so as to be used with maps. Therefore, if the co-ordinate transform is adequate for mono-radar, it is for multi-radar. The exception is for primary, as in the mono-radar case, primary data are often displayed without slant range correction. So there is a need to take special care in the multi-radar case for tracks with no mode C (primary only tracks, P+S or secondary tracks corresponding to aircraft only equipped with mode A transponders).

The final accuracy of the slant range correction has to be studied for every implementation, as it depends on factors which are site dependant, such as :

- the method being used for mode C estimation (default height, triangulation, deduction from speed, etc. ...)

- the distance between radar's and aircraft

- the distance between radar's and centre of projection for the co-ordinate transform.

Last but not least, item 1 is to be measured very cautiously, directly out of the tracker. At this level, one can easily think of means for comparing mono and multi radar accuracy. So this is the easiest thing to do. This comparison is needed to check that the tracker output is not precluding the use of the separation minima. But this is not sufficient.

[1] In France, the plots out of the radar's are called "tracked plots" which means that these are raw plots (raw positions and extracted mode A and mode C codes) with a track number given by the local tracking whose role is the filtering of the false plots.

[2] I suppose here that the extrapolation at the display time is linear. If it is not the case, considerations about longitudinal and transversal accelerations should be added.

As the performance of the tracker in position can in the end be jeopardised by either an imperfect extrapolation to the display time or an inadequate co-ordinate transform, we think that all of the above mentioned items must be evaluated before assessing the quality of a multi-radar system, in relation with an objective of separation minima.

4. FRENCH METHODOLOGY

4.1 Evaluation of the tracker accuracy

This sort of evaluation is always done at CENA with the use of recorded life data. The sample must be big enough so as to be representative from a statistical point of view. Several hours of opportunity traffic are therefore recorded at busy hours. The tools needed for reconstructing the true aircraft trajectories are :

- a chainer : so as to link in time the successive positions which corresponds to the same target. This can possibly be the Object Correlator from RASS.
- a smoother : so as to filter out the noise of the measured radar positions and get reference positions to which the tracker updates can be compared. This can possibly be the MURATREC software from RASS, but France has no experience yet in using it.

So as to assess the quality of a multi-radar tracker in comparison with mono-radar, we compare in France, for each radar being used in the multi-radar system, the radar accuracy and the tracker updates accuracy for this radar. This implies that some additional processing is done either to take back the tracker updates for this particular radar in the local co-ordinate system or to convert the radar measurements in the common plane used by the tracker.

Special attention is then given to the tail of the distribution of the positional errors both for mono-radar and for multi-radar. A systematic analysis of all the cases where the error is greater than x NM5 [1)]is carried out for the multi-radar system so as to correct them if possible. Then the percentage of residual errors for multi-radar is compared to that of the mono-radar. It is expected to be smaller. If it is not, then the multi-radar tracker has to be improved. If it is smaller, then the multi-radar tracker is considered as possibly allowing the target separation minima and the work goes on with the evaluation of the other items.

Remark : All this work has to be done with the use of the complete records or as much complete as possible, especially for manoeuvring trajectories. The defaults of the reference trajectories due to mis-functioning of the evaluation tools must be as few as possible and as detectable as possible so as not to be taken into account. This is the main problem in all the job.

1) $x \leq 2$ for En-Route as the target separation minima is 5 NM.
$x \leq 1$ for Approach as the target separation minima is 3 NM.

4.2 Evaluation of the extrapolation at the display time

One method could be the computation of the accuracy of the displayed tracks. But this implies that the reconstruction of the reference trajectories at the display time is possible. This is not the case with CENA tools for the time being. This could be possible with the use of MURATREC but, as already mentioned, France has no experience with (or no confidence in) this RASS software yet.

Another method could be the computation of the accuracy of the speed vector elaborated by the tracker. This implies that the reconstruction of the reference trajectories is good both in position and speed vector. As far as CENA home tools are concerned, this is not the case. The accuracy of the reconstructed speed vector is about the same order of magnitude as the one of the tracker itself, as soon as Multi Plot Variable Update (MPVU) techniques are used for multi-radar tracking.

So, in the absence of the appropriate tool, an approximate method is used for the time being : Extrapolations at the display time are compared with the positions of the reference plots corresponding to the updates out of the tracker used for the extrapolations. In this method, the positions which are compared do not correspond in time. So this method does not allow the calculation of standard deviation for the errors of the displayed positions. Nevertheless, the distribution of the deviations is studied and gives some representative clues for the quality of the extrapolation process.

Special attention is put on :

- the cases already found in the evaluation of the tracker (residual errors greater than x NM) so as to check how these situations are dealt with by the extrapolation process.
- all the cases on the tail of the distribution (errors greater than y NM [1])

The percentage of residual errors must not be greater than that of the mono-radar case.

4.3 Evaluation of the maximum of the errors in the co-ordinate transform of targets with no mode C

As mentioned in chapter 3, the errors induced in the co-ordinate transform by the slant range correction in case of total absence of mode C can not be neglected. Indeed, these errors can not be completely avoided as soon as the system is not informed at all of the aircraft flight level. So they have to be minimised so as not to waste the accuracy wealth of the tracker.

In France this problem is mainly studied with simulations, by comparison, for a given scenario, of the positions shown on the display when the flight level is known and the same positions obtained with a false estimation of the flight level.

[1] We use the same parameter as the one used for the evaluation of the tracker (x NM).

A scenario consists in assuming a given error in the estimation of the level and make the position of the target vary in relation with the position of the centre of projection for the co-ordinate transform.

As the results are site dependant, this is done for every implementation of a MRDPS in a new radar environment. If needed, the flight level estimation process used within the MRDPS is tuned and a test is done with real traffic so as to check that the maximum of the errors is never greater than 1 NM.

ANNEX 2
Attachment C

EXAMPLE METHODOLOGY FOR MULTI-RADAR TRACKING SYSTEMS

Minimum Radar Separation of 5 NM, used at the Maastricht UAC (Methodology also used by Austro Control)

1. GENERAL CONSIDERATIONS

1.1 The decision to uniformly apply a minimum radar separation value of 5 NM was taken in the early seventies, after a series of detailed studies jointly performed by the Operations and Engineering Directorates of the Agency Headquarters and the Maastricht UAC.

1.2 Since the initial adoption of the 5 NM radar separation standard, the Maastricht UAC is successfully providing safe ATC services within the Benelux and Northern Germany Upper Airspace for almost years now. On the basis of the present traffic growth factors, it is expected that the MAS-UAC will control over one million flights in 1997. The usage of the 5 NM radar separation minimum is certainly instrumental for the achievement of the associated high controller productivity.

1.3 Do we have the magic formulae to compute the acceptable minimum radar separation values? The answer is NO.

Since the initial adoption of the 5 NM radar separation standard, the proven safety records of the MAS-UAC have gradually resulted in a shift in emphasis from mathematical models(which are necessarily too simplistic to cover all possible factors, having an impact on the safe separation of air traffic) to suitable day-to-day quality assurance techniques.

1.4 Quality assurance means in fact adopting an attitude of constant vigilance, where working procedures and practices, processes and systems are continuously monitored and breaches of regulations or process/system deficiencies are minutely analysed and followed up if deemed necessary. Quality assurance has of course an operational and an engineering component.

1.5 At the operational level, organisational structures are in place to monitor the day-to-day operations, both from a safety and efficiency point of view. A dedicated Incident Investigation and Quality Assurance unit carefully follows up all reported real or perceived breaches of radar separation minima and other incidents, affecting the safety of operations. It is furthermore planned to enhance the MADAP system with an additional Safety Monitoring Facility(SMF), independent of the Short Term Conflict Alert (STCA) facility which is operationally used in MADAP since February 1980. Also advances in ATC Controller education and training techniques and tools(new in-house multi-purpose training facility) is a continuous contribution to ATC quality improvement.

1.6 Also from the technical point of view, there is a constant quality awareness and a perpetual endeavour to further improve the quality, availability, integrity, and capacity of systems and services. Vital technical subsystems supporting the 5 NM radar separation procedures, are the air-ground communications systems and the provision of a precise Air Situation Picture with a high degree of availability and displayed on high quality ATC screens.

A state-of-the-art VCS (voice communications system) was taken into operational use in 1996. The system integrates both ground-ground and ground-air voice communications and its ground part is fully digital technology. Separate back-up systems for both ground-ground and ground-air communications will be procured in 1997.

A well-designed and intuitive HMI subsystem is another important factor enhancing controller productivity and safety. The replacement of our present ODS is already far advanced. The new ODS will use high resolution raster-scan technology and a sophisticated windows type of HMI (COPS compliant).

1.7 The remaining part of this paper focuses only on the positive contribution to the 5NM separation minimum of the surveillance infrastructure, the aggregate radar coverage, the Radar Data Processing System (RDPS) and functions and tools basing on the availability of a precise Air Situation Picture.

2. RADAR SURVEILLANCE ASPECTS

2.1 Radar Coverage

The quality of the radar information is of paramount importance within the overall radar separation process. Since the decision to adopt a radar separation minimum of 5 NM as the basis for radar separations within the MAS-UIR, numerous evolutionary steps were taken in order to enhance the quality of the radar coverage inside and within the peripheral zone surrounding the MADAP area of jurisdiction. There exists indeed a permanent commitment to exploit all windows of opportunity to enhance the reliability, integrity and quality of the composite coverage of the integral radar sensor infrastructure.

The main improvements are:

- The Radar Sensor technology has shown a considerable progress, as a result of better antenna technology (e.g. the advent of LVA antennae) and the development of monopulse and MTD systems. The ‘old’ sliding window type of radar systems are gradually replaced by more sophisticated systems.

- The development and implementation of the 4-States Radar Data Distribution Network (RADNET) has allowed to have access to many radar systems, virtually without augmenting the communications costs. At present thirteen radars are simultaneously used by the MADAP Track Server to establish the Air Situation Picture, compared to four in the first years of MADAP. There is a steady process of integrating more and/or better radar sensors, duly taking into account cost and networking constraints. Especially many of the new radars, becoming available with the German Radar Modernisation and Replacement Programme (REMP) will become integrated in the MADAP Track Server during the timeframe from now up to the next millennium.

- In addition to the so-called Long Range Radars, a number of Airport radars were integrated in the recent past (Brussels ASR, Luxembourg ASR and Schiphol ASR). The new generation Airport radars, using SSR monopulse and PSR MTD technology are extremely attractive for tracking purposes due to their high sampling rate and inherent precision. It has further to be noted, that as a result of the monopulse technology, airport radars can henceforth support SSR coverage ranges of 140 NM or more. The REMP programme will deliver some ten ASR radars, which are potential candidates for integration by the MADAP Track Server.

- As a result of the Radar Sharing Concept and through the interconnection of RADNET with similar networks in e.g. France, the UK, Denmark, it is the intention to also integrate some radar facilities, located within the neighbouring areas surrounding the MAS-UIR. This is beneficial for the safe radar hand-overs between MAS-UAC sectors and sectors within adjacent/subjacent centres.

- Worth to mention is also that vital radars are connected to two separate RADNET nodes, via independent access links. The MADAP TS exploits this feature, by permanently monitoring the availability of radar status messages (north/sector messages) at both RSAPs (Radar Service Access Point). Path swapping to the alternate path occurs in case of failure of the active path.

Summarising, the development of RADNET and ASTERIX paved the way to optimally implement the Radar Sharing Concept. In principle many radar sensors, of a diverse type and nature, can be accessed against low communication cost, yielding a comprehensive coverage with a number of pronounced advantages:

- high data sampling rate, allowing the computation of precise track state variables and a faster detection of hazardous events from developing (e.g. unexpected horizontal or vertical manoeuvres).
- faster and more reliable manoeuvre detection (better discrimination between manoeuvre and measurement errors as a result of an observation under different aspect angles by the multiple sensors).
- compensation for coverage gaps of a particular sensor.
- optimal low coverage.
- higher availability of radar data as a result of resilience in communication network.
- the extensive multiple coverage allows to efficiently filter residual reflections, side/backlobe plots, splits, etc.
- best possible protection against transponder deficiencies, through the simultaneous use of many sensors, from different manufacturers and applying different parameter settings.

- good protection against resolution problems and garbling by simultaneously using multiple (default 5) sensors through different aspect angles and selection of the closest sensors (better resolution) per individual aircraft.

2.2 Weather Radars

A further measure to support the aircraft separation task was the provision of multi-sensor composite precipitation images, derived either from normal traffic radars or from dedicated weather radars. The main purpose is to visualise high CB activity to the control staff, assisting pilots to circumnavigate those hazardous areas.

2.3 Radar Monitoring and Evaluation

Substantial progress was made in the quality monitoring and performance evaluation of the radar stations used.

In addition to all the monitoring and control activities (RTQC) performed at the Radar Sites or at remote and central RMC facilities, a lot of improvements were introduced at Centre Level as well:

- On-line monitoring of the availability and status of the radars in operational use, together with the on-line assessment of systematic measurement biases in range and azimuth. The availability of radar data is enhanced via continuous path monitoring and swapping to redundant access paths in case of outages of the preferred path.

- More regular and detailed evaluation exercises, using standard methods, tools and performance criteria via the RASS tools. Those evaluation campaigns are at present still intermittent and off-line activities. The future will provide an on-line, pseudo real-time version of RASS, adequately monitoring the radar systems on a permanent basis.

- Standard error reporting procedures are in place, which permit Operational Staff to immediately file complaints concerning perceived radar or system deficiencies. Replay and browsing tools permit to investigate the reported problems from so-called LRC-tapes (legal recording). For every report a feedback is given to the Staff concerned.

- The integration of new or upgraded radars follows strict safety procedures, briefly outlined below:

  - Step 1: After the announcement of both the technical and operational release of the radar by the Owner Administration, an independent off-line technical evaluation is performed using the RASS facilities.
  - Step 2: A successful outcome of step 1, yields the necessary basis for the proper integration and tuning of the radar into the Track Server. Successful completion of these activities lead to the declaration of a technical release of the new or upgraded facility concerned.

  - Step 3: The last but not least step is an operational evaluation, conducted by Operations Staff, which upon successful completion results in the declaration of the Operational Release of the radar concerned. Thereafter the radar may actually be used, after suitable notification of the Owner Administration.

3. RADAR DATA PROCESSING SYSTEM

3.1 The Track Server

Most of the constituent components of the *main* Air Situation Picture in MADAP are created by an autonomous multi-radar data processing facility, which is generally called the Track Server (TS). The TS functionality was recently (June ‘96) segregated from the rest of the MADAP system and re-hosted on a dedicated platform in a redundant configuration (IBM-ES9221/model-211; modern CMOS technology mainframe). The TS works in a client/server relation with the remaining MADAP functional domains.

Some of the salient highlights of the TS are enumerated below:

3.1.1 Airspace covered and Track Capacity:

- Area covered: 544 * 432 Nm^2 (>800.000 square km)
- All levels
- Track capacity: 1024, (needs expansion, almost 900 simultaneous tracks during busy periods in Summer ‘96)

3.1.2 Radar Configuration and Optimal Adaptive Usage of Radar Coverage:

3.1.2.1 Radar Configuration

- The Track Server is currently configured to simultaneously process up to 32 radar stations(extensible).
- Both long-range and TMA radars
- Primary, SSR and Monopulse SSR Radars.

3.1.2.2 Coverage management through Auto-adaptive Network filters

Simultaneous processing of a high amount of available sensors yields a comprehensive and solid composite radar coverage, particularly beneficial for the lower airspace layers. The latter is important because the Air Situation as established by the MAS-UAC Track Server is not only used by the MADAP system itself, but also by many remote ATC and AD systems via real-time distribution over RADNET.

Using **all** data from many sensors would result in an extraordinary redundant coverage in certain upper airspace zones and could result in an extraneous loading of some RADNET trunks. The Track Server uses therefore the concept of *effective coverage factor,* N, where 2<= N <= 8. The current default is N=5. What this means is that, for a given Radar Configuration(list of wanted operational radars) and a given N, the Track Server automatically calculates a set of geographical filters (one per radar), such that every point in the Track Responsibility Grid is actually covered by the N **BEST** radars at that location(of course within the physical constraints). Many events changing the radar configuration (temporarily) or the coverage factor applied, result in the recalculation of the complete set of filter tables. Those adaptive filters are automatically submitted and implemented in the relevant RADNET nodes, thus achieving an optimum coverage for the smallest transmission bandwidth.

3.1.3 Input/Output

3.1.3.1 Input:

- ASTERIX Cat 1: Plots and/or monoradar tracks
- ASTERIX Cat 2: Radar service messages
- ASTERIX Cat 8: Weather messages

3.1.3.2 Output:

- ASTERIX Cat 0: Picture synchronisation
- ASTERIX Cat 3: Firm and tentative tracks
- ASTERIX Cat 9: Multi-radar weather images

3.1.3.3 Update Cycle:

- Each firm system track is updated every 4.8 seconds, asynchronous from the participating sensors.
- Tentative tracks are updated synchronous to originating sensor.

3.1.4 Track initiation and cancellation

3.1.4.1 Automatic Multi-radar Track Initiation:

- For all SSR targets
- For all primary targets
- Dynamic Clutter maps

3.1.4.2 Manual Track Initiation.

3.1.4.3 Manual and automatic Track Cancellation

3.1.5 Automatic estimation and correction for Range and Azimuth biases.

3.1.6 Precise co-ordinate transformation, entailing slant-range correction and stereographical projection.

3.1.7 Excellent robustness against residual systematic errors, spurious plots, wrong Mode A and Mode C codes, garbling and resolution phenomena.

3.1.8 Handling of all types of SSR Mode A code changes. Maintenance of same system track over Mode A code changes.

3.1.9 Track fusion, using up to 8 radars at a time to assess track state variables.

3.1.10 Multi-model tracking algorithms and determination Mode-of Flight:

- straight uniform motion

- turn filter
- longitudinal acceleration filter
- unknown manoeuvre filter

3.1.11 Tracking for Three Aircraft Performance Classes.

3.1.12 Vertical tracking (Mode C).

3.1.13 Multi-radar weather processing

3.1.14 ASSOCIATION between track data and CURRENT flight plan data.

3.1.15 Overall Co-ordinator between non-coherent ATC/AD centres.

3.1.16 Availability Considerations.

The TS has an excellent availability record, mainly as a result of:

- TS operates on modern hardware (ES9221/211 and RAID5 disks).
- Segregation of hardware across environments.
- Minimum amount of peripheral devices.
- Loose coupling of distributed co-operative processing elements.
- No failures/stops induced by other (non-RDPS) software components.
- Accelerated Restart mechanism: Recovery of Air Situation in 5 to 15 seconds.
- Fault-tolerant configuration of TS-ONL and TS-SBY.

Summarising, the non-exhaustive list of functionality's and characteristics enumerated above yields an Air Situation Picture, with the following key properties:

- precise track state variables (refer to Tracker Benchmark Tests)
- high integrity
- high track reliability (always one and only one track per target present)
- high availability

3.2 The Tracker Benchmark Tests

For each major release the TS is submitted to a performance benchmark test, supplemented with visual screen/plotting observations.

The benchmark tests are performed using a real-time simulation facility, which is a constituent part of the MADAP RDPS. The simulator allows to realistically navigate a set of targets along ATS routes or off-route, and to generate realistic plots for up to 32 radars in real-time, synchronous to the antenna revolution.

The plots are generated precisely emulating the radar behaviour, by using systematic errors, radar noise parameters and coverage characteristics as obtained by preceding off-line RASS evaluations.

The target trajectories can be interactively adapted by pilot input commands, or alternatively can execute a priory defined command chains (e.g. to compose highly manoeuvring flight paths) or automatically follow correlated flight plan routes.

There exists mutual client/server relations between TS and Simulator, running on different platforms. The simulator emulates the RADNET environment, together with the attached radar devices. The plots generated are submitted to the TS. The Simulator on its turn is one of the clients of the Air Situation Picture produced and disseminated by the TS.

The Simulator contains inter-ail a Statistics Subsystem, which calculates for every individual track update the TRUE state variables for the target concerned and compares the track estimated state variables to the true values, for the same point in time (asynchronous from plot generation).

Adequate statistical processing yields, amongst others, reliable assessments for the mean and standard deviations for position, ground speed and heading errors. The aforementioned deviations are also compared to a set of a priori defined maximum thresholds, which are a function of the Mode of Flight. The scores obtained represent the measured frequency of a deviation between track and true value lower than the relevant threshold.

All statistical figures are automatically printed at the end of the simulator session, per individual flight and for groups of flights. A typical benchmark duration is approx. two hours.

More detailed statistical analysis of the transient behaviour of the tracer, when switching between Modes of Flight, can be performed via supplementary off-line tools, using the recordings made during the on-line benchmark.

An example containing the description and results of a benchmark, which was used in the context of the procurement of the RFS (Radar Fallback System) is provided in Appendix 1. In this particular RFS context, only a limited set of eight conventional long range radars were used (sliding window type extractors).

Some salient results, having an significant impact on the choice of minimum separation values, are extracted from Appendix 1 and depicted in the tables below:

En-route Flights	
Parameter:	Value:
Mean Position Error	0.05 NM
Standard Deviation Position Error	0.05 NM
Pos. Dev < 0.25 NM for non-manoeuvre phase	99.55 %
Pos. Dev < 1 NM for manoeuvre phases	100 %
Mean Speed Error	0.0 kts
Standard Deviation Speed Error	2.6 kts
Speed Dev. < 20 kts(non-manoeuvre phase)	99.98 %
Speed Dev. < 70 kts(manoeuvre phases)	100%
Mean Heading Error	0.09 dg
Standard Dev Heading Error	2.99 dg

Heading Dev. < 10 dg(non-manoeuvre phase)	99.69 %
Heading Dev. < 90 dg(manoeuvre phases)	100 %

Highly manoeuvring flights	
Parameter:	Value:
Mean Position Error	0.06 NM
Standard Deviation Position Error	0.08 NM
Pos. Dev < 0.25 NM for non-manoeuvre phase	99.51 %
Pos. Dev < 1 NM for manoeuvre phases	100 %
Mean Speed Error	0.2 kts
Standard Deviation Speed Error	4.4 kts
Speed Dev. < 20 kts(non-manoeuvre phase)	99.56 %
Speed Dev. < 70 kts(manoeuvre phases)	100%
Mean Heading Error	-3.69 dg
Standard Dev Heading Error	9.40 dg
Heading Dev. < 10 dg(non-manoeuvre phase)	97.97 %
Heading Dev. < 90 dg(manoeuvre phases)	99.91 %

3.3 Radar Fallback System

For obvious reasons that an unexpected system stop cannot be planned, and in order to occasionally allow extensive tests at night time by Engineering Staff, an independent back-up Air Situation Picture is an absolute must.

3.3.1 Present situation

Despite the excellent availability of the TS as presented earlier, the MAS-UAC radar controllers dispose of an independent radar fallback Air Situation Picture. This picture is produced by a duplicated so-called Radar By-pass Processor (RBP system). The RBP has an independent communications part, an independent RDPS part, but shares the same ODS (Operational Input and Display system). The RBP has basically a mono-radar tracking function (mosaicing, capacity to process up to eight radars). The Code/Callsign correlation function provides for tracks with a callsign in the label for the traffic handled by the MAS-UAC.

3.3.2 Future situation

The duplicated RBP complex uses the same obsolete technology as the present ODS system. With the decommissioning of the present ODS, the RBP complex will be replaced by a new Radar Fallback System (RFS). The RFS complex consists of a distributed architecture of Unix platforms and has a separate communications subsystem(independent of RADNET), a set of seven mono-radar trackers and one multi-radar tracker, and last but not least a separate Display Processor per Controller position.

4. REMAINING RADAR-RELATED ATC FUNCTIONS

Without attempting to be exhaustive, a list of additional ATC functions/tools is given, which all base on the existence of an accurate and reliable Air Situation Picture and provide some positive contribution to the 5 NM minimum separation value:

4.1 STCA

STCA was introduced for operational use into MADAP in Feb. 1980. It is generally recognised that this function is highly appreciated by Control Staff and has significantly contributed to enhance controllers CONFIDENCE in the system.

4.2 Flight plan/Track Correlation

The tracks as produced by the TS are automatically correlated with active flight plans within the MADAP system. This correlation is in essence based on matching present or next Mode A codes, supplemented with a rudimentary position check. Manual correlation and decorrelation inputs are also available, for the rare occasions where the automatic mechanism needs manual assistance.

The aircraft identities are maintained upon planned code transition from present to next Mode A code. This is also true for transitions to distress codes and vice versa.

4.3 Automatic Mode A Code Assignment

The MADAP system has a sophisticated Mode A code management domain, which fully supports the ORCAM concept and guarantees the assignment of unique Mode A codes.

4.4 Divergence Detection and Automatic Flight plan Updates.

The actual progress of the track is permanently compared to the expected flight plan envelope. Warnings in the track label are generated when the track deviates too much from the planned trajectory. The ETO's over the various waypoints are automatically updated via predictions based on the present track state variables.

4.5 Intention/Attitude Management.

Vertical intentions are displayed in the track label. The proper execution of the intended vertical manoeuvres is permanently monitored (each track update cycle: 4,8 sec.). Start/stop and correct execution of a vertical manoeuvre is displayed in the track label. The controller is also alerted on a conflict between controller intention (or just the absence of an intention) and the actual vertical manoeuvre.

4.6 Verification of Separation and Resolution Advisories (VERA).

VERA is a tool to permanently monitor the predicted separation between two aircraft or an aircraft and a fixed point. The prediction is based on the present track state variables and is refreshed at every track update cycle(4.8 seconds). Deliberately no height is taken into account If the separation is predicted to become inferior to a certain minimum(present selection: 8 NM), it is shown to the controller from where onwards the infringement starts and all alternative turning options for both aircraft are provided.

Appendix 1: Tracker Benchmark Tests

Benchmark Tests for Accuracy Measurements of a Tracking System

A1 Radar Configuration

As depicted in Table 1, a set of eight conventional long-range radars were used to perform accuracy analysis of the MADAP RDPS.

Table 2 provides the necessary parameters for a realistic simulation of the radar noise and various probabilities of detection.

The parameters contained in Table 2 reflect the outcome of extensive radar evaluation campaigns.

Radar	***Type***	***Latitude N***	***Longitude E***	***Height (ASL) (m)***	***Max Range (NM)***	***Rotation Time (Sec.)***
DHEL	*S*	*52.55.28,8*	*4.46.38,7*	*23*	*176*	*6.0*
LEER	*M/S*	*51.50.14,7*	*5.08.21,4*	*35*	*200*	*9.6*
BERT	*M/S*	*50.52.27,3*	*4.37.05,5*	*120*	*140*	*12.0*
BOOS	*B/B*	*54.00.17,8*	*10.02.46,8*	*140*	*150*	*10.8*
BREM	*B/B*	*53.02.06,3*	*8.47.56,4*	*48*	*150*	*10.8*
DEIS	*S*	*52.15.13,4*	*9.29.33,3*	*432*	*150*	*12.0*
LUED	*B/B*	*51.16.06,0*	*7.37.51,7*	*547*	*150*	*10.8*
PFAL	*B/B*	*49.19.06,0*	*7.51.51,6*	*633*	*150*	*10.8*
Legend :	*S = Single Radar Station.* *M/S = Main Standby Configuration.* *B/B = Back to Back Radar.*					

Table 1. Radar Configuration for Tracking System Accuracy Measurements

Radar	***Type***	***Sigma Range (m)***	***Sigma Azimuth (deg)***	***Pd SSR (%)***	***Pd Prim (%)***	***Pd Mode C (%)***
DHEL	*S*	*77*	*0.14*	*96*	*n.a.*	*99*
LEER	*M/S*	*66*	*0.13*	*98*	*93*	*98*
BERT	*M/S*	*65*	*0.11*	*98*	*91*	*99*
BOOS	*B/B*	*44*	*0.18*	*98*	*93*	*95*
BREM	*B/B*	*56*	*0.18*	*95*	*93*	*98*
DEIS	*S*	*76*	*0.13*	*97*	*94*	*95*
LUED	*B/B*	*56*	*0.14*	*98*	*97*	*99*
PFAL	*B/B*	*52*	*0.15*	*97*	*93*	*99*
Legend :	*S = Single Radar Station.* *M/S = Main Standby Configuration.* *B/B = Back to Back Radar.*					

Table 2. Radar Plot Characteristics for Tracking System Accuracy Measurements

A2 Effective Coverage Factor

The accuracy measurements were obtained for the default effective coverage factor N=5, i.e. the system track was simultaneously updated with plot data from at maximum 5 radar stations.

A3 Simulated Traffic Scenarios

Table 3 provides the details of a set of sixteen "en-route" flights, with a moderate manoeuvre behaviour. Heading changes are performed with a banking angle of 25 degrees.

Table 4 defines a second group of flights which are constantly manoeuvring. Those flights perform an infinite iteration of a straight flight path of 20 nautical miles immediately followed by a turn of 175 degrees. The initial heading for all 16 flights is 0 degrees. The aircraft speeds vary from 240 up to 600 knots, whereas the banking angles applied vary from 15 to 60 degrees.

Target	***Speed (kts)***	***Level (FL)***	***Route Description***
1	*475*	*310*	*MIC LBE OSN DOM NOR GMH ROBEG MIC*
2	*410*	*310*	*AMICH HAM OSN RKN FOXTO BAM AMICH*
3	*345*	*310*	*AMICH DLE WERRA WRB OSN AMICH*
4	*390*	*310*	*ALS SWG WTM HOP ARKON DOM ALS*
5	*340*	*310*	*TALSA DHE JUIST MCH HOP LBE TALSA*
6	*245*	*310*	*TUSKA MCH DHE OBG TUSKA*
7	*450*	*310*	*TUSKA MCH RKN HMM BIGGE WERRA LBE TUSKA*
8	*455*	*310*	*HLZ DLE HOP WTM TUSKA EKERN HLZ*
9	*405*	*310*	*HLZ WRB NOR RKN OBG LBE HAM HLZ*
10	*485*	*310*	*WRB LBE LUB EKERN TUSKA MC4 WRB*
11	*500*	*310*	*LAU WERRA HAM LUB EKERN IND JUIST LAU*
12	*495*	*310*	*NOR DOM OSN LBE EKERN TUSKA WELGO NOR*
13	*495*	*310*	*WSK TB1 BIGGE GMH NOR LLK WSK*
14	*495*	*310*	*NOR TR10 LCK EKERN LUB DLE NOR*
15	*430*	*310*	*IND DHE LBE HLZ WERRA BAM IND*
16	*450*	*310*	*LAU LBE EKERN TUSKA WELGO LAU*

Table 3. "En-route" Benchmark Flights for Tracking System Accuracy Measurements

Target	*Speed (kts)*	*Level (FL)*	*Banking Angle (deg)*	*Start Position*	
				Lat (North)	*Long (East)*
1	*240*	*310*	*15*	*53.20.59*	*6.35.22*
2	*240*	*310*	*30*	*52.19.33*	*5.53.13*
3	*240*	*310*	*45*	*51.51.40*	*6.29.50*
4	*240*	*310*	*60*	*51.11.00*	*5.27.00*
5	*360*	*310*	*15*	*50.39.00*	*5.51.00*
6	*360*	*310*	*30*	*50.50.31*	*6.41.42*
7	*360*	*310*	*45*	*51.42.48*	*7.35.20*
8	*360*	*310*	*60*	*52.12.06*	*8.17.12*
9	*480*	*310*	*15*	*53.20.56*	*8.52.36*
10	*480*	*310*	*30*	*54.09.15*	*8.00.00*
11	*480*	*310*	*45*	*52.14.00*	*9.16.45*
12	*480*	*310*	*60*	*51.24.20*	*8.23.00*
13	*600*	*310*	*15*	*51.24.17*	*4.21.59*
14	*600*	*310*	*30*	*50.54.15*	*3.38.00*
15	*600*	*310*	*45*	*53.09.54*	*6.40.02*
16	*600*	*310*	*60*	*52.08.03*	*6.45.53*

Table 4. High Manoeuvring Benchmark Flights for Tracking System Accuracy Measurements

A4 Results Of The Benchmark Tests

The resulting state variables of every system track are every track update cycle (4.8 seconds) submitted to the MADAP simulator.

The simulator compares the state variables obtained from the tracker to the true values for the same point in time. Statistical analysis is performed per individual flight and in addition for the total population of flights of a particular category.

Within Tables 5 through 8 results are given for both the "Dynamic Track Selection" and "Track Fusion" techniques. For both techniques the same scenario was executed.

Table 5 depicts the aggregate results for the set of sixteen "en-route" flights, whereas the same results for the group of constant manoeuvring flights may be obtained from Table 7.

Table 6 and 8 provide for every state variable the measured frequency that the error on the estimated variable is inferior to a corresponding threshold value.

Separate thresholds are applied during the uniform straight motion and the manoeuvring flight phases. It has to be emphasised here that the decision to compare either against the one or the other threshold is taken by the simulator according to the real mode of flight. The transition phase from a manoeuvring phase to straight uniform motion is therefore integrally compared to the "straight" thresholds.

Table 6 reflects the results obtained for the sixteen "en-route" flights whereas Table 8 depicts the equivalent values for the set of constantly manoeuvring flights.

	Number of Track Updates		*16003*			
	Number of Track hours		*21.3*			
	Date		*07.10.1993*			
	Position (NM)		*Groundspeed (Kts)*		*Heading (deg)*	
	mean	*sigma*	*mean*	*sigma*	*mean*	*sigma*
MRT	*0.05*	*0.05*	*0.0*	*2.6*	*0.09*	*2.99*
SRT	*0.08*	*0.08*	*-0.2*	*5.7*	*0.09*	*4.22*

Table 5. Aggregate results for En-Route Flights

	Number of Track Updates		*16003*			
	Number of Track hours		*21.3*			
	Date		*07.10.1993*			
	Position (NM)		*Groundspeed (Kts)*		*Heading (deg)*	
	Straight < 0.25NM	*Manoeuvre < 1 NM*	*Straight < 20 Kts*	*Manoeuvre < 70 Kts*	*Straight < 10 deg*	*Manoeuvre < 90 deg*
MRT	*99.55%*	*100%*	*99.98%*	*100%*	*99.69%*	*100%*
SRT	*98.30%*	*99.86%*	*99.31%*	*98.45%*	*99.35%*	*100%*

Table 6. Frequency of variables being inferior to threshold for En-Route Flights

	Number of Track Updates		*15166*			
	Number of Track hours		*20.2*			
	Date		*07.10.1993*			
	Position (NM)		*Groundspeed (Kts)*		*Heading (deg)*	
	mean	*sigma*	*mean*	*sigma*	*mean*	*sigma*
MRT	*0.06*	*0.08*	*0.2*	*4.4*	*-3.69*	*9.40*
SRT	*0.13*	*0.13*	*-1.1*	*12.7*	*-6.77*	*12.22*

Table 7. Aggregate results for Manoeuvring Flights

	Number of Track Updates		*15166*			
	Number of Track hours		*20.2*			
	Date		*07.10.1993*			
	Position (NM)		*Groundspeed (Kts)*		*Heading (deg)*	
	Straight < 0.25NM	*Manoeuvre < 1 NM*	*Straight < 20 Kts*	*Manoeuvre < 70 Kts*	*Straight < 10 deg*	*Manoeuvre < 90 deg*
MRT	*99.51%*	*100%*	*99.56%*	*100%*	*97.97%*	*99.91%*
SRT	*95.92%*	*99.98%*	*95.05%*	*99.43%*	*95.86%*	*99.80%*

Table 8. Frequency of variables being inferior to threshold for Manoeuvring Flights

ANNEX 3
Attachment A

UK NATS
States' contributions to "Radar separation minima in High Complexity TMAs

Quote

RADAR SEPARATION MINIMA IN TMAs:

1. Radar Accuracy Considerations:

   The methodology here is the same as that applied to NATS' en-route radars when determining whether they can support a separation minimum of 5NM or 10NM. The analysis method is outlined in Par. 2.5, annex 2, attachment A of "Guidelines for the Application of the ECAC Radar Separation Minima".

   The same TLS of 2.5×10^{-10} collisions per flight hour is used. Radar azimuth error statistics are again obtained by analysing multiple radar recordings. Using the same passing frequency and average aircraft size as for the en-route case, the maximum range at which the given radar separation minimum (3NM or 2.5NM) can be supported is then calculated by comparing the calculated Horizontal Overlap Probability (HOP) with a critical value.

   Such analyses have shown that the Heathrow; Gatwick and Stansted radars used in TC can support a separation minimum of 3NM out to a range of 60NM from the radar heads. Similar analyses have been carried out for other radars that supply data to TC controllers.

2. The use of a 3NM separation standards in TMA airspace (i.e. TC in the case of Heathrow) require other conditions to be met.

3. A trial was conducted at Heathrow on the use of 2.5NM separations on final approach. The conditions under which this separation may be applied are more stringent than those for the 3NM case.

Unquote

FRANCE

Quote

"The methodology used to approve 3NM radar separation is the same as for 5NM radar separation. Therefore no changes are necessary."

Unquote

ANNEX 3
Attachment B

Airport Frankfurt

Operational procedures to implement 2.5 NM radar separation on final approach

For approaches to the parallel runways 07/25, the minimum radar separation on final approach between outer marker and runway threshold is only 2.5 NM (instead of 3 NM) if the following conditions are fulfilled:

a) The weight category of the preceding aircraft is lower or the same as the one of the succeeding aircraft; aircraft of category HEAVY including B 757 are not permitted as preceding aircraft;

b) The turn-off taxiways of the landing runway are visible from the control tower.

c) The landing runway is dry;

d) Compliance with the applicable separation minima is monitored by radar.

Reduced separation minima may also be applied to staggered approaches to parallel runways. In these cases, conditions b) and c) do not have to be fulfilled.

Arriving aircraft may be separated by less than the required radar separation minima, if they have been cleared for the parallel runway and if they have the preceding aircraft in sight.

ANNEX 3
Attachment C

EXAMPLE OF CONDITIONS FOR APPLYING 2.5 NM RADAR SEPARATION ON THE FINAL APPROACH TRACK AT HEATHROW AIRPORT

1. Introduction - Operational Conditions

Day only
Weather criteria 10 km and cloud ceiling of 1 500 ft.
A headwind component of approximately 10 knots
Runway should be dry.

2. Objective

The use of such 2.5 NM radar separation will provide the ability to:

a) In suitable weather, increase the tactically declared landing rate to alleviate delays (It is not intended to use it to increase the strategic capacity declaration).

b) Maintain a high landing rate in conditions of strong headwinds so that tactical capacity is not adversely affected.

3. Procedure

It is recognised and accepted that 2.5 NM final approach spacing will start to reduce when the first aircraft passes 4NM DME.

The Air Arrivals Controller will be the final arbiter as to the acceptance of the reduced separation. Under normal circumstances it will be Heathrow Aerodrome Supervisor that requests the commencement of the trial to the Heathrow GS. Should TC wish to start the trial co-ordination should take place between the GS and ADC supervisor. It is stressed that final authority for commencement remains with Air Arrivals. As with existing practices the factors to be taken into account are the prevailing surface winds, the wind on final approach and the time taken for aircraft to safely vacate the runway.

For the purposes of this procedure, control responsibility for inbound aircraft is deemed to be transferred to Aerodrome Control at 4 DME. The weather criteria selected for the procedure will allow aircraft at 4 DME to be visual to the Air Arrivals Controller. Even when the reported weather conditions are equal to or better than stated criteria, the air controller must ensure that aircraft are clearly and continuously visible on final from 4 NM. Control of the aircraft at 4 DME or less will be in accordance with reduced separation in the vicinity of the airfield.

Responsibility for separation for any aircraft outside 4 NM DME will rest with TC. Although aircraft may have established communications with Air Arrivals, TC will initiate any action considered necessary.

Should any action be taken by the Air Arrivals Controller to traffic inside 4 DME, which may affect the separation of a following aircraft outside 4 NM DME, then TC FIN must be notified of the action taken.

4 Monitoring

It is essential that there is no doubt as to whether the procedure is active at any moment. A captioned FPS (flight progress strip) holder is provided and must be displayed when 2.5 NM spacing is in operation. Periods of use must also be recorded on the daily occurrence report form. The proforma requires information on start and finish times, the general wind during the period, reason for cessation of the procedure and also reasons for refusing the procedure if either TC or Heathrow wished to commence. In addition, missed approaches are to be recorded on the daily occurrence report - whether this procedure is in use or not.

5. Procedure Conditions

5.1 The procedure will be limited to meteorological conditions equal to or better than a visibility of 10 kms and cloud ceiling of 1500 feet, and with a minimum recommended headwind component of approximately 10 knots.

5.2 The procedure will be conducted by day only.

5.3 Reduced separation will only be applied between pairs requiring no wake vortex separations, i.e. weight category of the leading aircraft is the same or less than the trailing aircraft.

5.4 Heavy wake vortex category aircraft and B757's are permitted to participate only when following smaller wake vortex category aircraft.

5.5 Reduced radar separation will be applied to ILS approaches only, within 15 NM from touchdown on the ILS localiser or on a closing heading for the ILS localiser.

5.6 Reduced radar separation will be applied to in-trail stable flight profiles under rigid speed control to 4 NM from touchdown, and must be stabilised 2.5 NM apart on approach by 8 NM.

5.7 Transfer of control of inbound aircraft will be deemed to take place at 4NM DME, transfer of communications may take place prior to this point. Final approach may be monitored on the Aerodrome Traffic Monitor (ATM) radar in line with existing procedures. However, the weather limits are such that the ARR Controller can visually monitor and apply visual separation to any aircraft that have passed 4 NM DME.

5.8 Runway and runway exit points must be visible from the tower.

5.9 The procedure will be suspended when wind shear is reported

5.10 The runway is to be dry

5.11 This procedure does not apply to parallel approaches.

5.12 To meet the required accuracy the approach radar should be located on the airport. The ATM and approach radar's must therefore display either the Heathrow 23 cm radar or the Heathrow Watchman. The radar displays must be continuously and stringently monitored.

5.13 The radar should have a minimum 15 rpm/4 second update rate and the accuracy of the radar and display processing must be assessed for magnitude of errors in displayed separation.

ANNEX 3
Attachment D

Airport VIENNA

Example of Operational Procedures to Implement 2.5 NM Radar Separation on Final Approach

1. Introduction

The procedures are applicable for the runways 11 and 29, and are applied exclusively for arriving aircraft on the final approach track within 10 NM of the landing threshold provided that the radars SRE/MSSR Vienna-Schwechat or MSSR East are in operation and in use.

2. Radar separation minimum

A radar separation minimum of 2.5 NM may be applied between two arriving aircraft, provided :

a) the preceding aircraft is not a B757 or of a heavy type, and the succeeding aircraft is of the same or higher wake turbulence category;

b) both aircraft are established on the final approach track;

c) braking action is reported as good and runway occupancy times are not adversely affected by runway contaminants such as slush, snow or ice;

d) the aerodrome controller is able to observe, visually or by means of surface movement radar (SMR) the runway in use and associated exit and entry taxiways;

e) aircraft approach speeds are closely monitored by the controller and when necessary adjusted so as to ensure that separation is not reduced below the minimum;

f) pilots have been made fully aware of the need to exit the runway in an expeditious manner ("After landing expedite vacating runway, + inbound + traffic behind");

g) runway occupancy time of landing aircraft of 50 seconds or less is achieved.

ANNEX 3
Attachment E

Airport FRANKFURT

Calculation of runway occupancy times at Frankfurt Airport

1. The Federal Administration of Air Navigation Services is currently examining in how far the separation minima between arriving aircraft can be reduced under certain circumstances. Separation minima of 2.5 NM for approaches were taken as a basis. One precondition is a runway occupancy time of 50 seconds or less.

2. For Frankfurt Airport, a calculation was carried out for all landing directions, and the results are presented in the chart enclosed.

   The runway occupancy time is defined as the elapsed time a landing aircraft is on a runway, from crossing of threshold until vacating the runway by reaching a distance of 30 m from the runway centre line.

   The runway occupancy time is composed of different phases;

   – Time from crossing the threshold to touchdown;
   – Time from touchdown to the runway turn-off point (braking time), including, if necessary, time for transition or a transition route after touchdown without run-up;
   – Time from the turn-off point to vacating the runway until reaching a distance of 30 m from the runway centre line.

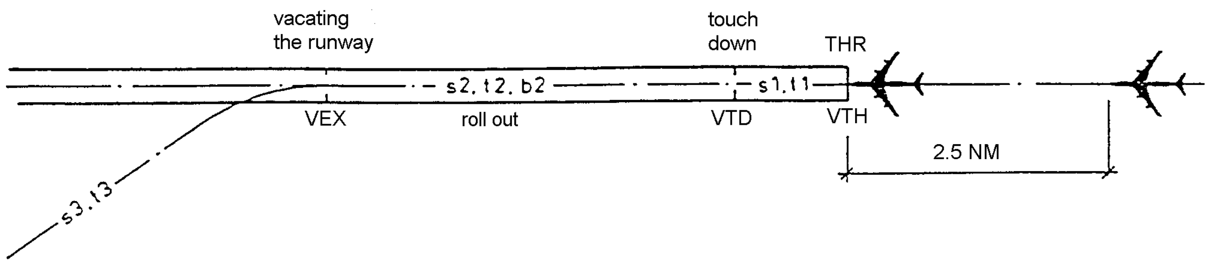
3. In order to determine the runway occupancy time, the following assumptions were taken as a basis.

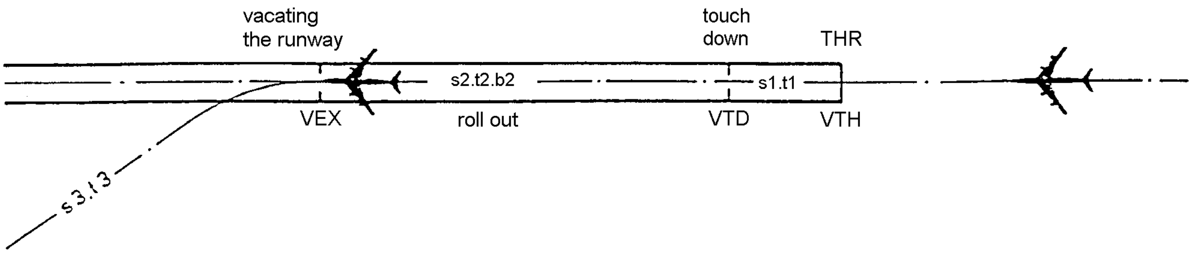
   – In order to calculate the turn-off time from the runway to vacating the runway, an approach speed of 120 kt is assumed for a B 727, for an A 300 an approach speed of 130 kt, and for a B 747 an approach speed of 140 kt. These assumptions are important for the determination of the roll-out distance.
   – The touchdown point is the location of the glide path transmitter;
   – After touchdown and roll-out, the aircraft takes the nearest (rapid) exit taxiway.

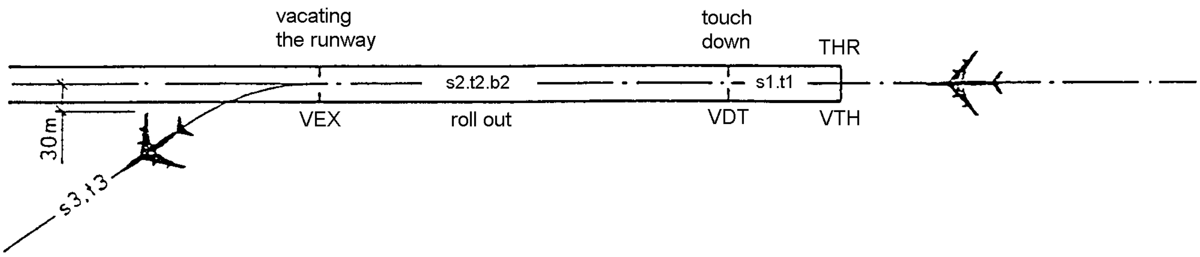
4. The results have shown that under the above-mentioned circumstances and assumptions runway occupancy times of 50 seconds and less can be achieved.

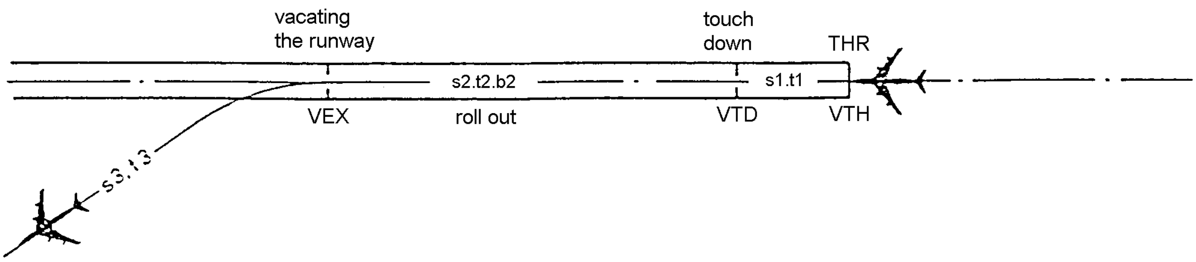
   The table also includes the following details:

   – The delay values b which were arithmetically calculated for the braking distance after touchdown; and
   – The distance of the following aircraft from the threshold in NM or km when the preceding aircraft has vacated the runway by reaching a distance of 30 m.


vacating
the runway
touch
down
THR
s2. t2. b2
s1. t1
VEX
roll out
VTD
VTH
2.5 NM
s3. t3


vacating
the runway
touch
down
THR
s2.t2.b2
s1.t1
VEX
roll out
VTD
VTH
s3.t3


vacating
the runway
touch
down
THR
s2.t2.b2
s1.t1
30m
VEX
roll out
VDT
VTH
s3.t3


vacating
the runway
touch
down
THR
s2.t2.b2
s1.t1
VEX
roll out
VTD
VTH
s3.t3

Runway Occupancy Time Airport Frankfurt

Runway Heading	Taxiway	Approach speed	Runway Occupancy Time	Decel-aration factor (b)	Distance of following aircraft to touchdown (Initial separation 2,5 NM)	
		KT	sec	$m/sec.^2$	NM	km
25 R	Gto	120	39,2	- 2,3	1,19	2,210
	Ato	120	44,3 [1)]	- 1,8	1,02	1,895
	Ato	130	47,5 [1)]	- 2,3	0,78	1,450
	Ato	140	49,8	- 1,8	0,56	1,045
25 L	G	120	41,0	- 2,4	1,13	2,100
	Hto	120	48,9 [1)]	- 1,5	0,87	1,610
	Hto	130	50,0 [1)]	- 2,4	0,69	1,290
	Hto	140	49,0 [1)]	- 2,5	0,59	1,100
07 R	Cto	120	44,8 [1)]	- 1,8	1,00	1,850
	Cto	130	48,1 [1)]	- 2,3	0,76	1,410
	Cto	140	50,0	- 1,7	0,56	1,045
07 L	Mto	120	47,1 [1)]	- 1,6	0,93	1,720
	Mto	130	50,0 [1)]	- 2,1	0,69	1,290
	Mto	140	49,2 [1)]	- 2,1	0,59	1,085
	Hto (07) planned	120	42,7	- 1,9	1,08	2,000

1) transition zone calculated without braking