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FOR THE SAFETY OF AIR NAVIGATION

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NAVIGATION DATA INTEGRITY MODEL

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Abstract:

With the increasing reliance on coordinate data implicit in Area Navigation (RNAV) and Global Navigation Satellite Systems (GNSS) the integrity and quality of such data become critical. This report presents the findings of a study undertaken to examine the various factors which govern the quality and integrity of coordinate data used in air navigation.

The study first defines explicitly various terms, such as *integrity*, *precision* and *accuracy*, which are necessary for a precise description of the processes involved in the assessment of the quality of navigation data. Descriptions are then given of the overall process by which navigation coordinate data are originated and promulgated and of the basic principles of quality assurance. A model describing and categorising the various types of coordinate data used in air navigation is then proposed along with various candidate methods for the provision of data integrity. Conclusions are drawn and recommendations made relating to the data model, quality framework, the use of Cyclic Redundancy Checks (CRC), data quality fields and NOTAM procedures.

Annexes are included which describe the use of CRC's and the relationships between various international quality standards.

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NAVIGATION DATA INTEGRITY MODEL

STASYS Ltd

SUMMARY

With the increasing reliance on coordinate data implicit in Area Navigation (RNAV) and Global Navigation Satellite Systems the integrity and quality of such data become critical. This report presents the findings of a study undertaken to examine the various factors which govern the quality and integrity of coordinate data used in air navigation.

The study first defines explicitly various terms, such as *integrity*, *precision* and *accuracy*, which are necessary for a precise description of the processes involved in the assessment of the quality of navigation data. Descriptions are then given of the overall process by which navigation coordinate data are originated and promulgated and of the basic principles of quality assurance. A model describing and categorising the various types of coordinate data used in air navigation is then proposed along with various candidate methods for the provision of data integrity. Conclusions are drawn and recommendations made relating to the data model, quality framework, the use of Cyclic Redundancy Checks (CRC), data quality fields and NOTAM procedures.

Annexes are included which describe the use of CRC's and the relationships between various international quality standards.

FOREWORD

The advent of Area Navigation (RNAV) and Global Navigation Satellite Systems (GNSS) will inevitably result in an increase in reliance upon air navigation coordinate data. As such reliance becomes safety critical, attention will focus upon data quality, reliability and integrity.

This study, commissioned by EUROCONTROL in response to issues raised by the on-going WGS 84 implementation programme, provides a comprehensive treatment of the subject of coordinate integrity in the field of air navigation.

The purpose of the study was to examine all aspects of coordinate data integrity, determine and describe the factors involved, and provide clear conclusions and recommendations. Whilst the conclusions reached in this report do not necessarily reflect the views of the EUROCONTROL Agency, it is clear that they have been drawn from a thorough and well-balanced study and it is to be hoped that this report will provide the basis for an increased awareness and a clearer understanding of the issues involved.

Many people were consulted during the preparation of this report and their contributions have been generously acknowledged by the authors. The major credit for the quality of the work, however, must be given to the authors themselves, John Curtis and Jeremy Davidson of STASYS Ltd.

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NAVIGATION DATA INTEGRITY MODEL

STUDY REPORT

prepared for

EUROCONTROL

November 1994

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FOREWORD

This report results from a short study into the preservation of the integrity of navigation data, undertaken by STASYS Ltd on behalf of EUROCONTROL.

During the study, the authors received information and advice from a number of organizations and companies involved in the processing of navigation data. In particular, the authors wish to acknowledge the following for their generous contribution in time and interest: Mrs U Malik of SITA Flight Operations Services; Mr B Hohnberg and Mr R Sieprath of Jeppesen Aviation Organization and Government Programs; Mr K Reid and Mr S Stebbings of British Airways Navigation Services; Mr L Whittington of Racal Avionics Ltd NavData Services; and representatives of the UK CAA National Air Traffic Services.

We are particularly grateful to Mr Roland Rawlings and Mr Conrad Cleasby, of EUROCONTROL, for their assistance and counsel throughout the study; their rapid and detailed responses to our many queries were a significant help to us keeping within the tight timescale.

J D Curtis
Director

Certificate Number FM27061

CONTENTS

EXECUTIVE SUMMARY

Traditional navigation techniques have relied upon the ability to fly to or from point navigation aids and, whilst the coordinates of the navigation aids have been provided, this information has not been used as part of the navigation process. Increasing use is now being made of Area Navigation (RNAV) systems which derive the aircraft position from such sources as Inertial Navigation Systems (INS), Omega, VHF Omni-directional Range (VOR)/Distance Measuring Equipment (DME), Dual or multi DME and Global Navigation by Satellite Systems(GNSS).

For such operations the track actually flown by the aircraft depends upon the coordinates defining both the track and the location of ground navigation aids. With the advent of precision RNAV (RNP 1) routes from 1998 and the extension of RNAV application to Terminal Area procedures, greater precision is required and it is necessary to ensure that the data defining the track to be flown is of an accuracy and integrity which is consistent with the RNP requirements.

ICAO has adopted the World Geodetic System 1984 (WGS 84) as the common geodetic reference system for civil aviation and is developing appropriate documents to ensure a rapid and comprehensive implementation of this standard, worldwide. Within ECAC, the implementation of WGS 84 is being coordinated by the EUROCONTROL Agency who, under EATCHIP, are currently developing standards and procedures to ensure that the surveying of positions in the WGS 84 system meets the overall accuracy requirements.

The collation, storage, maintenance and subsequent distribution of this navigation data is the responsibility of each individual national Aeronautical Information Service (AIS). Navigation data from all the ICAO Contracting States are, in turn, collated, maintained, stored and distributed to FMS manufacturers and airlines by commercial data providers. If the high levels of accuracy and integrity required by the RNP standards are to be achieved, it will be necessary to develop quality assurance procedures and standards for all agencies who have responsibility for handling navigation data.

The study concentrated on the maintenance of the integrity of navigation data which are loaded electronically in the FMS. Navigation data contained in Amendments and Supplements to the Aeronautical Information Publications (AIP), issued by the AIS, are included in this process. However, the procedure for changing data at short notice, using the NOTAM procedure, currently requires significant human involvement throughout the process and was not addressed in this report.

OVERVIEW OF THE NAVIGATION DATA PROCESS

The process of collecting, storing and disseminating navigation data is described in the RTCA document Do 200, 'Preparation, Verification and Distribution of User-Selectable Navigation Data Bases' which, together with Do 201, 'User recommendations for Aeronautical Information Services', addresses some of the quality issues that affect the navigation data process. While the former was originally produced primarily for use by the FMS manufacturers and commercial data providers and the latter is addressed specifically at the AIS, the procedures, described in Do 200, and the standards, detailed in Do 201, can be applied to every stage of the navigation data collection and distribution cycle.

The quality requirements for the delivered navigation data must be specified by the end users of the data. These requirements must include:

a. A definition of the data required.

b. A clear statement of the accuracy requirements for each different data type.

c. A clear statement of the integrity requirements for each different data type.

d. A clear statement of the traceability requirements for changes to each data type.

DATA CLASSIFICATION

It has not been possible to identify an existing, comprehensive, formally agreed statement concerning the end user's requirements for accuracy and integrity in navigation positional data. At present, there is no clear statement of these user requirements for all data classes, although there is work in progress to agree the requirements for Precision Area Navigation (PRNAV) in both the en-route and terminal phases of flight. It is understood that, in the latter context, there is an overall requirement that there must be less than one fatal landing attributable to a landing system in every 10^7 landings and that error rates are assumed to be evenly distributed between the error sources. For the purposes of this report, a data model has been developed consisting of nine classes of data as detailed in the table overleaf.

QUALITY FRAMEWORK

Given that the users of navigation data do specify the quality requirements, it follows that every organization providing such data must provide evidence that it is meeting the stated requirement.

Whatever system is chosen by the individual organizations, a community-wide Quality Framework is required which details the Standard Procedures, algorithms and formats that can be referenced, as necessary, in each organization's Quality System.

These Standards would have to be properly documented and ratified by the whole navigation data community, although not all the Standards are expected to be mandatory. In many cases, the Standards may be expressed in terms of statements of requirement, rather than as technical solutions. However, mandatory technical solutions are expected to be specified in cases where a common agreed interface is required between independent navigation data processors.

Summary of Navigation Data Integrity Model		
CATEGORY	Describes the safety sensitivity of data	
Critical Data	There is a **high probability** that, as a result of using corrupted Critical Data, an aircraft would be placed in a life threatening position	
Essential Data	There is a **low probability** that, as a result of using corrupted Essential Data, an aircraft would be placed in a life threatening position	
Routine Data	There is a **very low probability** that, as a result of using corrupted Routine Data, an aircraft would be placed in a life threatening position	
TYPE	Describes the method by which the data was obtained	
Surveyed Points	A surveyed point is a clearly defined physical point, specified by latitude and longitude, that has been determined by a survey.	
Declared Points	A declared point is a point in space, defined by latitude and longitude, that is not dependent upon, nor formally related to, any known surveyed point.	
Calculated Points	A calculated point is a point in space which need not be specified explicitly in latitude and longitude, but which has been derived, by mathematical manipulation, from a known surveyed point.	
CLASS	Describes operational useage (For example:)	Accuracy & Integrity Requirements
1	Runway Threshold FAF FACF MAPt	0.3m Critical CAT I : 3×10^{-8} CATIII : 8×10^{-10}
2	Navigation Check Points	0.5m Essential 3×10^{-5}
3	MLS (Az, Elev, Back-Az) Helicopter Landing Area	1m Critical 3×10^{-8}
4	DME/P	3m Critical 3×10^{-8}
5	Obstructions in Approach/Take-off Area	3m Routine 1×10^{-3}
6	Terminal Navaids Terminal Waypoints	30m Essential 1×10^{-5}
7	ARP, HRP Obstructions at Aerodrome and in Circling Area	30m Routine 1×10^{-3}
8	En-route Navaids En-route Waypoints Gates, Groundlights and Obstacles	100m Essential 1×10^{-5}
9	Airspace Designation, Communications Sites, ILS, Decca, Loran	100m Routine 1×10^{-3}

The Procedures and Standards included in the Quality Framework must, as a minimum address the following areas:

a. **Data Input** The transfer of data from written or printed form into a form that is stored in a computer is the greatest entered in a database by the surveyors/designers themselves and, thereafter, kept in electronic/magnetic form throughout the subsequent navigation data cycle, the requirement for verifying the manual input would be significantly reduced.

   When a data item is first entered into electronic format it will need either to be provided with the ability to be verified on subsequent transfer or, to provide assurance that it has not been corrupted while stored. The mechanism proposed for achieving this is the use of a Cyclic Redundancy Check (CRC), which must be produced from the name (Identifier) of the position, its latitude, longitude, altitude and data quality, as appropriate. It is proposed that the data originator generates a CRC before transmitting Critical or Essential Data in electronic format.

b. **Data Validation** Data validation checks can be performed once the data item is held in electronic format and can be used to detect a number of the errors induced by manual data entry or subsequent data corruption. However, the integrity of the data cannot be improved very much by such checks.

c. **Data Transfer** When data is transferred between computer systems, there is a risk of corruption in transit. It is normal practice to provide protection and assurance by the use of CRC. The level of assurance provided by the CRC, that the received copy of the data is exactly the same as the transmitted copy, must be at least as high as the required level of integrity for any individual item within the set of transferred data.

d. **Auditability and Traceability** If integrity is to be assured and demonstrable, all coordinates must be traceable to their source by an unbroken trail. A record must be kept of the details of any changes made to the data. Such records may be electronic or paper-based, although certain change information must remain with the data item throughout the navigation data cycle. This report includes a design proposal for a data field, called the data quality field, which could be transferred automatically with the data.

e. **Corrective Action** At present, there is no formal Procedure for reporting errors and taking corrective action - most corrections are done on a one-to-one basis with the AIS. A Standard Procedure for reporting errors, and issuing subsequent amendments, would ensure that all interested parties are kept informed and source-errors in navigation data-related databases are corrected in an ordered and timely fashion.

f. **Documentation** Standard algorithms and working practices should be clearly detailed in one document. At present, RTCA Do 200 addresses the problem from the viewpoint of the Navigation Data Vendors. RTCA Do 201 identifies areas of concern that need to be addressed by the AIS organizations. The proposed Quality Framework, and the associated Procedures and Standards, would apply equally to all parties involved in the data process, from the originators to the end users.

RECOMMENDATIONS

The higher risks associated with critical data and the increasing propensity for post-incident litigation means that, it may be necessary to develop a more formal relationship between the provider of navigation data and the data user with respect to the quality of the data provided.

It is recommended that

a. The data model, detailed in this report, be considered for adoption as a basis for an internationally agreed Standard which will be a mandatory requirement on all navigation data community members.

b. RTCA Do 200 be developed into a Quality Framework document which details the Procedures and references the Standards that apply to all organizations involved in the production or maintenance of navigation data. RTCA Do 201 be developed into a Standards document which details the algorithms and working practices that may apply to any organization involved in the production or maintenance of navigation data. The data transfer Standards continue to be detailed in stand-alone documents such as ARINC 424

c. All Critical and Essential navigation data items be protected by individual embedded CRC, which are applied throughout the data process, from the point of origin of the data to the point of use. Procedures be developed to allow the regeneration of CRC whenever the data format changes. The same 32 bit CRC algorithm that has been adopted for use in the MLS be implemented as the standard CRC for the protection of Critical Data and, if feasible, Essential Data. (Otherwise, the CCITT 16 bit CRC algorithm be implemented as the standard CRC for the protection of Essential Data.)

d. The data quality field proposed in this report be adopted as a standard for all electronic navigation data transfer formats.

e. All organizations be mandated to protect navigation data during transfer, through the use of a 32 bit CRC. The specific CRC algorithms chosen need only be agreed between the parties participating in the data exchange.

f. A study be undertaken into the integrity of data within the NOTAM system.

1. INTRODUCTION

This report investigates the issue of air navigation data integrity. As a result of new technologies, which are being introduced in navigation, information processing and communications, a greater reliance is being placed upon positional data which is used in air navigation. This necessitates a re-examination of the accuracy and integrity requirements that are placed upon the data and of the means of meeting these requirements.

1.1 PURPOSE OF REPORT

Traditional navigation techniques have relied upon the ability to fly to or from point navigation aids. Whilst the coordinates of the navigation aids have been provided, this information has not been used as part of the navigation process. Increasing use is being made of Area Navigation (RNAV) systems which derive the aircraft position from such sources as Inertial Navigation Systems (INS), Omega, VHF Omni-directional Range (VOR)/Distance Measuring Equipment (DME), Dual or multi DME and Global Navigation by Satellite Systems(GNSS). Based on these data, the RNAV system generates appropriate instructions to the autopilots which enable the aircraft to follow the flight-planned route during the departure, en-route, approach and landing phases of flight.

For such operations the track actually flown by the aircraft depends upon the coordinates defining both the track and the location of ground navigation aids. With the advent of precision RNAV (RNP 1[*]) routes from 1998 and the extension of RNAV application to Terminal Area procedures, greater precision is required and it is necessary to ensure that the data defining the track to be flown is of an accuracy and integrity which is consistent with the RNP requirements.

ICAO[†] has adopted the World Geodetic System 1984 (WGS 84) as the common geodetic reference system for civil aviation and is developing appropriate documents to ensure a rapid and comprehensive implementation of this standard, worldwide. Within ECAC[‡], the implementation of WGS 84 is being coordinated by the EUROCONTROL Agency who, under EATCHIP[§], are currently developing standards and procedures to ensure that the surveying of positions in the WGS 84 system meets the overall accuracy requirements.

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* RNP: Required Navigation Performance. This specifies the performance accuracy required on a defined route portion of airspace. At present four levels of performance have been defined by ICAO for en-route operations. Requirements for Terminal and final approach procedures are in development.

RNP 1	1 NM 95% containment {ie within an RNP 1 airspace, the navigation performance of the population of aircraft will ensure that 95% will be within 1NM of the defined centreline. (for information: see section 3.3.1 of ICAO DOC 9613-AN/937 Manual on Required Navigation Performance (RNP))}
RNP 4	4 NM 95% containment (in some areas including Europe, it may be necessary to use RNP 5 to allow continued operation using Omega)
RNP 12.5	12.5 NM containment (equivalent to the present requirement for operation in the North Atlantic track structure)
RNP 20	20 NM containment

† ICAO: International Civil Aviation Organization

‡ ECAC: European Civil Aviation Conference

§ EATCHIP: European Air Traffic Management Harmonisation and Integration Programme

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This report addresses the requirements for a system of quality assurance that will ensure that positional navigation data maintains a level of integrity suitable for the navigation process. It provides an initial framework from which the procedures and standards necessary for a suitable quality assurance system can be developed.

1.2 REPORT STRUCTURE

The report is divided into four main sections. The first section expands the definitions, given in the glossary at Annex A, of several of the more important concepts discussed in the report. The second section addresses the navigation data gathering and processing activities and the requirements for quality assurance. The third section identifies the positional navigation data, the requirements for accuracy and integrity, the sources and the relationships between the various data items; from these considerations a data model is developed to categorise the data according to the users' requirements. The fourth section introduces and describes the Quality Framework that is considered to be necessary to achieve the required assurance and proposes Procedures and Standards that would need to be implemented throughout the navigation data community. The use of Cyclic Redundancy Checks (CRC) for ensuring data integrity and the applicability of existing international standards are discussed at Annexes B and C. Annex D contains details of referenced documents and a short Index is provided at Annex E.

2 DEFINITIONS

2.1 INTRODUCTION

It is important that there is a common understanding of the terms used when discussing accuracy, integrity, quality and quality assurance. Whilst the glossary at Annex A contains short definitions of the terminology employed in this report, this section expands the interpretation of several of the more important concepts where it is felt that the reader could misinterpret the author's intentions if a wider, more general, definition of the word were to be used.

2.2 ACCURACY

The definition of accuracy given in the glossary of this report is:

The degree of conformity with a standard, or a value accepted as correct or true. For measured positional data the accuracy is normally expressed in terms of a distance from a stated position within which there is a defined confidence of the true position falling.

For the EUROCONTROL WGS 84 Implementation programme, the accuracy requirements are based upon a 95% confidence level. The underlying statistical distribution for positional data in two dimensions is usually taken to be the circular normal distribution. The probability (P) of a point actually falling within a circle of radius $c\sigma$ around its reported position, where σ represents the standard univariate deviation and c is a numeric coefficient, is

$$P = 1 - \exp\left(\frac{-c^2}{2}\right) \quad or \quad P = 1 - e^{-\frac{c^2}{2}}$$

The Circular Error Probable (CEP) is the radius of the circle within which 50% of the measurements lie, that is, 1.1774σ. The radius within which 95% of the measurements lie is 2.448σ or 2.079 x CEP. The additive properties of the distribution follow the root sum square rule so that the root mean square error is $\sqrt{2}\sigma$.

2.3 INTEGRITY

The glossary definition of integrity is given as:

The extent to which modification of software or data can be controlled in a computer system. The assurance that a data item retrieved from a storage system has not been corrupted or altered in any way since the original data entry or latest authorised amendment.

Integrity is often confused or combined with data 'security', that is, the protection of data and software from access or corruption by persons who have no right to view or alter the data. Whilst integrity checks can be used as part of a security system, this aspect is not addressed here. In the context of this report, integrity concerns the degree of assurance that can be given that a data item has a value which is the same as that originally provided by the surveyor or procedure designer.

Integrity is expressed in terms of the probability that a data item, retrieved from a storage system with no evidence of corruption, does not hold the same value as intended. For example, an integrity of 3×10^{-8} means that an undetected corruption can be expected in no more than three data items in every 100 000 000 data items processed. In the context of this paper no attempt is made to link accuracy and integrity: data that have an accuracy of 1m with 95% confidence and are protected to ensure 3×10^{-8} integrity will, in at least 99 999 997 transfers out of every 100 000 000, have the same accuracy (1m with 95% confidence) after the transfer.

2.4 PRECISION

The glossary definition of precision is given as:

The smallest difference that can be reliably distinguished by a measurement process.

The precision with which a measurement is taken is no guarantee of the accuracy of that measurement, but may be used, together with a statement of error probability, to define the accuracy of the measurement. Precision takes no account of systematic errors, whereas accuracy does.

2.5 QUALITY

The glossary definition of quality is given as:

The ability of a product to meet its stated requirements, that it is fit for its specified purpose. There is no single or absolute measure of quality although statements about the quality of a process or item may be based upon physical measurements and observations.

The quality of data is a measure of how well it meets the requirements of the data user. These requirements may include levels of accuracy, integrity and traceability. If, for example, the user-defined accuracy requirement for a data item is 1m at 95% confidence then, data meeting that requirement have the same degree of quality as data with an accuracy of 0.001m at 99.99% confidence. Moreover, if the integrity requirement is, say, 1×10^{-7}, and this is met by the data with the lower accuracy but not by the data with the higher accuracy, then the data with the lower accuracy have a higher data quality.

2.6 REPEATABILITY

The glossary definition of repeatability is given as:

The level to which, irrespective of accuracy, a measurement, when repeated, will agree with the previous value.

The consistency of the results provides a measure of the degree of repeatability. In determining the consistency, the precision of the repeated measurements must be taken into account.

2.7 RESOLUTION

The glossary definition of resolution is given as:

The smallest difference between two adjacent values which can be represented in a measuring system. The number of decimal points or the scale of units to which a measured or calculated data item can be recorded, displayed or transferred.

The terms 'precision' and 'resolution' are often interchangeable in general use, but this is not the case in this report where resolution is a measure of the data field capacities that are available within a specific system design. (Example: 54° 33′ 15″ is expressed to a resolution of one second.) Any process that manipulates data subsequent to the original measurement or definition must not imply an increase in the precision to which the data were originally measured or defined, regardless of the resolution available within the system itself.

For example, for a point to be surveyed and reported to an accuracy of 1m with 95% confidence, it may have been measured to a precision of 0.1m. However, it must not subsequently be accorded a value with more resolution than its previously reported precision, such as, for example, 0.11m. Similarly, data must not be displayed in such a way as to imply a greater accuracy than they have: a distance of 100m must not be displayed as 100.00m if it has only been measured to an accuracy of 1m. Where a greater resolution is available in a database, there must be a clear indication of the actual resolution when the data were originated. This is usually achieved using a separate field to indicate the actual resolution.

2.8 VALIDATION

The glossary definition of validation is given as:

The activity whereby a data item is checked as having a value which is fully applicable to the identity ascribed to the data item.

Validation checks are often confused with verification checks (see paragraph 2.9). Validation checks include range limit checks, related record/field checks and data item relationship checks. Range limit checks ensure that data fields, which have been accorded specific ranges of values, do not hold data values outside that range. Related record/field checks ensure that appropriate data are held in related records/fields - for example, every waypoint used to identify an ATS route must be defined and every waypoint field holding a VOR Identifier must be supported by location data, frequency data, declination data, etc. Moreover each VOR frequency must also be within the VHF range used by VORs for the ATS route to be valid. Data item relationship checks, including collinearity checks, elevation checks and geographical vicinity checks, are also considered to be validation checks.

Validation checks provide some assurance that data have been correctly entered, maintained or transferred and they can assist the checking of the integrity of the data to a limited degree. However, validation checks cannot be used to improve the reported data quality. Their primary use is to filter out gross errors.

2.9 VERIFICATION

The glossary definition of verification is given as:

The activity whereby the value accorded to a data item is checked against the source of that value.

Verification is a process for checking the integrity of a data item. It usually takes place when data are input to a database where it can take the form of a visual check of the input data against the original source document by an independent checker or an automatic check of the same data item which is entered two or more times by one or more data entry operators. Recomputation and confirmation of CRC values is also a form of verification check.

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3 NAVIGATION DATA AND THE REQUIREMENT FOR QUALITY ASSURANCE

3.1 OVERVIEW OF THE AIS PROCESS

3.1.1 Introduction

The document containing the International Standards and Recommended Practices (SARPS) for AIS, Annex 15 to the Convention on International Civil Aviation, specifies that each Contracting State must provide an AIS to collect and disseminate information needed to ensure the safety, regularity and efficiency of air navigation[*]. This information includes details of the available air navigation facilities and associated procedures. It is incumbent upon the national aviation authority to ensure that all the required information, originated by the providers of a number of different aeronautical services, such as aerodromes, air traffic, search and rescue, communications and meteorology, is collated and disseminated to all interested aviation users in a timely and accurate fashion.

3.1.2 National AIS Responsibilities

Each State publishes permanent aeronautical information, such as the physical characteristics of aerodromes; the types and locations of navigation aids (navaids); details of the various aeronautical services available and the procedures associated with those services and facilities, in a manual known as the Aeronautical Information Publication (AIP). This paper document uses text, tables and charts to present the information. (The format of this document is expected to change in the near future and any references to AIP sections in this report are based upon a Draft AIP Amendment 2 dated 1 March 1991. Amendment 28 to Annex 15 to the Convention on Civil Aviation requires the AIP to be structured to allow standardised electronic data storage and retrieval, with effect from 25 April 1996[†], although a standard digital data transfer format has yet to be agreed.)

Permanent changes to the AIP are published in AIP Amendments. Changes of a short duration, that is, of less than 28 days, or operationally significant changes that happen at short notice, that is, with less than, say, 50 days notice[‡], are distributed by NOTAM[§]. Temporary changes of more than 3 months duration and operationally significant changes, that have an extensive effect on the AIP text or graphics, are published in AIP Supplements. Related information that does not qualify for inclusion in the AIP, or in a NOTAM, is published in Aeronautical Information Circulars (AIC).

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* Aeronautical Information Services Manual Doc 8126-AN/872 Chapter 1

† Amendment 28 to Annex 15, Chapter 4, paragraph 4.1.1 *Applicable as of 25 April 1996, an Aeronautical Information Publication shall contain in three parts, sections and sub-sections uniformly referenced to allow for standardized electronic data storage and retrieval, ...*

‡ Doc 8126 Chapter 4, Paragraph 4.4.6/7 *There are three significant dates associated with the AIRAC system: the effective date, the publication date and the latest date for the raw data to reach AIS. It is the responsibility of AIS to determine what the latest dates are for raw data to reach it. ...Ideally there should be an interval of 42 days between the publication date and the effective date.*

§ NOTAM: Notice to Airmen - distributed via the Aeronautical Fixed Telecommunication Network (AFTN)

AIP Amendments and AIP Supplements are published in accordance with internationally agreed Aeronautical Information Regulation and Control (AIRAC) procedures, which follow a 28 day cycle of agreed effective dates. Publication dates should precede effective dates by an interval of 42 days, in order to allow 14 days for distribution and, thereby, give at least 28 days notice of the change. The AIS information flow is described in Figure 1.

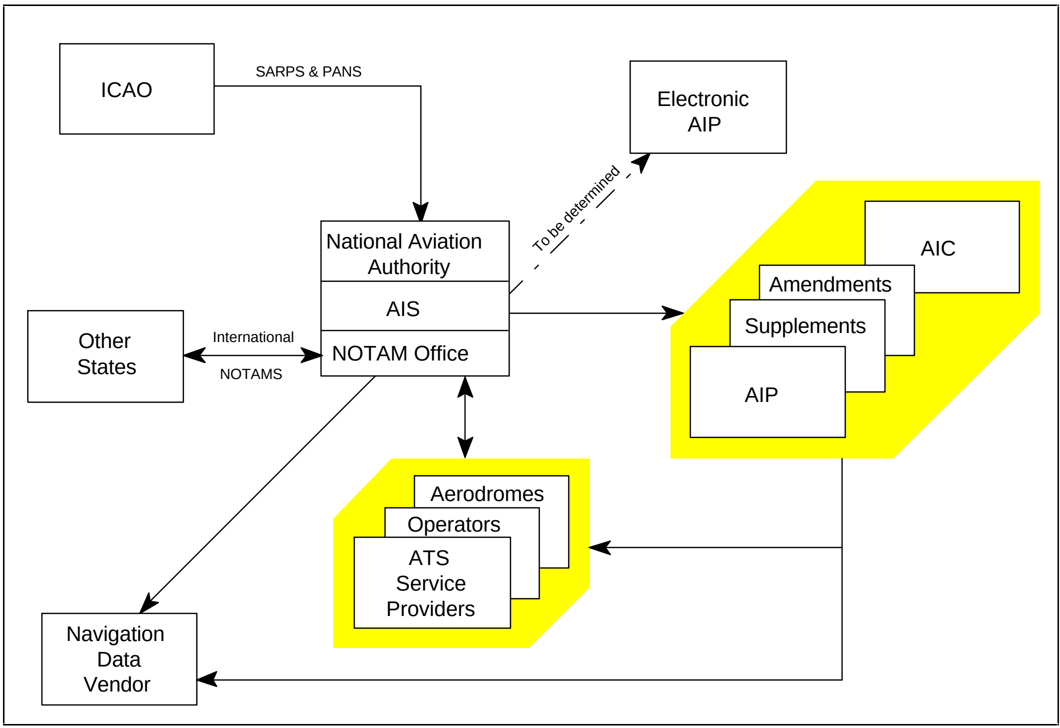

Figure 1 - The AIS Process

This report concentrates on the maintenance of the integrity of navigation data which are loaded electronically into the FMS. AIP Amendments and Supplements are included in this process. AIC information does not include relevant navigation information. The procedure for changing data at short notice, using the NOTAM procedure, currently requires significant human involvement. However, the procedures and methods necessary to ensure the integrity of data, processed through the NOTAM system, have not been addressed in this report.

3.1.3 Commercial Use of AIS Data

The information, provided by the AIS of all the Contracting States, is collated by a number of commercial organizations. These companies, known collectively as the Navigation Data Vendors*, utilise this information to develop and maintain databases to support FMS equipment and the publication of commercial international AIP-type manuals, charts and electronic aeronautical information libraries. The Navigation Data Vendors sell AIS-related data to FMS manufacturers and airlines.

* eg. Jeppesen, Racal and Swissair

Current navigation databases, used by the FMS, have limited storage capacities. The data must often be tailored and selected according to the geographic area covered by the en-route phases, the airports selected and the airline/company-specific requirements such as company routes and fuel policy. Moreover, the engine/airframe combination and the status of the FMS software, in a particular aircraft, further constrains the range of options available. The flow of data from originator to airline is described in Figure 2.

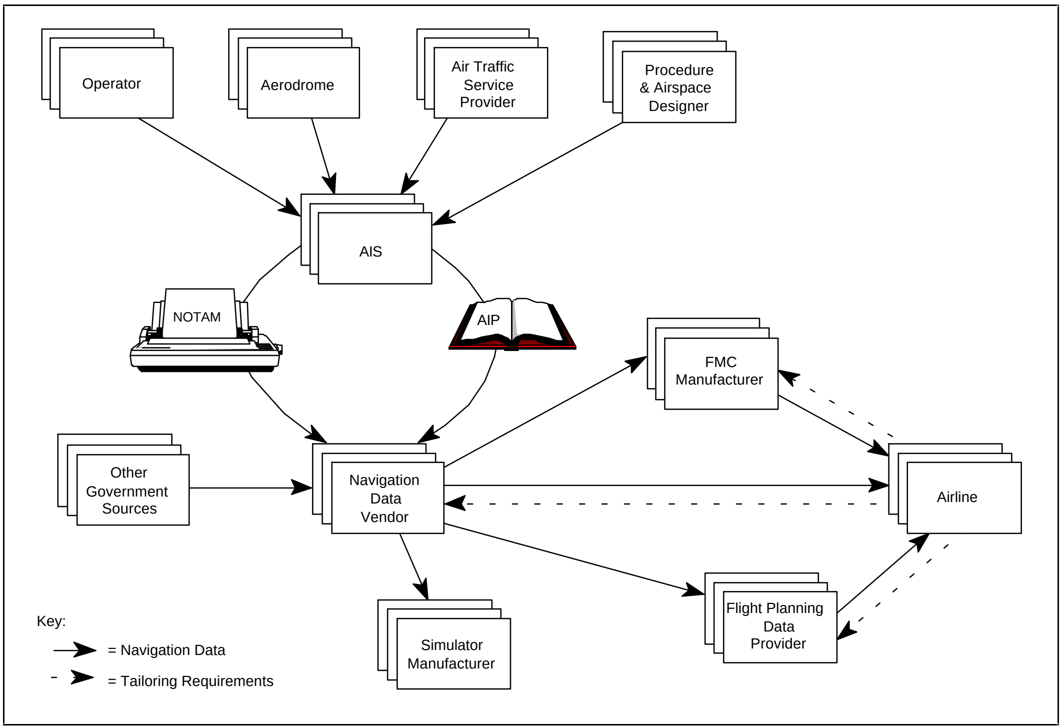

Figure 2 - The Flow of Navigation Data

3.1.4 Documenting the Navigation Data Process

The process of collecting, storing and disseminating navigation data is described in RTCA* document Do 200†, 'Preparation, Verification and Distribution of User-Selectable Navigation Data Bases'. While it is clear from the title that this document was originally produced primarily for FMS manufacturers, the four-step process of Assembly/Selection/Format/Distribution can be applied to each and every stage of the navigation data collection and distribution cycle.

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* RTCA: Radio Technical Commission for Aeronautics - RTCA Inc is a non-profit organization which operates as a Federal Advisory Committee developing consensus recommendations on major aviation-related communication, navigation and surveillance issues.

† Do 200 and Do 201 are documents that address a number of aeronautical information requirements and design standards that are needed in support of computer-based systems. Both documents are, at the time of writing, under review by RTCA SC 181.

a. Assembly

The assembly process involves the collation of data from various sources. In the first stage of the navigation data cycle, this may include inputs from surveyors, procedure designers and other organizations responsible for defining AIS data. In later stages, it may involve collating inputs from different Navigation Data Vendors. During the assembly process, it is imperative that adequate checks are carried out to ensure that the received data are error free and that no errors are introduced during the assembly process itself. If errors are identified in the received data, they must be reported to the originator. If errors are identified as having been introduced during the assembly process, there must be a procedure for reviewing and, if necessary, correcting the assembly procedures. The source, accuracy and reported integrity of each data item, together with details of any changes made to received data, must be recorded to assist in any future audit activity.

b. Selection

The selection process involves picking specific data items from the database, or document library, according to predefined criteria. In the case of national AIS offices, this may be to produce an AIP Amendment or, for Navigation Data Vendors, to update a specific FMS being operated by a particular airline. During the selection process, it is important that sufficient checks are made to ensure that the data items chosen meet the user's criteria and that no errors have been introduced since the assembly phase. If errors are found, there must be a procedure for identifying the source of the error, reviewing the assembly and selection procedures and, if necessary, taking corrective action. Quality information concerning the source, the accuracy and the integrity of each data item must be included in the selection. However, it may not be possible to maintain an electronic record if the target equipment is incapable of processing it. A record of selection activities must be kept for audit purposes.

c. Format

The format process involves arranging the data in a configuration that is acceptable to the user. This may take the form of the Universal Data Delivery Format (UDDF) for a surveyor providing data to the aviation authority; the AIP hard copy format for an AIS publishing data (in the future it is expected that a standard digital AIP format will be developed for electronic transfer); the ARINC* 424 format for the transfer of data for navigation, flight planning or simulator use from one database to another; or a proprietary FMS format for loading in a FMS database. Here again, sufficient checks must be made to ensure that the data items are compatible with the format selected and that no errors have been introduced since the selection phase. Furthermore, procedures must exist to identify the source of any error and to take appropriate corrective action.

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* ARINC: Aeronautical Radio Inc provides secretariat and technical staff for various airline committees including the Airlines Electronic Engineering Committee (AEEC) and maintains technical specifications and standards documents on their behalf.

d. Distribution

The distribution process involves the delivery of the formatted data to nominated users. This may be an electronic transfer via magnetic media or solid state devices, via direct computer to computer links, or, as a hard copy transfer, in the form of surveyor's notes or an Amendment to the AIP. Hard copies can only be subjected to a manual verification, but electronic transfer methods allow automatic verification checks to be made and CRCs to be used to protect the integrity of the data whilst it is in transit. The choice of CRC algorithm and the size of data package that is to be protected will depend upon the integrity requirements of the user as well as the risk of corruption posed by the transfer medium.

The navigation data process is described in Figure 3 which has been developed from diagrams in RTCA Do 200.

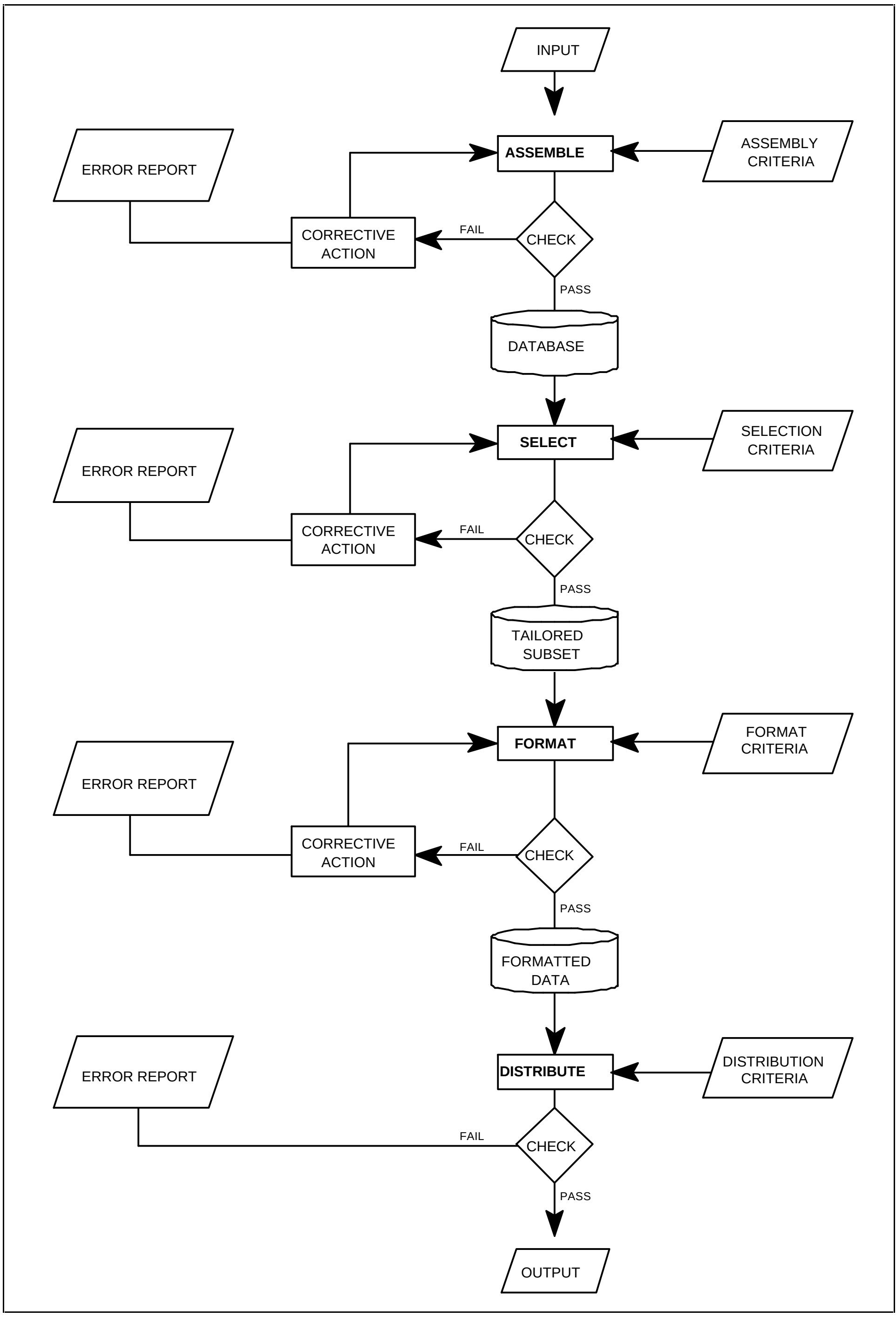

Figure 3 - The Navigation Data Process

3.2 QUALITY ASSURANCE

3.2.1 Overview

Most organizations produce a product, or provide a service, that is intended to meet a user's requirements. Although these requirements are often detailed in a specification, there is a danger that deficiencies in the specification documents, or in the subsequent production process, may result in a deliverable that fails to meet the user's actual needs. Consequently, Quality System guidelines have been developed, by national and international standards organizations, which can be used to create an effective internal quality management structure and to provide adequate quality assurance to the clients/customers.

3.2.2 Quality Assurance Concepts

The principal concepts of any Quality System include the following objectives:

a. The organization must achieve and sustain the quality of the product or service so as to meet continually the client's stated or implied needs.

b. The organization must provide confidence to its own management that the intended quality is being achieved and maintained.

c. The organization must provide confidence to the client that the intended quality is being achieved and maintained.

3.2.3 Quality Assurance Aims

It is the aim of every Quality System to ensure that:

a. Quality problems are detected as early as possible in the production process.

b. Effective corrective action is implemented to rectify any quality problems detected and to identify and resolve the root causes of such problems.

c. Sufficient evidence is available to management, and, if required contractually, to clients/customers, to demonstrate the efficacy of the Quality System and thus to provide the necessary assurance that the delivered product meets the stated quality requirements.

3.2.4 Quality System Structure

The main elements of any Quality System include details of:

a. The organizational structure of the Quality System and the related management responsibilities within the overall organization.

b. Quality Procedures in the areas of marketing, design, purchasing, material control (input), production, product inspection and testing (output), storage, delivery and after sales service.

c. Particular and detailed Procedures for the control of received materials and finished products that do not conform to the required Standards.

d. Particular and detailed Procedures for corrective action to be taken in the event of non-conformance to, or an identified deficiency in the Quality System.

e. Internal audit Procedures and external audit requirements, if identified as necessary.

f. Procedures for documenting the Quality System and recording material reviews, product tests and inspections, audit activity, reported deficiencies and non-conformances.

3.2.5 Procedures

Methods of operation that normally remain constant within an organization, that is, those that are not solely related to specific contracts, are usually documented within the organization's Quality System as Procedures. Procedures describe the actions and controls established to ensure that the Quality System functions effectively. They identify who is responsible for implementing the controls, where the controls are to be implemented and why the controls are necessary. Procedures may call up specific Standards that have to be applied as part of the controls or as part of the process itself.

Procedures may be specific to the organization or may be agreed with other similar organizations at a local, national or international level. Procedures that are not specific to the organization are identified within the Quality System as external Procedures.

3.2.6 Standards

Individual Procedures may call up working practices, formats or algorithms that are used by a number of different elements within the production process or that are agreed with other organizations which are active in the same field. In some cases, organizations may agree to the common implementation of complete Procedures. Such Procedures, working practices, formats or algorithms are defined as Standards and must be fully documented and agreed by all the affected parties. Standards that are not specific to the organization are identified within the Quality System as external Standards.

3.2.7 Quality Assurance and the Navigation Data Process

The quality requirements for the collection, maintenance, storage and distribution of navigation data must be specified by the end users of the data. These requirements must include:

a. A definition of the data required

b. A clear statement of the accuracy requirements for each data type.

c. A clear statement of the integrity requirements for each data type

d. A clear statement of the traceability requirements for changes to each data type.

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4 AIS DATA

4.1 REQUIREMENT FOR ACCURACY

For AIS data to be useable it must be accurate and, in this context, it can be sub-divided into two distinct categories: evaluated data and reference data. Evaluated data include such information as positional data, elevation, runway length, declared distances, platform bearing characteristics and magnetic variation; while reference data include navaid identifiers, navaid frequencies, waypoint names, Rescue and Fire Fighting facilities, hours of operation and telephone numbers.

The accuracy requirement for the reference data is absolute - the information is either correct or it is not. Conversely, the degree of accuracy required of the evaluated data will vary depending upon the use to which the data are to be put. It follows that it is incumbent upon the users of the data to specify the accuracy requirements. This report only addresses evaluated positional data but many of the Procedures, identified in this report, may be applied to other evaluated data and to reference data, if required.

4.2 REQUIREMENT FOR INTEGRITY

The use to which a data item is put also forms the basis for determining its integrity requirement. For example, it is unlikely that a wrong telephone number will have a significant effect on airline operations, whereas, there is a high probability that the misplacement of a waypoint, at a critical point in the landing phase, could be life threatening. All navigation data items must be categorised according to a set of criteria based upon the potential impact that a corrupted data item may have upon operations. It has not been possible to identify an existing formally agreed statement concerning any such set of criteria and the following structure is therefore proposed:

a. Critical Data — There is a **high probability** that, as a result of position (For example, navigational data used during the final phases of a precision approach). It is recommended that Critical Data items meet an integrity requirement in the region of 1×10^{-7}.

b. Essential Data — There is a **low probability** that, as a result of using corrupted Essential Data, an aircraft would be placed in a life threatening position (For example, navigation data used during the en-route phase). It is recommended that Essential Data items meet an integrity requirement in the region of 1×10^{-5}.

c. Routine Data — There is a **very low probability** that, as a result of using corrupted Routine Data, an aircraft would be placed in a life threatening position (For example data that are not used for navigation). It is recommended that Routine Data items meet an integrity requirement in the region of 1×10^{-3}

Again, it is incumbent upon the users to specify the integrity requirements.

4.3 TYPES OF POSITIONAL DATA

4.3.1 General

Many of the items of information provided by an AIS include positional data. These may be detailed in an AIP in terms of latitude and longitude, as a mark on a chart or as bearing and range from a previously defined position. In some cases, the point is further defined by altitude (height above mean sea level) but this is not standard throughout and is not addressed in this report. For the purposes of this report, three types of positional data have been defined: surveyed points, declared points and calculated points. The data types are summarised in Table 1.

4.3.2 Surveyed Points

A surveyed point is a clearly defined physical point, specified by latitude and longitude, that has been determined by a survey, conducted in accordance with standards developed for the implementation of WGS 84. Communication facilities; gates; locations of activities of a dangerous nature (such as flare stacks); navaids; navigation check points; obstacles; obstructions and runway thresholds are usually surveyed points.

4.3.3 Declared Points

A declared point is a point in space, defined by latitude and longitude, that is not dependent upon, nor formally related to, any known surveyed point. RNAV waypoints; reporting points; airspace boundary points and oceanic entry and exit points are often declared points. It is worth noting that, outside this report, the term 'defined points' is sometimes used to mean the same as declared points.

4.3.4 Calculated Points

A calculated point is a point in space which need not be specified explicitly in latitude and longitude, but which has been derived, by mathematical manipulation, from a known surveyed point. A fix, specified by radial/bearing and range from a known surveyed point such as a navaid, or by the intersection of a number of radials/bearings from a number of navaids, is an example of a calculated point. En-route waypoints, which are computed from the intersection of great circle routes, or cross radial fixes on great circle routes, are also calculated points, albeit that they are reported in latitude and longitude.

Table 1: Types of Positional Data

Type	Examples
Surveyed	Thresholds, navaids, obstructions, navigation check points, gate positions
Declared	FIR/UIR boundaries, reporting points, Prohibited/Restricted airspace
Calculated	Waypoints, FAF, FACF, MAPt, ARP

4.4 SOURCES OF POSITIONAL DATA

It is normally the responsibility of nominated technical branches within the Aviation Authority of a Contracting State to ensure the origination of the raw data required to be promulgated by the AIS. On receipt of the raw data, the technical branches must check, record and edit the data so that it can be released in a standard format[*].

Raw AIS data containing positional information can originate from a number of different sources:

a. The location of navaids and communication facilities are normally provided by the owner/operator[†] of the equipment.

b. Specific aerodrome information is normally provided by the owner/operator[†] of the aerodrome.

c. Airspace divisions and restrictions may be defined by the national aviation authority, national military authorities or other government bodies. A search and rescue agency may issue temporary restrictions.

d. Standard Instrument Departures (SID), Standard Terminal Arrival Routes (STAR), Approach and Holding procedures are usually determined by the air traffic service provider responsible for the procedure, in conjunction with the appropriate technical branch within the national aviation authority, who may have access to computer-aided modelling facilities to validate the procedure design.

It has been the experience of the Navigation Data Vendors that shortfalls in the data, provided by the AIS, have to be made up through a wider data gathering exercise. This is achieved, not only by reviewing a range of government publications that are not necessarily directly related to aviation, but also maintaining regular contact with organizations that are involved in the installation and maintenance of navaids, as well as responding to feedback from customers. This extra data gathering activity forms a significant part of the added-value that is considered to be provided by the Navigation Data Vendors.

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* ICAO Doc 8126-AN/872, Chapter 3, paragraph 3.1.1

† This may, in some States, be the National Aviation Administration itself, or a designated authority, such as Military Survey.

4.5 CLASSIFICATION OF POSITIONAL DATA WITH RESPECT TO ACCURACY AND INTEGRITY

4.5.1 Introduction

The positional AIS data can be divided into a number of classes based upon the user requirements for accuracy and integrity. At present, there is no clear statement of these user requirements for all data classes, although there is work in progress to agree the requirements for Precision Area Navigation* (PRNAV) in both the en-route and terminal phases of flight. It is understood that, in the latter context, there is an overall requirement that there must be less than one fatal landing attributable to a landing system in every 10^7 landings and that error rates are assumed to be evenly distributed between the error sources. In most landing systems the three main error sources are considered to be the equipment, the signals in space and the associated data and it follows that, for the overall requirement to be met, the associated data must have an integrity of 0.3×10^{-7} (3×10^{-8}).

For the purposes of this report a data model has been developed based upon

a. A working paper of the EUROCONTROL WGS 84 Implementation Group.

b. Information gained from RTCA minutes.

c. Discussions with experts at the UK CAA, EUROCONTROL and some of the Navigation Data Vendors.

Nine classes of data have been identified - based upon combinations of the accuracy and integrity requirements that are currently understood to exist. Table 2 compares the nine classes of data with the accuracy requirements and resolutions identified in various reference documents.

4.5.2 Class 1 Data

Class 1 data consist of critical path points. Critical path points are those points specified on the final approach path between, and including, the final approach course fix (FACF), the final approach fix (FAF), the missed approach point (MAPT) and the runway threshold.

The EUROCONTROL WGS 84 Surveying Standard currently requires a minimum accuracy of 1m for runway thresholds, to match current ILS requirements. The RTCA Special Committee (SC) 159 has identified an accuracy requirement of 0.3m (1ft) for critical path points which will be used in GNSS-based approaches.

Some critical path points, such as runway threshold, are determined by survey, while others are expected to be calculated using a bearing and range from the runway threshold.

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* PRNAV: Equivalent to RNP1

RTCA SC 159 has also recommended that critical path points have an integrity of 3 x 10^{-8} to allow Wide Area Differential (WAD) GNSS-based CAT I approaches*. The ICAO All Weather Operations Panel (AWOP), in considering RNP for precision approach and landing, has identified similar integrity requirements for CAT I path points and a higher integrity requirement of 8 x 10^{-10} for CAT III path points†.

Class 1 data are assessed as Critical Data and the integrity requirement is considered to be 3 x 10^{-8} at present.

4.5.3 Class 2 Data

Class 2 data comprise navigation check points. Navigation check points are located at aerodromes and are used to validate aircraft navigation systems.

The EUROCONTROL WGS 84 Surveying Standard has identified a minimum accuracy requirement of 0.5m at 95% confidence for check points, which may be used by GNSS equipped aircraft, although the AIP only provides check point data to 0.1′ (15.2m), which is more than current INS equipment requires. If the method of system validation requires the use of a navigation check point, then the check point must have the same, or better, accuracy requirements than the navigation points that the system is intended to use. The use of check points for GNSS equipped aircraft is under discussion in ICAO. If a decision is made to use check points only for INS equipment, the accuracy requirement is expected to be reduced to 100m. Navigation check points may be nominated gate positions or specified locations on the apron or the manoeuvring area.

Navigation check points must always be determined by survey.

The navigation check point data are only used when an aircraft is on the ground and, in the case of GNSS equipment, the chances are extremely small ($<10^{-10}$) that an error in the check point data would not cause the equipment check to fail. Moreover, the INS is not used in a stand-alone mode in the terminal phases of flight.

Class 2 data are assessed as Essential Data and the integrity requirement is considered to be 1 x 10^{-5}.

4.5.4 Class 3 Data

Class 3 data comprise elements of the Microwave Landing System (MLS) with the exception of the Distance Measuring Equipment/Precision (DME/P). The MLS navaids are used to provide approach and landing guidance for precision approaches up to CAT IIIc. There are three main elements to an autoland system: data, signals in space and autoland equipment.

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* At present the only planned implementation involves WADGPS.

† Two working papers dealing with this topic have been developed in AWOP Working Groups and are expected to be presented at the 15th AWOP Panel meeting in September 1994. A paper on RNP Precision Approaches and Landings was published in the Spring 1994 issue of the American Institute of Navigation and included these integrity figures.

The EUROCONTROL WGS 84 Surveying Standard has identified a minimum positional accuracy requirement of 1m at 95% confidence for MLS equipment.

The positions of the elements of the MLS equipment must always be determined by survey.

Class 3 data are assessed as Critical Data and the integrity requirement is considered to be 0.3×10^{-7} (3×10^{-8}).

4.5.5 Class 4 Data

Class 4 data consist of DME/P equipment which is used, in conjunction with MLS equipment, to provide distance information during precision approaches.

The EUROCONTROL WGS 84 Surveying Standard has identified a minimum positional accuracy requirement of 3m at 95% confidence for DME/P equipment.

The position of the DME/P equipment must always be determined by survey.

Class 4 data are assessed as Critical Data and the integrity requirement is considered to be 3×10^{-8}.

4.5.6 Class 5 Data

Class 5 data consist of aerodrome obstructions in the approach and take off areas.

The position of an obstruction in the approach and take off areas is described in the AIP in terms of bearing and range from the relevant threshold to a resolution of 1° and 1m. Threshold positional information has an accuracy requirement of 0.3m but, as a 1° error would subtend 2m at a range of 1000m and Annex 15 Amendment 28 requires resolution of only 0.1″ (3m), an accuracy requirement of 3m has been assumed for obstructions.

The position of the obstructions must always be determined by survey.

Information on aerodrome obstructions, in the approach and take off areas, is used to define obstacle limitation surfaces which, in turn, are used by procedure designers for the construction of instrument flight procedures and for specifying minimum safe altitudes/heights for each segment of the procedure*. Procedures are verified by flight-check before they are published in the AIP.

Class 5 data are assessed as Routine Data and the integrity requirement is considered to be 1×10^{-3}.

* ICAO PANS-OPS Doc 8168, Volume II - Construction of Visual and Instrument Flight Procedures

4.5.7 Class 6 Data

Class 6 data include non-precision terminal navaids and terminal waypoints.

The EUROCONTROL WGS 84 Surveying Standard has identified a minimum positional accuracy requirement of 30m at 95% confidence for navaids that are used for non-precision approaches. This includes VOR, DME, TACAN, marker and NDB equipment. It has been assumed that the waypoints used during arrival/departure, with the exception of the critical path points, need to be derived to the same accuracy as the navaids and this is reflected in the AIP resolution - 1″ (30.6m). This includes any unmarked/unnamed waypoints that may be calculated to fit the SID/STAR/Approach procedures which are described in the AIP in plain text or diagrams.

All navaid positions must be determined by survey while terminal waypoints may be surveyed, where related to a ground feature, or calculated.

Class 6 data are assessed as Essential Data and the integrity requirement is considered to be 1×10^{-5}.

4.5.8 Class 7 Data

Class 7 data include Aerodrome Reference Points (ARP) and obstructions referenced to the ARP.

The ARP is calculated as the approximate centre of mass of all useable runways at an aerodrome. The AIP allows a resolution of 1″ (30.66m) for the ARP and a similar accuracy requirement has been assumed. The position of an obstruction at an aerodrome, or in the circling area, is described in terms of bearing and range from the ARP to a resolution of 1° and 1m and an accuracy requirement of 30m has been assumed, although Annex 15 Amendment 28 provides for a resolution of 0.1″ (3m).

All obstructions must be determined by survey, ARPs are calculated.

Information on obstructions within the aerodrome boundary, or in the circling area, is checked against the obstacle limitation surfaces, defined for each runway at the aerodrome, to ensure that the volume of airspace, required to protect the aeroplane in the final phase of a visual approach-to-land manoeuvre, is not compromised[*].

Class 7 data are assessed as Routine Data and the integrity requirement is considered to be 1×10^{-3}.

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* ICAO Annex 14 - Aerodromes defines the relationship between obstacle limitation surfaces and runway use

4.5.9 Class 8 Data

Class 8 data include en-route navaids; aeronautical ground lights; air navigation obstacles; ATS route details; en-route waypoints and gate information.

The EUROCONTROL WGS 84 Surveying Standard has identified a minimum positional accuracy requirement of 100m at 95% confidence for navaids that are used for en-route operations. This includes VOR, DME/N and TACAN equipment. Aeronautical ground lights and air navigation obstacles have a resolution of 1″ (30.66m) in the AIP but, it would seem sensible to apply the same accuracy requirement as for en-route navaids.

The positions of all navaids, aeronautical ground lights and air navigation obstacles must be determined by survey.

It has also been assumed that positional details of all categories of ATS routes; en-route waypoints; reporting points; route intersections and oceanic entry and exit points must be declared or calculated to the same accuracy as en-route navaids.

The accuracy and integrity requirements for gates have not been formally articulated in any current documents. Some gate positions may be nominated as navigation check points and will require the accuracy and integrity of Class 2 data.

In the future, it is anticipated that automated low visibility facilities* will be developed to allow precision taxiing from the runway to the gate/stand. Under such circumstances, the accuracy and integrity of all gate/stand positions will become critical. However, it is expected that a number of other points, such as taxiway centreline positions and holds, on the apron and manoeuvring area, will also have to be identified and surveyed to meet this requirement. It would seem sensible to consider the requirements for gate/stand positional data at that time. A current accuracy requirement of 100m (3.239″) has been assumed.

Class 8 data are assessed to be Essential Data and the integrity requirement is considered to be 1 x10^{-5}.

4.5.10 Class 9 Data

Class 9 data consist of all other positional data provided in the AIP. These include ILS positions; airways marker positions and airspace designation details which are not considered to have a major operational impact. ILS coordinates have been placed in this class because the navigation equipment relies on a received signal. The signal, which defines the centreline, has been calibrated by flight check and the navigation equipment does not use the locations of the ILS equipment in any calculations. A similar argument applies to airways markers.

The resolution in the AIP for ILS and airways marker coordinates is 1″ but it is difficult to see why accuracy requirements better than 100m are necessary.

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* Such as the Advanced Surface Movement Guidance and Control Systems (A-SMGCS)

All airspace is classified according to its use and all permanent airspace limits are detailed in the AIP in latitude, longitude and height. Circular airspace is defined by a centre point together with a radius. The resolution available in the AIP is 1″ but this does not accord with the accuracy that is required of en-route navaids. The accuracy requirement is, therefore, assumed to be no better than 100m (3.239″).

ILS and airways marker coordinates are surveyed. All points used to delineate airspace are either Calculated Points or Declared Points.

Class 9 data are assessed to be Routine Data and the integrity requirement is considered to be 1 x 10^{-3}.

4.5.11 Table 3 provides a summary of the navigation data integrity model.

4.6 RELATIONSHIPS BETWEEN DATA ITEMS

It is possible to identify a number of generic relationships between certain types of data item. Such relationships may range from simple statements that all data items relating to a specific aerodrome are located within a radius of 10 km of the ARP, to specific declarations that the positions of the critical path points are collinear within 0.5m. It has not been possible to identify a document in the public domain that formally identifies these relationships - even siting restraints for navaids are not defined in any detail. It is understood that many of the Navigation Data Vendors' validation routines are based upon such relationships. These validation routines form a further aspect of the added-value that the Navigation Data Vendors are considered to provide.

Validation checks are considered in more detail in paragraph b and Table 4, Proposed Validation Checks, on page 38, includes details of a number of positional relationships that have, thus far, been identified. The list contains a representative sample but is not exhaustive. This report has concentrated primarily on the integrity of geographical coordinates and the list, in Table 4, does not include any relationships based on height. There is a clear link between the threshold elevation and the elevation of the MLS Elevation antenna. It is likely that a number of other height-related relationships exist. Some of the Navigation Data Vendors also include validation checks between the reported elevation of a facility and the ground elevation, at the same coordinates, detailed in government survey documents.

Table 2 : Navigation Data Integrity Requirements Comparison

Class	Operation	Data Items (Type of Point: S=Surveyed, D=Declared, C=Calculated)	Survey Accuracy Requirements (95% Confidence)	Integrity Requirements	ICAO Annex 15 Amendment 28	AIP Use (Resolution) GEN 2-1-1:Normally 1″ AREA APPENDIX 1 (En-route Chart): 0.1′ AD 2 (Aerodrome, Area, SID, STAR, Instrument Approach and Visual Approach charts): 0.1′	424 Use (Resolution)	UDDF Use (Resolution)
1	Critical Path Points	Runway Threshold (S) Final Approach Course Fix (C) Final Approach Passing Points (C) Missed Approach Point(S/C) Final Approach Fix(S/C)	0.3 m (0.01″)	Critical 3×10^{-8} (CAT I) 8×10^{-10} (CAT III)	AD 2.12: Runway Threshold: 0.01 ″	AD2(13):Threshold 1″	Waypoint Records (0.01″) Runway Records (0.01″) (SID/STAR/ Approach Records call up Waypoints)	38/39: Runway Centreline End (0.0001″) 45/46: Displaced Threshold (0.0001″)
2	Navigation Check Points	Check locations (S)	0.5 m (0.016″)	Essential 3×10^{-5}	AD 2.8: Check locations N/A AD 3.8: Check locations N/A	AD 2 (Aircraft Parking/Docking Chart): INS Coordinates 0.1′	Gate Records (0.01″)	
3	Landing and Take-off	MLS (S) (Azimuth, Elevation, Back Azimuth, Datum) Helicopter alighting areas (S)	1 m (0.03″)	Critical 3×10^{-8}	AD 2.16: Helicopter landing area (TLOF/FATO) 0.01″ AD 3.12: Heliport data (TLOF/FATO) 0.01″ AD 2.19: Navaids & Landing aids 0.01″	AD2(17): Helicopter alighting area 1″ AD 2(20): Radio Navigation / Landing facilities 1″	MLS Records (0.01″) Heliport Records (0.01″)	61/62: Navaid (0.0001″) 65: Shortest Distance from Navaid to Runway Centreline (1 ??) 66: Navaid Associated Distance (1 ??)
4	Final Approach	DME/P (S)	3 m (0.097″)	Critical 3×10^{-8}	AD 2.19: Navaids & Landing aids 0.01″	AD 2(20): Radio Navigation / Landing facilities 1″	VHF Navaid Records (0.01″)	61/62: Navaid (0.0001″)
5	Obstructions	Obstructions in Approach/Take Off Areas (Brg/rge from Threshold) (S)	3 m (0.097″)	Routine 1×10^{-3}	AD 2.10: Aerodrome obstacles 0.1″ AD 3.10: Heliport obstacles 0.1″	AD2(10): Obstruction 1°/1m from Threshold		73/74:Object in Approach/Primary Area (0.01″)

6	Departure, Arrival and Non-precision Approaches (Navaids and Terminal Waypoints)	DME (S) (Arc Centre Fix), VOR (S), TACAN (S), Terminal NDB (S), Marker (S) (Middle & Outer), RNAV waypoint (F), SID/STAR/Approach waypoint (C)	30 m (0.97″)	Essential 1 x 10^{-5}	AD 2.19: Navaids & Landing aids 0.01″ AD3.18: Heliport navaids and landing aids 0.01″	AD 2(20): Radio Navigation / Landing facilities 1″	VHF Navaid Records (0.01″) Waypoint Records (0.01″)	61/62: Navaid (0.0001″) 65: Shortest Distance from Navaid to Runway Centreline (1 ??) 66: Navaid Associated Distance (1 ??)
7	Reference Points and Obstructions	ARP (C) HRP (S) Obstructions at aerodrome and in circling area (Brg/rge from ARP) (S)	30m (0.97	Routine 1 x 10^{-3}	AD 2.2: ARP 1″ AD 3.2: HRP 1″ AD 2.10: Aerodrome Obstacles 0.1″	AD2(2): ARP 1″ AD5: Heliport 1″ AD2(10): Obstruction 1°/1m from ARP	Airport Records (0.01″)	19/20: ARP (0.0001″) 88/89: Object not in Approach/Primary area (0.01″)
8	En-route: Navaids, Holding Patterns (Terminal and En-route), Routes and Designated Points (Waypoints) Gates	DME/N (S), VOR (S), TACAN (S), NDB (S), Lower ATS Routes, Upper ATS Routes, RNAV Routes, Advisory Routes, Helicopter Routes RNAV waypoint (C), Reporting point, Holding point, ATS/MET Reporting point, named/unnamed/uncharted airway/off-route intersection, FIR/UIR CAS intersection, Oceanic entry/exit waypoint (D). Aeronautical Ground Lights (S) - En route Air Navigation Obstacles (S) Aircraft Stands (S)	100m (3.239″)	Essential 1 x 10^{-5}	ENR 4.1: En-route navaids 1″ ENR 3: Upper & Lower ATS routes, RNAV routes, Helicopter routes, reporting points, holding points 1″ ENR 4.3: Significant points 1″ ENR 4.4: Aeronautical ground lights N/A	AREA 4-1-1: Navigation facilities, En-route 1″ AREA 3-1-1: Lower ATS routes 1″ AREA 3-2-1: Upper ATS routes 1″ AREA 3-3-1: RNAV routes 1″ AREA 3-4-1: Helicopter routes 1″ AREA 4-3-1: Designated 5-letter points (tbd?) AREA 4-4-1: Aeronautical ground lights 1″ AREA 5-4-1: Air Navigation Obstacles 1″ GEN 2-1-1: Grid on aircraft parking/docking chart 0.1′	VHF Navaid Records (0.01″) NDB Navaid Records (0.01″) Waypoint Records (0.01″) Gate Records (0.01″)	61/62: Navaid (0.0001″)

9	Airspace Designations, Other AIP Coordinate Information	FIR/UIR, TMA, T/FIA, HPA, CTR, ATZ, TIZ, HPZ (D/C) Prohibited, Restricted and Danger Areas (D) Military Training Areas (D) Activities of a Dangerous Nature (S) Gliding Sites/Areas, Parachute Jumping Sites (S) Airport Communications (S), Heliport Communications (S), En-route Communications (S) ILS (Glide Slope and Localizer) (S) Decca, Loran and Consol stations (S) Airways Marker (S),	100m (3.239″)	Routine 1×10^{-3}	ENR 2.1: FIR/UIR 1′, TMA 1″ AD 2.17: ATZ 1″ AD 3.16: Heliport ATS airspace 1″ ENR 5.1: P/R/D Areas in ctl zone/area 1″, outside ctl zone/area 1′ ENR 5.2: Military ex & trg areas in ctl zone/area 1″, outside ctl zone/area 1 ′ ENR 5.3: Activities of a dangerous nature 1′ ENR 5.4: Air Navigation Obstacles 1″ ENR 4.2: Special navaids 1″	AREA 2-1-1: FIR/TMA/TIA/FIA/HPA/ CTR/ATZ/TIZ/HTZ/HPZ 1″ AD 2(18): ATS airspace 1″ AREA 5-1-3: Prohibited, Restricted and Danger Areas 1″ AREA 5-2-1: Major military exercises and training areas 1″? AREA 5-3-1: Other activities of a dangerous nature 1″ AREA 5-5-2:Gliding Areas 1″ AREA 5-6-1: Parachute Jumping Sites AD 2(19): ATS communication facilities 1″ AREA 4-2-1: Special navigation systems 1″ GEN 3-6-3: SAR units 1″ AREA 1-6-1: Radar stations 1″	Restrictive Airspace Records (0.01″) FIR/UIR Records (0.01″) Airport Communication Records (0.01″) Heliport Communication Records (0.01″) Enroute Communication Records (0.01″) Localizer and Glide Slope Records (0.01″) Airways Marker Records (0.01″)	

Note:

1. The resolution provided for positional data in ARINC 424 Navaid, Localiser and Glide Path, Localiser Marker, Airways Marker, Restrictive Airspace, FIR/UIR and Communications records exceeds the data model accuracy requirements by one or two points (Up to 4 characters per lat/long).

2. The resolution provided in the UDDF is in the process of being clarified. Although it may seem to exceed current requirements when compared with the data model accuracy requirements, survey methods routinely achieve accuracies commensurate with such resolution. In order that good survey data, which may be required to support future navigation requirements that have still to be defined, is not lost, it is recommended that the UDDF resolution is maintained to allow such survey data to be recorded and archived.

3. The UDDF documentation available to the study did not include full details of the units of measurement used and this is indicated in the table by use of a '?'.

Table 3:Summary of Navigation Data Integrity Model		
CATEGORY	Describes the safety sensitivity of data	
Critical Data	There is a **high probability** that, as a result of using corrupted Critical Data, an aircraft would be placed in a life threatening position	
Essential Data	There is a **low probability** that, as a result of using corrupted Essential Data, an aircraft would be placed in a life threatening position	
Routine Data	There is a **very low probability** that, as a result of using corrupted Routine Data, an aircraft would be placed in a life threatening position	
TYPE	Describes the method by which the data was obtained	
Surveyed Points	A surveyed point is a clearly defined physical point, specified by latitude and longitude, that has been determined by a survey.	
Declared Points	A declared point is a point in space, defined by latitude and longitude, that is not dependent upon, nor formally related to, any known surveyed point.	
Calculated Points	A calculated point is a point in space which need not be specified explicitly in latitude and longitude, but which has been derived, by mathematical manipulation, from a known surveyed point.	
CLASS	Describes operational useage (For example:)	Accuracy & Integrity Requirements
1	Runway Threshold FAF FACF MAPt	0.3m Critical CAT I : 3 x 10^{-8} CATIII : 8 x 10^{-10}
2	Navigation Check Points	0.5m Essential 3 x 10^{-5}
3	MLS (Az, Elev, Back-Az) Helicopter Landing Area	1m Critical 3 x 10^{-8}
4	DME/P	3m Critical 3 x 10^{-8}
5	Obstructions in Approach/Take-off Area	3m Routine 1 x 10^{-3}
6	Terminal Navaids Terminal Waypoints	30m Essential 1 x 10^{-5}
7	ARP, HRP Obstructions at Aerodrome and in Circling Area	30m Routine 1 x 10^{-3}
8	En-route Navaids En-route Waypoints Gates, Groundlights and Obstacles	100m Essential 1 x 10^{-5}
9	Airspace Designation, Communications Sites, ILS, Decca, Loran	100m Routine 1 x 10^{-3}

4.7 PATH TERMINATORS

The aviation authorities and the service providers publish approach, missed approach, departure and holding procedures in the AIP, in the form of graphical representations or textual instructions. These give details of course, altitude and, where necessary, speed for each leg of the procedure. The Navigation Data Vendors and the FMS manufacturers convert this information into a series of instructions for the FMS. The current method of documenting SIDs/STARs and Approaches is known as the Path and Terminator method. A set of 2 letter alphabetic codes, known as Path Terminators, has been defined for the specific types of flight path and for the specific ways of terminating each leg. Different FMS designs use different sets of path terminators and the task of describing the appropriate flight path for the appropriate aircraft/FMS type requires considerable specialist knowledge.

With the advent of RNAV terminal procedures and the development of the next generation of FMS equipment, the requirement for path terminators is expected to be much simplified. However, some path terminators, such as those for holding patterns, procedure turns, and 'heading/course/track to fix/altitude/manual termination' may continue to be used for the foreseeable future. Moreover, aircraft equipped with the current generation FMS equipment can be expected to be operating and, therefore, using the current range of path terminators until 2015.

Path terminators are interpreted from the AIS data, by the Navigation Data Vendors and the FMS manufacturers, when specific database loads are being assembled and formatted for particular FMS equipments. The validation checks for path terminators are based, in the main, on the path terminator rules set out in ARINC 424 and on proprietary Operational Flight Programme (OFP)/Aircraft Number/Path Terminator matrices, that are agreed between the user airline and the Navigation Data Vendor. Further manual checks are often made which compare the displayed flight path on the FMS with the flight path printed on the source approach plates. The detailed methods and Standards that may be developed to improve the quality assurance of Path Terminators are considered to be beyond the scope of this report.

5 SOLUTIONS

5.1 QUALITY REQUIREMENTS

The user must define the quality that is required of the navigation data. At present, there are no such formal quality requirements in existence. However, there are a number of initiatives in this area from ICAO, RTCA and EUROCONTROL which are being coordinated.

5.2 QUALITY SYSTEMS

5.2.1 Types of Quality System

In order to ensure the quality of the delivered product, every organization involved in processing navigation data must employ a Quality System. There are a number of definitions of Quality Systems* available:

a. ISO 9000 - 9004† is a set of internationally agreed Standards which aims to clarify the principal quality concepts, describe the basic set of elements from which Quality Systems can be developed and define the Quality System requirements for a number of quality assurance models.

b. EN 29000 - 29004‡ is a set of European Standards which is identical to the ISO 9000 series.

c. BS5750§ is a set of British Standards which similarly mirror the ISO 9000 and EN 29000 Standards

d. ANSI/ASQC Q90 - Q94# is a set of US Standards that are functionally identical to the ISO series.

The individual documents within each set of Standards are equivalent and future use of ISO nomenclature in this report should be read as including the other equivalent national standards (see also Annex D):

- ISO 9000: Guidelines for selection and use of quality management and quality assurance Standards.

- ISO 9001: Specification for design/development, production, installation and servicing. (A general purpose quality assurance model)

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* A survey by ISO in 1992 identified 48 countries with national standards that are identical or equivalent to the ISO 9000 Standard.

† ISO: International Organization for Standardization

‡ EN: Europäische Norm (European Standard)

§ BS: British Standard

ANSI/ASQC: American National Standards Institute/American Society for Quality Control - Q90 Series soon to be known as the Q9000 Series

- ISO 9002: Specification for production and installation. (A quality assurance model tailored to production and installation)

- ISO 9003: Specification for final inspection and test. (A quality assurance model solely for final inspections and testing)

- ISO 9004: Guide to quality management and Quality System elements.

- ISO 9000-3: Guidelines for the application of ISO 9001 to the development, supply and maintenance of software.

ISO 9002 and 9003 are not considered to be suitable for the navigation data process in that they concentrate on providing quality assurance through final inspections and installation testing. The nature of the navigation data process, with the large number of data sources and the frequent amendments, militates against final product testing and, hence, favours process control.

Many large, multinational organizations employ in-house Quality Systems which they consider to be as good as the international and national Standards. The biggest difference between in-house and external Standards often lies in the use of external auditors to validate and regularly assess the Quality System. There is sometimes an unwillingness to open a system to independent audit but this generally reflects concerns about commercially sensitive information, rather than any attempt to conceal bad practices.

Once the users of navigation data have specified the quality requirements, every organization providing such data must provide evidence that it is meeting the stated requirement. This may be achieved by each organization demonstrating the efficacy of its own Quality System to each customer. However, such an approach requires a significant commitment from the individual users, who would have to conduct regular inspections to satisfy themselves that the Quality System is performing satisfactorily. Many users may not be able to provide this commitment, on cost grounds alone, and may choose to rely instead on the reputation of the supplier, the reputation of one of the other customers using that supplier or an external accreditation organization.

A growing number of government and international agencies now require tenderers to have ISO 9000 accreditation. Accordingly, more and more organizations are adopting this international standard. As all the Quality System Standards are based upon the same concepts, share the same aims and espouse similar structures and disciplines, the change from one system to the other is usually relatively straightforward. However, the initial cost can be high because the manuals and other Quality System documentation have to be updated and staff usually require some re-training.

5.2.2 Quality Framework

Whatever system is chosen by the individual organizations, a community-wide Quality Framework is required which details the standard Procedures, algorithms and formats that can be referenced, as necessary, in each organization's Quality System.

These Standards need to be properly documented and ratified by the whole navigation data community, although not all the Standards are expected to be mandatory. In many cases, the Standards may be expressed in terms of statements of requirement, rather than as technical solutions. However, mandatory technical solutions are expected to be specified in cases where a common agreed interface is required between independent navigation data processors. Nonetheless, it would be acceptable for a particular user, for example, to use a proprietary data transfer format with a particular Navigation Data Vendor or a proprietary CRC that accords the same protection as an agreed Standard CRC. Conversely, some Standards, such as the quality requirements for specific navigation systems to meet a defined RNP, or minimum validation and verification requirements, may be expected to be mandatory.

The development and maintenance of a Quality Framework is expected to be an ongoing activity which would reflect changes in requirement as well as technological developments.

5.2.3 Quality Documentation

RTCA Do 200 currently describes some of the Procedures and Standards that are necessary to assure quality in the navigation data process. Further related Standards are detailed, to varying degrees of complexity, in RTCA documents Do 178B and Do 201, and in ARINC 424. Every effort must be made to keep duplication to a minimum and reference must be made, where necessary, to the appropriate paragraphs in such documents. However, it may be sensible to rationalise the layout of Do 200 so that it could be used to detail the standard Procedures. The standard working practices, algorithms and formats that are agreed within the community could be included in annexes to Do 200 or, could be detailed in other documents, such as Do 201 and Do 178B, which would then be referenced in Do 200.

5.3 STANDARD PROCEDURES

5.3.1 General

RTCA Do 200 provides a suitable vehicle for describing the navigation data process and the Procedures necessary to meet the requirements for accuracy, integrity, traceability and auditability during the assembly, selection, format and distribution stages. However, there are a number of Procedures that may be included in a Quality Framework that are not, at present, addressed by Do 200 (for example integrity checking and corrective action procedures). Furthermore, some of the Procedures that are included could be expanded to provide a more comprehensive Standard (for example validation checks).

5.3.2 Procedures to Ensure Accuracy

The accuracy of data is determined at the point where the data originates. In the case of surveyed data, the Procedures necessary to ensure accuracy are being addressed in the WGS 84 Implementation Programme. Declared points must be declared to the accuracy required by the data model. Procedures for calculating points must not only be detailed in the Quality Framework and take account of the accuracy of the source data but must also ensure that subsequent mathematical manipulation maintains the same, or a lower, accuracy depending upon the data model requirements.

5.3.3 Procedures to Ensure Integrity

If data integrity is to be assured, there must be clearly defined Procedures for all stages of the navigation data process, from the point where the data are originated to the point where the data are used. Apart from rigorous manual independent verification, there is little that can be done to ensure the integrity of data held in a manual system. However, once the data are held on electronic media, there are a number of options available. When choosing appropriate methods to protect the integrity of electronically stored data, consideration must be given to the integrity requirements for the data and the risk posed to the data.

a. Manual Data Entry

The transfer of data from written or printed form into a form that is stored in a computer is the **greatest potential source of error in the entire process**. Careful consideration must be given to the means by which this transfer is to be performed and verified, if end to end integrity, at the required levels, is to be achieved.

Most manual data entry Procedures for data with high integrity requirements involve the entry process being repeated more than once, often using different operators, with the data being compared automatically within the machine. A less satisfactory method involves the data being entered by one operator and then manually checked against the source documents by another operator. With the multiple entry method, the number of independent data entries to be compared is dependent upon the required level of integrity. When typing successive latitude/longitude pairs, it is estimated that the chance of making an error is between 1 in 100 entries and 1 in 10 000 entries, ie between 10^{-2} and 10^{-4}. Only well trained and motivated staff, working without undue time pressures, are likely to achieve a performance approaching the better figure, whilst 10^{-2} may be the lowest that is deemed acceptable. Automatic comparison of input from two independent data entry clerks leaves a risk of between 10^{-4} and 10^{-8} that a single lat/long pair will have an undetected error. With three operators, the risk reduces to between 10^{-6} and 10^{-12}. High staff costs mean that commercial pressures often result in savings being made in the data entry area, by reducing the number of operators, and it is considered unlikely that a data entry standard, based upon double or triple entry, would be internationally achievable.

If the positional data were to be entered in a database by the surveyors/designers themselves and, thereafter, kept in electronic/magnetic form throughout the subsequent navigation data cycle, the requirement for verifying the manual input would be significantly reduced. The probability that the surveyor/designer enters the wrong value into a machine, without correction, is likely to be the same as the probability that he enters the wrong value in a printed report. Consequently, there is effectively no loss of integrity induced by the transfer process if this is performed by the originator of the data.

Any subsequent process which results in amendment to the data introduces a similar level of risk. Consequently, any Procedures, which allow positional data to be amended by operator input, must include sufficient verification checks to ensure that the integrity requirements are maintained.

b. Validation Checks

Validation checks, which can be performed once the data item is held in electronic format, will detect many of the errors induced by manual data entry, but it is doubtful whether integrity can be improved even by one order of magnitude on the basis of validation checks alone. (For example, in ARINC 424, a position, defined in latitude and longitude to a precision of 0.01″, requires 19 characters. If any error greater than 1′ can be detected by data validation checks, only 58% (11/19) of the occasions where there is a single digit error in the lat/long pair will be detected. Hence 40% of data input errors may remain undetected.) The effectiveness of validation checks in identifying subsequent corruption also depends upon the redundancy available within the data format (For example, ARINC 424 only uses a small subset of valid codes within the whole range of values that can be represented by EBCDIC[*] or ASCII[†]) and range checks can be effective in some circumstances. In general, the integrity of the data can be maintained by validation checks but cannot be much improved. It is, therefore, of **vital importance that the required level of integrity is achieved when the data item is first entered in electronic format**.

c. Software Aspects

Whenever data are manipulated by a computer program, even if it is simply to extract an item from the database and output it onto magnetic media, there is a risk that, as a result of software error, the resultant data item will not be a true copy of the original. Accordingly, all software used to manipulate data must be subject to rigorous testing, verification and validation. Once software has been proved, it must be kept under strict configuration control. The configuration management system must ensure that the same level of testing is carried out whenever the software is modified in any way.

In addition to the threat to integrity posed by a software fault, there is a threat from computer viruses, which may be introduced via executable code in applications software and utilities. This must also be addressed by the configuration management system.

* EBCDIC: Extended Binary Coded Decimal Interchange Code

† ASCII: American Standard Code for Information Interchange

Detection of errors introduced by residual software faults or viruses can be afforded by conducting regular validation and verification checks, in addition to those carried out upon initial acceptance.

d. Data Retention Aspects

Although hardware reliability has improved markedly over the years, there is still a risk of corruption from component failure or power surge/spike. Detection of corruption caused by hardware faults can be improved by the use of validation and verification checks at regular intervals.

e. Data Transfer Aspects

The risk to data, while being written to or read from magnetic/optical storage media, depends upon the devices used and the methods employed in the packing and handling of the media. Protection is provided by the software controlling the reading from/writing to the media, which can incorporate verification routines and, by the Procedures for handling, packing and shipping media which must be detailed in the Quality System.

When data are transferred from one computer system to another, there is a risk of corruption in transit. The risk is present whether the transfer medium is magnetic tape, floppy disk, solid state device or communications link. A sufficient level of verification is required so that undetected corruption does not occur. It is normal practice to provide this protection and assurance by the use of CRC. Depending on the anticipated noise characteristics of the transfer medium, the CRC can be used to protect small blocks of data - or entire files. Any block or file which fails the CRC, performed by the receiving unit, is requested to be transmitted again until it is either received without failure, or a predetermined number of retransmissions has been tried and the transfer is determined to have failed. The algorithm for the generation of the CRC must be agreed by both the transmitter and the receiver of the data. The level of assurance provided by the CRC, that the received copy of the data is exactly the same as the transmitted copy, must be at least as high as the required level of integrity for any individual item within the set of transferred data.

f. Data Use Aspects

Consideration must be given as to whether the Procedures for the production and delivery of data to the airborne FMS have provided the necessary level of integrity when the data are eventually extracted from the FMS database for final use. The probability of corruption after delivery into the FMS will depend upon the design of the FMS itself. It is likely that no current FMS will be able to provide the required level of integrity for Critical Data without carrying out a verification check immediately before the data item is used.

g. System Environment Aspects

Whilst not strictly covered by the definition of integrity given in the glossary, it could be said that failure to communicate a declared change to the positional data, in a timely manner, would constitute a failure of the data integrity. An important reason for not achieving the required timescales for data change notification could be a failure of a computer system used within the process of dissemination. The effects of such system failure can only be mitigated by the use of independent, geographically separated back-up systems and regular archiving.

h. Positional Data Verification

The preceding paragraphs have identified several stages at which verification of positional data must be provided. The verification process needs to confirm that the position is that of the referenced item and, moreover, that it has not been changed unintentionally from that of the original input.

When a data item is first entered into electronic format it will need to be provided with the ability to be verified on subsequent transfer and to provide assurance that it has not been corrupted while stored. The mechanism proposed for achieving this is the use of a CRC, which must be produced from the name (Identifier) of the position, its latitude, longitude, altitude and data quality, as appropriate. A collection of points, and the relationships between them, which describe a procedure could, in some cases, have the entire data set used to produce the CRC. The chosen CRC algorithm must be agreed between the system which produces the CRC and all systems which wish to receive the data. Furthermore, it must meet the level of integrity required for the individual data items to be transferred.

It is proposed that the data originator generates a CRC before transmitting Critical or Essential Data in the UDDF format. Similarly, the procedure designer should generate the CRC when the waypoints/path points are defined, prior to flight test.

It would be simplest if the data could be preserved in the same format as that produced by the data originator, for the entire life of the data item in the system. This is not likely to be achievable, not only because of the number of different FMS manufacturers, but also because of the undesirability of constraining future developments to an inappropriate choice of a standard based upon current system capabilities. Moreover, the current ARINC 424 data exchange standard is character based (both ASCII and EBCDIC formats may be used), whereas it is more convenient to carry out any data manipulations and comparisons in a numeric format. Consequently, it is proposed that it be allowable for a system to accept data in one format (a character format, say), to translate it to another (for example, a bit-oriented format), and to produce a new CRC to assure subsequent integrity. The procedure by which this is achieved will be required to satisfy a Standard and to be performed by validated software. This mechanism could also be used to gather data together, each item of which was protected by an individual CRC up to that point, into a logical collection of data which is subsequently protected by a single CRC.

The current ARINC 424 data exchange format does not lend itself easily to attachment of CRCs to individual items of positional data. However, if the integrity of Critical Data items is to be guaranteed, space would have to be found in five ARINC 424 record types for a 32 bit (ie 4 character) CRC. It is considered that a 16 bit (ie 2 character) CRC would provide just sufficient assurance for Essential Data items as long as it was used in conjunction with a comprehensive and effective Quality System. A further three ARINC 424 record types would be affected by the introduction of CRCs for Essential Data.

5.3.4 Procedures to Ensure Traceability and Auditability

If integrity is to be assured and demonstrable, all coordinates must be traceable to their source by an unbroken trail. A record must, therefore, be kept of any changes made to the data; the reason for the change; references associated with the change; the source of the change; the identity of the person making the change and the date of the change. Such records may be electronic or paper-based, although certain change information must remain with the data item throughout the navigation data cycle, to provide the unbroken trail and must, wherever possible, be stored in an associated field or record. The field/record structure would have to be agreed as a standard, to allow the information to be exchanged automatically. This latter information, known as the data quality field, is expected to include, as a minimum, an indication as to whether the data item is based upon WGS 84, an indication as to whether the data item has been modified by any organization other than the originator, and the reported accuracy of the data.

Any errors identified in the database must be corrected. Errors caused by system failure can be corrected by referral back to source documents/data records. Errors identified in the source data must be referred to the originator, who must issue an appropriate amendment. At present, there is no formal Procedure for reporting errors and taking corrective action - most corrections are done on a one-to-one basis with the AIS. A Standard Procedure for reporting errors, and issuing subsequent amendments, would ensure that all interested parties are kept informed and source-errors in navigation data-related databases are corrected in an ordered and timely fashion. A record must be kept of errors identified, together with the corrective action taken.

5.4 STANDARD ALGORITHMS, FORMATS AND WORKING PRACTICES

5.4.1 General

Standard algorithms and working practices should be clearly detailed in one document. At present, RTCA Do 200 addresses the problem from the viewpoint of the Navigation Data Vendors and FMS manufacturers. RTCA Do 201 identifies areas of concern that need to be addressed by the AIS organizations. The proposed Quality Framework, and the associated Procedures and Standards, would apply equally to all parties involved in the data process, from the originators to the eventual users. It is recommended that Do 200 be used to provide the Quality Framework and identify the required Procedures, while Do 201 details the Standard algorithms and working practices. Standard data formats are best defined in the existing stand-alone documents such as ARINC 424 and the UDDF.

5.4.2 Algorithms

The following algorithms are considered to be candidates for inclusion in a Navigation Data Quality Framework:

a.CRC Algorithm

Annex C provides details of CRC algorithms and the integrity protection than can be achieved.

b.Algorithms for Calculating Points

Do 201 provides recommended priorities for defining, and rules for the calculation of, waypoint coordinates.

c.Algorithms for calculating Path Terminators

ARINC 424 provides details of the methods by which Path Terminators are to be interpreted. Do 201 provides recommendations on the information that must be provided in the AIS Terminal Procedures to enable the appropriate points to be calculated.

5.4.3 Working Practices

The following working practices are considered to be candidates for inclusion in a Quality Framework for navigation data:

a. Naming conventions.

Do 201 details naming conventions that must be used. These only concern the use of unique pronounceable names and do not address the purpose of the named point, or its relationship to other points.

b. Rounding conventions.

A standard must be agreed with respect to rounding up and rounding down when using navigation data in calculations.

c. Validation routines.

Validation checks provide a means of independently confirming the integrity of data items. Some validation checks are outlined in Do 200 but these are not all-embracing. It may be possible to agree a comprehensive, standard set of checks from which a minimum agreed number would have to be applied at defined stages, throughout the navigation data cycle, to data items, depending upon their integrity criteria. Table 4 provides a non-exhaustive list of some of the validation routines that may be defined.

d. Verification routines.

The methods of verifying a data item, which is input manually, and the method of calculating CRCs and comparing the result with the reported CRC, must be fully documented and referenced as Standards. Verification routines used during the read/write processes are proprietary to the individual computer and software manufacturers and must not be detailed in the Quality Framework.

Table 4: Proposed Validation Checks for Positional Data

		Related Items	Relationship
Positional Relationships	1	For a specific runway: Runway Threshold Positions (at each end of a runway), Final Approach Course Fix, Final Approach Passing Points including MAPt and FAF	Collinear within 0.5m of a line of least squares fit (Provided that a Standard Algorithm is declared for the derivation of the line and the subsequent collinearity check)
	2	For a specific runway: Runway Threshold Positions, MLS Azimuth/Back Azimuth, Localizer	For MLS: collinear within 5m of a line through the threshold positions For ILS Localizer: collinear within 100m of a line through the threshold positions Within a circle with a radius of 5000m
	3	For a specific runway: Runway Threshold Positions, ILS Glide Slope Positions, MLS Elevation Positions	Collinear within 200m of a line through the threshold positions
	4	For a specific runway: Runway Threshold Position (at the glide slope/elevation end), ILS Glide Slope Position, MLS Elevation Position	MLS/ILS within 500m of threshold position
	5	For a specific aerodrome: ARP, Runway Threshold Positions, Gate Positions, VOR/DME/TACAN used for non-precision approaches, Marker Beacon Positions, Obstructions	Within a circle with a radius of 10 000m
	6	For a specific navaid: VOR, Co-located DME/TACAN	Within a circle with a radius of 700m
	7	For a specific navaid: VOR, Associated DME/TACAN	Within a circle with a radius>700m and <10 000m
	8	For a specific MLS: MLS Azimuth/Back Azimuth	Distance between Azimuth and Back Azimuth >runway length and <runway length plus 1000m
Range Checks		In accordance with ARINC 424, AIP and UDDF field definitions. (The database design may use one field definition to accommodate data items which have different accuracy requirements, for example, latitude and longitude fields may be defined to 0.001″ but may also be used to hold data items that only have an accuracy requirement of 1″. In such cases, the range check must include an examination of the unused parts of each field to ensure that they are set to zero.)	
Related Record or Field		Every waypoint called up in ATS route descriptions, including SIDs/STARs/Approaches and Holding Patterns, FIR/UIRs and Restrictive Airspace must itself be properly defined within the database/delivered product. Every navaid associated with a named waypoint or ATS route must itself be properly defined within the database/delivered product. Data held in related fields in navaid records must be within the limits appropriate to the navaid type, for example, VOR frequency between 10.00 to 117.95 with the least significant digit 0 or 5. The range and bearing between waypoints on an ATS route, calculated in accordance with Do 201, using the given waypoint coordinates and taking account of the magnetic variation and station declination, as appropriate, must be the same as the magnetic track and distance provided by the AIS for that leg. The calculated bearing between the threshold coordinates at each end of a runway must be the same as the runway bearing. Note that, with displaced thresholds the calculated distance may not agree with the published runway length. First two digits of runway identifier must be the same as the most significant two digits of the runway magnetic bearing (unless runway identifier annotated as being 'True').	

e. Reporting Data Quality.

Every user of navigation data needs to know the accuracy of received measured data in order to determine whether they are suitable for their planned use. Data must be provided to the agreed standard unless indicated otherwise. The method of indicating whether the data meet the required Standard, must itself be standardised. Users may wish to receive an indication of the quality of the data in simple terms, such as good/bad (such as with the use of an *, as specified in Annex 15 to the Convention on International Civil Aviation), or, they may prefer to receive an accuracy report for each measured data item. It is proposed that a suitable field for reporting data quality/accuracy be defined and that this field be incorporated in all appropriate data transfer format Standards. The requirement for traceability can be met through documentation that accompanies a new data load and it is not considered necessary to include such detailed information in a data quality field. Table 5 details a possible data quality field design.

Table 5: Proposed Data Quality Field Values

Accuracy (a)	Data Quality Field		
	Original AIS Data	Modified Data	Not WGS 84 Data/No Quality Information Available
a>100m	0	A	*
100m≥a>50m	1	B	
50m≥a>30m	2	C	
30m≥a>10m	3	D	
10m≥a>5m	4	E	
5m≥a>3m	5	F	
3m≥a>1m	6	G	
1m≥a>0.5m	7	H	
0.5m≥a>0.3m	8	J	
0.3m≥a	9	K	

5.4.4 Formats

a. Survey Data

The UDDF details the format to be used when reporting surveyed data to the AIS.

b. AIP

Annex 15 to the Convention on International Civil Aviation details the format to be used when reporting AIS data in printed form. Standardization of a transfer format for an Electronic AIP (E-AIP) is currently under consideration.

c. Navigation/Flight Planning and Simulation databases

ARINC 424 details the format to be used when preparing navigation reference data tapes/disks for merging with operational FMS software, flight planning system software and simulator software and can be considered to be the standard format for electronic transfer of navigation data.

6 CONCLUSION AND RECOMMENDATIONS

The higher risks associated with critical data and the increasing propensity for post-incident litigation by passengers and their relatives means that, in the future, it may be necessary to develop a more formal relationship between the provider of navigation data and the data user with respect to the quality of the data provided. This may involve independent external audits of the Quality System and/or legally accountable statements by the providers about the quality of the data.

However, before a Quality System can be established, it is imperative that the quality requirements are fully documented and the standard Procedures, working practices, algorithms and formats are agreed with all parties. In the navigation data process, the data integrity and accuracy requirements are not clearly defined, although there is, already, a degree of standardization in some of the Procedures and formats currently in use.

It is anticipated that these quality requirements would apply to every organization providing AIS-based data for a particular navigation system or for specific navigation purposes and, therefore, it may be appropriate for them to be documented in an ICAO publication.

In order to develop an effective AIS Quality System, therefore, the following initial requirements need to be satisfied:

6.1 DATA MODEL

A Standard set of navigation data quality requirements needs to be agreed and published in an appropriate ICAO document. It has not been possible to identify an internationally agreed document that details the integrity, traceability and auditability requirements for navigation data. ICAO Annex 15 (Amendment 28) does go some way towards addressing the accuracy requirements, although it discusses resolution rather than accuracy. There is work in progress to provide an ICAO guidance document which would define these requirements but it is not expected to be included in any of the ICAO Annexes. RTCA SC 181* WG3 is considering including the requirements in Do 200 but this document is unlikely to be accepted by all AIS organizations.

It is recommended that the data model, detailed in this report, be considered for adoption as the basis for an internationally agreed Standard and, thus, represent a mandatory requirement on all navigation data community members.

* RTCA SC 181 meets jointly with EUROCAE.41

6.2 QUALITY FRAMEWORK

A Quality Framework must be agreed and published, preferably in an ICAO document. The Framework must detail the agreed Procedures and Standards, necessary to meet the accuracy and integrity requirements, for use in Quality Systems employed by organizations involved in processing navigation data. Alternatively, the RTCA Do 200 and Do 201 documents could be amended and supplemented to provide adequate vehicles. Whilst some detailed Procedures within the Quality Framework may be identified as mandatory, many are expected to be of an advisory nature.

It is recommended that:

a. RTCA Do 200 be developed into a Quality Framework document which details the Procedures and references the Standards that apply to all organizations involved in the production or maintenance of navigation data.

b. RTCA Do 201 be developed into a Standards document which details the algorithms and working practices that may apply to any organization involved in the production or maintenance of navigation data.

c. The data transfer Standards continue to be detailed in stand-alone documents such as ARINC 424.

6.3 EMBEDDED CRC

A standard needs to be agreed for protecting Critical and Essential Data, as defined in the data model, throughout the navigation data process. This could be achieved through the use of embedded CRCs which remain with the data items. A standard bit level format would have to be agreed for representing, as a minimum, the identifier, latitude, longitude, altitude and data quality for use with the CRC algorithm throughout the navigation data process. Failing that, a procedure would be required for verifying positional data whenever the data format is changed and the CRC is regenerated.

It is recommended that:

a. All Critical and Essential navigation data items be protected by individual embedded CRC, which are applied throughout the data process, from the point of origin of the data to the point of use.

b. Procedures be developed to allow the regeneration of CRC whenever the data format changes.

c. The same 32 bit CRC algorithm that has been adopted for use in the MLS is implemented as the standard CRC for the protection of Critical Data.

d. Consideration be given to protecting Essential Data with the same 32 bit CRC algorithm as that used for Critical Data. If this is not feasible, the CCITT* 16 bit CRC algorithm, detailed in Annex C, be implemented as the standard CRC for the protection of Essential Data.

6.4 DATA QUALITY FIELD

A standard data quality field for each positional data item needs to be agreed to provide information as to whether the data meet the accuracy requirements and whether the data have been modified since origination. This will require changes to the associated data transfer formats such as ARINC 424 and the UDDF.

It is recommended that the data quality field proposed in this report be adopted as a standard for all electronic navigation data transfer formats.

6.5 DATA TRANSFER CRC

A standard procedure needs to be agreed for protecting all navigation data to the level of integrity commensurate with the highest integrity requirement of data items being transferred through the use of a suitable CRC.

It is recommended that all organizations be mandated to protect navigation data during transfer, through the use of a 32 bit CRC. The Standard CRC algorithm which is recommended for data transfer use should be the same as that which is used to protect individual Critical Data items. However, it is not considered necessary to mandate the use of the Standard CRC algorithm - the specific CRC algorithms chosen need only be agreed between the parties participating in the data exchange.

6.6 NOTAM PROCEDURES

The current procedures for disseminating changes to published navigation data at short notice, the NOTAM system, rely upon considerable human involvement and provide no obvious protection against data corruption. As there will always be occasion for data to change at short notice, a method needs to be devised to ensure the integrity of Critical and Essential Data under these circumstances.

It is recommended that a study be undertaken into the maintenance of integrity of Critical and Essential Data within the NOTAM system.

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* CCITT: Comité Consultatif Internationale de Télégraphique et Téléphonique

ANNEX A - GLOSSARY OF TERMS AND ACRONYMS

Accuracy	The degree of conformity with a standard, or a value accepted as correct or true. For measured positional data the accuracy is normally expressed in terms of a distance from a stated position within which there is a defined confidence of the true position falling.
Assembly	The process of merging navigation information from multiple data sources into a database and establishing a baseline for subsequent processing. The database contents must be traceable to an original government source document or must be user defined. The assembly process must also include checking the data and may also include correcting the data. (Definition taken from Do 200)
Audit	A documented examination and analysis of objective evidence, collecting and analysing information in order to confirm compliance with applicable Standards.
Collinear	A state whereby three or more points occupy positions in which the perpendicular distance of any of the points from the least square line drawn through them is less than a specified amount.
Configuration Management	The activity whereby changes to a product are controlled and documented.
Consistency	A state whereby actual relationships between different data items match the declared or implicit relationships for these items.
Consistency Check	The confirmation of the correctness of the relationships between data items. For three points to be collinear, for example, a consistency check would involve ensuring that the collinearity criteria are met.
Cyclic Redundancy Check (CRC)	A process whereby a sequence of N data bits is manipulated by an algorithm to produce a block of n bits, known as the CRC, where n is less than N. A check of the integrity of the data can be performed by comparing the result of the application of the algorithm with the declared expected result. By careful choice of the algorithm employed, in conjunction with the relative values of n and N, it can be guaranteed that more than a specified proportion of the original N bits must be corrupted before there is any possibility of the same resultant n bit code being produced.
Database	A file of data so structured that appropriate applications may draw from the file and update it. Primarily refers to data stored electronically and accessed by computer, rather than in files of physical records.
Database Management System (DBMS)	A software program which acts as an interface between the user and the database itself, allowing the user easily to access and update the information stored in the database.
Data Quality	The confidence that the data provided reflects the initial measurement and meets its stated specified accuracy. There is no single measure of data quality but it may, for example, be illustrated by a set of nominal values derived from the accuracy of the original measurements and the integrity that is calculated to be provided to a specific data item by the existing quality assurance measures.
Declination	The angular difference between True North and the zero degree radial of a navaid at the time that the navaid was last adjusted.

Distribution	The duplication of formatted navigation data and the shipping and loading of the database into the target system for application. Distribution is usually achieved by transferring the data from one medium to another, with each transfer being verified. (Definition taken from Do 200)
Final Approach Course Fix	A named and defined fix used to establish an aircraft on the final approach course or for entry to the final approach segment.
Flight Management System (FMS)	An on-board computerised management system which integrates positional information derived from navigation facilities with stored flight plan details and AIS data, together with manual inputs, to provide piloting instructions.
Integrity	The extent to which modification of software or data can be controlled in a computer system. The assurance that a data item retrieved from a storage system has not been corrupted or altered in any way since the original data entry or latest authorised amendment.
ISO	International Organization for Standardization - a worldwide federation of national Standards bodies (ISO member bodies) responsible for preparing International Standards in liaison with other international organizations and governmental and non-governmental bodies. Draft International Standards adopted by ISO technical committees are circulated to member bodies for approval. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.
Point	A precise geographical location in space defined by an agreed set of parameters. Navigation data can relate to one of three types of point as follows:
Calculated Point	A point in space, which is not explicitly specified in latitude and longitude, but which has been derived by mathematical manipulation from a known surveyed point. For example, a VHF Navaid Fix which is specified by a bearing and range.
Declared Point	A point in space, defined by latitude and longitude, that is not dependent upon, or formally related to any known surveyed point.
Surveyed Point	A point in space, specified by latitude and longitude, that has been determined by a survey conducted in accordance Standards laid down with respect to WGS 84.
Precision	The smallest difference that can be reliably distinguished by a measurement process.
Procedure	A set of activities necessary to carry out a particular process and the individual responsibilities pertaining to those activities.
Quality	The ability of a product to meet its stated requirements, that it is fit for its specified purpose. There is no single or absolute measure of quality although statements about the quality of a process or item may be based upon physical measurements and observations.
Quality Assurance	The process of ensuring that predefined Standards of quality are incorporated in the final product, by use of predefined methods. All activities and functions which affect the level of quality of a product are of concern to quality assurance.
Quality Management	The implementation of a quality assurance system.

Repeatability	The level to which, irrespective of accuracy, a measurement, when repeated, will agree with the previous value.
Resolution	The smallest difference between two adjacent values which can be represented in a measuring system. The number of decimal points or the scale of units to which a measured or calculated data item can be recorded, displayed or transferred. (Example: 54° 33′ 15″ is expressed to a resolution of one second.)
Significant Figure	A mathematical term relating to the number of figures that are used to describe a data item. (Example: 1.4×10^4, 14, 1.4 and 0.014 all have two significant figures)
Standard	A specific document, algorithm, procedure, definition, format, dimension or unit of measurement that is approved by a recognised body. Standards may be external, such as ISO or ICAO Standards, or internal to an individual organization.
Validation	The activity whereby a data item is checked as having a value which is fully applicable to the identity ascribed to the data item.
Verification	The activity whereby the value accorded to a data item is checked against the source of that value.

AEEC	Airlines Electronic Engineering Committee
AFTN	Aeronautical Fixed Telecommunications Network
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation and Control
AIS	Aeronautical Information Service
ANSI/ASQC	American National Standards Institute/American Society for Quality Control
ARINC	Aeronautical Radio Incorporated
ARP	Aerodrome Reference Point
ASCII	American Standard Code for Information Interchange
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATS	Air Traffic Services
AWOP	All Weather Operations Panel
BS	British Standard
CAA	Civil Aviation Authority
CASE	Computer Aided Software Engineering
CAT	Categories of Precision Approach (CATI, CATII, CATIIIa, CATIIIb, CATIIIc)
CCITT	Comité Consultatif Internationale de Télégraphique et Téléphonique
CEP	Circular Error Probable
CRC	Cyclic Redundancy Check
DBMS	Database Management System
DME	Distance Measuring Equipment
DME/P	Distance Measuring Equipment/Precision
E-AIP	Electronic Aeronautical Information Publication
EBCDIC	Extended Binary Coded Decimal Interchange Code
EN	Europäische Norm (European Standard)
FACF	Final Approach Course Fix
FAF	Final Approach Fix
FIR	Flight Information Region
FMC	Flight Management Computer
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GP	Generating Polynomial
GPS	Global Positioning System

ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
INS	Inertial Navigation System
ISO	International Organization for Standardization
LAN	Local Area Network
MAC	Message Authentication Code
MAPt	Missed Approach Point
MLS	Microwave Landing System
NAVAIDS	Navigation Aids
NATS	National Air Traffic Services
NDB	Non-directional Beacon
NOTAM	Notice to Airmen
OFP	Operational Flight Programme
OODBMS	Object Oriented Database Management System
OODM	Object Oriented Data Model
PANS	Procedures for Air Navigation Services
PRNAV	Precision Area Navigation
RDBMS	Relational Database Management System
RNAV	Area Navigation (Previously known as Random Navigation)
RNP	Required Navigation Performance
RTCA	Radio Technical Commission for Aeronautics
RTCA Do	Document produced under aegis of RTCA
RTCA SC	RTCA Special Committee
SARPS	Standards and Recommended Practices
SID	Standard Instrument Departure
SQL	Structured Query Language
STAR	Standard Terminal Arrival Route
TACAN	Tactical Navigation
TLOF/FATO	Touchdown and Lift-off / Final Approach and Take-off
UDDF	Universal Data Delivery Format
UIR	Upper Information region
WAD	Wide Area Differential
WGS 84	World Geodetic System 1984
VHF	Very High Frequency
VOR	VHF Omni-directional Ranging

ANNEX B - USE OF CRCs FOR ENSURING POSITIONAL DATA INTEGRITY

1 INTRODUCTION

Cyclic Redundancy Check (CRC) was introduced as a better method than use of check sums or parity bits for error detection within serially transmitted digital data which was subject to burst error (eg short periods of corruption due to atmospheric effects on radio propagation). An n bit number is produced from the data string, by a process which can produce all 2^n possible values of the number, and appended to the end of the transmitted data. The recipient applies the same algorithm and checks that the result is the same; if it is not, an error is declared. Retransmission of failed data is requested until the CRC check is passed.

2 INTEGRITY ASSURANCE

CRC offers absolute assurance of error detection when there is only a single period of "burst error" within the stream of data which was subjected to the CRC, provided that the sub-string containing all affected bits is shorter than the length of the CRC employed. If the separation of corrupted bits is greater than the length of the CRC, the probability of an undetected error is the probability that the same CRC will be produced from both the original and the corrupted data. Assuming an "even" mapping of valid data strings to CRC, the probability of undetected error rises to a maximum of 2^{-n} when the number of bits protected by the CRC is several times the length of the CRC itself.

The following table gives the length of CRC required to achieve different levels of assurance of detection of multiple bit error in the data, where there is no guarantee that the separation of the bits in error is less than the length of the CRC.

Table B1 : Relationship Between Integrity and CRC Length

Level of Integrity	Length of CRC	
	Bits	Characters
3.9×10^{-3}	8	1
1.5×10^{-5}	16	2
6.0×10^{-8}	24	3
2.3×10^{-10}	32	4

In order to achieve an integrity assurance of 3×10^{-8}, it is therefore necessary to employ a 32 bit CRC.

3. GENERATING A CRC

The algorithm by which a CRC is produced is defined by a Generating Polynomial (GP). The GP for an n bit CRC is of order n; the coefficients are either 0 or 1, with the constraints that the polynomial is primitive and that the coefficients of x^0 and of x^n are both 1.

To generate a CRC, a data block is divided by a GP. The resulting remainder, the CRC, is usually tagged onto the end of the data block. When the data is subsequently checked, an identical division is performed on the data although the remainder is now included. If no errors have occurred, the remainder from this division should be zero.

This can be shown with the following mathematics, carried out using modulo 2 arithmetic.

Let D = Data, GP = Generator polynomial, Q = Quotient, R = Remainder (suffixes T and R denote Transmitter and Receiver respectively).

Then

$D = Q_T \text{ x } GP + R_T$ - at transmitter

$D + R_T = Q_R \text{ x } GP + R_R$ - at receiver

Which can be represented as

$$D = Q_R \text{ x } GP + R_R + R_T$$

It follows that

$$Q_T \text{ x } GP \text{ x } R_T = Q_R \text{ x } GP + R_R + R_T$$

Cancel GP and R_T to give

$Q_T = Q_R$ if $R_R = 0$ (ie no errors)

A CRC can be implemented with simple shift registers and exclusive OR (XOR) gates. For clarity, the following example is performed manually.

3.1 EXAMPLE OF A CRC GENERATION

For this example, the data = 11011001, the GP = 11001 and the CRC is 4 bits long. (One of the pre-requisites for the GP is that it is 1 bit longer than the CRC). Four zeros are appended to the data (the length of the CRC) and the data (with the four zeros added) is XORed with the GP. This operation yields a quotient and a remainder (the CRC).

Table B2 : Data Divided by GP to Generate the CRC

					1	0	0	1	1	1	1	1	QUOTIENT			
1	1	0	0	1	1	1	0	1	1	0	0	1	0	0	0	0
	X	O	R		1	1	0	0	1							
					0	0	0	1	0	0	0	1				
								1	1	0	0	1				
								0	1	0	0	0	0			
									1	1	0	0	1			
									0	1	0	0	1	0		
										1	1	0	0	1		
										0	1	0	1	1	0	
											1	1	0	0	1	
											0	1	1	1	1	0
												1	1	0	0	1
												0	0	1	1	1

Remainder (CRC)

The CRC is now appended to the data. When the receiver of the data passes this string through the same calculation again, there will be a zero remainder if no errors have occurred.

Table B3 : Data with CRC Divided by GP to Establish Whether Corruption has Occurred

					1	0	0	1	1	1	1	1				
1	1	0	0	1	1	1	0	1	1	0	0	1	0	1	1	1
	X	O	R		1	1	0	0	1							
					0	0	0	1	0	0	0	1				
								1	1	0	0	1				
								0	1	0	0	0	0			
									1	1	0	0	1			
									0	1	0	0	1	1		
										1	1	0	0	1		
										0	1	0	1	0	1	
											1	1	0	0	1	
											0	1	1	0	0	1
												1	1	0	0	1
												0	0	0	0	0

Remainder = 0 (no errors)

4. STANDARD CRC ALGORITHMS

There is no universally agreed standard for CRCs of different lengths. For a 16 bit CRC, there are two *de facto* standards, one supported by ANSI and the other by CCITT:-

CRC-16 (ANSI) $1 + x^2 + x^{15} + x^{16}$

CRC-CCITT $1 + x^5 + x^{12} + x^{16}$

For 32 bit CRCs, the *de facto* industry standard has been established by the algorithm which is used on the majority of installed LANs, but a different algorithm has been selected for protection of MLS data

CRC - (LAN) $1 + x^2 + x^4 + x^5 + x^7 + x^8 + x^{10} + x^{11} + x^{16} + x^{23} + x^{26} + x^{32}$

CRC - MLS $1 + x^1 + x^3 + x^4 + x^8 + x^9 + x^{13} + x^{14} + x^{31} + x^{32}$

There is no immediately apparent qualitative or quantifiable advantage of one 32 bit CRC algorithm over another. There may be some advantage in commonality with the MLS data, but this might be outweighed by the confidence conferred by the greater "installed base" of the CRC employed in LANs.

ANNEX C - RELATED INTERNATIONAL STANDARDS

1 INTRODUCTION

During the study, a number of international standards were investigated to determine their applicability to the navigation data integrity requirements. The ISO 9000 series, covering Quality Assurance, were considered to be pertinent and are discussed in the body of the report. This annex provides brief résumés of other standards that were considered.

2 ISO 7064: 1985

ISO 7064 is a specification for check character systems for use in information interchange, and guidance on choice and methods of application.

It describes check character systems capable of protecting strings against errors that occur when data items are manually copied or keyed; it includes conformance requirements for products described as generating check characters or checking strings using those systems; it includes guidance on selection of check character systems for application; it excludes systems designed specifically to permit both error detection and automatic correction, to detect fraud or to check strings interchanged only between machines.

The check character systems rely on similar principles to cyclic redundancy checks in binary systems in as much as check characters are appended to the string to be protected in such a way that any modification to the original string can be detected due to the properties of the check characters. The general principle behind each of the check character systems is the same, but the systems fall into two distinct categories, hybrid and pure systems, which differ in the exact algorithm used. Within these two groups different systems are defined to deal with different types of strings (numeric, alphanumeric and alphabetic) and to produce either one or two check characters. The advantage of calculating two check characters is that more errors can be detected, but this is offset by the increased complexity of the algorithm used to generate the check characters and validate the protected string.

The general method employed by all the systems is as follows:

- Assign a number to each of the characters in the character set used in the message. The character to number mapping is defined in the standard.

- Calculate the check character(s) and append to the protected string.

- When the protected string is checked using the algorithm if no errors exist an expected result will be produced.

The error rates achievable with this method are, at best, 3 errors in 10^5 using the 1271-36 check system with 2 check characters applied to alphanumeric data blocks. While it would seem logical that this system could be extended to achieve lower error rates than for the cases studied in the standard, the penalty in the form of increased processing overheads was considered to be too great. This system may be of use if applied to the data at source, i.e. by the surveyor, to improve the integrity of the data entry procedure if the data are to be maintained in a manual system. However, this was not pursued for the following reasons:

- The report recommends that the data are stored in an electronic format from the time of origination.

- The integrity requirements for both critical and essential data exceed that which can be provided by this standard.

3 BS ISO/IEC 9075: 1992

ISO 9075 defines the data structures and basic operations on SQL data. It also describes syntax and semantics of SQL:

- For specifying and modifying the structure and integrity constraints of SQL data.

- For declaring and invoking operations on SQL data and cursors.

- For declaring database language procedures and embedding them into a standard programming language.

It specifies an Information Schema that describes the structures and integrity constraints of SQL data. The extent of the integrity constraints available in the standard definition of SQL as defined by this document is to define the valid states of SQL data by constraining the values in the base tables. This encompasses all the ideas of primary and foreign keys and user defined constraints. A constraint can be a table constraint, a domain constraint or an assertion.

The applicability of this standard is limited, as any DBMS which conforms to standard SQL should offer all of the functionality described in this document. This is a general standard and does not approach the solution needed for a safety critical system requiring high levels of integrity.

4 BS ISO/IEC 9797: 1990

ISO 9797 defines a data integrity mechanism using a cryptographic check function employing a block cipher algorithm.

It specifies a method of using a key and an n-bit algorithm in block cipher mode to calculate an m-bit cryptographic check value which can be used in a data integrity mechanism to detect that data have not been altered in an unauthorised manner.

The standard merely suggests an implementation procedure, detailed in Figure 1, for any n-bit algorithm and any key length without giving any indication of the algorithm to be used. The procedure suggested sequentially encrypts the data using an algorithm and ultimately produces a MAC, Message Authentication Code, which can then be used to protect the data from unauthorised change. The degree of integrity offered by the integrity mechanism is dependent upon the length and secrecy of the key and the nature of the cryptographic algorithm used and therefore the level of integrity offered by this system is not quantifiable.

The application of this standard could be extended from simply restricting access to data by unauthorised users to protect against corruption or loss of data, but it is unlikely that this would be an optimal solution as this function is not the primary aim of the standard.

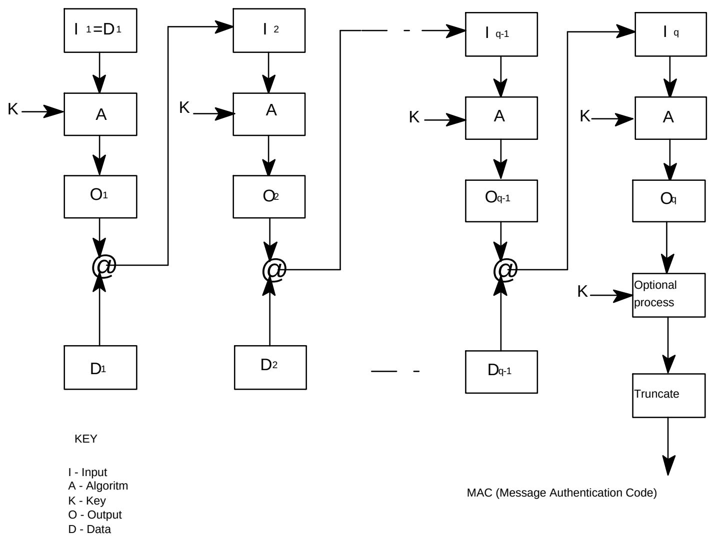

Figure 1 - Suggested Procedure for MAC Generation.

ANNEX D - REFERENCES

1 American Institute of Navigation Journal, Spring 1994 Issue

2 ARINC SPECIFICATION 424-11 - Navigation System Data Base, August 20 1993

3 EUROCONTROL WGS 84 Surveying Standard - Navigation Facilities, Draft 1.3

4 CAO International Standards and Recommended Practices

Annex 14 - Aerodromes, First Edition, July 1990
Annex 15 - Aeronautical Information Services, Amendment 28, March 1994

5 ICAO Procedures for Air Navigation Services

Doc 9613 - Manual of Required Navigation Performance, 1994
Doc 8126 - Aeronautical Information Services Manual, Fourth Edition, 1991
Doc 8168 - Volume II - Construction of Visual and Instrument Flight Procedures, Fourth

Edition, Amendment 6, 1993

6 ISO Documentation

ISO 9000:1994 - Quality management and quality assurance standards - Guidelines for selection and use

ISO 9001:1994 - Quality systems - Model for quality assurance in design/development, production, installation and servicing

ISO 9002:1994 - Quality systems - Model for quality assurance in production and installation

ISO 9003:1994 - Quality systems - Model for quality assurance in final inspection and test

7 RTCA Documentation

Do 178B - Software Considerations in Airborne Systems and Equipment Certification, December 1 1992

Do 200 - Preparation, Verification and Distribution of User-selectable Navigation Data Bases, November 28 1988

Do 201 - User recommendations for Aeronautical Information Services, November 28 1988

ANNEX E - INDEX

Rapport No CEE 276
Tâche CEE No. AT57
Date: Décembre 1994

<u>TRADUCUCTION FRANCAISE</u>

MODELE D'INTEGRITE POUR LES DONNEES DE NAVIGATION

STASYS LTD

SOMMAIRE

Par suite de la confiance croissante dans les coordonnées de position pour la navigation de surface (RNAV) et du système global de la navigation par satellites (GNSS), l’intégrité et la qualité de telles données deviennent critiques. Ce rapport présente les résultats d’une étude qui a été faite pour examiner les différents facteurs qui déterminent la qualité et l’intégrité des coordonnées de position appliquées dans la navigation aérienne.

En premier, l’étude définit explicitement plusieurs expressions, comme *intégrité*, *précision* et *fidélité*, termes indispensables pour décrire précisément les processus utilisés pour évaluer la qualité des données de navigation. Suit une description du processus général par lequel les coordonnées de position pour la navigation sont développées et promulguées ainsi que les principes de base pour assurer leur qualité. Suivent la proposition d’un modèle qui décrit et catégorise les différents types de données appliquées dans la navigation aérienne, ainsi que plusieurs méthodes qui se proposent d'assurer l’intégrité des données. En fin de compte, conclusions et recommendations sont faites sur le modèle des données, l’encadrement de la qualité, l’application des contrôles de redondance cyclique (CRC), les champs de qualités des données et les procédures NOTAM.

Des annexes qui décrivent l’utilisation des CRC et la relation entre les différentes normes internationales de qualité sont jointes.

SYNTHESE

Les techniques traditionnelles de navigation se fondent sur l'aptitude des aéronefs à se diriger vers les aides ponctuelles à la navigation ou à s'en éloigner; mais, alors que les coordonnées de ces aides étaient connues, ces informations n'étaient pas exploitées dans le cadre de la procédure de navigation. Aujourd'hui, on utilise de plus en plus les systèmes de navigation de surface (RNAV), qui calculent la position des aéronefs à partir de sources telles que les systèmes de navigation par inertie (INS), Omega, les radiophares omnidirectionnels VHF (VOR)/les dispositifs de mesure de la distance (DME), les DME doubles ou multiples et le Système global de navigation par satellites (GNSS).

Pour ces opérations, la trajectoire effectivement empruntée par l'aéronef dépend des coordonnées définissant tant la trajectoire que l'emplacement des aides au sol à la navigation. Avec la mise en place des routes RNAV de précision (RNP 1) à compter de 1998 et l'extension de l'application de RNAV aux procédures de région terminale, une plus grande précision est requise; il faut aussi s'assurer que les données définissant la trajectoire à emprunter sont d'une précision et d'une intégrité répondant aux exigences RNP.

L'OACI a adopté le Système géodésique mondial (WGS 84) en tant que système commun de référence géodésique pour l'aviation civile, et elle prépare actuellement les documents appropriés pour assurer une application rapide et globale de cette norme au niveau mondial. Au sein de la CEAC, la mise en oeuvre du WGS 84 est en cours de coordination par l'Agence EUROCONTROL qui, dans le cadre d'EATCHIP, élabore actuellement les normes et procédures visant à assurer que le relevé de position du système WGS 84 réponde à l'ensemble des exigences de précision.

La classification, la mémorisation, la mise à jour et la diffusion ultérieure de ces données de navigation relève de la responsabilité du Service d'Information Aéronautique (AIS) de chaque Etat. Ensuite, les données de navigation de tous les Etats contractants de l'OACI sont, à leur tour, répertoriées, mémorisées, mises à jour, et communiquées aux fabricants de FMS et aux compagnies aériennes par des fournisseurs commerciaux de données. Pour atteindre les hauts niveaux de précision et d'intégrité requis par les normes RNP, il faudra mettre au point des procédures d'assurance qualité et définir des normes à l'intention de tous les organismes appelés à traiter les données de navigation.

L'étude a été centrée sur le maintien de l'intégrité des données de navigation qui sont chargées électroniquement dans le FMS. Les données de navigation figurant dans les amendements et suppléments aux Publications d'information aéronautique (AIP), diffusés par l'AIS, relèvent de cette procédure. Cependant, la procédure de modification des données à brève échéance, à l'aide de la procédure NOTAM, nécessite habituellement une intervention humaine non négligeable d'un bout à l'autre et n'est pas étudiée dans le présent rapport.

APERÇU GENERAL DE LA PROCEDURE RELATIVE AUX DONNEES DE NAVIGATION

La procédure de collecte, de mémorisation et de diffusion des données de navigation est décrite dans le document RTCA Do 200, intitulé "Preparation, Verification and Distribution of User-Selectable Navigation Data Bases", qui, de même que le Do 201, intitulé : "User recommendations for Aeronautical Information Services", traite de certaines des questions relatives à la qualité qui affectent la procédure relative aux données de navigation. Si le premier était, à l'origine, essentiellement destiné aux fabricants FMS et aux fournisseurs commerciaux de données, et si le second est spécialement conçu pour l'AIS, les procédures, décrites dans le Do 200, et les normes, dont l'énoncé précis figure dans le Do 201, peuvent être appliquées à chaque étape du cycle de collecte et de distribution des données de navigation.

Les exigences de qualité relatives aux données de navigation fournies doivent être spécifiées par les utilisateurs finals des données. Ces exigences doivent porter, entre autres, sur les aspects suivants :

a. La définition des données requises.

b. L'énoncé explicite des exigences de précision associées à chaque type de données.

c. L'énoncé explicite des exigences d'intégrité associées à chaque type de données.

d. L'énoncé explicite des exigences relatives à l'historique des modifications apportées à chaque type de données.

CLASSIFICATION DES DONNEES

Il n'a pas été possible de relever l'existence d'un énoncé exhaustif et officiel des exigences des utilisateurs finals en matière de précision et d'intégrité des données de navigation de position. A l'heure actuelle, il n'existe pas de description précise de ces exigences pour toutes les catégories de données, encore que des travaux sont en cours pour convenir des exigences relatives à la navigation de surface de précision (PRNAV), tant pour la phase en route que pour la phase terminale du vol. Il est entendu que, dans ce dernier contexte, il existe une exigence globale, à savoir qu'il doit y avoir moins d'un atterrissage fatal imputable à un système d'atterrissage pour 10^7 atterrissages, et que les taux d'erreur sont supposés être répartis également entre les sources d'erreur. Un modèle de données a été mis au point pour les besoins du présent rapport regroupant neuf catégories de données (cf. tableau plus loin).

CADRE DE QUALITE

Les utilisateurs des données de navigation faisant état d'exigences relatives à la qualité, il s'en suit que chaque organisme fournissant ces données doit prouver qu'il répond à l'exigence indiquée.

Quel que soit le système choisi par les divers organismes, il est nécessaire de disposer, à l'échelle de la communauté, d'un cadre de qualité où soient détaillés les procédures, algorithmes et formats standard susceptibles de figurer, le cas échéant, dans le système de qualité de chaque organisme.

Ces normes devront être dûment documentées et ratifiées par l'ensemble de la communauté des données de navigation, mais ne devraient pas toutes être obligatoires. Dans de nombreux cas, elles peuvent être exprimées sous la forme d'énoncés des exigences, plutôt qu'en termes de solutions techniques. Cependant, des solutions techniques obligatoires devraient être spécifiées dans les cas où une interface commune agréée est requise entre des processeurs indépendants de données de navigation.

Les procédures et les normes incluses dans le cadre de qualité doivent, au minimum, recouvrir les aspects suivants :

a. **Encodage des données:** Le transfert des données d'un formulaire manuscrit ou imprimé vers un format emmagasiné dans la mémoire d'un ordinateur constitue la plus grande source potentielle d'erreur dans l'ensemble de la procédure. Si les données de position pouvaient être encodées dans une base de données par les responsables de relevés/concepteurs eux-mêmes et conservées ensuite sous forme électronique/magnétique tout au long du traitement ultérieur des données de navigation, l'exigence relative à la vérification de l'entrée manuelle serait sensiblement réduite.

   Lorsqu'une donnée est mémorisée sous forme électronique, il faut soit la fournir avec la possibilité qu'elle soit vérifiée lors d'un transfert ultérieur, soit apporter la preuve qu'elle n'a pas été altérée au moment de la mémorisation. Le mécanisme proposé pour y parvenir est l'utilisation d'un Contrôle de redondance cyclique (CRC), qui doit être produit à partir du nom (identificateur) de la position, de sa latitude, de sa longitude, de son altitude et de la qualité de ses données, selon le cas. Il est suggéré que l'émetteur de données génère un CRC avant de transmettre des données critiques ou essentielles par la voie électronique.

b. **Validation des données:** Dès que la donnée existe sous une forme électronique, il est possible de procéder à la vérification de validation des données ; cette procédure peut servir à détecter un certain nombre des erreurs imputables à l'encodage manuel ou à l'altération ultérieure de ces données. Ces vérifications ne peuvent cependant pas améliorer sensiblement l'intégrité des données.

c. **Transfert des données:** Un risque d'altération existe au cours du transfert des données d'un système informatique à un autre. Il est d'usage de prévoir une protection et une garantie au moyen du CRC. Le niveau de garantie que fournit le CRC (à savoir, la copie des données reçue doit être rigoureusement la même que la copie transmise) doit être au moins aussi élevé que le niveau requis d'intégrité de chaque élément au sein d'un ensemble de données transférées.

d. **Contrôlabilité et possibilité de retour à la source:** Pour que l'intégrité soit garantie et démontrable, on doit pouvoir remonter, de manière ininterrompue, à la source de toutes les coordonnées. Il convient de conserver tous les détails relatifs aux modifications qui ont été apportées aux données; les relevés peuvent s'effectuer éventuellement sous forme électronique ou sur support papier, encore que certaines données relatives à ces changements doivent être conservées avec la donnée pendant toute la durée du cycle de traitement des données de navigation. Le présent rapport inclut une proposition de conception d'un champ de données, appelée champ de la qualité des données, qui pourrait être automatiquement transféré avec les données.

e. **Mesures correctives:** A l'heure actuelle, il n'existe pas de procédure formelle permettant de signaler les erreurs ni de prendre des mesures correctives - la plupart des corrections sont effectuées une par une en collaboration avec l'AIS. Une procédure standard, servant au signalement des erreurs et à la publication des amendements ultérieurs, garantirait la correction ordonnée et ponctuelle des erreurs à la source dans les bases de données relatives aux données de navigation, et que toutes les parties intéressées en soient informées.

f. **Documentation:** Les algorithmes et méthodes de travail standard devraient être présentés de manière détaillée dans un document unique. Actuellement, le document RTCA Do 200 traite de la question du point de vue des fournisseurs de données de navigation. Le document RTCA Do 201 fait état de domaines présentant un intérêt pour les organismes AIS. Le cadre de qualité proposé ainsi que les procédures et normes connexes s'appliqueraient également à toutes les parties concernées par le traitement des données, depuis les émetteurs jusqu'aux utilisateurs finals.

RECOMMANDATIONS

Comme suite à l'élévation des risques liés aux données critiques et à la tendance croissante à l'apparition de litiges survenant après des incidents, il faudra peut-être instaurer une relation plus formelle entre le fournisseur de données de navigation et l'utilisateur de ces données quant à la qualité de ces dernières.

Il est recommandé :

a. que le modèle de données dont il est question dans le présent rapport soit examiné en vue de son adoption comme base d'une norme agréée à l'échelon international, qui constituerait un impératif à respecter par tous les membres de la communauté des données de navigation.

b. que le RTCA Do 200 devienne un document relatif au cadre de qualité, qui énonce les procédures d'une manière détaillée et désigne les normes applicables à tous les organismes chargés de la production ou de la mise à jour des données de navigation; que le RTCA Do 201 devienne un document normatif reprenant dans le détail les algorithmes et méthodes de travail applicables à tous ces organismes ; et que les normes visant le transfert des données continuent d'être décrites avec précision dans des documents autonomes, tels que l'ARINC 424.

c. que tous les éléments critiques et essentiels des données de navigation soient protégés au moyen de CRC intégrés, applicables tout au long du traitement de ces données, de leur origine à leur utilisation ; que des procédures soient élaborées pour permettre la régénération des CRC en cas de modification du format des données ; que le même algorithme CRC à 32 bits, qui a été adopté en vue de son utilisation dans le MLS, soit mis en service en tant que CRC standard pour la protection des données critiques et, dans la mesure du possible, des données essentielles. (A défaut, que l'algorithme CRC à 16 bits du CCITT soit mis en oeuvre en tant que CRC standard pour la protection des données essentielles.)

d. que le champ de la qualité des données, proposé dans le présent rapport, soit adopté en tant que norme pour tous les formats de transfert électronique des données de navigation.

e. que toutes les organisations soient tenues de protéger les données de navigation pendant leur transfert, et ce au moyen d'un CRC de 32 bits; que les algorithmes CRC particuliers choisis ne soient convenus qu'entre les parties participant à l'échange de données.

f. que soit entreprise une étude de l'intégrité des données dans le cadre du système NOTAM.

1 INTRODUCTION

Le présent rapport traite de l'intégrité des données de navigation aérienne. Suite à l'introduction des nouvelles technologies dans les domaines de la navigation, du traitement de l'information et des communications, on tend à s'appuyer davantage sur les données de position qui sont utilisées dans la navigation aérienne, d'où la nécessité de procéder au réexamen des exigences de précision et d'intégrité imposées aux données, et des moyens de répondre à ces exigences.

1.1 OBJET DU PRESENT RAPPORT

Les techniques traditionnelles de navigation se fondent sur l'aptitude des aéronefs à se diriger vers les aides ponctuelles à la navigation ou à s'en éloigner. Mais, alors que les coordonnées de ces aides étaient connues, ces informations n'étaient pas exploitées dans le cadre de la procédure de navigation. A l'heure actuelle, on utilise de plus en plus les systèmes de navigation de surface (RNAV), qui calculent la position des aéronefs à partir de sources telles que les systèmes de navigation par inertie (INS), Omega, les radiophares omnidirectionnels VHF (VOR)/les dispositifs de mesure de la distance (DME), les DME doubles ou multiples, et le Système global de navigation par satellites (GNSS). Sur la base de ces données, le système RNAV envoie les instructions appropriées aux pilotes automatiques qui permettent aux aéronefs de suivre la route prévue au cours des phases de départ, de route, d'approche et d'atterrissage.

Pour ces opérations, la trajectoire effectivement empruntée par l'aéronef dépend des coordonnées définissant tant la trajectoire que l'emplacement des aides au sol à la navigation. Avec la mise en place des routes RNAV de précision (RNP 1[1]) à compter de 1998 et l'extension de l'application de RNAV aux procédures de région terminale, une plus grande précision est requise; il faut aussi s'assurer que les données définissant la trajectoire à emprunter sont d'une précision et d'une intégrité répondant aux exigences RNP.

L'OACI[2] a adopté le Système géodésique mondial (WGS 84) en tant que système commun de référence géodésique pour l'aviation civile, et elle prépare actuellement les documents appropriés pour assurer une application rapide et globale de cette norme au niveau mondial. Au sein de la CEAC[3], la mise en oeuvre du WGS 84 est en cours de coordination par l'Agence EUROCONTROL qui, dans le cadre d'EATCHIP[4], élabore actuellement les

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[1]RNP :	"Required Navigation Performance", Qualité de navigation requise. Spécifie la précision des performances requise sur une portion définie de l'espace aérien. A l'heure actuelle, quatre niveaux de performances ont été définis par l'OACI pour les opérations en route. Les critères relatifs aux procédures de région terminale et d'approche finale sont en cours d'élaboration.
RNP 1	Maintien de 95% à 1 NM (à savoir, dans un espace aérien RNP 1, les performances de navigation de la population des aéronefs assureront que 95% de celle-ci se situera à moins d'1 NM de la ligne centrale définie (pour de plus amples informations, cf. section 3.3.1 du document 9613-AN/937 de l'OACI : "Manuel de la qualité de navigation requise (RNP)")
RNP 4	Maintien de 95% à 4 NM (dans certaines régions, notamment l'Europe, l'utilisation du RNP 5 pourrait s'avérer nécesssaire en vue d'une exploitation continue à l'aide d'Omega)
RNP 12,5	Maintien de 12,5 NM (équivalent au critère actuel relatif à l'exploitation du réseau de routes sur l'Atlantique nord)
RNP 20	Maintien de 20 NM
[2] OACI:	Organisation de l'Aviation civile internationale
[3] CEAC :	Conférence européenne de l'Aviation civile
[4] EATCHIP :	Programme européen d'harmonisation et d'intégration du contrôle de la circulation aérienne

normes et procédures visant à assurer que le relevé de position du système WGS 84 réponde à l'ensemble des exigences de précision.

La classification, la mémorisation, la mise à jour et la diffusion ultérieure de ces données de navigation relève de la responsabilité du Service d'Information Aéronautique (AIS) de chaque Etat. Ensuite, les données de navigation de tous les Etats contractants de l'OACI sont, à leur tour, répertoriées, mémorisées mises à jour, et communiquées aux fabricants de FMS et aux compagnies aériennes par des fournisseurs commerciaux de données. Pour atteindre les hauts niveaux de précision et d'intégrité requis par les normes RNP, il faudra mettre au point des procédures respectant les normes et assurant la qualité des données de navigation à l'intention de tous les organismes chargés de les traiter.

Le pésent rapport rend compte des exigences relatives à un système d'assurance qualité qui assurera le maintien, au moyen des données de navigation de position, d'un niveau d'intégrité approprié pour la procédure de navigation. Il présente un cadre qui servira de point de départ à l'élaboration des procédures et normes nécessaires à un système d'assurance qualité approprié.

1.2 STRUCTURE DU RAPPORT

Le rapport se divise en quatre sections principales. La première complète les définitions - énoncées dans le glossaire de l'Annexe A - de plusieurs des concepts les plus importants qui y sont examinés. La deuxième section traite des activités de regroupement et de traitement des données de navigation et des exigences relatives à l'assurance qualité. La troisième section décrit les données de navigation de position, les exigences relatives à la précision et à l'intégrité, les sources et les relations entre les diverses données ; sur la base de ces observations, un modèle de données est mis au point en vue de classer les données par catégorie en fonction des besoins des utilisateurs. La quatrième section présente et décrit le cadre de qualité jugé nécessaire pour obtenir l'assurance requise, et propose des procédures et normes qui devraient être mises en oeuvre dans l'ensemble de la communauté des données de navigation. L'utilisation des contrôles de redondance cyclique (CRC) visant à assurer l'intégrité des données et l'applicabilité des normes internationales existantes sont examinées dans les Annexes B et C. L'Annexe D contient des précisions sur les documents de référence et on trouvera un bref index à l'Annexe E.

6 CONCLUSION ET RECOMMANDATIONS

Comme suite à l'élévation des risques liés aux données critiques et à la tendance croissante à l'apparition de litiges survenant après des incidents, à l'instigation des passagers ou de leurs proches, il faudra peut-être instaurer, dans l'avenir, une relation plus formelle entre le fournisseur de données de navigation et l'utilisateur de ces données quant à la qualité de ces dernières. Cela entraînera peut-être l'organisation d'audits externes indépendants du système de qualité et/ou des déclarations, ayant une portée juridique, formulées par les fournisseurs de données à propos de la qualité de ces mêmes données.

Cependant, avant qu'un système de qualité puisse être mis en place, il est impératif que les exigences de qualité soient dûment documentées et que les procédures standard, les méthodes de travail, les algorithmes et les formats soient convenus avec toutes les parties. Dans le cadre du traitement des données de navigation, les exigences relatives à l'intégrité et à la précision des données ne sont pas clairement définies, bien qu'il existe déjà un certain degré de normalisation dans quelques-uns des formats et procédures habituellement utilisés.

On prévoit que ces critères de qualité s'appliqueront à tout organisme fournissant des données AIS à un système de navigation déterminé ou à des fins particulières de navigation, il pourrait donc être utile qu'ils soient documentés dans une publication OACI.

Afin de mettre au point un système de qualité AIS efficace, il convient tout d'abord de satisfaire aux exigences suivantes :

6.1 MODELE DE DONNEES

Il convient de souscrire à un ensemble normalisé de critères relatifs à la qualité des données de navigation et de les publier dans un document OACI approprié. Au niveau international, il n'a pas été possible de trouver de document énonçant dans le détail les exigences relatives à l'intégrité, au suivi de parcours et à la contrôlabilité des données de navigation. L'Annexe 15 de l'OACI (Amendement 28) décrit dans une certaine mesure les exigences relatives à la précision, mais traite de la résolution plutôt que de la précision. On travaille actuellement à l'élaboration d'un document d'orientation OACI qui définirait ces exigences, mais il n'est pas prévu de l'intégrer à une quelconque des Annexes de l'OACI. Le WG3 du Comité spécial 181 de la RTCA[5] étudie la possibilité d'inclure ces exigences dans le Do 200, mais il est peu probable que tous les organismes AIS acceptent ce document.

Il est recommandé que le modèle de données, décrit dans le présent rapport, soit examiné en vue de son adoption comme base d'une norme reconnue à l'échelon international, qui constituerait donc un impératif à respecter par tous les membres de la communauté des données de navigation.

6.2 CADRE DE QUALITE

Un cadre de qualité doit être arrêté et publié, de préférence sous la forme d'un document OACI. Ce cadre doit reprendre dans le détail les procédures et normes agréées, nécessaires pour répondre aux exigences de précision et d'intégrité, en vue de son utilisation dans les systèmes de qualité utilisés par les organismes chargés de traiter des données de navigation. Ou bien, les Documents 200 et 201 de la RTCA pourraient être amendés et complétés de manière à constituer des supports appropriés. Alors que certaines procédures détaillées,

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[5] Le Comité spécial 181 de la RTCA se réunit conjointement avec l'EUROCAE 41.

s'inscrivant dans le cadre de qualité, peuvent être considérées comme étant obligatoires, d'autres devraient revêtir un caractère instigateur.

Il est recommandé :

a. que le RTCA Do 200 devienne un document relatif au cadre de qualité, qui énonce les procédures d'une manière détaillée et désigne les normes applicables à tous les organismes chargés de la production ou de la mise à jour des données de navigation;

b. que le RTCA Do 201 devienne un document normatif reprenant dans le détail les algorithmes et méthodes de travail applicables à tout organisme chargé d'assurer la production ou la mise à jour des données de navigation;

c. que les normes visant le transfert des données continuent d'être décrites avec précision dans des documents autonomes, tels que l'ARINC 424.

6.3 CRC INTEGRES

Il convient d'établir une norme en vue de la protection des données critiques et essentielles, telle qu'elle a été définie dans le modèle de données, pour l'ensemble de la procédure des données de navigation. On pourrait, à cette fin, utiliser les CRC intégrés au niveau de chaque donnée. Un format standard devra être arrêté au niveau des bits, qui tiendra compte, au minimum, de l'identificateur, de la latitude, de la longitude, de l'altitude et de la qualité des données à utiliser avec l'algorithme CRC tout au long du traitement des données de navigation. A défaut, une procédure sera nécessaire pour vérifier les données de position, chaque fois que le format des données sera modifié et que le CRC sera régénéré.

Il est recommandé :

a. que le modèle de données dont il est question dans le présent rapport soit examiné en vue de son adoption comme base d'une norme agréée à l'échelon international, qui constituerait un impératif à respecter par tous les membres de la communauté des données de navigation.

b. que des procédures soient élaborées pour permettre la régénération des CRC en cas de modification du format des données;

c. que le même algorithme CRC à 32 bits, qui a été adopté en vue de son utilisation dans le MLS, soit mis en service en tant que CRC standard pour la protection des données critiques ;

d. que l'on examine la possibilité de protéger les données essentielles au moyen du même algorithme CRC à 32 bits que celui qui est utilisé pour les données critiques ; à défaut, que l'algorithme CRC à 16 bits du CCITT[6], décrit dans le détail à l'Annexe C, soit mis en oeuvre en tant que CRC standard pour la protection des données essentielles.

[6] CCITT : Comité consultatif international télégraphique et téléphonique

6.4 CHAMP DE LA QUALITE DES DONNEES

Il convient d'arrêter un champ standard de la qualité des données pour chaque donnée de position, afin de savoir si ces données répondent aux exigences de précision et si elles ont été modifiées depuis leur émission. Il faudra pour cela modifier les formats connexes de transfert des données, tels qu'ARINC 424 et UDDF.

Il est recommandé que le champ de la qualité des données, proposé dans le présent rapport, soit adopté en tant que norme pour tous les formats de transfert électronique des données de navigation.

6.5 CRC DE TRANSFERT DES DONNEES

Une procédure standard doit être arrêtée pour protéger toutes les données de navigation à un niveau d'intégrité en rapport avec l'exigence la plus élevée pour le transfert de chaque donnée au moyen d'un CRC approprié.

Il est recommandé que tous les organismes soient tenus de protéger les données de navigation pendant le transfert, au moyen d'un CRC de 32 bits. L'algorithme CRC standard, recommandé pour les besoins du transfert de données, devrait être le même que celui qui est utilisé pour protéger les données critiques. Cependant, il n'est pas jugé nécessaire de rendre obligatoire l'utilisation de l'algorithme CRC standard, les algorithmes CRC particuliers choisis ne devant être convenus qu'entre les parties participant à l'échange de données.

6.6 PROCEDURES NOTAM

Les procédures actuelles de diffusion, à brève échéance, des modifications à apporter aux données de navigation publiées, à savoir le système NOTAM, sont largement tributaires de l'intervention humaine et ne prévoient pas de protection évidente contre l'altération des données. Puisque ces dernières seront toujours susceptibles d'être modifiées à brève échéance, il faudrait mettre au point une méthode visant à assurer l'intégrité des données critiques et essentielles dans ces conditions.

Il est recommandé d'entreprendre une étude sur le maintien de l'intégrité des données critiques et essentielles dans le cadre du système NOTAM.

Sommaire du modèle d'intégrité pour les données de navigation	
CATEGORIE	Décrit la sensibilité des données quant à la sécurité
Données critiques	l existe une forte probabilité que, suite à l'utilisation de données critiques altérées, un aéronef soit placé dans une situation périlleuse
Donnés essentielles	Il existe une faible probabilité que, suite à l'utilisation de données essentielles altérées, un aéronef soit placé dans une situation périlleuse
Données courantes	Il existe une probabilité très faible que, suite à l'utilisation de données courantes altérées, un aéronef soit placé dans une situation périlleuse
TYPE	Décrit la méthode par laquelle les données ont été obtenues
Repères	Un repère est un point physique clairement défini, précisé par sa latitude et sa longitude, qui a été déterminé par relevé
Points déclarés	Un point déclaré est un point dans l'espace, défini par sa latitude et sa longitude, qui n'est ni fonction de tout repère connu ni formellement lié à celui-ci.
Points calculés	Un point calculé est un point dans l'espace qui ne doit pas être défini en latitude et longitude, mais qui a été calculé, par traitement mathématique, à partir d'un repère connu.

CATEGORIE	Décrit l'utilisation opérationnelle (par exemple :)	Exigences de précision & d'intégrité
1	Seuil de piste FAF FACF MAPt	0.3m Donnée critique CAT I : 3×10^{-8} CATIII : 8×10^{-10}
2	Points de contrôle de navigation	0.5m Donnée essentielle 3×10^{-5}
3	MLS (Az, Elev, Back-Az) Aire d'atterrissage pour hélicoptères	1m Donnée critique 3×10^{-8}
4	DME/P	3m Donnée critique 3×10^{-8}
5	Obstacles dans l'aire d'approche/de décollage	3m Donnée courante 1×10^{-3}
6	Aides à la navigation en région terminale Points de cheminement en région terminale	30m Donnée essentielle 1×10^{-5}
7	ARP, HRP Obstacles sur l'aérodrome et dans le tour de piste	30m Donnée courante 1×10^{-3}
8	Aides à la navigation en route Points de cheminement en route Portes, feux au sol et obstacles	100m Donnée essentielle 1×10^{-5}
9	Désignation de l'espace aérien Sites des communications ILS, Decca, Loran	100m Donnée courante 1×10^{-3}