EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

Integrity of Aeronautical Information - Aeronautical Data Origination

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Abstract

This document consists of a European Standard for Aeronautical Data Origination. This document sits within an overall family of documents that provide a European Standard for the Integrity of Aeronautical Information.

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1.1	24 January 2003	First Edition	All
1.2	28 April 2003	Initial document restructuring	All
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2.3	01 April 2004	Update following stakeholder comments	Several
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2.6	30 May 2006	Update following review at internal coordination meeting #2	All
2.61	02 August 2006	Editorial corrections following internal coordination meeting #3	Several

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1 Introduction

1.1 General

1.1.1 This is one of a set of documents that have been produced by EUROCONTROL to support the implementation of processes and systems throughout the Aeronautical Information data process.

1.1.2 This document “Integrity of Aeronautical Information – Aeronautical Data Origination” replaces EUROCONTROL Survey Standard 007 and sets out the minimum requirements for the origination of navigation-related data applying to all organisations involved in the data origination process.

1.1.3 The requirements cover the surveying of radio navigation aids and calculated or derived points whose coordinates contribute to air navigation.

1.2 Relationship with other documents

1.2.1 This document provides a means of compliance with Annex 5 Part D of the Implementing Rule for aeronautical data and information quality issues by the European Commission. For other parts of Annex 5, the document should be read in connection with the following specifications:

a. Integrity of Aeronautical Information Principles – Abbreviations and Definitions.

contains the meaning of abbreviations and the definitions of terms used throughout the guidance material.

b. Integrity of Aeronautical Information: Principles - Data and Quality Management.

presents details on how the integrity of information may be improved and maintained. It applies to those organisations within States who operate within the data processing chain, from the point of origination, through to the publication by the Aeronautical Information Services (AIS) and distribution to the next intended user.

c. Integrity of Aeronautical Information - Data Publication.

sets out the minimum requirements for the process involved in the provision of aeronautical data publication and applies to all organisations within the European Civil Aviation Conference (ECAC) Area involved in the publication process for Aeronautical Information.

d. Integrity of Aeronautical Information - Data Exchange.

contains all the requirements which apply explicitly to the exchange of aeronautical information from one point within the data processing chain to another.

Note: The above list will need to be reviewed and reference numbers added after completion of the consultation process on the implementing rule.

1.3 Applicability of the document

1.3.1 Data origination includes all activities prior to receipt of data by the relevant National Administration responsible for AIS.

1.3.2 The items addressed in this document do not necessarily apply to all organisations responsible for data origination. Responsible organisations involved shall determine the exact applicability of the requirements within this document to their own responsibilities and functions.

NOTE: *The organisations considered to be affected by this specification include (but may not be limited to):*

- *Surveyors;*
- *Aerodrome/airport authorities;*
- *Civil Aviation Authorities (CAAs);*
- *Air Navigation Service Providers (ANSPs);*
- *State/national AIS;*
- *Airspace planners;*
- *Procedure designers;*
- *Suppliers/installers of equipment requiring survey;*
- *Other data originators (eg national mapping agencies, terrain/obstacles database providers, etc).*

1.4 Scope of data/activities covered by this document

1.4.1 The requirements relate to the management of surveyed, calculated and derived aeronautical data.

1.4.2 Where a state has decided to use this document as the means of compliance, it should be applied to all navigation facilities and aerodromes within that State.

1.5 Definitions

1.5.1 The definitions and requirements stated in this document are such that they comply with the requirements and recommendations laid down by the Convention on International Civil Aviation and the Annexes thereto. Where the International Civil Aviation Organisation (ICAO) definitions and specifications do not support the specific task of data origination, they have been elaborated in this document from other sources without compromising the original ICAO provision.

1.6 Document structure and drafting convention

1.6.1 Structure

1.6.2 Section 2 specifies requirements for Surveyed Data, whilst Section 3 specifies requirements for Calculated and Derived Data. These two sections are supported by a number of annexes as follows:

- A Data requirements (Normative).
- B WGS-84, ITRF and ETRF89 (Normative).

- C Monumentation (Normative).
- D Description of facilities (Normative).
- E Survey reports (Normative).
- F Heliport data (Normative).
- G GPS survey best practice guide (Recommended).
- H Computation of threshold coordinates (Recommended).
- I Heighting (Informative)

1.6.3 Drafting convention

1.6.4 where requirements are identified as being necessary to achieve the required data quality it is designated by “shall” – Peter Green to provide correct wording

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2 Surveyed Data

2.1 Reference system specification

2.1.1 In accordance with ICAO Annex 15, all horizontal aeronautical points shall be referenced to WGS-84.

2.1.2 Access to WGS-84 has historically been difficult to realise with centimetric precision. However, the WGS-84 coordinate system has now been aligned with the International Terrestrial Reference System (ITRS) realised through the International Terrestrial Reference Frame (ITRF) at a defined epoch. . Annex15 identifies the ITRF 2000 specification which is freely available and many data and information sources support activities to determine ITRF coordinates using GPS survey techniques. Further explanation and guidance is provided in Annex B.

2.1.3 States should use latest applicable ITRF epoch available at the time of the survey and shall record the epoch used.

2.1.4 All surveyed vertical aeronautical data points shall be referenced to WGS-84.

2.1.5 All surveys shall record the height of the surveyed point relative to the GRS 80 ellipsoid. A geoid model sufficient to meet the ICAO requirements shall be used to satisfy the ICAO requirements for the issue of data in accordance with ICAO Annex 15 (i.e. that height data be expressed relative to mean sea level together with the assumed geoid ellipsoid separation).

Recommendation: *WGS-84 cannot meet all ICAO vertical accuracy requirements and therefore all surveys should be undertaken using the current ITRS epoch – (see Annex B).*

2.1.6 Unless otherwise specified, all heighting requirements shall refer to ellipsoidal heights.

NOTE: *Appendix I deals with issues related to the determination of geoid undulations at aerodromes.*

2.2 Facilities and corresponding minimum data requirements

2.2.1 Requirements

2.2.1.1 The requirements stated in Annex A shall be achieved as a minimum. In particular:

- All terrain data shall be surveyed to meet the accuracy requirements of Table A-1.
- All significant obstacles shall be surveyed to meet the accuracy requirements of Table A-2.
- The navigation facility data requirements specified in Table A-3 shall be achieved for all facilities listed in Table A-4. For these points organisations should follow the guidelines in Annex G for control points, see G.2.9.

2.2.1.2 All position accuracies shall relate to a probability of 95% (2 x sigma) containment, unless otherwise stated.

2.2.1.3 Where existing coordinates of radio navigation facilities that meet the accuracy and quality requirements are converted to ITRF mathematically, then the conversion process shall be shown to be such that the required coordinate accuracies are maintained.

2.2.1.4 Survey accuracies shall be such that the accumulated errors of observations and computations are sufficiently small to support the positional accuracy requirements for facilities laid down in this document.

2.2.1.5 An analysis of the accumulated error shall be presented for each survey.

NOTE: *This includes, but is not limited to:*

- *The accumulated error being presented in its component parts, each showing the accuracy achieved and that the result is consistent with the survey technique used;*
- The accumulated error calculations being clearly reported and compared against the declared accuracy requirement.

NOTE: *The geographical coordinate accuracy of the various facilities has been set in accordance with both current and anticipated operational requirements.*

Recommendation: *All survey observations should be made and recorded to the resolution and accuracy of the equipment used, so that future requirements for surveys of greater precision might be met.*

Recommendation: *Organisations should follow best practice guidelines in Annex G to achieve the requirements.*

2.3 Units

2.3.1 All published positions and dimensions shall be in accordance with the requirements laid down by ICAO.

2.3.2 In this regard, positions shall be published in the form of sexagesimal degrees (Degrees Minutes Seconds and decimals of a Second) to the resolutions laid down by ICAO in Annexes to the Convention on International Civil Aviation.

2.3.3 Dimensions and distances shall be quoted in one of the following units;

a) Metres;

b) Feet (1 ft = 0.3048 m)[1] ;

c) Nautical Miles (1 NM = 1852 m)[2].

2.4 Aerodrome survey control network

2.4.1 General requirements

2.4.1.1 In order to determine the position of navigation facilities at, and in the vicinity of, designated aerodromes, a network of survey control stations shall be established at each such aerodrome.

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[1] ISO standards handbook 31, *Quantities and units*. ICAO Annex 5

[2] ISO standards handbook 31, *Quantities and units*. ICAO Annex 5

2.4.1.2 Where the primary means of collecting spatial data at an aerodrome uses traditional, optical techniques (including the use of total station theodolites), then the aerodrome control network shall consist of a minimum of two intervisible survey stations at a minimum lateral separation of 500 metres.

NOTE: *Annex G gives best practice guidelines for the establishment of control points at aerodromes using GPS or other space based positioning systems.*

Recommendation: *The aerodrome survey control network should consist of a minimum of four stations so as to provide sufficient redundancy to be able to sustain the loss of any one survey station and still enable orientation to be checked.*

Recommendation: *Survey stations should be strategically located so as to provide maximum utility in subsequent surveys*.

NOTE: *The monuments of existing aerodrome survey control networks may be used for the purposes laid down in this document.*

2.4.2 Control network accuracy requirements

2.4.2.1 The position of each survey station in the control network shall be determined to an accuracy of 0.1 metres (2 sigma or 95% confidence interval) in each axis (east-north-up or XYZ geocentric Cartesian) with respect to ITRF.

2.4.2.2 The aerodrome survey control network shall have an internal relative precision of better than 0.1m.

2.4.2.3 At least once every five years, the positions of the control stations in the aerodrome control network shall be checked by measuring vectors to national or international control stations.

2.4.2.4 If the new computed value of a control station's position has changed by 50 mm compared to the published value, then the station's position shall be re-measured and verified according to the standards laid down in this document.

2.4.3 Monumentation of survey control stations

2.4.3.1 Station construction

2.4.3.1.1 The survey stations shall consist of standard types of survey monument (See Annex C).

NOTE: Different types of monument will be appropriate for different locations and ground conditions on the aerodrome. It is for the Surveyor, under the guidance of the National Administration, to decide on the most appropriate type.

Recommendation: *Investigation should be made prior to the installation of survey stations to ensure that underground cables and services are not affected by the installation.*

Recommendation: *Where the survey network consists of fewer than the recommended four stations*, *station monumentation should be as durable and secure as is practicable.*

2.4.3.2 Station numbering

2.4.3.2.1 Each survey station shall carry an individual number.

NOTE: *This will ensure that, where a station has been destroyed and subsequently replaced by a new station in approximately the same location, mis-identification does not occur.*

Recommendation: *Station labelling and numbering should be such that there is no doubt as to the provenance or identity of the survey station.*

Recommendation: *Uniform labels (eg stamped disks) should be used at individual aerodromes for all survey stations.*

Recommendation: *An unambiguous numbering system, identifying the aerodrome, year number and station number should be used (See Annex C).*

Recommendation: *Where an existing, substantial topographic surface feature is used as a survey station, the station number should be clearly marked with durable paint.*

NOTE: *When an existing station is not used or if it is not possible to relabel then a high quality description should be prepared.*

2.4.3.3 Station location plan

2.4.3.3.1 An aerodrome survey network plan, at a scale of 1/2000, or other appropriate standard cartographic scale, indicating the location of all survey stations and principal topographic features, shall be prepared.

2.4.3.4 Station descriptions

2.4.3.4.1 Comprehensive aerodrome survey network station descriptions shall be prepared, consisting of a written description and a clear diagram indicating tie dimensions and direction indicators to other visible points on the aerodrome network, and so that they are orientated to True North, or alternatively, have the direction of True North indicated on the description.

Recommendation: *A photograph of the station showing background detail should be included in the description*.

Recommendation: *Regular inspections should be made to check on the general condition of the aerodrome survey network and any disturbance or damage recorded*.

2.4.4 Determination of control coordinates

2.4.4.1 One of the following methods of coordinate determination shall be used to fix the positions of the aerodrome survey control network.

2.4.4.2 **Method 1: Direct geodetic connection:** Survey measurements shall be taken to connect the aerodrome survey control network to the ITRF geodetic frame in such a way that the survey error in the connection does not contribute significantly to the coordinate error of the aerodrome network.

NOTE: *This is the preferred option, in that it consists of the most accurate method of observation and incorporates a directly observed connection to the approved geodetic reference frame.*

2.4.4.3 For each point in the aerodrome control network static relative positioning GPS vectors shall be measured to a minimum of two points on an appropriate geodetic network.

NOTE: *It is recommended that three or more points be used. Observation and post-processing guidelines for these operations are given in Annex G.*

2.4.4.4 **Method 2: Derived geodetic connection:** Where this method is adopted, a full description of the transformation method and the values of the transformation parameters shall be included in the report.

NOTE: *Where the local relationship between the existing geodetic control network and ITRF is known to an accuracy commensurate with the requirements laid down in this standard, nationally/regionally approved standard transformation methods may be used to determine the coordinates of an existing aerodrome survey control network.*

2.4.4.5 Full details of the connection of the existing aerodrome survey control network to the existing geodetic network shall be included in the survey report.

NOTE: *In this regard, an 'existing' network is taken to mean one which existed at the aerodrome prior to the implementation at that aerodrome of WGS-84.*

2.4.5 Determination of local relationship between the known existing datum and ITRF

2.4.5.1 Where existing relative surveys need to be related to ITRF (e.g. aerodrome obstacle surveys) observations shall be taken to determine the local relationship (difference in Latitude, Longitude, orientation and scale) between the known existing datum and ITRF, except where the required information is provided by a derived geodetic connection.

2.4.5.2 Where used, the local relationship between the known existing reference system and ITRF shall be determined to an accuracy commensurate with the relative accuracy of the data to be transformed.

2.4.5.3 The values and accuracies of the local relationship shall be declared in the survey report.

2.5 Survey requirements for aerodrome facilities[3]

2.5.1 Runway centrelines and thresholds

2.5.1.1 For surveying purposes, the centreline reference point of a runway shall be the centre-line of the defined landing area on the load-bearing surface.

2.5.1.2 Where the edge of the runway is irregular, or connected to a taxiway, an appropriate theoretical line shall be selected, which best identifies the probable edge of the runway.

2.5.1.3 Where the thresholds are marked by appropriate threshold markers, then these should be taken as the threshold point.

2.5.1.4 Where no threshold marker exists, the threshold shall be determined by the National Administration and marked according to ICAO Annex 14.

2.5.1.5 Where no threshold marker exists, and there is no other indication of the threshold position, then the centreline of the threshold lights immediately in advance (in the

[3] Aerodrome facilities equate to those in Area 3 and Area 4. (See Annex A)

direction of landing) of the threshold paint markings (piano keys) shall be taken as the threshold.

2.5.1.6 Where there is no threshold marker, or threshold lighting, then the Surveyor shall select an appropriate point for survey in accordance with Annex D.

2.5.1.7 Survey witness marks shall be installed to enable the threshold survey point to be re-established in the event of re-surfacing, re-painting or verification.

2.5.1.8 In addition, two associated runway centreline points, at a separation of not less than 10% of the runway length, shall be surveyed to aid co-linearity testing.

2.5.1.9 The Surveyor shall, in processing the survey data, determine and report on the co-linearity of the three points.

2.5.1.10 The distance from the point surveyed as the threshold to the end of the paved surface at the near end of the runway shall be determined to an accuracy of 0.1m.

Recommendation: *Where a runway has a threshold at each end, the two thresholds and two further runway centreline points should be surveyed. The co-linearity should then be determined for the group of four points.*

2.5.2 Derived threshold coordinates

2.5.2.1 Where a point has been selected for survey, which is not coincident with the runway threshold, but offset along the centreline, then the coordinates of the threshold shall be determined by the National Administration. A method of calculation for this task is shown in Annex H.

2.5.2.2 The newly derived threshold coordinates shall be submitted to the same co-linearity check as specified in Paragraph 2.5.1.9 and following.

2.5.3 Aircraft stands

2.5.3.1 The front, nose-in point of the stand, where the taxiway centreline intersects the limit of the stand, shall be surveyed.

2.5.3.2 Numerous different stand paint markings exist and a diagram shall be prepared by the Surveyor showing the arrangement of markings in use together with an indication of the point surveyed.

NOTE: *Where all the stands at the aerodrome are marked uniformly then only a single diagram need be prepared.*

2.5.4 All other aerodrome radio navigation facilities

2.5.4.1 For all other aerodrome radio navigation facilities which require survey, the centre of the transmitting antenna shall be surveyed, except where a different specific survey point is standardised for the facility as indicated in Annex D.

2.5.4.2 If the organisation is in doubt about the facilities described in Annex D, the National administration shall be responsible for clarification.

2.6 Surveying requirements for off-aerodrome radio navigation facilities[4]

2.6.1 General requirements

2.6.1.1 The coordinates of off-aerodrome radio navigation facilities shall meet the data requirements laid down in Table A-3.

2.6.1.2 Where the quality of existing coordinates cannot be determined they shall be re-determined to the accuracy laid down in Table A-3.

Recommendation: *In all cases, surveyed coordinates should be published in preference to coordinates determined by graphical methods.*

2.6.2 Description of off-aerodrome radio navigation facilities

2.6.2.1 For off-aerodrome radio navigation facilities not described in Annex D, the horizontal coordinates of the geometric centre of the facility antenna shall be surveyed.

2.6.2.2 If the organisation is in doubt about the facilities described in Annex D, the National administration shall be responsible for clarification.

2.6.2.3 Where coaxial co-located VOR/DME are surveyed, the position of the DME element shall be taken as the position.

NOTE: *For non-coaxial co-located VOR/DME with a separation between antennas greater than 30 metres, it will be necessary to survey both antennas.*

2.6.2.4 Where it is not possible to connect directly to ITRF, the method of local connection shall be described.

2.7 Use of software

2.7.1 Where software is used for any of the survey processing, it shall be demonstrated that it functions correctly. See EUROCONTROL specification (number to be provided).

2.7.2 Where survey techniques are being used that lend themselves to an independent check using manual computation, then this shall be the preferred method to verify correct use of software

2.7.3 In place of a manual computation check, the verification may be carried out by occupying an existing known point at the aerodrome and comparing the calculated coordinates with the published values.

NOTE: *The check point will preferably be one of the aerodrome control network stations.*

2.7.4 The difference between the calculated and published values shall be shown to be within the 95% confidence interval for the measurement technique being used.

[4] Off aerodrome facilities equate to those in Areas 1 and 2. (See Annex A)

2.8 Survey report requirements

2.8.1 Where no national reporting practice exists, all survey work undertaken to determine the coordinates of en-route/off-aerodrome navigation facilities should be reported in the format laid out in Annex E.

2.8.2 Where existing national reporting practice differs from that shown in Annex E, the National Administration should employ standards that meet or exceed the requirements of this standard.

2.8.3 The geodetic connection shall be fully described in detail where monumented survey control stations are not installed as part of an off-aerodrome radio navigation facility survey.

2.9 Quality assurance

2.9.1 General

2.9.1.1 **NOTE:** In addition to the general requirements for Data Management and Quality Assurance specified in EUROCONTROL Specification (number to be provided) the following specific requirements also apply to the survey of data.

2.9.2 Calibration of survey equipment

2.9.2.1 All survey equipment deployed in relation to surveys covered by this standard shall be shown to be calibrated and to perform to an accuracy appropriate to the task.

2.9.2.2 Equipment calibration shall be shown to be valid for the time of use.

2.9.2.3 Details of the calibration process and results shall be included in the survey report.

2.9.3 Quality records

2.9.3.1 All coordinates shall be traceable to their source of production by an unbroken audit trail, as required by Annex 15.

2.9.3.2 Information on the source of production shall include:

a) Name of Surveyor;

b) Surveying organisation;

c) Date of survey;

d) Method of survey;

e) Equipment used

f) Method of marking employed

g) Description of surveyed point (textual supported by explanatory photographs sufficient to ensure correct identification of the point surveyed)).

2.9.3.3 Records shall be maintained for a period of ten years for all designated coordinates which are published in each national AIP.

2.10 Maintenance of data

2.10.1 Each Requesting Authority and Origination Authority shall be responsible for maintaining surveyed, calculated and derived data at all times in accordance with the requirements of this document.

2.10.2 This shall apply throughout the lifetime of each data item, commencing from the time of first survey, calculation or derivation.

2.10.3 Maintaining coordinate data shall include a periodic review of the difference between the latest ITRS epoch and the reference frame used in the original survey or that used in the most recent recalculation of the coordinates. Where the sum of the position errors resulting from these differences together with original survey precision, exceeds the declared accuracy requirements for that coordinate, the data shall be recomputed to the latest ITRF epoch.[5]

2.10.4 A check of valid navigation related facilities shall be performed every year, paying particular attention to the presence of new obstacles.

2.10.5 Each surveyed data item shall be re-calculated no less than once every five years in order to take account of long term changes in geodetic relationships (see Annex B). The control should be checked by re-measurement every five years, and if there was a significant change then the navaid positions and obstacle coordinate data could be re computed using a datum transformation. This relies upon the aerodrome maintaining a control network.

2.10.6 Each State shall derive its own requirements for the frequency at which surveyed data items are re-calculated (based upon its own local geodetic relationships) and therefore determine (where appropriate) more stringent requirements than those specified in paragraph 2.10.5.

2.10.7 Each State shall determine its own requirements for the frequency at which data items are completely re-surveyed.

[5] Note that ETRF89 is gradually drifting away from ITRF and already differs by approximately 1m. Additionally, the new space based navigation developments including Galileo, the revitalised GLONASS, improved GPS, WAAS and EGNOS, will all be implemented with ITRF as their reference frame. Further details are provided in Annex B and specifically in B.8.3.

3 Calculated and derived data

3.1 Reference system specification

3.1.1 The reference system for all co-ordinate data shall be WGS-84.

3.1.2 In accordance with ICAO all calculated and derived vertical references shall be expressed in MSL, AGL or Flight Level.

3.2 Units

3.2.1 All positions, bearings, magnetic variations, heights/altitudes and distances shall be published in accordance with the resolution and integrity requirements laid down in Appendix 7 to ICAO Annex 15 and Appendix 6 to ICAO Annex 4.

3.2.2 Units of measurement shall be in accordance with ICAO Annex 5.

3.3 Source data

3.3.1 Co-ordinate data shall either be:

a. Calculated using geodesic algorithms and source data that has been defined in WGS-84. For example:

- A bearing and distance from a point.
- The intersection of bearings from two points.
- The intersection of distances from three points.

b. Derived from source data that has been defined in WGS-84. For example:

- Manually selected points along a line of longitude or latitude

3.3.2 Bearing data shall be calculated using geodesic algorithms and source data that has been defined in WGS-84.

3.3.3 Magnetic variation should be determined by survey.

3.3.4 Station declination shall be provided by the service provider responsible for the navaid. The date of measurement and the annual rate of change of magnetic variation should be included.

NOTE: *The Station Declination is the difference between True North and the VOR North Alignment and should not exceed 1.5° of the current Magnetic Variation unless the VOR has been aligned to True North.*

3.3.5 Height/altitude data shall be:

a. Determined by geodetic survey or,

b. Determined by analysis of a suitable digital terrain model or,

c. Calculated by adding specified values (e.g. Minimum Obstacle Clearance) to data determined in a) to b) above or,

d. Specified by airspace designers, taking account of minimum altitudes/flight levels determined in a) to c) above.

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3.4 Data management

3.4.1 The data management requirements specified in Eurocontrol specification (number to be added) shall apply to the origination and management of calculated and derived data.

3.5 Quality assurance

3.5.1 The quality assurance requirements specified in Eurocontrol specification number to be added) shall apply to the origination, management and distribution of calculated and derived data. Further guidance on quality assurance for instrument flight procedure design is provided in ICAO PANS Aircraft Operations Vol II (Doc 8168) and the ICAO Quality Manual for Instrument Flight Procedure Design (to be issued).

3.6 Airspace design

3.6.1 Airspace designers shall follow the criteria laid down in ICAO SARPS Annex 11 and Doc 4444 PANS Air Traffic Management. Where States choose to apply national criteria, they shall ensure that the modifications do not result in any increase in risk to the intended operation and shall file with ICAO a difference in relation to Annex 11. The justification and the modified criteria shall be clearly documented.

3.6.2 Terminal airspace designers shall also take account of Terminal Airspace Design Guidelines provided in EUROCONTROL Airspace Planning Manual, Section 5.

3.7 Instrument flight procedure design

3.7.1 General

3.7.1.1 Instrument flight procedures shall be designed in accordance with the criteria which are laid down in ICAO Doc 8168 PANS Aircraft Operations Vol II and further detailed in ICAO Doc 9368 Instrument Flight Procedures Construction Manual. Where States choose to apply national criteria, they shall ensure that the modifications do not result in any increase in risk to the intended operation. The justification and the modified criteria shall be recorded. The EUROCONTROL Guidance Material 'Design of Terminal Procedures EUROCONTROL NAV.ET1.ST10 for Area Navigation' should also be considered.

3.7.2 Software tool qualification

3.7.2.1 Software tools used to support instrument flight procedure design shall be subject to qualification .

NOTE: G*uidance on qualifying Instrument Flight Procedure Design Tools is provided in the ICAO Manual for Flight Procedure Design Tool Validation (to be issued).*

3.7.3 Training and qualification of designers

3.7.3.1 Instrument flight procedure designers shall be suitably qualified and shall have successfully completed recognised training courses. Specialist courses related to Area Navigation (RNAV) and Required Navigation Performance (RNP) operations shall be completed prior to commencing the design of any RNAV or RNP instrument flight procedures.

NOTE: *Further guidance on training Instrument Flight Procedure Designers is provided in the ICAO Manual for Flight Procedure Designer Training (to be issued).*

3.7.4 Verification of procedure designs

Recommendation: *All instrument flight procedures should be independently verified by a qualified instrument procedure designer prior to publication. The verification process should check that the criteria have been applied, the available guidance has been followed and the proposed procedure meets the requirements for the intended operation. The results of each verification should be recorded together with the conclusions.*

NOTE: *Further guidance on instrument flight procedure design verification is provided in the ICAO Quality Manual for Instrument Flight Procedure Design (to be issued).*

3.7.5 Area Navigation

3.7.5.1 Instrument flight procedure designers should take account of the guidance provided in EUROCONTROL NAV.ET1.ST10, Guidance Material for the Design of Terminal Procedures for Area Navigation, when constructing instrument flight procedures for RNAV applications. Divergence from this guidance should be supported by a comprehensive analysis with supporting flight trials data and the analysis, results and conclusions recorded.

Recommendation: *In addition to the standard verification process, all RNAV procedures should be validated and checked for flyability. Guidelines on validation and flyability checks are provided in the ICAO Doc 8071, Manual on Testing of Radio Navigation Aids, and the ICAO Quality Manual for Instrument Flight Procedure Design (to be issued), as well as the EUROCONTROL Guidance Material 'The Validation of RNAV Procedures' and 'The Flight Inspection of RNAV Procedures'.*

3.7.6 Publication

3.7.6.1 Instrument flight procedures shall be published in a standardised format in the State AIP in accordance with ICAO SARPs Annexes 4 and 15. RNAV procedures shall be described in a clear and unambiguous fashion as detailed in ICAO Doc 8168 PANS Aircraft Operations Vol II. Further information is provided in the EUROCONTROL Guidance Material. Prior to publication, the RNAV procedure description shall be validated to ensure that the dataset is complete, coherent and correct. A final check of the published data shall be made when the AIP/chart amendment is issued in order to ensure that no errors have been introduced during the data transfer process.

3.7.6.2 Final Approach Segment (FAS) data blocks shall be wrapped by the Instrument Flight Procedure Designer using an approved CRC-generation algorithm and suitably qualified software.

NOTE: *FAS Data Block publication requirements are detailed in ICAO Doc 8168 PANS Aircraft Operations Vol II.*

3.7.7 Flight Inspection and Validation

NOTE: *Validation is the necessary final quality assurance step in the procedure design process, prior to publication. Flight inspection may be necessary to* *validate the navaid coverage and performance assumptions made during the design process. Flight validation provides a means, but not the only means, of procedure validation*

Recommendation: *The flight inspection should address the following areas:*

a. *The coverage and quality of service provided by the DME/DME navaid infrastructure over the whole procedure, if appropriate.*

b. *The identification of any electromagnetic interference or other distortions, e.g. multipath, that has a deleterious effect on the received navaid signals.*

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NOTE: *The flight validation may be used to check:*

a. *The obstacle environment against which the design has been designed.*

b. *The flyability of the procedure: The applicability of this check is restricted to the aircraft type used for the flight check and the prevailing weather conditions at the time of the flight check. It is therefore of limited value in determining the flyability of the procedure for the range of aircraft and a range of meterological conditions.*

c. *The correctness of the waypoint data and the supporting fix, track and distance data. This does not constitute a check of the operational database as flight validations are generally carried out prior to the effective date of the procedure.*

d. *The charting, required infrastructure, visibility and other operational factors.*

e. *The airport infrastructure including runway classification, lighting, communications, runway markings, and availability of local altimeter setting.*

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NOTE: *Minor modifications to existing instrument flight procedures do not usually require additional flight checks.*

NOTE: *Further guidance on the flight inspection of instrument flight procedures is provided in the ICAO Doc 8071, Manual on Testing of Radio Navigation Aids and in the EUROCONTROL Guidance Material 'The Flight Inspection of RNAV Procedures'.*

A Survey Data requirements (Normative)

A.1 Introduction

A.1.1 The minimum accuracy for surveyed aeronautical data items is specified in ICAO Annex 11 and Annex 14. The requirements and specification for the publication of this data is specified in ICAO Annex 15 and Annex 4. ICAO requirements on the minimum accuracy of data items differ between these Annexes.

A.1.2 The requirements for surveyed data presented in this annex apply the most stringent ICAO requirements from those given in ICAO Annexes 4, 11, 14 and 15.

A.1.3 This document requires that surveyed accuracy shall always be greater than or equal to the maximum published data accuracy.

A.1.4 The survey data requirements are divided into three categories: terrain, obstacle and navigation related facilities.

NOTE: *It might be stated that there is a 95% probability that a particular coordinate value is within 10cm of the truth. It is usually assessed through precision, which is a measure of the internal consistency of data. Precision and accuracy will be identical when coordinates are free of the effects of any biases and outliers in the data. In GPS, coordinate accuracy is mainly a function of the fidelity of the processing model and the satellite geometry, and it is usually expressed as standard deviations of individual coordinate values.*

NOTE: *Reliability is related to integrity and often subdivided into two categories. Internal reliability is a measure of the probability of outliers or biases of a specified size remaining undetected, and external reliability is a measure of the impact of any such biases or outliers on the coordinates. In GPS positioning, reliability is largely a function of redundancy – the more the amount of redundant data then the greater the reliability. Most GPS post processing packages nowadays output formal measures of reliability, such as marginally detectable errors and biases.*

A.2 Terrain data requirements

A.2.1 Data originators shall ensure that all terrain data is surveyed to the accuracy requirements presented in Table A-1, as referenced in Section 2.

Areas/Attributes	**Area 1**	**Area 2**	**Area 3**	**Area 4**
Horizontal Accuracy	50.0 m	5.0 m	0.5 m	2.5 m
Vertical Accuracy	30.0 m	3.0 m	0.5 m	1.0 m
Vertical Resolution	1.0 m	0.1 m	0.01 m	0. 1 m
Confidence Level	90%	90%	90%	90%
Terrain Database Post Spacing	3 arc second (approx. 90m)	1.0 arc second (approx. 30 m)	0.6 arc second (approx. 20 m)	0.3 arc second (approx. 9 m)

Table A-1: Summary of Terrain Data Requirements

Note: Areas 1,2,3,4 are as defined in Annex 15

A.2.2 Within a radius of 10 km, terrain shall be recorded with the Area 2 numerical requirements provided in Table A-1, excluding sub areas where flight operations are restricted due to high terrain or “no fly” conditions, which are included in Area 1.

A.2.3 Terrain located between 10 and 45 km from the Aerodrome Reference Point (ARP) that penetrates the horizontal plane 120 metres above the lowest runway elevation shall be collected and recorded in accordance with the Area 2 numerical requirements.

A.2.4 Terrain located between 10 km and 45 km from the ARP that does not penetrate the horizontal plane 120 metres above the lowest runway elevation shall be collected and recorded in accordance with the Area 1 numerical requirements.

A.3 Obstacle data requirements

A.3.1 Significant obstacles shall be surveyed to the data accuracy requirements presented in Table A-2, as referenced in Section 2.

A.3.2 Significant obstacles within Area 1 may be defined as En-route obstacles. Significant obstacles within Area 2 and the Aerodrome TMA include obstacles within circling area, approach and take-off areas as well as the aerodrome itself.

Areas/Attributes	**Area 1**	**Area 2**	**Area 3**
Horizontal Accuracy	50.0 m [Annex 15]	5.0 m [Annex 15]	0.5 m [Annex 15]
Vertical Accuracy	30.0 m [Annex 15]	3.0 m [Annex 15]	0.5 m [Annex 15]
Vertical Resolution	1.0 m [Annex 15]	0.1 m [Annex 15]	0.01 m [Annex 15]
Confidence Level	90%	90%	90%

Table A-2: Summary of Obstacle Data Requirements

NOTE: *No obstacles should be located within Area 4.*

A.4 Navigation facility data requirements

A.4.1 Table A-3 presents the minimum requirements for aeronautical navigation facility data, as referenced in Section 2.

Areas/Attributes	**Area 1 + 2**	**Area 3 & Area 4**
Horizontal Accuracy	30 m [Annex 4]	0.5 m [Annex 14]
Horizontal Resolution	1 m	0.1 m
Vertical Accuracy	30 m [Annex 4, 11, 15]	0.25 m [Annex 14]
Vertical Resolution	1 m	0.1 m
Magnetic variation	1 degree [Annex 11]	1 degree [Annex 14]
Declination	1 degree	0.1 degree
Confidence Level	95%	95%

Table A-3: Summary of Navigation Facility Data Quality Requirements

A.4.2 Further guidance on satisfying the heighting requirements presented in Table A-1, Table A-2 and Table A-3 is provided within Annex I.

A.4.3 Table A-4 presents the navigation related facilities to be surveyed.

Point	Horiz. (m)	Vert. (m)	Mag. (⁰)	Dec. (⁰)
Landing Threshold to Runway Centreline	✓			
Landing Threshold to Taxiway Centreline	✓			
Precision Approach Rwy LTP and FRAP	✓	✓		
CAT I/II/III Rwy End and Landing Threshold	✓	✓		
LTP Ellipsoid Height		✓		
Non-precision Rwy End and Landing Threshold	✓	✓		
Runway Threshold	✓			
Runway End (flight path alignment point)	✓			
Runway centre line points	✓	✓		
Taxiway centre line points	✓			
FATO	✓	✓		
TLOF	✓	✓		
LAHSO location	✓			
Arrest gear location	✓			
Runway shoulder	✓			
Stopway	✓			
Clearway	✓			
Taxiway segment	✓			
Taxiway shoulder	✓			
Taxiway guidence line	✓			
Taxiway intersection marking	✓			
Taxiway holding position	✓			
Exit line	✓			
Apron	✓			
Stand guidence line	✓			
Parking stand location	✓			
Deicing area	✓			
Construction area	✓			
VHF Navaid – Terminal	✓	✓		✓
NDB Navaid – Terminal	✓	✓	✓	
VHF Navaid – En-route	✓	✓		✓
NDB Navaid – En-route	✓	✓	✓	
TACAN	✓	✓		
DME	✓	✓		

Point	Horiz. (m)	Vert. (m)	Mag. (⁰)	Dec. (⁰)
ILS Localizer (Azimuth) Antenna	✓	✓	✓	
ILS Glide Slope Antenna	✓	✓		
MLS Localizer (Azimuth) Antenna	✓	✓	✓	
MLS Glide Slope Antenna	✓	✓		
ILS or MLS DME	✓	✓		
MLS DME/P	✓	✓		
GBAS (LAAS) Reference Point	✓	✓		
Aerodrome Surface Movement Points	✓			
Aircraft stand-points/INS check-points	✓			
Significant obstacles in the approach and take-off area	✓	✓		
Obstacles in the circling area and at the aerodrome/heliport	✓	✓		
Obstacles en-route	✓	✓		
Navigation Check points	✓			
Aerodrome	✓	✓		✓
Survey control point	✓	✓		

Table A-4: Navigation related facilities

B WGS-84, ITRF and ETRF89 (Normative)

B.1 Geodetic relationships

B.1.1 The following definitions elaborate upon those quoted in Section 2. The geodetic descriptions given here are sufficient for aviation purposes. They are not intended as definitive geodetic statements.

B.2 World Geodetic System of 1984 (WGS-84)

B.2.1 WGS-84 is defined by the United States Department of Defence. Details of the datum can be found in the following publications:

- DMA TR 8350.2-A;
- DMA Technical Report Supplement to Department of Defence World Geodetic System 1984 Technical Report.
- WGS-84 is accurate globally to 1-2 metres.

B.3 Geometric constants of the WGS-84 ellipsoid

Semi-major axis	a = 6378137.000 m
Semi-minor axis	b = 6356752.314 m
First eccentricity	e = 0.0818191908426
(First eccentricity)^2	e^2= 0.00669437999013
Flattening	f = 1/298.257223563

Table B-1: Geometric Constants

B.4 The International Terrestrial Reference System (ITRS)

B.4.1 Precise geodetic measuring techniques for long base-lines use for example Satellite Laser Ranging (SLR) and Very Long Base-Line Interferometry (VLBI) as well as differential GPS measurement. Techniques available guarantee a precision of 1-3 cm over distances up to about 5000 km. Global networks of such stations are observing continuously. Since 1987 a new International Earth Rotation Service (IERS) is operating making use of these observations and producing every year a new global set of x, y, z-coordinates.

This work has led to a precise worldwide terrestrial coordinate system, called the International Terrestrial Reference System (ITRS). The ITRS is maintained by the IERS and the realization of the ITRS is the International Terrestrial Reference Frame (ITRF) – see below.

Plate tectonic movement was incorporated in that coordinate system using results of recent measurements and a global geophysical model. Thus, it is a model with changing coordinates due to movements of tectonic plates on which the ground stations are located. However, this reference system provides the fundamental position of the Earth to within 10 cm and the orientation of the axes to correspondingly high accuracies. Since 1988, the IERS has defined the mean spin axis, the IERS Reference Pole (IRP) and the zero meridian and the IERS Reference Meridian (IRM).

Whilst WGS 84 is fixed, the maintenance of a datum at the higher level of accuracy of the ITRS requires constant monitoring of the rotation of the Earth, the motion of the pole and the movement of the plates of the crust of the Earth, on which the ground stations are located.

B.5 International Terrestrial Reference Frame (ITRF):

B.5.1 An accurate geodetic reference frame that consists of a globally distributed network of survey stations whose positions and velocities are determined by several independent measurement technologies. Positions and velocities are published periodically by the IERS, and each published set is identified by the epoch of the station positions. Thus, the published position of a point in ITRF97 is valid at the epoch 1st January 1997, whereas the position of the point at some future time must take into account the effect of the point's velocity. The ITRF uses the same system parameters as WGS-84. For example it has an associated ellipsoid, known as GRS 80, which has effectively the same parameters as that of WGS-84.

B.5.2 The ITRF identifies changes, inter alia, resulting from earth tectonic plate movements, it is important that a survey record includes the epoch number for the ITRF used.

B.6 European Terrestrial Reference Frame 1989 (ETRF 89):

B.6.1 ETRF was established as a subset of the International Terrestrial Reference Frame (ITRF) at a 1989 epoch. It is a precise geodetic reference frame established by a limited number of survey stations throughout Europe whose relative positions are known to an accuracy in the order of 2-3 cm. ETRF forms the basis for geodetic survey in Europe. The absolute differences between ETRF 89 and WGS-84 are, within Europe, of the order of 1 m. ETRF 89 provides a convenient means by which WGS-84 can be accessed in Europe and since WGS 84 is only accurate to 1-2 metre, the two can be regarded as identical.

B.6.2 Position in ETRF 89 can be computed by either measuring position vectors directly from ETRF 89 stations or by computing position in one of the ITRS realisations and then applying a standard transformation.[6]

B.7 European Reference System (EUREF):

B.7.1 The European Reference System (EUREF) is the name given to official geodetic networks established by various national and regional survey campaigns, which were undertaken to densify the ETRF 89 network. These may carry various year numbers (such as EUREF 91) and be related to only one particular region. They may carry the name of the national network. In each case, however, they derive their controlling coordinates from ETRF 89 and, for the purposes of this standard are considered to be compatible with ETRF 89 and, consequently, a realisation of WGS-84.

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[6] http://www.epncb.oma.be/coordina.html correct on 20/12/02

B.7.2 Further details may be obtained by correspondence with national geodetic organisations or through the Comité Européen des Responsables de la Cartographic Officielle (CERCO) via national geodetic organisations.

B.8 Using the International Reference Frame (ITRF)

B.8.1 Migrating from existing ETRF coordinates to ITRF

B.8.1.1 Eurocontrol Standard 007 (ES007) required positions to be in ETRF89. It is proposed to transform all existing position data to the current ITRS realisation and to relate all future works to the appropriate ITRF. The following notes explain how this can be accomplished and explain the rationale behind the proposal.

B.8.1.2 Because the relationship between the two frames is well established the migration to ITRF can be managed relatively easily, and can be achieved with sufficient accuracy, on the basis of a transformation alone. The transformation parameters relating ETRF89 to the current ITRS realisation are published on an annual basis. An existing set of ETRF89 coordinates can be transformed to the appropriate ITRS realisation simply by applying the requisite parameters (see B.6.2). For this to be achieved whilst, ensuring appropriate data accuracy and integrity, it is important that it is possible to confirm:

- the original survey was undertaken in accordance with ES007
- that the point surveyed has been recorded in accordance with ES007 and can be identified
- that the data has been maintained by a means that ensures that it could not have been changed (original records retained, Data secured under CRC etc).
- that the transformation and subsequent data management can be undertaken by a process that meets Eurocontrol specification (number to be added)

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B.8.2 Determining position in the ITRF

B.8.2.1 There are two main options for fixing survey stations in Europe to the current ITRS realisation:

1) Using data from CORS sites with ITRF coordinates and velocities, as well as IERS and IGS data products, in conjunction with GPS data acquired at the required point by the user. This option enables direct connection to the ITRF in a relatively simple and established way. Note that some care must be taken in ensuring that the connection to the reference frame is robust in terms of redundancy.

2) An alternative approach within Europe is to first establish the coordinates of the control station by fixing to ETRF89 using EUREF (or other suitable stations derived from the EUREF network) stations. These coordinates can then be transformed to ITRF using the appropriate transformation parameters (see B.6.2)[7].

[7] This method might be attractive to a number of States since the availability of a relatively dense network of Stations as a result of the EUREF campaign simplifies the logistics involved in establishing the position of the control station

B.8.3 Outline of differences between ETRF and ITRF

B.8.3.1 Both ETRF and ITRF use the same system parameters: ellipsoid, density, rotation rate etcetera. On the 1st of January, 1989 they were completely consistent, as the ETRF was defined as a sub-set of the ITRF at that epoch. The principal difference between the two frames is, however, fundamental:

B.8.3.2 Assuming they are correct, the co-ordinates of a point in ETRF remain constant for all time, provided that no local disturbance causes the point to move. Hence, the definition of a position in ETRF requires only the coordinate values (and their associated uncertainties, depending on the position fixing technique applied). ETRF can be thought of as a rigid network of points, which, whilst it is clearly driven by plate tectonics and thus moves as a block, is nevertheless internally consistent. On the other hand, the complete specification of a point in the ITRF requires both position and velocity (as well as the associated uncertainties).

B.8.4 Rationale behind the change of ETRF to ITRF

B.8.4.1 Whilst the usage of ETRF89 is conceptually simple and relatively easy to manage, it introduces one fundamental problem. The ETRF89 network is gradually drifting away from the ITRF at a rate of a few millimetres per year, and the ITRF is the accepted realisation of WGS-84. In the long run the difference between ETRF and ITRF (and hence WGS 84) coordinates for the same point will become too great to meet the Annex 15 requirements. Whilst the concept of position in the ITRF includes velocity it will not be necessary to treat aerodrome control networks and the positions of points measured from this control as moving continually. Instead, it will only be necessary to carry out the initial measurements and then monitor the position of the control network over time, checks being carried out on an annual basis. Once the position of the control has changed by a threshold value the network can be re-measured and the majority of the associated detail positions can be computed by using a transformation. The key gain of this approach is that the published coordinate values will be valid in both a global and a regional sense.

B.8.4.2 The move towards ITRF is emphasised by the new GPS control segment (as is being developed by the Aerospace Corporation) which will utilise elements of the IGS tracking station network. All broadcast ephemeredes will be expressed in ITRF and Galileo broadcast orbits will be in ITRF.

B.8.4.3 Obtaining and monitoring positions of navigation aids in ITRF as a surveying task is becoming progressively more and more straightforward and within the technical capability of surveying firms. Low Earth Orbiter spacecraft studies have demonstrated near real-time positioning in space at the level of 5 cm radially. Additionally, satellite orbit prediction and determination has steadily improved along with better receiver hardware, and improved reference frames. Real-time positioning in ITRF at the level of a few centimetres is going to be a reality.

B.8.4.4 As a result of the dynamic nature of ITRS, the difference between the latest ITRS epoch and that originally used for the survey will need to be reviewed regularly when maintaining coordinate data. Where this difference, together with the original survey precision, is such as to prevent meeting the declared accuracy requirements for that coordinate being met, the coordinate will need to be recomputed the to the latest ITRF epoch.

B.9 Free data services

B.9.1 Several sources of free GPS and reference frame data are accessible via the Internet. These can be used to gain access to the ITRF and ETRF in a relatively straightforward manner:

- IGS products (precise orbits, satellite clock models): NASA web site;[8]
- UK GPS RINEX data and ETRF control station coordinates: National GPS Network site;[9]
- Ordnance Survey Ireland GPS RINEX data: Ordnance Survey website;[10]
- EUREF GPS RINEX data: EURF website;[11]
- ETRS to ITRS transformations: EURF website;[12]
- IERS (International Earth Rotation Service) products: IERS website;[13]
- CDDIS (Crustal Dynamics Data Information Service):CDDIS (NASA) website.[14]

B.10 Other useful websites

B.10.1 Resources for information on networks and techniques:

- EUREF Permanent network site;[15]
- GPS time and date converter (useful as part of the on-line data acquisition service), available on the SOPAC website;[16]
- US coastguard Navigation Centre (general information on GPS status and development).[17]

[8] http://igscb.jpl.nasa.gov correct on 25/05/06

[9] http://www.ordnancesurvey.co.uk/oswebsite/gps/ correct on 25/05/06

[10] http://www.osi.ie/gps/index.asp correct on 25/05/06

[11] http://www.epncb.oma.be/_dataproducts/datacentres/index.php correct on 02/08/06

[12] http://www.epncb.oma.be/_trackingnetwork/coordinates/stationcoordinates.php correct on 02/08/06

[13] http://www.iers.org correct on 25/05/06

[14] http://cddisa.gsfc.nasa.gov/cddis.html correct on 25/05/06

[15] http://www.epncb.oma.be correct on 25/05/06

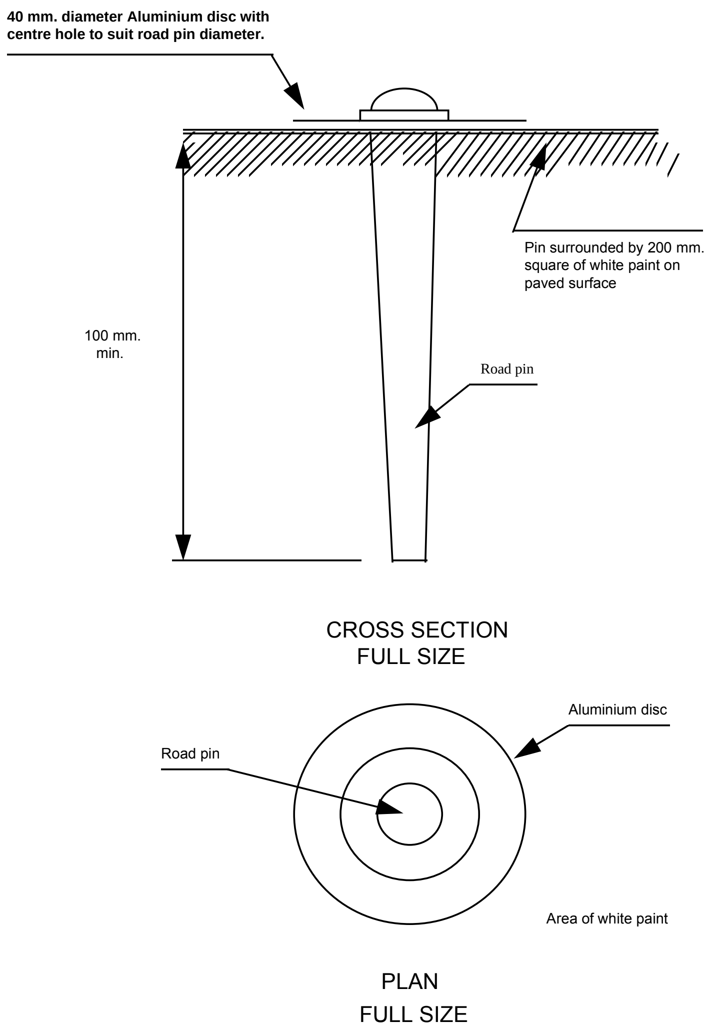
[16] http://sopac.ucsd.edu/scripts/convertDate.cgi correct on 25/05/06

[17] http://www.navcen.uscg.gov/gps/default.htm correct on 25/05/06

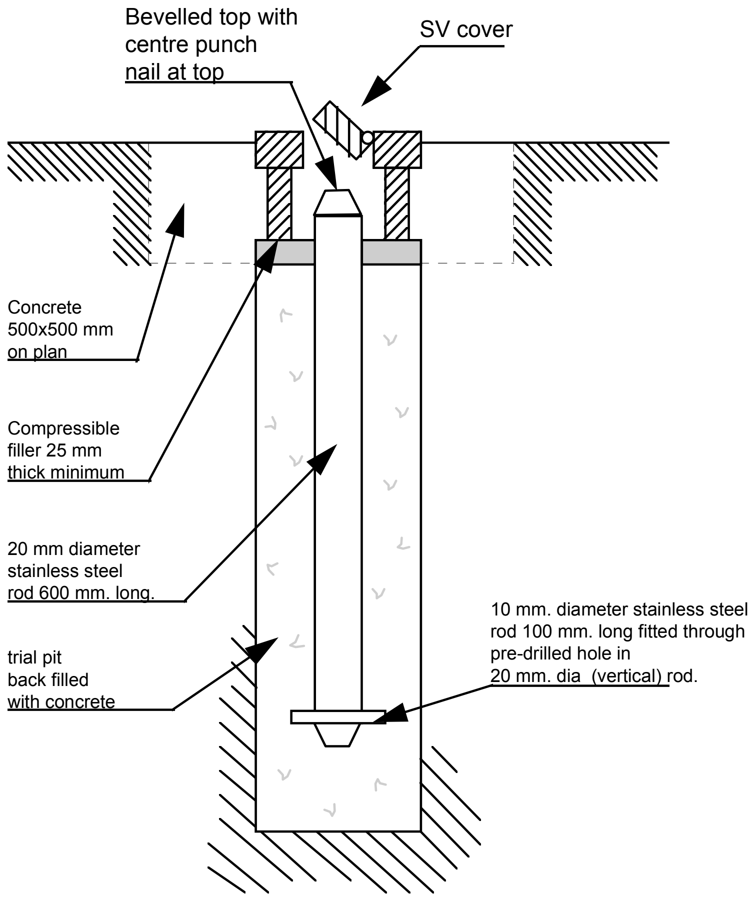
C Monumentation (Informative)

C.1 Where survey markers are installed they shall be of a type appropriate for the task and for the surface and ground type in which they are installed. Designs of suggested survey markers are shown in this section, but other types of marker may be equally appropriate.

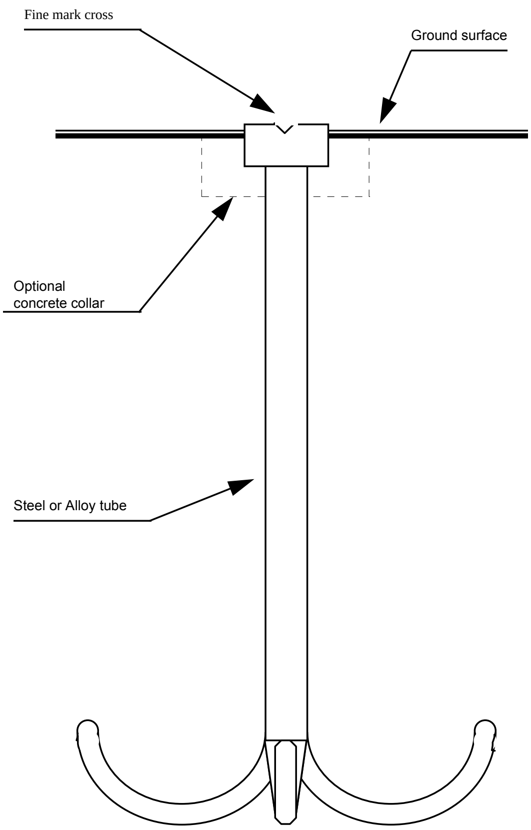
C.2 Survey monumentation Type 1



C.3 Survey monumentation Type 2



C.4 Survey monumentation Type 3



Length to be agreed according to ground conditions.
The illustration is diagrammatic only and is not intended
to refer to any particular proprietary type.

C.5 Example numbering system for survey markers

Recommendation: *Each survey control point which forms part of the aerodrome survey control network should be marked in the field with a unique identification number.*

Recommendation: *The system of numbering should include the aerodrome identifier, the station identifier and the year of establishment.*

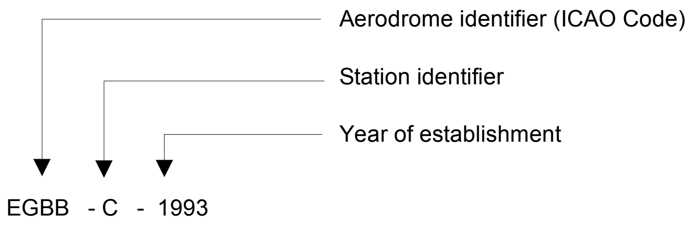
NOTE: *Although the aerodrome identifier will be the same for each station at that aerodrome, and therefore serve no local purpose, its inclusion is important for identification purposes in digital databases.*

Recommendation: *Station identifiers, be they alphabetic or numeric, should be assigned chronologically with the construction of the station.*

NOTE: *The inclusion of the year number allows the time of establishment to be referenced and mitigates against confusion where replacement stations have been established. Alternatively, a simple consecutive numbering system can be used.*

Recommendation: *Whilst numbering systems will vary from State to State, it is important that each system should include a means whereby the stations are not confused with other surveys, which may be conducted at the aerodrome.*

NOTE: *A simple consecutive numbering system alone, without other identifiers, would not be suitable.*



D Description of facilities (Normative)

D.1 General

D.1.1 This annex sets out to standardise the determination of threshold points and navaids for survey purposes. For guidance on survey points for runway and taxiway intersections and holding points see ICAO Doc 9674 (WGS-84 Manual).

D.1.2 Where the location of the actual threshold is not known and imbedded threshold lights do not exist, then the most appropriate 'Type a' diagram shall be selected to indicate the point surveyed.

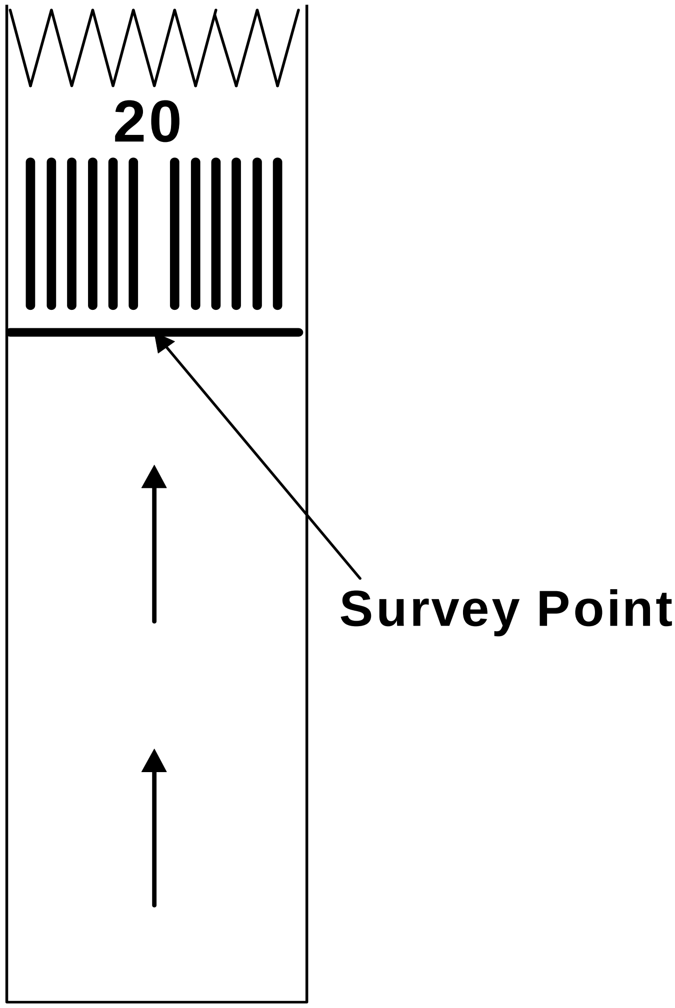
D.1.3 Where none of the diagrams of Annex D is appropriate, a new diagram shall be prepared, showing the actual arrangement of markings and the point selected for survey.

D.1.4 Wing-bar threshold lights and lights installed ahead of the runway hard surface shall have no direct survey status with respect to thresholds.

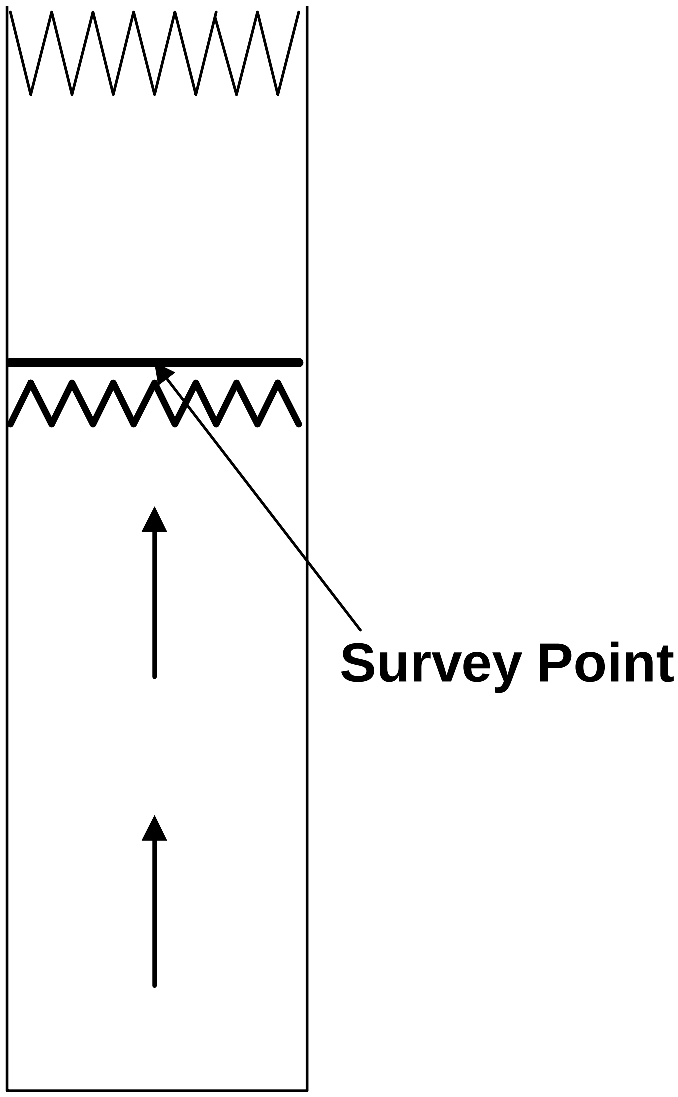
D.1.5 Where existing national standards are used then the survey report shall indicate the equivalence to the diagrams shown in this Annex.

D.1.6 The following illustrations shall indicate the planimetric position to be surveyed

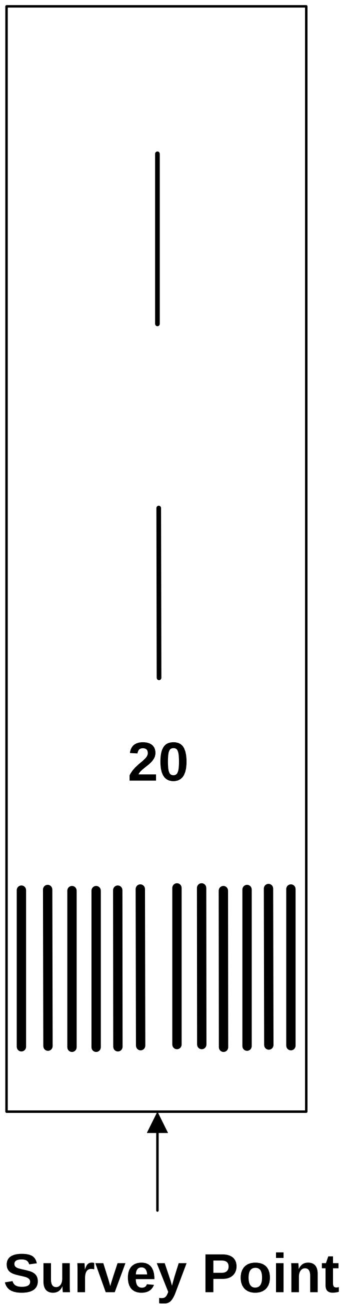
D.2 Marking example Type 1 (Normative)



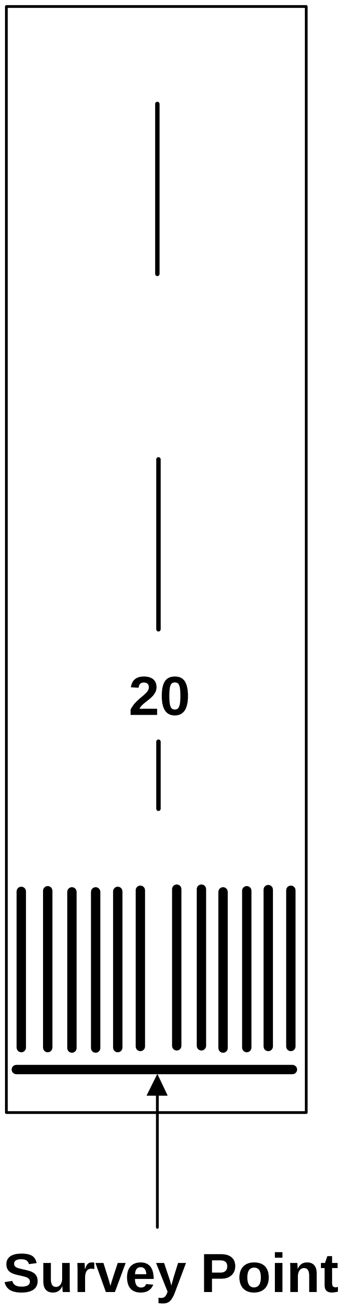
D.3 Marking example Type 2 (Normative)



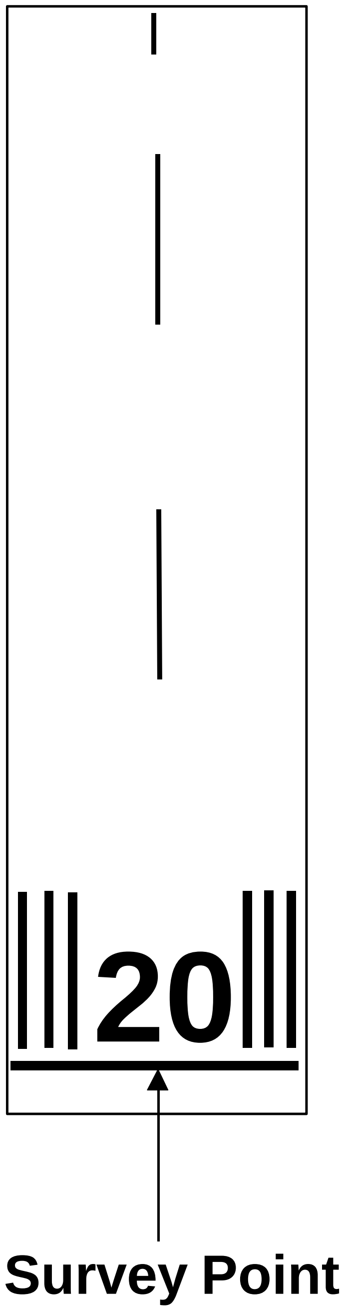
D.4 Marking example Type 3 (Informative)



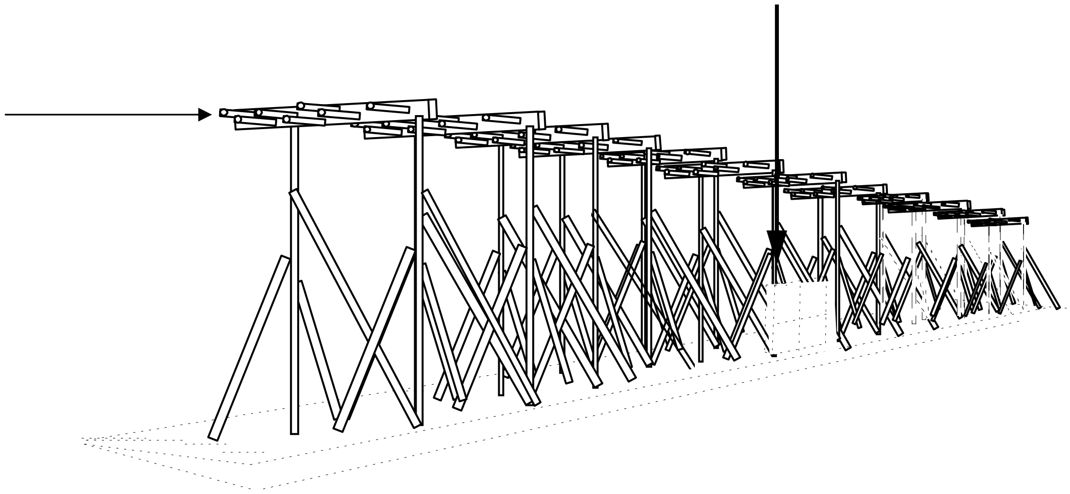
D.5 Marking example Type 4 (Informative)

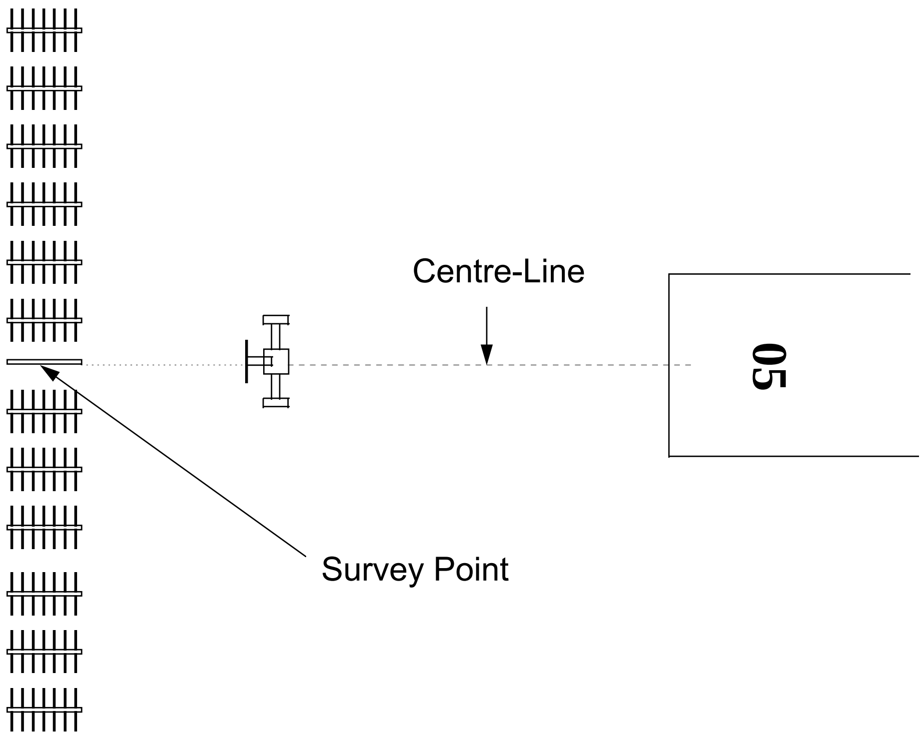


D.6 Marking example Type 5 (Informative)

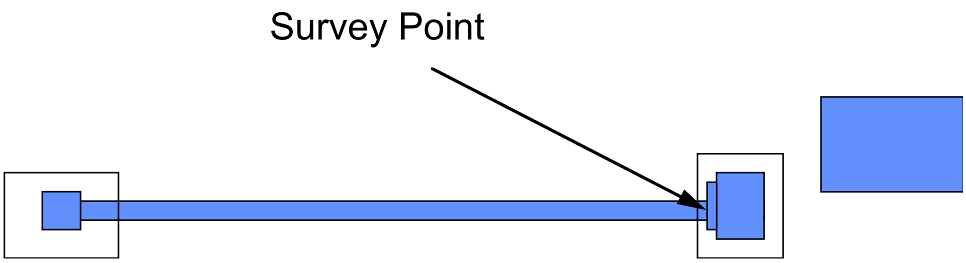


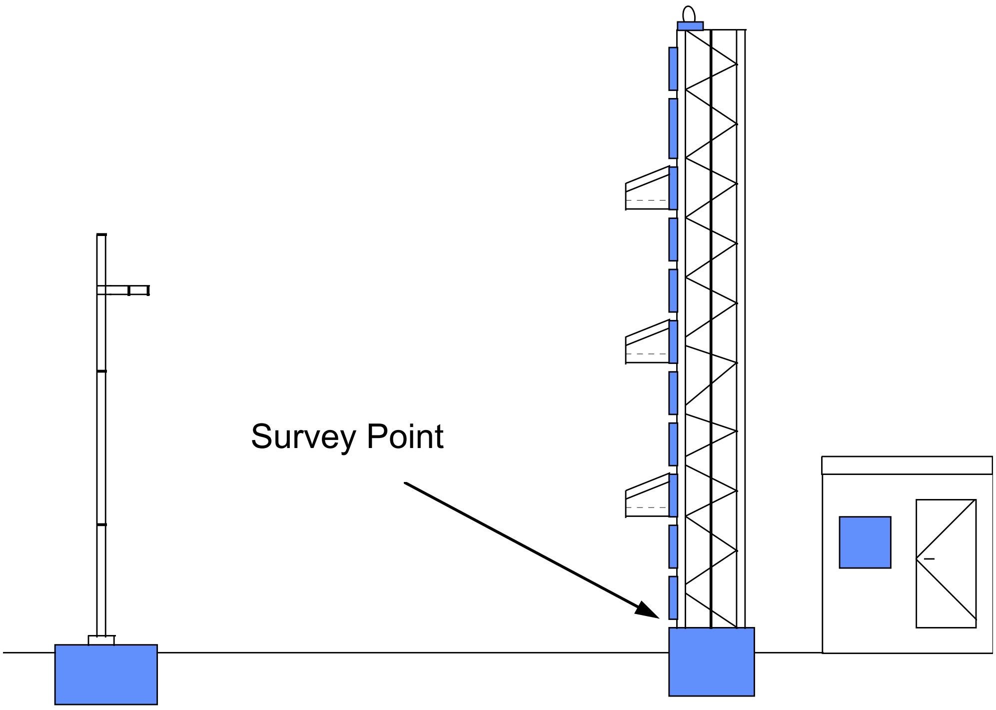
D.7 ILS localiser (Example)



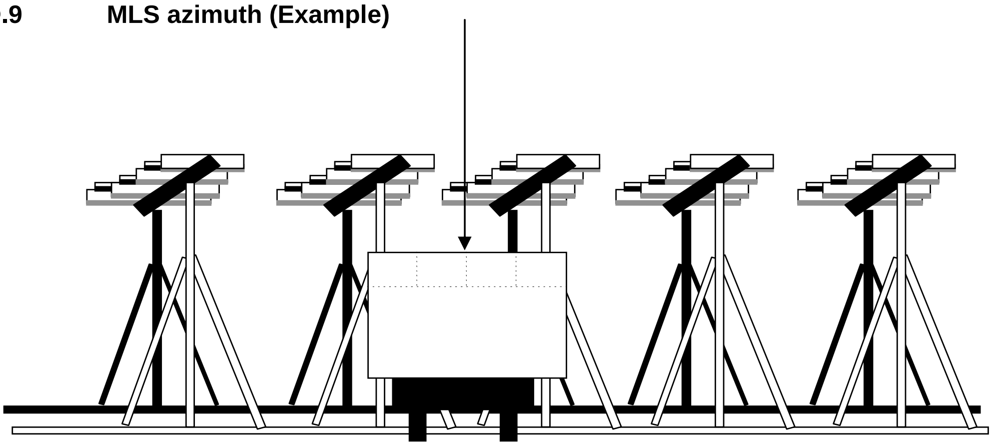


D.8 ILS glide path (Example)



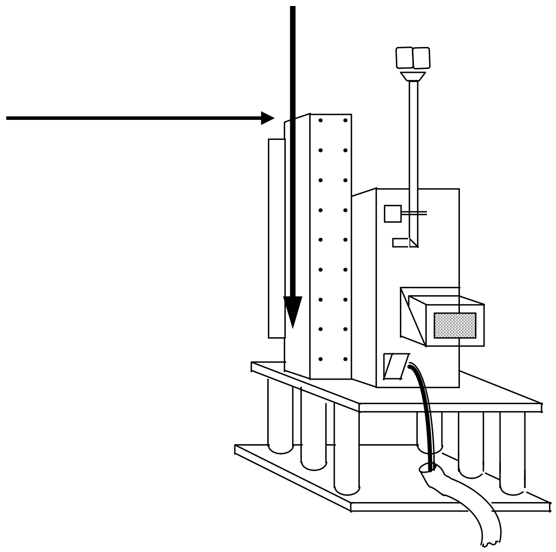


D.9 MLS azimuth (Example)

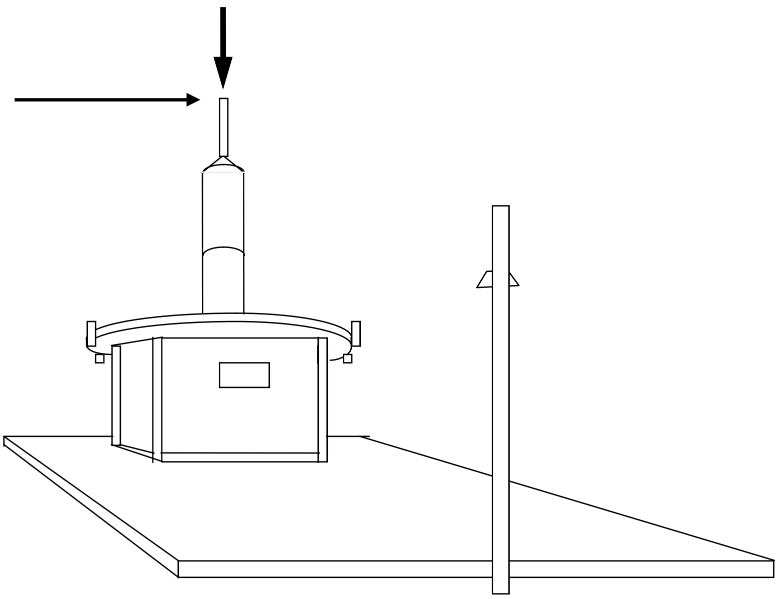


NOTE: *It is recommended that you refer to the local authority for the survey point.*

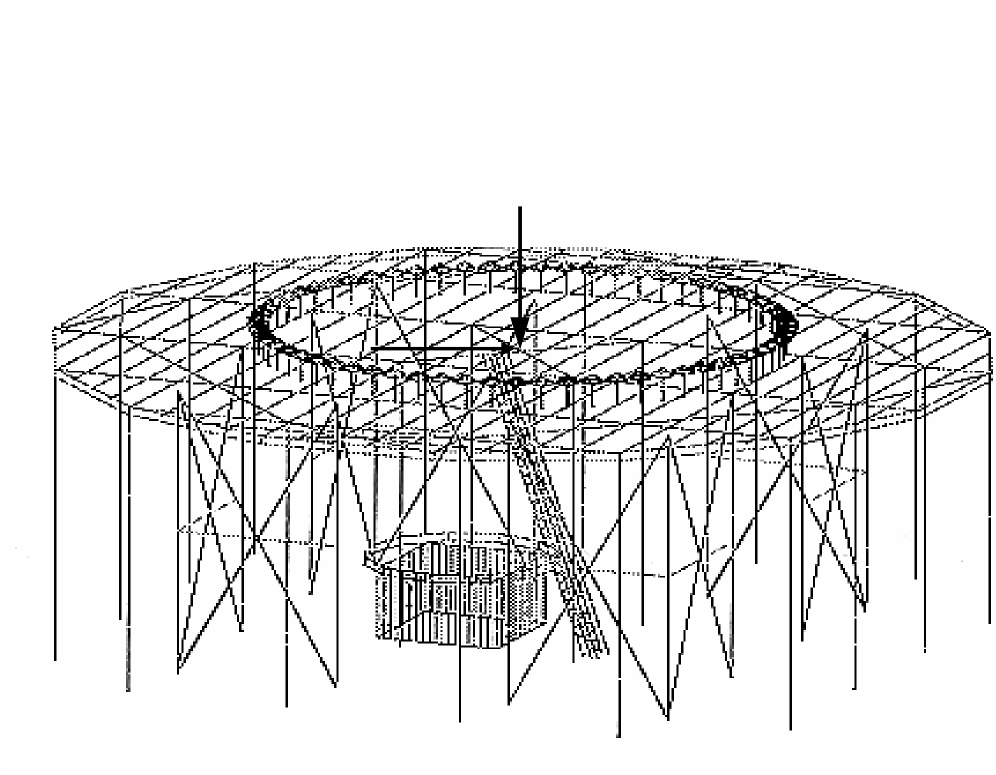
D.10 MLS glide path (Example)



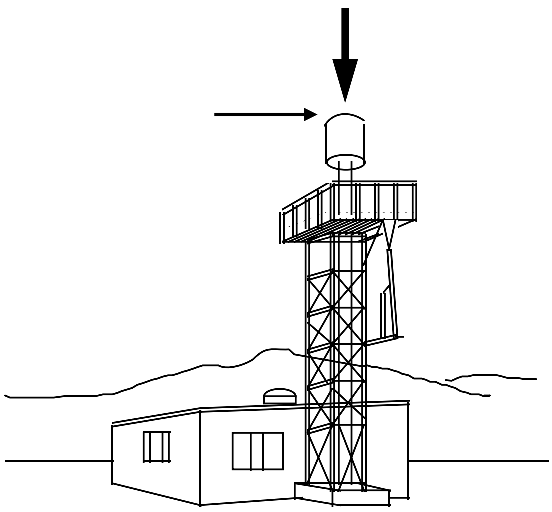
D.11 VOR/DME (Example)



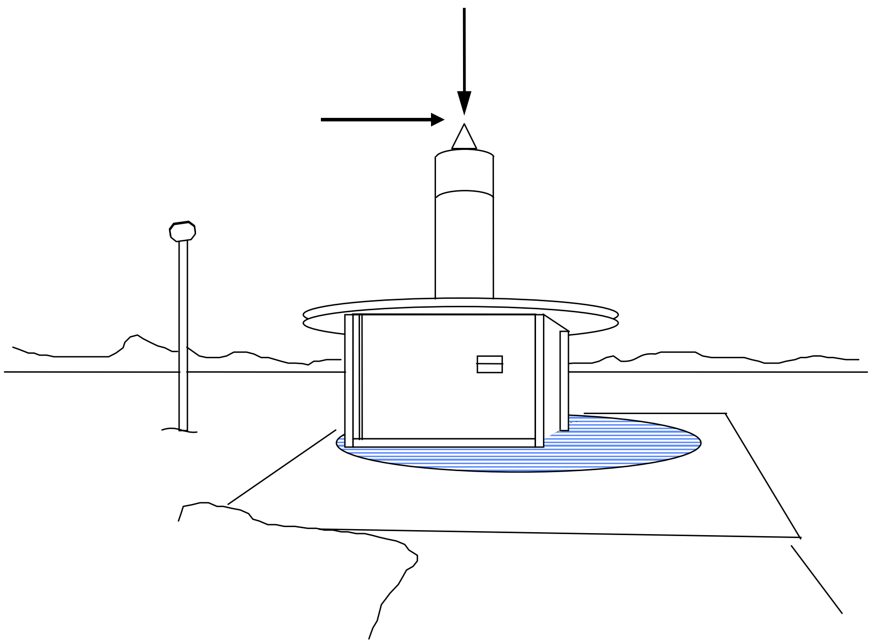
D.12 DVOR/DME (Example)



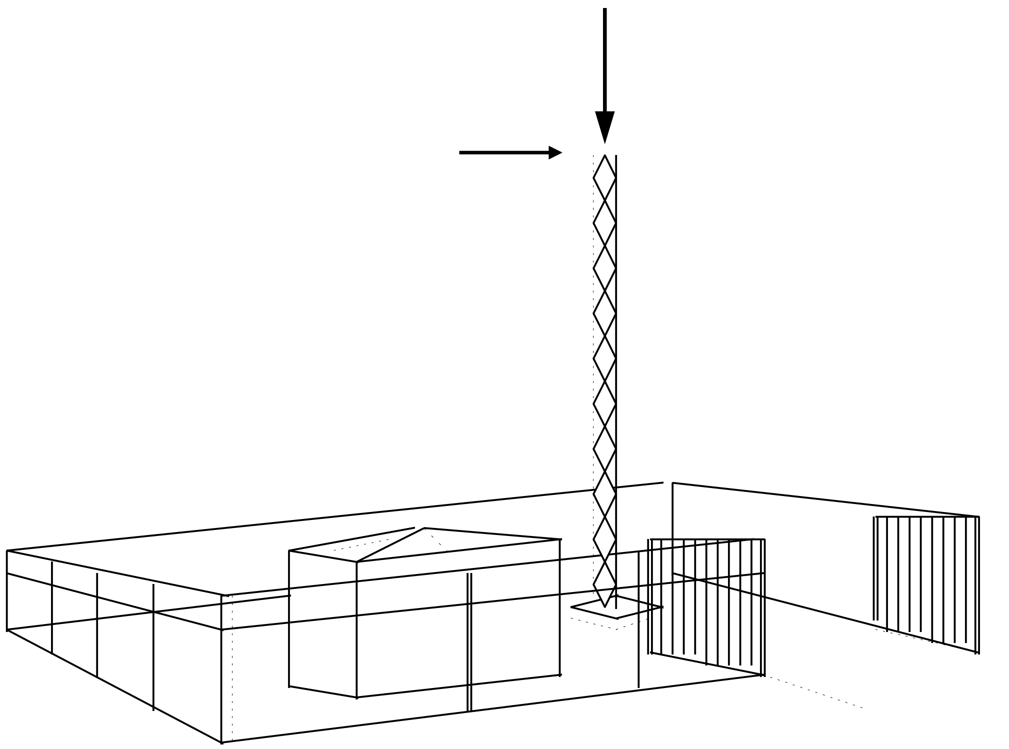
D.13 TACAN (Example)



D.14 VOR (Example)



D.15 NDB, locator (Example)



E Survey reports (Informative)

E.1 Geodetic connection

E.1.1 A survey report conforming to the following general format shall be provided.

1	Receipt note signed on behalf of the commissioning organisation indicating the date of receipt of the survey report and confirming its completeness.
2	Historical data, including: Name of Surveyor, Surveying organisation, date of survey, method of survey, and equipment used. See Section 2.
3	Description of the method of survey.
4	Full details of the connection of the existing aerodrome survey control network to the existing geodetic network and the source of the control coordinates (i.e. original descriptions and coordinate lists from the National Geodetic Organisation, or lists cross-referenced to previous surveys). See Section 2.4.4.
5	Aerodrome Survey network plan, see Section 2.4.3.3.
6	Survey station descriptions, and/or photos, including station labelling and numbering, see Section 2.4.3.2.
7	Schedule of points surveyed showing date of monumentation, description and survey.
8	Quality control report indicating equipment calibration information and the method of checking of the survey. Demonstrable evidence that the accuracy requirements have been met, including details of the error budget analysis.

Table E-1: Contents List - Geodetic Connection

E.1.2 Records of actual observations shall be provided in a separate indexed volume.

Recommendation: *To enable independent computation of the geodetic connection, the GPS data used (where GPS techniques have been applied) should be supplied digitally (preferably on a CD) in RINEX format (See Section G.2.12). .Similar requirements could be made for E.2 (Aerodrome Survey) and E.3 (Radio Navigation Aid Survey). This should be feasible and should drive groups to operate in a standard way using the defined station naming conventions and recommended operational procedures. Auditing of procedures should be made faster.*

E.1.3 Cross references to observations shall be made in the survey report.

E.2 Aerodrome Survey

E.2.1 A survey report conforming to the following general format shall be provided.

1	Receipt note signed on behalf of the commissioning organisation indicating the date of receipt of the survey report and confirming its completeness.
2	Historical data, including: Name of Surveyor, Surveying organisation, date of survey, method of survey, and equipment used. See Section 2.
3	Description of the method of survey.
4	Details of the observations made cross referenced to the control survey (i.e. those observations that provide connection to the control points).
6	Description and/ or photographs of each navigation facility surveyed.
5	Facility survey plan and cross referenced witness diagrams (where necessary).
6	Schedule of points surveyed showing horizontal coordinates, vertical coordinates, Magnetic variation, Declination and date of survey where the requirement is indicated in Annex A.
7	Quality control report indicating details of calibration process and results, the method of checking of the survey. See Section 2. Accumulated error analysis, including: ▪ The accumulated error being presented in its component parts, each showing the accuracy achieved and that the result is consistent with the survey technique used; ▪ The accumulated error calculations being clearly reported and compared against the declared accuracy requirement. See Section 2.2.1.5. Demonstrable evidence that the requirements in Annex A have been met.

Table E-2: Contents List - Aerodrome Survey

E.2.2 Records of actual observations shall be provided in a separate indexed volume.

E.2.3 Cross references to observations shall be made in the survey report.

E.3 Radio navigation aid survey

E.3.1 A survey report conforming to the following general format shall be provided.

1	Receipt note signed on behalf of the commissioning organisation indicating the date of receipt of the survey report and confirming its completeness.
2	Historical data, including: Name of Surveyor, Surveying organisation, date of survey, method of survey, and equipment used. See Section 2.
3	Description of the method of survey.
4	Details of the local connection for the individual radio navigation aids. The geodetic connection shall be fully described in detail where monumented survey control stations are not installed as part of an off-aerodrome radio navigation facility survey. See Section 2.8.3.
6	Description and/ or photographs of each navigation facility surveyed.
5	Survey diagram showing the local survey connection by which the coordinates of the centre of the aid were obtained.
6	Schedule of points surveyed showing horizontal coordinates, vertical coordinates, Magnetic variation, Declination and date of survey where the requirement is indicated in Annex A.
7	Quality control report indicating details of calibration process and results, the method of checking of the survey. See Section 2. Accumulated error analysis, including: ▪ The accumulated error being presented in its component parts, each showing the accuracy achieved and that the result is consistent with the survey technique used; ▪ The accumulated error calculations being clearly reported and compared against the declared accuracy requirement. See Section 2.2.1.5. Demonstrable evidence that the requirements in Annex A have been met.

Table E-3: Contents List – Radio Navigation Aid Survey

E.3.2 Records of actual observations shall be provided in a separate indexed volume.

E.3.3 Cross references to observations shall be made in the survey report.

F Heliport data (Normative)

F.1 Heliport survey points

F.1.1 In order to clarify the points to be surveyed for those heliports for which coordinates are required to be published, the following requirements are provided, reference ICAO Annex 14 Volume 2.

F.1.2 The order of accuracy of the field work shall be such that the resulting operational navigation for the phases of flight shall be within the maximum deviations, with respect to an appropriate reference frame, as indicated herein: (ICAO Annex 14 Vol 2, 2.1.2).

F.1.3 The geometric centre of the touchdown and lift-off area, thresholds of the final approach and take-off area (where appropriate) shall be 1 m. (ICAO Annex 14 Vol 2, 2.1.2 'b').

F.1.4 The geographical coordinates of the geometrical centre of the touchdown and lift-off area and/or of each threshold of the final approach and take-off area (where appropriate) shall be measured and reported to the aeronautical information services authority in degrees, minutes, seconds and hundreds of seconds. (ICAO Annex 14 Vol 2, 2.4.2)

Recommendation: *Where there is an aiming point marking (see F.5) the geometric centre of the equilateral triangle should be taken as the surveyed point.*

F.2 Aiming point marking

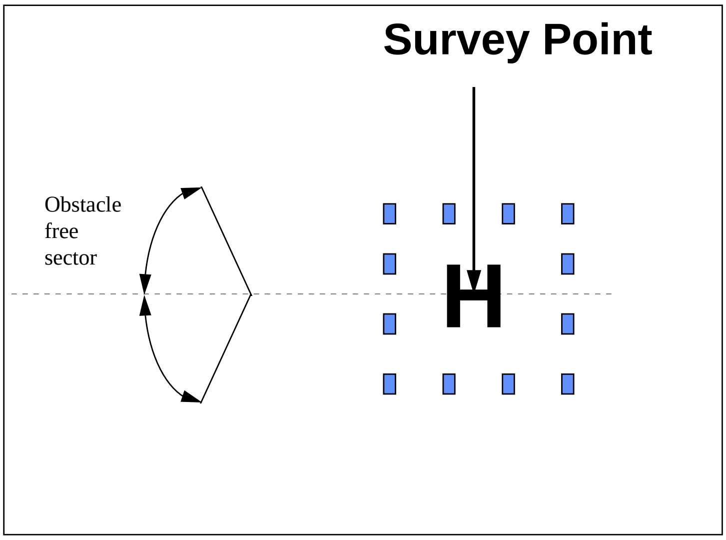
Recommendation: *An aiming point marking should be provided at a heliport where it is necessary for a pilot to make an approach to a particular point before proceeding to the touchdown and lift-off area. (ICAO Annex 14 Vol II, 5.2.6.1)*

F.2.1 The aiming point marking shall be located within the final approach and take-off area. (ICAO Annex 14 Vol 2, 5.2.6.2)

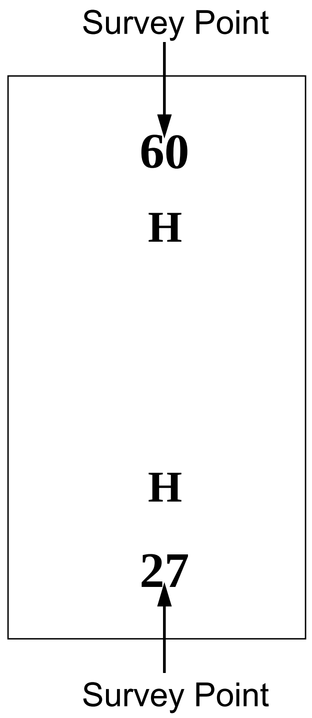
F.2.2 The aiming point marking shall be an equilateral triangle with the bisector of one of the angles aligned with the preferred approach direction. (ICAO Annex 14 Vol 2, 5.2.6.3)

NOTE: *An Aiming Point is not a mandatory requirement according to Annex 14.*

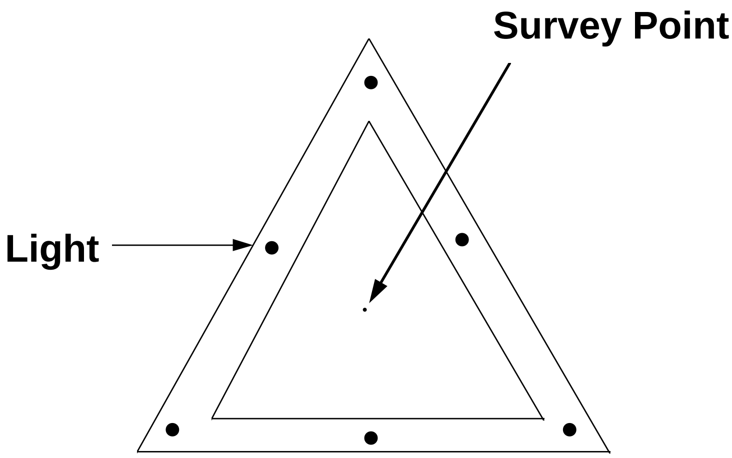
F.3 Heliport identification



F.4 FATO threshold



F.5 Aiming point



G GPS survey procedures (Recommended)

G.1 General

G.1.1 This annex provides best practice guidance for:

- The establishment of control points (Section 2.4);
- GPS surveying of facilities (Sections 2.2 and 2.5).

G.1.2 This information is intended to supplement the requirements stated in this document and thereby assist in their interpretation.

G.2 Establishment of control points

G.2.1 Major themes:

- Measuring connection to a 3-D geodetic reference frame;
- Careful measurement of GPS antenna heights;
- Choice of siting for control stations;
- Use of almanacs for observation session planning;
- Elevation mask angle definition;
- Hardware selection issues;
- Use of precise orbits in post-processing;
- Redundancy;
- Antenna phase centre variation in mixed receiver networks;
- Re-visiting survey stations;
- Backing up data in RINEX format;
- Choice of software;
- Computation.

G.2.2 Measuring connection to a 3-D geodetic reference frame

G.2.2.1 Many countries in Europe maintain continually operating reference stations (CORS) at points that have publicly available ETRF89 coordinates. Data from these stations is freely available via the Internet. Using data from such stations in conjunction with static observations at a new point is a relatively straightforward and a very cost-effective method of determining ETRF89 coordinates. Many of these countries have also participated in international observation campaigns, or carried out their own surveys to densify their networks, by occupying the existing triangulation network monumentation with GPS. These 'passive' stations are generally at a much greater spatial density than the CORS stations, and again, their coordinates are in many cases freely available. The use of passive network stations close to an aerodrome (say less than 30 km) may be more straightforward than using CORS data over longer baseline lengths, see Section G.2.13. Once ETRF coordinates of a suitable quality have been computed these should be transformed to ITRF values using the published European Reference Frame (EUREF) coordinate transformations.

G.2.2.2 If connection to the ETRF frame cannot be accomplished then the use of the latest realisation of the ITRF series is recommended. This can be via the core IGS/ITRF stations themselves, or via national sub-networks that have demonstrably good connections to the ITRF. Ties to WGS-84 via ETRF89 should be made directly to points with coordinates in ETRF89, provided that these coordinates have known and suitable accuracies and that the suitable EUREF transformation set is applied to compute the final ITRF coordinates.The recommended procedure is to effect the tie directly to ITRF stations using IGS data products, although this may be technically more challenging due to the density of suitable control stations within Europe at this time.

G.2.3 Careful measurement of GPS antenna heights

G.2.3.1 The principal source of gross error in GPS surveying is the erroneous measurement of the antenna height. All GPS processing software computes point solutions and inter-receiver baselines with respect to the antenna phase centre. The manufacturer determines the offset in position between the antenna phase centre and some physical mark on the equipment that is accessible to the user, known as the antenna reference point. It is up to the user to determine the vertical offset between the antenna reference point and the ground mark that is being surveyed. This parameter is what is customarily termed the antenna height.

G.2.3.2 Therefore, it is vital that all users of the equipment understand fully the precise location of the antenna reference point. This is always indicated in the equipment documentation, but may vary from manufacturer to manufacturer.

G.2.3.3 Many receivers do have the antenna reference point at the base of the antenna pre-amplifier. If this is the case the following procedure is recommended.

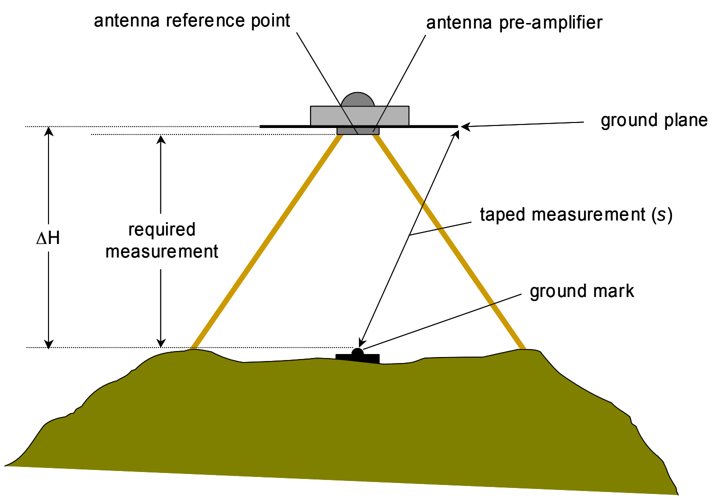


Figure G-1: Recommended antenna height measurement scheme for antennas using the pre-amplifier base as the antenna reference point.

G.2.3.4 Measure the slant range distance (s) from the ground mark to the edge of the antenna ground plane. This can be done using a hand-tape, measuring to a resolution of 1 mm. Provided that the antenna is correctly levelled this measurement should be the same in all directions. The following assumes the antenna has a circular ground plane. If this is not the case, the principles of the method are readily adapted to other shapes. Using Pythagoras' theorem and the known (if provided by manufacturer) or measured radius of the ground plane, calculate the vertical distance from the ground mark to the centre of the ground plane (ΔH). Subtract the known (if provided by the manufacturer) or measured vertical offset between the ground plane and the base of the pre-amplifier from ΔH to compute the required measurement. In the field, the only measurement that needs to be taken and recorded is the slant range distance, s, and this should be checked at a few points around the ground plane. In all circumstances when determining the so-called 'antenna height' reference should be made to the manufacturer's guidelines.

G.2.3.5 There are some useful web resources covering high precision measurements of antenna geometry for example, the UCAR UNAVCO facility website[18].

G.2.3.6 The procedure for determining the GPS antenna height parameter should be clearly documented and executed with great care. Diagrams should be supplied to survey crew personnel so that there is no ambiguity and so that clear records are created of the measurements made in the field.

G.2.4 Choice of siting for control stations

G.2.4.1 The quality of the computed coordinates in a GPS survey can be greatly enhanced by suitable site selection. In the northern hemisphere, most of the GPS constellation appears in the southern half of the sky. Therefore, to increase the availability of satellites the station should have clear lines of sight to the south, preferably down to the horizon. In general, the fewer the number of obstructions between the station and the skyline, the better the results of the survey.

G.2.4.2 Another limiting factor on computed precision is the effect of signal multipath. Multipath effects are caused by the signal from the satellite being reflected by objects in the vicinity of the antenna. These reflected signals interfere with the direct signal, distorting the computed range between the antenna and the satellite. Multipath effects can be mitigated primarily by careful selection of station position. In general:

- Avoid places where reflecting surfaces are above the level of the antenna, this can include wire mesh fences and anything that absorbs water, such as wood;
- Use an antenna with a choke ring or ground plane.

G.2.4.3 If it is not practical to site a station in a benign multipath environment then it is appropriate to carry out some form of multipath assessment prior to establishment of a permanent station.

G.2.4.4 Some consideration should be given to potential radio-frequency (RF) interference. This is particularly problematic at microwave communication antenna stations. The jamming caused at such locations can be intermittent depending on whether the station is transmitting or not. Therefore it is possible that testing of GPS signal acquisition at the station could be successful at one time, and a

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18 http://www.unavco.ucar.edu/project_support/equipment/permanent_station/antennas/ant_cals.html correct on 20/12/02

complete failure at others. In general, it is best to avoid any station locations near to microwave transmitters.

G.2.4.5 It is useful to carry out an azimuth-elevation skyline survey at a station as part of a station assessment exercise. Most commercial GPS processing software has functionality that allows the user to input azimuth-elevation data, and, in conjunction with GPS almanac data, assess the satellite availability at a station as a function of time.

G.2.4.6 Control points should always be sited in secure locations to avoid risks of equipment loss and damage to the station monumentation. At the same time the station must be accessible to the personnel using it, and have suitable skyline characteristics.

G.2.4.7 Control station monumentation should always be founded in stable ground, preferably such that seasonal variations in temperature and moisture do not adversely affect its position. The ideal ground surface is exposed bedrock. Tarmac surfaces are to be especially avoided.

G.2.4.8 The suitability of a proposed GPS control point location should be assessed in terms of:

- Satellite availability;
- Multipath environment;
- RF interference;
- Security;
- Access;
- Stability.

G.2.5 Use of almanacs for observation session planning

G.2.5.1 Part of the information that is modulated onto the GPS signal and can be decoded by a receiver is an almanac. This consists of an approximate trajectory for all of the GPS satellites based on their current orbits. This information can be used to predict the availability and visibility of the satellites at any point on the surface of the Earth.

G.2.5.2 A useful number that is calculated from the number of satellites available at a particular time, and the relative geometry between the receiver and the satellites, is a Dilution of Precision (DOP) factor. A DOP factor can be used to scale an estimate of the uncertainty in a GPS pseudorange measurement and this reflects how autonomous point positioning is affected due to the availability and geometrical strength of the satellite network. Hence, for precise coordinate estimation, low DOP factors are preferable. A low DOP factor is around 1-2, a high DOP factor is >3. Commercial site assessment software can compute DOP factors, and their time variation, from the GPS almanac.

G.2.5.3 When planning an observation schedule for a particular day it is advisable to refer to a relatively recent almanac. Observation schedules should be built around maximising the number of satellites that are tracked, and avoiding parts of the day where DOP factors become unfavourable.

G.2.5.4 There are several kinds of DOP factors that can be computed. These are:

- HDOP – horizontal dilution of precision;
- PDOP – positional dilution of precision;
- VDOP – vertical dilution of precision;
- TDOP – time dilution of precision;
- GDOP – geometric dilution of precision.

G.2.5.5 The DOP factor used depends on the application – if the survey is for horizontal positioning alone then HDOP is used, if the survey is for height only then the VDOP parameter is appropriate, etc. Formally these parameters are computed from combinations of the elements of a position fix covariance matrix. Note that DOP factors were developed for autonomous point positioning but they are nevertheless still useful in planning other types of GPS survey.

G.2.5.6 Prior to carrying out any GPS fieldwork the impact of satellite availability and the associated DOP factors should be assessed. Observation sessions should be planned around maximising the number of satellites available and periods of favourable DOP characteristics.

G.2.6 Elevation mask angle definition

G.2.6.1 An elevation mask angle is a form of filter that can be applied when acquiring raw observations in the field, and in the post-processing of data. The mask angle specifies a minimum elevation at a GPS observation station below which the receiver (in the case of data acquisition) will stop recording the signals received from all satellites. In the case of post-processing, the mask angle sets the minimum elevation of satellites that contribute to the solution. In the field, the principal function of the mask angle for data acquisition is to reduce the volume of data that is recorded, and in particular to filter out data that would never be used in analysis. In post-processing, the mask angle can be raised to filter out signals that have been adversely affected by atmospheric effects, multipath or diffraction. Under some circumstances (for example, where there has been serious multipath contamination) the mask angle can be set as high as 30-40° yet still giving improved point solutions.

G.2.6.2 In general in the field, when tracking satellites for the positioning of control points, the mask angle should be set to 10° as it is always possible to filter out bad data in the processing, but it is not possible to add in potentially good data if it is not recorded in the first place. In post-processing of data there are no rules for the setting of mask angles, although it is generally reasonable to start at 15° and alter the value if necessary.

G.2.7 Hardware selection issues

G.2.7.1 The GPS signal is refracted in the ionosphere, and the degree of signal delay caused by this refraction depends upon the signal frequency. GPS signals consist of codes modulated onto two carrier waves of different frequencies. These two frequencies are denoted as L1 and L2. By recording observations of both frequency signals, the user can eliminate the effect (to first order) of the ionospheric refraction. GPS receivers are available in both single and dual frequency models. Over short baselines (say 5 to 10 km), two single frequency receivers used in conjunction can achieve good results by using differencing techniques, and these remove the ionospheric refraction by subtracting one signal from another. Over longer distances, the ionospheric refraction becomes spatially de-correlated, and the performance of single frequency receivers then degrades. Over longer baselines, it is necessary to use the more expensive dual frequency receivers. Note that over very short baselines the relative positioning results derived from single frequency observations can be better than those computed using both the L1 and L2 observables because of the degraded noise characteristics of the L2 signal compared to that on L1. However, it should also be considered that some real-time kinematic applications over short baselines, whilst using L1 signals only for computing the relative positioning, still rely upon L1 and L2 combinations for ambiguity resolution.

G.2.7.2 Receivers can be equipped with choke ring antennas or ground planes. These are hardware multipath mitigation devices. They add cost and weight to a receiver, whilst at the same time reducing the impact of multipath on coordinate precision.

G.2.7.3 The suitability of using single or dual frequency GPS equipment must be assessed in terms of the accuracy requirements of the final coordinates of the surveyed features. Similar consideration should be given to the type of antenna used, and whether it requires a ground plane or choke ring.

G.2.8 Use of precise orbits in post-processing

G.2.8.1 Precise orbits are computed for all of the GPS satellites by various agencies operating under the umbrella organisation, the International GPS Service (IGS). These precise orbits are better than their broadcast counterparts (which are available in real-time in the field) by around two orders of magnitude. However, the most precise versions are not available until about two weeks after the date that the GPS observations are collected in the field.

G.2.8.2 There is a simple relation between the precision of a baseline, its length and the precision of the orbit used in the computation. As the length of a baseline increases it becomes more and more important to use a precise orbit in the baseline computation to maintain a given precision.

G.2.8.3 If s is the baseline separation between two receivers, with δs the uncertainty in the baseline separation, and r is the distance to the satellite then δr, as given below, is the ‘acceptable’ uncertainty in the satellite position.

$$\frac{\delta r}{r} = \frac{\delta s}{s}$$

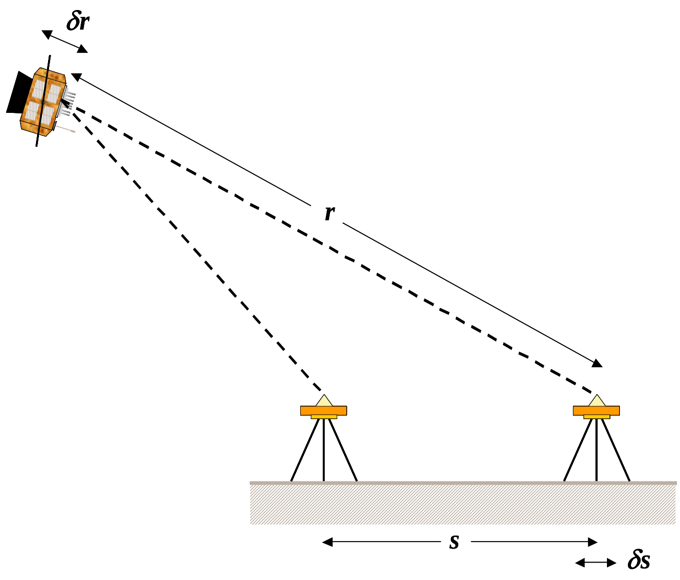


Figure G-1: Uncertainty in satellite position

G.2.8.4 So, for example, if the required specification were 20 mm of precision over a baseline of 100 km, then it would be necessary to use an ephemeris with an orbital precision of around 4 metres.

G.2.8.5 Precise orbits are available free of charge over the Internet via the IGS web page.[19]

G.2.8.6 The precision of the ephemeris used in baseline computations should be commensurate with the precision specifications of the survey.

G.2.9 Redundancy

G.2.9.1 This guidance also applies to critical points marked in **Error! Reference source not found.**.

G.2.9.2 When establishing a new control point it is important to use at least two independent baselines in the computation of the new station. Whilst GPS can achieve outstanding results for almost minimal effort, the traditional surveying concepts of independent check and redundancy still apply, particularly in the issue of quality control and the trapping of gross errors. Ideally, baselines would be observed on different days, using differing control points and with rotation of survey crew personnel.

G.2.9.3 The free availability of GPS data from continually operating reference stations (CORS) now makes it possible to carry out checks on positioning by computing baselines between the new station and points in the national network.

[19] http://igscb.jpl.nasa.gov correct on 25/05/06

G.2.10 Antenna phase centre variation in mixed receiver networks

G.2.10.1 The phase centre of an antenna varies as a function of the azimuth and elevation of the satellite that is being tracked. Each antenna type tends to have its own characteristic phase centre variation. Hence, if a relatively small network is being observed with a set of antennas of a common type, and they are all oriented in the same sense (for example with a particular mark on the antenna pointing to the North), then the antenna phase centre variations will be the same at each point in the network. Hence, the relative vectors between the phase centres will be the same as the relative vectors between the geometric instrument centres and there will be no bias in the observations. However, if a baseline is observed by antennas of mixed types and the differing phase centre variations are not considered in the data processing, then the relative position vectors will be in error. The principal component of phase centre variations is in the vertical, but horizontal phase centre variations do occur in some antennas.

G.2.10.2 Phase centre variation data for many receivers is available through the IGS and UNAVCO.[20]

Recommendation: *Unless detailed information about GPS antenna phase centre variation is known, and software is being used that can accommodate this knowledge then network GPS observations should be made with common antenna types. Care must be taken that all antennas have a common orientation when deployed at survey stations.*

G.2.11 Re-visiting survey stations

G.2.11.1 It is common practice to occupy a new station at least twice, and if possible to do this using differing observation crew personnel on each visit. This helps to trap gross errors in the measurement of the antenna height, and provides for independent estimates of the vectors leading into the station. If possible, a cross-section of reference points in the area should be used, provided that they are of homogeneous quality.

G.2.12 Backing up data in RINEX format

G.2.12.1 In the same way that ASCII data is a universal text data format that can be read by almost all computers there is a universal text-based format for GPS phase, pseudorange, navigation and meteorological data, known as RINEX. RINEX stands for Receiver INdependent EXchange format. Most commercial GPS processing software will enable the user to export their raw GPS data in RINEX format.

G.2.12.2 All GPS project data from aerodromes should be backed up and archived in a RINEX format.

G.2.12.3 This allows for the independent validation of any GPS data processing by another agency, and also guards against the proprietary format data becoming unreadable as software versions evolve. RINEX is also the primary way of importing GPS data into third-party scientific GPS data processing software.

[20] http://www.unavco.ucar.edu/science_tech/dev_test/antennas/igs_01.pcv correct on 20/12/02

G.2.13 Choice of software

G.2.13.1 The establishment of control points by GPS fixed to ITRF is clearly a high precision task. However, this does not preclude the use of standard software processing packages. Provided that care is taken in the siting of stations, and that sufficient time-spans of data have been observed, then baselines of up to 80 km can be computed using commercial software. This does depend on the quality of the software used, and less developed packages will work up to about 30 km.. Once baseline lengths start to exceed 30 km then the characteristics of the systematic biases and noise in GPS data start to de-correlate and more sophisticated models are needed. Under these circumstances, high precision 'scientific' GPS processing software should be used. Such packages include:

- GIPSY-OASIS II – written by NASA's Jet Propulsion Laboratory;
- BERNESE – written by the University of Berne in Switzerland;
- GAMIT – written at Massachusetts Institute of Technology, USA.

G.2.13.2 Using such software, the precisions attainable using commercial software baselines of up to 80km can be achieved on baselines of up to 2000km. There are also free and commercial GPS data processing services available over the internet that use scientific processing packages, such as:

- JPL's auto-GIPSY service;[21]
- GPS Solutions commercial processing service.[22]

G.2.14 Computation

G.2.14.1 Where possible it is recommended that the results of a GPS survey for control points should include the full variance-covariance matrix. This is useful in analysis of the network quality and in combining network data with other results. As a minimum, the computed coordinates should be published with their formal standard deviations as given by the processing software.

G.2.14.2 If independent baselines have been computed from a number of reference stations in an area then the range of values obtained for the control point from each relative position vector should be published. Note that the final value of the point coordinates will still be obtained from some combination of the individual baseline solutions.

G.2.14.3 Note that some EGNOS and WAAS enabled hardware can measure phase observables from the geostationary satellites in these systems. These signals will appear like conventional GPS signals, but as their performance is not at the same level as GPS phase signals care should be taken to either down-weight these observables or to eliminate them from the processing.

[21] http://milhouse.jpl.nasa.gov/ag correct on 25/05/06

[22] http://www.gps-solutions.com/online.html correct on 25/05/06

G.3 GPS surveying of facilities

G.3.1 Observation technique types

G.3.1.1 There are many methods by which such GPS surveying can be accomplished. The acronyms below may have alternative meanings in some guides/literature, and hence they cannot be regarded as definitive. The headings followed by (RT) are real-time techniques, that is, the coordinates of the point being surveyed are accessible to the Surveyor at the time of occupation of the point:

- RGPS – static relative positioning using phase and pseudorange;
- DGPS – broadcast differential pseudorange corrections (RT);
- KGPS – kinematic GPS positioning using phase and pseudorange;
- RTK GPS – real-time kinematic positioning using phase and pseudorange (RT);
- Navigation solution – low precision single receiver applications (RT);
- PPP – precise point positioning, high precision single receiver applications using post-processing in conjunction with internet data services;
- Regional RTK corrections supplied by service provider (RT);
- WADGS – wide area differential GPS using corrections from networks of receivers, in conjunction with geostationary satellites (such as the European wide EGNOS system) (RT).

G.3.2 Hardware selection

G.3.2.1 The distinction between dual and single frequency receivers that was made for the section on control point measurement above applies equally well in data acquisition.

G.3.3 Operational procedures

G.3.3.1 For pre-survey planning for the establishment of control it is advisable to quantify what availability of satellites there will be throughout the day and to assess the DOP variations that might be encountered, see Section G.2.5. This is particularly important where any real-time kinematic applications are being planned, as they generally require a minimum of six satellites available for most of the observation period. It is also advisable to set the satellite elevation mask angle to 15° in the schedule planning software, as this gives a reasonable estimate of the satellite availability when using a roving receiver.

G.3.3.2 Most real-time GPS equipment includes measures of quality that can be accessed in the field. It is advisable to understand fully how these have been derived and how they can be used to maintain a certain level of homogeneity in the survey results.

G.3.3.3 Wherever practicable (and if needed), one of the aerodrome principal control points should be used as a base station.

G.3.3.4 Initialisation points for kinematic data chains should always be chosen in areas with low skylines and minimal obstructions. The occurrences of loss of lock or cycle slip both increase the initialisation time necessary and reduce the likelihood of correct integer ambiguity resolution.

G.3.3.5 A known control point should be occupied in all kinematic surveys (no matter what the accuracy requirements) as part of the chain of points measured by the roving receiver. This should be done at both the beginning and the end of a survey. This procedure is to ensure that no gross error has been made in the antenna height measurement of either the rover or the base station, or in the values of the base station coordinates used. Wherever possible, the coordinates of the control point derived from the rover occupation should be checked in real-time against the published values. Note that this procedure forms part of a normative process in the standard (see Section 2.7).

G.3.3.6 Kinematic surveys using a roving receiver should generally be carried out in areas of open landscape with a good view of the skyline. In more built up environments these techniques can be less reliable and inefficient. In this case, alternative measurement techniques should be considered (for example, using conventional surveying techniques).

G.3.3.7 Where single frequency DGPS equipment is being used, care should be taken that the achievable coordinate precision is sufficient for the task. Typically, code multipath errors at both the rover and reference receivers can be the major limiting factor. Phase smoothing of the code observations can greatly mitigate these effects, but is not necessarily used by all equipment. These code-multipath effects can vary strongly according to the environment of the receiver and therefore occupation of a known point in a very favourable multipath environment is not necessarily a guarantee that all points in the chain will meet the required precision. The manufacturer’s stated precision of the equipment should be used as a guideline as to the suitability of the equipment.

G.3.3.8 Real-time kinematic surveys can be logged as coordinate data only, and the raw observations can be discarded. It is, however, recommended that if possible, all raw observations should be recorded to enable post-processing.

G.3.4 Real-time quality control

G.3.4.1 The quality of GPS positioning depends upon a number of factors such as satellite geometry (as typically represented by a DOP value), the number and elevation of satellites, hardware, environmental factors, processing models and accuracy of ephemeris etc. It is extremely difficult to give precise guidelines covering all the possible combinations of these factors. However, modern GPS equipment provides real-time assessment of data quality and this should be monitored carefully to ensure that specifications are being met.

G.4 Summary

G.4.1 In this document positioning accuracy requirements are principally divided into on-aerodrome and off-aerodrome categories.

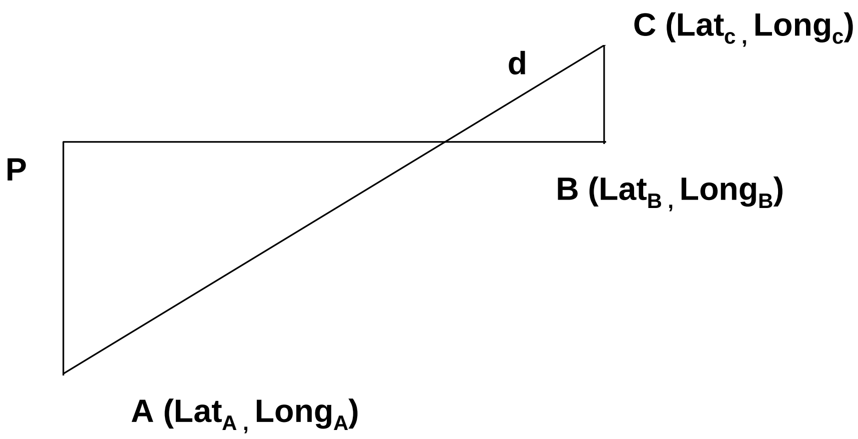
G.4.2 For on-aerodrome operations, the most suitable techniques use either GPS phase observations or a combination of both phase and pseudorange. For control work, static RGPS positioning is recommended. For spatial data acquisition, it is recommended to use RTKGPS or some similar kinematic technique.

G.4.3 For off-aerodrome operations, single frequency DGPS techniques (increasingly using EGNOS corrections, in which case there will be no need for a base station) will meet most requirements provided that the separation between the rover and the base station receivers does not exceed 10 km and that care is taken in the definition of the reference frame.

H Computation of threshold coordinates (Recommended)

H.1 Where the centreline point actually surveyed does not coincide with the threshold then the threshold coordinates can be derived from those surveyed by using the following method. As recommended in paragraph 2.5.2.1.

H.2 Computation of coordinates of a threshold longitudinally offset from the point surveyed



H.3 Angles in decimal degrees.

Given: $A(LatA, LongA)$ Runway centreline point

$B(LatB, LongB)$ Surveyed point

d (metres) Longitudinal offset to new threshold

Find: $C(LatC, LongC)$

PB $= (LongB - LongA) \times 1852 \times 60 \times Cos((LatB + LatA)/2)$

PA $= (LatB - LatA) \times 1852 \times 60$

AB $= +\sqrt{(\mathrm{PB}^2 + \mathrm{PA}^2)}$

k $= d/AB$

LatC $= LatB + k(LatB - LatA)$

LongC $= LongB + k(LongB - LongA)$

NOTE: *Using the naming convention described, the above formula works for all cases. Where the offset is from B towards A the dimension d should be entered as negative.*

NOTE: *Longitudes West of Greenwich should be entered as negative.*

NOTE: *These are approximate formulae and should only be used where d is small (i.e. less than 200m).*

I Heighting (Informative)

I.1 Introduction

I.1.1 This Annex is referenced in Section 2 and Annex A.

I.1.2 The long-term aim of EUROCONTROL is to guide the surveying of navaids in Europe to conform to ICAO standards for heighting. The ICAO standards use two distinct reference surfaces for heighting applications: an ellipsoid and the geoid.

I.1.3 The ICAO standards use the following terms:

- Ellipsoidal height – the distance along the normal to the specified ellipsoid through the point
- Geoid undulation – the height of the geoid above the specified ellipsoid along the normal to the ellipsoid through the point

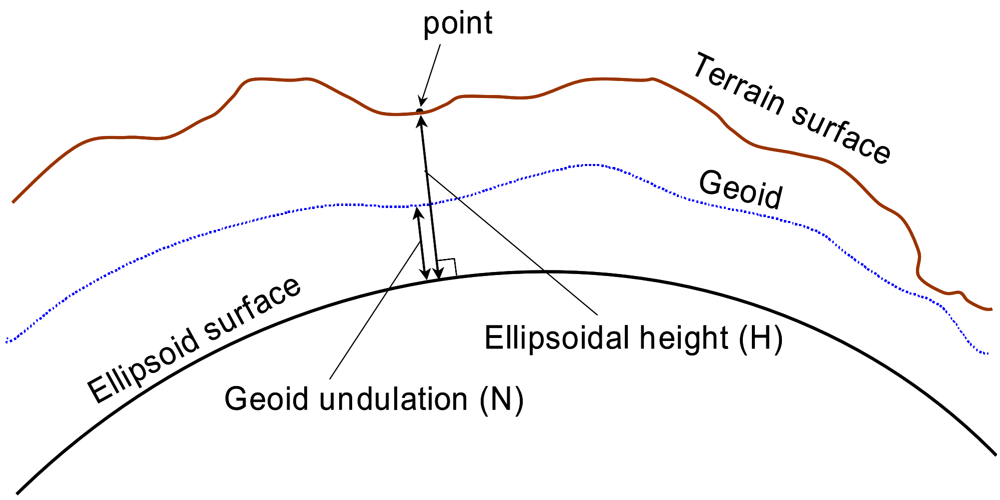


Figure I-1: Geoid undulations with respect to an ellipsoid

I.1.4 The most stringent accuracy requirements covered by the standards are geoid undulations and ellipsoidal heights for several on-aerodrome facilities. These accuracy requirements are 0.25 m (95% confidence interval) for both measurements. This can be readily achieved for computing ellipsoidal heights using appropriate GPS equipment. However, achieving these accuracy requirements for geoid undulations is more difficult at the present time. Proposed methodologies for determining the geoid undulations are given below.

I.1.2 Method 1

I.1.2.1 A country's national mapping agency (or some university departments) may have access to a scientifically determined geoid. This may be based on a combination of terrestrial gravity measurements, long wavelength gravity field data from a global gravity field model, marine gravity data, satellite altimetry data over the oceans, levelling and GPS data. Provided this geoid is of sufficient accuracy, and is referenced to the appropriate ellipsoid, then, given values of the latitude and longitude of a point, the required geoid undulation can be interpolated directly from the data. Provided that the geoid model used by the agency/department is of sufficient accuracy this method is optimal in that only approximate values of the latitude and longitude of the point are required to obtain the geoid undulation to the required accuracy. The remainder of the heighting process can be carried out using appropriate interpolation software.

I.1.3 Method 2

I.1.3.1 If a country's levelling system is free from limiting systematic biases, and the offset between the country's tide gauge datum and the geoid is known (Δh), then geoid undulations can be computed by measuring the height of a point above the levelling datum (h) and the ellipsoid (H). The geoid undulation at that point is then given by the relationship:

$$N = H - h + \Delta h$$

I.1.3.2 It is vital that a realistic estimate of the quality of the country's heighting network be obtained from the relevant authorities prior to carrying out the survey work.

I.1.3.3 Note that it is possible to invert this process in order to determine ellipsoidal heights by obtaining heights via levelling connections to benchmarks, adding the geoid undulation at that point and then applying the datum offset from the geoid. As previously mentioned the method should only be used when the benchmark values are known with sufficient accuracy.

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