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World Geodetic System — 1984 (WGS-84) Manual

Approved by the Secretary General
and published under his authority

Second Edition — 2002

International Civil Aviation Organization



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AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

The Council of the International Civil Aviation Organization (ICAO), at the thirteenth meeting of its 126th Session on 3 March 1989, approved Recommendation 3.2/1 of the fourth meeting of the Special Committee on Future Air Navigation Systems (FANS/4) concerning the adoption of the World Geodetic System — 1984 (WGS-84) as the standard geodetic reference system for future navigation with respect to international civil aviation. FANS/4 Recommendation 3.2/1 reads:

“Recommendation.— Adoption of WGS-84

That ICAO adopts, as a standard, the geodetic reference system WGS-84 and develops appropriate ICAO material, particularly in respect of Annexes 4 and 15, in order to ensure a rapid and comprehensive implementation of the WGS-84 geodetic reference system.”

The Council, at the ninth meeting of its 141st Session on 28 February 1994, adopted Amendment 28 to Annex 15, introducing the provisions concerning the promulgation of WGS-84-related geographical coordinates. Consequential amendments to Annexes 4, 11 and 14, Volumes I and II, were adopted by the Council on 1 March 1995, 18 March 1994 and 13 March 1995, respectively. On 20 March 1997 the Council, at the seventeenth meeting of its 150th Session, adopted Amendment 29 to Annex 15 introducing publication of the vertical component of the WGS-84 geodetic reference system. Consequential amendments to Annexes 4 and 14, Volumes I and II, were adopted by the Council on 20 March 1998 and 21 March 1997, respectively. The Standards and Recommended Practices (SARPs) in Annexes 11 and 14, Volumes I and II, govern the determination (accuracy of the field work) and reporting of geographic coordinates in terms of the WGS-84 geodetic reference system. Annexes 4 and 15 SARPs govern the publication in textual or graphical form of geographic coordinates (resolution) and vertical

components. States’ aeronautical information service departments will publish in their Aeronautical Information Publications (AIPs), on charts and store in electronic databases where applicable, geographic coordinate and vertical component values based on WGS-84 which are supplied by the other State aeronautical services, such as the air traffic service and the aerodrome/heliport authority.

The purpose of this manual is to furnish guidance on the provision of geographic coordinates and vertical component values referenced to the WGS-84 datum in order to assist States in the uniform implementation of the SARPs on WGS-84 as contained in:

Annex 4 — *Aeronautical Charts*;

Annex 11 — *Air Traffic Services*;

Annex 14 — *Aerodromes*,
Volume I — *Aerodrome Design and Operations* and
Volume II — *Heliports*;

Annex 15 — *Aeronautical Information Services*.

This manual has been prepared in consultation and coordination with the European Organization for the Safety of Air Navigation (EUROCONTROL) and will be amended periodically. Users are invited to forward to ICAO suggestions for improvements or additions based on their practical experience when using the manual. Errors or discrepancies noticed in the manual should be brought to the attention of:

The Secretary General
International Civil Aviation Organization
999 University Street
Montreal, Quebec, Canada H3C 5H7

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Chapter 1

INTRODUCTION

1.1 EFFECTS OF USING DIFFERING COORDINATE REFERENCE SYSTEMS IN AVIATION

1.1.1 Geodetic datum problems in air navigation were first encountered in Europe in the early 1970s during the development of multi-radar tracking systems for EUROCONTROL's Maastricht Upper Airspace Centre (UAC), where plot data from radars located in Belgium, Germany and the Netherlands were processed to form a composite track display for air traffic controllers. Discrepancies in the radar tracks were found to be the result of incompatible coordinates.

1.1.2 In the mid-1970s, during trajectography experiments with the French SAVVAN system (Système Automatique de Vérification en Vol des Aides à la Navigation, i.e. Automatic In-flight Navigation Aids Checking System), positional “jumps” were noticed when switching between Distance Measurement Equipment (DME) transponders located in different States. Once more, the errors could only be attributed to incompatibility of the coordinates of ground aids.

1.1.3 If a ground-based radar navigation aid is coordinated in two or more different geodetic reference datums, aircraft horizontal position determination will have two or more different sets of latitude and longitude values. In metric units aircraft locations could show a discrepancy of up to several hundred metres when simultaneously located and tracked by two radars: Radar datum 1 and Radar datum 2 (see Figure 1-1). This could lead to a situation where an aircraft close to a border between two States with different geodetic reference datums could be seen by radars in the two States as having different positions and the potential for misinterpreting aircraft separations and clearances from restricted areas.

1.1.4 Thus, the main source of systematic errors is the non-use of a common geodetic reference datum for determining radar positions; the solution is to derive the radar positions from a common geodetic reference frame.

1.1.5 There are many geodetic reference datums in use throughout the world providing references for the charting of particular areas. Each datum has been produced by fitting a particular mathematical earth model (ellipsoid) to the true shape of the earth (geoid) in such a way as to minimize the differences between the ellipsoid and the geoid over the area of interest. Most ellipsoids in current use were derived in the 1800s and were normally referenced to a local observatory. These different datums and ellipsoids produce different latitude and longitude grids and, hence, different sets of geographical coordinates. States developed their own geodetic datums which usually differed from those of adjacent States. As distance requirements increased beyond national boundaries, new requirements arose for datums on at least a continental scale.

1.1.6 Looking at the current situation, it must be acknowledged that in the en-route environment, the use of ground-based navigation aids in different reference frames does not have any significant effect since the primary means of navigation remains the use of VOR or NDB signals to define radial tracks to or from the beacon with turning points either at the beacon or at a distance from it, defined by the DME. In such circumstances, published coordinates of the navaid do not affect the track flown by the aircraft. This will dramatically change either in the approach and landing phase or where reduced lateral aircraft separation is implemented, i.e. Area Navigation (RNAV) and Required Navigation Performance (RNP) systems with higher accuracy and integrity requirements. Therefore, these discrepancies will no longer be tolerable and will demand the introduction of a common geodetic reference system for use by international civil aviation.

1.1.7 The United States Department of Defense (World Geodetic System Committee) defined and developed a number of geocentric reference systems to which other geodetic networks may be referred. The continued development using increasingly available satellite information resulted in the World Geodetic System — 1960 (WGS-60), — 1966 (WGS-66), — 1972 (WGS-72) and the current definition — 1984 (WGS-84).

1.2 MAGNITUDE OF THE PROBLEM

1.2.1 The discrepancies between one geodetic reference frame and another depend upon the:

- a) order of magnitude of the three origin shifts;
- b) magnitude of the three axial rotations;
- c) scale factor value; and
- d) shape of the reference ellipsoid (if working in geographical coordinates).

Note.— Most States already have a national reference frame with a specific set of datum parameters. The datum discrepancies range from metres to kilometres.

1.2.2 Figure 1-2 illustrates the magnitude of positional differences for Europe between points expressed in different geodetic datums. The figure represents the differences in seconds of arc between values in national geodetic datums and WGS-72 in five States for latitude and longitude, respectively. WGS-72 has been used for this illustration because the transformation parameters from the national geodetic datums were known. From Figure 1-2, it can be deduced that the differences in position of points with respect to different national geodetic datums and WGS-72 can be in the order of a few hundred metres for a particular State.

1.3 NAVIGATIONAL IMPLICATIONS

1.3.1 Geographical coordinates used in the civil aviation environment today are generally of two type: ground-derived coordinates and navigation system-derived coordinates. Ground-derived coordinates are those that are obtained through surveys, calculations and measurements. They are published by the civil aviation authorities in Aeronautical Information Publications (AIPs) and charts made available to the public. Navigation system-derived coordinates, on the other hand, are coordinates generated by the airborne systems from accelerometers and ground-based or satellite-based signals.

1.3.2 Ground-derived coordinates (latitude and longitude) are determined with measurements and calculations on mathematical reference models. These models represent the shape of the earth in a particular geographic region and are called geodetic datums. For example, coordinates used by civil aviation in the United States are mathematically referenced or calculated to the North American Datum (NAD),

in Japan to the Tokyo Datum (TD) and in Europe to the European Datum (ED). Each of these datums uses a different mathematical model that “best fits” or provides the best representation of the earth’s shape in that specific geographic region. Even though States seldom publicize a geodetic datum, it is common practice for a State to use a specific datum for all mapping, charting and geodetic activities. The mathematical parameters of these datums differ, the location of the centre of each datum differs and, except for those States that have already converted to an earth-centred datum, none of the datum centres coincides with the centre of gravity of the earth.

1.3.3 Unlike ground-derived coordinates, navigation system-derived coordinates are earth-centred. The Inertial Navigation System (INS) uses accelerometers on a gyro- or laser ring-stabilized platform to sense movement and determine aircraft position. The alignment of the platform relates to the earth’s centre of mass and rotation resulting in INS-generated coordinates that are referenced to the earth’s centre. This means that published coordinates as referenced to local geodetic datums will not compare, directly, with INS-generated coordinates. Because INS is normally aligned with local coordinates before take-off, it is the most accurate within the area defined by the local datum. Inter-datum flights up to the present have not been hindered by the “coordinate shift” which is small compared with the drift of the INS on the en-route phase of long-distance flights.

1.3.4 Coordinates derived by the airborne Global Navigation Satellite System (GNSS) from signals received from satellites will be earth-centred because the GNSS satellites operate with an earth-centred reference model, i.e. WGS-84. GNSS coordinates will not compare with coordinates based on local geodetic datums except in areas where coordinates have been readjusted to an earth-centred datum. This means that the difference between the coordinates of a point referenced to a local geodetic datum and the coordinates of that same point referenced to the earth-centred WGS-84 datum has to be taken into account.

1.4 SOLUTION TO THE PROBLEM

1.4.1 The solution to this problem was to adopt WGS-84 as a common geodetic reference frame for civil aviation (see the Foreword). To facilitate implementation of the WGS-84 reference frame, this guidance material was prepared.

1.4.2 The first step in the implementation of any coordinate transformation proposal is to carry out an

inventory. In order to make an assessment of the quality of the published aeronautical geographical coordinates required for air navigation, it is necessary to review all existing related records of aeronautical coordinate data.

1.4.3 A sample questionnaire designed for survey inventory is provided in Appendix G. Information provided through the use of such a questionnaire will allow for accurate estimates and identification of those items for which a field survey is required in order to verify positions.

1.4.4 Analysis of the questionnaire data will identify the navigation aids and aerodrome/heliport points and facilities that need to be resurveyed. It will also identify those positions where the geographical coordinates satisfy the required accuracy and integrity to allow for direct transformation to the WGS-84 geodetic reference frame by mathematical means alone.

1.4.5 In principle, there are two approaches which can be used as stand-alone or combined methods to transform a survey given in adequately accurate coordinates to WGS-84.

- a) Survey at least three control stations (covering the area under consideration) to obtain WGS-84 coordinates and determine the datum parameters between the local reference frame and WGS-84.

- b) Determine by a computational datum transformation WGS-84 coordinates for all remaining points.

1.4.6 There are two general groups of air navigation points for which geographical coordinates are required (see Table 1-1).

1.4.7 The preceding paragraphs considered the horizontal element of the WGS-84 geodetic system. However, WGS-84 is a three-dimensional reference frame coordinated in X, Y, Z or in ϕ, λ and h . Geographical coordinates are expressed in latitude ϕ and longitude λ while the parameter h is the geometric (ellipsoidal) height above the WGS-84 ellipsoid.

1.4.8 GNSS-derived heights are referenced to the WGS-84 ellipsoid which will usually differ from the “normal” (orthometric) height at the same point. The difference will be of significance in the aerodrome environment when navigating with GNSS sensors. The difference between orthometric height (geoid height, elevation) and WGS-84 ellipsoidal height must therefore be made available to the aviation community. The height that separates geoid and WGS-84 ellipsoid is the geoid undulation.

1.4.9 Geoid undulation is required for airport elevations, runway thresholds and touchdown and lift-off areas (TLOFs) or thresholds of final approach and take-off areas (FATOs) at heliports. (See also Appendix B.)

Table 1-1. Air navigation-related coordinates of interest

<i>Area/en-route coordinates</i>	<i>Aerodrome/heliport coordinates</i>
ATS/RNAV route points	Aerodrome/heliport reference points
Holding points	Runway, FATO thresholds
En-route radio navigation aids	Terminal radio navigation aids
Restricted/prohibited/danger areas	FAF, FAP and other IAP essential points
Obstacles — en route	Runway centre line points
FIR boundaries	Aircraft standpoints
CTA, CTZ	Aerodrome/heliport obstacles
Other significant points	

FIGURES FOR CHAPTER 1

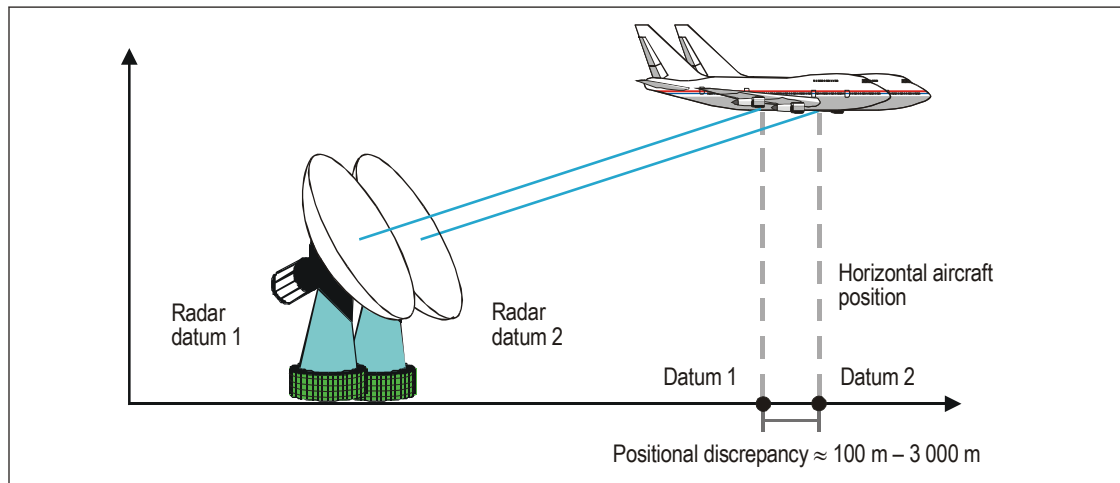
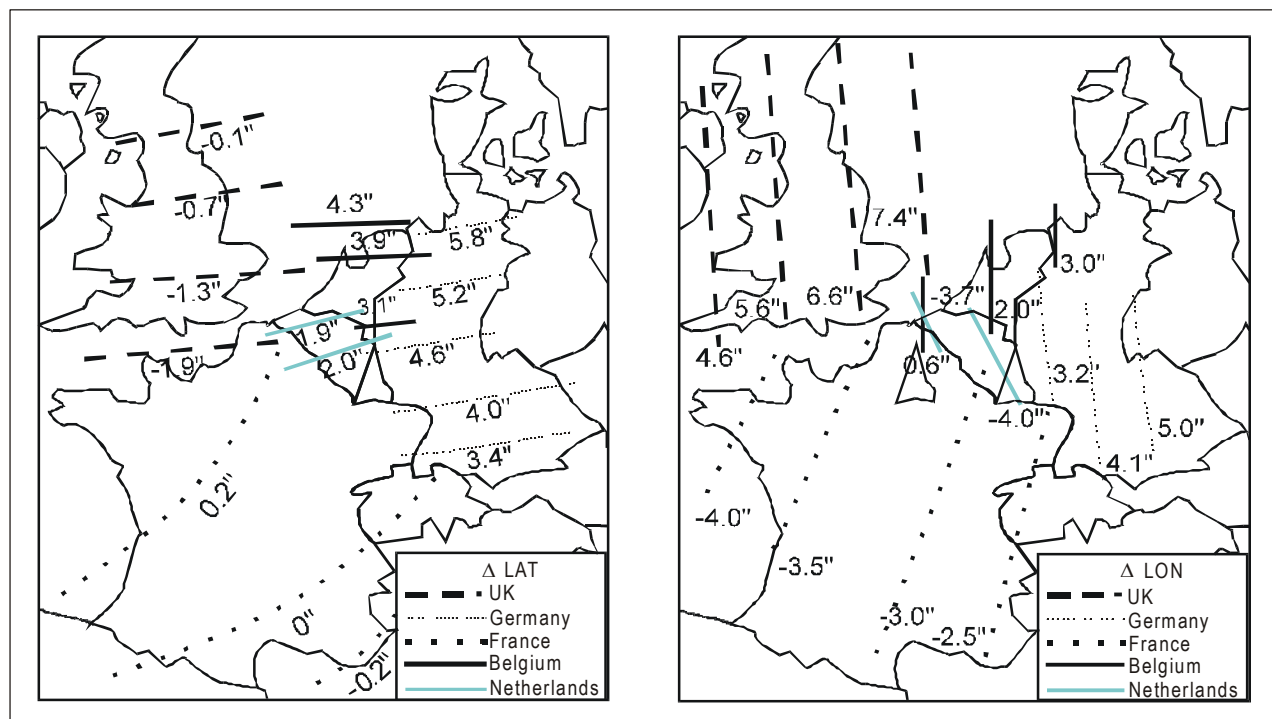


Figure 1-1. Datum problem in air navigation

Figure 1-2. ΔLAT , ΔLON between local and WGS-72 (")

Chapter 2

ACCURACY, RESOLUTION AND INTEGRITY OF AERONAUTICAL DATA

2.1 GENERAL

2.1.1 Traditional navigation techniques have relied upon the ability to fly to or from point navigation aids. While the coordinates of the navigation aids have been provided, this information has not been used as part of the navigation process. Increasing use is being made of Area Navigation (RNAV) systems which derive the aircraft position from such sources as Inertial Navigation Systems (INS), Omega, VHF omni-directional radio range/distance measuring equipment (VOR/DME), dual or multi-DME and Global Navigation Satellite Systems (GNSS). Based on aeronautical data, RNAV systems generate appropriate instructions to the autopilots which enable the aircraft to follow the planned route during the departure, en-route and approach phases and eventually, with the implementation of GNSS, the landing phases.

2.1.2 For such operations, the track actually flown by the aircraft depends upon the coordinates defining both the track and the position of ground-based navigation aids. With the advent of precision RNAV (RNP 1) routes and the extension of RNAV application to terminal area (TMA) procedures, higher precision is required, and it is necessary to ensure that the data defining the track to be flown are of an accuracy, resolution and integrity consistent with the RNP requirements.

2.2 TYPE AND CLASSIFICATION OF POSITIONAL DATA

2.2.1 Air navigation points can be divided into two basic groups (as outlined in Table 1-1):

- a) area/en-route points; and
- b) aerodrome/heliport points.

2.2.2 Besides this basic categorization, air navigation points can be categorized by the type of positional data.

Three types of positional data have been defined: surveyed points, calculated points and declared points (see Tables 2-1 to 2-5).

- a) *Surveyed point.* A surveyed point is a clearly defined physical point, specified by latitude and longitude, that has been determined by a survey, conducted in accordance with the guidance provided in this manual. Communication facilities, gates, nav aids, navigation checkpoints, obstacles and runway thresholds are usually surveyed points.
- b) *Calculated point.* A calculated point is a point in space that need not be specified explicitly in latitude and longitude, but that has been derived, by mathematical manipulation, from a known surveyed point. A fix, specified by radial/bearing and range from a known surveyed point such as a nav aid or by the intersection of a number of radial/bearings from a number of nav aids, is an example of a calculated point. En-route way-points, which are computed from the intersection of routes or from cross radial fixes on routes, are also calculated points, albeit they are reported in latitude and longitude.
- c) *Declared point.* A declared point is a point in space, defined by latitude and longitude, that is not dependent upon, nor formally related to, any known surveyed point. Flight information region (FIR) boundary points and prohibited, restricted or danger area points that are outside control areas are often declared points.

2.3 SOURCE OF RAW AERONAUTICAL DATA

It is the responsibility of relevant technical services, within the appropriate authority of a Contracting State, to ensure the determination of raw aeronautical data required for

promulgation by the aeronautical information service (AIS). On receipt of the raw data, the relevant technical services must check, record and edit the data so that they can be released to the next intended user in a standard format. Raw aeronautical data containing positional information can originate from a number of different sources.

- a) *En-route*. The surveyed positions of navaids and communication facilities are normally provided by the owner/operator (ATC) of the equipment.
- b) *SID, STAR, Instrument approach procedures*. The calculated positions are normally determined by the air traffic service provider responsible for the procedure, in coordination with the technical branch dealing with the procedure design within the State aviation authority.
- c) *Aerodrome/heliport*. The surveyed positions of thresholds, gates, obstacles and navaids, etc. located at the aerodrome/heliport are normally provided by the owner or operator of the aerodrome/heliport.
- d) *Airspace divisions and restrictions*. The declared positions are normally defined by State civil aviation or military authorities or other government bodies.

2.4 ACCURACY REQUIREMENTS

2.4.1 For aeronautical data to be usable, it must be accurate and, in this context, can be subdivided into two distinct categories:

- a) evaluated aeronautical data; and
- b) reference aeronautical data.

2.4.2 Evaluated aeronautical data include such information as positional data, elevation, runway length, declared distances, platform-bearing characteristics and magnetic variation. Reference aeronautical data include navaid identifiers, navaid frequencies, way-point names, rescue and fire-fighting facilities, hours of operation, telephone numbers, etc.

2.4.3 The accuracy requirement for the reference data is absolute; the information is either correct or incorrect. Conversely, the required degree of accuracy of the evaluated data will vary depending upon the use to which the data are put. This manual addresses primarily evaluated positional data but many of the procedures may be applied to other evaluated aeronautical data and to reference data,

if required. Tables 2-1 to 2-5 contain accuracy requirements for aeronautical data as specified in Annex 11 and in Annex 14, Volumes I and II. The requirements for quality assurance and aeronautical data processing procedures are provided in more detail in Chapter 6.

Definition of *Accuracy*. A degree of conformance between the estimated or measured value and the true value.

Note.— For measured positional data the accuracy is normally expressed in terms of a distance from a stated position within which there is a defined confidence of the true position falling.

2.4.4 Accuracy requirements are based upon a 95% confidence level (see Table 2-6). The underlying statistical distribution for positional data in two dimensions is usually taken to be the circular normal distribution. The probability P of a point actually falling within a circle of radius $c\sigma$ around its reported position, where σ represents the standard univariate deviation and c is a numeric coefficient, is:

$$P = 1 - \exp(-c^2/2).$$

2.4.5 The Circular Error Probable (CEP) is the radius of the circle within which 50% of the measurements lie, that is, 1.1774σ . The radius within which 95% of the measurements lie is 2.448σ or $2.079 \times \text{CEP}$. Table 2-6 relates σ error values, probable errors and probabilities in one, two and three dimensions.

2.4.6 The RNP types (see Table 2-7) specify the navigation performance accuracy of all the user and navigation system combinations within an airspace. RNP types can be used by airspace planners to determine airspace utilization potential and as input for defining route widths and traffic separation requirements, although RNP by itself is not a sufficient basis for setting a separation standard.

2.5 RESOLUTION REQUIREMENTS

Definition of *Resolution*. A number of units or digits to which a measured or calculated value is expressed and used.

2.5.1 Resolution of positional data is the smallest separation that can be represented by the method employed to make the positional statement. Care must be taken that the resolution does not affect accuracy; the resolution is always a rounded value as opposed to a truncated value. The order of publication and the charting resolution of aeronautical data must be that specified in Tables 2-1 to 2-5.

Definition of **Precision**. The smallest difference that can be reliably distinguished by a measurement process.

Note.— In reference to the geodetic surveys, precision is a degree of refinement in performance of an operation or a degree of perfection in the instruments and methods used when making measurements.

2.5.2 The terms “precision” and “resolution” are often interchangeable in general use. Here precision is a measure of the data field capacities that are available within a specific system design. (Example: 54° 33' 15" is expressed to a resolution of one second.) Any process that manipulates data subsequent to the original measurement or definition cannot increase the precision to which the data were originally measured or defined, regardless of the resolution available within the system itself.

2.6 INTEGRITY REQUIREMENTS

Definition of **Integrity (aeronautical data)**. A degree of assurance that an aeronautical data and its value has not been lost nor altered since the data origination or authorized amendment.

2.6.1 General

2.6.1.1 The integrity of the data can be regarded as the degree of assurance that any data item retrieved from a storage system has not been corrupted or altered in any way since the original data entry or its latest authorized amendment. This integrity must be maintained throughout the data process from survey to data application. In respect to AIS, integrity must be maintained to the next intended user.

2.6.1.2 Integrity is expressed in terms of the probability that a data item, retrieved from a storage system with no evidence of corruption, does not hold the same value as intended. For example, an integrity of 1×10^{-8} means that an undetected corruption can be expected in no more than one data item in every 100 000 000 data items processed. Loss of integrity does not necessarily mean loss of accuracy. However, it does mean that it is no longer possible to prove that the data are accurate without a further verification of the data from the point at which integrity can be confirmed.

2.6.1.3 The integrity requirements for data are not absolute. The risk associated with a point being in error is dependent upon how that data point is being used. Thus, the integrity of a point at threshold used for landing needs a higher integrity than one used for en-route guidance. It is important to note that a lower accuracy does not necessarily imply a lower integrity requirement.

2.6.2 Requirement for integrity

2.6.2.1 A data item's use forms the basis for determining its integrity requirement. Aeronautical data integrity requirements must therefore be based upon the potential risk resulting from the corruption of data and upon the particular use of the data item. Consequently, the following classification of data integrity must apply.

- a) *Critical data*. There is a high probability when using corrupted critical data that the continued safe flight and landing of an aircraft would be severely at risk with the potential for catastrophe.
- b) *Essential data*. There is a low probability when using corrupted essential data that the continued safe flight and landing of an aircraft would be severely at risk with the potential for catastrophe.
- c) *Routine data*. There is a very low probability when using corrupted routine data that the continued safe flight and landing of an aircraft would be severely at risk with the potential for catastrophe.

2.6.2.2 To each of these types of data, an integrity level requirement has been assigned as follows.

- a) *Critical data: 1×10^{-8}* . This level is given to the runway threshold data which define the landing point. The level of integrity has been derived from the integrity requirement for autoland and is defined to ensure that the overall process, of which aeronautical data are only a part, has the required integrity.
- b) *Essential data: 1×10^{-5}* . This level is assigned to points which, while an error can in itself result in an aircraft being outside of the envelope required, excursion does not necessarily result in a catastrophe. Examples include en-route navigation aids and obstacles. The reason why obstacle data can be held with a relatively lower level of integrity is that, while the data need to be accurate at the time the procedures are designed, any subsequent corruption should have no impact on the safety of the aircraft on the condition that it conforms to the procedure requirements.
- c) *Routine data: 1×10^{-3}* . This level is assigned to data for which errors do not affect the navigation performance. These include FIR boundary points.

Note.— A classification of aeronautical data with respect to integrity are provided in Tables 2-1 to 2-5.

TABLES FOR CHAPTER 2

Table 2-1. Aeronautical data quality requirements (latitude and longitude)

<i>Latitude and longitude</i>	<i>Accuracy data type</i>	<i>Publication resolution</i>	<i>Chart resolution</i>	<i>Integrity classification</i>
Flight information region boundary points	2 km (1 NM) declared	1 min	as plotted	1×10^{-3} routine
P, R, D area boundary points (outside CTA/CTZ boundaries)	2 km (1 NM) declared	1 min	as plotted	1×10^{-3} routine
P, R, D area boundary points (inside CTA/CTZ boundary)	100 m calculated	1 sec	as plotted	1×10^{-5} essential
CTA/CTZ boundary points	100 m calculated	1 sec	as plotted	1×10^{-5} essential
En-route NAVAIDS and fixes, holding, STAR/SID points	100 m surveyed/calculated	1 sec	1 sec	1×10^{-5} essential
Obstacles en-route	100 m surveyed	1 sec	as plotted	1×10^{-3} routine
Aerodrome/heliport reference point	30 m surveyed/calculated	1 sec	1 sec	1×10^{-3} routine
NAVAIDS located at the aerodrome/heliport	3 m surveyed	1/10 sec	as plotted	1×10^{-5} essential
Obstacles in the circling area and at the aerodrome/heliport	3 m surveyed	1/10 sec	1/10 sec (AOC Type C)	1×10^{-5} essential
Significant obstacles in the approach and take-off area	3 m surveyed	1/10 sec	1/10 sec (AOC Type C)	1×10^{-5} essential
Final approach fixes/points and other essential fixes/points comprising instrument approach procedures	3 m surveyed/calculated	1/10 sec	1 sec	1×10^{-5} essential
Runway threshold	1 m surveyed	1/100 sec	1 sec	1×10^{-8} critical
Runway end (flight path alignment point)	1 m surveyed	1/100 sec	—	1×10^{-8} critical
Runway centre line points	1 m surveyed	1/100 sec	1/100 sec	1×10^{-8} critical
Taxiway centre line points	0.5 m surveyed	1/100 sec	1/100 sec	1×10^{-5} essential
Ground taxiway centre line points, air taxiways and transit routes points	0.5 m surveyed/calculated	1/100 sec	1/100 sec	1×10^{-5} essential
Aircraft/helicopter standpoints/INS checkpoints	0.5 m surveyed	1/100 sec	1/100 sec	1×10^{-3} routine
Geometric centre of TLOF or FATO thresholds, heliports	1 m surveyed	1/100 sec	1 sec	1×10^{-8} critical

Table 2-2. Aeronautical data quality requirements (elevation/altitude/height)

<i>Elevation/altitude/height</i>	<i>Accuracy data type</i>	<i>Publication resolution</i>	<i>Chart resolution</i>	<i>Integrity classification</i>
Aerodrome/heliport elevation	0.5 m or 1 ft surveyed	1 m or 1 ft	1 m or 1 ft	1×10^{-5} essential
WGS-84 geoid undulation at aerodrome/heliport elevation position	0.5 m or 1 ft surveyed	1 m or 1 ft	1 m or 1 ft	1×10^{-5} essential
Runway or FATO threshold, non-precision approaches	0.5 m or 1 ft surveyed	1 m or 1 ft	1 m or 1 ft	1×10^{-5} essential
WGS-84 geoid undulation at runway or FATO threshold, TLOF geometric centre, non-precision approaches	0.5 m or 1 ft surveyed	1 m or 1 ft	1 m or 1 ft	1×10^{-5} essential
Runway or FATO threshold, precision approaches	0.25 m or 1 ft surveyed	0.5 m or 1 ft	0.5 m or 1 ft	1×10^{-8} critical
WGS-84 geoid undulation at runway or FATO threshold, TLOF geometric centre, precision approaches	0.25 m or 1 ft surveyed	0.5 m or 1 ft	0.5 m or 1 ft	1×10^{-8} critical
Obstacle Clearance Altitude/Height (OCA/H)	as specified in PANS-OPS (Doc 8168)	—	as specified in PANS-OPS (Doc 8168)	1×10^{-5} essential
Threshold crossing height, precision approaches	0.5 m or 1 ft calculated	0.5 m or 1 ft	0.5 m or 1 ft	1×10^{-8} critical
Obstacles in the approach and take-off areas	1 m or 1 ft surveyed	1 m or 1 ft	1 m or 1 ft	1×10^{-5} essential
Obstacles in the circling areas and at the aerodrome/heliport	1 m or 1 ft surveyed	1 m or 1 ft	1 m or 1 ft	1×10^{-5} essential
Obstacles en-route, elevations	3 m (10 ft) surveyed	3 m (10 ft)	3 m (10 ft)	1×10^{-3} routine
Distance Measuring Equipment/Precision (DME/P)	3 m (10 ft) surveyed	3 m (10 ft)	—	1×10^{-5} essential
Distance Measuring Equipment (DME) elevation	30 m (100 ft) surveyed	30 m (100 ft)	30 m (100 ft)	1×10^{-5} essential
Instrument approach procedures altitude	as specified in PANS-OPS Doc 8168)	—	as specified in PANS-OPS (Doc 8168)	1×10^{-5} essential
Minimum altitudes	50 m or 100 ft calculated	50 m or 100 ft	50 m or 100 ft	1×10^{-3} routine

Table 2-3. Aeronautical data quality requirements (declination and magnetic variation)

<i>Declination/variation</i>	<i>Accuracy data type</i>	<i>Publication resolution</i>	<i>Chart resolution</i>	<i>Integrity classification</i>
VHF NAVAID station declination used for technical line-up	1 degree surveyed	1 degree	—	1×10^{-5} essential
NDB NAVAID magnetic variation	1 degree surveyed	1 degree	—	1×10^{-3} routine
Aerodrome/heliport magnetic variation	1 degree surveyed	1 degree	1 degree	1×10^{-5} essential
ILS localizer antenna magnetic variation	1 degree surveyed	1 degree	—	1×10^{-5} essential
MLS azimuth antenna magnetic variation	1 degree surveyed	1 degree	—	1×10^{-5} essential

Table 2-4. Aeronautical data quality requirements (bearing)

<i>Bearing</i>	<i>Accuracy data type</i>	<i>Publication resolution</i>	<i>Chart resolution</i>	<i>Integrity classification</i>
Airway segments	1/10 degree calculated	1 degree	1 degree	1×10^{-3} routine
En-route and terminal fix formations	1/10 degree calculated	1/10 degree	1/10 degree	1×10^{-3} routine
Terminal arrival/departure route segments	1/10 degree calculated	1 degree	1 degree	1×10^{-3} routine
Instrument approach procedure fix formations	1/100 degree calculated	1/100 degree	1/10 degree	1×10^{-5} essential
ILS localizer alignment	1/100 degree surveyed	1/100 degree True	1 degree	1×10^{-5} essential
MLS zero azimuth alignment	1/100 degree surveyed	1/100 degree True	1 degree	1×10^{-5} essential
Runway and FATO bearing	1/100 degree surveyed	1/100 degree True	1 degree	1×10^{-3} routine

Table 2-5. Aeronautical data quality requirements (length/distance/dimension)

<i>Length/distance/dimension</i>	<i>Accuracy data type</i>	<i>Publication resolution</i>	<i>Chart resolution</i>	<i>Integrity classification</i>
Airway segments length	1/10 km or 1/10 NM calculated	1/10 km or 1/10 NM	1 km or 1 NM	1×10^{-3} routine
En-route fix formations distance	1/10 km or 1/10 NM calculated	1/10 km or 1/10 NM	2/10 km (1/10 NM)	1×10^{-3} routine
Terminal arrival/departure route segments length	1/100 km or 1/100 NM calculated	1/100 km or 1/100 NM	1 km or 1 NM	1×10^{-5} essential
Terminal and instrument approach procedure fix formations distance	1/100 km or 1/100 NM calculated	1/100 km or 1/100 NM	2/10 km (1/10 NM)	1×10^{-5} essential
Runway and FATO length, TLOF dimensions	1 m or 1 ft surveyed	1 m or 1 ft	1 m (AD chart) 0.5 m (AOC chart)	1×10^{-8} critical
Stopway length	1 m or 1 ft surveyed	1 m or 1 ft	0.5 m (AOC chart)	1×10^{-8} critical
Landing distance available	1 m or 1 ft surveyed	1 m or 1 ft	1 m (AD chart) 0.5 m (AOC chart)	1×10^{-8} critical
ILS localizer antenna — runway end and FATO end, distance	3 m or 10 ft calculated	3 m (10 ft)	as plotted	1×10^{-3} routine
ILS glide slope antenna — threshold, distance along centre line	3 m or 10 ft calculated	3 m (10 ft)	as plotted	1×10^{-3} routine
ILS markers — threshold distance	3 m or 10 ft calculated	3 m (10 ft)	2/10 km (1/10 NM)	1×10^{-5} essential
ILS DME antenna — threshold, distance along centre line	3 m or 10 ft calculated	3 m (10 ft)	as plotted	1×10^{-5} essential
MLS azimuth antenna — runway end and FATO end, distance	3 m or 10 ft calculated	3 m (10 ft)	as plotted	1×10^{-3} routine
MLS elevation antenna — threshold, distance along centre line	3 m or 10 ft calculated	3 m (10 ft)	as plotted	1×10^{-3} routine
MLS DME/P antenna — threshold, distance along centre line	3 m or 10 ft calculated	3 m (10 ft)	as plotted	1×10^{-5} essential

Table 2-6. Accuracy and probability

<i>Accuracy expression</i>	<i>One-dimensional probability</i>	<i>Two-dimensional probability</i>	<i>Three-dimensional probability</i>
Three sigma	99.7%	98.9%	97.1%
Two sigma	95.0%	86.0%	78.8%
One sigma	68.0%	39.3%	19.9%
Probable error	50.0% (0.67 σ)	50.0% (1.18 σ)	50.0% (1.54 σ)

Table 2-7. RNP types

<i>Accuracy</i>	<i>RNP 1</i>	<i>RNP 4</i>	<i>RNP 12.6</i>	<i>RNP 20</i>
95% position accuracy in the designated airspace	± 1.85 km (± 1.0 NM)	± 7.4 km (± 4.0 NM)	± 23.3 km (± 12.6 NM)	± 37 km (± 20.0 NM)

Chapter 3

THE GLOBAL WGS-84 COORDINATE SYSTEM

3.1 DEFINITION OF THE WGS-84 COORDINATE SYSTEM

3.1.1 The World Geodetic System — 1984 (WGS-84) coordinate system is a Conventional Terrestrial System (CTS), realized by modifying the Navy Navigation Satellite System (NNSS), or TRANSIT, Doppler Reference Frame (NSWC 9Z-2), in origin and scale, and rotating it to bring its reference meridian into coincidence with the Bureau International de l'Heure (BIH)-defined zero meridian.

3.1.2 Origin and axes of the WGS-84 coordinate system are defined as follows.

- a) *Origin* is the earth's centre of mass.
- b) *Z-axis* is the direction of the Conventional Terrestrial Pole (CTP) for polar motion, as defined by BIH on the basis of the coordinates adopted for the BIH stations.
- c) *X-axis* is the intersection of the WGS-84 reference meridian plane and the plane of the CTP's equator, the reference meridian being the zero meridian defined by the BIH on the basis of the coordinates adopted for the BIH stations.
- d) *Y-axis* completes a right-handed, earth-centred, earth-fixed (ECEF) orthogonal coordinate system, measured in the plane of the CTP equator, 90° east of the X-axis.

Note.— An illustration of the WGS-84 coordinate system origin and axes, which serve also as the geometric centre and the X, Y, and Z axes of the WGS-84 ellipsoid, is given in Figure 3-1.

3.1.3 WGS-84 is an earth-fixed global reference frame, including an earth model, and is defined by a set of primary and secondary parameters. The primary parameters, given in Table 3-1, define the shape of an earth ellipsoid, its

angular velocity, and the earth mass which is included in the ellipsoid of reference.

3.1.4 The secondary parameters define a detailed Earth Gravity Field Model (EGFM) of the degree and order $n = m = 180$. The WGS-84 EGFM, through $n = m = 180$, is to be used when calculating WGS-84 geoid heights, WGS-84 gravity disturbance components, and WGS-84 $1^\circ \times 1^\circ$ mean gravity anomalies via spherical harmonic expansions. Expansions to this degree and order ($n = m = 180$) are needed to accurately model variations in the earth's gravitational field on or near the earth's surface. The WGS-84 EGFM, through $n = m = 41$, is more appropriate for satellite orbit calculation (e.g. GPS navigation satellites) and prediction purposes.

3.2 REALIZATION OF THE WGS-84 COORDINATE SYSTEM

3.2.1 The origin and the orientation of coordinate axes in WGS-84 are defined by the X, Y, Z coordinates of the five GPS monitoring stations (see Figure 3-2).

3.2.2 Historically, the coordinates of the GPS tracking sites have been determined by the use of Doppler measurements to the TRANSIT satellite navigation system. Data, observed over long periods, have been processed in order to derive precise station coordinates. The use of TRANSIT Doppler measurements in WGS-84 is a good example of the practical realization of a reference system. It should be pointed out, however, that errors can spread into the procedures used to realize reference frames.

3.3 ACCURACY OF WGS-84 COORDINATES

3.3.1 The accuracy, one sigma, (1σ) of WGS-84 coordinates directly determined in WGS-84 by GPS Satellite Point Positioning, their respective precise ephemerides and ground-based satellite tracking data acquired in static mode,

in terms of geodetic latitude ϕ , geodetic longitude λ , and geodetic height h , is:

- a) horizontal — $\sigma\phi = \sigma\lambda = \pm 1 \text{ m (1 } \sigma\text{)}$; and
- b) vertical — $\sigma h = \pm 1 \dots 2 \text{ m (1 } \sigma\text{)}$.

3.3.2 These errors incorporate not only the observational error but also the errors associated with placing the origin of the WGS-84 coordinate system at the earth's centre of mass and with determining the correct scale. These absolute values should not be confused with the centimetre-precision of GPS differential positioning. At the time WGS-84 was established, only satellite Doppler measurements with corresponding accuracy were available to determine the ground control segment of WGS-84.

3.3.3 The WGS-84 coordinates of a non-satellite-derived local geodetic network station will be less accurate

than the WGS-84 coordinates of a GPS station. This is due to the distortions and surveying errors present in local geodetic datum networks, i.e. the lack of a sufficient number of properly placed GPS stations collocated with local geodetic networks for use in determining the transformation parameters and the uncertainty introduced by the datum transformation.

3.3.4 The accuracy of $\pm 1 \text{ m}$ in the definition of WGS-84 is sufficient for nearly all air navigation applications. Additional considerations may be necessary if, for example, satellite-based landing systems down to Category III are to be used in the future. Precision approach Category III needs a vertical accuracy of 0.6 m and a horizontal accuracy of 6.0 m, which cannot be supplied by WGS-84 according to its accuracy definition, but can be supplied, for instance, by International Terrestrial Reference Frame (ITRF).

Table 3-1. Parameters of WGS-84

<i>Parameter</i>	<i>Abbreviation</i>	<i>WGS-84</i>
Semi-major axis	a	6 378 137 m
Angular velocity	ω	$7.292115 \times 10^{-5} \text{ rad s}^{-1}$
Geocentric gravitational constant (Mass of the earth's atmosphere included)	GM	$398\,600.5 \text{ km}^3 \text{ s}^{-2}$
Normalized second degree zonal harmonic coefficient of the gravitational potential	$\bar{C}_{2,0}$	$-484.16685 \times 10^{-6}$
Flattening (derived from $\bar{C}_{2,0}$)	f	1/298.257223563

FIGURES FOR CHAPTER 3

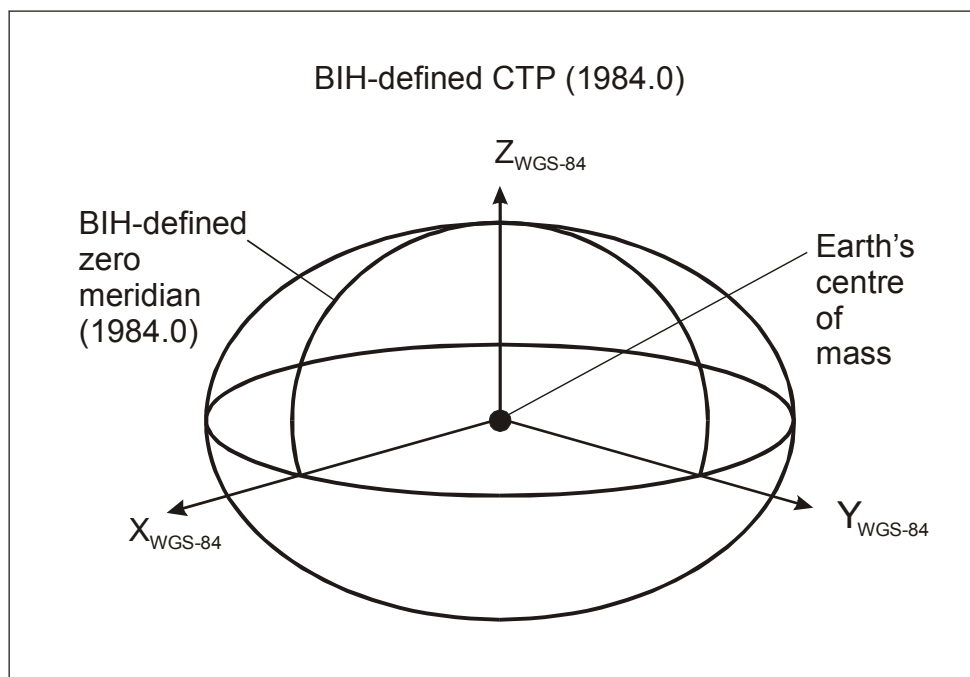


Figure 3-1. The WGS-84 coordinate system definition

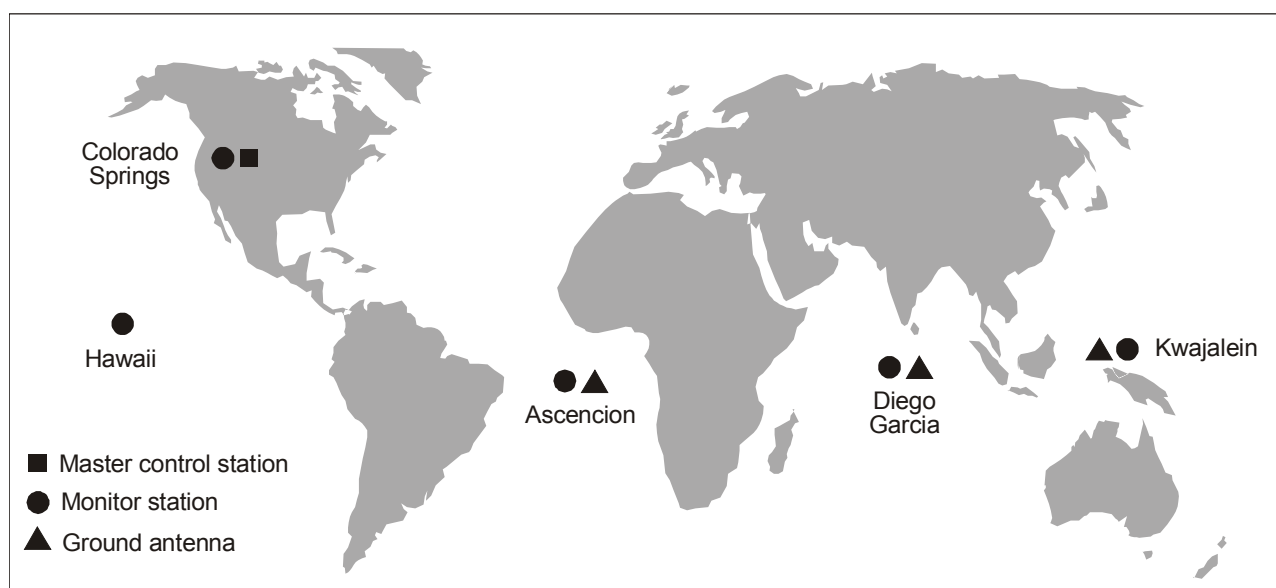


Figure 3-2. Realization of origin and orientation of WGS-84

Chapter 4

A GUIDE TO OBTAIN WGS-84 COORDINATES

4.1 GENERAL

This chapter is intended to be a guide with “recipes” for users to produce WGS-84 coordinates. The user of the manual is guided through the steps necessary, depending on the existence and the quality of aeronautical data, to obtain WGS-84 coordinates. The first question to be answered is:

Are coordinates of the required accuracy available?

Yes If these coordinates are available in a local reference frame, then proceed to 4.2 (Scenario 1). If the available coordinates have been digitized from maps, then proceed to 4.4 (Scenario 3).

When considering the use of existing data, it is important to check and control the coordinates of navigation facilities with respect to accuracy and integrity before transforming them to WGS-84 by mathematical means. One has to keep in mind that coordinates in air navigation could be safety-critical and that high-integrity requirements have to be fulfilled. In order to fulfil the quality requirements for coordinates, the surveyor must ensure that:

- a) point labels have not been interchanged or misidentified;
- b) the coordinates can be verified by aid of redundant measurements; and
- c) the accuracy is predictable and sufficient.

No If coordinates of the required accuracy are not available or if, for example, the integrity requirements cannot be fulfilled, a resurvey with related field work must be performed. The different methods of performing this resurvey to provide accurate WGS-84 coordinates are explained under 4.3 (Scenario 2).

4.2 SCENARIO 1: COORDINATES IN A LOCAL REFERENCE FRAME ARE AVAILABLE

Two approaches exist to transform coordinates given in national coordinates to WGS-84 coordinates. They are dependent on knowledge of the transformation parameters and the type of coordinate system, and can be used as stand-alone methods or combined.

4.2.1 Checking the type of coordinate system

4.2.1.1 Before carrying out a datum transformation, check if the transformation parameters from the local reference frame to WGS-84 are known and answer the following question:

Are all transformation parameters known?

Yes Perform a computational datum transformation by using the datum transformation formulae (4.2.2 refers) to determine the WGS-84 coordinates. Several software programmes exist to support this procedure, e.g. the DATUM programme.

Note.— DATUM performs coordinate transformations between a variety of existing geodetic reference frames and WGS-84.

No Use the GPS surveying technique, at known control stations (covering the area under consideration), to obtain WGS-84 coordinates. Since these control stations are known in the local reference frame and in WGS-84, two sets of coordinates for identical stations exist. These can then be used to determine the datum parameters in the Helmert Formula. At least three known control stations have to be surveyed by GPS to obtain additional WGS-84 coordinates necessary for determining all seven Helmert transformation parameters (using the Inverse Helmert Formula). In practice, however, it is usual to

have as many common points as possible to obtain the best estimate of the parameters by least squares.

Note.— See Appendix A for information on GPS surveying. See Appendix D for a detailed description of the Helmert Formula.

4.2.1.2 For the following example, it is assumed that only the shifts of origin between the local reference frame and the WGS-84 have to be determined and that, therefore, only one known control station was GPS-surveyed. The inverse Helmert Formula for solving the three shift of origin parameters reads:

$$\begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS-84} - \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Local}$$

Shift of
origin

Assumption: No change in orientation ($\epsilon_X = \epsilon_Y = \epsilon_Z = 0$) and scale ($\mu = 1$) between the local reference frame and WGS-84.

4.2.1.3 After determining all necessary transformation parameters, proceed as explained at the beginning of 4.2.1.1. The method of referencing a local (i.e. relative) and sufficiently accurate GPS aerodrome survey to WGS-84 by simply measuring the coordinate differences between one aerodrome point to a known and monumented WGS-84 station is called direct geodetic connection. In applying this procedure, all the airport coordinates can be directly transformed to WGS-84. The problem, however, is that not many geodetic stations exist worldwide for which accurate WGS-84 coordinates are known. It is therefore recommended to use, if available, ITRF stations for this purpose. If no ITRF station is near the aerodrome or navigation facility, the connection survey can be very laborious. In this case, long distances have to be traversed by surveying, which could be very expensive.

4.2.2 Horizontal datum transformations

4.2.2.1 There are three different approaches for transforming coordinates from a local datum to WGS-84. Use the:

- a) *Helmert Formula* to carry out the transformation in rectangular Cartesian coordinates X , Y , Z , using three-, four-, or seven-parameter transformations depending on the availability and/or reliability of the transformation parameters. The Helmert Formula can also be applied for spatial ellipsoidal

coordinates f , l , h by transforming from ellipsoidal coordinates to rectangular coordinates and vice versa.

- b) *Standard Molodensky Formula* to solve the transformation in curvilinear coordinates f , l , h .
- c) *Multiple Regression Equation* approach to account for the non-linear distortion in the local geodetic datum. (Only recommended for large areas).

Note.— See Appendix D for a detailed description of these datum transformation formulae and Table B-1 for a list of reference ellipsoids and parameters.

4.2.2.2 Accuracy considerations

4.2.2.2.1 Because of error propagation, a datum transformation will never improve the survey accuracy. In most cases the accuracy of the transformed coordinates in the absolute sense is worse than the accuracy of the original coordinates. The user has to check, in particular, whether the resulting coordinate accuracy still meets the requirements. Furthermore, this quality control may be difficult to perform.

4.2.2.2.2 Two of the several reasons known for this loss of accuracy are:

- a) because the datum or transformation parameters are, in many cases, only weakly determined, substantial discrepancies of up to 50 m in datum parameters can occur between published values from different reference sources. Furthermore, the accuracy of a navigation aid's original coordinates may not be sufficient, and in many cases the accuracy of the datum parameters is undefined; and
- b) there may be a slight distortion in the national network in the area under consideration.

4.2.2.3 Limitations of transformations

4.2.2.3.1 It should be noted that random and systematic errors in local survey data transform directly to WGS-84. Because of geodetic network geometry and error propagation in these networks, the local datum parameters for a State are not constant in practice but vary with location in the geodetic network.

4.2.2.3.2 The signal-to-noise ratio for the datum parameters is, in many cases, close to one, i.e. the noise level is very high relative to the magnitude of the datum

parameter itself. For example, the orientation angles of a datum could be published, typically as, say, $0.5'' \pm 0.3''$.

4.2.2.3.3 The predicted error, or uncertainty, is often larger than the value itself. Figure 4-1 shows, in a qualitative manner, how the errors in transformation procedures propagate into transformed coordinates.

4.2.2.3.4 The error sources in a datum transformation are errors in the shift parameters, the orientation parameters and the scale factor. The scale factor error is incorporated in the above in that it is treated like an orientation error, in radians, applied to the coordinate value to be transformed by multiplication. Even an accurate survey with an internal accuracy of, say, 0.1 m may show, after the transformation parameters have been applied, only 1 m level accuracy in WGS-84. Here the difference between absolute and relative point accuracy has to be considered.

4.3 SCENARIO 2: COORDINATES OF THE REQUIRED ACCURACY ARE NOT AVAILABLE

4.3.1 New field survey techniques

4.3.1.1 If coordinates of the required accuracy are not available, a new field survey must be performed using one, or a combination of, the following techniques:

- a) conventional surveying;
- b) GPS surveying; or
- c) photogrammetric surveying.

4.3.2 Best technique(s) for new field survey

4.3.2.1 In deciding which of the above techniques is (or are) the most efficient for the new field survey, the following may be used as guidance.

- a) Use the GPS technique for surveying limited and relatively small areas in a very economical way.
- b) Use the photogrammetric technique if the area to be surveyed is very large.
- c) Use conventional surveying if the area to be surveyed contains many obstructions which would lead to GPS signal losses or multipath.

Note.— There is no doubt that a complete resurvey of the point using differential GPS satellite surveying techniques (relative to a known station with WGS-84 coordinates) is the most accurate approach for determining precise WGS-84 coordinates.

4.3.3 Determination by conventional terrestrial surveying

4.3.3.1 Figure 4-2 shows how WGS-84 coordinates can be obtained by conventional terrestrial surveying.

4.3.3.2 Some of the conventional surveying instruments of modern type (levelling instrument, theodolite, distance meter, total station) have interactive field computational capabilities. After downloading the data via an interface into an office computer, final post-processing could be carried out. Before the derived coordinates can enter the survey database, they have to be quality-controlled, and integrity checks have to be performed. Various graphic visualizations of data and results can also be done.

Note.— For more information on conventional surveying, see Appendix E.

4.3.4 Determination by GPS surveying

4.3.4.1 Most of the field surveying which is necessary for the positioning of navigation aids, radars, runways, etc., is best carried out by differential GPS satellite surveying. This method has the advantages of 24-hour all-weather operations, ease of use, speed, economy, high accuracy and, most importantly, direct compatibility with the WGS-84 datum.

4.3.4.2 GPS receivers store the field data. After finishing the survey, the data have to be downloaded to a computer where they are post-processed using software packages provided by GPS hardware manufacturers and/or universities. The processing can be done either by individual baseline or in a multisession-multistation network approach. Again, before the derived coordinates can enter the survey database, they have to be quality-controlled, and integrity checks have to be performed. Various visualizations of data and results can also be performed.

Note.— For the choice of the GPS surveying technique, (static, rapid static, kinematics survey, etc.) which depends to a great extent on the desired accuracy, see Appendix A and Table A-2.

4.3.5 Determination by aero-photogrammetry

4.3.5.1 Figure 4-3 shows the determination of WGS-84 coordinates by using photogrammetric flights. The parameters of the photogrammetric flight have to be determined as a function of anticipated coordinate accuracy of the ground stations. If no WGS-84 coordinates at ground stations are available, they have to be established using GPS differential surveying techniques. Thus, a network of ground control points whose coordinates and heights are known in advance is an essential requirement for referencing the newly derived coordinates to a national datum. The points to be coordinated have to be marked so that a unique identification in the aerial photos is possible.

4.3.5.2 If necessary, permission must be obtained to release photo data. These data are then developed and the stereo model construction is carried out in a photogrammetric instrument in the office. After inputting the ground control coordinates and, if available, GPS-derived camera positions, the data are processed by a bundle block adjustment.

4.3.5.3 Again, before the derived coordinates can enter the survey database, they have to be quality-controlled, and integrity checks have to be performed. Various visualizations of data and results can then be done.

Note.— For more information on aero-photogrammetry and the minimization of ground control stations, see Appendix E.

4.4 SCENARIO 3: COORDINATES DIGITIZED FROM MAPS ARE AVAILABLE

Note.— This section helps the user transform coordinates to WGS-84, if the coordinates are available from digitized maps.

4.4.1 Restrictions

4.4.1.1 While digitized data have no inherent scale information, the accuracy of the data is clearly limited by the corresponding accuracy of the analogue map from which the data were originally extracted and of the digitizing process involved. A new analogue map may be printed using a larger scale than that of the original map, but this does not increase the accuracy to the level normally associated with the larger scale. The problem is further compounded by the frequent revision and updating of the database with newly surveyed field data. Furthermore, the

digitizing process involves the straightening and squaring of regular objects, leading to apparently “well drawn” maps even after the enlargement process.

4.4.1.2 The most important drawback of digitized maps, however, is the very nature of an analogue database. High-precision mapping coordinates are generally given in national grid northings and eastings, which have been obtained by converting geodetic (ellipsoidal) coordinates into a map projection. In addition, one must consider the more significant projection scale and orientation errors inherent in all map projections. While these can be reduced by the judicious use of an orthomorphic projection (e.g. Transverse Mercator), they are still substantial, rendering the process of extracting coordinate information from a map precarious. For example, if the grid coordinates of two points are extracted from the map and the grid distance computed, the distance would be up to 30 cm per kilometre shorter than the value measured on the ground. This is significant and may have serious implications.

4.4.1.3 Therefore, when digitizing coordinates from maps, the following points should be considered:

- a) It is necessary to check by which technique the map was established (from analogue data/digitizing of other maps, from digital data, etc.).
- b) In order to convert the northings and eastings to geographical coordinates, it is necessary to know the exact formulae of the map projection.
- c) It is necessary to know the original datum of the projected coordinates as well as the new one, when transforming.
- d) Datum coordinate transformation can only be applied after converting map projection coordinates to geodetic coordinates.
- e) The resulting accuracy of digitized coordinates should be checked and verified in order to decide whether the anticipated accuracy requirements have been met.

4.4.1.4 WGS-84 is the definition of the centre of mass of the Earth as determined in 1984 and all charts produced prior to that date using a different geodetic reference will not correspond exactly to new charts based on WGS-84. Finally, one has to bear in mind that maps never contain ellipsoidal heights. For example, heights in different maps may refer to:

- a) different zero points (tide gauges); or

- b) different types of height systems. (There are not only orthometric heights, but also so-called normal heights, for example, in Eastern Europe.)

4.4.2 Transformations

4.4.2.1 To transform coordinates digitized from maps to WGS-84, it is essential to answer the following question:

Is the kind of map projection, which was used in the local survey for mapping the reference ellipsoid to the plane and for computing the plane metric coordinates, known?

- No* If this question cannot be answered or the projection is not known, then Scenario 2 applies and a resurvey should be performed.
- Yes* If the type of map projection is known, the inverse map projection has to be calculated to compute latitude and longitude of the digitized metric coordinates on the reference ellipsoid.

Note.— See Appendix F for different types of map projections.

4.4.2.2 All datum transformations require the use of the ellipsoidal height h in the local system, which is:

$$h = H + N$$

where H is the orthometric height (elevation) and N is the geoid undulation (height). In general, only the orthometric height is known (and found also on maps). The geoid undulation has to be taken from a digital model (if available). However, an investigation was made checking the effect of an unknown (orthometric) height on the transformed latitude and longitude of a point using the Helmert Formulae. By assigning heights ranging from 0 m to 8 000 m, it was concluded that the effect on both latitude and longitude was negligible (less than 15 cm at 8 000 m). Consequently, for a point of known latitude and longitude but unknown (orthometric) height, an arbitrary height of 0 m could be assigned without significantly affecting the transformation.

4.4.2.3 Because national surveying agencies are using different kinds of reference ellipsoids, the next step is to determine which reference ellipsoid is being used in order to perform the datum transformation from the local datum to the global datum. Sometimes it may be possible to transform directly from the local datum to WGS-84. If not, then a further transformation from the global datum to WGS-84 has to be undertaken.

FIGURES FOR CHAPTER 4

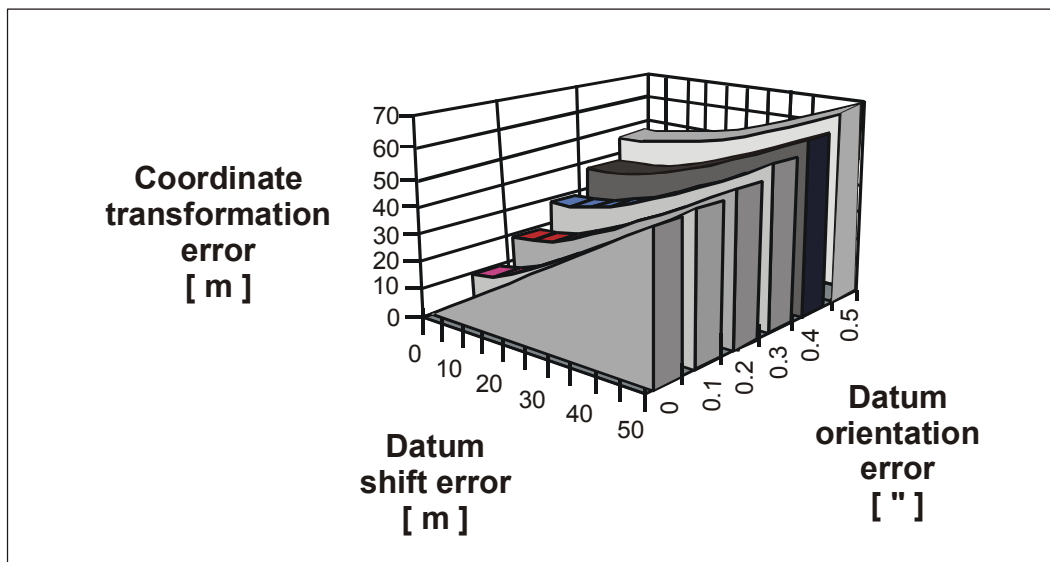


Figure 4-1. Error propagation in datum transformation

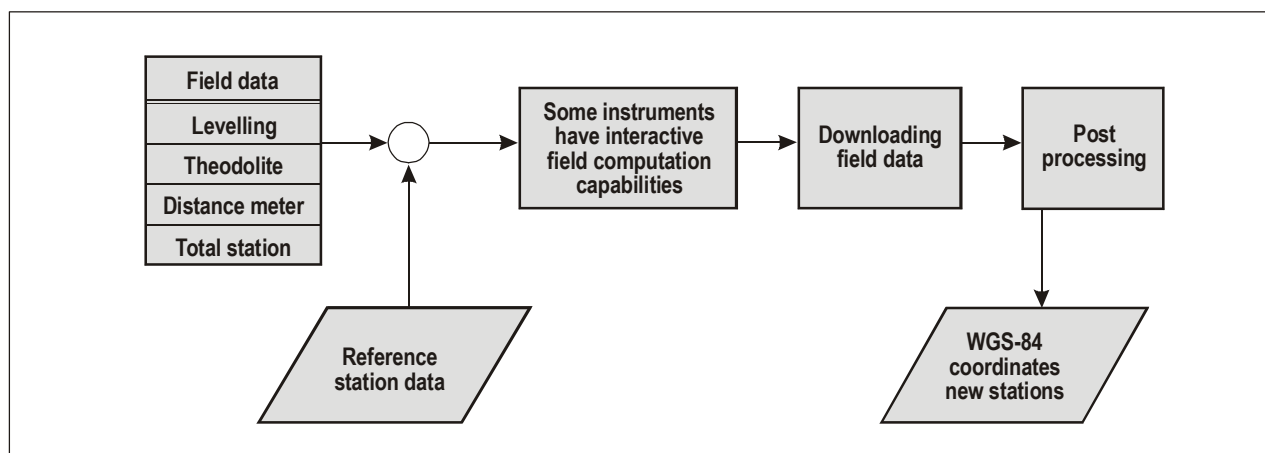


Figure 4-2. From terrestrial surveying data to WGS-84 coordinates

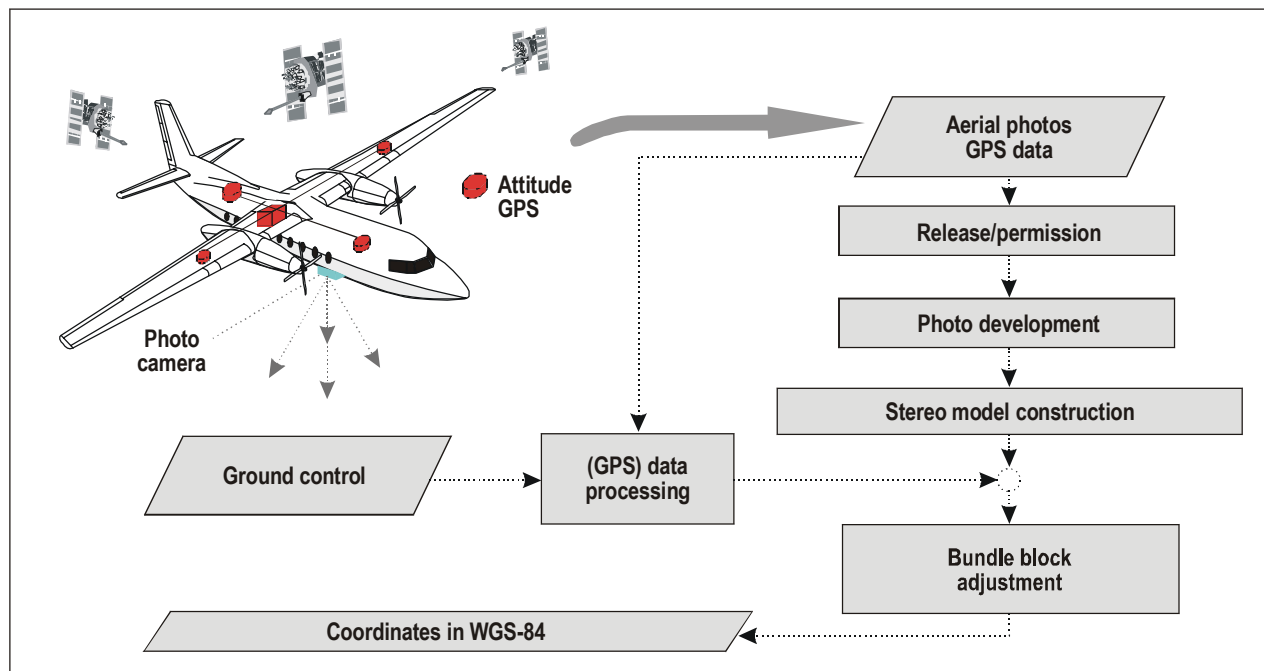


Figure 4-3. From results of photogrammetric flights to WGS-84 coordinates

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Chapter 5

SURVEYING GUIDANCE

5.1 INTRODUCTION

This chapter sets out guidance for surveying the geographical positions of navigation aids and navigation points brought about by the adoption of WGS-84 as a common geodetic reference frame for international civil aviation. The particular accuracy of the field work values has been based on operational requirements and is in accordance with the provisions set forth in Annexes 11 and 14, Volumes I and II while resolutions requirements are set forth in Annexes 4 and 15. The specified accuracies can, in many cases, easily be exceeded using modern survey instrumentation.

5.1.1 Application of requirements

5.1.1.1 The requirements contained in this chapter apply to all aerodromes/heliports selected by national administrations for international and domestic use and they relate to the surveying, with respect to WGS-84, of the geographical coordinates of navigation elements. Those navigation aids and points whose coordinates contribute directly to air navigation are considered in this chapter as navigation elements. Surveying guidance covers the determination of coordinates, i.e. latitudes and longitudes of certain navigation positions.

5.1.1.2 The results of the surveying of WGS-84-related geographical positions of navigation elements must be reported to the aeronautical information service of the national administration, in accordance with the provisions in Annexes 11 and 14.

5.1.1.3 This chapter includes surveying requirements for those aerodrome/heliport positions, such as designated aircraft stands and navigation checkpoints, whose coordinates may be used for the purpose of checking, calibrating or initializing navigation equipment. The list of navigation elements to be surveyed is given in Table 5-1.

5.2 GENERAL SPECIFICATIONS

5.2.1 The geodetic datum to which coordinates of navigation elements must be referenced is WGS-84. This requirement will be achieved by surveying with respect to an appropriate global geodetic reference frame.

5.2.2 All aeronautical coordinate data which meet the specifications of this manual must be such that their quality can be demonstrated. The accuracy of the field work, with respect to determination of the geographical coordinates of the various navigation elements, has been set in accordance with both current and anticipated operational requirements. Where a navigation aid serves more than one phase of flight and is thereby subject to different operational requirements, the more stringent surveying accuracy requirement must apply.

5.2.3 All position accuracies must relate to a probability of 95% (2σ) containment unless otherwise stated. Units of measurement must be in accordance with the survey custom and practice of the particular State. All published geographical positions and dimensions must be in accordance with ICAO requirements. In this regard, geographical positions must be published in the form of sexagesimal degrees (degrees, minutes, seconds and decimals of a second) and to the publication resolutions in Annex 15, Appendix 7 and the charting resolutions in Annex 4, Appendix 6.

5.2.4 Dimensions and distances must be quoted in one of the following units:

- a) metres (m);
- b) feet (1 ft = 0.3048 m); or
- c) nautical miles (1 NM = 1 852 m).

5.2.5 Aerodrome/heliport survey control network

In order to determine the position of navigation elements at, and in the vicinity of, designated aerodromes/heliports, a

Table 5-1. Minimum survey accuracy and integrity requirements for navigation elements

Note.— Accuracies are those relative to the established aerodrome/heliport survey control network except where marked by an asterisk () when they relate to absolute coordinates with respect to the datum.*

<i>Latitude and longitude</i>	<i>Accuracy data type</i>	<i>Integrity classification</i>
En-route NAVAIDS and fixes, holding, STAR/SID points	100 m surveyed/calculated	1×10^{-5} essential
Aerodrome/heliport reference point	30 m surveyed/calculated	1×10^{-3} routine
NAVAIDS located at the aerodrome/heliport	3 m surveyed	1×10^{-5} essential
Obstacles in the circling area and at the aerodrome/heliport	3 m surveyed	1×10^{-5} essential
Significant obstacles in the approach and take-off area	3 m surveyed	1×10^{-5} essential
Final approach fixes/points and other essential fixes/points comprising instrument approach procedure	3 m surveyed/calculated	1×10^{-5} essential
Runway (landing) threshold	1 m surveyed	1×10^{-8} critical
Runway end (flight path alignment point)	1 m surveyed	1×10^{-8} critical
Runway centre line points	1 m surveyed	1×10^{-8} critical
Taxiway centre line points	0.5 m surveyed	1×10^{-5} essential
Ground taxiway centreline points, air taxiways and transit routes points	0.5 m surveyed/calculated	1×10^{-5} essential
Aircraft standpoints/INS checkpoints	0.5 m surveyed	1×10^{-3} routine
Geometric centre of TLOF or FATO thresholds at heliports	1 m surveyed	1×10^{-8} critical
WGS-84 geoid undulation at aerodrome/heliport elevation position	0.5 m or 1 ft surveyed	1×10^{-5} essential
WGS-84 geoid undulation at runway or FATO threshold, TLOF geometric centre, non-precision approaches	0.5 m or 1 ft surveyed	1×10^{-5} essential
WGS-84 geoid undulation at runway or FATO threshold, TLOF geometric centre, precision approaches	0.25 m or 1 ft surveyed	1×10^{-8} critical
Aerodrome/heliport survey control network (datum transfer)	1 m * surveyed	1×10^{-8} critical

network of survey control stations must be established at each such aerodrome/heliport. The network must consist of a minimum of two inter-visible survey stations at a minimum lateral separation of 500 m. The aerodrome/heliport survey control network may consist of a minimum of four stations so as to provide sufficient redundancy to be able to sustain the loss of one survey station and still enable the orientation to be checked. Survey stations must be strategically located so as to provide maximum utility in subsequent surveys. The monuments of existing aerodrome/heliport survey control networks may be used for the purposes laid down in this chapter.

5.2.6 Control network accuracy requirements

5.2.6.1 The position of each survey station must be determined to an accuracy of 1 m with respect to an appropriate geodetic reference frame. The control network must have an internal accuracy consistent with the need to provide control for the survey of navigation elements to the accuracies set out in the relevant Annexes and in this chapter. The aerodrome/heliport survey control network may have an internal consistency of better than 10 cm.

5.2.6.2 Mathematical transformation methods based on a single set of average transformation parameters, which relate known (existing) datum to WGS-84, must not be used for the purpose of determining the coordinates of the aerodrome/heliport survey control network.

5.2.7 Monumentation of survey control stations

The survey control stations must consist of standard types of survey monuments (see Attachment A to this chapter). Different types of monuments will be appropriate for different locations and ground conditions at the aerodrome/heliport; it is the surveyor's responsibility, under the guidance of the national administration, to decide on the most appropriate type. Investigation may be made prior to the installation of a survey monument to ensure that underground cables and services are not affected by the installation. Where the survey network consists of fewer than the recommended four stations, monuments of a larger size must be used.

5.2.8 Station numbering

5.2.8.1 Each survey station must carry an individual number. This will ensure that, where a station has been destroyed and subsequently replaced by a new station in approximately the same location, misidentification does not occur.

5.2.8.2 Station labelling and numbering must be such that there is no doubt as to the provenance or identity of the survey station. Uniform labels (e.g. stamped disks) may be used at individual aerodromes/heliports for all survey stations. An unambiguous numbering system, identifying the aerodrome/heliport, year and station number, may be used (see Attachment A to this chapter). Where an existing, substantial topographic surface feature is used as a survey station, the station must be clearly marked with durable paint.

5.2.9 Station location plan

An aerodrome/heliport survey network plan, at a scale of 1:2 000 or other appropriate standard cartographic scale, indicating the location of all survey stations and principal topographic features must be prepared. The plan may be orientated to true north or, alternatively, have the direction of true north indicated on the plan.

5.2.10 Station descriptions

5.2.10.1 A comprehensive aerodrome/heliport survey network station description must be prepared. This must consist of a written description and a clear diagram indicating the dimensions and direction indicators to other visible points on the aerodrome/heliport survey control network.

5.2.10.2 A photograph of the station showing background detail may be included in the description. Inspections may be made to check on the general condition of the aerodrome/heliport survey network, and any disturbance or damage must be recorded.

5.2.11 Determination of control coordinates

5.2.11.1 One of the following methods of coordinate determination must be used to fix the positions of the aerodrome/heliport survey control network.

- a) *Direct geodetic connection.* Survey measurements must be taken to connect the aerodrome/heliport survey control network to a national or international (e.g. 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/heliport survey control network. 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. Static differential GPS connections may be made to, preferably, three points on an appropriate geodetic network but, in all cases, must be made to a minimum of two.
- b) *Derived geodetic connection.* Where the local relationship between the existing geodetic control network and WGS-84 is known to an accuracy commensurate with the requirements in this manual, then standard, nationally or regionally approved transformation methods may be used to determine the coordinates of an existing aerodrome/heliport survey control network. Where this method is adopted, a full description of the transformation method and the values of the transformation parameters must be included in the report. Full details of the connection of the existing aerodrome/heliport survey control network to the existing geodetic network must be included in the survey report (an existing network means one that existed at the aerodrome/heliport prior to the implementation of WGS-84 at that aerodrome/heliport).



- c) *Direct observation of WGS-84.* For those regions where national or international coordinates are unavailable, the coordinates of the aerodrome/heliport survey control network must be determined by direct observation of WGS-84 by using an appropriate type of geodetic GPS receiver. All such observations must be controlled by simultaneous observations made at points of known absolute WGS-84 coordinates. The observation and computation method must be such that the absolute coordinates of the aerodrome/heliport survey control network are determined to the accuracy stated in this chapter.

5.2.12 Determination of the local relationship between the known existing datum and WGS-84

5.2.12.1 Where existing relative surveys need to be related to WGS-84 (e.g. aerodrome/heliport obstacle surveys), observations must be taken to determine the local relationship (difference in latitude, longitude, orientation and scale) between the known existing datum and WGS-84, except where the required information is provided by a derived geodetic connection.

5.2.12.2 Where used, the local relationship between the known existing geodetic datum and WGS-84 must be determined to an accuracy commensurate with the relative accuracy of the data to be transformed. The values and accuracies of the local relationship must be declared in the survey report.

5.2.13 Report requirements

5.2.13.1 All survey work undertaken to determine the coordinates of navigation facilities at aerodromes/heliports must be reported in the format specified in Attachment C to this chapter. Where an existing national reporting practice differs from that shown in this chapter, the national administration may make a case in support of the national practice, where the national practice can be shown to be compatible.

5.2.13.2 Table 5-1 lays down the minimum survey accuracies that must be achieved. These accuracies can, in many cases, easily be exceeded using modern survey instrumentation. All survey observations may 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. Where surveys are undertaken using equipment or techniques that yield height data as well as horizontal position, these must be comprehensively recorded and included in the survey report.

5.3 SURVEY REQUIREMENTS FOR AERODROME/HELIPORT-RELATED NAVIGATION ELEMENTS

5.3.1 Runway centre lines and thresholds

5.3.1.1 For surveying purposes, the centre line of a runway must be taken as being the geometric centre of the width of the bearing surface, this definition taking precedence over any existing runway centre line markings or lighting. Where the edge of the runway is irregular or connected to a taxiway, an appropriate theoretical line must be selected which best identifies the probable edge of the runway.

5.3.1.2 For surveying purposes, threshold positions must be taken as being at the geometric centre of the runway and at the beginning of the paved surface, i.e. the beginning of that portion of the runway usable for landing. Where thresholds are marked by appropriate threshold markings (e.g. displaced thresholds), these must be taken as the threshold points. Where threshold lighting is surveyed, the locations must be described on the diagram accompanying the report. Where there is no threshold lighting, the surveyor must select an appropriate point for survey in accordance with the diagrams shown in Attachment B to this chapter.

5.3.1.3 If the runway has only one threshold certified for landing, the runway end position must be surveyed. For surveying purposes, the runway end position (flight path alignment point) must be taken as being at the geometric centre of the runway and at the end of the paved surface, i.e. the end of that portion of the runway usable for landing.

5.3.1.4 Survey witness marks must be installed to enable the threshold survey point to be re-established in the event of resurfacing, repainting or verification. In addition, two associated runway centre line points, at a separation of not less than 10% of the runway length, must be surveyed. The surveyor must, in processing the survey data, determine and report on the collinearity of the three points. Where a runway has a threshold at each end, then the two thresholds and the two additional runway centre line points may be surveyed, the collinearity then being determined for the group of four points.

5.3.2 Derived threshold coordinates

5.3.2.1 Where a point has been selected for survey which is not coincident with the runway threshold but offset along the centre line, then the coordinates of the threshold must be determined by the national administration. One method of calculation for this task is shown in Attachment D to this chapter.

5.3.2.2 The newly derived threshold coordinates must be submitted to the same collinearity check as specified in 5.3.1.4.

5.3.3 Taxiways and stand/checkpoints

5.3.3.1 General guidelines

5.3.3.1.1 In accordance with the operational requirements for advanced surface movement guidance and control systems (A-SMGCS), pilots should be provided with continuous guidance and control during the landing roll-out, taxiing to the parking position and from the parking position to the runway holding point to line up for an appointed take-off position, and during the take-off roll.

5.3.3.1.2 Since determination of the appropriate taxiway centre line points and aircraft stand points for pilot guidance and control are predicated on the aerodrome/heliport surface markings, application of the following paragraphs must be restricted to those aerodromes/heliports that conform to the SARPs for markings included in Annex 14, Volume I, 5.2 and Volume II, 5.2.11 and 5.2.12.

5.3.3.1.3 Diagrams depicting appropriate points on aerodrome/heliport movement areas are shown in Attachment B to this chapter.

5.3.3.1.4 Except as provided in 5.3.3.2.1, for surveying purposes the centre (mid-width) of the taxiway centre line marking, apron taxilane marking or the aircraft stand guide line marking must be taken as the reference datums. Survey witness marks must be installed to enable the taxiway centre line, apron taxilane and aircraft stand guide line marking survey points to be re-established in the event of resurfacing or repainting, and for verification purposes.

5.3.3.1.5 The points of commencement and ends of straight sections of taxiways, apron taxilanes and aircraft stand point guidance lines markings must be surveyed. Sufficient additional points must be surveyed to maintain the required accuracy along the lines.

5.3.3.1.6 For curved sections of taxiways, apron taxilanes and aircraft stand guide line markings, the commencement and end of the curved section centre line must be surveyed together with the position of the centre point of the arc and its radius. In the case of a compound curve, the centre and radius of each arc and the commencement and end of each of the arcs must be surveyed. Where this is impracticable in the field, a series of sequential points must be surveyed along the curved section of the centre line with a maximum arc to chord distance not exceeding 0.25 m for taxiways and 0.10 m for apron taxilanes and aircraft stand

guide line markings. Sufficient points must be surveyed to maintain the required accuracy along the lines. The surveyor must, in processing the data, conduct a graphical inspection of the survey points to ensure collinearity.

5.3.3.2 Taxiways

5.3.3.2.1 Annex 14, Volume I, 5.2.8.5 and Figure 5-6 recommend that taxiway markings on the runway are offset by 0.9 m parallel to the runway centre line and associated runway centre line marking to enable pilots to visually distinguish between the runway centre line markings and taxiway markings for exits from the runway. However, to permit uninterrupted transition from the actual runway centre line to the taxiway centre line and to provide the required continuity of guidance for the aircraft navigation data base, differentiation must be made between the surface markings and the actual path the aircraft must follow. Therefore, for the guidance of aircraft entering or exiting the runway for take-off or landing, the following must be surveyed:

- a) the point at which the radius of turn, prescribed by the appropriate authority for each taxiway, is tangential to the runway centre line (as determined under 5.3.1.1) and the point at which that radius of turn joins the taxiway centre line marking at a tangent;
- b) the point that prescribes the centre of the arc; and
- c) the radius of the arc.

Where this is impracticable in the field, a series of sequential points must be surveyed along the curved section of the centre line of taxiways.

5.3.3.2.2 Where taxiway centre line marking is provided on a runway that is part of a standard taxi route, or a taxiway centre line is not coincident with runway centre line, the following points must be surveyed:

- a) the point on the taxiway marking at which the taxiway enters the runway;
- b) the points at which the taxiway deviates from a straight line;
- c) the intersection of the taxiway centre line marking and boundary of each “block” that has been published as part of the airport movement and guidance control system; and
- d) the point on the taxiway marking at which the taxiway exits the runway.



5.3.3.2.3 In defining taxiways, the following points must be surveyed at the centre of the centre line marking of each taxiway, as appropriate:

- a) intermediate holding positions and runway holding positions (including those associated with the intersection of a runway with another runway when the former runway is part of a standard taxi route) and for points established for the protection of sensitive areas for radio navigation aids;
- b) taxiway intersection markings;
- c) intersection of other taxiways, including taxiways described in paragraph 5.3.3.2.2;
- d) intersections of “blocks” defined for surface movement, guidance and control systems;
- e) commencement and end of selectable taxiway lighting systems provided as part of the surface movement, guidance and control systems, where different from subparagraph d) above; and
- f) at stop bars.

5.3.3.2.4 In defining a helicopter air taxiway, the centre of each air taxiway marker must be surveyed, as appropriate.

5.3.3.3 Aircraft standpoints

5.3.3.3.1 In defining the aircraft stands, the following points must be surveyed at the centre of the guide line marking of the aircraft stands, as appropriate:

- a) taxilane centre lines;
- b) lead-in line(s);
- c) turning line;
- d) straight section of the turning line;
- e) nosewheel stopping position;
- f) true heading of the alignment bar; and
- g) lead-out line(s).

5.3.3.3.2 Where aircraft stands are utilized by more than one aircraft type and different guide line markings exist, a diagram must be prepared by the surveyor showing the arrangement of the markings in use, together with an indication of the points surveyed. Where all the stands at an

aerodrome/heliport are marked uniformly, only a single diagram need be prepared.

5.3.4 Navigation checkpoints

Where navigation checkpoints used for the validation of navigation systems are surveyed, their coordinates must be determined to the accuracy laid down in Table 5-1. Where these checkpoints coincide with aircraft stands, the nosewheel stopping position must be surveyed in accordance with 5.3.3.3.

5.3.5 Road holding positions

In accordance with local requirements, significant points shall be surveyed to meet the needs of the surface movement guidance and control system for vehicular traffic on the movement area of the aerodrome.

5.3.6 All other aerodrome/heliport navigation elements

For all other aerodrome/heliport navigation elements that require surveying, the geometric centre of the element must be surveyed except where a different specific survey point is standardized for the element, as indicated in Attachment B to this chapter.

5.4 AERODROME/HELIPORT SURVEY REPORT REQUIREMENTS

All survey work undertaken to determine the coordinates of navigation elements at aerodromes/heliports must be reported in the format laid out in Attachment C to this chapter. Where an existing national reporting practice differs from that shown in this chapter, the national administration may make a case in support of the national practice, where the national practice can be shown to be compatible.

5.5 SURVEY REQUIREMENTS FOR NAVIGATION AIDS

5.5.1 En-route and aerodrome/heliport navigation aids

5.5.1.1 The coordinates of en-route and aerodrome/heliport navigation aids must meet the accuracy requirements specified in Table 5-1. Where existing coordinates of



navigation aids that meet the accuracy and integrity requirements are converted to WGS-84 mathematically, the conversion process must be shown to be such that the required coordinate accuracies are maintained.

5.5.1.2 Where the quality (for surveying purposes this relates to accuracy and integrity requirements) of existing coordinates cannot be determined, they must be surveyed to the accuracy specified in Table 5-1. In all cases, surveyed coordinates may be published in preference to coordinates determined by graphical methods.

5.5.2 Description of en-route and aerodrome/heliport navigation aids

The diagrams of the most common en-route and aerodrome/heliport navigation aids are shown in Attachment B to this chapter. For navigation aids not described in Attachment B, the position of the geometric centre of the antenna must be surveyed. Where collocated VOR/DME are surveyed, the position of the DME element must be taken as the position for both systems.

5.6 EN-ROUTE SURVEY REPORT REQUIREMENTS

All survey work undertaken to determine the coordinates of en-route navigation elements must be reported in the format

specified in Attachment C to this chapter. Where an existing national reporting practice differs from that shown in this chapter, the national administration may make a case in support of the national practice, where the national practice can be shown to be compatible.

5.7 USE OF SOFTWARE

Where software is used for any of the survey processing, it must be demonstrated that it functions correctly. This demonstration must take the form of a written report showing that the software produces the same results as standard computation.

5.8 DIGITAL FORMAT FOR THE DELIVERY OF SURVEY DATA

A digital format for the delivery of survey data is included in Chapter 7. This format may be used for the delivery in digital form of all survey data. Where a national standard predates the format in Chapter 7 or where the State prefers its own format, the relationship between the two formats must be described in detail.

Attachment A. MONUMENTATION

1. GENERAL

Where survey markers are installed, they must 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 Figures 5A-1, 5A-2 and 5A-3, but other types of markers may be equally appropriate.

2. NUMBERING SYSTEM FOR SURVEY MARKERS

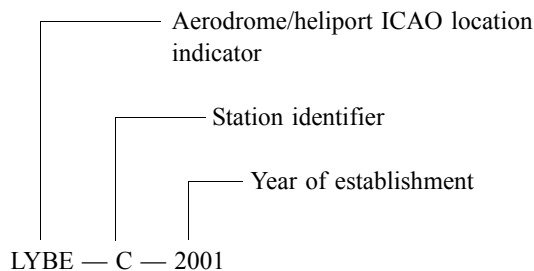
2.1 Each survey control point that forms part of the aerodrome/heliport survey control network may be marked in the field with a unique identification number.

2.2 The system of numbering may include the aerodrome/heliport identifier, the station identifier and the year of establishment. Although the aerodrome/heliport identifier will be the same for each station at that aerodrome/heliport and, therefore, will serve no local purpose, its inclusion is important for identification purposes in digital databases.

2.3 Station identifiers, whether alphabetic or numeric, may be assigned chronologically with the construction of the station. The inclusion of the year allows the time of establishment to be referenced and lessens confusion where replacement stations have been established. Alternatively, a simple consecutive numbering system can be used.

2.4 While numbering systems will vary from State to State, it is important that each system include a means whereby the stations are not confused with other survey markers being established at the same aerodrome/heliport. A simple consecutive numbering system alone, without other identifiers, would not be suitable.

Example:



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FIGURES FOR ATTACHMENT A

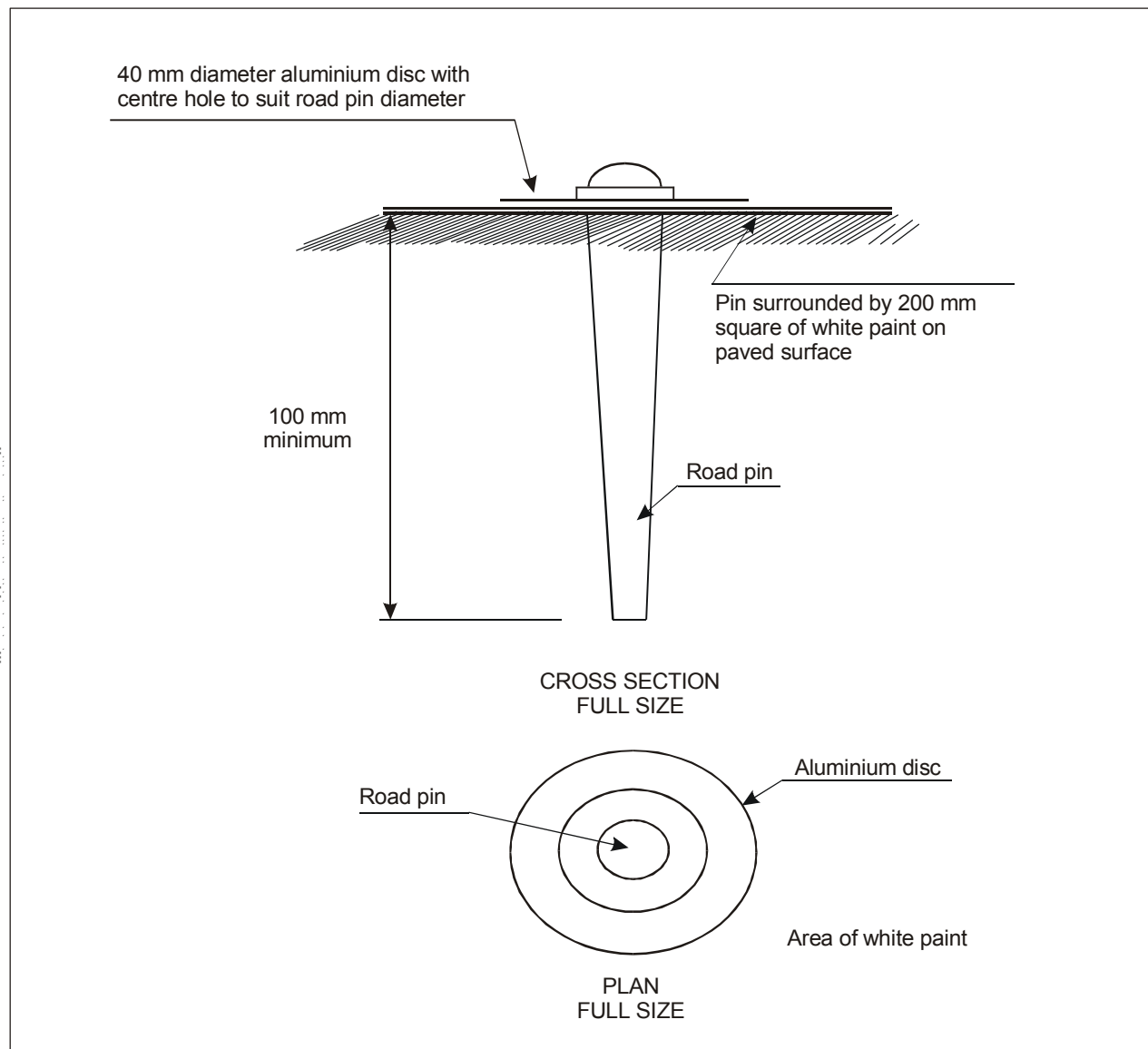


Figure 5A-1. Survey marker

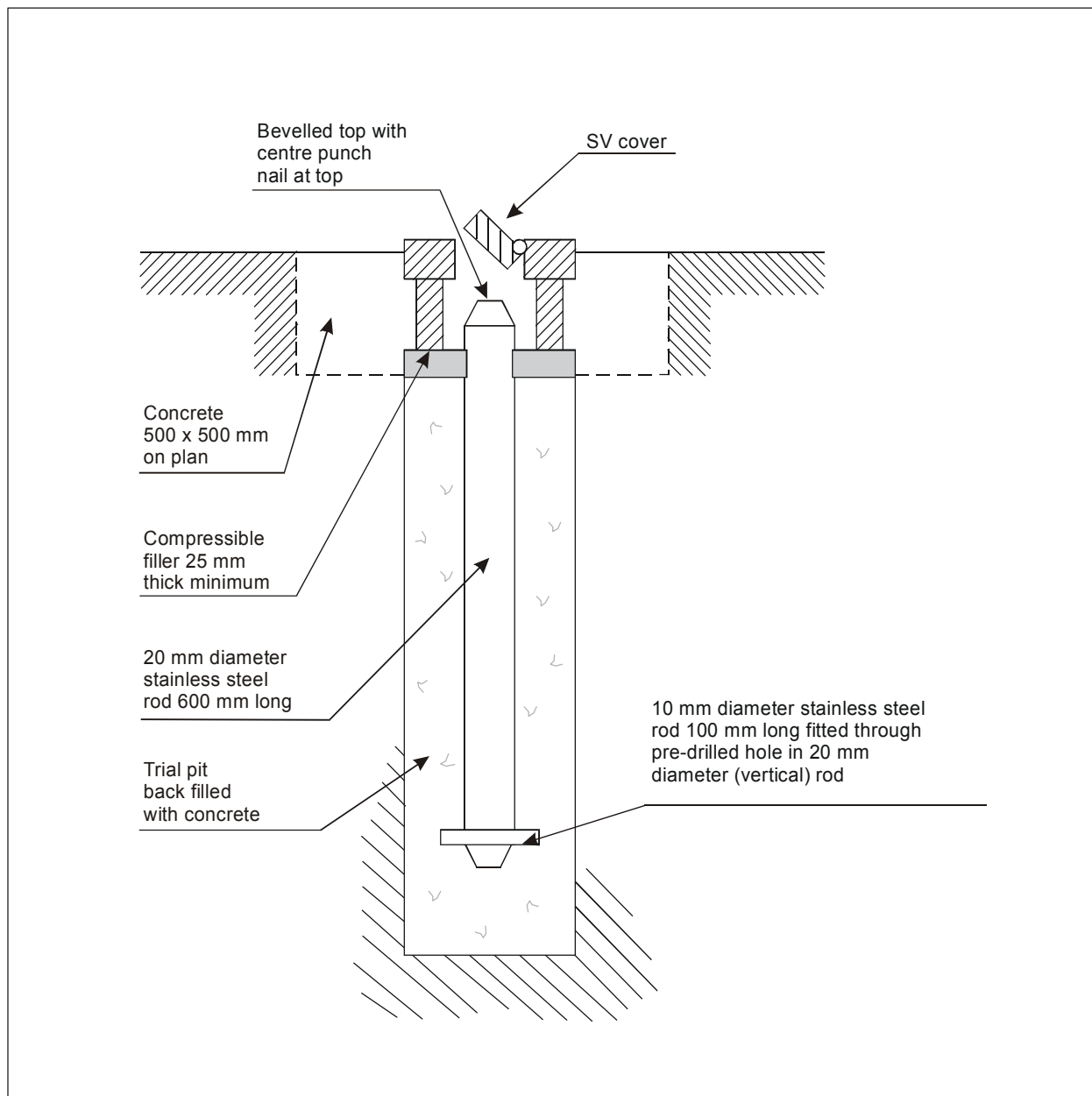


Figure 5A-2. Survey marker