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MILITARY COMMITTEE JOINT STANDARDIZATION BOARD (MCJSB)

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MCJSB

STANAG 2215 IGEO (EDITION 7) – EVALUATION OF LAND MAPS, AERONAUTICAL CHARTS AND DIGITAL TOPOGRAPHIC DATA

Reference: NSA(AIR)0935-IGEO/2215 dated 1 October 2002 (Edition 6)

1. The enclosed NATO Standardization Agreement, which has been ratified by nations as reflected in the NATO Standardization Document Database (NSDD), is promulgated herewith.

2. The reference listed above is to be destroyed in accordance with local document destruction procedures.

ACTION BY NATIONAL STAFFS

3. The MCJSB considers this an editorial edition of the STANAG; previous ratifying references and implementation details are deemed to be valid.

Cihangir AKSIT, TUR Civ
Director, NATO Standardization Agency

Enclosure:
STANAG 2215 (Edition 7)

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STANAG 2215
(Edition 7)

NORTH ATLANTIC TREATY ORGANIZATION
(NATO)

NATO STANDARDIZATION AGENCY
(NSA)
STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: EVALUATION OF LAND MAPS, AERONAUTICAL CHARTS AND DIGITAL TOPOGRAPHIC DATA

Promulgated on 13 July 2010

Cihangir AKSIT, TUR Civ
Director, NATO Standardization Agency

RECORD OF AMENDMENTS

No.	Reference/date of Amendment	Date entered	Signature

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Director NATO Standardization Agency under the authority vested in him by the NATO Standardization Organisation Charter.

2. No departure may be made from the agreement without informing the tasking authority in the form of a reservation. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3. Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

4. Ratification, implementation and reservation details are available on request or through the NSA websites (internet http://nsa.nato.int; NATO Secure WAN http://nsa.hq.nato.int).

FEEDBACK

5. Any comments concerning this publication should be directed to NATO/NSA – Bvd Leopold III - 1110 Brussels - Belgium.

STANAG 2215
(Edition 7)

NATO STANDARDIZATION AGREEMENT
(STANAG)

EVALUATION OF LAND MAPS, AERONAUTICAL CHARTS AND DIGITAL TOPOGRAPHIC DATA

ANNEX A: Standard System for the Evaluation of Land Maps, Aeronautical Charts and Digital Topographic Data

Related Documents: NATO GEOGRAPHIC POLICY

STANAG 2211 IGEO	-	GEODETIC DATUMS, PROJECTIONS, GRIDS, AND GRID REFERENCES
STANAG 3591 IGEO	-	CRITERIA FOR MAXIMUM ELEVATION FIGURE FOR AERONAUTICAL CHARTS
STANAG 3676 IGEO	-	MARGINAL INFORMATION ON LAND MAPS, AERONAUTICAL CHARTS AND PHOTOMAPS
STANAG 3809 IGEO	-	DIGITAL TERRAIN ELEVATION DATA (DTED) EXCHANGE FORMAT
STANAG 4278 C3	-	METHOD OF EXPRESSING NAVIGATION ACCURACY
STANAG 7016 IGEO	-	MAINTENANCE OF GEOGRAPHIC MATERIALS
ISO 19114	-	GEOGRAPHIC INFORMATION – QUALITY EVALUATION PROCEDURES

AIM

1. The aim of this agreement is to enable producers of geographic material to standardise the system of evaluation of land maps, aeronautical charts and digital topographic data to be used by NATO armed forces.

AGREEMENT

2. Participating nations agree to use the standard system for the evaluation of land maps, aeronautical charts and digital topographic data.

DETAILS OF THE AGREEMENT

3. The details of the Agreement appear at Annex A.

IMPLEMENTATION OF THE AGREEMENT

4. This STANAG is implemented when a nation has issued the necessary orders/instructions to the forces concerned putting the details of this Agreement into effect.

STANDARD SYSTEM FOR THE EVALUATION OF LAND MAPS, AERONAUTICAL CHARTS AND DIGITAL TOPOGRAPHIC DATA

1. The evaluation of the adequacy of topographic data, whether in graphical or digital form, for their intended military purposes comprises the separate assessment of the following aspects:

   a. Absolute geometric accuracy in terms of WGS84 datum.

   b. Horizontal (or planimetric) accuracy.

   c. Vertical accuracy.

   d. Currency status.

   e. Effective date.

However, it is not recommended that geographical products whose scale is less than 1:250,000 are assessed for accuracy because they incorporate considerable generalization to the point that the concept of accuracy measurement is no longer appropriate. The same principle applies to digital products with a resolution equivalent to a scale less than 1:250,000. Although the provisions of this STANAG are inappropriate to the accuracy of small scale products, it is the responsibility of producers to ensure that necessary quality standards are maintained.

2. The provisions of this STANAG are designed primarily to enable producers to evaluate their products. They will however need to inform users, in particular, about the accuracy of the products they supply. Many users will not possess an adequate understanding of the significance of the expressions of accuracy employed. It is therefore recommended that producers supplement accuracy statements provided to users with a full explanation based on the terms and provisions of this STANAG. Moreover, it is suggested that in communicating information to users, the use of alphanumeric rating codes (See Para 5 below) is avoided because these are designed for reporting purposes among the producer community. Instead actual accuracy values should be supplied.

3. Hitherto communication of accuracy information has been hindered by the use of a variety of terms, some of which may not always be properly understood. In future, the terminology set out in Appendix 1 is to be used consistently.

4. The following accuracy standards refer to evaluations in terms of absolute accuracy. However, fundamental accuracy statements can also be made in terms of the internal consistency of the product. This is of particular value to the users. The term agreed for this is Point-to-Point accuracy. See Appendix 1 for definitions of the above terms.

5. In all cases, the assessments of accuracy are based on comparisons between values on the product being assessed and more accurate source material. This more accurate source material could be, for example, surveyed data or values taken from a much larger scale product, typically with a scale ratio of 1:5 or more. It must be stressed that in all cases, when an accuracy evaluation is carried out, the co-ordinate systems used must be identical i.e. same geodetic datum and grid, otherwise differences in datum and projection properties etc. will distort the results. When source and tested data are in terms of different co-ordinates, one set must be transformed/converted before the comparisons are made. The criteria on which the assessments are based are listed in Parts I to VII below, which assign ratings as follows:

a. Ratings for Map, Chart or Raster Product.

(1) A letter to denote absolute geometric accuracy in terms of WGS84 (Part I).

(2) A letter to denote absolute horizontal accuracy (Part II).

(3) A number to denote absolute vertical accuracy (Part IV).

(4) A letter to denote currency status (Part VI).

(5) A two digit number to denote the effective date of information (Part VII).

b. Ratings for Non-Raster Digital Product (products always referenced to WGS84)

(1) A letter to denote absolute geometric accuracy in terms of WGS84 (Part I).

(2) A letter to denote point-to-point horizontal accuracy (Part III).

(3) A number to denote point-to-point vertical accuracy (Part V).

(4) A letter to denote currency status (Part VI).

(5) A two digit number to denote the effective date of information (Part VII).

Note: Matrices of point elevation data are included within b, but raster-type elevation data (eg maximum elevation) is outside the scope of this STANAG.

6. The combination of these ratings to form a six digit alphanumeric code gives the complete evaluation to be used for reporting purposes. Examples are given in Part VIII.

PART I - ABSOLUTE GEOMETRIC ACCURACY IN TERMS OF WGS84

7. The absolute geometric accuracy of graphical or digital products is determined by combining results of absolute horizontal and absolute vertical accuracy assessments (See Part II and Part IV below) determined with respect to WGS84 datum. The absolute geometric accuracy rating will be the poorer of the separate horizontal and vertical accuracy ratings. For products that show height, the reference is the WGS84 vertical datum, currently defined as the EGM96 geoid model.

Table 1 - Absolute Geometric Accuracy in Terms of WGS84

Rating	Horizontal and Vertical Ratings in Terms of WGS84 Datum	
	CMAS Rating (See Table 2)	LMAS Rating (See Table 3)
A	A	0
B	B	1
C	C	2
D	D	3
E	Product not referenced to WGS84	

PART II – ABSOLUTE HORIZONTAL ACCURACY

8. The absolute horizontal accuracy of graphical or digital products is determined by the position of well-defined diagnostic features. For graphical products this entails excluding points displaced by exaggerated symbolization. In digital data, horizontal features will normally be depicted as centre-line data at a specified data resolution with feature dimensions and other attributes separately coded. For both types of product the positions of 90% of well defined points will fall within the limits set out in Table 2 below, in relation to their true position referred to in the horizontal datum of the product. See Appendix 2 for explanation of evaluation criteria and formulae to be used as the basis of Para 5a.(2).

9. The producer may wish to claim different Accuracy Ratings for different sub-regions of the product. Indeed different CMAS values may have been evaluated, for example where the product was derived from different source map series. Any such accuracy sub-region should be delineated by a string of planimetric co-ordinate pairs defining a polygon. If accuracy sub-regions are used then any overall accuracy value stated for the product will be the worst of the sub-regional values.

PART III POINT-TO-POINT HORIZONTAL ACCURACY

10. The point-to-point horizontal accuracy of digital products is determined by the position of well-defined features. 90% of co-ordinate differences between any two well defined points will fall within the limits set out in Table 2, in relation to their true co-ordinate differences. See Appendix 2 for explanation of evaluation criteria and formulae to be used as the basis of Para 5b.(2).

Table 2 –Horizontal Accuracy (CMAS)

Rating	Measurement at Product Scale	Map Scale or Equivalent Digital Data Resolution				
		1:25,000	1:50,000	1:100,000	1:200,000	1:250,000
A	0.5 mm	12.5 m	25 m	50 m	100 m	125 m
B	1.0 mm	25 m	50 m	100 m	200 m	250 m
C	2.0 mm	50 m	100 m	200 m	400 m	500 m
D	>2.0 mm	Poorer than Rating C				
E	Not determined					

PART IV ABSOLUTE VERTICAL ACCURACY

11. The absolute vertical accuracy of graphical or digital products is determined by the heights of diagnostic features and areas. The heights of 90% of all points evaluated from the map, chart or digital terrain model will fall within the limits set out in Table 3 relative to their true heights referred to in the vertical datum of the product. See Appendix 2 for explanation of evaluation criteria and formulae to be used as the basis of Para 5a.(3).

12. In considering heights taken from graphical products or Digital Terrain Matrices, the vertical accuracy rating will be taken from Table 3, below.

13. The producer may wish to claim different Accuracy Ratings for different sub-regions of the product. Indeed different LMAS values may have been evaluated, for example where the product was derived from different source map series. Any such accuracy sub-region should be delineated by a string of planimetric co-ordinate pairs defining a polygon. If accuracy sub-regions are used then any overall accuracy value stated for the product will be the worst of the sub-regional values.

PART V POINT-TO-POINT VERTICAL ACCURACY

14. 90% of the differences between the true and known height differences between any two points will fall within the limits set out in Table 3, below. See Appendix 2 for explanation of evaluation criteria and formulae to be used as the basis of Para 5b.(3).

Table 3 –Vertical Accuracy (LMAS) of Graphical Products

Rating	Map Scale or Equivalent Digital Data Resolution				
	1:25,000	**1:50,000**	**1:100,000**	**1:200,000**	**1:250,000**
0	2.5m	5m	10m	20m	25m
1	5m	10m	20m	40m	50m
2	10m	20m	40m	80m	100m
3	Poorer than Rating 2				
4	Not determined				

PART VI CURRENCY

15. For abbreviated reporting purposes the rating codes as indicated in the following table are to be used. However, in communicating information to users, particularly in respect of a product that is in some way deficient, producers are encouraged to provide statements which describe the deficiencies.

Table 4

Rating	Currency
M	Product which meets the appropriate currency criteria.
R	Product which fails to meet the appropriate currency criteria and for which maintenance action is needed.
X	Not determined

PART VII EFFECTIVE DATE

16. The possible degradation of a product is indicated by the effective date of the information used in its compilation or revision. For abbreviated reporting purposes a rating indicated by the last two digits of the date is used. In some circumstances a single date may not be ideal in that the validity of different elements may vary because sources have differed in their currency. Under these circumstances a judicious compromise will be necessary.

Table 5

Rating	Effective Date
87	Information correct up to 1987

PART VIII RATING EXAMPLES

17. The following are examples of the use of the ratings in the foregoing tables to form an evaluation:

a. 1:50,000 Map. Compiled 1979 from information correct to 1977. Datum ED50. CMAS 40 metres, LMAS 20 metres. Roads and railways 80% correct. Names not spelled according to NATO policy. **EB2R77**.

b. 1:250,000 Series 1501 Sheet. Revised 1983 from information correct to 1982. Datum OSGB36 CMAS 120 metres, LMAS 20 metres. All map detail meets appropriate maintenance criteria. **EA0M82**.

c. 1:50,000 map. Produced directly from a civil map dated 1980. CMAS 20 metres, LMAS 9 metres. Does not meet maintenance criteria because planimetry is not on prescribed datum and does not have a military grid. **EA1R80**.

d. 1:100,000 ASRP Product. Produced 1996 using product compiled 1980 in terms of ED50 and revised 1991. CMAS 45 metres with respect to ED50 and 55m with respect to WGS84, LMAS 15 metres. **BA1M91**.

e. DLMS DTED Level 2 Square. Compiled in 1987 from source material dated 1984. Absolute horizontal accuracy with respect to WGS84 25 metres. Point-to-point horizontal accuracy 35 metres. Absolute vertical accuracy with respect to WGS84 5 metres. Point-to-point vertical accuracy 7 metres. There are no appropriate maintenance criteria at present. **AB1X84**.

TERMINOLOGY AND DEFINITIONS

1. The following terms and definitions relating to map data accuracy are used within this agreement:

a. Absolute Geometric Accuracy. The uncertainty in the 3-dimensional position of a point with respect to a geometric reference system caused by random and systematic errors. The only geometric reference system that this should be determined for is the WGS84 reference system, combined with the EGM96 geoid model to define mean sea level.

b. Absolute Horizontal Accuracy. The uncertainty in the horizontal position of a point with respect to the horizontal datum required by a product specification caused by random and any systematic errors. The value is normally expressed as a circular error at the 90% confidence level (See CMAS).

c. Absolute Vertical Accuracy. The uncertainty in the height of a point with respect to the vertical datum required by a product specification, caused by random and any systematic errors. The value is normally expressed as a linear error at the 90% confidence level (See LMAS).

d. Accuracy. The degree of conformity with a standard.

e. Circular Error. Distance in the horizontal plane between a true or known position and the measured or derived position. Note for practical purposes, circular error is often taken to be the circular error estimate (CE), See below.

f. Circular Error Confidence Levels. Statement of horizontal accuracy may involve the use of the following circular error confidence levels:

	Level	Symbol	Confidence
(1)	Circular Standard Deviation	σ_C	39.35%
(2)	Circular Probable Error	CPE	50.00%
(3)	Mean Square Error	MSE	63.21%
(4)	Circular Map Accuracy Standard	CMAS	90.00%
(5)	Navigation Accuracy	NA	95.00%
(6)	Circular Near Certainty Error	$3.5\sigma_C$	99.78%

g. Circular Error Estimate (CE). CE is the radius of the circle, in the local horizontal plane, centred at an estimated position, within which the true position lies with a certain probability given by the confidence level.

h. Circular Map Accuracy Standard (CMAS). The CE 90% Confidence Level, the CMAS, is used to define achieved or required Absolute Horizontal Accuracies. Accuracy requirements in Table 2 page A-3, are expressed in terms of CMAS.

i. Diagnostic Points. Well defined points of known horizontal and/or vertical accuracy used to determine the accuracy assessments of less accurate products. The points should be sufficient in number to obtain accuracy assessments within 10% of the true value and should be well distributed over the evaluated product.

j. Error Types. The following definitions of error are used:

(1) Gross Errors. Gross errors or mistakes are normally removed by quality assurance procedures and should not form part of the evaluation of accuracy.

(2) Systematic Errors. Systematic errors are those which are consistent in magnitude and direction and obey some, perhaps unknown, law. They may be removed if either the cause is known or can be evaluated by statistical procedures. Unresolved systematic error in an accuracy sample gives rise to Bias in the sample mean.

(3) Random Errors. Random errors are those remaining after the elimination of all gross errors and known or resolvable systematic errors in a data set. Random errors are assumed to form part of a Normal (Gaussian) Distribution.

k. Linear Error. The difference between the true or known value of a quantity and the measured or derived value. Note for practical purposes, linear error is often taken to be the linear error estimate (LE), See below.

l. Linear Error Confidence Levels. The definition of linear error may involve the use of the following error statements:

	Level	Symbol	Confidence
(1)	Probable Error	PE	50.00%
(2)	Standard Error	σ	68.27%
(3)	Linear Map Accuracy Standard	LMAS	90.00%
(4)	Navigation Accuracy	NA	95.00%
(5)	Linear Near Certainty Error	3σ	99.73%

m. Linear Error Estimate (LE). LE is the interval, on either side of the estimate, within which the true value lies with a certain probability given by the confidence level.

n. Linear Map Accuracy Standard (LMAS). The LE 90% Confidence Level, the LMAS, is used to define achieved or required Absolute Vertical Accuracy statements. Accuracy requirements in Table 3, page A-4, are expressed in terms of LMAS.

o. Navigation Accuracy (NA). The 95% Confidence Level, NA, is used to define achieved or required Absolute Horizontal Accuracies or Absolute Vertical Accuracies, as specified in STANAG 4278, Method of Expressing Navigation Accuracies.

p. Outlier. A residual that is so large that the observation should be treated as a gross error.

q. Point to Point Horizontal Accuracy. The uncertainty in the difference in horizontal positions between any 2 points. The value is expressed as a circular error at the 90% confidence level.

r. Point to Point Vertical Accuracy. The uncertainty in the difference in heights between any 2 points expressed as a linear error at the 90% confidence level.

s. Residual. The difference between an observed value and the expected value, if error-free.

t. Resolution. The minimum spatial separation between data elements. It is the terms applied to digital data sets to represent the concept that, in graphical products, is expressed as "scale". The practical effect for example is that a digital data set with a resolution equivalent to 1:50,000 will have a minimum separation between data elements comparable to that likely to be extracted from a 1:50,000 graphical product.

EVALUATION CRITERIA AND FORMULAE

HORIZONTAL ACCURACY

1. Sampling.

a. In order to compute accuracy indices at the 90% confidence level it is recommended that a sample of at least 167 diagnostic points is used for each product or for each sub-regional area where the product was derived from more than one source, for example from different map series. 167 diagnostic points produces 166 degrees of freedom in the statistics. This size of sample leaves an uncertainty of ± 10% in the computed accuracy indices at the 90% confidence level. Note that the formulae in this Appendix apply only when at least 167 sample points are measured to represent a population which is large compared with the sample size; this is the normal case. For less than 167 points it will be necessary to apply factors to the computed indices in order to achieve a figure that meets the 90% confidence limit in order to comply with the requirements of this STANAG. Details of these factors are given under the section headed Small Samples. Nevertheless the largest possible sample should be used.

b. The sampling scheme should be designed to provide samples which are representative of the product or sub-regional area, dependent on the producing agency's knowledge of source materials and production methods. The diagnostic points should be spread throughout the map or data set in such a way that all areas and types of feature are represented fairly in the sample. In the case of maps, the sample should include a representative selection of features from each colour plate (except colour plates used solely as fill).

c. The diagnostic points should be well defined features (excluding those unavoidably displaced through exaggerated symbolization), sometimes called "hard detail". Hard detail consists of point features and the intersection of linear features but excludes features likely to be displaced by generalisation or conventionalisation. Features which cannot be interpreted as a precise location on the ground should be excluded. On the other hand points which are likely to be precisely positioned (eg trig points) should be avoided. Despite these provisions, cases will occur in areas of sparse detail where a representative sample of suitable diagnostic points does not exist. In these cases, some relaxation of the criteria is permissible in order to produce an accuracy evaluation although in extreme cases it will not be possible to produce a meaningful accuracy statement.

2. Circular Error.

a. As applied to the positions of features depicted on maps or contained in digital topographic data sets the theory of circular error considers that a certain percentage of the error in the two axes E and. N, will lie within a circle of a certain radius of the mean error. The Circular Standard Deviation of measured differences between the tested product and the reference source, σ_{CM} may be computed from the linear standard deviations of E and N:

$$\sigma_{CM} = \sqrt{\frac{\sigma_E^2 + \sigma_N^2}{2}}$$
$$= \sqrt{\frac{1}{2}\left[\frac{\sum\left(\delta E_i - \overline{\delta E}\right)^2 + \sum\left(\delta N_i - \overline{\delta N}\right)^2}{n-1}\right]}$$

Where δE_i δN_i are respectively the individual differences between the measured and the "true". Eastings and Northings from the reference source of each diagnostic point. The recommended sign convention is measured minus reference value.

$\overline{\delta E}$ $\overline{\delta N}$ are the arithmetical means of all values of δE_i and δN_i respectively.

n is the number of diagnostic points.

When there are no significant errors known to exist in the reference source, σ_{CM} can be taken to equal σ_C, the overall circular standard deviation.

b. Such an index of Circular Standard Deviation, σ_C, represents a confidence level of 39.35%. Other indices of probability are recognised and are tabulated below, together with factors to convert one index to another. See also Appendix 1 for explanation of the indices.

Circular Error Conversion Factors

To / From	σ_C (39.35%)	CPE (50.00%)	MSE (63.21%)	CMAS (90.00%)	NA (95.00%)	$3.5\sigma_C$ (99.78%)
σ_C (39.35%)	1.0000	1.1774	1.4142	2.1460	2.4477	3.5000
CPE (50.00%)	0.8493	1.0000	1.2011	1.8227	2.0789	2.9726
MSE (63.21%)	0.7071	0.8325	1.0000	1.5174	1.7308	2.4749
CMAS (90.00%)	0.4660	0.5486	0.6590	1.0000	1.1407	1.6309
NA (95.00%)	0.4085	0.4810	0.5778	0.8767	1.0000	1.4298
$3.5\sigma_C$ (99.78%)	0.2857	0.3364	0.4040	0.6131	0.6994	1.0000

These conversion factors apply only when the indices are computed from samples with no significant systematic error.

3. Treatment of Errors in Reference Sources. When significant error is known to exist in the reference source against which a product is being tested, that error must be taken into account. Two different circumstances may be encountered:

a. When it is only possible to test a product by comparing it with its own source material, then accuracy testing will only reveal the degradation of accuracy in the compilation or data extraction processes. To assess the product accuracy the following formula should be applied:

$$\sigma_C = \sqrt{\sigma_{CM}^2 + \sigma_{CR}^2}$$

Where σ_C is the Circular Standard Deviation of errors in the tested product.

σ_{CM} is the Circular Standard Deviation of measured differences between the tested product and the reference source.

σ_{CR} is the Circular Standard Deviation of errors in the reference source.

b. Conversely, when the reference source used for testing is truly independent from the product being tested, then accuracy testing will produce a computed result which includes the error of the reference source as well as the error of the tested product. To assess the product accuracy the following formula should be applied:

$$\sigma_C = \sqrt{\sigma_{CM}^2 - \sigma_{CR}^2}$$

Note: Care must be taken when applying this rule because as the value of σ_{CR} approaches that of σ_{CM}, the results become over optimistic. The ratio σ_{CR} : σ_{CM} must not be more than 1:3. Ideally the reference source should be at a much larger scale, of ratio 1:5 or less.

4. Separate Error Quotations. The above are measures of random error. Systematic error, represented by $\overline{\delta E}$ and $\overline{\delta N}$ should normally be quoted separately if present.

5. Absolute Horizontal Accuracy.

a. To establish the accuracy ratings specified in Annex A, Table 2, it is necessary to determine Absolute Horizontal Accuracy by combining random and systematic error. When there is no systematic error (ie when $\overline{\delta E}$ and $\overline{\delta N}$ do not significantly differ from zero (See "Significance Testing of Computed Bias", para 15)) the formulae given above provide the Absolute Horizontal Accuracy, with

$$\text{CMAS} = 2.146 \cdot \sigma_C$$

When the product contains a bias (ie when $\overline{\delta E}$ and/or $\overline{\delta N}$ differ significantly from zero (see "Significance Testing of Computed Bias", para.15)) the following formulae should be used to determine Absolute Horizontal Accuracy at the 90% confidence level (See Appendix 4, Ref C):

$$CMAS = \sigma_C \cdot \left[1.2943 + \sqrt{\left(\frac{d}{\sigma_C}\right)^2 + 0.7254} \right]$$

Where d is the mean vector error (bias)

$$d = \sqrt{\left(\overline{\delta E}\right)^2 + \left(\overline{\delta N}\right)^2}$$

b. The circular error conversion factors in para 2b are not valid for accuracy assessments of biased samples computed by these formulae.

6. Point-to-Point Accuracy. The accuracy of one point with respect to another point within the same data set, can be calculated by multiplying the random error of the data set as a whole (from paras 2 and 3 above) by the factor $\sqrt{2}$.

7. Accuracy of Edges or Linear Features. Some user applications require a statement of the horizontal accuracy of edges or linear features rather than points. The absolute horizontal accuracy of edge features is normally expected to be that of points, divided by $\sqrt{2}$.

VERTICAL ACCURACY

8. Sampling.

a. It is recommended that at least 167 sample points are used for each product (or for each sub-regional area where the product was derived from more than one source, for example from different map series). This size of sample leaves an uncertainty of ±10% in the computed accuracy indices at the 90% confidence level. Note that the formulae in this Appendix apply only when there are at least 167 sample measurements taken to represent a population which is large compared with the sample size; this the normal case. For less than 167 points it will be necessary to apply factors to the computed indices in order to achieve a figure that meets the 90% confidence limit in order to comply with the requirements of this STANAG. Details of these factors are given under the section headed Small Samples. Nevertheless the largest possible sample should be used.

b. The sampling scheme should be designed to provide samples which are representative of the product or sub-regional area, dependent on the producing agency's knowledge of source materials and production methods. The diagnostic points should be spread throughout the map or data set in such a way that all areas are represented fairly in the sample and should be representative of the different types of terrain; high and low points, slopes and level etc.

c. The diagnostic points should in preference be selected from the most accurately heightened points on the reference source so long as the tested product does not replicate the point or have made use of it during product generation. Priority order should be given to surveyed spot heights, photogrammatically heightened points, contour intersections with grid lines or hard map detail, and then estimated heights. If the co-ordinate systems of the tested and reference products are different, the reference source's co-ordinates must first be converted into the tested product's co-ordinate system before the height is estimated.

9. Linear Error

a. The Linear Standard Deviation of measured differences between the tested product and the reference source, σ_M may be computed as follows:

$$\sigma_M = \sqrt{\frac{\sum\left(\delta H_i - \overline{\delta H}\right)^2}{n-1}}$$

Where δH_i are the individual differences between the measured and the "true" heights from the reference source of each diagnostic point.

$\overline{\delta H}$ is the arithmetical mean of all values of δH_i

n is the number of diagnostic points.

b. Such an index of Linear Standard Deviation, σ, represents a confidence level of 68.27%. Other indices of probability are recognised and are tabulated below, together with factors to convert one index to another. See also Appendix 1 for explanation of the indices:

Linear Error Conversion Factors

From \ To	PE (50.00%)	σ (68.27%)	LMAS (90.00%)	NA (95.00%)	3σ (99.73%)
PE (50.00%)	1.0000	1.4826	2.4387	2.9058	4.4478
σ (68.27%)	0.6745	1.0000	1.6449	1.9600	3.0000
LMAS (90.00%)	0.4101	0.6080	1.0000	1.1916	1.8239
NA (95.00%)	0.3441	0.5102	0.8392	1.0000	1.5306
3σ (99.73%)	0.2248	0.3333	0.5483	0.6533	1.0000

These conversion factors apply only when the indices are computed from samples with no significant systematic error.

10. Treatment of Errors in Reference Sources. When significant error is known to exist in the reference source against which a product is being tested, that error must be taken into account. Two different circumstances may be encountered:

a. When it is only possible to test a product by comparing it with its own source material, then accuracy testing will only reveal the degradation of accuracy in the compilation or data extraction processes. To assess the product accuracy the following formula should be applied:

$$\sigma = \sqrt{\sigma_M^2 + \sigma_R^2}$$

Where σ is the Linear Standard Deviation of errors in the tested product.

σ_M is the Linear Standard Deviation of measured differences between the tested product and the reference source.

σ_R is the Linear Standard Deviation of errors in the reference source.

b. Conversely, where the reference source used for testing is truly independent from the product being tested, then accuracy testing will produce a computed result which includes the error of the reference source as well as the error of the tested product. To assess the product accuracy the following formula should be applied:

$$\sigma = \sqrt{\sigma_M^2 - \sigma_R^2}$$

Note: Care must be taken when applying this rule because as the value of σ_R approaches that of σ_M, the results become over optimistic. The ratio $\sigma_R : \sigma_M$ must not be more than 1:3. Ideally the reference source should be at a much larger scale, of ratio 1:5 or less.

11. Separate Error Quotations. The above are measures of random error. Systematic error represented by $\overline{\delta H}$ should normally be quoted separately if present.

12. Absolute Vertical Accuracy.

a. To establish the accuracy ratings specified in Annex A, Table 3, it is necessary to determine Absolute Vertical Accuracy by combining random and systematic error. When there is no systematic error (ie when $\left|\overline{\delta H}\right|$ is not significantly different from zero (See "Significance Testing of Computed Bias", para 15)) the formulae given above provide the Absolute Vertical Accuracy, with

$$\text{LMAS} = 1.645 \cdot \sigma$$

When the product contains a bias b (ie when $\left|\overline{\delta H}\right|$ differs significantly from zero (See "Significance Testing of Computed Bias", para.15)) the following formulae may be used to determine Absolute Vertical Accuracy at the 90% confidence level:

Intermediate quantity, $b = \left|\overline{\delta H}\right|$

(1) When the bias is less than 1.4 σ, use the following formula (Appendix 4, Ref B).

$$\text{LMAS} = \sigma \cdot \left[1.645 + 0.92 \cdot \left(\frac{b}{\sigma}\right)^2 - 0.28 \cdot \left(\frac{b}{\sigma}\right)^3\right]$$

Note: The above formula fails when $b > 1.4 \cdot \sigma$

(2) On the rare occasions when the bias exceeds 1.4σ use the following formula (Appendix 4, Ref B).

$$\text{LMAS} = \sigma \cdot \left[1.282 + \left(\frac{b}{\sigma}\right)\right]$$

Note: The above formula fails when $b < \sigma$

b. The linear error conversion factors in para 9b are not valid for accuracy assessments of biased samples computed by these formulae.

13. Point-to-Point Accuracy. The accuracy of one point with respect to another point within the same data set, can be calculated by multiplying the random error of the data set as a whole (from paras 9 and 10 above) by the factor $\sqrt{2}$.

OUTLIER DETECTION

14. It should be noted that the accuracy figures are only valid if gross errors have been removed. These can be detected by statistical testing of residuals, R. A residual is considered to be a potential outlier (ie not part of the representative data set) if the absolute value of the residual is larger than a defined value. This value equates to the standard deviation of the observation multiplied by a statistical factor, M, (See below). Outliers should be removed from data set before final cartometric test figures are computed. However, before rejecting a data point the values should be investigated and corrected if necessary. Only one point should be rejected at a time and the process repeated until no more outliers are detected. Note that the outlier detection tests rely on there being a sufficiently large sample of points observed. The computation of residuals and the test factor, M, are as follows:

a. Linear Test.

Residual, R = $\left(\delta x_i - \overline{\delta x}\right)$

R is a potential outlier where | R | > $M_1 \cdot \sigma_x$

where x can represent eastings, northings or height.

M_1 = 3 for large samples, corresponding to 99.73%, close to Near Certainty Error, but more practically for small samples,

$M_1 = 1.9423 + 0.5604 \cdot \log_{10} v$ See Appendix 4, Ref C

and

$v = n - 1$ degrees of freedom

b. Circular Test.

Residual, R = $\sqrt{\left(\delta E_i - \overline{\delta E}\right)^2 + \left(\delta N_i - \overline{\delta N}\right)^2}$

R is a potential outlier where I R I > $M_2 \cdot \sigma_c$

where M2 = 3.5 for large samples, corresponding to 99.78%, close to Near Certainty Error, but more practically for small samples,

M_2 = $\sqrt{2.5055 + 4.6052 \cdot \log_{10} v}$ see Appendix 4, Ref C

and

v = $n - 1$ degrees of freedom

The small sample computation of M_1 and M_2 reflect an outlier defined such that there should be no sample points with a probability less than 1 in 3.5v. Illustrative values are as follows:

v	Probability	M_1 (linear)	M_2 (circular)
30	99.05%	2.770	3.051
40	99.29%	2.840	3.144
80	99.64%	3.009	3.357
120	99.76%	3.107	3.476
160	99.82%	3.177	3.558
166	99.83%	3.186	3.568

SIGNIFICANCE TESTING OF COMPUTED BIAS

16. To determine whether or not a computed bias $\bar{x}$ (which could be mean shift in eastings, northings or height) is significant, it should be tested against the t distribution. The bias should be considered to be significant at the 90% confidence level if zero does not lie in the range $\left(\bar{x} - t_{10\%} \cdot \sigma_{\bar{x}}\right)$ to $\left(\bar{x} + t_{10\%} \cdot \sigma_{\bar{x}}\right)$, where

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}}$$

And $t_{10\%}$ is the value which ensures a confidence level of 90% based on a t distribution for $n-1$ degrees of freedom. Illustrative values areas follows:

Degrees of Freedom v	$t_{10\%}$
30	1.697
40	1.684
80	1.664
120	1.658
160	1.654
166	1.654
∞	1.645

With large samples, the t distribution may be approximated by the Normal distribution, in which case $t_{10\%}$ will be 1.645.

SMALL SAMPLES

16. When sample sizes of less than 167 points are used for an accuracy evaluation, it will be necessary to apply a factor to the statistical indices determined in order to derive a figure that is more representative of the accuracy assessment of no more than 10% at the 90% confidence level. The smaller the sample size, the larger the factor will be. The appropriate statistical test for assessing the level of error detectable at a certain confidence level is the x^2 test. To test for the level of accuracy detectable at the 90% confidence level values for $x_v^2(0.95)$ must be used. The scale factor to be applied to CMAS and LMAS figures produced from a small sample is computed from the formula:

$$\text{Scale factor} = \frac{\sqrt{v / x_v^2(0.95)}}{1.1}$$

where, v is the degree of freedom, $n-1$

$x_v^2(0.95)$ is the x^2 statistic that gives a probability of 0.95 with v degrees of freedom.

Illustrative values are given below:

Degrees of Freedom v	**Possible error** $=\sqrt{v / x_v^2(0.95)}$		**Factor to be applied to CMAS or LMAS**
30	1.274	(27.4%)	1.16
40	1.228	(22.8%)	1.12
50	1.199	(19.9%)	1.09
60	1.179	(17.9%)	1.07
70	1.163	(16.3%)	1.06
80	1.151	(15.1%)	1.05
90	1.141	(14.1%)	1.04
100	1.133	(13.3%)	1.03
110	1.126	(12.6%)	1.02
120	1.120	(12.0%)	1.02
130	1.114	(11.4%)	1.01
140	1.110	(11.0%)	1.01
150	1.106	(10.6%)	1.01
160	1.102	(10.2%)	1.00
166	1.100	(10.0%)	1.00

It should be noted that wherever possible the correct number of points should be observed rather than simply observing a small sample and applying the scale factor.

SOFTWARE FOR ACCURACY ASSESSMENTS

1. The following Excel program may be used to make horizontal and vertical accuracy assessments for a mapping product easier to compute (See explanatory notes on page A3-4). The formulae are given in full on pages A3-2 to A3-4. The Rating system used is that recommended for Map, Chart or Raster Product.

	A	B	C	D	E	F
1	**DATE**:	4.9.00			1/Scale	50000
2						
3	**INPUT DATA**					
4				Lower	**MPV**	Upper
5		Mean E difference =		-17.1982	**-15,56**	-13.9218
6		Mean N difference =		1.9713	**3.51**	5.0487
7		Mean H difference =		0.2329	**2.18**	4.1271
8						
9		Standard deviation E =		7.3986	**8.4**	9.7481
10		Standard deviation N =		6.9494	**7.89**	9.1563
11		Standard deviation H =		9.8433	**11.05**	12.6287
12		Circular Standard Error =		7.1776	**8.1490**	9.4568
13						
14	No. plan points =		73	Degrees of Freedom =		**72**
15	No. height points =		89	Degrees of Freedom =		**88**
16						
17	**OUTLYING POINT CHECK**					
18						
19	Circular Tolerance:		27.0994			
20	Tolerance for E diff:		25.0585	-40.62	< E diff <	9.50
21	Tolerance for N diff:		23.5370	-20.03	< N diff <	27.05
22	Tolerance for H diff:		33.5035	-31.32	< H diff <	35.68
23						
24	**ANALYSIS**			Lower	**MPV**	Upper
25						
26	**HEIGHT**:					
27	Bias-free Estimate of LMAS			16.19	**18.18**	20.77
28	Linear Point-to-Point Accuracy			22.90	**25.70**	29.38
29	(Intermediate quantity b/Sigma)			0.221	**0.197**	0.173
30	Significance of Avge H diff:			YES	**YES**	NO
31	Absolute LMAS (bias model 1)			16.61	**18.55**	N/A
32	Absolute LMAS (bias model 2)			N/A	**N/A**	N/A
33	Selected LMAS figure			16.61	**18.55**	20.77
34	Adjusted LMAS figure				**19.27**	
35	**Rating**				**2**	
36						
37	**PLAN**:					

38	Bias-free estimate of CMAS	15.40	**17.49**	20.29
39	Plan Point-to-Point Accuracy	21.78	**24.73**	28.70
40	Systematic Shift		**15.95**	
41	Significance of Shift	YES	**YES**	YES
42	(Intermediate quantity d/SigmaC)	2.222	**1.957**	1.687
43	Absolute CMAS with bias	26.37	**27.94**	30.11
44	Selected CMAS figure	26.37	**27.94**	30.11
45	Adjusted CMAS figure		**29.48**	
46	**Rating**		**B**	

Example Calculation using Excel spreadsheet

The formulae and input-cells for the spreadsheet are as follows.

Scale

F1 Input Value (series dependent)

Observed Data

Lower Limit (best)

D5 =E5-(E9*TINV(0.1,F14)/SQRT(C14)) Plan
D6 =E6-(E10*TINV(0.1,F14)/SQRT(C14)) Plan
D7 =E7-(E11*TINV(0.1,F15)/SQRT(C15)) Height
D9 =E9*SQRT(F14/CHIINV(0.05, F14)) Plan
D10 =E10*SQRT(F14/CHIINV(0.05,F14)) Plan
D11 =E11*SQRT(F15/CHIINV(0.05,F15)) Height
D12 =SQRT(SUMSQ(D9,D10)/2) Plan

Most Probable Value

E5 Input Value (sheet dependent) Plan
E6 Input Value (sheet dependent) Plan
E7 Input Value (sheet dependent) Height
E9 Input Value (sheet dependent) Plan
E10 Input Value (sheet dependent) Plan
E11 Input Value (sheet dependent) Height
E12 =SQRT(SUMSQ(E9,E10)/2) Plan

Upper Limit (worst)

F5 =E5+(E9*TINV(0.1,F14)/SQRT(C14)) Plan
F6 =E6+(E10*TINV(0.1,F14)/SQRT(C14)) Plan
F7 =E7+(E11*TINV(0.1,F15)/SQRT(C15)) Height
F9 =E9*SQRT(F14/CHIINV(0.95,F14)) Plan
F10 =E10*SQRT(F14/CHIINV(0.95,F14)) Plan
F11 =Ell*SQRT(F15/CHIINV(0.95,F15)) Height
F12 =SQRT(SUMSQ(F9,F10)/2) Plan

Degrees of Freedom

C14 Input Value (sheet dependent) Plan
F14 =C14-1 Plan
C15 Input Value (sheet dependent) Height

F15 =C15-1 Height

Outlying Point Check
C19 =E12*SQRT(2.5055+4.6052*LOG10(F14)) Plan
C20 =E9*(1.9423+0.5604*LOG10(F14)) Plan
C21 =E10*(1.9423+0.5604*LOG10(F14)) Plan
C22 =E11*(1.9423+0.5604*LOG10(F15)) Height
Lowest Acceptable Value

D20 =E5-C20 Plan
D21 =E6-C21 Plan
D22 =E7-C22 Height
Highest Acceptable Value

F20 =E5+C20 Plan
F21 =E6+C21 Plan
F22 =E7+C22 Height

Height Test

Lower Limit (best)

D27 =D11*1.6449
D28 =D27*SQRT(2)
D29 =ABS(E7)/D11
D30 =IF(D29<(TINV(0.1,F15)/SQRT(C15)),"NO","YES")
D31 =IF(AND(D30="YES",D29<1.4),D11*(1.645+0.92*D29^2-0.28*D29^3),"N/A")
D32 =IF(AND(D30="YES",D29>=1.4), D11*(1.282+D29),"N/A")
D33 =IF(D30="NO",D27,IF(NOT(D31="N/A"),D31,IF(NOT(D32="N/A"),D32,"ERROR")))
Most Probable Value

E27 =E11*1.6449
E28 =E27*SQRT(2)
E29 =ABS(E7)/E11
E30 =IF(E29<(TINV(0.1,F15)/SQRT(C15)),"NO","YES")
E31 =IF(AND(E30="YES",E29<1.4),E11*(1.645+0.92*E29^2-0.28*E29^3),"N/A")
E32 =IF(AND(E30="YES",E29>=1.4),E11*(1.282+E29),"N/A")
E33 =IF(E30="NO",E27,IF(NOT(E31="N/A"),E31,IF(NOT(E32="N/A"),E32,"ERROR")))
E34 =E33*SQRT(F15/CHIINV(0.95, F15))/1.1
E35 =IF((E34/$F1)<=0.0001,"0",IF((E34/$F1)<=0.0002,"1",IF((E34/$F1)<=0.0004,"2","3")))

Upper Limit (worst)

F27 =F11*1.6449
F28 =F27*SQRT(2)
F29 =ABS(E7)/F11
F30 =IF(F29<(TINV(0.1, F15)/SQRT(C15)),"NO","YES")
F31 =IF(AND(F30="YES",F29<1.4), F11*(1.645+0.92*F29^2-0.28*F29^3),"N/A")
F32 =IF(AND(F30="YES",F29>=1.4),F11*(1.282+F29),"N/A")
F33 =IF(F30="NO",F27,IF(NOT(F31="N/A"),F31,IF(NOT(F32="N/A"),F32,"ERROR")))

Plan Test

Lower Limit (best)

D38 =D12*2.146
D39 =D38*SQRT(2)
D41 =IF(E40<((D12*TINV(0.1, F14))/SQRT(C14)),"NO","YES")
D42 =E40/D12
D43 =IF(D41="YES",D12*(1.2943+SQRT(D42^2+0.7254)),"N/A")
D44 =IF(D41="NO",D38,D43)

Most Probable Value

E38 =E12*2.146
E39 =E38*SQRT(2)
E40 =SQRT(SUMSQ(E5,E6))
E41 =IF(E40<((E12*TINV(0.1,F14))/SQRT(C14)),"NO","YES")
E42 =E40/E12

E43 =IF(E41="YES",E12*(1.2943+SQRT(E42^2+0.7254)),"N/A")
E44 =IF(E41="NO",E38,E43)
E45 =E44*SQRT(F14/CHIINV(0.95, F14))/1.1
E46 =IF((E45/$F1)<=0.0005,"A",IF((E45/$F1)<=0.001,"B",IF((E45/$F1)<=0.002,"C","D")))

Upper Limit (worst)

F38 =F12*2.146
F39 =F38*SQRT(2)
F41 =1F(E40<((F12*TINV(0.1,F14))/SQRT(C14)),"NO","YES")
F42 =E40/F12
F43 =IF(F41="YES",F12*(1.2943+SQRT(F42^2+0.7254)),"N/A")
F44 =IF(F41="NO",F38,F43)

Notes:

1. This spreadsheet presupposes that there are no significant errors in the reference source. If there are any such errors affecting heights, the mean difference and standard deviation figures must already have been adjusted for them.

2. The shaded boxes are for user input data. All other sections are computed.

3. In addition to the calculations of most probable values, the spreadsheet also computes the values at the upper and lower limits for 90% confidence, to give an idea of the uncertainty in the derived statistic.

Softcopy users will find the Excel spreadsheet labelled A3b.

Spreadsheet A3b

DATE:	4.9.00			1/Scale	50000
INPUT DATA					
			Lower	**MPV**	Upper
	Mean E difference =		-17.1982	**-15.56**	-13.9218
	Mean N difference =		1.9713	**3.51**	5.0487
	Mean H difference =		0.2329	**2.18**	4.1271
	Standard deviation E =		7.3986	**8.4**	9.7481
	Standard deviation N =		6.9494	**7.89**	9.1563
	Standard deviation H =		9.8433	**11.05**	12.6287
	Circular Standard Error =		7.1776	**8.1490**	9.4568
No. plan points =		73	Degrees of Freedom =		**72**
No. height points =		89	Degrees of Freedom =		**88**
OUTLYING POINT CHECK					
Circular Tolerance:		27.0994			
Tolerance for E diff:		25.0585	-40.62	< E diff <	9.50
Tolerance for N diff:		23.5370	-20.03	< N diff <	27.05
Tolerance for H diff:		33.5035	-31.32	< H diff <	35.68
ANALYSIS			Lower	**MPV**	Upper
HEIGHT:					
Bias-free Estimate of LMAS			16.19	**18.18**	20.77
Linear Point-to-Point Accuracy			22.90	**25.70**	29.38
(Intermediate quantity b/Sigma)			0.221	**0.197**	0.173
Significance of Avge H diff:			YES	**YES**	NO
Absolute LMAS (bias model 1)			16.61	**18.55**	N/A
Absolute LMAS (bias model 2)			N/A	**N/A**	N/A
Selected LMAS figure			16.61	**18.55**	20.77
Adjusted LMAS figure				**19.27**	

Rating		**2**	
PLAN:			
Bias-free estimate of CMAS	15.40	**17.49**	20.29
Plan Point-to-Point Accuracy	21.78	**24.73**	28.70
Systematic Shift		**15.95**	
Significance of Shift	YES	**YES**	YES
(Intermediate quantity d/SigmaC)	2.222	**1.957**	1.687
Absolute CMAS with bias	26.37	**27.94**	30.11
Selected CMAS figure	26.37	**27.94**	30.11
Adjusted CMAS figure		**29.48**	
Rating		**B**	

REFERENCES

A. Melvin E Shultz: Circular Error Probability of a Quantity Affected by a Bias. Geo-Sciences Branch, ACIC, St Louis, June 1963.

B R Atkin and R W Lucas: Computational Models for Incorporating Bias into Linear and Circular Map Accuracy Standards. MCE RE Technical Memorandum No 1/89, Feltham, 1989.

C. A C Ruffhead: Approximating Functions for Map Accuracy Calculations. DGIA, Feltham, March 2001.