27 February 1948

FROM: Chairman of JMPC Ad-hoc Committee on Universal Military Grid Referencing System

TO: Colonel Northrup, U. S. Army
Captain Hobbs, U. S. Navy
Colonel Tison, U. S. Air Force

Reference: (a) JIC 410/M of 23 January 1948

Enclosure: (A)

1. In accordance with directive contained in par. 1 of reference (a), a committee consisting of Colonel Mills, Commanding Officer, Army Map Service (Chairman), Mr. Bloom of the Aeronautical Chart Service and Mr. Medina of the U. S. Hydrographic Office has devised a universal military grid referencing system which it considers suitable for the Armed Forces.

2. This is submitted for consideration. Enclosure (A) contains complete information on the system. It is requested that this proposal be transmitted to the operating forces for study.

3. Should the Army, Navy or Air Force believe that there is another system more suitable than that described in Enclosure (A), complete information regarding such a system should be submitted to this ad-hoc committee for investigation and consideration.

4. In view of the urgency for an early decision, action should be expedited. Approval, or any recommended changes, are desired by 15 April 1948.

W. H. Mills

W. H. MILLS
Colonel, Corps of Engineers
Chairman, JMPC Ad-hoc Committee
on Universal Military Grid
Referencing System

Copies:

Navy: 25
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AF: 25
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Joint Mapping Photography Committee
Ad-hoc Committee on
Universal Military Grid Referencing System

A PROPOSED STANDARD UNIVERSAL MILITARY GRID REFERENCING SYSTEM

1. INTRODUCTION

There is a mandatory and urgent need for a standard referencing system, for use by the Armed Forces. Such a system must have the following outstanding characteristics:

a. It must meet the individual and collective requirements of the Army, Navy and Air Forces in such a way that all services speak the same language.

b. It must insure positive identification of any point in the world, without danger of ambiguity, particularly at spheroid and datum junctions.

c. It must be simple to understand, brief and capable of being abbreviated either for large-scale or for local operations; and adapted to the requirements of fighter pilots traveling at high speed.

d. It must be suitable for rapid computations of range and azimuth, with the required accuracy.

e. It must be usable in Polar areas.

f. It must avoid difficulties arising from the reversal of sign at the 0 and 180th meridians and the Equator.

2. PRESENT SITUATION

a. Section IV, W. D. Circular No. 33, 5 February 1937, establishes the Universal Transverse Mercator Grid as the official grid for the Department of the Army. Accordingly, all maps published by the Army since 5 February 1947 bear the UTM Grid. In the interests of consistency, the U. S. Hydrographic Office has also surprinted the UTM Grid on all approach and bombardment charts, and on all hydrographic charts designed for use in amphibious training exercises. The UTM Grid supersedes an undersirable heterogeneous system which included the World Polyconic Grid, the U. S. Polyconic Grid, the Panama Grid and approximately 80 so-called British Grids. Since the projection of the grid is conformal, the grid can normally be applied to a map constructed on any of the standard projections.[1]

[1] The merits of the UTM Grid and the deficiencies of the others are discussed in Appendix I.

b. The following are the grid referencing systems which are authorized and/or presently in use by the various armed forces[2]; none can satisfactorily fill the requirements for a universal system as outlined in paragraph 1, above:

(1) Fire Control Referencing (FM 6-40, 1 June 1945, Chapter 2, Section 1, pp. 163-164: also, see Appendix II-1): This is the system presently authorized for use by the Army.

(a) Advantages: The system is suitable for rapid computations of range and azimuth; no difficulties arise from the reversal of sign at the 0° and 180° meridians and at the Equator.

(b) Deficiencies: Designed originally for fire control use by the Army, it does not fill the needs of the Air Force and the Navy; it is not adaptable to world wide use; it does not provide for spheroid junctions; while it allows for abbreviation in local areas, conversely it does not allow for abbreviation for large scale activities; it does not provide for referencing in the polar areas; it is lengthy and awkward due to use of sheet-names, decimals, hyphens and parentheses.

(2) Pacific World War II Practice (see Appendix II-2): Finding the authorized referencing system inadequate, the Commanders of the Pacific Theaters devised a new system to fit their needs. This was a compromise between the Fire Control and British Grid referencing systems. To a certain degree, this alleviated but did not eliminate the deficiencies of the authorized system.

(a) Advantages: The system is suitable for rapid computations of range and azimuth; no difficulties arise from the reversal of sign at the 0° and 180° meridians and at the Equator; a reference is brief and not complicated with decimals, hyphens and parentheses.

(b) Deficiencies: While fairly satisfactory for the local needs of the Army and Navy, it did not fill the needs of the Air Force; it is not adaptable to world wide use; it does not provide for spheroid junctions; it does not provide for abbreviation; it does not provide for referencing in polar areas; while the awkwardness of the authorized system was eliminated, ambiguities in reporting outside grid zones could result.

(3) British Grid Referencing (TM 44-225, Section IX, pp. 70-72; also, see Appendix II-3): By agreement, U. S. Forces used the British Grids wherever they existed.

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[2]Regulations also provide for the Point Designation Grid (TM 44-225, 30 June 1944, Section V, pp 63-64), the Jan grid (TM 44-222, Section VI, pp. 65-66), and the Thrust Line Method (TM 44-222, Section VII, p. 67). These are special purpose systems and their continued use will not be affected by the adoption of a standard referencing system.

(a) Advantages: The system is suitable for rapid computations of range and azimuth; no difficulties arise from the reversal of sign at the 0° and 180° meridians and at the Equator; a reference is brief and not complicated with decimals, hyphens and parentheses.

(b) Disadvantages: It does not fill the needs of the Air Force and Navy; it is not easily adaptable to world wide use due to lack of order and homogenity; it does not provide for spheroid junctions; while it permits slight abbreviation in local areas, no provision is made for similar abbreviation for large scale activities; it does not allow for referencing in polar areas; the number of grid and datum junctions was excessive resulting in frequent difficulty in rapid computation of range and distance when origin and destination were in different grid areas.

(4) Air Defense Grid (TM 44-225, Section X, pp. 72-79)

(a) Advantages: The Air Defense Grid referencing partially satisfies large scale use of the Air Force.

(b) Disadvantages: The system does not satisfy the requirements of the Army and Navy; the system does not lend itself to the use of the pilot in fighter support; while it is fairly satisfactory in reporting areas in world wide activities it is not satisfactory for reporting spot positions; while it provides for abbreviation, in certain areas if the first letter of the reference is dropped, the nearest similar reference is near enough to create ambiguity; it is not suitable for rapid computation of range and azimuth; it does not provide for polar areas; it is ambiguous at datum junctions.

3. PROPOSED SYSTEM

a. General

The proposed system is based on the Universal Transverse Mercator Grid between 80° N and 80° S; in the polar areas it is based on Polar Stereographic grids.

(1) In conjunction with these grids, the reference system meets all the requirements for a referencing system as outlined in paragraph 1, above.

(a) It provides for the individual and collective needs of the Army, Navy and Air Force. The basic principles followed by any of the armed forces in giving a reference are alike; a reference cited by any one branch will be readily recognized by all and will permit easy conversion when required.

(b) It provides a positive and unambiguous identification for any point on the globe especially at spheroid and datum junctions.

(c) Since the referencing in all cases follows the basic and simple system of reading "right-up", a reference is easily understood. A reference is brief and is capable of being abbreviated either for local or large scale activities, thus satisfying any and all needs.

(d) It is well suited for rapid computation of range and azimuth.[3]

(e) It is suitable for polar areas. Azimuth will agree with that now in use by polar aviators; this avoids the difficulties of meridian convergence which are a necessary feature of computations in latitude and longitude.

(f) There is no reversal of sign at any meridian or any other junction of zones.

(2) The system has the following additional merits:

(a) The coordinates always increase to the east and to the north, except in the polar regions where the direction of positive coordinates is unambiguously indicated.

(b) The system conforms to the spherical surface of the earth. The grid lines can be considered as a system of coordinates whose position on the earth's surface is as exactly fixed as meridians and parallels.

(c) As the grid is conformal, it can easily be applied to a map constructed on any of the conventional projections, unless they are so extended as to have unusually large distortions.

b. First division - 8° NS x 6° EW rectangles

(1) Between 80° N and 80° S the world is divided into rectangles 8° NS x 6° EW (See Exhibit E-H). The columns (6° wide) are identified by the Universal Transverse Mercator (UTM) Zone numbers -- that is, starting at the 180° meridian the columns are numbered from 1 to 60 consecutively proceeding easterly. The rows (8° NS) are identified by letters; starting from 80° south and proceeding northerly the rows are lettered consecutively from C to X (I and O omitted). The designation (called the grid zone designation) of such an 8° NS x 6° EW rectangle is determined by reading (right-up) first the column designation (as 54) and second the row designation (as U); as: 54U

(2) The north polar area above the 80° parallel is divided into two parts by the 0° and 180° meridians. The half beginning west of 0° is identified as Y; the half beginning east of 0° is identified as Z.

[3]See Appendix I.

(See Exhibit I). Similarly, the south polar area below 80° is divided into two halves by the 0° and 180° meridians; these halves are identified by A and B respectively.

c. Second division - 100,000 meter squares

(1) Between 80° N and 80° S each 8° x 6° rectangle is divided into 100,000 meter squares based on the UTM grid for the zone. Every column of squares is identified by a letter; likewise, every row of squares is identified by a letter. (See Exhibits A and B). On the equator, starting at the 180° meridian, and proceeding easterly for 18°, the 100,000 meter columns, including partial columns (caused by convergence), are lettered A to Z (I and O omitted) consecutively. The 100,000 meter rows are labelled from A to V (I and O omitted) reading from south to north, with the partial alphabet being repeated every 2,000,000 meters. Every odd numbered 6° wide UTM Zone will have the alphabet of the 100,000 meter row letters beginning at the equator; the even numbered 6° wide UTM Zones will have the alphabet of the 100,000 meter row letters beginning at the ~~1,000~~500,000 meter northing grid line north of the equator. This staggering will considerably lengthen the distance between duplicating letters and will permit necessary manipulation along spheroid junctions. Below the equator the 100,000 meter row letters will continue consecutively following the plan of the letters above in the same zone. The designation of a 100,000 meter grid square is determined by reading (right-up) first its column designation (as X) and second its row designation (as Q): as: XQ.

(2) Under this system a 100,000 meter square designation will not be repeated in an area 18° NS x 18° EW. This will normally eliminate the necessity of preceding grid references within such an area by the grid zone designation (54U in b (1) above) even though report is being made from as many as two grid zones away.

(3) In the polar areas the 100,000 meter columns at right angles to the 90° - 90° meridians are lettered from J to Z in zone designation Y and A to R in zone designation Z (I and O omitted; also omitted are D, E, M, N, V and W to avoid confusion with 100,000 meter squares in adjoining UTM zones. Starting at the 80° line the 100,000 meter rows at right angles to the 0° - 180° meridians are labelled A to Z consecutively (I and O omitted). The identification of a 100,000 meter square consists of two letters, reading right-up (See Exhibit I).

d. Grid references for U. S. Army

(1) A U. S. Army reference shall consist of a number and a letter (the grid zone designation) followed by two letters (identifying the 100,000 meter square in which the point of reference lies), followed by a group of numbers expressing to the required accuracy the E and N coordinates of the referred point within the 100,000 meter square; examples:

(a) 54UXQ (locating a point within 100,000 meters)

(b) 54UXQ55 (locating a point within 10,000 meters)

(c) 54UXQ5354 (locating a point within 1,000 meters)

(d) 54UXQ539544 (locating a point within 100 meters)

(2) Normally, a general reference is seldom located to an accuracy of more than the closest 100 meters. To provide for the needs of surveying and to anticipate any contingency, the following references are provided:

(a) 54UXQ53925443 (locating a point within 10 meters)

(b) 54UXQ5392354432 (locating a point within 1 meter)

(c) 54UXQ539234544321 (locating a point within 0.1 meter)

(3) Normally, all elements of a grid reference shall not be used. Those to be omitted will depend upon the size of the area of activities. Thus:

about 18°05'

(a) If activities are confined to an area not exceeding 18° EW x 18° NS, the grid zone designation (54U) usually will be omitted. In such an area, a reference to the closest hundred meters usually will read: XQ539544

(b) If activities are confined to an area not exceeding 100,000 meters NS x 100,000 meters EW, in addition to omitting the grid zone designation, the 100,000 meter square identification (XQ) will be omitted; the point will be referenced only by numbers. Thus, in such an area, a reference to the closest hundred meters will read: 539544

(c) Numerical reference: The numerical part of a reference taken from a 1,000 meter grid, will be a six digit number; for example: 539544. The "53" represents the 10,000 and 1,000 digits of the easting grid line to the west of the referenced point, the "9" represents the estimated tenths from the easting grid line to the point, the "54" represents the 10,000 and 1,000 digits of the northing grid line south of the referenced point, and the "4" represents the estimated tenths from the northing grid line to the point. (See Exhibit C). To maintain a relationship between similar grid references from different scale maps, the numerical part of a reference taken from a 10,000 meter grid will be a four digit number; for example: 5354. The "5" represents the 10,000 digit of the easting grid line to the west of the referenced point, the "3" represents the estimated tenths from the easting grid line to the point, the second "5" represents the 10,000 digit of the northing grid line south of the referenced point, and the "4" represents the estimated tenths from the northing grid line to the point. (See Exhibit D).

e. Tad Grid References

(1) A TAD reference shall consist of two letters (identifying the 100,000 meter square containing the point of reference (see paragraph 3 c, above), followed by four numerals (the 10,000 and 1,000 digits of the northing grid line south of the point and the 10,000 and 1,000 digits of the easting grid line west of the point, (the identification of the 1,000 meter grid square containing the point), followed by a letter (identifying the 200 meter grid square containing the point). (See Exhibit F). Example: XQ5354J

(2) The first two letters (XQ) normally shall be omitted; they will not be used unless the reference is being reported more than 100,000 meters away. Thus, the usual TAD reference will be written simply as: 5354J

(3) The plan for lettering the 200 meter squares follows:

A	B	C	D	E
F	G	H	I	J
K	L	M	N	O
P	Q	R	S	T
U	V	W	X	Y

f. Air Defense references

(1) A reference shall consist of the grid zone designation (as 54U), followed, if necessary, by two letters (identifying the 100,000 meter square containing the point), followed, if necessary, by a group of numbers expressing to the required accuracy the E and N coordinates of the referred point within the 100,000 meter square; (See Exhibit G). Examples:

(a) 54U (locating a point within a rectangle 8° NS x 6° EW)
(b) 54UXQ (locating a point within 100,000 meters)
(c) 54UXQ55 (locating a point within 10,000 meters)
(d) 54UXQ5354 (locating a point within 1,000 meters)

(2) If reports are being confined to an area not exceeding 18° NS x 18° EW, the grid zone designation may be omitted and the reference read as:

(a) XQ (locating a point within 100,000 meters)

(b) XQ55 (locating a point within 10,000 meters)

(c) XQ5354 (locating a point within 1,000 meters)

4. CONCLUSION

It is felt that the system outlined above is a homogeneous solution of the problem and will satisfactorily fill the needs of the Navy, the Air Force and the Army. The needs of the various grid users are provided for and a standardization is effected.

the British coast artillery, Navy and Air Force covered the coastal area with three incompatible, incommensurable grid systems. Intolerable confusion which resulted from the use of these grids during the numerous German air raids in the Battle of Britain makes it highly probable that these conflicting systems would have led to at least a few local disasters had there been an invasion of Great Britain.

3. Basic Requirements

3.01. Primary Purpose of a Grid. The primary purpose served by the military grid on a map is to provide quick solutions to problems of distance and azimuth for the firing of weapons. It provides a quick simple means for referring to spot locations and for designating targets. It is an essential tool in coordination of military operations.

3.02. The coordination of the efforts of the many arms used on land, sea, and air, is a problem so complex as to make mandatory a single simple solution for problems of target designation and determination of range and azimuth. This requirement is believed to be so important in war that the use of a single system of limited but adequate accuracy is held to be better than the simultaneous use of two incompatible but otherwise more accurate systems.

3.03. The characteristics of the using arms and weapons which affect the design of the system to be adopted involve relatively little research. As a general rule, it has been assumed that permanently emplaced batteries will be more accurate in their fire than batteries temporarily emplaced in the fields. Therefore, the following table appears to provide sufficient criteria to determine the desirable accuracies of the grid system adopted.

Probable Errors of Different Caliber
Permanently Emplaced Guns at Ranges Shown

Range in Yards	Probable Errors in Yards						Minimum Probable Relative Errors	
	6" Gun		8" Gun		16" Gun			
	Range	Defl.	Range	Defl.	Range	Defl.	Range	Deflection
10,000	22	2	68	3	18	3	1:555	1:5,000
15,000	35	4	70	5	28	4	1:535	1:3,750
20,000	52	6	73	8	40	6	1:500	1:3,333
25,000	68	8	77	13	52	7	1:480	1:3,571
30,000			83	19	63	9	1:476	1:3,333
35,000					73	10	1:479	1:3,500
40,000					80	10	1:500	1:4,000
45,000					*77	*7	*1:584	*1:6,428

*These values appear unusual.

4. Desirable Characteristics

4.01. Primarily a grid system should be accurate enough for all weapons and all military uses other than for very long distance missiles, should be quickly applicable to any previously ungridded native map, should yield readily to simple computing methods and should provide simple numerical designators for location of targets.

4.02. Plane System. The system of coordinates desired is one with which all computations for the most accurate artillery firing can be simply yet accurately performed and especially one in which the integrity of angles is preserved. A mathematically exact graticule, such as that presented by the meridians and parallels, requires the use of geodetic functions to solve the spherical triangles involved, and entails a long, time-consuming complicated computation. Moreover, due to the convergence of the meridians, the arc of the parallel intercepted between any two meridians becomes shorter as the latitude increases. Complicated geodetic formulas would be necessary in the computation of any distance except one along a meridian. Complex fire control instruments would be needed, manned by personnel highly trained in a branch of advanced mathematics. Neither the personnel, the instruments, nor the time are normally available. As a consequence, the system adopted should be one in which plane trigonometry can be employed in the solution of triangles. In such a plane system for general application to large areas, the simplest and quickest computations can be secured through use of a grid network of equally spaced parallel and mutually perpendicular lines.

4.03. Grid Accuracy. A high degree of accuracy is, of course, desirable. However, grid accuracies which are greatly in excess of the accuracies for the most precise weapon using the grid appear to be neither necessary nor practicable. By reference to paragraph 3.03 above, it will be noted that the probable errors of artillery weapons are much greater in range than are their probable errors in deflection. The minimum probable error of permanently emplaced guns rarely is less than 1/555 in range and 1/5,000 in deflection. Consequently, a suitable military grid should be one designed to conform to these minimum probable errors.

4.04. Adaptability to Various Projections. The grid system selected should be adaptable for use on native maps without complicated recomputation or redrafting of that map. There are many map projections used in the making of large scale maps throughout the world. It is desirable to be able to overprint the adopted grid system on any or all of these projections without the introduction of errors in range and azimuth beyond that probable in good artillery practice.

4.05. Unit of Measure. Three general systems of linear measure are commonly encountered on maps and in grids: the metric system, the so-called English system, and the nautical system. Mixtures of these systems unfortunately are prevalent. This matter is further complicated by the fact that three differing elements are involved - map quantities, grid quantities, and the quantities employed by the using arms and weapons.

a. Map quantities include azimuths, horizontal distances, contour intervals, and underwater depths. To the map user, the unit of measure in which horizontal distances on a map are expressed is not particularly important, as the conversion from map distances to ground distances is frequently done graphically against either an appropriately graduated bar scale on the map or range scale. However, the unit of linear measure used in the basic survey of the map may complicate the computation and compilation of trig lists for fire control. This latter operation is already quite complex due to the differing origins of longitude, datum planes, spheroids and schemes of projection, and other variations encountered in the native surveys of the world. Thus, the conversion from one unit of linear measure to another incommensurable unit adds an operation subject to mistakes and affecting final accuracies.

b. Contour intervals and spot elevations should, but may not, be in the same unit of measure as the horizontal distances, in order to provide for the ready calculation of true slant ranges, defilade, mask, profile, etc.

c. Underwater depths are generally expressed either in meters or in fathoms, although shoal water depths may be also expressed in feet. It is highly desirable that these units of measure be the same as the horizontal unit in order to be readily useful in the computation of underwater profiles and beach gradients.

d. The military grid, while essentially concerned with angles and horizontal distances, must be precisely related to the computed geographic positions. The necessary correlation between the vertical unit of measure and the horizontal unit of measure on the grid as indicated in b above, is essential for the quick solution of problems involving defilade, mask and true gun target distance.

e. The using arms and weapons are not entirely coordinated in the units of measure employed in the laying of the piece. The Coast Artillery measures azimuths in degrees and hundredths of a degree from grid south as the origin. The Field Artillery measures angles in mils, with field orientation of base circles. The Coast Artillery measures its range in yards, while the Field Artillery may measure it in yards or meters. Due to the tangent relationship of the mil, Field Artillery can readily transpose from angular measure to linear distance in either meters or yards. Each artillery weapon is served and laid by employing a multiplicity of tabular information, plotting tools, and gunner's instruments. All these things must be related to the unit of measure selected for map and grid quantities. At the present moment, due to the recent tremendous concentration of field artillery weapons in the European campaigns and to the use of the metric system throughout in that area, our Field Artillery is well equipped and trained in the use of the metric system. The Seacoast Artillery of the United States, including the Panama Canal and

Oahu, are not so equipped or trained. They use the yard-hundredths of a degree system, except in the coast defenses of San Diego where the coast Defense grid is graduated in feet rather than in yards.

f. Existing Conditions. The majority of the large scale maps of the world are made on the metric system. Exceptions to this rule are the United States, Canada, Australia, United Kingdom, Union of South Africa, India, Melanesia, and Middle East. The following table shows the unit of measure of native maps and military grids employed in operational areas of the recent campaigns.

	MAP UNITS			GRID UNITS	
AREA	HORIZONTAL UNIT (Map Bar Scale)	VERTICAL UNIT (Map Contour)	DEPTH UNIT (Bathymetric Contour)	GRID UNIT	GRID TYPE
1. France	Meter	Meter	Meter	Meter	Lambert
2. Germany	Meter	Meter	Meter	Meter	Trans. Merc.
3. Italy	Meter	Meter	Meter		
4. Tunisia	Meter	Meter	Meter	———	———
5. Libya	Meter	Meter	Meter	Meter	Trans. Merc.
6. Egypt	Meter	Meter	Fathom	Meter	Trans. Merc.
7. Okinawa	Meter, Chō	Meter	Meter	Meter	Unknown
8. Burma	Miles	Foot	Fathom	Yard	Lambert
9. China	Li, Meter	Meter	Foot	Meter	Lambert
10. Russia	Meter	Meter	Foot	Meter	Trans. Merc.
11. Hawaii	Mile	Foot	Fathom	Yard	Polyconic
12. Philippines	Mile	Foot	Fathom	Yard	Polyconic
13. Poland	Meter	Meter	Meter	Meter	Stereographic
14. Holland	Meter	Meter	Meter	Meter	Stereographic
15. Belgium	Meter	Meter	Meter	Meter	Bonne
16. Japan	Meter, Chō	Meter	Meter	Meter	Trans. Merc.

4.06. Width of Zone. An inherent fault of any system of plane coordinates applied to the surface of a spheroid is the fact that inaccuracies increase as the zone is extended east and west or in other cases, as the belt is extended north and south. It is also desirable, although not entirely necessary, to keep at a minimum the deviation of grid north from true north. This deviation likewise increases materially as the distance from the central meridian increases. These inaccuracies can be kept within reasonable limits by the adoption of narrow grid zones. It has been stated only semi-facetiously that there are three military engineering axioms:

a. It always rains in war.
b. It's always too cloudy to get aerial mapping photographs.
c. Battles are always fought on grid junctions.

This last axiom is spoken from the depths of bitter experience, rendering it obvious that a grid zone should include as much area as possible so as to obviate too frequent junctures between grid zones on the battlefield. However, this desirable criterion cannot be widely applied without including intolerable inaccuracies of the grid. Elimination of the undesirable features consequent upon fighting a battle on a grid juncture can be partially accomplished by providing for overlap between grid zones. The 9 degree width of the military grid system presently prescribed for use in the United States introduces appreciable inaccuracies near the edges. A reduction in width to 6 degrees betters this situation materially. The computation of ranges and azimuths where the gun position is located in one grid zone and the target in another can be provided for by a half degree overlap between grid zones, enabling the coordinates of the gun zone to be extended a half a degree into the grid zone in which the target is located.

5. Comparison of Grids

5.01. Polyconic Grid. For military purposes, a grid may be regarded as a set of perfect squares ruled on a plane map, scale 1:1, and then transferred to the earth's surface. Evidently after being transferred to the earth's surface the squares will no longer be perfect; and distortions they will have received in being put on the surface of the earth will reflect the distortions of the projection used for the map.

a. The polyconic projection is defined as one which the central meridian and all parallels are mapped to scale and with true curvature. All other lines are stretched, the amount increasing as the square of the distance from the central meridian, and being greatest for north-south lines. Angular errors also appear, increasing with distance from the central meridian. Of course it is possible to compute these errors, at least roughly, and to allow for them, and this is regularly done by engineer survey troops. But the corrections are generally considered beyond what is to be expected of artillery units in the field, and for that reason all mention of them is omitted in artillery technical manuals, even when survey procedures are discussed. It is proper, therefore, to compare the errors of the projection as shown in the following table, directly with the errors of the guns (Section 3.03).

Errors of U. S. Military Grid at 4°30' from Central Meridian, and 30° Latitude

True Range (yds)	True Azimuth 0°				True Azimuth 45°				True Azimuth 90°		True Azimuth 90° (cont'd)	
	Range Error (yds)	Relative Error	Defl. Error (yds)	Relative Error	Range Error (yds)	Relative Error	Defl. Error (yds)	Relative Error	Range Error (yds)	Relative Error	Defl. Error (yds)	Relative Error
10,000	23	1:435	0	0	12	1:836	12	1:836	0	0	0	0
30,000	70	1:428	4	1:7500	35	1:859	35	1:859	0	0	0	0
40,000	93	1:430	8	1:5000	47	1:850	47	1:850	0	0	0	0

It is evident that at 40,000 yards, and an azimuth of 45°, the error of the grid in deflection is almost five times the probable error of a 16-inch gun. Errors of the above amount are characteristic of the so-called non-conformal projections, i.e., those in which the shapes, as well as the scale of small areas is distorted. Such non-conformal grids were widely used prior to World War I; but most of them have been abandoned in recent years, chiefly, no doubt, because of the breakdown of the old French Bonne grid during the War. In addition to its lack of conformality, the polyconic projection possesses the disadvantage that it has not been studied thoroughly from a mathematical standpoint. Hence the small corrections needed for precise surveys are not known; the transformation from other grids to the polyconic is not known; not even the transformation from one polyconic belt to another has been studied.

b. So far as grid junctions are concerned, the polyconic is theoretically excellent; it can be extended indefinitely both north and south, so that the world can be divided up into meridional strips. In practice, the present World Polyconic has two latitudinal junctions, one near 24°, due to failure to put the origin of the old U. S. grid sufficiently far south; the other is near 49°, and is due to inaccuracy in the old tables which amounts to 1.1 meters.

c. The polyconic grid is not well suited for foreign maps due to its lack of conformality. By the older laborious hand methods of grid plotting, this introduced no difficulties other than laborious calculations; but the use of the coordinatograph, for rapid plotting of grids and projections, requires a conformal grid.

5.02. Cassini-Soldner Grid. This is a non-conformal grid, very similar to the polyconic, and open to the same objections. It differs only in that the grid east-west lines, rather than the parallels are represented to true scale and with true curvature.

5.03. The Bonne Grid. Both meridians and parallels are represented to true scale on the Bonne projection; the error shows up on lines which run NE to SW, or NW to SE. It is just as bad as in the case of the other non-conformal projections; and this projection has been generally abandoned.

5.04. The Stereographic Grid. The stereographic grid may be briefly defined as a conformal grid (that is, one having zero angular distortions for small distances, and very small angular distortions for any distance) in which the scale error is zero on a standard circle. The fact that this grid is conformal insures that within about 200 miles of the center-point, the error in deflection will be less than the error of the most accurate guns. The range error is considerably larger than the deflection error, but is considerably less than the range error of permanently emplaced artillery. Unfortunately, this grid cannot be extended more than 300 miles from its center point and grid zones are circular in shape. It is quite suitable for small roughly circular countries such as Poland, Holland, or Rumania, which use it; but on a world-wide basis it would lead to a great multiplicity of grid junctions, and points where three or more grids meet could not be avoided.

5.05. Lambert Grid. Like the stereographic, the Lambert is a conformal projection. It may be defined as a conformal projection in which the scale errors are zero along two parallels. It is well suited to the mapping of moderately large areas, and has been extensively used by the British and French, especially in recent years. The numerical values of the errors are similar to those for the Transverse Mercator given in the next paragraph. The errors are very small in deflection, as is necessary for an artillery grid. It is readily adaptable to gridding maps on other projections. In general, a slight change of scale only would be required. On the other hand, the rapidly increasing grid declination makes it impracticable to extend the grid more than about 15° from the central meridian (except along the Equator, where grid declination is always zero). For this reason, the British and French were forced to introduce numerous zones, and to permit junctions of three grids at the same point. These numerous grid zones necessary, both north-south and east-west, make the Lambert undesirable for extensive world coverage.

5.06. Transverse Mercator Grid. The Transverse Mercator grid may be defined as a conformal grid in which the central meridian is represented by a straight line at true scale. It is well suited to large areas, and is being used by the Germans, Russians, British, and Japanese. The errors at a given point vary little in all azimuths and average values for different ranges are given in the following table for 30° north latitude and for $3\frac{1}{2}$° from the central meridian.

True Range (yds)	Transverse Mercator Grid Range Error (yds)	Relative Error	Transverse Mercator Grid Deflection Error (yds)	Relative Error
10,000	10	1:1000	0	0
30,000	30	1:1000	3	1:10000
40,000	40	1:1000	5.8	1:6900

Obviously, the grid is well suited to artillery purposes since the inevitable errors are thrown into range rather than deflection. The grid can be extended indefinitely in latitude like the polyconic. Hence it is never necessary to have a grid junction involving more than two grids (except, of course, near the Poles). Transformation of coordinates from one belt to another can be done by a formula already worked out. The formula is always the same, and is very simple in character. The grid declination will remain moderate throughout the belt. The grid can be readily adapted to use on other projections. Much theoretical work has already been done on this subject by a large group of mathematicians, including especially Professor W. K. Hristow. Extensive computations, especially for the Balkan countries, were done by the German High Command (O. K. H.) during World War II which could, in an emergency, be promptly utilized if the proposed projection is adopted. In addition, much geodetic data of foreign areas on file at Army Map Service are on this system. The projection is well suited for converting data on various spheroids to a common basis. Traverse and lower orders of triangulation may be computed and adjusted directly on the grid due to its conformality. This feature, which is a large saving in field and office, is not practicable where a non-conformal projection such as the present Polyconic is used.

5.07. Tabular Comparison of Grids.

GRID SYSTEM	APPLICABILITY TO FOREIGN MAPS**	GRID JUNCTIONS	MAXIMUM RELATIVE RANGE ERRORS* (45,000 yds)	MAXIMUM RELATIVE DEFLECTION ERRORS* (45,000 yds)
Polyconic	Very poor	Few & simple	1/1228	1/2454
Cassini-Soldner	" "	" "	1/1228	1/2454
Bonne	" "	Many & complex	1/2454	1/615
Stereographic	Good	" "	1/2454	1/15,360
Lambert	"	" "	1/2416	1/7,663
Transverse Mercator	Excellent; much work already done	Few & simple	1/2416	1/7,663

* Range and deflection errors are maximum values within 160 miles from the center of the projection, whether the center is a line, as in the Transverse Mercator, Lambert, Cassini-Soldner, and Polyconic, or a point as with the other two. The figures are based on GSGS "Survey Computation". 160 miles is the approximate distance (at 40° of latitude) from the center of the proposed Transverse Mercator Zones to the junctions, about 3° of longitude. The actual maximum errors of the present World Polyconic grid are considerably larger, since the grid zones are 9° in width.

6. Conclusions as to System to be Adopted

6.01. The Lambert Orthomorphic projection is conformal but is not suitable as it requires grid zone junctures both north and south and east and west. The polyconic grid system now prescribed for use as military grid on all maps of U. S. is inaccurate in both azimuth and distance. The greater inaccuracy is in azimuth and is more than the probable error in deflection of permanently emplaced guns. The transverse mercator grid is conformal and is

**A grid system is considered applicable to a foreign map if it can be put on most maps without changing map or grid except in scale.

immediately applicable without plottable error, to the majority of the map projections commonly encountered on the native maps of the world. The transverse mercator grid reduces inaccuracies to a point where they are compatible with the accuracies required by all modern artillery weapons. This grid is sufficiently accurate to eliminate the necessity for a special Coast Artillery grid in the vicinity of coast defense locations.

APPENDIX II

1. FIRE CONTROL REFERENCING

Existing regulations of the Department of the Army (See FM 6-40, Part Four, Chapter 2) designate the following method for reading a grid reference:

a. Designation of sheet, parenthesis, X coordinate, decimal, location to nearest yard, a dash, Y coordinate, decimal, location to nearest yard, parenthesis.

Example: Annapolis (804.729-1286.684)

b. When the map is definitely understood, its designation may be omitted.

Example: (804.729-1286.864)

c. If the location to the nearest 10 or nearest 100 yards only is desired, or if the measurements cannot be made with greater accuracy, the digits indicating units or tens may be omitted.

Examples: (1) (804.72-1286.68) to nearest 10 yards

(2) (804.7-1286.7) to nearest 100 yards

d. For expediency it is permissible to include only two digits to the left of the decimal point (10,000 and 1,000 digits), omitting any preceding digits.

Examples: (1) (04.729-86.684)

(2) (04.72-86.68)

(3) (04.7-86.6)

e. If the point is fixed within an area 10,000 yards square, only one digit need be given before the decimal point of each coordinate:

Examples: (1) (4.729-6.684)

(2) (4.72-6.68)

(3) (4.7-6.7)

f. If a large number of points are being designated by the abbreviated coordinates shown in example (3), the decimals and dashes may be omitted and the reference given as (4767).

2. PACIFIC WORLD WAR II PRACTICE

During the war, the Pacific and Southwest Pacific Commands found it feasible to use a system for reading general grid references similar to that used with British Grids. Apparently, a broad interpretation of existing regulations was made to find authority for the change. The name of the map was not mentioned (authority: see 1 b above): digits to the left of the 10,000 and 1,000 unit digits were omitted (authority: see 1d above); decimals and dashes were omitted (authority: see 1 f above).

a. A reference on a map employing a 1,000 unit interval was determined by reading: the 10,000 and 1,000 digits of the easting line to left of point, estimated tenths (100 units) eastward to point, the 10,000 and 1,000 digits of the northing line south of the point, estimated tenths (100 units), northward to the point. This was written as a 6 digit continuous number.

Example: 143286

b. A similar procedure was follows in reading a reference on a map using a 10,000 unit interval, except that the digits for the grid lines were for the 100,000 and 10,000 units (the last four digits being omitted) and the estimated tenths represented 1,000 units. Thus, a reference for the same point cited in (1) above, was read as: 214128

c. There were two major faults with the Pacific system: danger of confusion between a reference taken from a map bearing a 1,000 unit interval and from one of a 10,000 unit interval, inasmuch as both were six digit numbers; and lack of connection between references for a common point taken from a 1,000 unit grid and from a 10,000 unit grid, inasmuch as in reading a reference from a 1,000 unit grid the principal digits were the 10,000 and 1,000 ones and for a reference from a 10,000 unit grid the principal digits were the 100,000 and 10,000 ones. Thus, references for a common point might read: 047866 (from a 1,000 unit grid) and 804286 (from a 10,000 unit grid).

3. BRITISH GRID REFFRENCING

References for British Grids are read according to the following methods:

a. Maps bearing a 10,000 unit interval (1:100,000 to 1:500,000): letter of 500,000 unit square (written as a small capital letter), letter of 100,000 unit square (written as a large capital letter), 10,000 digit of easting line to the left of the point, estimated tenths (1,000 units) eastward to point, 10,000 digit of northing line south of the point, estimated tenths (1,000 units) northward to the point.

Example: cA1428

This locates point to nearest 1,000 units.

b. Maps bearing a 1,000 unit interval (1:5,000 to 1:100,000 inclusive): Letter of 100,000 unit square, 10,000 and 1,000 digits of easting line to left of point, estimated tenths (100 units) eastward to point, 10,000 and 1,000 digits of northing line south of the point, estimated tenths (100 units) northward to the point.

Example: A143286

This locates point to nearest 100 units.