AERONAUTICAL NAVIGATION USING GPS

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ABSTRACT

Navigation in air has defined routes and ways which should be followed by any airplane. The routes of air navigation are defined on charts and maps. The routes are different than ground roads, that they are defined using radio signals transmitted from a permanent station. The pilot normally has a plane chart for the journey, from stand in departure airport to the stand of arrival airports. Each country has a defined air space at its boarders of neighbour countries, and extended over parts of the seas or oceans, if the country has shores on these sea or oceans. From these air spaces of countries the airspace is covered and routes are defined. The routes lengths and azimuths are used to be calculated, relative to the national ellipsoid of each country. The new calculation of routes is depending on WGS84, since a GPS receiver will be fixed on each airplane, in order to define instantly its position according to WGS84. Therefore the route information should be referenced to WGS84. Since the airplane defines its position using GPS, the signals of navigation station are not needed. But, alternatively a permanent GPS station working 24 hours a day, calculates the corrections of GPS satellite and transmits these corrections to airplanes, to correct the determination of their positions using GPS. Accordingly, a network of GPS consists of permanent stations has to be built, replacing the traditional system of navigational stations.

Keywords: Aeronautical Navigation ; ICAO ; Aerodrome; En-route chart; Approach surface.

INTRODUCTION

Aeronautical navigation is the science which mainly uses geodesy to determine the movement of an aircraft. A journey of an aircraft starts from stand at departure airport to runway, taking off and climb to en-route, en-route take off, descent to approach, landing and taxi to stand at arrival airport. During this journey all movements ought to be determined geodetically as coordinates of latitude, longitude , azimuth and altitude.

The local geodetic datum of each country is used to determine the route coordinates, but recently International Civilian Aviation Organization (ICAO) decided to use WGS84 as reference for all aeronautical information of all countries.

As the coordinates of aircraft movements are referenced on WGS84, then all ground and air points should be determined on the same reference. The main points ought to be determined on WGS84 are runways, navigational aids, stands, aprons and places for services, that in addition of points of enroute map (En-route chart).Therefore, the aeronautical information can be divided into two main parts :

Firstly: area of radius of 15 km around the airport (Aerodrome surfaces).

Secondly: the air space of the country (En-route chart).

AERODROME

Aerodrome is the area around an airport which is covered by a rotated radius of 15 km from the airport centre (Aerdrome Reference Point, ARP. Figure 1 shows that this area can be divided into

a - Approach surface

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b - Transation surface
c - Inner horizontal surface
d - Conical surface
e - Outer horizontal surface

These surfaces are imaginary and have an elevation which an airplane altitude is respected, and any obstacles should be either removed or shown on charts. [1, 2]

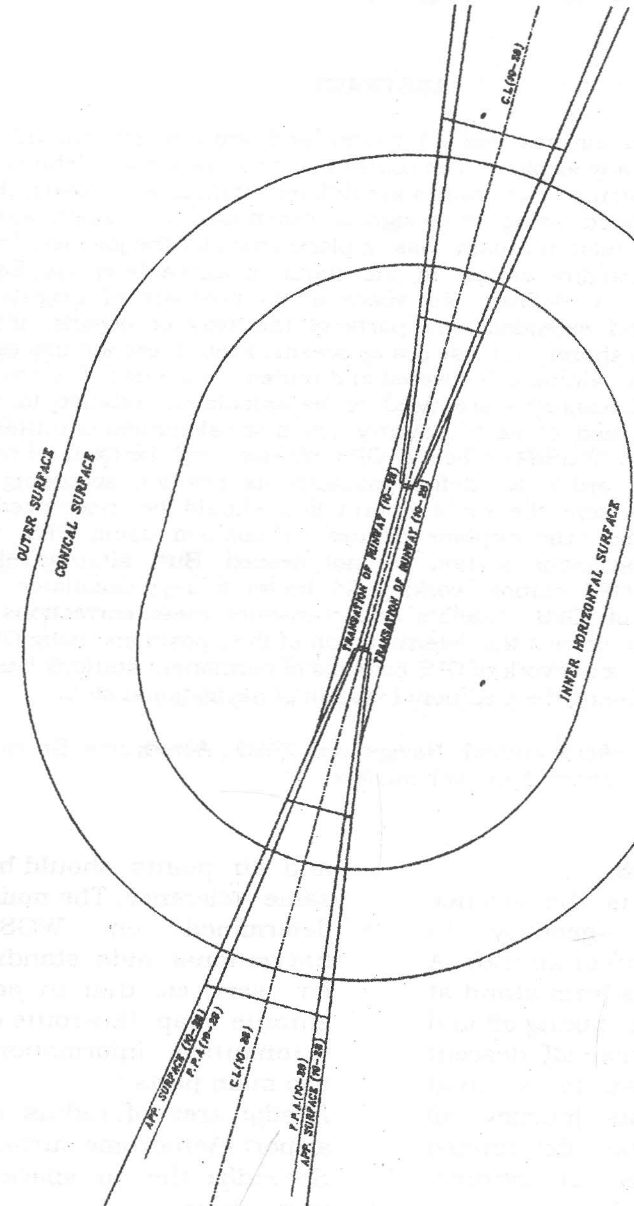

Figure 1 Approach surfaces

EN- ROUTE MAP

On this map air routes and main topographical features are shown; see for examle figure 2. En-rout map (chart) of Egypt covers all Egypt and parts of Red and Mediterranean seas. Points of this chart are classified as points on earth and imaginary points, such as the boundaries points and intersection of routes. For each route length, azimuth and coordinates of its terminals are to be geodetically and magnetically calculated. Graticules have to be projected comformally, in Egypt gnomonic oblique, tangent at latitude 30° and longitude 31°, is used.

The main points of En-route chart are the navigation aids, which their coordinates are determined on WGS84 by observations. All calculations of routes are done using geodetic mathematical formulae. [3, 4]

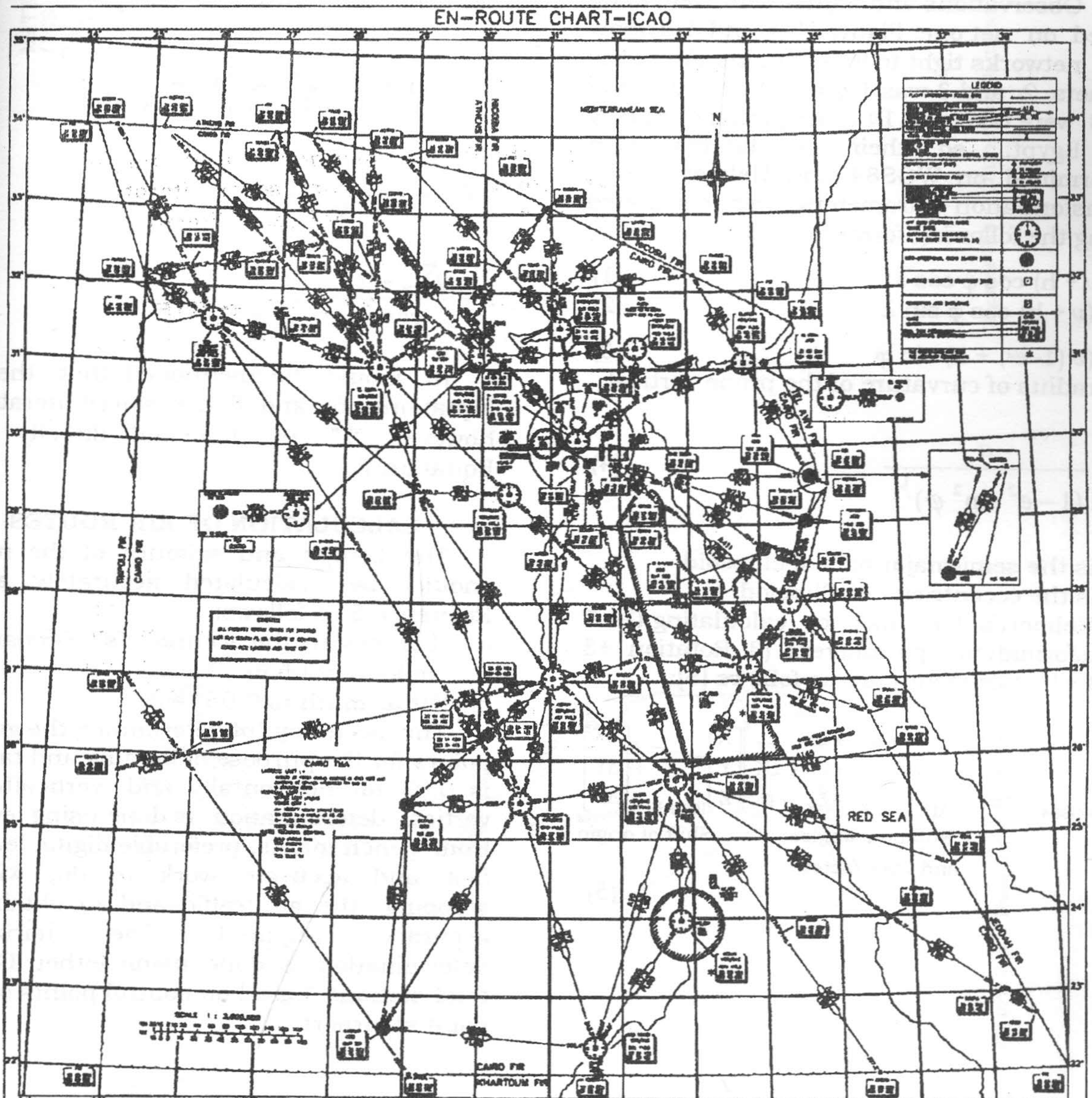

Figure 2 En-route chart

GPS OBSERVATIONS

In order to determine the coordinates on WGS84, as reference datum for Egypt, three networks have been designed. The first consists of 5 points covering Egypt, and observed for 72 hours, 24 hours, 3 times with interval of 3 weeks. Adjustment of first net was done referenced to four International GPS Geodynamics Service (IGS) stations, with an accuracy of 0.1 ppm. Nets 2 and 3 consist of 15 points, in between points of 1st net. Observations and adjustment were done based on net one. Figures 3-a and 3-b show the networks tight to IGS stations. Accuracy of nets 2 and 3 was 1 ppm. Observations of GPS were taken on 1st order points of Survey of Egypt, so their coordinates were determined on WGS84 and Helmert 1906. Transformation parameters were calculated using the following formula [5, 6].

$$X=(\upsilon + h) \cos \varphi \cos \lambda \quad (1)$$

$$Y = (\upsilon + h) \cos \varphi \sin \lambda \quad (2)$$

$$Z = (\upsilon (1-e^2) + h) \sin \varphi \quad (3)$$

υ = radius of curvature of the prime vertical

$$\upsilon = \frac{a}{(1-e^2 \sin^2 \varphi)^{1/2}} \quad (4)$$

a is the semi-major axis of ellipsoid

e^2 is the eccentricity of ellipsiod

Helmert's formulae for calculating the 7 transformation parameters (3 Rotation +3 shift +1 scale factor) are as follows [5]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{IOCAl} + \begin{bmatrix} +\mu & +\xi_Z & -\xi_Y \\ -\xi_Z & +\mu & +\xi_X \\ +\xi_Y & -\xi_X & +\mu \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{IOCAL} + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad (5)$$

Rotation angles and scale factor — Shift of origin

Solving those equations will give the seven the unknown parameters, therefore number of equations should be 7 or greater. Normally at least 3 points known their coordinates on the two systems form 9 equations and so, solution will give the 7 paremeters using least squares.

Afterwards, the back transformation from WGS84 global cartesian coordinates into ellipsoid WGS84 coordinates φ, λ, h are performed, where

$$(\varphi, \lambda, h)_{WGS84} \leftarrow (X, Y, Z)_{WGS84}$$

$$\varphi = \arctan \frac{Z}{\sqrt{X^2 + Y^2}} \left[1 - e^2 \frac{\nu}{\nu + h}\right]^{-1} \quad (6)$$

$$\lambda = \arctan \frac{Y}{X} \quad (7)$$

$$h = \frac{\sqrt{X2 + Y2}}{\cos \varphi} - \nu \quad (8)$$

It should be mentioned that, the two Equations 6 and 8 are solved iteratively, however "λ" is obtained directly from Equation 7.

CALCULATION OF AIR ROUTES

The Length and azimuth of the routes should be calculated accurately as in Reference 5 as follows:

a - For lengths the accuracy is 0.05 nautical miles ≅ 92.5 m

b - For azimuth to 0.05° = 3′

The accuracy of determining the ground points for the purpose of landing and take off is 0.03 mt horizontally and vertically. The vertical determination is done using leveling from bench marks, preferable digital level for fast and accurate work to do, without stopping the air traffic and to obtain the accuracy required. The horizontal determination is done using either GPS or total stations, based on control points of GPS point at airport.

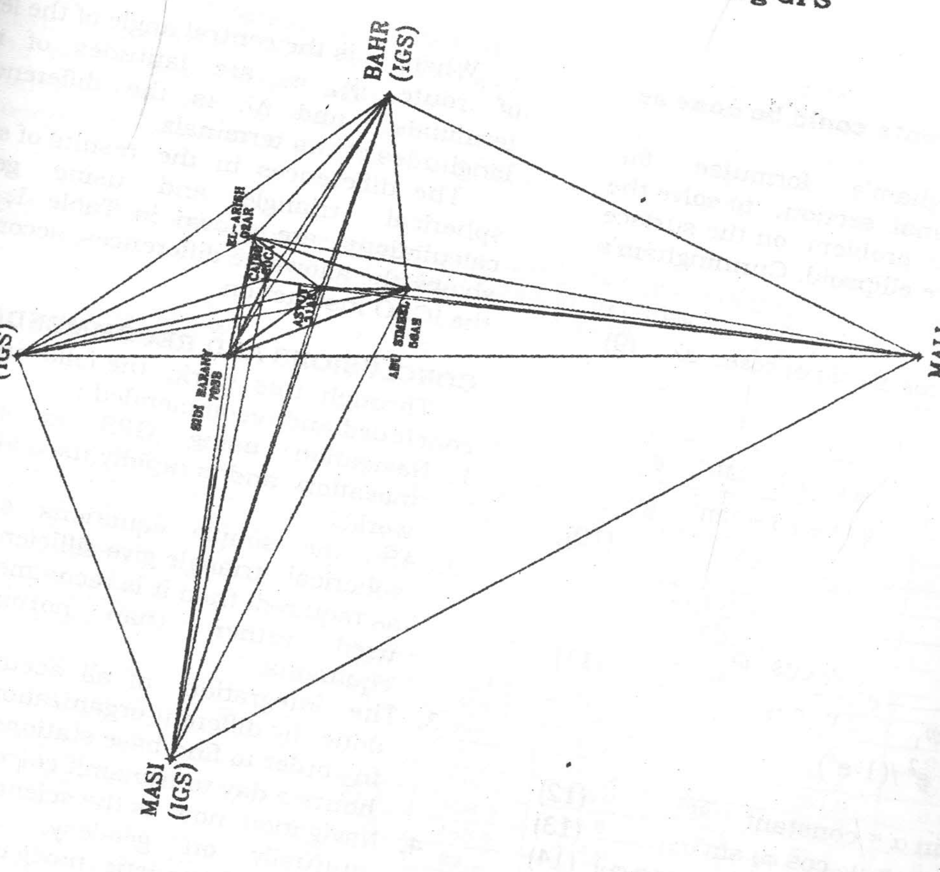

Figure 3-b Connection between the basic network and point of IGS

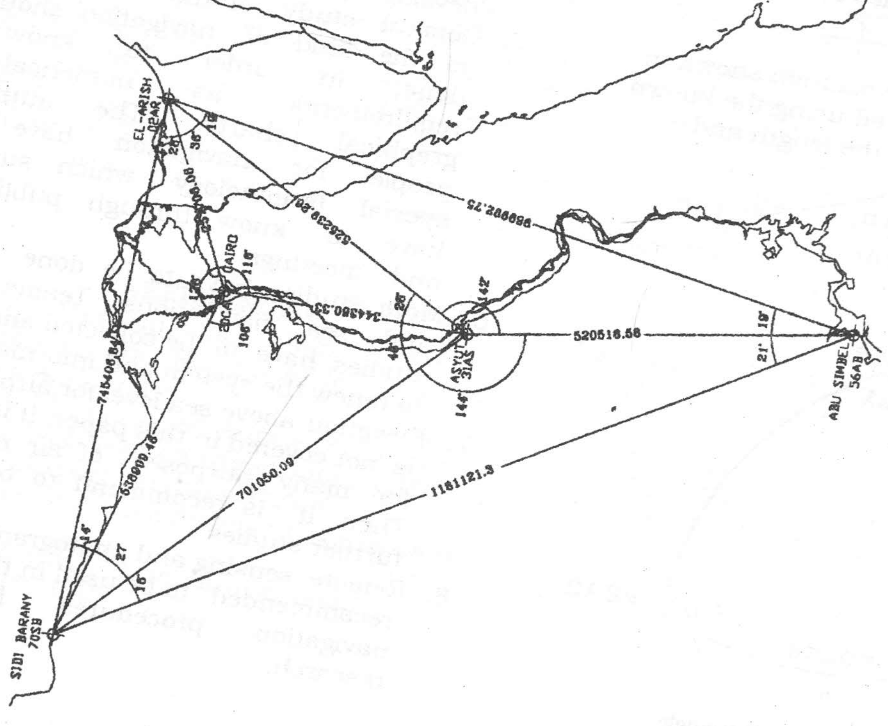

Figure 3-a Basic network

The calculation of route could be done as follows:

a- Using Cunningham's formulae for azimuth of normal section, to solve the inverse geodetic problem on the surface of the reference ellipsoid. Cunningham's formulae [7]

$$\cot \alpha_{12} = (\Lambda_{12} - \cos \Delta\lambda) \sin \varphi_1 \operatorname{cosec} \Delta\lambda \quad (9)$$

$$\Lambda_{12} = \frac{\tan \varphi_2}{(1+\varepsilon) \; + \tan \varphi_1} + e^2 \sqrt{\frac{(1+\varepsilon) + \tan^2 \; \varphi_2}{(1+\varepsilon) + \tan^2 \; \varphi_1}}, \quad (10)$$

or

$$= \frac{\tan \; \varphi_2}{(1+\varepsilon) \tan \; \varphi_1} + e^2 \frac{\nu_1 \cos \; \varphi_2}{\nu_2 \cos \; \varphi_1} \quad (11)$$

where $\varepsilon = e^2/(1-e^2)$

and $\nu \cos \varphi \sin \alpha = \text{constant}$ (12)

$\nu_1 \cos \varphi_1 \sin \alpha_{12} = \nu_2 \cos \varphi_2 \sin \alpha_{21}$ (13)

$\alpha_{21} = \sin^{-1} (\nu_1 \cos \varphi_1 \sin \alpha_{12} / \nu_2 \cos \varphi_2)$ (14)

Where φ_1, φ_2 is the latitudes of terminal points.

b- The spherical triangle solution shown in Figure 4, can be solved using the known formulae to find out the length and azmith of the route

$$\frac{\cos\varphi_2}{\sin\alpha_{12}} = \frac{\cos\varphi_1}{\sin\alpha_{21}} = \frac{\sin n}{\sin \Delta\lambda}$$

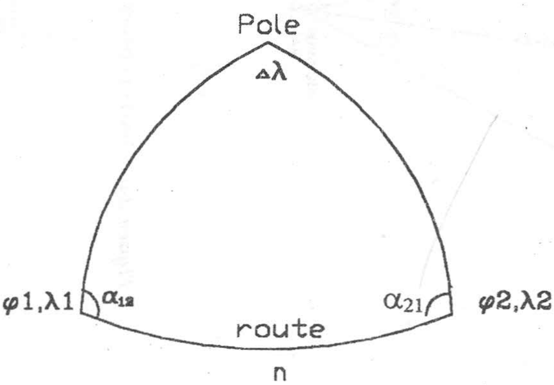

Figure 4 Spherical triangle

Where n is the central angle of the length of route, φ_1, φ_2 are latitudes of route terminals, and $\Delta\lambda$ is the difference of longitudes of two terminals.

The differences in the results of solving spherical triangle and using geodetic calculations are shown in Table 1, which shows the allowable differences, according to the ICAO instruction.

CONCLUSIONS AND RECOMMENDATIONS

Through this work, the following can be concluded and recommended :

1. Navigation using GPS is the new inovation and is rapidly used all over the world.
2. AS the simple equations of solving spherical triangle give sifficient accuraey as required, then it is recommended to be used rather than normal section equations.
3. The integration of all accurate points done by different organizations is a must in order to find base stations working 24 hours a day to transmit corrections.
4. Navigation now is the science depending mutually on geodesy, therefore the branch of geodetic navigation must be developed, and so specialists are needed.
5. General study of the subjects related to the kind of navigation should be done, in order to know the requirements as numerical or graphical charts. The authorized people for navigation have their special terminology which surveyors have to know through publications and meetings.
6. More studies have to be done on land and sea navigations. Teams of the studies have to be collected and trained to renew the system and information.
7. Elevation above sea level for airport items is not covered in this paper, it is required for many purposes of air navigation. Then it is recommend to be done in further studies .
8. Remote sensing and photogrammetry are recommended to be used in the same air navigation procedures in further research.

9. Geographical Information System (GIS) can be a good subject for air navigation to record any change with data on GIS layers and omit if this information is temporary. Also GIS can be used as a base for simulated training in the field of air navigation.
10. Auto cartography, i.e. automated digital maps and charts can be recommended for future studies as a good subject

Table 1 Differences in the results of solving spherical triangle and using geodetic calculations

Name of line	Length	Azimuth by solving triangle		Azimuth by using chumming formulae		Ddif. between two solving	
	NM	Fore Azimuth	Back Azimuth	Fore Azimuth	Back Azimuth	Fore Azimuth	Back Azimuth
	15.6	88.7	268.6	88.7	268.6	" 0.0	" 0.0
ELARISH - ELGORA	47.9	76.6	257.0	76.7	257.1	- 0.1	-0.1
BOMOR – TULOP	58.8	213.0	32.7	213.2	32.9	-0.2	-0.2
SHARM - HURG.	68.5	268.6	89.3	268.7	89.3	-0.1	0.0
ELFAYOUM – KATAB	78.3	151.4	331.6	151.1	331.5	0.3	0.1
PASOS – ELARISH	82	275.6	94.8	275.5	94.8	0.1	0.0
HURGHADA – NABED	86.3	269.4	88.5	269.1	88.4	0.3	0.1
NEW VALLEY – DAKHLA	97.8	194.2	14.0	194.2	14.1	0.0	-0.1
ASYUT – NEWVALLEY	100.1	151.4	331.9	151.3	331.9	0.1	0.0
ELARISH – TABA	106.9	358.5	178.5	358.5	178.5	0.0	0.0
ASWAN – LUXOR	117.5	214.5	34.0	214.6	34.2	-0.1	-0.2
ASWAN – ABUSIMBEL	119.4	81.0	261.9	81.0	261.9	0.0	0.0
NEWVALLEY – LUXOR	121.1	129.1	309.9	128.9	309.7	0.2	0.2
ASYUT – LUXOR	125.3	268.5	89.8	268.4	89.6	0.1	0.2
SHARM – SEMRU	139.4	133.6	314.6	133.5	314.5	0.1	0.1
ELDABA – FAYOUM	143.4	82.2	263.3	82.2	263.4	0.0	-0.1
ASRAB – IMRAD	161.1	94.3	275.4	94.3	275.4	0.0	0.0
OWENAT – ABUSIMBLE	171.3	185.0	4.9	185.0	4.9	0.0	0.0
DAKHLA – OWENAT	190.9	123.5	304.7	123.3	304.5	0.2	0.2
LUXOR – SEDVA	194.7	162.9	343.3	162.8	343.2	0.1	0.1
NEW VALLEY – ABUSIMBLE	205.6	128.3	309.9	128.3	309.8	0.0	0.1
SID BARANI – KATAB	208.8	145.8	326.9	145.7	326.8	0.1	0.1
SID BARANI – DANAD	209.7	76.0	257.7	76.1	257.7	-0.1	0.0
TULOP – POSITION	213.5	197.4	16.9	197.5	17.0	-0.1	-0.1
LUXOR - ABUSIMBEL	296.3	142.6	323.9	142.4	323.8	0.2	0.1
TULOP - ATMUL							

In the table, the lengths have been calculated from spherical triangle only.

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ملخص البحث

يتناول البحث موضوعات الخرائط والمعلومات الخاصة بالملاحة الجوية طبقا لمواصفات المنظمة الدولية للطيران المدنى وهذه المعلومات من إحداثيات وخرائط طبقا للنظام العالمى WGS 84 ولتحديد الإحداثيات فى هذا النظام تم إنشاء ثلاث شبكات جى بى إس تغطى مطارات جمهورية مصر العربية بالكامل.

الشبكة الأولى تتكون من خمس نقاط تم رصدها ثلاث مرات لمدة ٢٤ ساعة كل ثلاث أسابيع وتم ربط هذه الشبكة على أربعة نقاط من شبكة إى جى إس.

الشبكة الثانية تتكون من سبعة نقاط تم ربطها على أربعة نقاط من الشبكة الاولى ورصدت لمدة أربعة ساعات لكل النقاط فى نفس الوقت.

الشبكة الثالثة تتكون من ثمانية نقاط ربطت على ثلاث نقاط من الشبكة الأولى ورصدت لمدة أربع ساعات لكل النقاط فى نفس الوقت وتم عمل التصحيحات للشبكات وتناول البحث إنتاج خرائط الطرق الجوية وطريقة إخراجها . ويعتبر رصد الملاحة الجوية بواسطة جى بى إس من الطرق المستخدمة عالميا.