King Fahd University of Petroleum and Minerals

Aerospace Engineering Department

# Astrodynamics I

# (AE 570)

## Term Project

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## ABSTRACT

In the Middle East region, many satellites were lunched to cover the region like Arab-Sat and Nile-Sat. But the latest satellite Arab-Sat 4A that was lunched over the Middle East region for communication purposes on 28th Feb 2006 failed to reach its designed Geostationary Satellite Orbit (GSO orbit) due to a problem occurred in the rocket propulsion system that was carrying the satellite.

So in this paper, we study how to track satellites generally while orbiting in their orbits and we concentrate on this special case for Arab-Sat 4A, detailed study will be about its new orbit after it failed to reach the GSO orbit and what regions it could cover on earth in the new situation.

## ACKNOWLEDGEMENT

"In the name of Allah (God), Most Gracious, Most Merciful. Read, In the name of thy lord and Cherisher, Who created man from a [leech - like] clot. Read, and thy Lord Is Most Bountiful, He Who taught [the use of] the pen. Taught man that which he know not. Nay, but man doth Transgress all bounds. In that he looketh upon himself as self-sufficient. Verily, to thy Lord is the return [of all]. " (The Holy QURAN, Surah No. 96).
Above and first of all, I thank and pray to Allah for His guidance and protection throughout my life including the years of this study. I am happy to have had a chance to glorify His name, in the sincerest way, through his small accomplishment, and I ask Him, with hope in Him, to accept my efforts. And secondary my peace upon His Prophet, MOHAMMED (salla Allah alihe wa sallam). I wish to thank my direct supervisor **Dr: Ayman Kassem** for providing me with some sources, which deal with the subject, and for his support, comments, suggestions, constructive criticism, encouragement, knowledge and help through this project.

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# 1. INTRODUCTION

Now days the space is not a space any more, it is so crowded with satellites used for different applications like communication, weather monitoring, spying, and many other applications.

Satellites have to be tracked from time to time to see weather they are still orbiting in their orbits or not for some possible reasons.

In the Middle East region, many satellites were lunched to cover the region like Arab-Sat and Nile-Sat. But the latest satellite Arab-Sat 4A that was lunched over the Middle East region for communication purposes on 28$^{th}$ Feb 2006 failed to reach its designed orbit (geosynchronous orbit GSO) due to a problem occurred in the rocket separation phase that was carrying the satellite.

In this paper, we study how to track satellites generally while orbiting in their orbits (orbit propagation tracking) by using available data about the orbit like the semi-major axis (a), the eccentricity (e) the inclination angle and so on. But we concentrate on Arab-Sat 4A, as a case study for orbit propagation tracking. Detailed study will be about its new orbit after it failed to reach the GEW orbit and what regions it could cover in the new situation.

### Arab-Sat 4A:

Arab-Sat 4A is a 3.3-tonne geostationary communications satellite which carries 24 C-band and 16 Ku-band transponders to provide voice, video and internet services to all Arab countries. The spacecraft was to have offer a wide range of services in the Middle East for ARABSAT, the communications satellite operator based in Riyadh, Kingdom of Saudi Arabia with following specification.

**Table 1**. Arab-Sat 4A specification

| | |
|---|---|
| **Nation** | Saudi Arabia |
| **Application** | Communication |
| **Operator** | Arabsat |
| **Lunching Vehicle** | Proton's Briz-M |
| **Equipment** | 24 act. C-band transponders, 16 act. Ku-band transponders |
| **Lifetime** | 15 years |
| **Mass** | 3341 kg |
| **Orbit** | GEO |

28.02.2006 (23:10) - **Arabsat 4A Launch**

Launch vehicle: **Proton-M**, Launch site: **Baikonur**, Launch complex: **Proton LC, Pad 200, Launcher 39**

Launch window: Feb. 28 - March 1, 2006.

Spacecraft:

| Name | Index | Orbit type | Apogee, km | Perigee, km | Orbit inclination | Orbital period, min | Mass, kg |
|---|---|---|---|---|---|---|---|
| **Arabsat 4A** | | GSO | 35792.98 | 3156.95 | 14.2 | 689.2 | 3340 |

ARABSAT 4

1 28943U 06006A 06082.53518356 .00004790 00000-0 74251-2 0 284

2 28943 51.5608 93.4753 5081311 16.9233 355.2574 5.25860235 1195

Name Arabsat

geostationary-satellite orbit (GSO),

Apogee, 35792.98 km

Perigee, 3156.95 km

Orbit inclination 14.2 deg.

Orbital period, 689.2 min

**Figure 1**. Arab-Sat 4A mission data

**Arab-Sat 4A Problem:**

The satellite failed to reach geostationary orbit following a premature shutdown of the lunching vehicle that was carrying Arab-Sat 4A (Proton's Briz-M) upper stage. According to several sources, the Briz-M upper-stage had shut down 27 minutes and 31 seconds into a planned 31-minute second burn. It is unlikely that it could be made geostationary because the transfer orbit attained an apogee of 14,700 km only (instead of the usual 36,000 km). The satellite is a Euro-star E2000+ model equipped with 24 transponders in C-band and 20 transponders in Ku-band. With a launch mass of about 3,350 kg, it is the thirtieth Euro-star to orbit. The satellite is also known as BADR-ONE. ArabSat's situation was similar to that of Eight years ago, Asiasat 3, a communications satellite that was launched eight years ago toward a standard geosynchronous orbit over Earth's equator — only to be similarly stuck halfway due to a Russian rocket failure. In that earlier case, engineers came up with a bold scheme to steer Asiasat 3 deep into space and use the moon's gravity to change its orbit into a useful one. This time, however, the hopes for space magic were dashed by the satellite's deliberate demise. As soon as ArabSat's predicament became known a month ago, experts began working on plan similar to that used in 1998. They found that while there was not quite enough fuel on board for such a rescue mission, they could park the satellite in a convenient location where a robotic space tug, already under development by Orbital Recovery, could push it to a money-making orbit. Neither the satellite's original owners nor the European insurance team who assumed ownership once their client declared a "total loss" of the vehicle, turned out to be interested in attempting such a rescue. The satellite builder, EADS Astrium Aerospace in Germany, was told to send the destruct commands to the satellite on Thursday 2nd March. But unfortunately the satellite was noted by an informal network of highly skilled amateur satellite watchers who had been monitoring Arab-Sat 4A since its launch.

**Variety of proposals**

During the month that Arab-Sat 4A circled Earth in its intermediate orbit, planners on Earth came up with a variety of proposals for salvaging a useful mission even if it could not reach the intended geosynchronous orbit. Since the spacecraft contained a significant amount of rocket fuel, it had more than enough to reach the moon, or even head for interplanetary space.

The problem was, as a communications satellite it had no scientific instrumentation, and its communication system was not designed for lunar distances. Nevertheless, imaginative orbital designers studied flight paths that would place the satellite into lunar orbit or even into one of the "gravity-neutral zones" in the Earth-moon system. One orbit that would have ranged behind the moon was suggested for a station keeping demonstration, to obtain experience in operating a communications relay to support future human missions to the moon.

Arab-Sat 4A was also considered for a close flyby over the lunar surface, where its radio transmitter could function as makeshift radar sounder to seek hints of ice in the bottoms of lunar polar craters. Alternately, the 3-ton spacecraft could have been aimed to impact directly inside one of the suspect craters, allowing other spacecraft to look for water vapor in the ejected debris.

None of these missions interested the satellite owners, however, and their urgent cash-flow requirements frustrated several attempts to obtain private transition funding for operations.

## 2. PROJECT NATURE:

This project will be devoted to study how to propagate satellites orbits generally while orbiting in their orbits and we concentrate on this special case for Arab-Sat 4A. Detailed study will be about its new orbit after it failed to reach the GEW orbit and what regions it could cover on earth in the new situation and finally what possible ΔV could be applied to correct it from present orbit to its designed GEW orbit.

## 3. BACKGROUND INFORMATION:

In this part, all relations and equations used to get the orbit of any satellite and its region covered on the earth map are investigated by using the data for Arab-Sat 4A as study case in this paper. The whole work is going to be focused on Arab-Sat 4A example. However, this example could be implemented for any other satellite orbit just we need to change the satellites data.

➔ Our main target is to find the regions that are going to be covered by Arab-Sat 4A. To do so, we need to go through sequence of steps.

First of all, we start by presenting the data of Arab-Sat 4A after it failed to reach its planned orbit by the help of Tow Line Element (TLE) produced by NORAD system as follows:

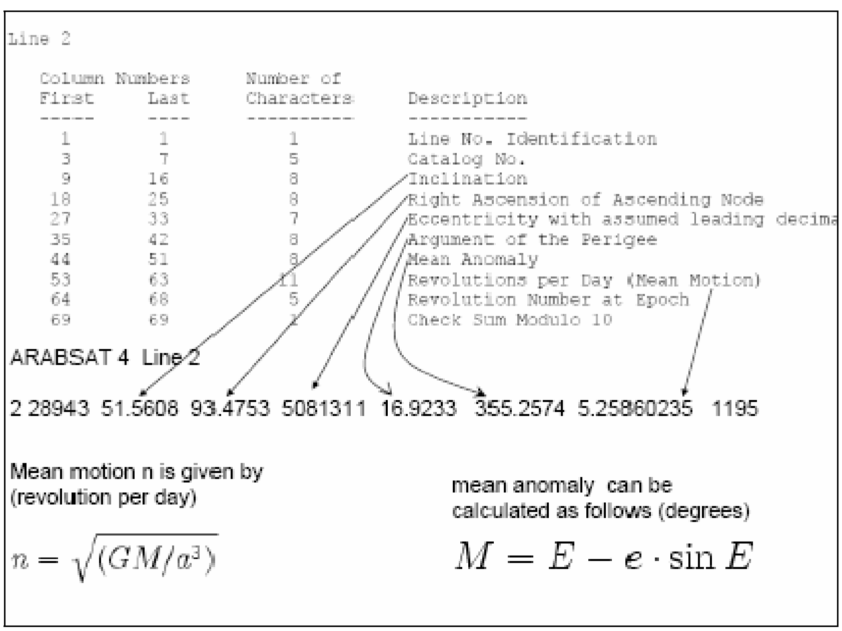


**Figure 2**. Arab-Sat 4A data after failure

1- We first start by defining the time of the satellite. That's actually taken from the TLE data in figure 1.
The time representation is on the form 06082.53518356.
Where:

- The first two digits represent the year ➔ 2006.
- The next digits represent the number of days ➔ 82.53518356 days.

But for astronomical calculation, the time should be formed in the Julian day form as follows:

- Year = 2006
- Month = 3
- Day = 23

We enter the year (Y), the month (MO) and the day (D) to get the Julian day (Jd) by the following relations:

A = (Y/100)…………………………………………………………………………(1)
B = (A / 4)………………………………………………………………………...(2)
C = (2 - A +B)……………………………………………………………………(3)
E = (365.25 * (Y + 4716))………………………………………………………...(4)
F = (30.6001 * (MO +1))…………………………………………………………(5)
Jd = C+D+E+F-1524.5……………………………………………………………(6)

2- Finding the earth longitude with time by taking the Greenwich as our reference as follows:

- Earth longitude = GST………………………………………………………(7)
- GST = $GST_0$ + Earth Rotation * Time…………………………………………(8)
- $GST_0$ = 99.6910+36000.7689*T+0.0004*$T^2$…………………………………..(9)

Where:

- GST is the Greenwich Sidereal Time.
- $GST_0$ is the angle (time) in degrees between Greenwich longitude (0 longitude) and the x-axis (vernal equinox).
- T = T = JD / 36525……………………………………………………………..(10)

And JD is the Julian day numbers and the unit of $GST_0$ is in degrees.

- Earth Rotation is the earth rotation speed and it is equal to 4.167 x $10^{-3}$ deg/s.

3- Finding the longitude and the latitude of the satellites as follows:

- The satellite longitude can be found as follows:

  ➔ Satellite longitude = $\tan^{-1}(YI/XI)$……………………………………………...(11)

  ➔ Satellite latitude = $\tan^{-1}(ZI/(XI^2+YI^2)^{1/2})$…………………………………...(12)

Where:

- XI, YI and ZI are the inertial axes of the satellite. We can get the inertial axes by transforming the orbital axes x, y and z to XI, YI and ZI respectively by the transformation matrix TM.

$$TM = \begin{bmatrix} C(\omega)\,C(\Omega) - S(\omega)\,C(i)\,S(\Omega) & C(\omega)\,S(\Omega) + S(\omega)\,C(i)\,C(\Omega) & S(\omega)\,S(i) \\ -S(\omega)\,C(\Omega) - C(\omega)\,C(i)\,S(\Omega) & -S(\omega)\,S(\Omega) + C(\omega)\,C(i)\,C(\Omega) & C(\omega)\,S(i) \\ S(i)\,S(\Omega) & -S(i)\,C(\Omega) & C(i) \end{bmatrix}$$

- TM is the transformation matrix from inertial axes to orbital axes, so to get the inertial axes from the orbital axes we take the inverse of TM. The letters in the above matrix C and S stand for cosine and sin respectively. And the angles $\Omega$, $\omega$ and i stand for the right ascension of ascending node angle, the argument of the perigee angle and the orbit inclination angle respectively.

- The orbital axes can be found by the following formulas:

- $x = r\ \cos\theta$……………………………………………………………………...(13)

- $y = r \sin\theta$……………………………………………………………………….(14)

- $z = 0$…………………………………………………………………………….(15)

Where:

- $r = p / (1+ e \cos\theta)$…………………………………………………………...(17)

- $p = a (1 – e^2)$……………………………………………………………………...(18)
- $\theta = 2 * \tan^{-1} [\tan (E_2/2) * (1 + e)^{1/2}/(1 - e)^{1/2}]$…………………………………..(19)
- $E_2 = (\mu/a^3)^{1/2} * Time + E_1 - e \sin E_1$…………………………………………....(20)
- $E_1$ can be found from the following formula:

$$M = E_1 – e \sin E_1 \text{ ……………………………………………...(21)}$$

- M is the mean anomaly and it is equal to 355.2574 deg from (TLE).

- a is the semi-major axis of the orbit and it is calculated from the following formula:

$$a = (\mu/n^2)^{1/3} \text{ ………………………………………………………(22)}$$

- $\mu = 3.968 \times 10^{14}\ m^3 / s^2$.
- n is the mean motion of the satellite and it is equal to 5.25860235 (revolution per day) (from TLE).
- e is the eccentricity of the orbit and it is equal to 0.5081311 (from TLE).

➔ Including the J2 Perturbation in which the right ascension of ascending node angle (Ω) and the argument of the perigee angle (ω) are affected as follows:

$\Omega = \Omega_0 + \Omega_{\_dot} \times Time$ ……………………………………………………………(23)

$\omega = \omega_0 + \omega_{\_dot} \times Time$ ……………………………………………………………(24)

Where:

- $\Omega_{\_dot} = -2 \times 10^{14} a^{-7/2} \cos (i) (1-e^2)^{-2}$ [deg/day]………………………………(25)
- $\omega_{\_dot} = 10^{14} a^{-7/2} (4-5 \sin^2(i)) (1-e^2)^{-2}$ [deg/day]……………………………...(26)

- $\Omega_0$ is the right ascension of ascending node angle of the orbit and it is equal to 93.4753 deg (from TLE).
- $\omega_0$ is the argument of the perigee angle of the orbit and it is equal to 16.9233 deg (from TLE).

- *i* is the inclination angle of the orbit and it is equal to 51.5608 deg (from TLE).

4- Finding the latitude and the longitude projection on earth map as follows:

➔ To specify the regions of earth that could be covered by the satellite with time, we take the difference between the earth longitude and the satellite longitude and by considering only the satellite latitude since the earth latitude is fixed as follows:

- longitude = Earth longitude - Satellite longitude……………………………...(27)
- latitude = Satellite latitude……………………………………………………(28)

# 4. CALCULATION STEPS:

➔ **Flow Chart**

Matlab and excel software used to make calculations as shown in the following flow chart:

Calculating the Julian day

↓

Inside the Time Loop

↓

$GST_0$ ➔ GST ➔ Earth longitude

$J_2$ for Ω and ω ➔ eccentric anomaly $E_2$ ➔ θ ➔ r ➔ orbital axes x, y and z ➔

➔ Transformation matrix TM ➔ inverse of transformation matrix TT ➔

➔ Inertial axes XI, YI and ZI ➔ satellite longitude and latitude

Longitude = Earth longitude – satellite longitude

Latitude = satellite latitude

Plotting

## 5. RESULTS AND DISCUSSION:

Excel used only to find the initial value of the eccentric anomaly $E_1$ by using interpolation technique as follows:

From equation 21, we have:

$$M = E_1 - e \sin E_1$$

M = 355.2574 deg from (TLE).

**Table 2**. Initial eccentric anomaly $E_1$

| E1 | E1_RAD. | Eccentricity | Mean anomaly | Mean anomaly_ fixed | Difference |
|---|---|---|---|---|---|
| 349.4 | 6.0981803 | 0.5081311 | 6.191651757 | 6.200411315 | 0.008759558 |
| 349.6 | 6.101671 | 0.5081311 | 6.193398405 | 6.200411315 | 0.00701291 |
| 349.8 | 6.1051616 | 0.5081311 | 6.195143935 | 6.200411315 | 0.00526738 |
| 350 | 6.1086523 | 0.5081311 | 6.196888369 | 6.200411315 | 0.003522946 |
| 350.2 | 6.1121429 | 0.5081311 | 6.198631728 | 6.200411315 | 0.001779587 |
| **350.4** | 6.1156336 | 0.5081311 | 6.200374034 | 6.200411315 | **3.72813E-05** |
| 350.6 | 6.1191243 | 0.5081311 | 6.202115306 | 6.200411315 | -0.001703991 |
| 350.8 | 6.1226149 | 0.5081311 | 6.203855568 | 6.200411315 | -0.003444253 |
| 351 | 6.1261056 | 0.5081311 | 6.205594839 | 6.200411315 | -0.005183524 |
| 351.2 | 6.1295962 | 0.5081311 | 6.207333142 | 6.200411315 | -0.006921827 |
| 351.4 | 6.1330869 | 0.5081311 | 6.209070498 | 6.200411315 | -0.008659183 |
| 351.6 | 6.1365775 | 0.5081311 | 6.210806928 | 6.200411315 | -0.010395613 |

As shown in table 2, the value of $E_1$ = 350.4 deg.

The Matlab program was implemented for the day 23rd of March 2006.the output is as follows:

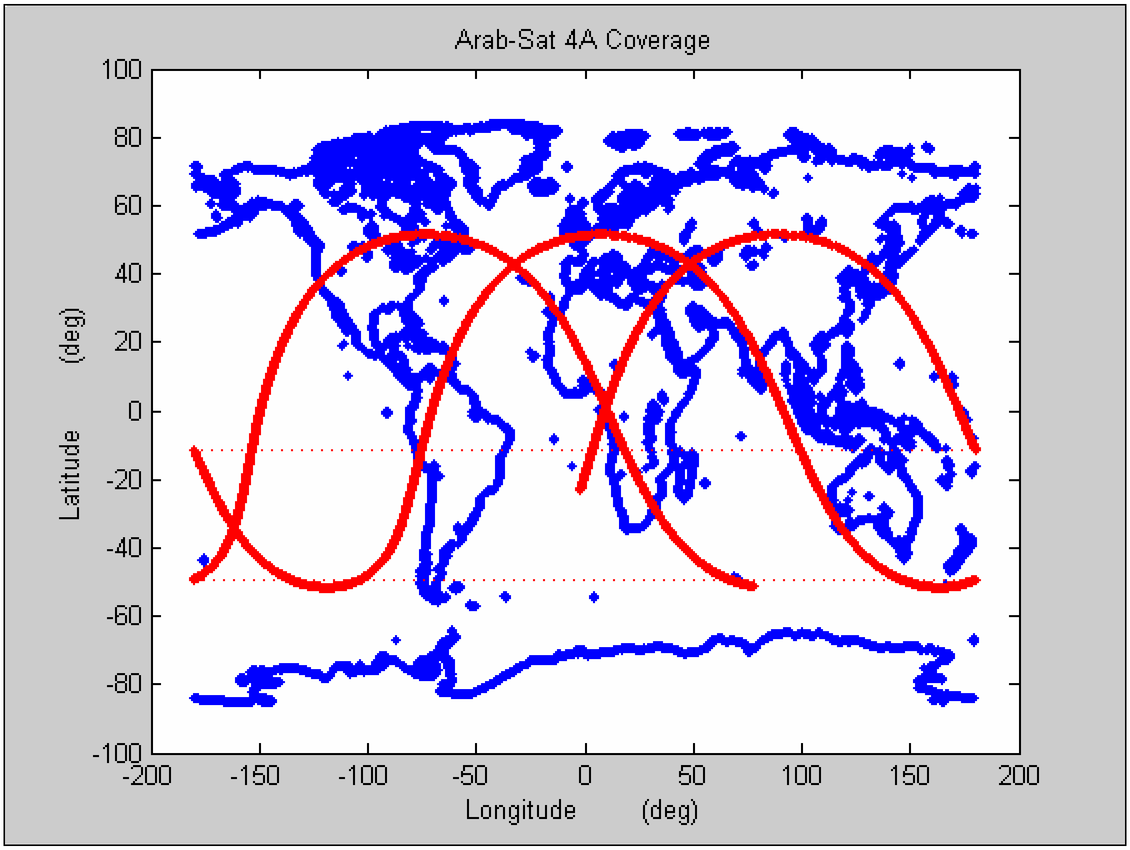


Figure 3. Arab-Sat 4A Coverage

As shown in figure 3, the Arab-Sat 4A does not pass by Saudi Arabia which is the owner of this satellite in about three periods while it passes by some Arabian countries like Egypt, Sudan and Morocco. That indicates that there will not be a benefit from being in the present orbit for the owner.

But generally speaking, the above simulation could be used for any other satellite just by changing the characteristics of the satellite like the inclination angle, the eccentricity and other possible parameters. And we can propagate any satellite by using the above Matlab code.

## 5. CONCLUSION

The paper was devoted to study how to propagate orbits, and the satellite Arab-Sat 4A was studied specially as study case for such type of problems. A Matlab code was generated to calculate all parameters and plot the satellite propagation on earth map to see the regions that could be covered by the satellite.

As mentioned above, the Arab-Sat 4A was used in this paper as a model of satellite. It was noted from the results that the Arab-Sat 4A was covering little part of the Arabian countries but the major part of the Arabian region was not covered by this satellite including the owner country of the satellite Saudi Arabia.

The project goals were achieved with good and reasonable results. A great knowledge was earned from this project. And high percentage of the course topics was included in this paper.

However for me I thank Allah for all the success in doing this paper and the success in applying the principles and knowledge of this course and contribute them to related practical beneficial application in our daily life. It was very powerful tool in learning and it helped me a lot in understanding the course contents. Finally, I thank the person who was behind this work and who spent lots of his valuable time and effort for giving me all support and great help **Dr. Ayman Kassem** .

# REFERENCES


1. Spaceflight dynamics, by William E. Wiesel.

2. http://www.islamicfinder.org/Hcal/index.php?home

3- http://space.skyrocket.de/doc_sdat/arabsat-4a.htm

4- http://www.msnbc.msn.com/id/11999597/

5- Dr. Ayman Kassem, KSA, KFUPM, Aerospace Engineering Department.

# APPENDIX

The excel file:

| E1 | E1_Rad _ | Eccentricity (e) | Mean anomaly | Mean anomaly_fixed | Difference |
|---|---|---|---|---|---|
| 300 | 5.235988 | 0.5081311 | 5.67604213 | 6.200411315 | 0.524369185 |
| 300.2 | 5.239478 | 0.5081311 | 5.678643254 | 6.200411315 | 0.521768061 |
| 300.4 | 5.242969 | 0.5081311 | 5.681239026 | 6.200411315 | 0.519172289 |
| 300.6 | 5.24646 | 0.5081311 | 5.683829458 | 6.200411315 | 0.516581857 |
| 300.8 | 5.24995 | 0.5081311 | 5.686414561 | 6.200411315 | 0.513996754 |
| 301 | 5.253441 | 0.5081311 | 5.688994346 | 6.200411315 | 0.511416969 |
| 301.2 | 5.256932 | 0.5081311 | 5.691568823 | 6.200411315 | 0.508842492 |
| 301.4 | 5.260422 | 0.5081311 | 5.694138005 | 6.200411315 | 0.50627331 |
| 301.6 | 5.263913 | 0.5081311 | 5.696701902 | 6.200411315 | 0.503709413 |
| 301.8 | 5.267404 | 0.5081311 | 5.699260526 | 6.200411315 | 0.501150789 |
| 302 | 5.270894 | 0.5081311 | 5.701813887 | 6.200411315 | 0.498597428 |
| 302.2 | 5.274385 | 0.5081311 | 5.704361998 | 6.200411315 | 0.496049317 |
| 302.4 | 5.277876 | 0.5081311 | 5.70690487 | 6.200411315 | 0.493506445 |
| 302.6 | 5.281366 | 0.5081311 | 5.709442514 | 6.200411315 | 0.490968801 |
| 302.8 | 5.284857 | 0.5081311 | 5.711974943 | 6.200411315 | 0.488436372 |
| 303 | 5.288348 | 0.5081311 | 5.714502167 | 6.200411315 | 0.485909148 |
| 303.2 | 5.291838 | 0.5081311 | 5.717024198 | 6.200411315 | 0.483387117 |
| 303.4 | 5.295329 | 0.5081311 | 5.719541049 | 6.200411315 | 0.480870266 |
| 303.6 | 5.29882 | 0.5081311 | 5.72205273 | 6.200411315 | 0.478358585 |
| 303.8 | 5.30231 | 0.5081311 | 5.724559255 | 6.200411315 | 0.47585206 |
| 304 | 5.305801 | 0.5081311 | 5.727060635 | 6.200411315 | 0.47335068 |
| 304.2 | 5.309291 | 0.5081311 | 5.729556882 | 6.200411315 | 0.470854433 |
| 304.4 | 5.312782 | 0.5081311 | 5.732048008 | 6.200411315 | 0.468363307 |
| 304.6 | 5.316273 | 0.5081311 | 5.734534025 | 6.200411315 | 0.46587729 |
| 304.8 | 5.319763 | 0.5081311 | 5.737014947 | 6.200411315 | 0.463396368 |
| 305 | 5.323254 | 0.5081311 | 5.739490784 | 6.200411315 | 0.460920531 |
| 305.2 | 5.326745 | 0.5081311 | 5.741961549 | 6.200411315 | 0.458449766 |
| 305.4 | 5.330235 | 0.5081311 | 5.744427255 | 6.200411315 | 0.45598406 |
| 305.6 | 5.333726 | 0.5081311 | 5.746887914 | 6.200411315 | 0.453523401 |
| 305.8 | 5.337217 | 0.5081311 | 5.749343539 | 6.200411315 | 0.451067776 |
| 306 | 5.340707 | 0.5081311 | 5.751794142 | 6.200411315 | 0.448617173 |
| 306.2 | 5.344198 | 0.5081311 | 5.754239737 | 6.200411315 | 0.446171578 |
| 306.4 | 5.347689 | 0.5081311 | 5.756680335 | 6.200411315 | 0.44373098 |
| 306.6 | 5.351179 | 0.5081311 | 5.75911595 | 6.200411315 | 0.441295365 |
| 306.8 | 5.35467 | 0.5081311 | 5.761546594 | 6.200411315 | 0.438864721 |
| 307 | 5.358161 | 0.5081311 | 5.76397228 | 6.200411315 | 0.436439035 |
| 307.2 | 5.361651 | 0.5081311 | 5.766393022 | 6.200411315 | 0.434018293 |
| 307.4 | 5.365142 | 0.5081311 | 5.768808832 | 6.200411315 | 0.431602483 |
| 307.6 | 5.368633 | 0.5081311 | 5.771219724 | 6.200411315 | 0.429191591 |
| 307.8 | 5.372123 | 0.5081311 | 5.77362571 | 6.200411315 | 0.426785605 |
| 308 | 5.375614 | 0.5081311 | 5.776026804 | 6.200411315 | 0.424384511 |

| | | | | | |
|---|---|---|---|---|---|
| 308.2 | 5.379105 | 0.5081311 | 5.778423019 | 6.200411315 | 0.421988296 |
| 308.4 | 5.382595 | 0.5081311 | 5.780814369 | 6.200411315 | 0.419596946 |
| 308.6 | 5.386086 | 0.5081311 | 5.783200866 | 6.200411315 | 0.417210449 |
| 308.8 | 5.389577 | 0.5081311 | 5.785582525 | 6.200411315 | 0.41482879 |
| 309 | 5.393067 | 0.5081311 | 5.787959358 | 6.200411315 | 0.412451957 |
| 309.2 | 5.396558 | 0.5081311 | 5.79033138 | 6.200411315 | 0.410079935 |
| 309.4 | 5.400049 | 0.5081311 | 5.792698604 | 6.200411315 | 0.407712711 |
| 309.6 | 5.403539 | 0.5081311 | 5.795061043 | 6.200411315 | 0.405350272 |
| 309.8 | 5.40703 | 0.5081311 | 5.797418712 | 6.200411315 | 0.402992603 |
| 310 | 5.410521 | 0.5081311 | 5.799771625 | 6.200411315 | 0.40063969 |
| 310.2 | 5.414011 | 0.5081311 | 5.802119794 | 6.200411315 | 0.398291521 |
| 310.4 | 5.417502 | 0.5081311 | 5.804463234 | 6.200411315 | 0.395948081 |
| 310.6 | 5.420993 | 0.5081311 | 5.806801959 | 6.200411315 | 0.393609356 |
| 310.8 | 5.424483 | 0.5081311 | 5.809135984 | 6.200411315 | 0.391275331 |
| 311 | 5.427974 | 0.5081311 | 5.811465321 | 6.200411315 | 0.388945994 |
| 311.2 | 5.431465 | 0.5081311 | 5.813789986 | 6.200411315 | 0.386621329 |
| 311.4 | 5.434955 | 0.5081311 | 5.816109992 | 6.200411315 | 0.384301323 |
| 311.6 | 5.438446 | 0.5081311 | 5.818425354 | 6.200411315 | 0.381985961 |
| 311.8 | 5.441937 | 0.5081311 | 5.820736086 | 6.200411315 | 0.379675229 |
| 312 | 5.445427 | 0.5081311 | 5.823042203 | 6.200411315 | 0.377369112 |
| 312.2 | 5.448918 | 0.5081311 | 5.825343718 | 6.200411315 | 0.375067597 |
| 312.4 | 5.452408 | 0.5081311 | 5.827640647 | 6.200411315 | 0.372770668 |
| 312.6 | 5.455899 | 0.5081311 | 5.829933003 | 6.200411315 | 0.370478312 |
| 312.8 | 5.45939 | 0.5081311 | 5.832220802 | 6.200411315 | 0.368190513 |
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| 355 | 6.195919 | 0.5081311 | 6.240205336 | 6.200411315 | -0.039794021 |
| 355.2 | 6.199409 | 0.5081311 | 6.241928765 | 6.200411315 | -0.04151745 |
| 355.4 | 6.2029 | 0.5081311 | 6.243651677 | 6.200411315 | -0.043240362 |
| 355.6 | 6.206391 | 0.5081311 | 6.245374092 | 6.200411315 | -0.044962777 |
| 355.8 | 6.209881 | 0.5081311 | 6.247096032 | 6.200411315 | -0.046684717 |
| 356 | 6.213372 | 0.5081311 | 6.248817519 | 6.200411315 | -0.048406204 |
| 356.2 | 6.216863 | 0.5081311 | 6.250538573 | 6.200411315 | -0.050127258 |
| 356.4 | 6.220353 | 0.5081311 | 6.252259218 | 6.200411315 | -0.051847903 |
| 356.6 | 6.223844 | 0.5081311 | 6.253979473 | 6.200411315 | -0.053568158 |
| 356.8 | 6.227335 | 0.5081311 | 6.255699362 | 6.200411315 | -0.055288047 |
| 357 | 6.230825 | 0.5081311 | 6.257418904 | 6.200411315 | -0.057007589 |
| 357.2 | 6.234316 | 0.5081311 | 6.259138123 | 6.200411315 | -0.058726808 |
| 357.4 | 6.237807 | 0.5081311 | 6.260857039 | 6.200411315 | -0.060445724 |
| 357.6 | 6.241297 | 0.5081311 | 6.262575675 | 6.200411315 | -0.06216436 |
| 357.8 | 6.244788 | 0.5081311 | 6.264294051 | 6.200411315 | -0.063882736 |
| 358 | 6.248279 | 0.5081311 | 6.266012189 | 6.200411315 | -0.065600874 |

| | | | | | |
|---|---|---|---|---|---|
| 358.2 | 6.251769 | 0.5081311 | 6.267730112 | 6.200411315 | -0.067318797 |
| 358.4 | 6.25526 | 0.5081311 | 6.26944784 | 6.200411315 | -0.069036525 |
| 358.6 | 6.258751 | 0.5081311 | 6.271165395 | 6.200411315 | -0.07075408 |
| 358.8 | 6.262241 | 0.5081311 | 6.272882798 | 6.200411315 | -0.072471483 |
| 359 | 6.265732 | 0.5081311 | 6.274600073 | 6.200411315 | -0.074188758 |
| 359.2 | 6.269223 | 0.5081311 | 6.276317239 | 6.200411315 | -0.075905924 |
| 359.4 | 6.272713 | 0.5081311 | 6.278034318 | 6.200411315 | -0.077623003 |
| 359.6 | 6.276204 | 0.5081311 | 6.279751333 | 6.200411315 | -0.079340018 |
| 359.8 | 6.279695 | 0.5081311 | 6.281468305 | 6.200411315 | -0.08105699 |
| 360 | 6.283185 | 0.5081311 | 6.283185254 | 6.200411315 | -0.082773939 |

The Matlab code:

```
clc;format short

% The program is based on Arabsat4A 2 line element (TLE)

% for Julian date and orbital elememts.



%Enter the year

Y=2006;

%Enter the month

MO=3;

%Enter the day

D=23;



if MO==1

   Y=Y-1

   MO=13

end



   if MO==2

      Y=Y-1

      MO=14

   end



% calculating the Julian date:

A=floor(Y/100);

B=floor(A/4);

C=floor(2-A+B);

E=floor(365.25*(Y+4716));
```

```
F=floor(30.6001*(MO+1));

jd=C+D+E+F-1524.5;




i=0;



for ii=1:10:40176   % accounter in seconds

    delta_t=46224 +ii-1 ;

i=i+1;


T=jd/36525;


EARTH_ROT=4.167e-3 ;  %in deg/sec



GST_0=99.6910+36000.7689*T+0.0004*T^2; %in deg


GST_deg = GST_0 + EARTH_ROT * delta_t;   %in deg


GST_rad = GST_deg*pi/180;   %in rad


long_earth=((GST_rad/2/pi)-floor((GST_rad/2/pi)))*2*pi; % in rad




long_earth_deg=long_earth*180/pi;  %(earth longitude)
```

```
e=0.5081311; % from TLE

mu=3.986e14; % in meter3/s2

n= (2*pi/(24*60*60))*5.25860235;  % mean motion in 1/s  from TLE


a=(mu/n^2)^(1/3);

p=a.*(1-e.^2);


i_angle=51.5608*pi./180; % in rad     from TLE



c_omega_0_deg=93.4753;  % in deg      from TLE

s_omega_0_deg=16.9233;  % in deg      from TLE

% for J2 perturbation

c_omega_dot=-2e14*a^(-7/4)*cos(i_angle)*(1-e^2)^(-2);   % in deg/day

s_omega_dot=1e14*a^(-7/4)*(4-5*(sin(i_angle))^2)*(1-e^2)^(-2);  % in deg/day



c_omega=(c_omega_0_deg+c_omega_dot/(24*60*60)*delta_t)*pi/180;   % in rad

s_omega=(s_omega_0_deg+s_omega_dot/(24*60*60)*delta_t)*pi/180;  % in rad


M_deg=355.2574; % Mean anomaly in deg     from TLE

M_rad=355.2574*pi/180; % Mean anomaly in rad

% By using excel sheet interpolation E1=

E1_deg=350.4045; %in deg

E1=350.4045*pi/180; %in rad
```

```
% to find E2, we make 10 iterations

% to find E2, we make 10 iterations

E2_0=sqrt(mu/a^3)*delta_t+E1-e*sin(E1);
E2_1=E2_0+e*sin(E2_0);
E2_2=E2_0+e*sin(E2_1);
E2_3=E2_0+e*sin(E2_2);
E2_4=E2_0+e*sin(E2_3);
E2_5=E2_0+e*sin(E2_4);
E2_6=E2_0+e*sin(E2_5);
E2_7=E2_0+e*sin(E2_6);
E2_8=E2_0+e*sin(E2_7);
E2_9=E2_0+e*sin(E2_8);
E2_10=E2_0+e*sin(E2_9);


E2=((E2_10/2/pi)-floor((E2_10/2/pi)))*2*pi;  % in rad

% Now we calculate the true anomaly theta

theta=2*atan((tan(E2/2))*((1+e)/(1-e))^0.5); % in radian

  % finding the orbital axes
r=p/(1+e*cos(theta));
```

```
x=r*cos(theta);

y=r*sin(theta);

z=0;



%%% TM is the matrix from inetia to orbital, []_O=T*[]_I


TM=[cos(s_omega)*cos(c_omega)-sin(s_omega)*cos(i_angle)*sin(c_omega)
cos(s_omega)*sin(c_omega)+sin(s_omega)*cos(i_angle)*cos(c_omega)        sin(s_omega)*sin(i_angle);

   -sin(s_omega)*cos(c_omega)-cos(s_omega)*cos(i_angle)*sin(c_omega)                                  -
sin(s_omega)*sin(c_omega)+cos(s_omega)*cos(i_angle)*cos(c_omega)       cos(s_omega)*sin(i_angle);

    sin(i_angle)*sin(c_omega)                  -sin(i_angle)*cos(c_omega)                       cos(i_angle)];



%%% TT is the matrix from inetia to orbital, []_I=TT*[]_O

TT=inv(TM);

TX=TT(1,:);

TY=TT(2,:);

TZ=TT(3,:);


% finding the inertial axes


XI=TX*[x;y;z];

YI=TY*[x;y;z];

ZI=TZ*[x;y;z];

xx(i)=XI;yy(i)=YI;zz(i)=ZI;


long_sat(i)=atan2(YI,XI);  %in rad  (satellite longitude)
```

```
if long_sat(i)<0

   long_sat(i)=2*pi+long_sat(i);  %in radian

end



 long_sat_deg(i)=long_sat(i)*180/pi;  % in deg





lat_sat(i)=atan2(ZI,(YI^2+XI^2)^0.5);  % in rad     (satellite latitude)

 lat_sat_deg(i)=lat_sat(i)*180/pi;  % in deg



long_dif(i) =  long_earth - long_sat(i); % in rad     (longitude)

     if long_dif(i)>pi

         long_dif(i)=long_dif(i)-2*pi;

     elseif long_dif(i)<-pi

         long_dif(i)=long_dif(i)+2*pi;

     end

  long_dif_deg(i)= long_dif(i)*180/pi;  % in deg

lat_dif_deg(i) = lat_sat(i)*180/pi; % in deg    (latitude)

en

hold on

plot(long_dif_deg,lat_dif_deg,'r:.')

title('Arab-Sat 4A Coverage')

xlabel('Longitude        (deg)')

ylabel('Latitude        (deg)')
```