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Design and Analysis of Trajectory Calculation for Nano Satellite Orbiting in LEO

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Abstract— The space race introduced a phenomenal growth in the computation of the orbits of artificial satellites. The objective of this project is to derive an effective technique to estimate the orbital and trajectory data for the LEO Nano satellites. To design the accurate orbit and trajectory of a satellite information regarding the variables responsible for the deviation in the path of satellites. The variables that needs to be calculate to determine the position of the satellite. This can accomplished by making use of the orbit simulation software like GMAT, Orbitron and STK for acquiring the data and then incorporating the acquired data with MATLAB to get the result. The various effects on the satellite in space is slight deviation in the satellite from its orbit. To estimate the deflection from its actual coordinates to provide a relatively accurate method for the correction of the same. The purpose of research is consider three Indian Nano satellites are Jugnu, INS-1A and INS-1B. The selection of the satellite based on their efficiency and purpose of the mission. The Nano Satellites launched in space were the academic collaboration of the universities with their national space research centres for facilitation of research purpose with less expense.

Keywords— Nano satellite, GMAT, Orbitron, STK, LEO

I. INTRODUCTION

The space age, which started in 1957 with the launch of the very first Russian satellite Sputnik that introduced the world with a new era of technology. The advancement in space world has witnessed the revolutionized global communications, maritime navigation, and worldwide weather forecasting. These satellites have now become an important part of the global network, which was not possible before the near-earth space venture and exploration. With the launch of the Early Bird in 1965, nearly eight years ago after the launch of the first Sputnik, satellite communication came into picture at commercial level. The major consideration for satellite designing lies with the mission requirement that it is going to fulfill and the economic efficiency. The Nano satellites comes into picture, as they are highly economical as well as capable to serve the mission objective. The Nano satellites being economical and integrated with modern and advance technology for purpose research in this paper. The objective of this paper is to design the accurate orbit and trajectory of a satellite by acquiring the data regarding the various factors affecting the position of satellite in space using GMAT, Orbitron and STK simulation software and implementing the same acquired data for MATLAB interface. In addition, to the deflection in the satellite from its orbit resulting from gravitational effects, an attempt has been provide a high accuracy method for the correction of the same.

A. CubeSat Jugnu

The specification of the Nano satellites selected for purpose of research as given below-
A Nano Satellite is an artificial satellite characterized by its low weight, small size and its miniaturization to save cos. It has requires for cheaper launch vehicles and can be launched in multiple. The Nano satellites not only serve the purpose of communication, remote sensing and space science applications. It playing a vital role in the technical knowledge development by providing a means for direct, hands-on experience in all stages and aspects of a real satellite mission. [1] [2]. Jugnu has built, under the supervision of Dr. N. S. Vyas, which is capable to provide information on agriculture and disaster monitoring.

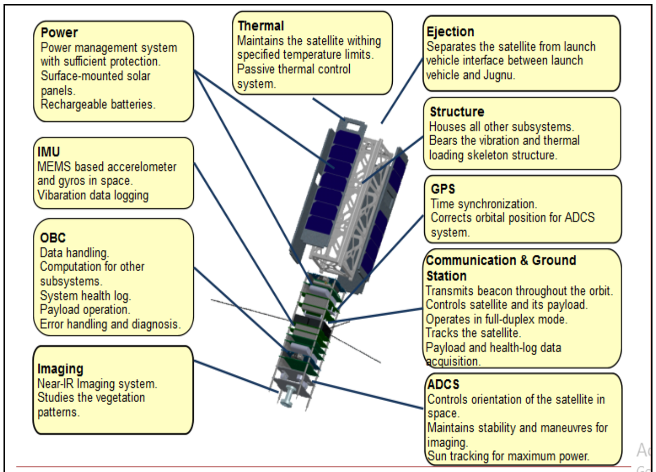

Figure. 1 Subsystem specification of Jugnu [3]

Table 1. Jugnu Satellite specification

Satellite properties	
Operator	IIT Kanpur
COSPAR ID	2011-058B
SATCAT no.	37839
Launch mass	3 kg.
Size	34 cm. ×10 cm. ×10 cm.
Mission Specification	
Mission type	Remote Sensing Technology
Launch date	12 October 2011
Rocket	PSLV-CAC18
Launch Site	Satish Dhavan FLP
Contractor	ISRO
Orbit Specification	
Reference System	Geocentric
Regime	Low Earth
Perigee	843.6 km.
Apogee	871.4 km.
Inclination	20 deg.
Period	101.9 minutes
Semi Major Axis	7228 km.

B. INS-1A

INS 1A which stands for ISRO nanosatellite is developed by Indian Space Research Organization (ISRO). The mission life is estimate to be six months to one year. INS 1A carries two payloads, both developed by ISRO's Space Application Centre (SAC):

- The Surface BRDF Radiometer (SBR) payload will measure the Bidirectional Reflectance Distribution Function (BRDF) of targets on the earth's surface and will take readings of the reflectance of different surface features.
- The Single Event Upset Monitor (SEUM), which monitor Single Event Upsets, generated due to high-energy radiation in space environment in COTS (Commercial Off-The-Shelf) electronic components.

Table 2. INS 1A Nano satellite specification

Satellite properties	
Operator	Indian Space Research Organization (ISRO)
COSPAR ID	2017-008B
SATCAT no.	41949
Launch mass	8.4 kg.
Size	304 mm. × 246 mm. × 364.3 mm.(stowed) 304 mm. × 246 mm. × 364.3 mm (deployed)
Mission Specification	
Mission type	Remote Sensing Technology
Launch date	15 February 2017
Rocket	PSLV-C37
Launch Site	Satish Dhavan Space Centre , Sriharikota
Orbit Specification	
Perapsis	500.8 km.
Apoapsis	515.4 km.
Inclination	97.5 deg.
Period	94.6 minutes
Semi Major Axis	6879 km.

C. INS 1B

INS 1B is one of two Nano-satellites designed and manufactured by ISRO, are part of the constellation of 104 satellites. INS 1B carries two payloads:

- The Earth Exosphere Lyman Alpha Analyzer (EELA) designed by the Laboratory for Electro-Optics Systems (LEOS) in Bengaluru. It has records terrestrial exospheric line-of-sight neutral atomic hydrogen Lyman Alpha flux and provides estimates for the interplanetary hydrogen Lyman Alpha background flux by means of deep space observations.
- The Origami Camera payload from ISRO's Space Application Centre (SAC). It has remote sensing color camera, with a novel lens assembly that helps in optical realization in a small package.

Table 3. INS 1B Nano satellite specification

Satellite properties	
Operator	Indian Space Research Organization (ISRO)
COSPAR ID	2017-008G
SATCAT no.	41954
Launch mass	9.7 kg.
Size	304 mm. × 246 mm. × 510 mm.(stowed) 304 mm. × 670 mm. × 510 mm.(deployed)
Mission Specification	
Mission type	Remote Sensing Technology

Launch date	15 February 2017
Rocket	PSLV-C37
Launch Site	Satish Dhavan Space Centre , Sriharikota
Orbit Specification	
Perapsis	500.7 km.
Apoapsis	514.8 km.
Inclination	97.5 deg.
Period	94.6 minutes
Semi Major Axis	6878km.

II. LITERATURE REVIEW

Orbit Design and simulation for Kufasat Nano satellite; a research paper by Mohammed Chessab Mahdi of Al-Furat Al-Awsat Technical University explains the detail orbit design using GMAT and Matlab. The satellite is design for Sun synchronous orbit with payload for image purpose. [3]
Trajectory design tools for liberation and cislunar environment; a conference paper presented in 6th International Conference on Astrodynamics tools and techniques on 16th March 2016 [4] [5] talks about the innovative trajectory design tools Adaptive Trajectory design and GMAT which has the ability to design multibody trajectory. The paper also provides solution to simplify trajectory design in support of lunar and liberation point.

The computation of satellite orbit trajectory; from Elsevier, Advances in computer, Volume 3 [6] focuses on computation of satellite orbit trajectory, orbit determination and tracking. Three mathematical formulation Cowells and Encke's methods are described the variation of parameters evaluated for computational efficiency. The deliberation theory is mainly to discuss general perturbation method.

Precise orbit determination of low earth satellite at AIUB using GPS and SLR data; by A. Jaggi, H. Bock, D. Thaller, K. So´snica, U. Meyer , C. Baumann , and R. Dach presented in ESA Living Planet Symposium [7]. Explains the classical numerical integration techniques used for dynamic orbit determination of satellites operating at high altitudes which is further extended by pseudo-stochastic orbit modelling techniques to efficiently cope with potential force model deficiencies for satellites at low altitudes.

Trajectory design for the transiting exoplanet survey satellite; a paper by Donald J. Dichmann, Joel J.K. Parker, Trevor W. Williams, Chad R. Mendelsohn presented in AIAA/AAS Astrodynamics Specialist Conference [8] Discusses the adaption of the schematic window methodology (SMW76) is used to assess the TESS mission constraint. Employment of Dynamical system theory in the circular restricted 3 body problem (CR3BP) which makes use of high-fidelity model and multiple shooting in GMAT to optimize the manoeuvre delta 'v' and mission constraint.

Orbit design and trajectory analysis for University Cube-Satellite project for remote sensing and for educational application; a conference paper from Global Space Exploration Conference Washington, DC. B by Ugur Guven, Gurunadh Velidi, Samaksh Behl [9] in which an optimal near polar, low earth orbit is calculated for the Nano satellite under study along with its structural configurations. The cubesat is design for different attitude adjustments systems explored in order to create the most stable configuration in orbit. The mission of this Nano satellite is remote sensing and for educational purposes such as seismic activity determination.[10]

The paper uses the following formulae and equations:[11]

1. The square of the **orbital period** of a planet is proportional to the cube of the semi-major axis of its orbit.

$$r = -GM\frac{r}{r^3}f1(t, r, r, \ddot{q}_1, \ldots \ldots . . q'_d, s_{1 \ldots\ldots s s=f.} \quad (1)$$

2. **Semi Major Axis (a)**: It gives the size of the orbit and is the distance between apogee and perigee divided by 2.

$$a = \sqrt[3]{\frac{P^2 GM}{4\pi^2}} \quad (2)$$

Where P is the orbital period, G is the gravitational constant; M is the combined mass of primary and secondary orbits.

3. **Eccentricity (e):** It gives the shape of the orbit. Its value ranges from 0 when the orbit is perfect circle to 1 when it is flat.

$$\vec{e} = \frac{\vec{v} * \vec{h}}{\mu} - \frac{\vec{r}}{r} \quad (3)$$

Where v is orbital speed, h is angular momentum vector, μ is standard gravitational parameter, and r is orbit radius.

4. **Inclination angle (I)**: It defines the orientation of the orbit with respect to the Earth's equator. It is the angle between Z and angular momentum h. The inclination ranges from 0 to 180. Degrees.

$$\cos i = \frac{\hat{z}.\vec{h}}{|\hat{z}||\vec{h}|} \quad (4)$$

5. **Right Ascension of Ascending Node (Ω)**: It is the angle from the vernal equinox to the ascending node. The ascending node is the point where the satellite passes through the equatorial plane moving from south to north. Right ascension is measured as a right-handed rotation about the pole Z.

$$\cos \Omega = \frac{I.\vec{n}}{|I||\vec{n}|} \quad (5)$$

If $n_j \leq 0 \; then \; \Omega = 360 - \Omega$

6. **Argument of Perigee (w)**: It gives the angle from the ascending node to the eccentricity vector, $\vec{e}$ measured in the direction of the satellite's motion. The eccentricity vector points from the center of the

Earth to perigee with a magnitude equal to the eccentricity of the orbit.

$$\cos w = \frac{\vec{n}.\vec{e}}{|\vec{n}||\vec{e}|} \quad (6)$$

If $e_k \leq 0$ *then* $w = 360 - w$

Where:

$\vec{n}$ is a vector pointing towards the ascending node (i.e. the z-component of n is zero)

$\vec{e}$ is the eccentricity vector (a vector pointing towards the perigee)

7. **True mean anomaly (*M*):** It gives the fraction of an orbit period that has elapsed since perigee, expressed as an angle. The mean anomaly equals the true anomaly for a circular orbit.

$$\cos v = \frac{\vec{e}.\vec{r}}{|\vec{e}||\vec{r}|} \quad (7)$$

If $\vec{r}\,\vec{v} < 0$ *then* $v = 360 - v$

$$\tan\frac{E}{2} = \sqrt{\frac{1-e}{1+e}}\tan\frac{v}{2}$$

$M = E - e \sin(E)$

Where *E* is eccentric anomaly.[12]

III. METHODOLOGY (GLOBAL MISSION ANALYSIS TOOL- GMAT)

GMAT is an open source trajectory design and optimization system developed by NASA and private Industry. An open source system mainly used to maximize the technology transfer and allow anyone to develop and validate new algorithms. GMAT is design the model and optimize spacecraft trajectories in flight regimes ranging from Low Earth orbit to lunar applications, interplanetary trajectories, and other deep space missions. The system supports constrained and unconstrained trajectory optimization, built-in features, make defining cost, and constraint functions trivial, so analysts can determine how their inclusion or exclusion effects solutions.

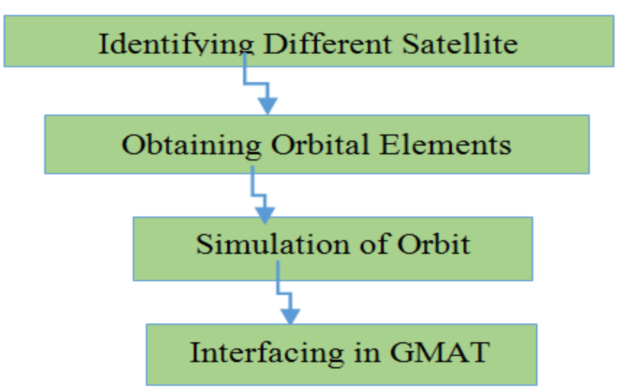

Figure 2. Signal flow diagram (GMAT)

The following flow chart depicts the process of obtaining results from GMAT:

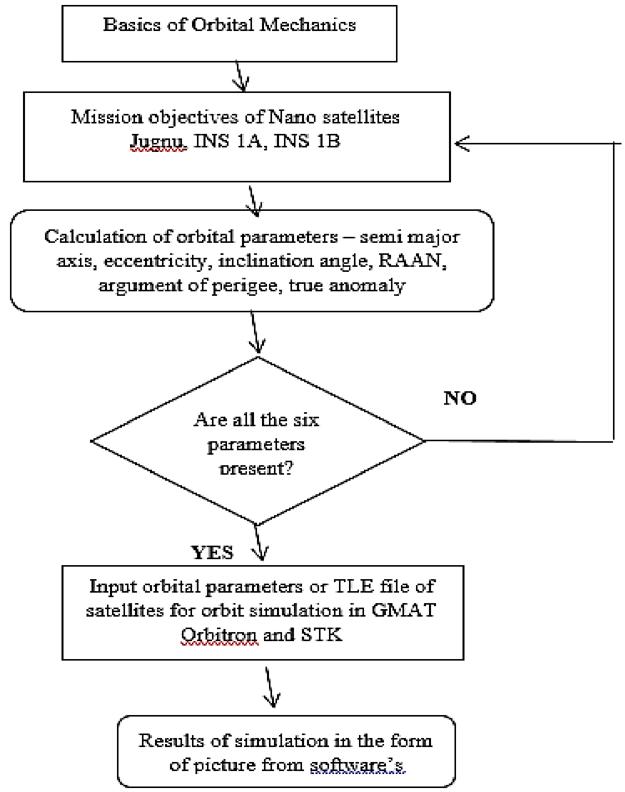

Figure 3. Flowchart for the adopted methodology for simulating the orbits

From Fig. 3 shows the methodology for Nano satellites Jugnu, INS 1A, INS 1B simulating the orbits. The first step for the project is to select three different satellites and determine their position in the Low Earth Orbit by obtaining the orbital elements for each satellite respectively. The second step is to design the accurate orbit and trajectory of the satellites by acquiring the data regarding the various factors affecting the position of satellite in space using GMAT, Orbitron and STK simulation software and implementing the same acquired data for MATLAB interface. To find the deflection in the satellites from their orbit due to perturbations and attempt to provide a high accuracy method for the correction of the same. After applying this process, two different types of views namely:

1. Orbit View: This is a 3D view of orbit of satellite traversing around Earth. This view makes analysis of satellite easier as you can rotate and zoom in/out to locate the satellite. The below picture shows an example of Orbit View:

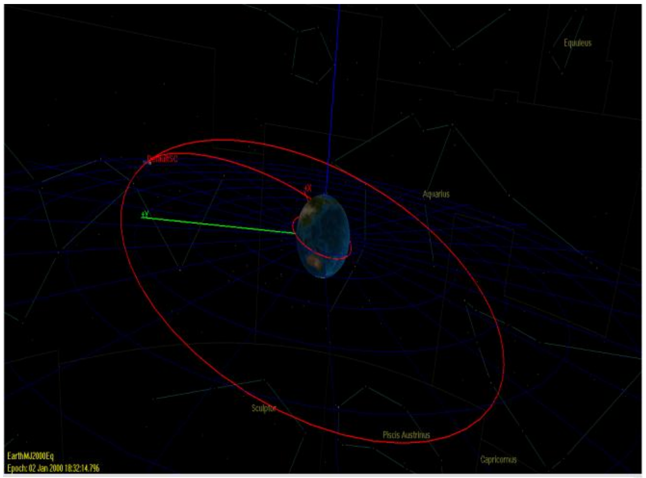

Figure 4. Satellite Orbit View

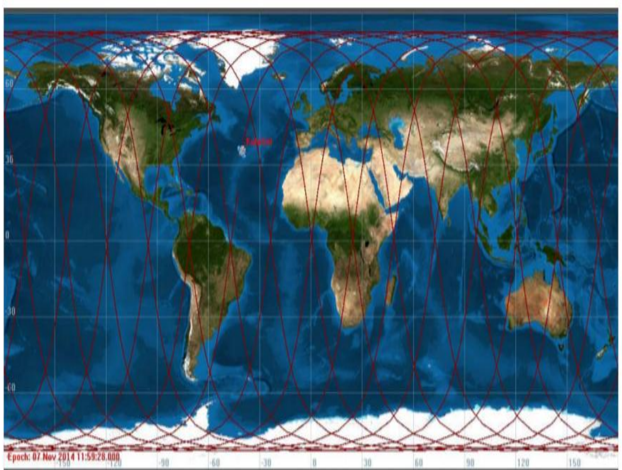

Figure 5. 2D Plot view for a satellite in GMAT

2. 2D View or Ground View: This view shows the ground track obtained for the computed Keplerian element which is simulated in GMAT, below figure shows a ground track of KufaSat projected onto a two-dimensional world map over one day:

A. ORBITRON

Orbitron is a one of the basic satellite tracking system. This platform provides information essential UFO hobbyists. Application shows the positions of satellites at any given moment (in real or simulated time). Due to predictable conditions of satellite movement in space, (lack of atmosphere) computer software can calculate a satellite's position for given moment.

The calculations based on known orbit parameters determined of the related satellite. The six Keplerian elements also known as orbital parameters like inclination, eccentricity, argument of perigee, mean motion (revolutions per day), tracks satellite for a reasonable period after epoch.

Orbital data for each object is grouped and distributed as a Two-Line Element (TLE) file. The TLE file used to get the parameters of the satellite in the software so that it tracks and determines its orbit path.

Below Fig. 6. illustrate a generalised view of Orbitron:

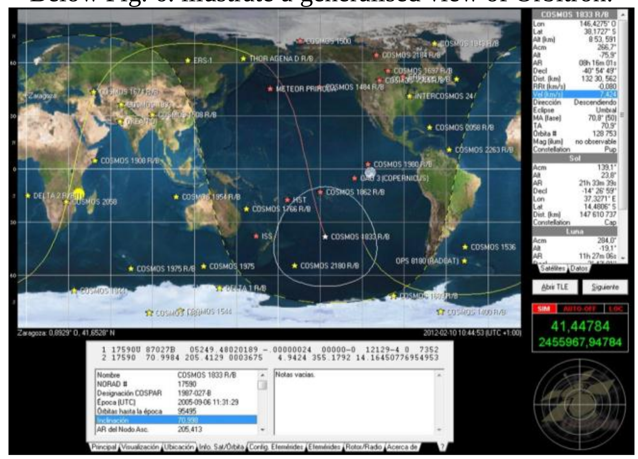

Figure 6. GUI of Orbitron

B. Satellite Tool Kit (STK)

STK is an orbit simulation software that provides four-dimensional modelling, simulation, and analysis of objects from land, sea, air, and space in order to evaluate system performance in real or simulated-time. This platform is capable of modelling an accurate Earth representation in time and space and can Run in real time or simulate in past or future time.

IV. SIMULATION RESULTS

In Fig. 7. Shows the GUI information of Satellite Tool Kit

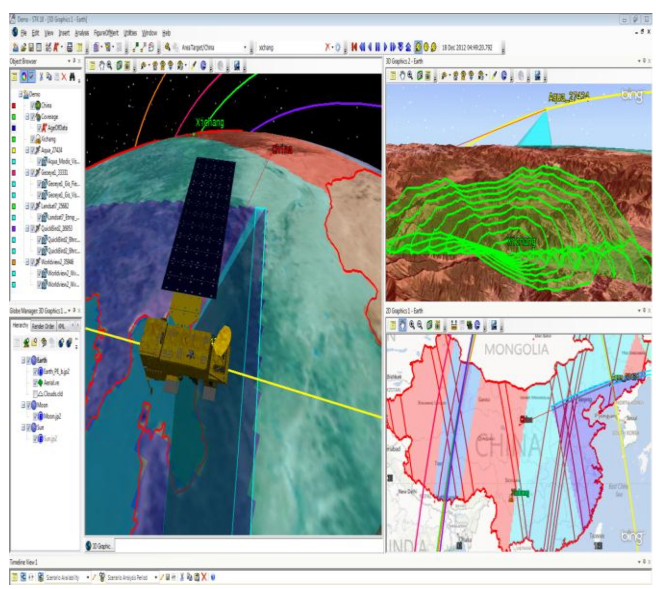

Figure 7. GUI of System Tool Kit

STK SIMULATION

From Fig.8. Shows the orbit path of Jugnu Nano satellites satellite from space on a 2D view. The orbital parameters are mention in the solver.

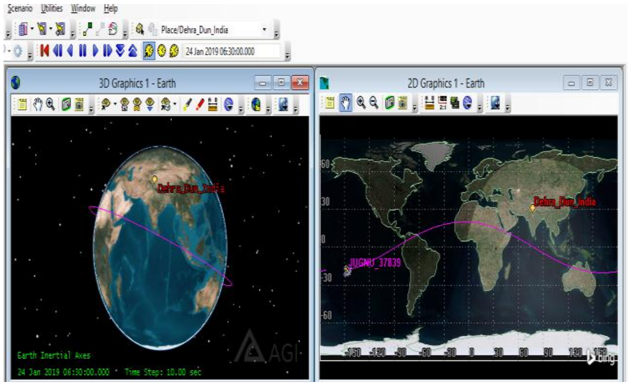

Figure 8. Orbit of Jugnu Nano satellite

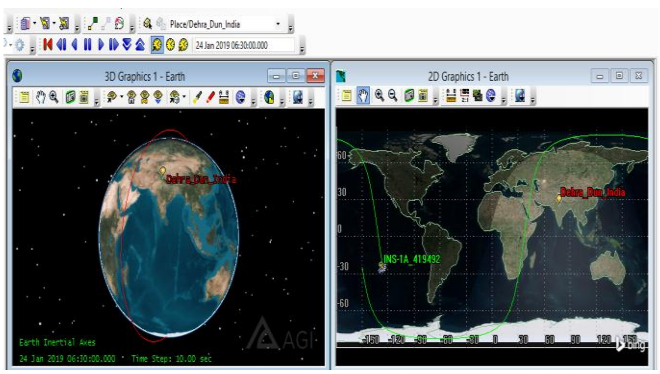

Figure 9. Orbit of INS 1A Nano satellite

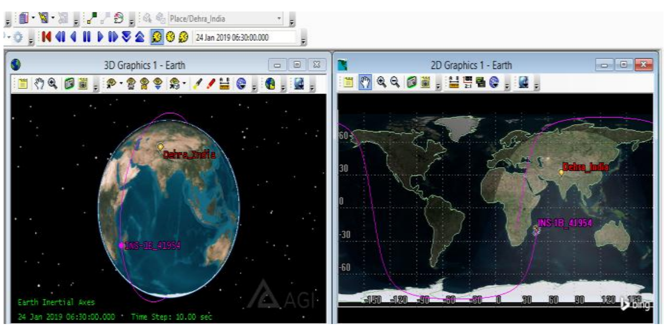

Figure 10. Orbit of INS 1B Nano satellite

From Fig.9 & 10. Shows the orbit path of INS 1A & INS 1B Nano satellites satellite from space on a 2D view. The orbital parameters are mention in the solver.

ORBITRON SIMULATION

Orbitron is a simple 2D solver in which TLE files are uploaded, for Jugnu, INS 1A & INS 1B satellite shown in the figure (11 & 12 & 13)TLE file for JUGNU is available in Directories of NASA and NORAD.

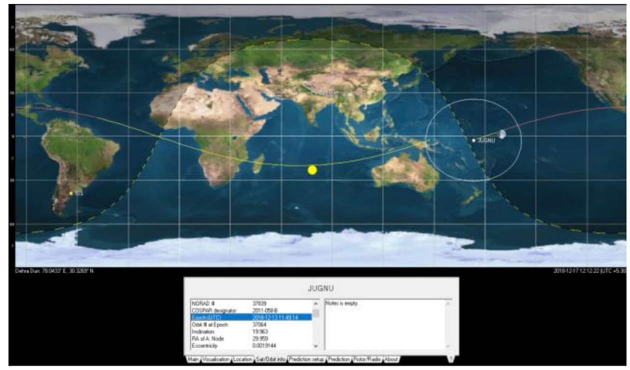
Figure 11. Orbit simulation of Jugnu performed on Orbitron

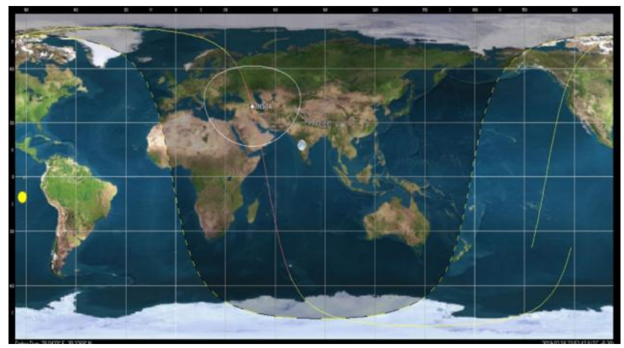
Figure 12. Orbit simulation of INS-1A performed on Orbitron


Figure 13. Orbit simulation of INS-1B performed on Orbitron

GMAT SIMULATION

GMAT solves or designs the orbit of Jugnu satellite through six Keplerian elements with different orbit view shown from Figure 14 & 15.The 2D view illustrate in the Figure 16.

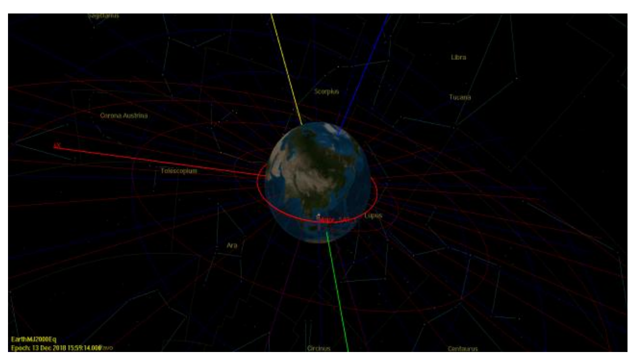
Figure 14. Satellite Orbit View 1 (GMAT)

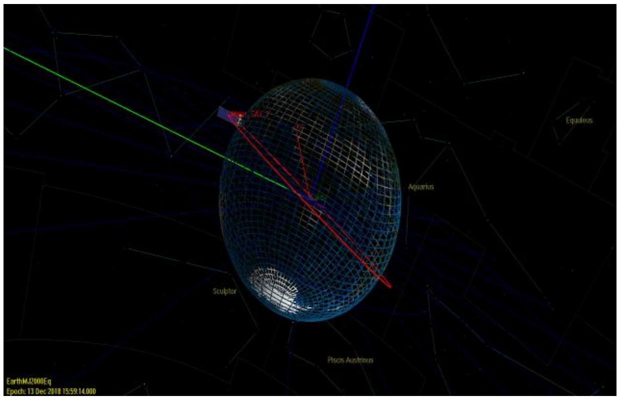

Figure 15. Satellite Orbit View 2 (GMAT)

2D plot view of Jugnu satellite as shown below

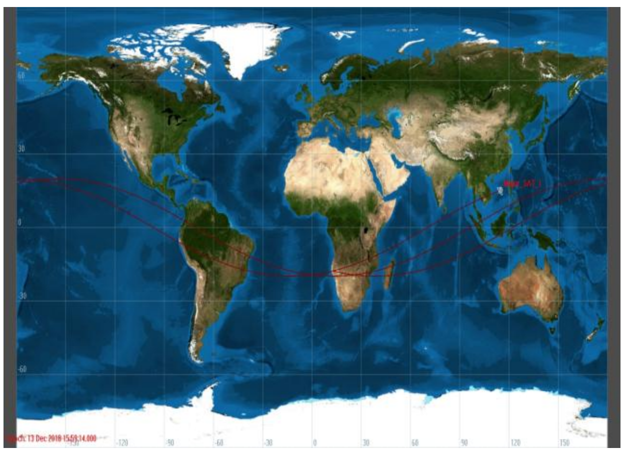

Figure 16. 2D view of Orbit on GMAT

V. CONCLUSION

Nano satellite or cube satellite technology is gradually emerging as an important technology in space industry over the last two decades. The space emerging countries and non-space countries are now in a race to operate small satellite mission. It is becoming popular among developing countries because of cost effective programme with great capability. The small satellite in space activity is extending the number of satellites for specific designed mission both for civilian and defence purpose. So, the number of associated launches, ground station and data collection and distribution system are getting more importance than ever. That is why the demand of LEO satellite tracking system for data collection and distribution is increasing.

The three Nano satellite chosen, each serve different research purpose is launch by Indian Space Research Organization (ISRO). Jugnu is built under the supervision of Dr. N. S. Vyas, which is capable to provide information on agriculture and disaster monitoring. INS-1A and INS-1B, which stands for ISRO nanosatellite, are part of the constellation of 104 satellites is developed by ISRO. The coordinates and satellite orbit trajectory were determined, and the orbit has been analyzed using three software's namely GMAT, STK and Orbitron and the differences in the orbit scenario. The project is analyses the orbits of three satellites in total and compare with the respective software's along with a MATLAB software interfacing of the data acquired.

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