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RESEARCH ARTICLE

SIMULATION AND ANALYSIS OF GEOSTATIONARY ORBIT USING GMAT

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ABSTRACT

Required calculations like delta-V budget, orbital elements and perturbations had been done for designing a geostationary orbit for a communication satellite in previous parts of my paper. Now designing, simulating and analysing GEO will be done here. To attain the orbit we need to set a differential corrector, create a required mission sequence to build impulsive burns which plays an important role to obtain a hohmann transfer. Then the three dimensionalorbital views, ground station, eclipse locator and contact locator are made. Report, ephemeris and XY plots are obtained to find out the exact position of the satellite from the different views from space and it can also show the values from the launching epoch till the mission life ends. All these works are completed and explained in a detailed manner with the help of GMAT software and a little introduction about this software is also described below. Various outputs like report and ephemeris file, eclipse and contact locator, simulation of GEO orbit, ground track plot and graphs had been obtained and explained in a cleared manner.

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INTRODUCTION

Designing an orbit for a satellite is been well understood, if it is shown through a detailed computation and simulation. GMAT is an optimized system developed by NASA. It is developed in a manner of open source software and is designed in such a way to maximize technology transfer, validate new algorithms and enable those new algorithms to quickly transition into the high fidelity core and also permit anyone to develop. This system is designed to model and optimize spacecraft trajectories ranging from low Earth orbit to lunar, interplanetary and other deep space missions. It also contains efficient propagators for spacecraft either single or as a coupled set, also initial value and boundary value solvers. Propagators synchronize the epochs of multiple vehicles and avoid fixed step integration and interpolation when designing. Trajectories and data can be viewed in any coordinate system defined in GMAT. Either using a graphical user interface (GUI) or a custom script language, users can interact with GMAT after the syntax used in The MathWorks' MATLAB® system. System elements can be expressed though interface and users can convert into two in either direction. By first creating and configuring resources such as spacecraft, propagators, optimizers and data files we can analysis model space missions in GMAT. To model the trajectory of the spacecraft and simulate mission events these resources are used in a mission sequence. Commands such as nonlinear constraints, inline equations, minimization, propagators, GMAT and MATLAB functions and script events are supported by mission sequence to simulate the mission. This software can display trajectories in a three-dimensional view, plot parameters against one another and save them to files for later processing. Graphic capabilities in GMAT are fully interactive, plot data as a mission is in run and allow users to zoom in and out into regions of interest. It allows users to rotate the view and set the focus to any object in the display, trajectories and data can be viewed in any coordinate system defined in GMAT.

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METHODS AND STEPS

Differential corrector

Boundary value problems is been solved by the differential corrector. It is mainly used to determine the maneuver components, which is required to achieve the orbital conditions. For a modelled mission, it is very much useful to refine a set of goals and set of variable parameters.

Supported algorithm details

It contains several algorithms include Newton Raphson, Broyden and Modified Broyden for solving boundary value problems. To compute the independent variables and the Jacobian of the constraints, these algorithms use finite differencing or other numerical applications. Broyden and Modified Broyden method usually take more iterations than Newton Raphson. So Newton Raphson method has been used. I would rather recommend to attain other algorithms to provide the best balance of performance and robustness.

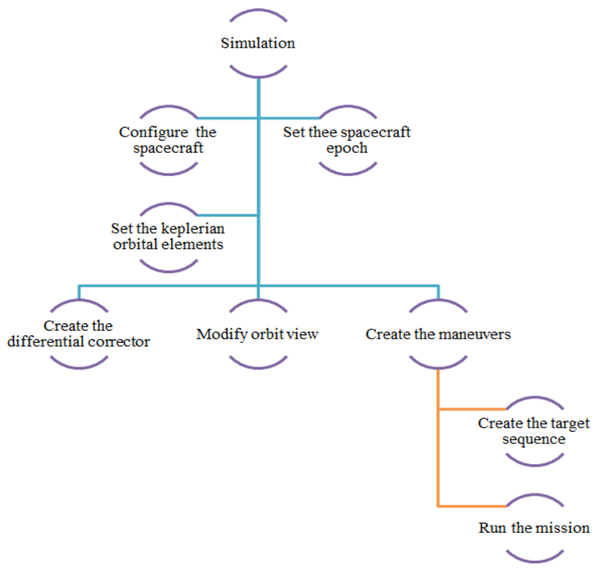
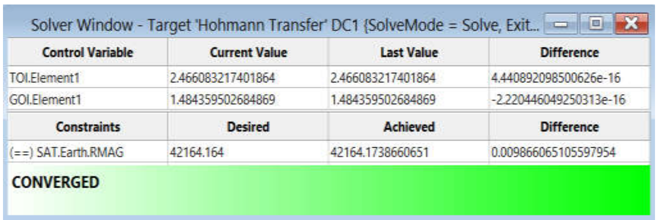


Figure 1. Flow chart represents the steps followed for simulation in GMAT

Newton-Raphson: It is a quasi-Newton that computes Jacobian using finite differencing. To compute the Jacobian, GMAT supports forward, central and backward differencing.



Solver Window - Target 'Hohmann Transfer' DC1 {SolveMode = Solve, Exit...

Control Variable	Current Value	Last Value	Difference
TOI.Element1	2.466083217401864	2.466083217401864	4.440892098500626e-16
GOI.Element1	1.484359502684869	1.484359502684869	-2.220446049250313e-16
Constraints	**Desired**	**Achieved**	**Difference**
(==) SAT.Earth.RMAG	42164.164	42164.1738660651	0.009866065105597954

CONVERGED

Figure 2. Differential Corrector for Hohmann Transfer

Mission tree

It is built to get a required hohmann transfer. It shows a hierarchical and ordered list of commands. It is a display of a GMAT script command mission sequence. Vary TOI and GOI are used to specify boundary value solver and perform TOI and GOI for two separate impulsive burns. Prop to apoapsis and periapsis are used to set the apogee and perigee distances.

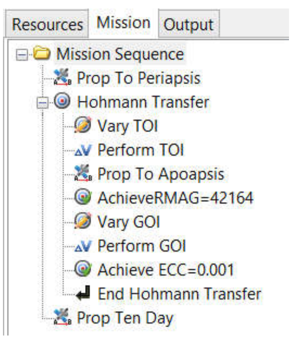


Figure 3. Mission Tree

Ground station

It creates a ground station model instantly. Ground station models a facility fixed to the surface of a celestial body. For defining the location of a ground station including spherical and Cartesian there are several state representations are available in this command. Finding several ground station contact times is considered to be a very similar process but instead we use the contact locator resource. After adding a ground station we configure a locator to find contact times between it and our spacecraft. For GEO simulation, we need to create a ground station which will be viewed from the final geostationary orbit. Our spacecraft is positioned over the Indian Ocean by looking at the default ground track plot window. Let's choose the Nagpur ground station.

Orbit view

This view allows us to plot 3-dimensional trajectories of a spacecraft or a celestial body. This orbital view is also used to plot trajectories of multiple spacecraft or heavenly bodies. By using either GUI or script interfaces of the software we can create orbit view resource. Multiple options in the orbit view plot will permit to customize the view of spacecraft's trajectories. Through Toogle On/Off command the option to start and stop plotting spacecraft's trajectories in an orbit view is been provided.

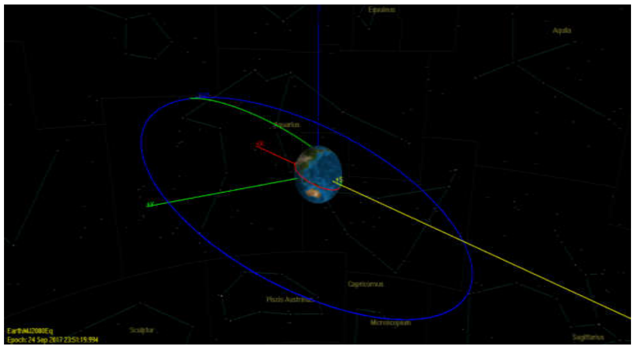


Figure 4. 3D View of Hohmann Transfer in GMAT

Ground track plot

This resource draws latitude and longitude life-system of a spacecraft into the texture map of the selected celestial body. It allows us to draw ground track plots of any number of spacecraft into a single texture map. By using either GUI or script interface of GMAT we can create ground track plot resource. Through Toogle On/Off command, it provides the option of when to plot and stop plotting ground track of a spacecraft. We can optimize more than one ground track plot in simulation.

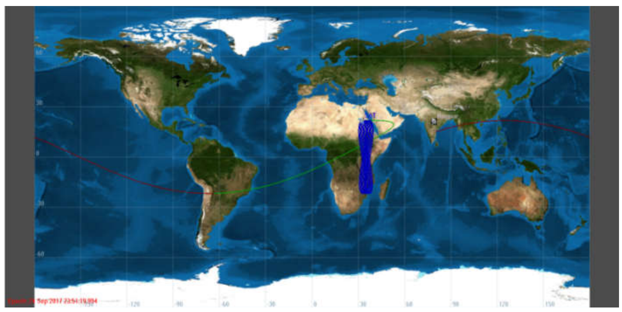


Figure 5. Ground Track of a GEOSatellite

RESULTS FROM SIMULATION

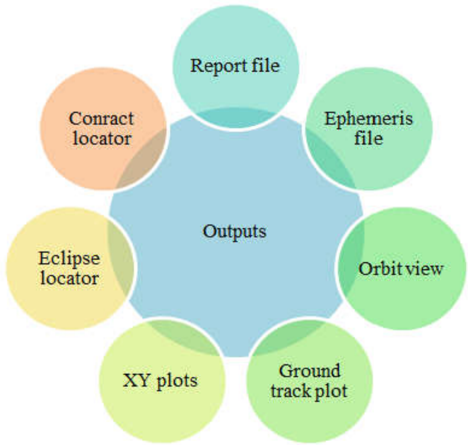


Figure 6. Flow chart for obtained outputs from simulation

Ephemeris file

It is a user defined source and that generates spacecraft's ephemeris data in a report format in any coordinate frames. The output of the ephemeris data is either created in CCSDC or SPK file formats. At default integration steps or by entering user selected step sizes, ephemeris file resource can be configured to generate ephemeris date. By creating multiple ephemeris file resource this software allows us to generate any number of ephemeris data files. Using either GUI or script interface, ephemeris file resource can be created. Usually spacecraft's ephemeris data is always provided in UTC epoch format. We can define our own initial and final epochs instead of generating file at default time span settings of initial and final spacecraft's epochs. Similarly, we can also generate the ephemeris file at the step size of our choice, instead of using the default integrator steps setting for step size field.

Report file

In this software, this resource allows us to write data to a text file which can be viewed after a mission run had been completed. It allows us to report user-defined arrays, strings, variables and object parameters. At the end of a mission, GMAT gives control over formatting generated properties of the output report file. It can also be created in either the GUI or script interface. Through Toogle On/Off command, software provides the option of when to write and stop writing data to a text file.

Eclipse locator

From the perpendicular of the Earth's orbit, its rotational axis is tilted to 23.5 degrees. At the same degrees the equator is tilted from the perpendicular of the Earth's orbit. As the Earth revolves around the Sun, the rotational axis stays in the same celestial location (the northern star). Earth's rotational axis tilt the angle and creates the seasons, the longer daylight in the summer and the less daylight in the winter, as the Sun appears to travel up and down from the Earth. If the Sun travel at the high points are Tropic of Cancer and the low points are Tropic of Capricorn. Basically satellite relays on two power sources they are solar panels and batteries. Solar panels convert the Sun's solar energy into electrical power which is used to run the satellite and also to charge the batteries. When the solar panels cannot power the satellite, batteries are used. Above the equator at an altitude of approximately 22,300 miles (36,000 kilometers), GEO satellites are placed. Therefore these satellites also travel at the same 23.5 degree tilt. Whenever the satellites and their solar panels are blocked from the Sun by the Earth this happens because of the two equinox seasons (autumnal and spring) reaches by the Sun. The satellite must rely on batteries at this time until the solar panels are again exposed to the Sun. This time is called as eclipse period.

As the Sun travels from one of the tropics to the equator, the eclipse starts slowly. During this time the satellite is blocked for a minute or two, at first. Until the sun reaches fall or spring equinox, the eclipse increases gradually. The satellite and their solar panels are blocked for 72 minutes. The eclipse becomes smaller and smaller as the sun continues to travel to the other tropic. The fall eclipse season runs from approximately 30 or 31 August until 15 October and the spring eclipse season runs from approximately 26 February until 12 or 13 April for station-kept satellites. This eclipse season occurs twice a year. The eclipse season starts and ends a little earlier for inclines orbit satellites, depending on the satellite's inclination. Usually satellites are designed and built with an extra percentage of battery capacity to ensure that they can function and continue to provide service even when the battery power degrades over time. Totally three eclipses were found. Single "total" eclipse event exist about 35 minutes. A total event consists of penumbra eclipses occurring adjacent to umbra eclipses, which is in the overlapping case.

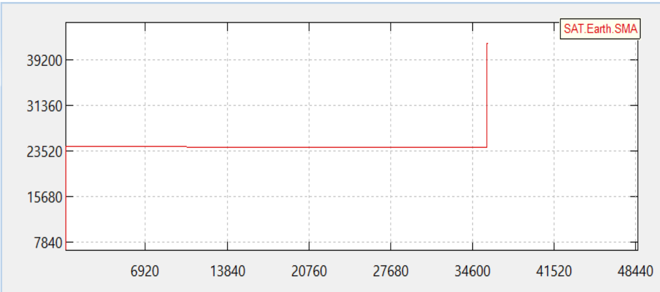
Contact locator

It is used to find line-of-sight events between a spacecraft and ground station. Thus is known as event locator. Along with the duration, it generates a text event report listing the beginning and ending times of each line-of-events. It can be performed over a subinterval or the entire propagation interval but optionally adjust for stellar aberration and light-time delay. It can limit contact events to a specified angle which is on the ground station and to search for times of occultation of other celestial body resources. As it can be performed between one spacecraft and ground station, each target-observer pair is observed pair is searched individually and thus results in a separate segment of resulting report. To customize the options per pair all pairs must use the same intervals and multiple contact locator resources. By listing one or more celestial body resources in the occulting body list, third-body can be included. Created celestial body can be used as an occulting body, including user defined ones. The central body of the ground station will be included automatically in the basic line-of-sight algorithm when no occultation is performed. After applying certain endpoint light-time adjustments, the contact locator searches the time interval of propagation of the target. Set the initial and final epoch to search a custom interval, and these epochs are assumed to be at the observer. So it must be valid when translated to the target (light-time delay and stellar aberration). Either using a transmit sense or receive sense, the contact locator can optionally adjust for both light-time delay and stellar aberration depending on the value of light-time direction. By limiting the searches near the transmit sense or the receive sense, the light-time direction affects the valid search. Stellar aberration has no effect on occultation searches because it can only be applied for the line-of-sight portion of the search.

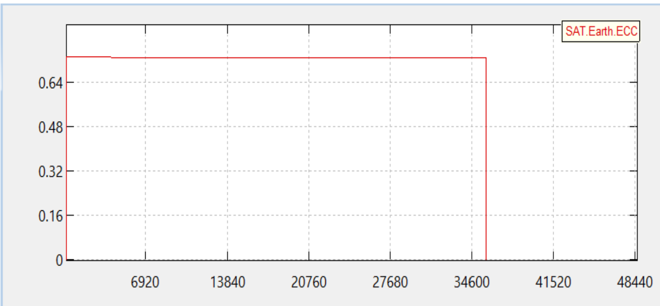
XY plots

GMAT allows us to plot data into the X and Y axis of the graph using XY plots. Using Script User Interface (GUI) of GMAT, we can create multiple XY plots. It also used to plot array elements, user-defined variables and spacecraft's parameters. GMAT's spacecraft and XY plots interact with each other throughout the entire mission duration. These graphs are also used to plot a function of a single independent variable with any number of parameters.

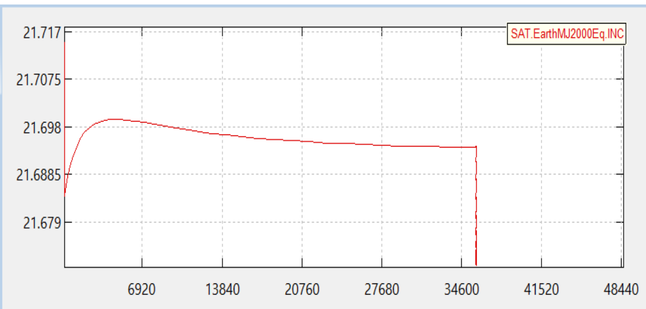
The graphs obtained for six keplerian orbital elements:



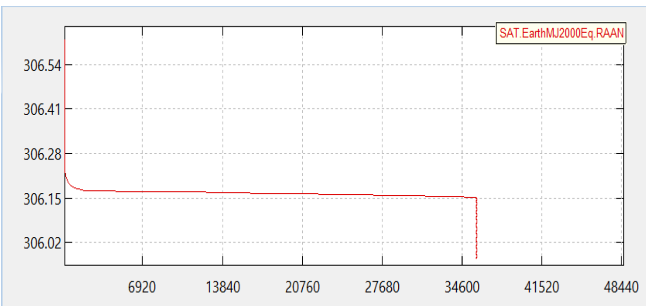
Graph 1. Satellite Altitude vs. Semi-Major Axis



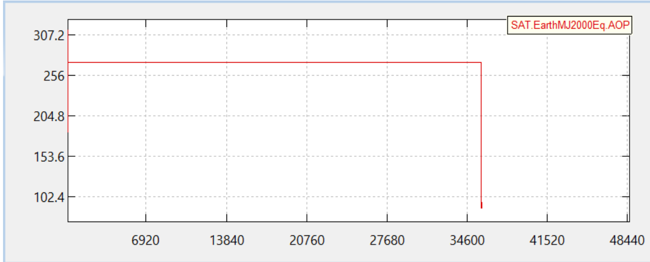
Graph 2. Satellite Altitude vs. Eccentricity



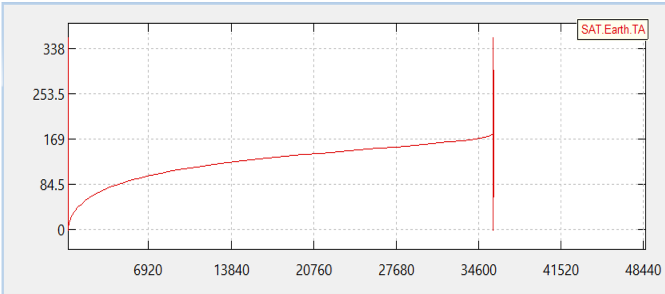
Graph 3. Satellite Altitude vs. Inclination



Graph 4. Satellite Altitude vs. Right Ascension



Graph 5. Satellite Altitude vs. Argument of Perigee



Graph 6. Satellite Altitude vs. True Anomaly

Conclusion

From the current and previous discussions of my publications, geostationary orbit for communication satellites been designed, simulated and various examinations made from the calculated values of delta-V, orbital elements and orbital perturbations. It results in obtaining fuel consumption from low ΔV total and building a constellation for better coverage, more survivability and higher reliability if a satellite is lost. By taking into consideration these two ideas will make a major revolution in the future missions of the GEO satellites.

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