CHAOTIC LUNAR CAPTURE DESIGNS
AND OPERATIONS OF A CUBESAT USING A LOW THRUST SYSTEM

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Master of Science

by
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Accepted by the faculty of the College of Science, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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This thesis focuses on creating the most efficient chaotic lunar capture design for the Lunar
IceCube mission by studying surrounding Characteristic Energy. Simulations will used to
consider the mission constraints first, and then the operational constraints of the low thrust
system and operational outages, with the recommended order by high to low risk level. The data
will then be documented in order to choose the most qualified trajectory sequence to complete
the chaotic capture successfully.

Accepted by: ____________________________, Chair
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III. Introduction

This thesis focuses on creating the most efficient chaotic lunar capture design for the Lunar IceCube (LIC shown in Figure 1) mission by studying the lunar Characteristic (C3) Energy of the orbit at various time intervals. Simulations will be used to consider the mission constraints first, and then the operational constraints of the low thrust system and communication outages, with the recommended order by high to low risk level. The data will then be documented in order to choose the most qualified series of maneuvers and propagations to complete the chaotic capture successfully.¹

The results of this project will be used by the LIC flight dynamics engineers at NASA Goddard Space Flight Center (GSFC) to analyze the effects of constraints on the nominal trajectory design. This thesis will explain how operational constraints can be inserted carefully to preserve the original trajectory design as much as possible by evaluating and recording the amount of risk at evenly staggered times throughout the trajectory design.

The thesis addresses the interconnection and impacts between mission operations and orbital dynamics, a balance that can be hard to find as both factors are crucial to the success of the mission. Specifically, the Characteristic energy sensitivity will be recorded at a pivotal

moment in the trajectory. This period of time, in the nine-month long course, from launch vehicle separation to lunar orbit, occurs right before the final lunar capture and lasts about 30 days. There are several mission risks associated with missing the calculated lunar insertion to our desired, science orbit. As a CubeSat mission, size, weight, and power resources are constrained, introducing increased risks that stem from low thrust propulsion and limited propellant, low power communication systems, and limited momentum wheel size, necessitating more frequent desaturation maneuvers. The analysis of this thesis will result in the most ideal design for the lunar capture in the LIC mission trajectory considering the requirements of the science orbit and mission. The research shown in this thesis increases understanding of navigating the chaotic three body problem in the Earth-Moon System with limited onboard resources to pave the way for future SmallSat experiments outside of Earth’s orbit.

This project was chosen based on the student’s capabilities, experience, and interest in orbital dynamics as well as a strong desire to work on the LIC mission. While the effort to optimize the navigation of LIC will continue up until and after the launch of Space Launch System (SLS) Exploration Mission 1 (EM-1), the method of optimization developed through analysis of this thesis will be useful for planning unexpected maneuvers during trajectory.

IV. Mission Background

i. Mission Relevance

On September 24, 2009, NASA announced that three instruments on different satellites observed water on the surface of the Moon.\(^2\) This announcement came as a surprise, as

liquid water cannot be held by the Moon, and water vapor is quickly decomposed by sunlight, but these two rules do not include water ice. There are regions on the moon referred to as Permanently Shadowed Regions (PSRs) that have never before been touched by sunlight. Because the Sun only shines around the equator of the Moon, the poles remain isolated from sunlight. This creates the perfect environment for water ice to exist. The questions have now transitioned to the quantity, location, and movement of water on the Moon, rather than the existence of water on the Moon. Because water is best seen in the infrared spectrum, an infrared spectrometer will be used to map water on a surface.3

The importance of locating water is a necessary step in the path to human exploration beyond Earth. Water is invaluable for three reasons for human space exploration: drinking water, humans must stay hydrated to survive, oxygen, the hydrogen component can be removed from water to provide a source of fresh breathing air, and hydrogen, the most efficient and lightest form of rocket fuel known. Water is a very costly resource to transport. If the cost to launch one pound of cargo on NASA’s space shuttle program was about $10,000, that would make a gallon of water at 8.34 pounds a total cost of $803,400.4 If water were readily available on the surface of the Moon, it would be more cost efficient to collect and process the water ice on site of the Moon’s surface, rather than transport the resource from Earth before journeying further into the solar system. The large amount of force needed to launch from the surface of the


Moon is significantly less than that of Earth, due to the decreased gravitational potential and the secondary effects of the atmosphere. Valuable resources can be saved by collecting a mission’s water supply from the surface of the Moon.5

ii. Spacecraft Bus Design

Lunar IceCube is a nanosatellite of 6U CubeSat size designed to scan the Moon’s surface for lunar volatiles using the Broadband InfraRed Compact High-Resolution Exploration Spectrometer (BIRCHES)6 instrument to improve our understanding of the volatile distribution on the Moon. It is destined to fly on the maiden voyage of the Space Launch System (SLS) Exploration Mission 1 (EM-1) on June 26, 2020 as part of the secondary payload carrying 12 other nanosatellite missions.

While the LIC spacecraft is being integrated at Morehead State University, major contributors to the mission come from various locations including NASA Goddard Space Flight Center (GSFC), providing the BIRCHES payload, Jet Propulsion Laboratory (JPL), preparing the Iris Deep Space Transponder, and The Busek Company, building the RF Ion BIT-3 thruster propulsion system. Other subsystems are being outsourced to Blue Canyon Technologies (BCT), Pumpkin, and SpaceMicro, which are, respectively producing an attitude determination and control subsystem using reaction wheels called the BCT XACT, solar panels and corresponding electrical power subsystem (EPS), and the on-board computer or command and data handling


(C&DH). The placement of these subsystems in the compact 6U CubeSat can be seen in Figure 2 below.  

![Lunar IceCube Spacecraft Subsystems Pictured in a Proportional 3D Model](image)

**Figure 2** Lunar IceCube Spacecraft Subsystems Pictured in a Proportional 3D Model  

Sending SmallSats to the Moon is a new frontier. The task of packing enough resources into this tiny spacecraft and protecting it from a harsh radiation and thermal environment is quite the challenge. However, the evolution of technology has given the LIC mission a great chance of success. Because this mission is the first of its kind, some of the subsystems aboard the LIC bus are being flown as technology demonstrations, such as the BIT-3. The operational success of LIC will result in flight qualifications of several technologies for deep space SmallSats.

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iii. Mission Trajectory

LIC’s travel through the Earth-Moon system begins with separation from the SLS EM-1 mission at “Bus Stop One”.

There are four available “Bus Stops” for secondary payloads to eject from that vary in distance from the Earth to the Moon once the Orion space capsule has separated from the SLS body. Figure 3 below outlines the trajectory of LIC from ejection of SLS to orbit around the Moon. The reason that LIC is not taking the last “Bus Stop” on SLS, closest to the Moon, is due to the limited thrust provided by the propulsion system. If separated closer to the Moon, LIC does not possess the ability to alter its trajectory about the Moon to prevent heliocentric escape and design a return trajectory for capture and transfer into the science orbit.

![Lunar IceCube ConOps](image)

**Figure 3 Lunar IceCube Concept of Operation**


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Consequently, LIC will be following a manifold trajectory starting with separation at a 36,500 km Earth altitude and a speed of approximately 1 m/s. At this first lunar fly by, the satellite’s orbital energy is very sensitive to velocity differences so a second ballistic lunar encounter must be planned and achieved at a later time to establish stable lunar capture energy. Using the gravitational forces of the Earth and Moon, LIC is able to drift away from the Moon, toward Earth, for 106 days before arriving at the second lunar fly by targeting the B-plane. In order to establish optimal capture around the Moon, LIC applies a series of correction maneuvers and propagations of various directions and durations. The spacecraft then begins an almost three-month journey spiraling downwards, closer to the surface of the Moon, and the desired science orbit of the mission.

V. Mission Constraints

i. Science Orbit Requirements

As mentioned before, water ice on the surface of the Moon is concentrated at the poles. Because this is where most water ice is believed to reside on the Moon, LIC is planned to follow a polar orbit in such that it covers both the south and the north pole, as well as the equator between. A polar orbit is a common requirement in

Figure 4 Three Stages of the Lunar IceCube Science Orbit


missions because it conveniently observes the entire body it orbits around. From this perspective, the BIRCHES instrument can thoroughly survey the prime area where water is predicted to collect.\textsuperscript{11} This accomplishes the first part of the science mission by locating and quantifying the amount of water on the Moon.

The predicted three-month long science mission around the Moon is to track the water as it moves over the surface during the planned three-month long mission around the Moon. The orbit is designed to graze the equator of the Moon by 100 km at perilune in order for BIRCHES to increase data resolution by collecting data close to the surface. LIC has a 5,000 km altitude at apolune of its highly eccentric orbit, where it can implement operations such as cooling, communications, station keeping, and calibration. Additionally, the infrared spectrometer requires a well-lit area in order to collect the science data. This requires the periapsis, or point during orbit when the spacecraft is nearest the Moon, to always be on the side of the Moon lighted by the Sun. To summarize, in order for science data to be collected, the spacecraft must fly in a polar, eccentric, lighted periapsis, and low perilune orbit around the Moon.\textsuperscript{12}

Each minute of the seven-hour science orbit is carefully scheduled for maximum efficiency. Referencing Figure 4 above, the orbit is sectioned off and assignments are made to each phase. If the orbit were described in clock-wise fashion starting where the Moon’s north pole crosses the orbit, the first action would be highlighted in green at perilune. This is the science portion of the operation. It lasts about an hour total with ten minutes of cooling and


calibration time pointing anti-lunar nadir before and after the forty minutes of science data collection, analyzing the Moon from north to south pole. The following four hours are characterized as “idle mode”. During this time, LIC will point its solar panels toward the Sun to charge the batteries. In the two hours left of the science orbit, LIC will remain stationary, cooling the bus and limiting activity in order to prepare BIRCHES accuracy for data collection. Communication will only occur once every three orbits, or about every twenty-one hours, simultaneously as LIC is charging via solar panels.\textsuperscript{13}

The Pumpkin solar panels are equipped with their own gimbaling system that allows them to be pointed separately from the body. The communication operation will begin with LIC pointing the x-axis toward the Earth and transmitting any science data collected and health statistics. In return, the spacecraft will wait to receive any commands from Morehead State University’s (MSU) 21-Meter Dish Antenna at DSS-17 ground station, that is currently being integrated with Deep Space Network (DSN) capabilities with support from JPL.\textsuperscript{14} When required, station keeping will be executed during one of the four-hour windows where the satellite is charging its solar panels. The thrusters will be initiated in the direction of the zenith while the solar panels face the Sun vector. The process starts over again when LIC’s orbit crosses the north pole of the Moon. A more detailed model of the assigned pointing phases is


picted below in Figure 5. Data collection is expected to continue for three months or as long as iodine propellant is available in the propulsion tank.15

![Diagram of spacecraft attitude control](image)

**Figure 5 Lunar IceCube Attitude Control Model During Lunar Orbit**


### ii. Power, Thermal, and Propellant Limitations

Due to the power and thermal restrictions of the CubeSat mission, neither the BIT-3 Ion Thruster, IRIS Transponder Radio, nor the BIRCHES infra-red spectrometer may operate at the same time. This situation creates a balancing act between continuous thrusting and critical communication time for attitude determination and correction parameters during the nine-month journey from separation of the launch vehicle to arrival at the first science orbit. In order to achieve the ideal science orbit without expending all available propellant, the ballistic capture

dynamics, launch and transfer correlations, and general chaotic motion in the Earth-Moon system
must be navigated accurately and methodically within the mission constraints.\textsuperscript{16}

Pumpkin, Inc. is developing the solar panels and EPS system for the spacecraft bus. At
2.24m in wing span, the solar array can generate 120 W of continuous power for the EPS to
distribute to the subsystem. The main source of that power drainage comes from the propulsion
system. At 65 W, the BIT-3 uses over half of the supplied power. Iris is the runner up in
consuming power at 38 W when transmitting, further illustrating why these two may not operate
at the same time. It would be impossible to dissipate the amount of heat created by these systems
before the payload would become ineffective.\textsuperscript{17}

While the Busek propulsion system, Iris radio, and Sun exposure produce large amounts
of heat that risk the thermal health of the bus, the largest concern is centered around the payload.
The payload temperature is maintained through subsystem isolation using a microcryocooler, and
the exposed opening of the sensor is protected by a motorized door.\textsuperscript{4} These methods will allow
BIRCHES to keep temperatures low enough to preserve its resolution until it is ready to be
utilized.\textsuperscript{18}

Because of limited propellant on the satellite, an unpredicted perturbation in the
trajectory could be fatal to the mission. The chances of recovering LIC in this situation would be
highly unlikely, considering the maneuvers necessary to compensate for the loss of judicious

for Water Ice.” \textit{IEEE Aerospace and Electronic Systems Magazine}, vol. 34, no. 4, 2019,

\textsuperscript{17} Malphrus, Benjamin K., et al. “The Lunar IceCube EM-1 Mission: Prospecting the Moon

maneuvering by the perturbation. Any abnormality in the planned path of flight when entering the area of combined gravitational forces of the Earth-Moon system could easily agitate the trajectory enough to cause the CubeSat to drift into the solar system so far that it becomes unrecoverable. Even if the situation would result in a recoverable orbit around the Moon, the chances of that orbit being ideal for collecting data with the BIRCHES instrument would be even more unlikely. Both of these scenarios require more propellant than LIC contains, and in order to prevent this disappointing loss, precise recording must be executed every time during the optimization of this lunar capture. Every milligram of propellant, outage in thrusting for communication, calculated prediction, and executed maneuver could mean the difference between success and failure in this significant demonstration of integrated cutting-edge technology.19

In order to complete the end of life requirements, LIC must have enough propellant remaining at the end of its mission to propel itself to crash into the Moon’s surface. The alternative, of thrusting LIC into deep space, away from low lunar orbit, out of the path of future spacecraft, would require more propellant that would take away from potential science data collection opportunities.20

iii. Ballistic Capture Dynamics

In combination with the BIT-3, LIC will utilize the natural motion of the Earth and Moon system to arrive at the Moon and obtain the specified lunar science orbit. Due to the chaotic


motion of the Earth-Moon system and low thrust of the engine, there are few options for the translunar trajectory. The required ballistic capture energy and specific science orbit elements contribute to the difficulty in planning this trajectory. The path of the spacecraft as it travels through space is outlined in Figure 6 below in a Sun-Earth rotating frame. This figure illustrates the complexity of this mission, but the colored “Transfer Key” pictured in the top right-hand corner of the image provides clarification. The blue color shows the beginning stages of the trajectory when LIC is completing the transfer from ejection to lunar capture by completing a series of two lunar flybys. The red lines represent the second phase of the trajectory when the spacecraft performs the initial low thrust lunar capture to set up the final low thrust lunar capture where LIC follows the Moon’s orbit, creating its own spiral orbit around the Moon’s path.21

The required ballistic capture dynamics for the mission can be achieved by altering the lunar approach phase of the trajectory. Small uncertainties or errors during this phase could result in an early lunar impact or in an inserted orbit that would require more propellant than available to achieve the desired science orbit. The maneuver durations and directions during the lunar approach are based on the level of stability of energy around the spacecraft at a certain point in space and moment in time. This level of stability can be studied by referencing the energy that the surrounding bodies create through gravitational forces. These energies are known as the C3 constants mentioned in the introduction of this thesis. These constants inform the

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decisions of the duration and direction of thrusts during the 86-day spiral to create the most efficient and accurate ballistic capture of LIC.  

![Diagram of Lunar IceCube trajectory](image)

**Figure 6** Trajectory of Lunar IceCube in a Sun-Earth Rotating Frame  

VI. Operational Constraints

i. Low Thrust Propulsion System

While the LIC science orbit has been easily attainable for other missions in the past, it is a much greater challenge for the low thrust system aboard LIC. The force emitted from the Busek BIT-3 Ion Thruster (shown in Figure 7 and Figure 8) is barely a match for the natural forces of gravity created by and between the Earth and Moon. The propulsion system emits a thrust of 1.24mN or 1.2km/s of Delta-V. It carries a limited supply of 1.3 kg of solid-storable iodine propellant. Without consistent, uninterrupted thrusting and accurate pointing, the mission...
could be easily thrown off course, but the continuous thrusting makes it very inconvenient to insert operational outages for communication and momentum unloads to maintain direct course to the Moon. The disruption in thrusting is necessary in order to power the Iris radio for communication.23

**Figure 7** Propulsion System Test of BIT-3 Thruster  

**Figure 8** BIT-3 Iodine Fueled RF Ion Engine System  

### ii. Low Power Communications

The radio of the satellite is arguably the most important system in the spacecraft. Revolutionary science could be discovered by an instrument collecting data in space, but without an operational communication system, this data inaccessible. The most essential part of LIC’s bus, the Iris Radio 2.1 Transponder, will operate in the high X-band frequency range.24 Both


versions of the Iris transponder are pictured below in Figure 9 and Figure 10. Communication to the satellite becomes most essential during the peak of chaos in the trajectory. This occurs during a 25-day burn directly before the 86-day spiral down burn that will place the spacecraft in the ideal orbit for BIRCHES to collect data. Because the time leading up to the spiral down burn determines the outcome of the final orbit, it becomes most crucial to confirm the expected spacecraft position and direction. By carefully plotting the energy over time of the 25-day burn, the stability of the orbit can be considered at each of the 25 days. The day with the most stable surrounding energy is identified, thrusting is temporarily terminated, and time for communication can be injected. This research informs crucial maneuver planning with the lowest possible risk to the mission.  

While the DSN has allotted the LIC mission three hours for communication per contact, the total thrusting outage time must be scheduled much longer in order to stay within thermal and power limitations. The thruster both creates a lot of heat that needs to be dissipated and consumes large amounts of power that must be regenerated before the spacecraft is capable of safely communicating with DSS-17 at MSU. The process for preparation of communication could take upwards of four hours depending on the spacecraft’s position to the Sun. Once communication has been received to verify the satellite’s position and a transmission has been sent with any corrections to the satellite’s position, the propulsion system will then prepare for thrusting again.  


The entire outage of communication time is scheduled for 12 hours based on the maximum amount of time needed to complete communication to provide margin. To prevent large variations from the desired trajectory, communication is scheduled to be conducted once a week during the initial and final low thrust lunar capture orbits. With the method developed by this thesis, the duration of communication can easily be changed if risk evaluations of the mission change.

iii. ACS Momentum Unloads

LIC is using the Blue Canyon Technologies (BCT) XACT attitude determination and control subsystem. It will utilize three 50 mNms reaction wheels, as shown in Figure 11, to maintain orientation in coordination with the BIT-3 propulsion system. All reaction wheels have limitations, and when the...
wheels become saturated with momentum, the system is unable to perform properly. In order to correct this, a method is used for unloading momentum to desaturate the wheels and resume normal operations. By slightly gimballing the thrusters at a small angle of about 5.5°, the spacecraft will move in a spiral creating the shape of a cone at a 17.2145° angle using 95% nominal thrust until excess momentum is unloaded. This is expected to take about 15 minutes depending on the depth of saturation of the reaction wheels. The ACS momentum unloading maneuvers will ideally occur at scheduled outages during trajectory when the optimal amount of time between unloads is identified.  

VII. Analysis Models

i. Given LIC Capture

This thesis was based on a pre-existing GMAT script written by an aerospace engineer at NASA GSFC, David C. Folta. The provided script contained a complete and thorough trajectory plan for the LIC specific mission but lacked the final science orbit requirements. The values of the orbit conditions in Table 1 represent the capture model in Figure 12. The energy around the position of the satellite in the orbit illustrated in this scenario is stable, shown by the value of C3, but BIRCHES would not be able to study data around the poles due to low inclination nor data near the equator due to high periapsis altitude. This model is presented to show the improvement in orbit conditions in the following trials described in this thesis.


i. **Trial 1: LIC Optimized Capture**

A precise approach to optimizing the gravitational forces exerted by the Moon were developed to manipulate the final low thrust lunar capture orbit that resulted in ideal conditions for BIRCHES data collection. By changing the duration and direction of the arrival maneuvers and propagations in the script, the effects on the final orbit were recorded and compared to determine the best results while using the smallest amount of propellant possible by utilizing natural propagations from the Earth-Moon system’s gravitational energy. Under these conditions, the LIC optimized capture was created. The final orbit can be seen in Figure 13 and the orbit conditions can be seen in Table 2, meeting the mission requirements of a polar, eccentric, lighted periapsis, and low perilune orbit around the Moon. The stability of the orbit is described by the value of the Characteristic or C3 energy, below 0 km²/s². The method of optimization is discussed later in the results section of this thesis.\(^{30}\)

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Figure 13 Lunar IceCube Optimized Capture Model
Source: David C. Folta, NASA GSFC, 2018.

Table 2 Lunar IceCube Optimized Capture Model Orbit Conditions
Source: David C. Folta, NASA GSFC, 2018.

<table>
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<th>Optimized Orbit Conditions</th>
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<td>RAAN</td>
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<tr>
<td>AOP</td>
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<tr>
<td>C3</td>
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<td>Periapsis Alt.</td>
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Trial 2: LIC Operational Constraint Capture

The sensitivity of the optimized LIC capture design offers little room for improvements or interruptions, but these are necessary for system maintenance. As stated before, because of thermal and power limits, neither the BIRCHES, BIT-3, or Iris transponder may operate at the same time. This requires hours of BIT-3 thrusting outages for Iris to communicate with the Deep Space Network (DSN). These outages must be carefully scheduled during the least sensitive parts of the trajectory where the Characteristic Energy (C3 Energy) is low enough or stable enough to maintain the desired trajectory. At this point, an operational capture considering mission operations is created based on the optimal capture in trial 1.

The final conditions of the LIC operational capture are pictured below in Figure 14 and stated in Table 3, meeting the mission requirements for science collection more accurately than Trail 1. The analysis model was affected in both a positive and negative way that creates a give-and-take choice for the engineer. Comparing these conditions in Tables 2 and 3, the inclination was obviously improved, but this required the satellite to spiral closer toward the Moon in order to achieve it. This results in a smaller periapsis altitude which is in the acceptable boundaries of
the requirements but could result in an early collision with the Moon before science data
collection can be completed in three months’ time. Remember, this lunar orbit capture scenario
takes into account the maximum amount of time needed to complete communication of 12 hours.
This provides some margin before the communication duration is finalized.

![Figure 14 Lunar IceCube Operational Capture Model]

Source: David C. Folta, NASA GSFC, 2018.

<table>
<thead>
<tr>
<th>Operations Orbit Conditions</th>
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<tr>
<td>Ecc</td>
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<td>Periapsis Alt.</td>
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Table 3 Lunar IceCube Operational Capture Model Orbit Conditions
Source: David C. Folta, NASA GSFC, 2018.

ii. Software

The General Mission Analysis Tool (GMAT) and AGI Systems Tool Kit (STK) Astrogator were used to develop an optimal lunar capture between the initial conditions of deployment from the SLS and the Moon. The research provided in this thesis was conducted using GMAT, but the final simulation submitted to NASA will be in AGI STK format.

1. NASA General Mission Analysis Tool (GMAT)

GMAT is an open source software system for space mission design, optimization, and navigation. It has capabilities to support missions ranging from lower Earth orbit to lunar orbit, libration point, and deep space missions using both a graphical user interface (GUI) and scripting interface. The software has tools for trajectory manipulation such as orbit transfers, B-Plane targeting, and optimal lunar fly-by. The software was developed by a
team of NASA, private industry, public, and private contributors with significant contributions from NASA GSFC.\textsuperscript{31}

2. AGI Software Defined Toolkit (STK)

STK is a closed source software system that provides four-dimensional modeling, simulation, and analysis of objects on land, sea, air, or space in order for mission planning or to evaluate system performance. Morehead State University offers students an educational license to make the program available to those that are interested in utilizing the software for projects. STK creates an inclusive modeling environment to simulate precise mission planning, design, training, and operations in real time.\textsuperscript{32}

VIII. Dynamical Systems Overview

i. The Two Body Problem

In order to better understand the results section of this thesis, a dynamical systems overview is given. As mentioned before, lunar C3 energy is the focus of analysis for optimizing lunar injection. C3 energy is an outcome of the two-body problem, the amount of excess energy over that required to escape from a massive body. This model becomes useful when considering the stability of LIC around the Moon.

The two-body problem considers two spherical point masses in space. Newton’s third law states that any action has an equal and opposite reaction.\textsuperscript{33} If there is a physical force between


the two bodies, they will begin to accelerate. Referencing Figure 15, if one point mass is negligible in size to the other, a center of mass is created between the two bodies and the smaller point will orbit the larger point. This renders the larger body motionless. If the angular momentum is constant, the mass ratio is known, and the relative distances are identified in this problem, two solutions emerge.\(^\text{34}\)

**Figure 15** Geometry of the Full Two Body Problem Model  

The solutions to the two-body problem are modeled in a plane on a long and short axis equilibria (shown in Figure 16). The plural of solutions is used because the two-body problem cannot be solved exactly. These models show an axis between the two bodies with the minimum moment of inertia aligning (long axis equilibria) and the moment of inertia perpendicular to the

axis (short axis equilibria). The long axis equilibria are chosen as the most energetically stable solution.\(^{35}\)

![Diagram of Long and Short Axis Equilibria](image)

**Figure 16 Configurations Investigated for the Full Two Body Problem**


### ii. Circular Restricted Three Body Problem (CRTBP)

The restricted three body problem, a special case of the n-body problem, considers two large finite masses orbiting circularly around their common center of mass. This model is pictured below in Figure 17. A significantly smaller third body is introduced, and the objective is to find the motion of this body under the gravitational influence of the two larger masses. This third body can be seen as negligible in this problem because the two larger bodies will impact the course of the third body, but the third body will not affect the motion of the larger two.\(^{36}\) In order to simplify the problem, several assumptions are made:

- Three Bodies: Massive Body 1, Massive Body 2, and Spacecraft
- \(M_1 > M_2 >> M_3\)
- All bodies are point masses
- Gravity is the only force acting
- \(M_1\) and \(M_2\) are in circular orbits about the center of mass (barycenter)
- Total Mass of \(M_1 + M_2\) = 1

---


• Distance between M1 and M2 1
• The position of M1 1-u
• The position of M2 u
• Orbit Period of the Two Primary Bodies 2π

\[ \sum F = m_3 \ddot{R}_{s/c} = -G \frac{m_3 m_1}{R_1^3} \dot{R}_1 - G \frac{m_3 m_2}{R_2^3} \dot{R}_2. \] (1)

**Figure 17 Three Body Circular Restricted Problem Model**


The three-body problem can then be solved using these assumptions and Newton’s laws of motion. Newton’s equation of motion for three gravitational bodies is stated in the equation 1 below. The three masses in the problem are represented by m1, m2, and m3 and the constant gravitational force is represented by G. The values of R1 and R2 are represented by the distance between the three bodies, previously mentioned, and stated in equations 2 and 3 for review.37

\[ R_1^2 = (x + \mu)^2 + y^2 + z^2 \]
\[ R_2^2 = (x - 1 + \mu)^2 + y^2 + z^2. \]

In addition to the Newton dynamics, the three-body problem can also be described using Hamiltonian equations. Variables in the Hamiltonian equations consider both the position and momentum of the of each of the three bodies as shown in equation 4. The Hamiltonian value itself is a variable in the set of equations. It represents the total energy of the system, both gravitational and kinetic. The exact calculation of the Hamiltonian is stated in equation 5. Studying a scenario using Hamiltonian or Newton mechanics will produce the same results to the three-body problem, but the Hamiltonian equations offer a different approach to understanding the energy and forces in the three-body problem.

\[
\frac{dr_1}{dt} = \frac{\partial H}{\partial p_1}, \quad \frac{dp_1}{dt} = -\frac{\partial H}{\partial r_1},
\]

\[
H = -\frac{Gm_1 m_2}{|r_1 - r_2|} - \frac{Gm_2 m_3}{|r_3 - r_2|} - \frac{Gm_3 m_1}{|r_3 - r_1|} + \frac{p_1^2}{2m_1} + \frac{p_2^2}{2m_2} + \frac{p_3^2}{2m_3}.
\]

In comparison to the two-body problem, the three-body problem is a more accurate representation of LIC’s trajectory with the three bodies in this problem being LIC, Earth, and the Moon. This thesis is based on the general understanding of these equations and the three-body problem in order to provide context for the analysis and results presented to optimize the lunar capture.


iii. Jacobi Systems and The Zero Velocity Curve

Consider a particle moving through the CRTB. Similar to the C3 energy of the two-body problem, the Jacobian energy is fixed at any point and does not vary. As the third body, LIC in this example, moves between the two larger point masses of the Earth and Moon, the Jacobian constant will change as the position of the spacecraft changes. For each Jacobian constant, the motion of the satellite is restricted from certain regions, called “forbidden regions”. These regions are generated using the zero-velocity curve.\(^{40}\) It represents a surface body of given energy the particle cannot cross, or it would have zero velocity on the surface. Similar to the C3 energy of the two-body problem, the larger the Jacobian constant, the more unstable the energy around the point in the orbit and vice versa. This phenomenon can be seen in Figure 18 below.

![Diagram](image)

**Figure 18** Evolution of Jacobian Constant of a Point Mass Traveling Through Space


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As the Jacobian energy changes, so does the zero-velocity curve. As the energy decreases around the point, the forbidden regions become smaller. The third, negligible body, becomes more at risk of drifting out of the system as forbidden regions shrink. This progression is shown in Figure 18, above, where the darker shaded areas represent the forbidden regions and the lighter regions show where the particle can travel freely.41

A special case of the three-body problem is also illustrated in the figure above. In the bottom right hand of the figure, three “+” signs can be identified around the two bodies. These represent Lagrange points where the gravitational forces from the two large bodies equal the centrifugal force on the third, smaller body. At these points, bodies can remain stationary without being at risk of drifting to deep space. This further illustrates the functionality of the three-body problem when planning the trajectory of an interplanetary spacecraft mission.

The Jacobian energy constant is the result of the movement of the circular restricted three body problem and is found by integrating a function containing the position of the spacecraft that results in a matrix that informs a determinate representative of the stability of the energy of the spacecraft at the inquired position in a circular restricted three body problem. This overview provides a realistic understanding of the gravitation environment that LIC will be traveling through as described in this thesis.

IX. Results

i. Lunar Capture Optimization

Each maneuver in the trajectory has four variables that can be manipulated in order to provide desired results. The BIT-3 thrusters must be directed within three-dimensional space and therefore need an X, Y, and Z input. The fourth variable that can be manipulated is the duration of each of the directed thrusts.

The X, Y, and Z directions in this analysis are based on azimuth and elevation pointing that was translated into the XYZ plane. Several combinations of azimuth and elevation thrust directions were tested for how well they met the science requirements. As shown in the GMAT source code for the optimized lunar capture, seven different combinations of azimuth and elevation were translated to the XYZ plane and simulated in the lunar capture. The test values in azimuth ranged from 130° to 230° and in elevation ranged from -20° to 20°. Some simulations did not converge at all while other crashed into the Moon long before the minimum 3 months needed for successful data collect. Some simulations produced orbit conditions with values that were too low in inclination, and some simulations produced orbit conditions that were too circular for the mission. The final decision came to az 130° and el -20°. Once the optimal direction was chosen, the duration was decreased and increased to find the most optimal final orbit. The duration that produced the most accurate final orbit conditions to the desired finally orbit was 133.9 days. The orbit conditions that resulted from this simulation can be seen in Table 4.

The physical difference can be seen in the evolution of the final orbit (Figures 19, 20, and 21) resulting from their respective orbit parameters in Tables 4, 5, and 6. The eccentricity, inclination, and periapsis altitude were all improved to meet science orbit requirements. By using
the B-Plane targeting technique with four variables, the software was able to converge on a solution to the problem. Once the variables had a solution, the final conditions now met the science orbit requirements. By altering the final orbit conditions at the beginning of the capture, precious propellant is reserved that can contribute to extending the amount of time for science orbit collection. The optimized and operational orbit conditions are within mission requirements and prove the validity of these proposed solutions to the lunar capture.

Table 4  LIC Given Capture Model Orbit Conditions  

![Figure 19 LIC Given Capture Model](image)

Table 5  LIC Optimized Capture Model Orbit Conditions  

![Figure 20 LIC Optimized Capture Model](image)
ii. Characteristic Energy Sensitivity

Every object in a ballistic trajectory has a constant specific orbital energy equal to the sum of its kinetic and potential energy. Characteristic Energy, or C3 Energy, is the measure of excess energy over that required to escape from a massive body. The energy is measured in units of length$^2$ time$^{-2}$ or velocity$^2$. The energy remains constant at a certain point, but as the spacecraft changes position, the C3 energy is subject to change at each of those positions. As mentioned before, the greater that the energy, the less stable the spacecraft is at that position and vice-versa.

The C3 energy of the LIC optimized trajectory simulation was studied during the 25-day burn that determines the final orbit elements, before the 86 day long spiral down burn. This creates the basis for making an informed decision of where to place operational outages in thrusting in order to minimize risk of LIC escaping the Earth-Moon system. During this research, the window of the scale stays between about -0.1 to 1. Operational outages are added when C3 energy is the smallest, or at least below 0, and within a reasonable amount of time to prevent risk of waiting too long between communication phases.

The recorded C3 energy during the 25-day orbit can be seen in Figures 22 and 23. The data in these graphs show that any error during this crucial time could result in an unrecoverable mission that has traversed further than the available propellant to retrieve the spacecraft into the
desired orbit. In order to get a full 12-hour window to allow the spacecraft bus to cool, transmit and receive communication, and warm back up to continue propulsion, the thrusting continues for nine days before the first communication occurs. The burn then continues for seven more days before another communication transfer can be completed followed by another seven days of thrusting before the final 86-day spiral down burn delivers the satellite to the desired science orbit. Because the difference in C3 energy can be very difficult to see between Figures 22 and 23, the difference is graphed in Figure 24. The difference becomes greater as the energy around the spacecraft becomes more stable. Toward the end of the 25-day burn, the energy comes more stable and level of risk decreases. This is caused by the Moon’s gravity becoming stronger on the spacecraft as it approaches the Moon and grows closer. This proves the level of risk was decreased by the optimization methods developed in this thesis.

![LIC Optimized Trajectory](image1.png)

**Figure 22 LIC Optimized Capture Model C3 Energy**
*Source: David C. Folta, NASA GSFC, 2018.*

![LIC Trajectory with Communication Outages](image2.png)

**Figure 23 LIC Operational Capture Model C3 Energy**
*Source: David C. Folta, NASA GSFC, 2018.*

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iii. Effects of Constraints on Optimized Design

Beyond the numbers, physical perturbations can be seen in the lunar capture once operational outages are implemented. In Figures 25 and 26 below, the blue represents natural propagations, the red shows maneuvers using thrust, and the two small yellow strips pointed out by yellow arrows are the 12-hour communication outages in thrusting. There is also a streak of white that represents the backward propagation needed to obtain the optimal angle for entering the Moon’s gravitational field. The axes can be seen as x in red, y in green, and z in blue. The Sun line is highlighted in yellow. The figure on the left is shown in a lunar inertial rotating frame and the figure on the right is in a Sun-Earth rotating frame. Obvious perturbations can be seen in Figure 25 immediately following the 12-hour communication outages in thrusting shown in yellow. This evidence of path disturbance shows how delicate and sensitive the Earth-Moon system is. The science of controlling movement through this motion can be unexpected but must always be precise.
X. Conclusion

This established method for determining the best lunar capture strategy for the mission will be used to produce an updated model for the updated launch date of the EM-1 mission of the SLS. Since the position of the planets changes every day, the system and motion of energy around them changes as well. Because the trajectory of the mission depends largely on the Earth Moon system’s natural motion to arrive at the final orbit due to mission and operational constraints, the low thrust lunar capture approach must be altered in the later stages of the trajectory, when the energy around the position of the satellite is more stable.

It is likely that the attitude and trajectory of the satellite will have to be altered frequently after launch, and the possibility of a launch delay always remains imminent. The method of optimization developed in this thesis can be used to provide a recipe to quickly produce a response to any unexpected perturbations the mission may encounter or, given a launch slip, reproduce a lunar capture resulting in a final orbit that meets the science mission requirements.
Unexpected perturbations and the possibility of a launch slip demonstrate two applications of the method developed in this thesis for determining the ideal lunar capture for LIC.

Two simulated, optimized, LIC capture models were created in the results section of this thesis from a given set of orbit conditions created by David C. Folta at GSFC. The goal of the first trial was to optimize the final orbit conditions to better meet the needs of the science requirements while minimizing the use of propellant. The second trial used the optimized results of the first trial to meet the objective of inserting outages in thrusting in order for communication to occur at critical points in the trajectory. While the method used to optimize these capture models was the same, the desired result influenced the decision of when and where in the trajectory to optimize.

In summary, the method developed in this thesis involves altering four variables in the LIC trajectory: X, Y, and Z thrust direction and duration. The variables are manipulated once LIC is in a stable capture around the Moon, unable to easily escape to deep space. This point in the trajectory occurs before the 90-day spiral down phase and after the second lunar flyby. By fluctuating the direction and duration of the thrust, experimenting with increasing and decreasing the value of the variables, and observing the resulting orbit conditions compared to the desired orbit conditions, informed decisions about the maneuver planning can be made. The behavior of the resulting orbit conditions can be unpredictable based on the natural motion of the Earth-Moon system so repetitive trial and error combined with rigorous documentation was used to create this method of optimization.

XI. Future Work

This thesis project has many more opportunities for continued research and optimization of the LIC capture design and operations. The model will also need to be updated as integration of LIC is conducted and values from thermal dissipation capabilities, momentum unloading frequency, communication and thrust outage frequency, etc. are finalized. In the following paragraph, additional topics for further review are given.

The study conducted in this thesis would be more complete if modeled with accurate momentum unloads using the thrusters at a gimbled angle spiraling around a cone as mentioned the ACS momentum unload section. The operational capture of LIC would be more accurate if communication or thrusting outages were shorter and more frequent. This thesis could be built upon by modeling the propulsion system and iodine tank in the simulation to run the mission through the three months of station keeping and record the propellant used and left over. This study could also be repeated using Jacobian energy constants rather than Characteristic energy constants. This can be done using MATLAB in combination with GMAT to improve the precision using three body dynamics rather than two body dynamics. Finally, it would be interesting to see the study modeled in STK simulation, as this will be the final format of the trajectory submitted to NASA.
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Monitor Data System for Deep Space Tracking.” *Journal of Information and
XIII. GMAT Source Code

i. LIC Optimized Capture

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%Created: 2018-06-15 12:37:54

%----------------------------------------
%------- Spacecraft
%----------------------------------------

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GMAT NearEarthForceModel.CentralBody  Earth;
GMAT NearEarthForceModel.PrimaryBodies  {Earth};
GMAT NearEarthForceModel.PointMasses  {Luna, Sun, Jupiter, Venus, Saturn, Mars};
GMAT NearEarthForceModel.Drag  None;
GMAT NearEarthForceModel.SRP  On;
GMAT NearEarthForceModel.RelativisticCorrection  Off;
GMAT NearEarthForceModel.ErrorControl  RSSStep;
GMAT NearEarthForceModel.GravityField.Earth.Degree  8;
GMAT NearEarthForceModel.GravityField.Earth.StmLimit  100;
'/data/gravity/earth/JGM2.cof';
GMAT NearEarthForceModel.GravityField.Earth.TideModel  'None';
GMAT NearEarthForceModel.SRP.Flux  1367;
GMAT NearEarthForceModel.SRP.SRPMODEL  Spherical;
GMAT NearEarthForceModel.SRP.Nominal_Sun  149597870.691;

Create ForceModel NearMoonForceModel;
GMAT NearMoonForceModel.CentralBody  Luna;
GMAT NearMoonForceModel.PointMasses  {Luna, Earth, Sun};
GMAT NearMoonForceModel.Drag  None;
GMAT NearMoonForceModel.SRP  On;
GMAT NearMoonForceModel.RelativisticCorrection  Off;
GMAT NearMoonForceModel.ErrorControl  RSSStep;
GMAT NearMoonForceModel.SRP.Flux  1367;
GMAT NearMoonForceModel.SRP.SRPModel  Spherical;
GMAT NearMoonForceModel.SRP.Nominal_Sun  149597870.691;

%-----------------------------------------------------

%-------- Propagators
%-----------------------------------------------------

Create Propagator NearEarthProp;
GMAT NearEarthProp.FM  NearEarthForceModel;
GMAT NearEarthProp.Type  PrinceDormand78;
GMAT NearEarthProp.InitialStepSize  60;
GMAT NearEarthProp.Accuracy  1e-012;
GMAT NearEarthProp.MinStep  0;
GMAT NearEarthProp.MaxStep  3600;
GMAT NearEarthProp.MaxStepAttempts  50;
GMAT NearEarthProp.StopIfAccuracyIsViolated  true;

Create Propagator NearMoonProp;
GMAT NearMoonProp.FM  NearMoonForceModel;
GMAT NearMoonProp.Type  PrinceDormand78;
GMAT NearMoonProp.InitialStepSize  600;
GMAT NearMoonProp.Accuracy  1e-012;
GMAT NearMoonProp.MinStep  0;
GMAT NearMoonProp.MaxStep  3600;
GMAT NearMoonProp.MaxStepAttempts  50;
GMAT NearMoonProp.StopIfAccuracyIsViolated  true;

%-----------------------------------------------------

%-------- Burns
%-----------------------------------------------------

Create ImpulsiveBurn TCM;
GMAT TCM.CoordinateSystem  Local;
GMAT TCM.Origin  Earth;
GMAT TCM.Axes  VNB;
% GMAT TCM.Element1  0.00124;
GMAT TCM.Element1  -0.001;
GMAT TCM.Element2  0;
GMAT TCM.Element3  0;
GMAT.TCM.DecrementMass  true;
GMAT.TCM.Tank  {IodineTank};
GMAT.TCM.Isp  2640;
GMAT.TCM.GravitationalAccel  9.810000000000001;

Create FiniteBurn FiniteBurn;
GMAT.FiniteBurn.Thrusters  {BIT3Thruster};
GMAT.FiniteBurn.ThrottleLogicAlgorithm  'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn1;
GMAT.FiniteBurn1.Thrusters  {BIT3Thruster1};
GMAT.FiniteBurn1.ThrottleLogicAlgorithm  'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn2;
GMAT.FiniteBurn2.Thrusters  {BIT3Thruster2};
GMAT.FiniteBurn2.ThrottleLogicAlgorithm  'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn3;
GMAT.FiniteBurn3.Thrusters  {BIT3Thruster3};
GMAT.FiniteBurn3.ThrottleLogicAlgorithm  'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn4;
GMAT.FiniteBurn4.Thrusters  {BIT3Thruster4};
GMAT.FiniteBurn4.ThrottleLogicAlgorithm  'MaxNumberOfThrusters';

%---------------------------------------------------%
%---------- Coordinate Systems
%---------------------------------------------------%

Create CoordinateSystem SunEcliptic;
GMAT.SunEcliptic.Origin  Sun;
GMAT.SunEcliptic.Axes  MJ2000Eq;

Create CoordinateSystem LunaInertial;
GMAT.LunaInertial.Origin  Luna;
GMAT.LunaInertial.Axes  MJ2000Eq;

Create CoordinateSystem SunEarthRotating;
GMAT.SunEarthRotating.Origin  Earth;
GMAT.SunEarthRotating.Axes  ObjectReferenced;
GMAT.SunEarthRotating.XAxis  R;
GMAT.SunEarthRotating.ZAxis  N;
GMAT.SunEarthRotating.Primary  Sun;
GMAT.SunEarthRotating.Secondary  Earth;
Create CoordinateSystem EarthMoon;
GMAT EarthMoon.Origin    Earth;
GMAT EarthMoon.Axes     ObjectReferenced;
GMAT EarthMoon.XAxis     R;
GMAT EarthMoon.ZAxis     N;
GMAT EarthMoon.Primary   Earth;
GMAT EarthMoon.Secondary Luna;

CREATE DifferentialCorrector DefaultDC;
GMAT DefaultDC.ShowProgress true;
GMAT DefaultDC.ReportStyle Normal;
GMAT DefaultDC.ReportFile 'DifferentialCorrectorDefaultDC.data';
GMAT DefaultDC.MaximumIterations 25;
GMAT DefaultDC.DerivativeMethod ForwardDifference;
GMAT DefaultDC.Algorithm NewtonRaphson;

CREATE OrbitView LunaView;
GMAT LunaView.SolverIterations Current;
GMAT LunaView.UpperLeft [ 0.5006802721088436 0.03369426751592357 ];
GMAT LunaView.Size [ 0.5510204081632653 0.7923566878980892 ];
GMAT LunaView.RelativeZOrder 2685;
GMAT LunaView.Maximized false;
GMAT LunaView.Add { LIC, Earth, Luna };
GMAT LunaView.CoordinateSystem LunarInertial;
GMAT LunaView.DrawObject [ true true true ];
GMAT LunaView.DataCollectFrequency 1;
GMAT LunaView.UpdatePlotFrequency 50;
GMAT LunaView.NumPointsToRedraw 0;
GMAT LunaView.ShowPlot true;
GMAT LunaView.MaxPlotPoints 20000;
GMAT LunaView.ShowLabels true;
GMAT LunaView.ViewPointReference Luna;
GMAT LunaView.ViewPointVector [ 22000 22000 0 ];
GMAT LunaView.ViewDirection Luna;
GMAT LunaView.ViewScaleFactor 4;
GMAT LunaView.ViewUpCoordinateSystem LunarInertial;
GMAT LunaView.ViewUpAxis Z;
GMAT LunaView.EclipticPlane Off;
GMAT LunaView.XYPlane  On;
GMAT LunaView.WireFrame  Off;
GMAT LunaView.Axes  On;
GMAT LunaView.Grid  Off;
GMAT LunaView.SunLine  On;
GMAT LunaView.UseInitialView  On;
GMAT LunaView.StarCount  7000;
GMAT LunaView.EnableStars  On;
GMAT LunaView.EnableConstellations  On;

Create ReportFile ReportFile1;
GMAT ReportFile1.SolverIterations  Current;
GMAT ReportFile1.UpperLeft  [ 0 0 ];
GMAT ReportFile1.Size  [ 0 0 ];
GMAT ReportFile1.RelativeZOrder  0;
GMAT ReportFile1.Maximized  false;
GMAT ReportFile1.Filename  'FuelMass.txt';
GMAT ReportFile1.Precision  16;
GMAT ReportFile1.WriteHeaders  true;
GMAT ReportFile1.LeftJustify  On;
GMAT ReportFile1.ZeroFill  Off;
GMAT ReportFile1.FixedWidth  true;
GMAT ReportFile1.Delimiter  ','; 
GMAT ReportFile1.ColumnWidth  23;
GMAT ReportFile1.WriteReport  true;

Create OrbitView OrbitView1;
GMAT OrbitView1.SolverIterations  Current;
GMAT OrbitView1.UpperLeft  [ 0.4163265306122449 0.2713375796178344 ];
GMAT OrbitView1.Size  [ 0.491156462585034 0.7719745222929937 ];
GMAT OrbitView1.RelativeZOrder  2669;
GMAT OrbitView1.Maximized  false;
GMAT OrbitView1.Add  { LIC, Earth, Luna, Sun }; 
GMAT OrbitView1.CoordinateSystem  SunEarthRotating;
GMAT OrbitView1.DrawObject  [ true true true true ];
GMAT OrbitView1.DataCollectFrequency  1;
GMAT OrbitView1.UpdatePlotFrequency  50;
GMAT OrbitView1.NumPointsToRedraw  0;
GMAT OrbitView1.ShowPlot  true;
GMAT OrbitView1.MaxPlotPoints  20000;
GMAT OrbitView1.ShowLabels  true;
GMAT OrbitView1.ViewPointReference  Earth;
GMAT OrbitView1.ViewPointVector  Earth;
GMAT OrbitView1.ViewDirection  Earth;
GMAT OrbitView1.ViewScaleFactor  1000000;
GMAT OrbitView1.ViewUpCoordinateSystem  SunEarthRotating;
GMAT OrbitView1.ViewUpAxis  Z;
GMAT OrbitView1.EclipticPlane  Off;
GMAT OrbitView1.XYPlane  Off;
GMAT OrbitView1.WireFrame  Off;
GMAT OrbitView1.Axes  On;
GMAT OrbitView1.Grid  Off;
GMAT OrbitView1.SunLine  On;
GMAT OrbitView1.UseInitialView  Off;
GMAT OrbitView1.StarCount  7000;
GMAT OrbitView1.EnableStars  On;
GMAT OrbitView1.EnableConstellations  Off;

Create OrbitView OrbitView2;
GMAT OrbitView2.SolverIterations  Current;
GMAT OrbitView2.UpperLeft  [ 0.06802721088436 0.03369426751592357 ];
GMAT OrbitView2.Size  [ 0.5510204081632653 0.7923566878980892 ];
GMAT OrbitView2.RelativeZOrder  2674;
GMAT OrbitView2.Maximized  false;
GMAT OrbitView2.CoordinateSystem  EarthMoon;
GMAT OrbitView2.DrawObject  [ true true true ];
GMAT OrbitView2.DataCollectFrequency  1;
GMAT OrbitView2.UpdatePlotFrequency  50;
GMAT OrbitView2.NumPointsToRedraw  0;
GMAT OrbitView2.ShowPlot  true;
GMAT OrbitView2.MaxPlotPoints  20000;
GMAT OrbitView2.ShowLabels  true;
GMAT OrbitView2.ViewPointReference  Earth;
GMAT OrbitView2.ViewPointVector  [ 0 0 30000 ];
GMAT OrbitView2.ViewDirection  Earth;
GMAT OrbitView2.ViewScaleFactor  1;
GMAT OrbitView2.ViewUpCoordinateSystem  EarthMoon;
GMAT OrbitView2.ViewUpAxis  Z;
GMAT OrbitView2.EclipticPlane  Off;
GMAT OrbitView2.XYPlane  Off;
GMAT OrbitView2.WireFrame  Off;
GMAT OrbitView2.Axes  On;
GMAT OrbitView2.Grid  Off;
GMAT OrbitView2.SunLine  On;
GMAT OrbitView2.UseInitialView  On;
GMAT OrbitView2.StarCount  7000;
GMAT OrbitView2.EnableStars  On;
GMAT OrbitView2.EnableConstellations  Off;

%---------------------------------------------------------------------
%---------- Arrays, Variables, Strings
%------------------------------------------
Create Variable BurnDuration1 BurnDuration2 BurnDuration3;
GMAT BurnDuration1 0;
GMAT BurnDuration2 0;
GMAT BurnDuration3 0;

%------------------------------------------
%-------- Mission Sequence
%------------------------------------------
BeginMissionSequence;
Propagate 'Prop for 780 sec' NearEarthProp(LIC) \{LIC.ElapsedSecs 780, OrbitColor \{255 0 0\}\};
Maneuver 'Maneuver 1 m/s Impulse' TCM(LIC);

Propagate 'Prop for 12 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs 43200.000, OrbitColor \{255 0 0\}\};

    BeginFiniteBurn 'Turn Thruster On' FiniteBurn(LIC);
    Propagate 'Burn for 2 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs 7200.000, OrbitColor \{15 127 254\}\};
    EndFiniteBurn 'Turn Thruster Off' FiniteBurn(LIC);

Propagate 'Prop for 2 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs 7200.000, OrbitColor \{255 0 0\}\};

Target DefaultDC \{SolveMode Solve, ExitMode SaveAndContinue, ShowProgressWindow true\};

    Vary 'Vary BIT3Thruster1.V' DefaultDC(LIC.BIT3Thruster1.ThrustDirection1 0.6879150054966399, \{Perturbation 0.00001, Lower -1, Upper +1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
    Vary 'Vary BIT3Thruster1.N' DefaultDC(LIC.BIT3Thruster1.ThrustDirection2 0.7094589104843158, \{Perturbation 0.00001, Lower -1, Upper +1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
    Vary 'Vary BIT3Thruster1.B' DefaultDC(LIC.BIT3Thruster1.ThrustDirection3 0.1531045377698647, \{Perturbation 0.00001, Lower -1, Upper +1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
    Vary 'Vary Burn Duration1' DefaultDC(BurnDuration1 81026.10000000001, \{Perturbation 0.1, Lower 1000, Upper 100000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});

    BeginFiniteBurn 'Turn Thruster On' FiniteBurn1(LIC);
Propagate 'Burn for 22 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs \ BurnDuration1, OrbitColor \ [15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn1(LIC);

Propagate 'Prop for 12 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs 43200.000, OrbitColor [255 0 0]\};

\text{Vary 'Vary BIT3Thruster2.V' DefaultDC(LIC.BIT3Thruster2.ThrustDirection1 0.9175757702481413, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary BIT3Thruster2.N' DefaultDC(LIC.BIT3Thruster2.ThrustDirection2 - 0.3578263062669203, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary BIT3Thruster2.B' DefaultDC(LIC.BIT3Thruster2.ThrustDirection3 - 0.1732484932024026, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary Burn Duration2' DefaultDC(BurnDuration2 102819, \{Perturbation 0.1, Lower 1000, Upper 150000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn2(LIC);
Propagate 'Burn for 28 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs \ BurnDuration2, OrbitColor \ [15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn2(LIC);

Propagate 'Prop for 10 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs 36000.000, OrbitColor [255 0 0]\};

\text{Vary 'Vary BIT3Thruster3.V' DefaultDC(LIC.BIT3Thruster3.ThrustDirection1 0.9611343479284352, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary BIT3Thruster3.N' DefaultDC(LIC.BIT3Thruster3.ThrustDirection2 - 0.238581130651876, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary BIT3Thruster3.B' DefaultDC(LIC.BIT3Thruster3.ThrustDirection3 - 0.138923753653054, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary Burn Duration3' DefaultDC(BurnDuration3 13367.7, \{Perturbation 0.1, Lower 1000, Upper 100000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn3(LIC);
Propagate 'Burn for 4 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs \ BurnDuration3, OrbitColor \ [15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn3(LIC);
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{ LIC.Luna.Periapsis, OrbitColor \[255 0 0]\};

Achieve 'Achieve BdotT' DefaultDC(LIC.LunaInertial.BdotT \{-8938.7006739595381000, \\
{Tolerance 0.001}\});
Achieve 'Achieve BdotR' DefaultDC(LIC.LunaInertial.BdotR \{4800.0006406646644000, \\
{Tolerance 0.001}\});

EndTarget; % For targeter DefaultDC

Propagate 'Prop 106 Days' NearEarthProp(LIC) \{ LIC.ElapsedDays \[105.96916263, OrbitColor \[255 0 0]\};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
LIC.BIT3Thruster4.ThrustDirection1 \[-1\];
LIC.BIT3Thruster4.ThrustDirection2 \[0\];
LIC.BIT3Thruster4.ThrustDirection3 \[0\];
Propagate 'Burn for 3.5 days' NearEarthProp(LIC) \{ LIC.ElapsedSecs \[303441.000, OrbitColor \[15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{ LIC.Luna.Periapsis, OrbitColor \[255 0 0]\};
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{ LIC.Luna.Periapsis, OrbitColor \[255 0 0]\};
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{ LIC.Luna.Periapsis, OrbitColor \[255 0 0]\};

Propagate 'Back Prop' BackProp NearMoonProp(LIC) \{ LIC.ElapsedDays \[-16.2, OrbitColor \[255 255 255]\};

% Propagate 'Prop to setup DV - 1.5 days' NearMoonProp(LIC) \{ LIC.ElapsedSecs \[129600, OrbitColor \[255 255 255]\};
% Propagate 'Prop to setup DV - 2 days' NearMoonProp(LIC) \{ LIC.ElapsedSecs \[172800, OrbitColor \[255 255 255]\};

Propagate 'Prop to setup DV - 2.5 days' NearMoonProp(LIC) \{ LIC.ElapsedSecs \[216000, OrbitColor \[255 0 0]\};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
LIC.BIT3Thruster4.ThrustDirection1 \[-0.6040227735550539\];
LIC.BIT3Thruster4.ThrustDirection2 \[-0.719846310392954\];
LIC.BIT3Thruster4.ThrustDirection3 \[0.3420201433256688\];
Propagate 'Burn for xx days' NearMoonProp(LIC) \{ LIC.ElapsedDays \[22.00, OrbitColor \[15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);

% LIC.BIT3Thruster4.ThrustDirection1  -1.;
% LIC.BIT3Thruster4.ThrustDirection2  0;
% LIC.BIT3Thruster4.ThrustDirection3  0;

%%% az 230 el  0
%%% Does Not Capture
% LIC.BIT3Thruster4.ThrustDirection1  -.642788;
% LIC.BIT3Thruster4.ThrustDirection2  -.766044;
% LIC.BIT3Thruster4.ThrustDirection3  0;
% LIC.BIT3Thruster4.ThrustDirection3  .3420;

%%% az 230 el  -20
%%% Does Not Capture
% LIC.BIT3Thruster4.ThrustDirection1  -0.6040;
% LIC.BIT3Thruster4.ThrustDirection2  -.7198;
% LIC.BIT3Thruster4.ThrustDirection3  0.3420;

%%% az 200 el  20
%%% Elliptical, but collides with Luna early
% LIC.BIT3Thruster4.ThrustDirection1  -.8830;
% LIC.BIT3Thruster4.ThrustDirection2  -.3214;
% LIC.BIT3Thruster4.ThrustDirection3  0.3420;

%%% az 170 el  0
%%% E  0.5, INC - 31, LP  761
% LIC.BIT3Thruster4.ThrustDirection1  -.9848;
% LIC.BIT3Thruster4.ThrustDirection2  0.1736;
% LIC.BIT3Thruster4.ThrustDirection3  0;

%%% az 150 el  0
%%% E  0.667, INC  30.679, LP  1484
% LIC.BIT3Thruster4.ThrustDirection1  -.8660;
% LIC.BIT3Thruster4.ThrustDirection2  0.5000;
% LIC.BIT3Thruster4.ThrustDirection3  0;

%%% az 150 el  -20
%%% CIRCULAR, E  0.08, INC  30, LP  4420
% LIC.BIT3Thruster4.ThrustDirection1  -.8138;
% LIC.BIT3Thruster4.ThrustDirection2  0.4618;
% LIC.BIT3Thruster4.ThrustDirection3  -.3420;

%%% az 130 el  -20
ii. LIC Two Body Operational Constraint Capture

%General Mission Analysis Tool (GMAT) Script
%Created: 2018-06-15 12:37:54

Create Spacecraft LIC;
GMAT LIC.DateFormat UTCGregorian;
GMAT LIC.Epoch '09 Oct 2018 17:02:15.204';
GMAT LIC.CoordinateSystem EarthMJ2000Eq;
GMAT LIC.DisplayStateType Cartesian;
GMAT LIC.X -21987.1300247;
GMAT LIC.Y -36808.7001619;
GMAT LIC.Z -492.8827009;
GMAT LIC.VX -0.6215788;
GMAT LIC.VY -3.9441402;
GMAT LIC.VZ -0.8708646;
GMAT LIC.DryMass 0.01;
GMAT LIC.Cd 2.2;
GMAT LIC.Cr 1;
GMAT LIC.DragArea 0.25;
GMAT LIC.SRPArea 0.3;
GMAT LIC.Tanks {IodineTank};
GMAT LIC.Thrusters {BIT3Thruster, BIT3Thruster1, BIT3Thruster2, BIT3Thruster3, BIT3Thruster4};
GMAT LIC.NAIFId -10001001;
GMAT LIC.NAIFIdReferenceFrame -9001001;
GMAT LIC.OrbitColor Red;
GMAT LIC.TargetColor Teal;
GMAT LIC. OrbitErrorCovariance  [ 1e+070 0 0 0 0 ; 0 1e+070 0 0 0 ; 0 0 1e+070 0 0 ; 0 0 0 1e+070 0 ];
GMAT LIC.CdSigma  1e+070;
GMAT LIC.CrSigma  1e+070;
GMAT LIC.Id  'SatId';
GMAT LIC.Attitude CoordinateSystemFixed;
GMAT LIC.SPADSRPScaleFactor  1;
GMAT LIC.ModelFile  'aura.3ds';
GMAT LIC.ModelOffsetX  0;
GMAT LIC.ModelOffsetY  0;
GMAT LIC.ModelOffsetZ  0;
GMAT LIC.ModelRotationX  0;
GMAT LIC.ModelRotationY  0;
GMAT LIC.ModelRotationZ  0;
GMAT LIC.ModelScale  1;
GMAT LIC.AttitudeDisplayStateType  'Quaternion';
GMAT LIC.AttitudeRateDisplayStateType  'AngularVelocity';
GMAT LIC.AttitudeCoordinateSystem  EarthMJ2000Eq;
GMAT LIC.EulerAngleSequence  '321';

%---------------------------------------
%-------- Hardware Components
%---------------------------------------

Create ChemicalTank IodineTank;
GMAT IodineTank.AllowNegativeFuelMass  true;
GMAT IodineTank.Pressure  1000;
GMAT IodineTank.Temperature  20;
GMAT IodineTank.RefTemperature  20;
GMAT IodineTank.Volume  10;
GMAT IodineTank.FuelDensity  1000;
GMAT IodineTank.PressureModel  PressureRegulated;

Create ChemicalThruster BIT3Thruster;
GMAT BIT3Thruster.CoordinateSystem  Local;
GMAT BIT3Thruster.Origin  Earth;
GMAT BIT3Thruster.Axes  VNB;
GMAT BIT3Thruster.ThrustDirection1  1;
GMAT BIT3Thruster.ThrustDirection2  0;
GMAT BIT3Thruster.ThrustDirection3  0;
GMAT BIT3Thruster.DutyCycle  1;
GMAT BIT3Thruster.ThrustScaleFactor  1;
GMAT BIT3Thruster.DecrementMass  true;
GMAT BIT3Thruster.Tank  {IodineTank};
GMAT BIT3Thruster.MixRatio  [ 1 ];
GMAT BIT3Thruster.GravitationalAccel 9.810000000000001;
GMAT BIT3Thruster.C1 0.00124;
GMAT BIT3Thruster.C2 0;
GMAT BIT3Thruster.C3 0;
GMAT BIT3Thruster.C4 0;
GMAT BIT3Thruster.C5 0;
GMAT BIT3Thruster.C6 0;
GMAT BIT3Thruster.C7 0;
GMAT BIT3Thruster.C8 0;
GMAT BIT3Thruster.C9 0;
GMAT BIT3Thruster.C10 0;
GMAT BIT3Thruster.C11 0;
GMAT BIT3Thruster.C12 0;
GMAT BIT3Thruster.C13 0;
GMAT BIT3Thruster.C14 0;
GMAT BIT3Thruster.C15 0;
GMAT BIT3Thruster.C16 0;
GMAT BIT3Thruster.K1 2640;
GMAT BIT3Thruster.K2 0;
GMAT BIT3Thruster.K3 0;
GMAT BIT3Thruster.K4 0;
GMAT BIT3Thruster.K5 0;
GMAT BIT3Thruster.K6 0;
GMAT BIT3Thruster.K7 0;
GMAT BIT3Thruster.K8 0;
GMAT BIT3Thruster.K9 0;
GMAT BIT3Thruster.K10 0;
GMAT BIT3Thruster.K11 0;
GMAT BIT3Thruster.K12 0;
GMAT BIT3Thruster.K13 0;
GMAT BIT3Thruster.K14 0;
GMAT BIT3Thruster.K15 0;
GMAT BIT3Thruster.K16 0;

Create ChemicalThruster BIT3Thruster1;
GMAT BIT3Thruster1.CoordinateSystem Local;
GMAT BIT3Thruster1.Origin Earth;
GMAT BIT3Thruster1.Axes VNB;
GMAT BIT3Thruster1.ThrustDirection1 -1;
GMAT BIT3Thruster1.ThrustDirection2 0;
GMAT BIT3Thruster1.ThrustDirection3 0;
GMAT BIT3Thruster1.DutyCycle 1;
GMAT BIT3Thruster1.ThrustScaleFactor 1;
GMAT BIT3Thruster1.DecrementMass true;
GMAT BIT3Thruster1.Tank {IodineTank};
GMAT BIT3Thruster1.MixRatio [ 1 ];
GMAT BIT3Thruster1.GravitationalAccel 9.810000000000001;
GMAT BIT3Thruster1.C1 0.00124;
GMAT BIT3Thruster1.C2 0;
GMAT BIT3Thruster1.C3 0;
GMAT BIT3Thruster1.C4 0;
GMAT BIT3Thruster1.C5 0;
GMAT BIT3Thruster1.C6 0;
GMAT BIT3Thruster1.C7 0;
GMAT BIT3Thruster1.C8 0;
GMAT BIT3Thruster1.C9 0;
GMAT BIT3Thruster1.C10 0;
GMAT BIT3Thruster1.C11 0;
GMAT BIT3Thruster1.C12 0;
GMAT BIT3Thruster1.C13 0;
GMAT BIT3Thruster1.C14 0;
GMAT BIT3Thruster1.C15 0;
GMAT BIT3Thruster1.C16 0;
GMAT BIT3Thruster1.K1 2640;
GMAT BIT3Thruster1.K2 0;
GMAT BIT3Thruster1.K3 0;
GMAT BIT3Thruster1.K4 0;
GMAT BIT3Thruster1.K5 0;
GMAT BIT3Thruster1.K6 0;
GMAT BIT3Thruster1.K7 0;
GMAT BIT3Thruster1.K8 0;
GMAT BIT3Thruster1.K9 0;
GMAT BIT3Thruster1.K10 0;
GMAT BIT3Thruster1.K11 0;
GMAT BIT3Thruster1.K12 0;
GMAT BIT3Thruster1.K13 0;
GMAT BIT3Thruster1.K14 0;
GMAT BIT3Thruster1.K15 0;
GMAT BIT3Thruster1.K16 0;

Create ChemicalThruster BIT3Thruster2;
GMAT BIT3Thruster2.CoordinateSystem Local;
GMAT BIT3Thruster2.Origin Earth;
GMAT BIT3Thruster2.Axes VNB;
GMAT BIT3Thruster2.ThrustDirection1 -1;
GMAT BIT3Thruster2.ThrustDirection2 0;
GMAT BIT3Thruster2.ThrustDirection3 0;
GMAT BIT3Thruster2.DutyCycle 1;
GMAT BIT3Thruster2.ThrustScaleFactor 1;
GMAT BIT3Thruster2.DecrementMass true;
GMAT BIT3Thruster2.Tank {IodineTank};
GMAT BIT3Thruster2.MixRatio [ 1 ];
GMAT BIT3Thruster2.GravitationalAccel 9.81000000000001;
GMAT BIT3Thruster2.C1 0.00124;
GMAT BIT3Thruster2.C2 0;
GMAT BIT3Thruster2.C3 0;
GMAT BIT3Thruster2.C4 0;
GMAT BIT3Thruster2.C5 0;
GMAT BIT3Thruster2.C6 0;
GMAT BIT3Thruster2.C7 0;
GMAT BIT3Thruster2.C8 0;
GMAT BIT3Thruster2.C9 0;
GMAT BIT3Thruster2.C10 0;
GMAT BIT3Thruster2.C11 0;
GMAT BIT3Thruster2.C12 0;
GMAT BIT3Thruster2.C13 0;
GMAT BIT3Thruster2.C14 0;
GMAT BIT3Thruster2.C15 0;
GMAT BIT3Thruster2.C16 0;
GMAT BIT3Thruster2.K1 2640;
GMAT BIT3Thruster2.K2 0;
GMAT BIT3Thruster2.K3 0;
GMAT BIT3Thruster2.K4 0;
GMAT BIT3Thruster2.K5 0;
GMAT BIT3Thruster2.K6 0;
GMAT BIT3Thruster2.K7 0;
GMAT BIT3Thruster2.K8 0;
GMAT BIT3Thruster2.K9 0;
GMAT BIT3Thruster2.K10 0;
GMAT BIT3Thruster2.K11 0;
GMAT BIT3Thruster2.K12 0;
GMAT BIT3Thruster2.K13 0;
GMAT BIT3Thruster2.K14 0;
GMAT BIT3Thruster2.K15 0;
GMAT BIT3Thruster2.K16 0;

Create ChemicalThruster BIT3Thruster3;
GMAT BIT3Thruster3.CoordinateSystem Local;
GMAT BIT3Thruster3.Origin Earth;
GMAT BIT3Thruster3.Axes VNB;
GMAT BIT3Thruster3.ThrustDirection1 -1;
GMAT BIT3Thruster3.ThrustDirection2 0;
GMAT BIT3Thruster3.ThrustDirection3 0;
GMAT BIT3Thruster3.DutyCycle 1;
GMAT BIT3Thruster3.ThrustScaleFactor 1;
GMAT BIT3Thruster3.DecrementMass true;
GMAT BIT3Thruster3.Tank {IodineTank};
GMAT BIT3Thruster3.MixRatio [ 1 ];
GMAT BIT3Thruster3.GravitationalAccel 9.81000000000001;
GMAT BIT3Thruster3.C1 0.00124;
GMAT BIT3Thruster3.C2 0;
GMAT BIT3Thruster3.C3 0;
GMAT BIT3Thruster3.C4 0;
GMAT BIT3Thruster3.C5 0;
GMAT BIT3Thruster3.C6 0;
GMAT BIT3Thruster3.C7 0;
GMAT BIT3Thruster3.C8 0;
GMAT BIT3Thruster3.C9 0;
GMAT BIT3Thruster3.C10 0;
GMAT BIT3Thruster3.C11 0;
GMAT BIT3Thruster3.C12 0;
GMAT BIT3Thruster3.C13 0;
GMAT BIT3Thruster3.C14 0;
GMAT BIT3Thruster3.C15 0;
GMAT BIT3Thruster3.C16 0;
GMAT BIT3Thruster3.K1 2640;
GMAT BIT3Thruster3.K2 0;
GMAT BIT3Thruster3.K3 0;
GMAT BIT3Thruster3.K4 0;
GMAT BIT3Thruster3.K5 0;
GMAT BIT3Thruster3.K6 0;
GMAT BIT3Thruster3.K7 0;
GMAT BIT3Thruster3.K8 0;
GMAT BIT3Thruster3.K9 0;
GMAT BIT3Thruster3.K10 0;
GMAT BIT3Thruster3.K11 0;
GMAT BIT3Thruster3.K12 0;
GMAT BIT3Thruster3.K13 0;
GMAT BIT3Thruster3.K14 0;
GMAT BIT3Thruster3.K15 0;
GMAT BIT3Thruster3.K16 0;

Create ChemicalThruster BIT3Thruster4;
GMAT BIT3Thruster4.CoordinateSystem Local;
GMAT BIT3Thruster4.Origin Luna;
GMAT BIT3Thruster4.Axes VNB;
GMAT BIT3Thruster4.ThrustDirection1 -1;
GMAT BIT3Thruster4.ThrustDirection2 0;
GMAT BIT3Thruster4.ThrustDirection3 0;
GMAT BIT3Thruster4.DutyCycle 1;
GMAT BIT3Thruster4.ThrustScaleFactor 1;
GMAT BIT3Thruster4.DecrementMass true;
GMAT BIT3Thruster4.Tank {IodineTank};
GMAT BIT3Thruster4.MixRatio [ 1 ];
GMAT BIT3Thruster4.GravitationalAccel 9.810000000000001;
GMAT BIT3Thruster4.C1 0.00124;
GMAT BIT3Thruster4.C2 0;
GMAT BIT3Thruster4.C3 0;
GMAT BIT3Thruster4.C4 0;
GMAT BIT3Thruster4.C5 0;
GMAT BIT3Thruster4.C6 0;
GMAT BIT3Thruster4.C7 0;
GMAT BIT3Thruster4.C8 0;
GMAT BIT3Thruster4.C9 0;
GMAT BIT3Thruster4.C10 0;
GMAT BIT3Thruster4.C11 0;
GMAT BIT3Thruster4.C12 0;
GMAT BIT3Thruster4.C13 0;
GMAT BIT3Thruster4.C14 0;
GMAT BIT3Thruster4.C15 0;
GMAT BIT3Thruster4.C16 0;
GMAT BIT3Thruster4.K1 2640;
GMAT BIT3Thruster4.K2 0;
GMAT BIT3Thruster4.K3 0;
GMAT BIT3Thruster4.K4 0;
GMAT BIT3Thruster4.K5 0;
GMAT BIT3Thruster4.K6 0;
GMAT BIT3Thruster4.K7 0;
GMAT BIT3Thruster4.K8 0;
GMAT BIT3Thruster4.K9 0;
GMAT BIT3Thruster4.K10 0;
GMAT BIT3Thruster4.K11 0;
GMAT BIT3Thruster4.K12 0;
GMAT BIT3Thruster4.K13 0;
GMAT BIT3Thruster4.K14 0;
GMAT BIT3Thruster4.K15 0;
GMAT BIT3Thruster4.K16 0;

%---------------------------------------------------------------
%-------- ForceModels
%---------------------------------------------------------------

Create ForceModel NearEarthForceModel;
GMAT NearEarthForceModel.CentralBody Earth;
GMAT NearEarthForceModel.PrimaryBodies {Earth};
GMAT NearEarthForceModel.PointMasses {Luna, Sun, Jupiter, Venus, Saturn, Mars};
GMAT NearEarthForceModel.Drag None;
GMAT NearEarthForceModel.SRP On;
GMAT NearEarthForceModel.RelativisticCorrection Off;
GMAT NearEarthForceModel.ErrorControl RSSStep;
GMAT NearEarthForceModel.GravityField.Earth.Degree 8;
GMAT NearEarthForceModel.GravityField.Earth.StmLimit 100;
'./data/gravity/earth/JGM2.cof';
GMAT NearEarthForceModel.GravityField.Earth.TideModel 'None';
GMAT NearEarthForceModel.SRP.Flux 1367;
GMAT NearEarthForceModel.SRP.SRPMODEL Spherical;
GMAT NearEarthForceModel.SRP.Nominal_Sun 149597870.691;

Create ForceModel NearMoonForceModel;
GMAT NearMoonForceModel.CentralBody Luna;
GMAT NearMoonForceModel.PointMasses {Luna, Earth, Sun};
GMAT NearMoonForceModel.Drag None;
GMAT NearMoonForceModel.SRP On;
GMAT NearMoonForceModel.RelativisticCorrection Off;
GMAT NearMoonForceModel.ErrorControl RSSStep;
GMAT NearMoonForceModel.SRP.Flux 1367;
GMAT NearMoonForceModel.SRP.SRPMODEL Spherical;
GMAT NearMoonForceModel.SRP.Nominal_Sun 149597870.691;

%----------------------------------------
%-------- Propagators
%----------------------------------------

Create Propagator NearEarthProp;
GMAT NearEarthProp.FM NearEarthForceModel;
GMAT NearEarthProp.Type PrinceDormand78;
GMAT NearEarthProp.InitialStepSize 60;
GMAT NearEarthProp.Accuracy 1e-012;
GMAT NearEarthProp.MinStep 0;
GMAT NearEarthProp.MaxStep 3600;
GMAT NearEarthProp.MaxStepAttempts 50;
GMAT NearEarthProp.StopIfAccuracyIsViolated true;

Create Propagator NearMoonProp;
GMAT NearMoonProp.FM NearMoonForceModel;
GMAT NearMoonProp.Type PrinceDormand78;
GMAT NearMoonProp.InitialStepSize 600;
GMAT NearMoonProp.Accuracy 1e-012;
GMAT NearMoonProp.MinStep 0;
GMAT NearMoonProp.MaxStep 3600;
GMAT NearMoonProp.MaxStepAttempts 50;
GMAT NearMoonProp.StopIfAccuracyIsViolated true;

%----------------------------------------
Create ImpulsiveBurn TCM;
GMAT TCM.CoordinateSystem Local;
GMAT TCM.Origin Earth;
GMAT TCM.Axes VNB;
GMAT TCM.Element1 0.00124;
GMAT TCM.Element2 0;
GMAT TCM.Element3 0;
GMAT TCM.DecrementMass true;
GMAT TCM.Tank {IodineTank};
GMAT TCM.Isp 2640;
GMAT TCM.GravitationalAccel 9.810000000000001;

Create FiniteBurn FiniteBurn;
GMAT FiniteBurn.Thrusters {BIT3Thruster};
GMAT FiniteBurn.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn1;
GMAT FiniteBurn1.Thrusters {BIT3Thruster1};
GMAT FiniteBurn1.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn2;
GMAT FiniteBurn2.Thrusters {BIT3Thruster2};
GMAT FiniteBurn2.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn3;
GMAT FiniteBurn3.Thrusters {BIT3Thruster3};
GMAT FiniteBurn3.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn4;
GMAT FiniteBurn4.Thrusters {BIT3Thruster4};
GMAT FiniteBurn4.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create CoordinateSystem SunEcliptic;
GMAT SunEcliptic.Origin Sun;
GMAT SunEcliptic.Axes MJ2000Eq;

Create CoordinateSystem LunarInertial;
GMAT LunaInertial.Origin   Luna;
GMAT LunaInertial.Axes    MJ2000Eq;

Create CoordinateSystem SunEarthRotating;
GMAT SunEarthRotating.Origin Earth;
GMAT SunEarthRotating.Axes ObjectReferenced;
GMAT SunEarthRotating.XAxis  R;
GMAT SunEarthRotating.ZAxis   N;
GMAT SunEarthRotating.Primary Sun;
GMAT SunEarthRotating.Secondary Earth;

Create CoordinateSystem EarthMoon;
GMAT EarthMoon.Origin   Earth;
GMAT EarthMoon.Axes ObjectReferenced;
GMAT EarthMoon.XAxis  R;
GMAT EarthMoon.ZAxis   N;
GMAT EarthMoon.Primary Earth;
GMAT EarthMoon.Secondary Luna;

%---------------------------------
%-------- Solvers
%---------------------------------

Create DifferentialCorrector DefaultDC;
GMAT DefaultDC.ShowProgress true;
GMAT DefaultDC.ReportStyle    Normal;
GMAT DefaultDC.ReportFile    'DifferentialCorrectorDefaultDC.data';
GMAT DefaultDC.MaximumIterations 25;
GMAT DefaultDC.DerivativeMethod ForwardDifference;
GMAT DefaultDC.Algorithm   NewtonRaphson;

%---------------------------------
%-------- Subscribers
%---------------------------------

Create OrbitView LunaView;
GMAT LunaView.SolverIterations Current;
GMAT LunaView.UpperLeft  [ 0.5006802721088436 0.03369426751592357 ];
GMAT LunaView.Size       [ 0.5510204081632653 0.7923566878980892 ];
GMAT LunaView.RelativeZOrder  2685;
GMAT LunaView.Maximized false;
GMAT LunaView.Add       { LIC, Earth, Luna};
GMAT LunaView.CoordinateSystem LunaInertial;
GMAT LunaView.DrawLine  [ true true true ];
GMAT LunaView.DataCollectFrequency  1;
GMAT LunaView.UpdatePlotFrequency  50;
GMAT LunaView.NumPointsToRedraw 0;
GMAT LunaView.ShowPlot true;
GMAT LunaView.MaxPlotPoints 20000;
GMAT LunaView.ShowLabels true;
GMAT LunaView.ViewPointReference Luna;
GMAT LunaView.ViewPointVector [ 22000 22000 0 ];
GMAT LunaView.ViewDirection Luna;
GMAT LunaView.ViewScaleFactor 4;
GMAT LunaView.ViewUpCoordinateSystem LunaInertial;
GMAT LunaView.ViewUpAxis Z;
GMAT LunaView.EclipticPlane Off;
GMAT LunaView.XYPlane On;
GMAT LunaView.WireFrame Off;
GMAT LunaView.Axes On;
GMAT LunaView.Grid Off;
GMAT LunaView.SunLine On;
GMAT LunaView.UseInitialView On;
GMAT LunaView.StarInitialView 7000;
GMAT LunaView.EnableStars On;
GMAT LunaView.EnableConstellations On;

Create ReportFile ReportFile1;
GMAT ReportFile1.SolverIterations Current;
GMAT ReportFile1.UpperLeft [ 0 0 ];
GMAT ReportFile1.Size [ 0 0 ];
GMAT ReportFile1.RelativeZOrder 0;
GMAT ReportFile1.Maximized false;
GMAT ReportFile1.Filename 'FuelMass.txt';
GMAT ReportFile1.Precision 16;
GMAT ReportFile1.WriteHeaders true;
GMAT ReportFile1.LeftJustify On;
GMAT ReportFile1.ZeroFill Off;
GMAT ReportFile1.FixedWidth true;
GMAT ReportFile1.Delimiter ', '
GMAT ReportFile1.ColumnWidth 23;
GMAT ReportFile1.WriteReport true;

Create OrbitView OrbitView1;
GMAT OrbitView1.SolverIterations Current;
GMAT OrbitView1.UpperLeft [ 0.4163265306122449 0.2713375796178344 ];
GMAT OrbitView1.Size [ 0.491156462585034 0.7719745222929937 ];
GMAT OrbitView1.RelativeZOrder 2669;
GMAT OrbitView1.Maximized false;
GMAT OrbitView1.Add { LIC, Earth, Luna, Sun };
GMAT OrbitView1.CoordinateSystem SunEarthRotating;
GMAT OrbitView1.DrawObject [ true true true ];
GMAT OrbitView1.DataCollectFrequency 1;
GMAT OrbitView1.UpdatePlotFrequency 50;
GMAT OrbitView1.NumPointsToRedraw 0;
GMAT OrbitView1.ShowPlot true;
GMAT OrbitView1.MaxPlotPoints 20000;
GMAT OrbitView1.ShowLabels true;
GMAT OrbitView1.ViewPointReference Earth;
GMAT OrbitView1.ViewPointVector Earth;
GMAT OrbitView1.ViewDirection Earth;
GMAT OrbitView1.ViewScaleFactor 1000000;
GMAT OrbitView1.ViewUpCoordinateSystem SunEarthRotating;
GMAT OrbitView1.ViewUpAxis Z;
GMAT OrbitView1.EclipticPlane Off;
GMAT OrbitView1.XYPlane Off;
GMAT OrbitView1.WireFrame Off;
GMAT OrbitView1.Axes On;
GMAT OrbitView1.Grid Off;
GMAT OrbitView1.SunLine On;
GMAT OrbitView1.UseInitialView Off;
GMAT OrbitView1.StarCount 7000;
GMAT OrbitView1.EnableStars On;
GMAT OrbitView1.EnableConstellations Off;

Create OrbitView OrbitView2;
GMAT OrbitView2.SolverIterations Current;
GMAT OrbitView2.UpperLeft [ 0.06802721088436 0.03369426751592357 ];
GMAT OrbitView2.Size [ 0.5510204081632653 0.7923566878980892 ];
GMAT OrbitView2.RelativeZOrder 2674;
GMAT OrbitView2.Maximized false;
GMAT OrbitView2.Add { LIC, Earth, Luna };
GMAT OrbitView2.CoordinateSystem EarthMoon;
GMAT OrbitView2.DrawObject [ true true true ];
GMAT OrbitView2.DataCollectFrequency 1;
GMAT OrbitView2.UpdatePlotFrequency 50;
GMAT OrbitView2.NumPointsToRedraw 0;
GMAT OrbitView2.ShowPlot true;
GMAT OrbitView2.MaxPlotPoints 20000;
GMAT OrbitView2.ShowLabels true;
GMAT OrbitView2.ViewPointReference Earth;
GMAT OrbitView2.ViewPointVector [ 0 0 30000 ];
GMAT OrbitView2.ViewDirection Earth;
GMAT OrbitView2.ViewScaleFactor 1;
GMAT OrbitView2.ViewUpCoordinateSystem EarthMoon;
GMAT OrbitView2.ViewUpAxis Z;
GMAT OrbitView2.EclipticPlane Off;
GMAT OrbitView2.XYPlane   Off;
GMAT OrbitView2.WireFrame   Off;
GMAT OrbitView2.Axes   On;
GMAT OrbitView2.Grid   Off;
GMAT OrbitView2.SunLine   On;
GMAT OrbitView2.UseInitialView   On;
GMAT OrbitView2.StarCount   7000;
GMAT OrbitView2.EnableStars   On;
GMAT OrbitView2.EnableConstellations   Off;

%----------------------------------
%-------- Arrays, Variables, Strings
%----------------------------------
Create Variable BurnDuration1 BurnDuration2 BurnDuration3;
GMAT BurnDuration1   0;
GMAT BurnDuration2   0;
GMAT BurnDuration3   0;

%----------------------------------
%------- Mission Sequence
%----------------------------------

BeginMissionSequence;
Propagate 'Prop for 780 sec' NearEarthProp(LIC) {LIC.ElapsedSecs   780, OrbitColor   [255 0 0]};
Maneuver 'Mauverner 1 m/s Impulse' TCM(LIC);

Propagate 'Prop for 12 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs   43200.000, OrbitColor   [255 0 0]};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn(LIC);
Propagate 'Burn for 2 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs   7200.000, OrbitColor   [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn(LIC);

Propagate 'Prop for 2 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs   7200.000, OrbitColor   [255 0 0]};

Target DefaultDC {SolveMode   Solve, ExitMode   SaveAndContinue, ShowProgressWindow   true};

Vary 'Vary BIT3Thruster1.V' DefaultDC(LIC.BIT3Thruster1.ThrustDirection1 0.6879150054966399, {Perturbation   0.00001, Lower   -1, Upper   1, MaxStep   0.002, AdditiveScaleFactor   0.0, MultiplicativeScaleFactor   1.0});
Vary 'Vary BIT3Thruster1.N' DefaultDC(LIC.BIT3Thruster1.ThrustDirection2 - 0.7094589104843158, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster1.B' DefaultDC(LIC.BIT3Thruster1.ThrustDirection3 - 0.1531045379698647, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary Burn Duration1' DefaultDC(BurnDuration1 81026.10000000001, {Perturbation 0.1, Lower 1000, Upper 100000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn1(LIC);
Propagate 'Burn for 22 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs BurnDuration1, OrbitColor [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn1(LIC);

Propagate 'Prop for 12 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 43200.000, OrbitColor [255 0 0]};

Vary 'Vary BIT3Thruster2.V' DefaultDC(LIC.BIT3Thruster2.ThrustDirection1 0.9175757702481413, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster2.N' DefaultDC(LIC.BIT3Thruster2.ThrustDirection2 - 0.3578263062669203, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster2.B' DefaultDC(LIC.BIT3Thruster2.ThrustDirection3 - 0.1732484932024026, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary Burn Duration2' DefaultDC(BurnDuration2 102819, {Perturbation 0.1, Lower 1000, Upper 150000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn2(LIC);
Propagate 'Burn for 28 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs BurnDuration2, OrbitColor [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn2(LIC);

Propagate 'Prop for 10 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 36000.000, OrbitColor [255 0 0]};

Vary 'Vary BIT3Thruster3.V' DefaultDC(LIC.BIT3Thruster3.ThrustDirection1 0.9611343479284352, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster3.N' DefaultDC(LIC.BIT3Thruster3.ThrustDirection2 - 0.238581130651876, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster3.B' DefaultDC(LIC.BIT3Thruster3.ThrustDirection3 - 0.138923753653054, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary Burn Duration3' DefaultDC(BurnDuration3 13367.7, \{Perturbation 0.1, Lower 1000, Upper 100000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn3(LIC);
Propagate 'Burn for 4 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs BurnDuration3, OrbitColor 15127254\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn3(LIC);

Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};

Achieve 'Achieve BdotT' DefaultDC(LIC.LunaInertial.BdotT -8938.7006739595381000, \{Tolerance 0.001\});
Achieve 'Achieve BdotR' DefaultDC(LIC.LunaInertial.BdotR 4800.0006406646644000, \{Tolerance 0.001\});

EndTarget; % For targeter DefaultDC

Propagate 'Prop 106 Days' NearEarthProp(LIC) \{LIC.ElapsedDays 105.96916263, OrbitColor [255 0 0]\};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
  LIC.BIT3Thruster4.ThrustDirection1 -1;
  LIC.BIT3Thruster4.ThrustDirection2 0;
  LIC.BIT3Thruster4.ThrustDirection3 0;
Propagate 'Burn for 3.5 days' NearEarthProp(LIC) \{LIC.ElapsedSecs 303441.000, OrbitColor 15127254\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};

Propagate 'Back Prop' BackProp NearMoonProp(LIC) \{LIC.ElapsedDays -16.2, OrbitColor [255 255 255]\};

% Propagate 'Prop to setup DV - 1.5 days' NearMoonProp(LIC) \{LIC.ElapsedSecs 129600, OrbitColor [255 255 255]\};
% Propagate 'Prop to setup DV - 2 days' NearMoonProp(LIC) {LIC.ElapsedSecs = 172800, OrbitColor = [255 255 255]};

Propagate 'Prop to setup DV - 2.5 days' NearMoonProp(LIC) {LIC.ElapsedSecs = 216000, OrbitColor = [255 0 0]};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
    LIC.BIT3Thruster4.ThrustDirection1 = -0.6040227735550539;
    LIC.BIT3Thruster4.ThrustDirection2 = -0.719846310392954;
    LIC.BIT3Thruster4.ThrustDirection3 = 0.3420201433256688;
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);

% % az 130 el -20
% % E 0.4, INC 61, LP 4804
    LIC.BIT3Thruster4.ThrustDirection1 = -.6040;
    LIC.BIT3Thruster4.ThrustDirection2 = 0.7198;
    LIC.BIT3Thruster4.ThrustDirection3 = -.3420;

% Propagate 'Burn for xx days' NearMoonProp(LIC) {LIC.ElapsedDays = 22.00, OrbitColor = [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

Propagate 'Burn for 98 days' NearMoonProp(LIC) {LIC.ElapsedDays = 98.00, OrbitColor = [44 157 211]};

Propagate 'Burn for 133.9 days' NearMoonProp(LIC) {LIC.ElapsedDays = 133.90, OrbitColor = [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

iii. LIC Operational Constraint Capture

%General Mission Analysis Tool(GMAT) Script
%Created: 2018-06-15 12:37:54

%------------------------------------------------------------------------
%------- Spacecraft
%------------------------------------------------------------------------

Create Spacecraft LIC;
GMAT LIC.DateFormat UTCGregorian;
GMAT LIC.Epoch '09 Oct 2018 17:02:15.204';
GMAT LIC.CoordinateSystem EarthMJ2000Eq;
GMAT LIC.DisplayStateType Cartesian;
GMAT LIC.X = -21987.1300247;
GMAT LIC.Y = -36808.7001619;
GMAT LIC.Z  -492.8827009;  
GMAT LIC.VX  -0.6215788;  
GMAT LIC.VY  -3.9441402;  
GMAT LIC.VZ  -0.8708646;  
GMAT LIC.DryMass  0.01;  
GMAT LIC.Cd  2.2;  
GMAT LIC.Cr  1;  
GMAT LIC.DragArea  0.25;  
GMAT LIC.SRPArea  0.3;  
GMAT LIC.Tanks  {IodineTank};  
GMAT LIC.Thrusters  {BIT3Thruster, BIT3Thruster1, BIT3Thruster2, BIT3Thruster3, BIT3Thruster4};  
GMAT LIC.NAIFId  -10001001;  
GMAT LIC.NAIFIdReferenceFrame  -9001001;  
GMAT LIC.OrbitColor  Red;  
GMAT LIC.TargetColor  Teal;  
GMAT LIC.OrbitErrorCovariance  [1e+70 0 0 0 0 0 0 0 0 0 1e+70 0 0 0 0 0 0 0 0 0 1e+70 0 0 0 0 1e+70 0 0 0 0 0 0 0 0 0 1e+70 ];  
GMAT LIC.CdSigma  1e+70;  
GMAT LIC.CrSigma  1e+70;  
GMAT LIC.Id  'SatId';  
GMAT LIC.Attitude CoordinateSystemFixed;  
GMAT LIC.SPADSRPScaleFactor  1;  
GMAT LIC.ModelFile  'aura.3ds';  
GMAT LIC.ModelOffsetX  0;  
GMAT LIC.ModelOffsetY  0;  
GMAT LIC.ModelOffsetZ  0;  
GMAT LIC.ModelRotationX  0;  
GMAT LIC.ModelRotationY  0;  
GMAT LIC.ModelRotationZ  0;  
GMAT LIC.ModelScale  1;  
GMAT LIC.AttitudeDisplayStateType  'Quaternion';  
GMAT LIC.AttitudeRateDisplayStateType  'AngularVelocity';  
GMAT LIC.AttitudeCoordinateSystem  EarthMJ2000Eq;  
GMAT LIC.EulerAngleSequence  '321';

%------------------------------------------------------
%-------- Hardware Components 
%------------------------------------------------------

Create ChemicalTank IodineTank;  
GMAT IodineTank.AllowNegativeFuelMass  true;  
GMAT IodineTank.Pressure  1000;  
GMAT IodineTank.Temperature  20;  
GMAT IodineTank.RefTemperature  20;
GMAT IodineTank.Volume 10;
GMAT IodineTank.FuelDensity 1000;
GMAT IodineTank.PressureModel PressureRegulated;

Create ChemicalThruster BIT3Thruster;
GMAT BIT3Thruster.CoordinateSystem Local;
GMAT BIT3Thruster.Origin Earth;
GMAT BIT3Thruster.Axes VNB;
GMAT BIT3Thruster.ThrustDirection1 1;
GMAT BIT3Thruster.ThrustDirection2 0;
GMAT BIT3Thruster.ThrustDirection3 0;
GMAT BIT3Thruster.DutyCycle 1;
GMAT BIT3Thruster.ThrustScaleFactor 1;
GMAT BIT3Thruster.DecrementMass true;
GMAT BIT3Thruster.Tank {IodineTank};
GMAT BIT3Thruster.MixRatio [1];
GMAT BIT3Thruster.GravitationalAccel 9.81;
GMAT BIT3Thruster.C1 0.00124;
GMAT BIT3Thruster.C2 0;
GMAT BIT3Thruster.C3 0;
GMAT BIT3Thruster.C4 0;
GMAT BIT3Thruster.C5 0;
GMAT BIT3Thruster.C6 0;
GMAT BIT3Thruster.C7 0;
GMAT BIT3Thruster.C8 0;
GMAT BIT3Thruster.C9 0;
GMAT BIT3Thruster.C10 0;
GMAT BIT3Thruster.C11 0;
GMAT BIT3Thruster.C12 0;
GMAT BIT3Thruster.C13 0;
GMAT BIT3Thruster.C14 0;
GMAT BIT3Thruster.C15 0;
GMAT BIT3Thruster.C16 0;
GMAT BIT3Thruster.K1 2640;
GMAT BIT3Thruster.K2 0;
GMAT BIT3Thruster.K3 0;
GMAT BIT3Thruster.K4 0;
GMAT BIT3Thruster.K5 0;
GMAT BIT3Thruster.K6 0;
GMAT BIT3Thruster.K7 0;
GMAT BIT3Thruster.K8 0;
GMAT BIT3Thruster.K9 0;
GMAT BIT3Thruster.K10 0;
GMAT BIT3Thruster.K11 0;
GMAT BIT3Thruster.K12 0;
GMAT BIT3Thruster.K13 0;
GMAT BIT3Thruster.K14 0;
GMAT BIT3Thruster.K15 0;
GMAT BIT3Thruster.K16 0;

Create ChemicalThruster BIT3Thruster1;
GMAT BIT3Thruster1.CoordinateSystem Local;
GMAT BIT3Thruster1.Origin Earth;
GMAT BIT3Thruster1.Axes VNB;
GMAT BIT3Thruster1.ThrustDirection1 -1;
GMAT BIT3Thruster1.ThrustDirection2 0;
GMAT BIT3Thruster1.ThrustDirection3 0;
GMAT BIT3Thruster1.DutyCycle 1;
GMAT BIT3Thruster1.ThrustScaleFactor 1;
GMAT BIT3Thruster1.DecrementMass true;
GMAT BIT3Thruster1.Tank {IodineTank};
GMAT BIT3Thruster1.MixRatio [1];
GMAT BIT3Thruster1.GravitationalAccel 9.81;
GMAT BIT3Thruster1.C1 0.00124;
GMAT BIT3Thruster1.C2 0;
GMAT BIT3Thruster1.C3 0;
GMAT BIT3Thruster1.C4 0;
GMAT BIT3Thruster1.C5 0;
GMAT BIT3Thruster1.C6 0;
GMAT BIT3Thruster1.C7 0;
GMAT BIT3Thruster1.C8 0;
GMAT BIT3Thruster1.C9 0;
GMAT BIT3Thruster1.C10 0;
GMAT BIT3Thruster1.C11 0;
GMAT BIT3Thruster1.C12 0;
GMAT BIT3Thruster1.C13 0;
GMAT BIT3Thruster1.C14 0;
GMAT BIT3Thruster1.C15 0;
GMAT BIT3Thruster1.C16 0;
GMAT BIT3Thruster1.K1 2640;
GMAT BIT3Thruster1.K2 0;
GMAT BIT3Thruster1.K3 0;
GMAT BIT3Thruster1.K4 0;
GMAT BIT3Thruster1.K5 0;
GMAT BIT3Thruster1.K6 0;
GMAT BIT3Thruster1.K7 0;
GMAT BIT3Thruster1.K8 0;
GMAT BIT3Thruster1.K9 0;
GMAT BIT3Thruster1.K10 0;
GMAT BIT3Thruster1.K11 0;
GMAT BIT3Thruster1.K12 0;
GMAT BIT3Thruster1.K13 0;
GMAT BIT3Thrust1.K14  0;
GMAT BIT3Thrust1.K15  0;
GMAT BIT3Thrust1.K16  0;

Create ChemicalThruster BIT3Thruster2;
GMAT BIT3Thruster2.CoordinateSystem  Local;
GMAT BIT3Thruster2.Origin  Earth;
GMAT BIT3Thruster2.Axes  VNB;
GMAT BIT3Thruster2.ThrustDirection1  -1;
GMAT BIT3Thruster2.ThrustDirection2  0;
GMAT BIT3Thruster2.ThrustDirection3  0;
GMAT BIT3Thruster2.DutyCycle  1;
GMAT BIT3Thruster2.ThrustScaleFactor  1;
GMAT BIT3Thruster2.DecrementMass  true;
GMAT BIT3Thruster2.Tank  {IodineTank};
GMAT BIT3Thruster2.MixRatio  [ 1 ];
GMAT BIT3Thruster2.GravitationalAccel  9.81;
GMAT BIT3Thruster2.C1  0.00124;
GMAT BIT3Thruster2.C2  0;
GMAT BIT3Thruster2.C3  0;
GMAT BIT3Thruster2.C4  0;
GMAT BIT3Thruster2.C5  0;
GMAT BIT3Thruster2.C6  0;
GMAT BIT3Thruster2.C7  0;
GMAT BIT3Thruster2.C8  0;
GMAT BIT3Thruster2.C9  0;
GMAT BIT3Thruster2.C10  0;
GMAT BIT3Thruster2.C11  0;
GMAT BIT3Thruster2.C12  0;
GMAT BIT3Thruster2.C13  0;
GMAT BIT3Thruster2.C14  0;
GMAT BIT3Thruster2.C15  0;
GMAT BIT3Thruster2.C16  0;
GMAT BIT3Thruster2.K1  2640;
GMAT BIT3Thruster2.K2  0;
GMAT BIT3Thruster2.K3  0;
GMAT BIT3Thruster2.K4  0;
GMAT BIT3Thruster2.K5  0;
GMAT BIT3Thruster2.K6  0;
GMAT BIT3Thruster2.K7  0;
GMAT BIT3Thruster2.K8  0;
GMAT BIT3Thruster2.K9  0;
GMAT BIT3Thruster2.K10  0;
GMAT BIT3Thruster2.K11  0;
GMAT BIT3Thruster2.K12  0;
GMAT BIT3Thruster2.K13  0;
GMAT BIT3Thruster2.K14 0;
GMAT BIT3Thruster2.K15 0;
GMAT BIT3Thruster2.K16 0;

Create ChemicalThruster BIT3Thruster3;
GMAT BIT3Thruster3.CoordinateSystem Local;
GMAT BIT3Thruster3.Origin Earth;
GMAT BIT3Thruster3.Axes VNB;
GMAT BIT3Thruster3.ThrustDirection1 -1;
GMAT BIT3Thruster3.ThrustDirection2 0;
GMAT BIT3Thruster3.ThrustDirection3 0;
GMAT BIT3Thruster3.DutyCycle 1;
GMAT BIT3Thruster3.ThrustScaleFactor 1;
GMAT BIT3Thruster3.DecrementMass true;
GMAT BIT3Thruster3.Tank {IodineTank};
GMAT BIT3Thruster3.MixRatio [ 1 ];
GMAT BIT3Thruster3.GravitationalAccel 9.81;
GMAT BIT3Thruster3.C1 0.00124;
GMAT BIT3Thruster3.C2 0;
GMAT BIT3Thruster3.C3 0;
GMAT BIT3Thruster3.C4 0;
GMAT BIT3Thruster3.C5 0;
GMAT BIT3Thruster3.C6 0;
GMAT BIT3Thruster3.C7 0;
GMAT BIT3Thruster3.C8 0;
GMAT BIT3Thruster3.C9 0;
GMAT BIT3Thruster3.C10 0;
GMAT BIT3Thruster3.C11 0;
GMAT BIT3Thruster3.C12 0;
GMAT BIT3Thruster3.C13 0;
GMAT BIT3Thruster3.C14 0;
GMAT BIT3Thruster3.C15 0;
GMAT BIT3Thruster3.C16 0;
GMAT BIT3Thruster3.K1 2640;
GMAT BIT3Thruster3.K2 0;
GMAT BIT3Thruster3.K3 0;
GMAT BIT3Thruster3.K4 0;
GMAT BIT3Thruster3.K5 0;
GMAT BIT3Thruster3.K6 0;
GMAT BIT3Thruster3.K7 0;
GMAT BIT3Thruster3.K8 0;
GMAT BIT3Thruster3.K9 0;
GMAT BIT3Thruster3.K10 0;
GMAT BIT3Thruster3.K11 0;
GMAT BIT3Thruster3.K12 0;
GMAT BIT3Thruster3.K13 0;
GMAT BIT3Thruster3.K14 0;
GMAT BIT3Thruster3.K15 0;
GMAT BIT3Thruster3.K16 0;

Create ChemicalThruster BIT3Thruster4;
GMAT BIT3Thruster4.CoordinateSystem Local;
GMAT BIT3Thruster4.Origin Luna;
GMAT BIT3Thruster4.Axes VNB;
GMAT BIT3Thruster4.ThrustDirection1 -1;
GMAT BIT3Thruster4.ThrustDirection2 0;
GMAT BIT3Thruster4.ThrustDirection3 0;
GMAT BIT3Thruster4.DutyCycle 1;
GMAT BIT3Thruster4.ThrustScaleFactor 1;
GMAT BIT3Thruster4.DecrementMass true;
GMAT BIT3Thruster4.Tank {IodineTank};
GMAT BIT3Thruster4.MixRatio [1];
GMAT BIT3Thruster4.GravitationalAccel 9.81;
GMAT BIT3Thruster4.C1 0.00124;
GMAT BIT3Thruster4.C2 0;
GMAT BIT3Thruster4.C3 0;
GMAT BIT3Thruster4.C4 0;
GMAT BIT3Thruster4.C5 0;
GMAT BIT3Thruster4.C6 0;
GMAT BIT3Thruster4.C7 0;
GMAT BIT3Thruster4.C8 0;
GMAT BIT3Thruster4.C9 0;
GMAT BIT3Thruster4.C10 0;
GMAT BIT3Thruster4.C11 0;
GMAT BIT3Thruster4.C12 0;
GMAT BIT3Thruster4.C13 0;
GMAT BIT3Thruster4.C14 0;
GMAT BIT3Thruster4.C15 0;
GMAT BIT3Thruster4.C16 0;
GMAT BIT3Thruster4.K1 2640;
GMAT BIT3Thruster4.K2 0;
GMAT BIT3Thruster4.K3 0;
GMAT BIT3Thruster4.K4 0;
GMAT BIT3Thruster4.K5 0;
GMAT BIT3Thruster4.K6 0;
GMAT BIT3Thruster4.K7 0;
GMAT BIT3Thruster4.K8 0;
GMAT BIT3Thruster4.K9 0;
GMAT BIT3Thruster4.K10 0;
GMAT BIT3Thruster4.K11 0;
GMAT BIT3Thruster4.K12 0;
GMAT BIT3Thruster4.K13 0;
GMAT BIT3Thruster4.K14 0;
GMAT BIT3Thruster4.K15 0;
GMAT BIT3Thruster4.K16 0;

%----------------------------------------
%-------- ForceModels
%----------------------------------------

Create ForceModel NearEarthForceModel;
GMAT NearEarthForceModel.CentralBody  Earth;
GMAT NearEarthForceModel.PrimaryBodies {Earth};
GMAT NearEarthForceModel.PointMasses {Luna, Sun, Jupiter, Venus, Saturn, Mars};
GMAT NearEarthForceModel.Drag None;
GMAT NearEarthForceModel.SRP On;
GMAT NearEarthForceModel.RelativisticCorrection Off;
GMAT NearEarthForceModel.ErrorControl RSSStep;
GMAT NearEarthForceModel.GravityField.Earth.Degree  8;
GMAT NearEarthForceModel.GravityField.Earth.StmLimit  100;
'./data/gravity/earth/JGM2.cof';
GMAT NearEarthForceModel.GravityField.Earth.TideModel 'None';
GMAT NearEarthForceModel.SRP.Flux 1367;
GMAT NearEarthForceModel.SRP.SRPModel Spherical;
GMAT NearEarthForceModel.SRP.Nominal_Sun 149597870.691;

Create ForceModel NearMoonForceModel;
GMAT NearMoonForceModel.CentralBody  Luna;
GMAT NearMoonForceModel.PointMasses {Luna, Earth, Sun};
GMAT NearMoonForceModel.Drag None;
GMAT NearMoonForceModel.SRP On;
GMAT NearMoonForceModel.RelativisticCorrection Off;
GMAT NearMoonForceModel.ErrorControl RSSStep;
GMAT NearMoonForceModel.SRP.Flux 1367;
GMAT NearMoonForceModel.SRP.SRPModel Spherical;
GMAT NearMoonForceModel.SRP.Nominal_Sun 149597870.691;

%----------------------------------------
%-------- Propagators
%----------------------------------------

Create Propagator NearEarthProp;
GMAT NearEarthProp.FM NearEarthForceModel;
GMAT NearEarthProp.Type PrinceDormand78;
GMAT NearEarthProp.InitialStepSize  60;
GMAT NearEarthProp.Accuracy 1e-12;
GMAT NearEarthProp.MinStep 0;
GMAT NearEarthProp.MaxStep 3600;
GMAT NearEarthProp.MaxStepAttempts 50;
GMAT NearEarthProp.StopIfAccuracyIsViolated true;

Create Propagator NearMoonProp;
GMAT NearMoonProp.FM NearMoonForceModel;
GMAT NearMoonProp.Type PrinceDormand78;
GMAT NearMoonProp.InitialStepSize 600;
GMAT NearMoonProp.Accuracy 1e-12;
GMAT NearMoonProp.MinStep 0;
GMAT NearMoonProp.MaxStep 3600;
GMAT NearMoonProp.MaxStepAttempts 50;
GMAT NearMoonProp.StopIfAccuracyIsViolated true;

%--------------------------------
%-------- Burns
%--------------------------------

Create ImpulsiveBurn TCM;
GMAT TCM.CoordinateSystem Local;
GMAT TCM.Origin Earth;
GMAT TCM.Axes VNB;
%% GMAT TCM.Element1 0.00124;
GMAT TCM.Element1 -0.001;
GMAT TCM.Element2 0;
GMAT TCM.Element3 0;
GMAT TCM.DecrementMass true;
GMAT TCM.Tank {IodineTank};
GMAT TCM.Isp 2640;
GMAT TCM.GravitationalAccel 9.81;

Create FiniteBurn FiniteBurn;
GMAT FiniteBurn.Thusters {BIT3Thruster};
GMAT FiniteBurn.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn1;
GMAT FiniteBurn1.Thusters {BIT3Thruster1};
GMAT FiniteBurn1.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn2;
GMAT FiniteBurn2.Thusters {BIT3Thruster2};
GMAT FiniteBurn2.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn3;
GMAT FiniteBurn3.Thrusters  {BIT3Thruster3};
GMAT FiniteBurn3.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

Create FiniteBurn FiniteBurn4;
GMAT FiniteBurn4.Thrusters  {BIT3Thruster4};
GMAT FiniteBurn4.ThrottleLogicAlgorithm 'MaxNumberOfThrusters';

%-----------------------------------------------------
%-------- Coordinate Systems
%-----------------------------------------------------

Create CoordinateSystem SunEcliptic;
GMAT SunEcliptic.Origin Sun;
GMAT SunEcliptic.Axes MJ2000Eq;

Create CoordinateSystem LunarInertial;
GMAT LunarInertial.Origin Luna;
GMAT LunarInertial.Axes MJ2000Eq;

Create CoordinateSystem SunEarthRotating;
GMAT SunEarthRotating.Origin Earth;
GMAT SunEarthRotating.Axes ObjectReferenced;
GMAT SunEarthRotating.XAxis R;
GMAT SunEarthRotating.ZAxis N;
GMAT SunEarthRotating.Primary Sun;
GMAT SunEarthRotating.Secondary Earth;

Create CoordinateSystem EarthMoon;
GMAT EarthMoon.Origin Earth;
GMAT EarthMoon.Axes ObjectReferenced;
GMAT EarthMoon.XAxis R;
GMAT EarthMoon.ZAxis N;
GMAT EarthMoon.Primary Earth;
GMAT EarthMoon.Secondary Luna;

%-----------------------------------------------------
%-------- Solvers
%-----------------------------------------------------

Create DifferentialCorrector DefaultDC;
GMAT DefaultDC.ShowProgress  true;
GMAT DefaultDC.ReportStyle  Normal;
GMAT DefaultDC.ReportFile  'DifferentialCorrectorDefaultDC.data';
GMAT DefaultDC.MaximumIterations  25;
GMAT DefaultDC.DerivativeMethod  ForwardDifference;
GMAT DefaultDC.Algorithm NewtonRaphson;

%-----------------------------------------------------------
%---------- Subscribers
%-----------------------------------------------------------

Create OrbitView LunaView;
GMAT LunaView.SolverIterations Current;
GMAT LunaView.UpperLeft [ 0.5 0.0325 ];
GMAT LunaView.Size [ 0.55 0.79 ];
GMAT LunaView.RelativeZOrder 5;
GMAT LunaView.Maximized false;
GMAT LunaView.Add {LIC, Earth, Luna, Sun};
GMAT LunaView.CoordinateSystem LunaInertial;
GMAT LunaView.DrawObject [ true true true ];
GMAT LunaView.DataCollectFrequency 1;
GMAT LunaView.UpdatePlotFrequency 50;
GMAT LunaView.NumPointsToRedraw 0;
GMAT LunaView.ShowPlot true;
GMAT LunaView.MaxPlotPoints 20000;
GMAT LunaView.ShowLabels true;
GMAT LunaView.ViewPointReference Luna;
GMAT LunaView.ViewPointVector [ 0 0 30000 ];
GMAT LunaView.ViewDirection Luna;
GMAT LunaView.ViewScaleFactor 25;
GMAT LunaView.ViewUpCoordinateSystem EarthMoon;
GMAT LunaView.ViewUpAxis X;
GMAT LunaView.EclipticPlane Off;
GMAT LunaView.XYPlane Off;
GMAT LunaView.WireFrame Off;
GMAT LunaView.Axes On;
GMAT LunaView.Grid Off;
GMAT LunaView.SunLine On;
GMAT LunaView.UseInitialView On;
GMAT LunaView.StarCount 7000;
GMAT LunaView.EnableStars On;
GMAT LunaView.EnableConstellations On;

Create OrbitView EarthMoonRotatingView;
GMAT EarthMoonRotatingView.SolverIterations Current;
GMAT EarthMoonRotatingView.UpperLeft [ 0.0679687499999999 0.0325 ];
GMAT EarthMoonRotatingView.Size [ 0.55 0.79 ];
GMAT EarthMoonRotatingView.RelativeZOrder 10;
GMAT EarthMoonRotatingView.Maximized false;
GMAT EarthMoonRotatingView.Add {LIC, Earth, Luna, Sun};
GMAT EarthMoonRotatingView.CoordinateSystem EarthMoon;
GMAT EarthMoonRotatingView.DrawObject true true true;
GMAT EarthMoonRotatingView.DataCollectFrequency 1;
GMAT EarthMoonRotatingView.UpdatePlotFrequency 50;
GMAT EarthMoonRotatingView.NumPointsToRedraw 0;
GMAT EarthMoonRotatingView.ShowPlot true;
GMAT EarthMoonRotatingView.MaxPlotPoints 20000;
GMAT EarthMoonRotatingView.ShowLabels true;
GMAT EarthMoonRotatingView.ViewPointReference Earth;
GMAT EarthMoonRotatingView.ViewPointVector [ 0 0 30000 ];
GMAT EarthMoonRotatingView.ViewDirection Earth;
GMAT EarthMoonRotatingView.ViewScaleFactor 100;
GMAT EarthMoonRotatingView.ViewUpCoordinateSystem EarthMoon;
GMAT EarthMoonRotatingView.ViewUpAxis Z;
GMAT EarthMoonRotatingView.EclipticPlane Off;
GMAT EarthMoonRotatingView.XYPlane Off;
GMAT EarthMoonRotatingView.WireFrame Off;
GMAT EarthMoonRotatingView.Axes On;
GMAT EarthMoonRotatingView.Grid Off;
GMAT EarthMoonRotatingView.SunLine On;
GMAT EarthMoonRotatingView.UseInitialView On;
GMAT EarthMoonRotatingView.StarInitialView 7000;
GMAT EarthMoonRotatingView.EnableStars On;
GMAT EarthMoonRotatingView.EnableConstellations Off;

Create OrbitView SunEarthRotatingView;
GMAT SunEarthRotatingView.SolverIterations Current;
GMAT SunEarthRotatingView.UpperLeft [ 0.415625 0.185 ];
GMAT SunEarthRotatingView.Size [ 0.48984375 0.77 ];
GMAT SunEarthRotatingView.RelativeZOrder 25;
GMAT SunEarthRotatingView.Maximized false;
GMAT SunEarthRotatingView.Add { LIC, Earth, Luna, Sun};
GMAT SunEarthRotatingView.CoordinateSystem SunEarthRotating;
GMAT SunEarthRotatingView.DrawObject true true true;
GMAT SunEarthRotatingView.DataCollectFrequency 1;
GMAT SunEarthRotatingView.UpdatePlotFrequency 50;
GMAT SunEarthRotatingView.NumPointsToRedraw 0;
GMAT SunEarthRotatingView.ShowPlot true;
GMAT SunEarthRotatingView.MaxPlotPoints 20000;
GMAT SunEarthRotatingView.ShowLabels true;
GMAT SunEarthRotatingView.ViewPointReference Earth;
GMAT SunEarthRotatingView.ViewPointVector [ 0 0 30000 ];
GMAT SunEarthRotatingView.ViewDirection Earth;
GMAT SunEarthRotatingView.ViewScaleFactor 100;
GMAT SunEarthRotatingView.ViewUpCoordinateSystem EarthMoon;
GMAT SunEarthRotatingView.ViewUpAxis Y;
GMAT SunEarthRotatingView.EclipticPlane Off;
GMAT SunEarthRotatingView.XYPlane Off;
GMAT SunEarthRotatingView.WireFrame Off;
GMAT SunEarthRotatingView.Axes On;
GMAT SunEarthRotatingView.Grid Off;
GMAT SunEarthRotatingView.SunLine On;
GMAT SunEarthRotatingView.UseInitialView Off;
GMAT SunEarthRotatingView.StarCount 7000;
GMAT SunEarthRotatingView.EnableStars On;
GMAT SunEarthRotatingView.EnableConstellations Off;

%-------------------------------------------------
%-------- Arrays, Variables, Strings
%-------------------------------------------------
Create Variable BurnDuration1 BurnDuration2 BurnDuration3;
GMAT BurnDuration1 0;
GMAT BurnDuration2 0;
GMAT BurnDuration3 0;

%-------------------------------------------------
%-------- Mission Sequence
%-------------------------------------------------
BeginMissionSequence;
Propagate 'Prop for 780 sec' NearEarthProp(LIC) {LIC.ElapsedSecs 780, OrbitColor [255 0 0]};
Maneuver 'Maneuver 1 m/s Impulse' TCM(LIC);

Propagate 'Prop for 12 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 43200.000, OrbitColor [255 0 0]};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn(LIC);
Propagate 'Burn for 2 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 7200.000, OrbitColor [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn(LIC);

Propagate 'Prop for 2 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 7200.000, OrbitColor [255 0 0]};

Target DefaultDC {solveMode Solve, exitMode SaveAndContinue, showProgressWindow true};

Vary 'Vary BIT3Thruster1.V' DefaultDC(LIC.BIT3Thruster1.ThrustDirection1 0.6879150054966399, {perturbation 0.00001, lower -1, upper 1, maxStep 0.002, additiveScaleFactor 0.0, multiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster1.N' DefaultDC(LIC.BIT3Thruster1.ThrustDirection2 - 0.7094589104843158, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster1.B' DefaultDC(LIC.BIT3Thruster1.ThrustDirection3 - 0.1531045379698647, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary Burn Duration' DefaultDC(BurnDuration1 81026.10000000001, {Perturbation 0.1, Lower 1000, Upper 100000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn1(LIC);
Propagate 'Burn for 22 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs BurnDuration1, OrbitColor [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn1(LIC);

Propagate 'Prop for 12 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 43200.000, OrbitColor [255 0 0]};

Vary 'Vary BIT3Thruster2.V' DefaultDC(LIC.BIT3Thruster2.ThrustDirection1 0.9175757702481413, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster2.N' DefaultDC(LIC.BIT3Thruster2.ThrustDirection2 - 0.3578263062669203, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster2.B' DefaultDC(LIC.BIT3Thruster2.ThrustDirection3 - 0.1732484932024026, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary Burn Duration2' DefaultDC(BurnDuration2 102819, {Perturbation 0.1, Lower 1000, Upper 150000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn2(LIC);
Propagate 'Burn for 28 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs BurnDuration2, OrbitColor [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn2(LIC);

Propagate 'Prop for 10 hrs' NearEarthProp(LIC) {LIC.ElapsedSecs 36000.000, OrbitColor [255 0 0]};

Vary 'Vary BIT3Thruster3.V' DefaultDC(LIC.BIT3Thruster3.ThrustDirection1 0.9611343479284352, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster3.N' DefaultDC(LIC.BIT3Thruster3.ThrustDirection2 - 0.238581130651876, {Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0});
Vary 'Vary BIT3Thruster3.B' DefaultDC(LIC.BIT3Thruster3.ThrustDirection3 - 0.138923753653054, \{Perturbation 0.00001, Lower -1, Upper 1, MaxStep 0.002, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});
Vary 'Vary Burn Duration3' DefaultDC(BurnDuration3 13367.7, \{Perturbation 0.1, Lower 1000, Upper 100000, MaxStep 600, AdditiveScaleFactor 0.0, MultiplicativeScaleFactor 1.0\});

BeginFiniteBurn 'Turn Thruster On' FiniteBurn3(LIC);
Propagate 'Burn for 4 hrs' NearEarthProp(LIC) \{LIC.ElapsedSecs BurnDuration3, OrbitColor [15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn3(LIC);

Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};

Achieve 'Achieve BdotT' DefaultDC(LIC.LunaInertial.BdotT -8938.7006739595381000, \{Tolerance 0.001\});
Achieve 'Achieve BdotR' DefaultDC(LIC.LunaInertial.BdotR 4800.0006406646644000, \{Tolerance 0.001\});

EndTarget; % For targeter DefaultDC

Propagate 'Prop 106 Days' NearEarthProp(LIC) \{LIC.ElapsedDays 105.96916263, OrbitColor [255 0 0]\};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
GMAT LIC.BIT3Thruster4.ThrustDirection1 -1;
GMAT LIC.BIT3Thruster4.ThrustDirection2 0;
GMAT LIC.BIT3Thruster4.ThrustDirection3 0;
Propagate 'Burn for 3.5 days' NearEarthProp(LIC) \{LIC.ElapsedSecs 303441.000, OrbitColor [15 127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};
Propagate 'Prop to Lunar Periapsis' NearEarthProp(LIC) \{LIC.Luna.Periapsis, OrbitColor [255 0 0]\};

Propagate 'Back Prop' BackProp NearMoonProp(LIC) \{LIC.ElapsedDays -16.2, OrbitColor [255 255 255]\};

% Propagate 'Prop to setup DV - 1.5 days' NearMoonProp(LIC) \{LIC.ElapsedSecs 129600, OrbitColor [255 255 255]\};
% Propagate 'Prop to setup DV - 2 days' NearMoonProp(LIC) {LIC.ElapsedSecs 172800, OrbitColor [255 255 255]};
% Propagate 'Prop to setup DV - 2.4 days' NearMoonProp(LIC) {LIC.ElapsedSecs 207360, OrbitColor [255 0 0]};
Propagate 'Prop to setup DV - 2.5 days' NearMoonProp(LIC) {LIC.ElapsedSecs 216000, OrbitColor [255 0 0]};
% Propagate 'Prop to setup DV - 2.6 days' NearMoonProp(LIC) {LIC.ElapsedSecs 224640, OrbitColor [255 0 0]};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
GMAT LIC.BIT3Thruster4.ThrustDirection1 -0.6040227735550539;
GMAT LIC.BIT3Thruster4.ThrustDirection2 -0.719846310392954;
GMAT LIC.BIT3Thruster4.ThrustDirection3 0.3420201433256688;
Propagate 'Burn for 9 days' NearMoonProp(LIC) {LIC.ElapsedDays 9.00, OrbitColor [15 127 254]};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

% Propagate 'Track for 1 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 3600.00, OrbitColor [184 134 11]};
% Propagate 'Track for 2 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 7200.00, OrbitColor [184 134 11]};
% Propagate 'Track for 3 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 10800.00, OrbitColor [184 134 11]};
% Propagate 'Track for 4 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 14400.00, OrbitColor [184 134 11]};
% Propagate 'Track for 5 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 18000.00, OrbitColor [184 134 11]};
% Propagate 'Track for 6 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 21600.00, OrbitColor [184 134 11]};
% Propagate 'Track for 7 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 25200.00, OrbitColor [184 134 11]};
% Propagate 'Track for 8 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 28800.00, OrbitColor [184 134 11]};
% Propagate 'Track for 9 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 32400.00, OrbitColor [184 134 11]};
% Propagate 'Track for 10 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 36000.00, OrbitColor [184 134 11]};
% Propagate 'Track for 11 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 39600.00, OrbitColor [184 134 11]};
Propagate 'Track for 12 hrs' NearMoonProp(LIC) {LIC.ElapsedSecs 43200.00, OrbitColor [184 134 11]};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
GMAT LIC.BIT3Thruster4.ThrustDirection1 -0.6040227735550539;
GMAT LIC.BIT3Thruster4.ThrustDirection2 -0.719846310392954;
GMAT LIC.BIT3Thruster4.ThrustDirection3 0.3420201433256688;
Propagate 'Burn for 7 days' NearMoonProp(LIC) \{LIC.ElapsedDays 6.00, OrbitColor [15127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

% Propagate 'Track for 1 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 3600.00, OrbitColor [184134 11]\};
% Propagate 'Track for 2 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 7200.00, OrbitColor [184134 11]\};
% Propagate 'Track for 3 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 10800.00, OrbitColor [184134 11]\};
% Propagate 'Track for 4 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 14400.00, OrbitColor [184134 11]\};
% Propagate 'Track for 5 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 18000.00, OrbitColor [184134 11]\};
% Propagate 'Track for 6 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 21600.00, OrbitColor [184134 11]\};
% Propagate 'Track for 7 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 25200.00, OrbitColor [184134 11]\};
% Propagate 'Track for 8 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 28800.00, OrbitColor [184134 11]\};
% Propagate 'Track for 9 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 32400.00, OrbitColor [184134 11]\};
% Propagate 'Track for 10 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 36000.00, OrbitColor [184134 11]\};
% Propagate 'Track for 11 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 39600.00, OrbitColor [184134 11]\};
Propagate 'Track for 12 hrs' NearMoonProp(LIC) \{LIC.ElapsedSecs 43200.00, OrbitColor [184134 11]\};

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);
GMAT LIC.BIT3Thruster4.ThrustDirection1 -0.6040227735550539;
GMAT LIC.BIT3Thruster4.ThrustDirection2 -0.719846310392954;
GMAT LIC.BIT3Thruster4.ThrustDirection3 0.3420201433256688;
Propagate 'Burn for 7 days' NearMoonProp(LIC) \{LIC.ElapsedDays 7.00, OrbitColor [15127 254]\};
EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);

BeginFiniteBurn 'Turn Thruster On' FiniteBurn4(LIC);

% % az 150 el 0
% % E 0.667, INC 30.679, LP 1484
GMAT LIC.BIT3Thruster4.ThrustDirection1 -.8660;
GMAT LIC.BIT3Thruster4.ThrustDirection2 0.5000;
GMAT LIC.BIT3Thruster4.ThrustDirection3 0;
Propagate 'Burn for xx days' NearMoonProp(LIC) \{LIC.ElapsedDays 86.00, OrbitColor [15 127 254]\};

% Propagate 'Burn for xx days' NearMoonProp(LIC) \{LIC.ElapsedDays 109.35, OrbitColor [15 127 254]\};

EndFiniteBurn 'Turn Thruster Off' FiniteBurn4(LIC);