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Aerospace Engineering
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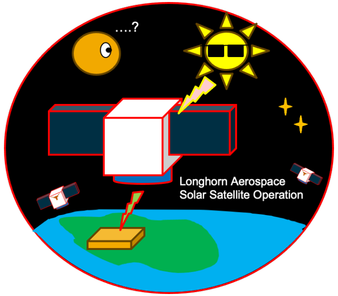
ASE374K
LASSO (Longhorn Aerospace Solar Satellite Operation) Project



4/12/2024
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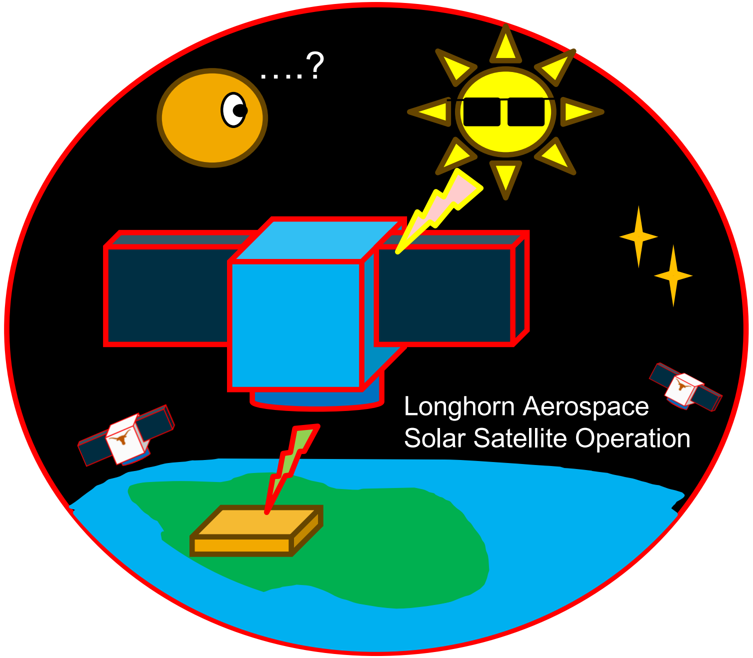


Mission Logo

I. Statement of Purpose

- We design Space Solar Power Satellite Mission and Solar Power Satellite which can charge the solar energy from sun and transmit energy to the ground.
- We are proposing architecture level system design process and end-to-end energy concepts and technology.
- Our project is divided by 4 sub-topics: Orbit Analysis, Energy Transmission Payload Analysis, Solar Energy acquisition (Solar Panel and Battery) and satellite structure analysis, and mission operation concept analysis.
- In mission operation analysis process, the validation of analysis of the other three sub-topics is proposed, including satellite ADCS (Attitude Determination and Control System) demonstration.
- Satellite constellation concept for continuous power transmission on ground and inter-satellite charge is proposed.
- In the future, inter-satellite charging technique and energy transmission cis-lunar regime will be studied.

II. Mission Statement and Objective

Mission Statement:

- Design Low-Earth-Orbit Solar Power Satellite ‘Redstone-1’ operation concept which receives solar power via solar panel and transmit energy to designated ground plant.

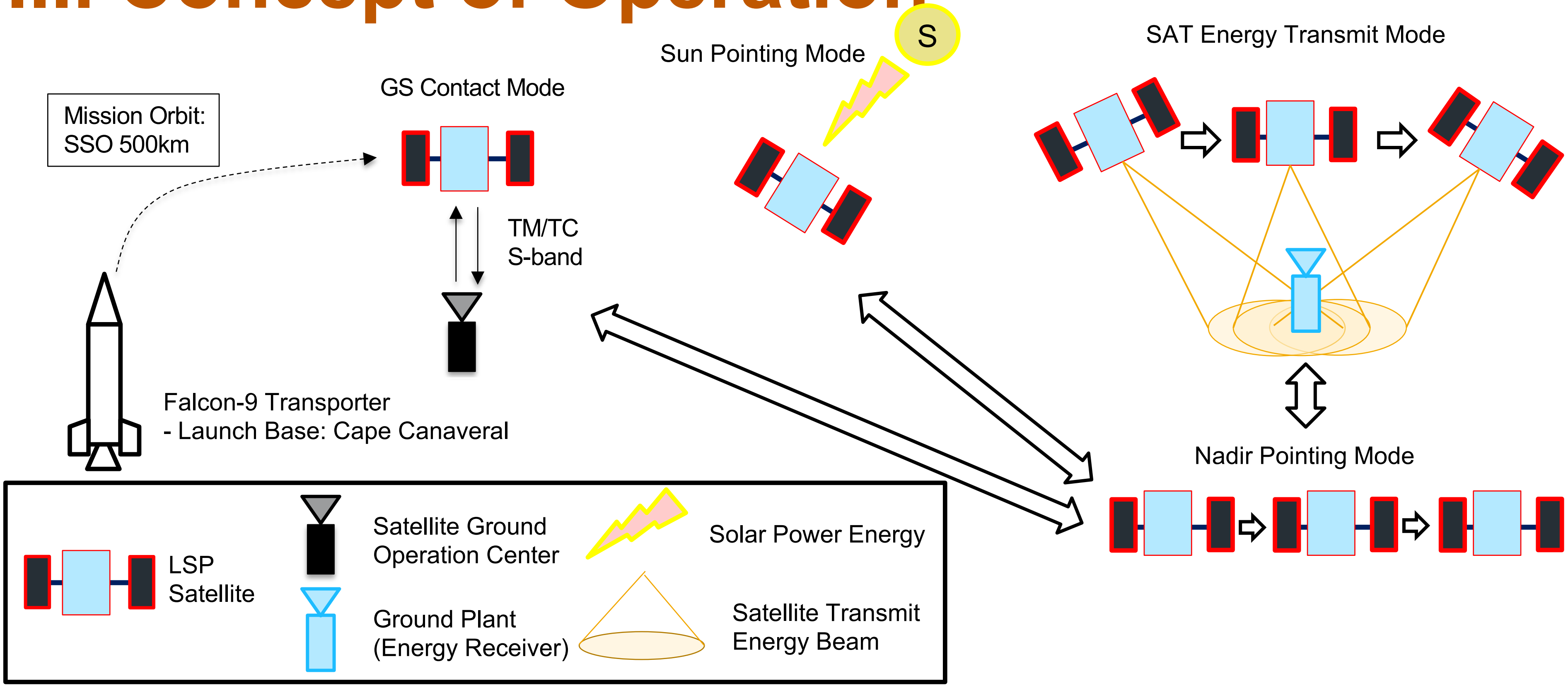
Primary Mission Objectives

- Satellite shall receive solar energy from sun more than [1,TBD] kJ per [1, TBD] orbit .
- Satellite shall transmit stored solar energy to [3, TBD] ground stations [1,TBD]kJ each per [1, TBD]week.

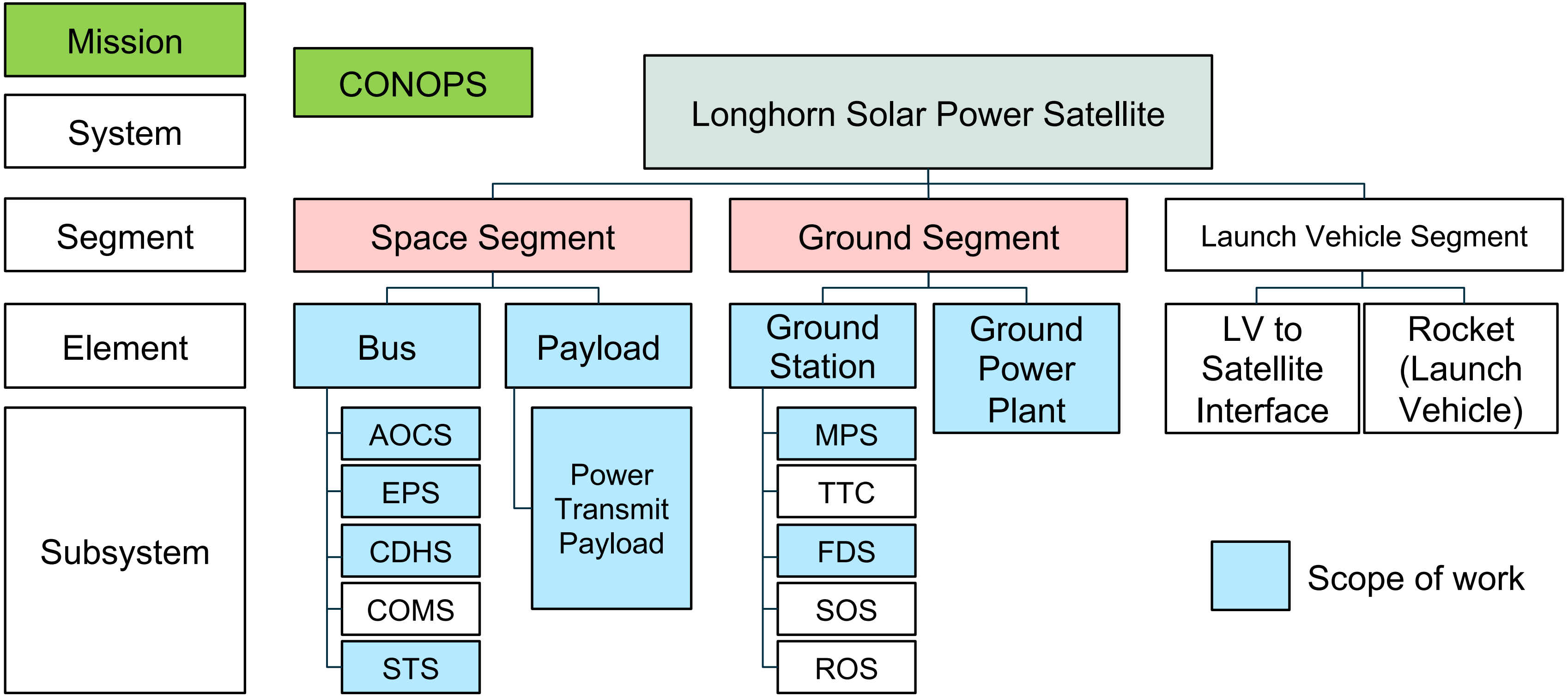
Secondary Mission Objective

- Satellite can transmit stored solar energy to cislunar orbit satellite or other satellites. [Concept Study]
- Propose constellation strategy for continuous solar power reception and transmission. [Concept Study]

III. Concept of Operation



IV. System Architecture, SOW



V. Work Breakdown

Orbit Analysis

Related to:

- Mission
- CONOPS

Description:

- Design Orbit which complies mission req and CONOPS
- Generate orbit design details (Contact Time, Slant range, Elevation Angle, Beta Angle, Eclipse Time)

Energy Transmission Analysis

Related to:

- Power Transmit Payload
- Ground Power Plant

Description

- Design Power transmission Payload and Ground Power Plant to match the mission requirement and given orbit environment
- Generate Energy Requirement

Solar Panel and Battery Analysis

Related to:

- EPS
- STS

Description

- Design Solar Panel and Battery which complies the Power Budget Requirement from Energy Transmission Payload
- Generate satellite physical characteristics
- Design CAD model

Mission Operation Analysis

Related to:

- AOCS
- CDHS
- MPS
- FDS

Description

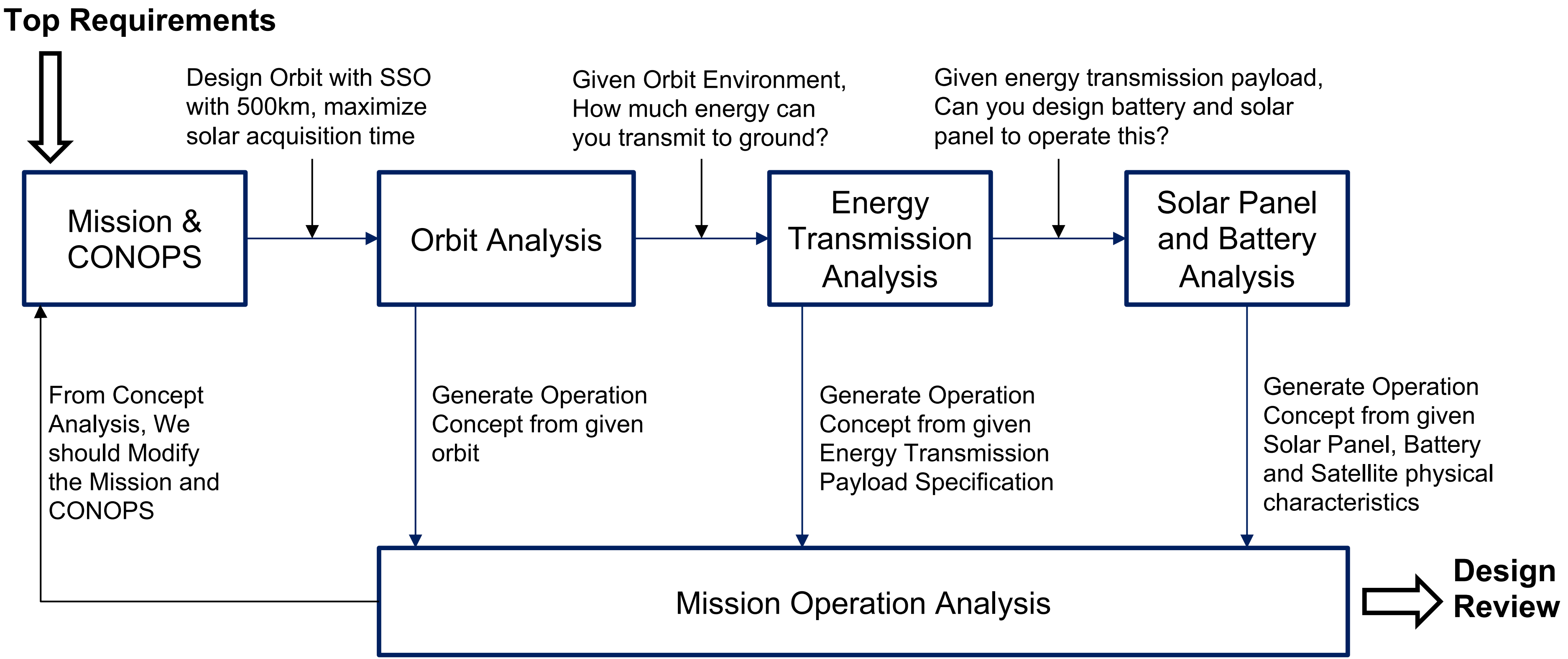
- Design operation concept from given orbit, payload and solar panel and battery to comply mission and CONOPS
- Validate the operation concept generated
- Proceed Satellite operation simulation

V. Work Flowchart (N-2 Chart)

Mission	Mission Statement Mission Requirement				
* Check CONOPS matches Mission * Design Advanced CONOPS	CONOPS	Orbit Requirement * SSO / 500km * Dawn-Dusk * Contact Time	Power Trans. Req. * Shall transmit meaningful power to ground	EPS Requirement * Shall store enough energy for 3 times contact pey day	Mission Operation Requrement
		Orbit Analysis	Contact Time Slant Range Elecation Angle	Beta Angle Eclipse Time	Mission Orbit Epoch Time Duration
		Request to Change Orbit	Energy Transmission Analysis	Payload Power Requirement * Allocate 300kWh per single charge	Operation Requirement for Energy Transmission
		Request to Change Orbit	Paylod Power Requirement Compliance	Solar Panel & Battery Analysis	Operation Requirement for Solar Power Charging
	Operation Concept Compliance	Validation & Verification	Validation & Verification	Validation & Verification	Mission Operation Analysis

- Mission and CONOPS are mostly related to orbit analysis. Orbit
- Energy Transmission and Solar Panel/Battery Analysis receives orbit environment and generate payload and EPS specification for each
- Mission operation part receives operation requirements and generate simulation results, check whether CONOPS and mission is possible

VI. Interface Management & Decision Process



VII. Mission Operation Analysis – Introduction

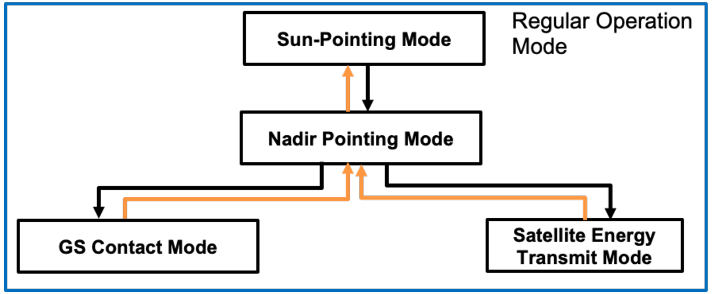
Orbit Analysis → Operation Concept from given orbit → **Mission Operation Analysis**

Energy Transmission Analysis → Operation Concept from given Energy Transmission Payload Specification → **Mission Operation Analysis**

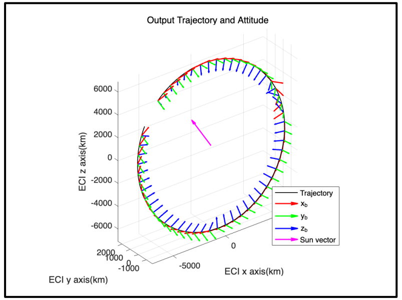
Solar Panel and Battery Analysis → Operation Concept from given Solar Panel, Battery and Satellite physical characteristics → **Mission Operation Analysis**

Mission Operation Analysis → From Concept Analysis, We should Confirm or Modify the Mission and CONOPS → **Mission & CONOPS**

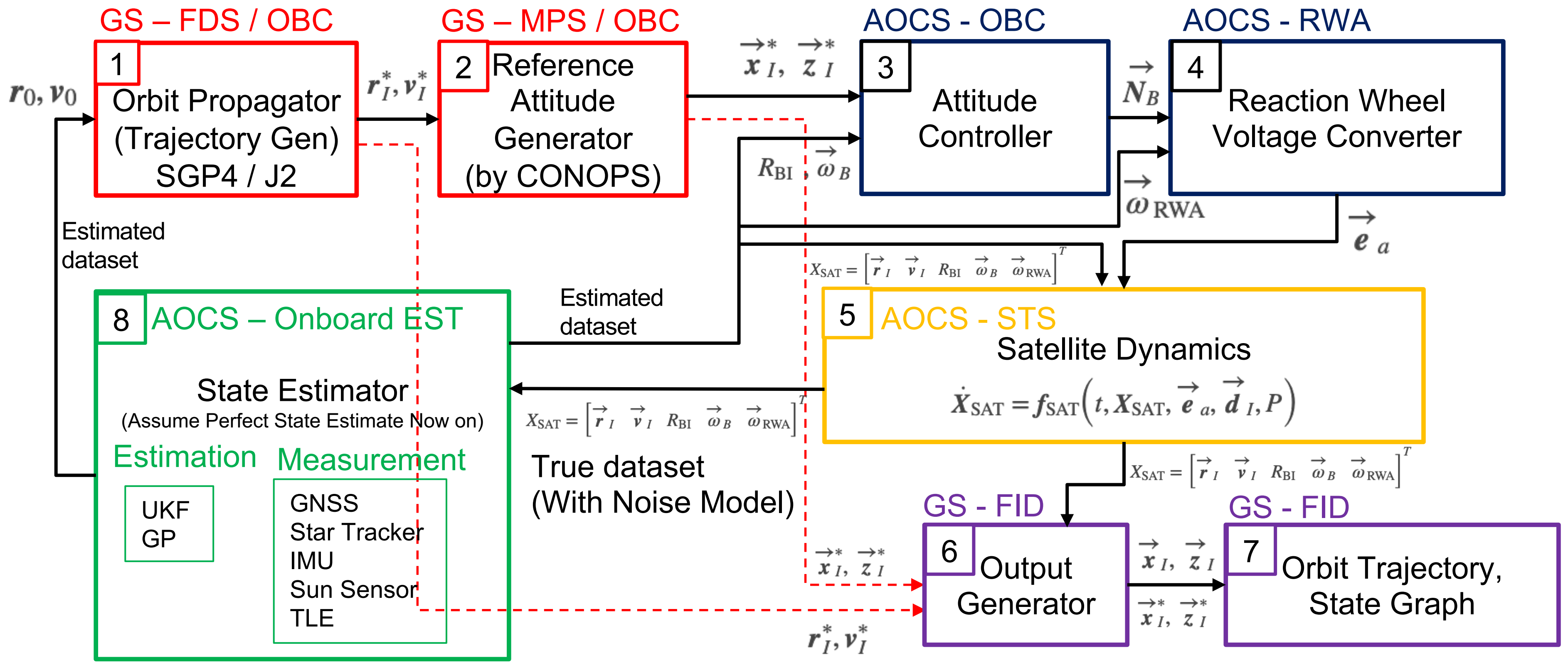
Operation Mode Design



Data plot by graph and visualization method



Mission Operation Analysis – SAT Controller



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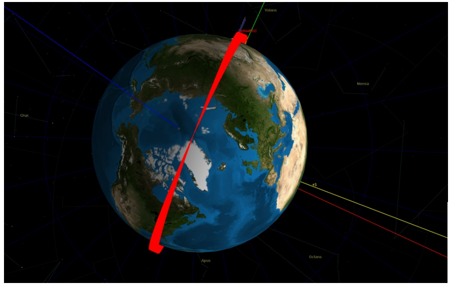
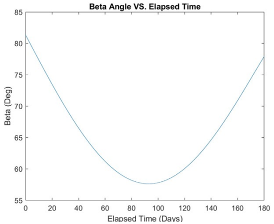
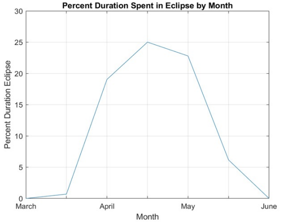
Mission Operation Analysis: from Orbit Analysis

From Orbit Analysis:

Dawn Dusk Orbit has been proposed on 500km orbit







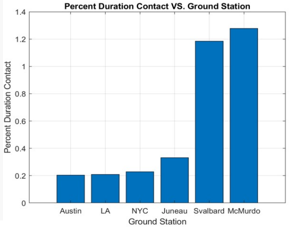
Elements

SMA	6857	km
ECC	0.0009999	
INC	97.319999	deg
RAAN	90	deg
AOP	90.000000	deg
TA	99.887749	deg

Epoch Format	UTCGreg
Epoch	19 Mar 2024
Coordinate System	EarthMJ2
State Type	Keplerian

Observer: GroundStation6

Start Time (UTC)	Stop Time (UTC)	Duration (s)
19 Mar 2024 12:19:57.659	19 Mar 2024 12:22:08.425	130.76583606
19 Mar 2024 13:52:47.394	19 Mar 2024 13:55:00.524	133.13075640
19 Mar 2024 15:25:21.591	19 Mar 2024 15:28:20.537	178.94601000
19 Mar 2024 16:58:26.444	19 Mar 2024 17:01:43.651	197.20705496
19 Mar 2024 18:32:51.836	19 Mar 2024 18:34:36.426	104.58998478
20 Mar 2024 08:45:16.993	20 Mar 2024 08:48:27.213	190.22031894
20 Mar 2024 10:18:37.327	20 Mar 2024 10:21:44.805	187.47824061
20 Mar 2024 11:51:59.879	20 Mar 2024 11:54:22.126	142.24734376
20 Mar 2024 13:24:59.717	20 Mar 2024 13:27:04.365	124.64812947
20 Mar 2024 14:57:33.311	20 Mar 2024 15:00:18.256	164.94494809
20 Mar 2024 16:30:24.359	20 Mar 2024 16:33:42.453	198.09441813
20 Mar 2024 18:04:16.151	20 Mar 2024 18:06:51.792	155.64080235
21 Mar 2024 08:17:17.213	21 Mar 2024 08:20:09.090	171.87715281
21 Mar 2024 09:50:31.433	21 Mar 2024 09:53:46.805	195.37172117
21 Mar 2024 11:23:55.343	21 Mar 2024 11:26:31.647	156.30366777
21 Mar 2024 12:57:04.500	21 Mar 2024 12:59:06.923	122.42245601
21 Mar 2024 14:29:42.102	21 Mar 2024 14:32:12.096	149.99336831
21 Mar 2024 16:02:22.847	21 Mar 2024 16:05:35.485	192.63770990
21 Mar 2024 17:35:50.825	21 Mar 2024 17:38:52.663	181.83878437
22 Mar 2024 07:49:18.657	22 Mar 2024 07:51:35.134	136.47743315
22 Mar 2024 09:22:21.562	22 Mar 2024 09:25:39.428	197.86582446
22 Mar 2024 10:55:44.835	22 Mar 2024 10:58:35.521	170.68574626
22 Mar 2024 12:29:01.085	22 Mar 2024 12:31:08.138	127.05320846
22 Mar 2024 14:01:46.608	22 Mar 2024 14:04:02.775	136.16697416
22 Mar 2024 15:34:20.880	22 Mar 2024 15:37:23.296	182.41648944
22 Mar 2024 17:07:29.996	22 Mar 2024 17:10:44.589	194.59240754
22 Mar 2024 18:42:11.712	22 Mar 2024 18:43:24.750	73.038539349
23 Mar 2024 07:21:35.561	23 Mar 2024 07:22:30.733	55.171980278
23 Mar 2024 08:54:08.375	23 Mar 2024 08:57:21.484	193.10892258
23 Mar 2024 10:27:29.005	23 Mar 2024 10:30:32.442	183.43669425
23 Mar 2024 12:00:49.704	23 Mar 2024 12:03:07.056	137.35112365
23 Mar 2024 13:33:45.280	23 Mar 2024 13:35:51.173	125.89297945
23 Mar 2024 15:06:17.430	23 Mar 2024 15:09:06.378	168.94807935
23 Mar 2024 16:39:11.447	23 Mar 2024 16:42:29.428	197.98107259
23 Mar 2024 18:13:11.470	23 Mar 2024 18:15:33.767	142.29691507



Task Activities for Mission Operation:

TA#1: Beta Angle and Sun Pointing Mode Validation

- Confirm whether Beta Angle for given elapsed days (0, 30, 60, 90): 90 ~ 180 days are symmetric
- Check whether satellite can align –y axis to sun vector in given elapsed days without significant attitude maneuver

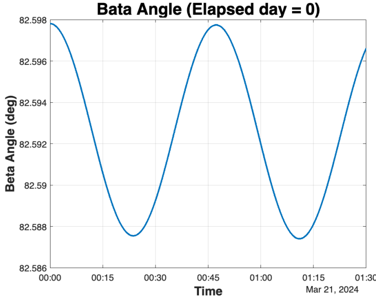
TA#2: Contact and Energy Transmission Mode Validation

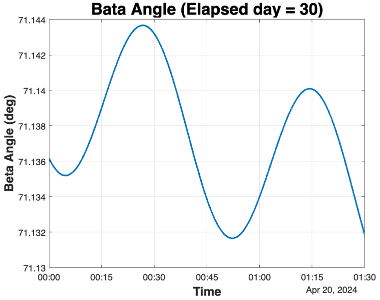
- Confirm whether satellite can maneuver adequately to fully utilize 100 ~ 200 seconds contact time.
- Check whether satellite can transit operation mode in 1 orbit, from sun-pointing mode to power transmission mode, and return to sun-pointing mode

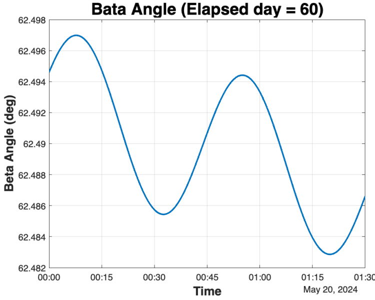
TA#3: Constellation Concept Study

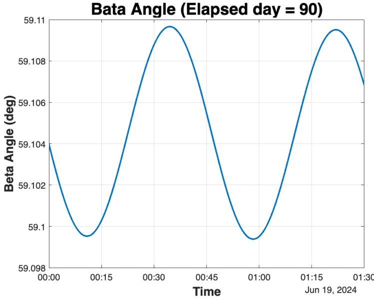
- From Orbit Analysis, we have found Contact time and contact opportunity can be significantly larger for high latitude area such as Svalbard or McMurdo
- We can proceed constellation concept study for these areas for continuous power transmission

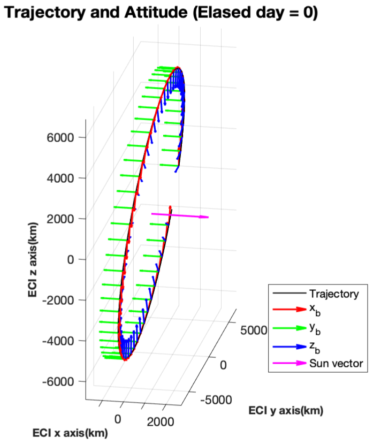
Case Study 1-1 : Dawn-Dusk Orbit & Beta Angle

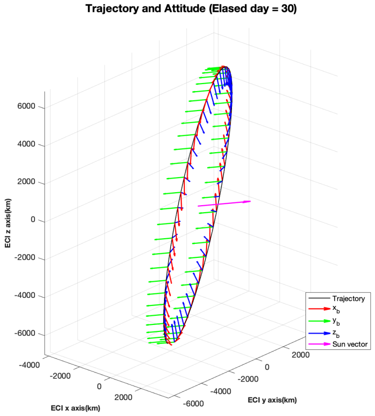


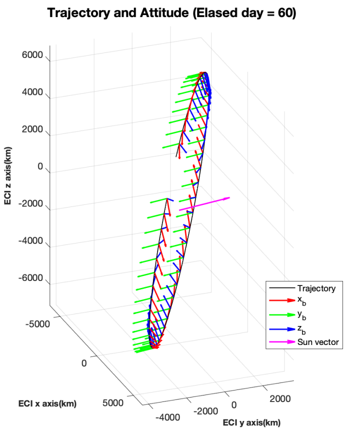


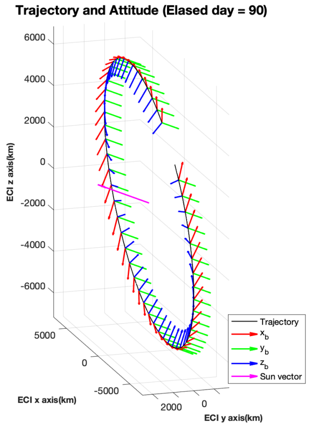






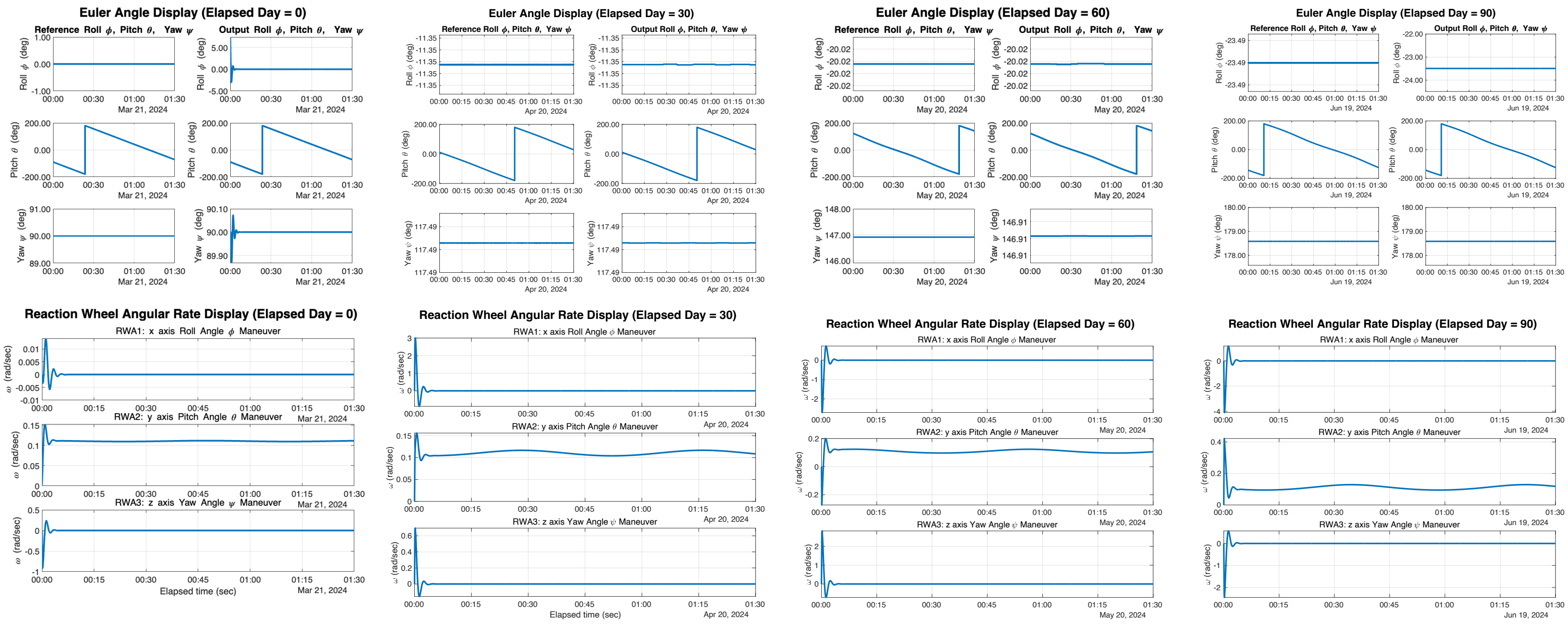






- Given MATLAB simulation matches the beta angle expressed by GMAT

Case Study 1-2 : Sun Pointing Mode Analysis



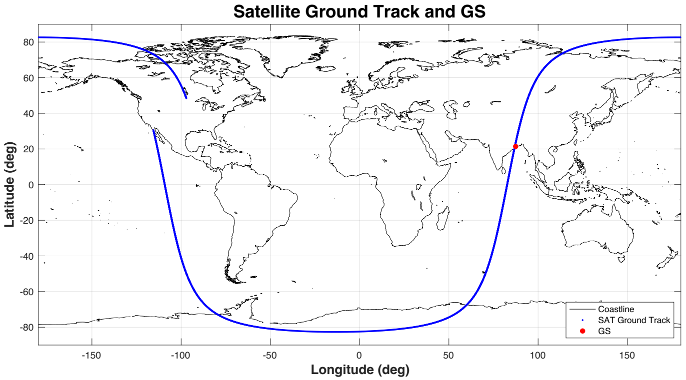
- Initially Nadir Pointing Mode, changed to Sun Pointing Mode
- No gimbal lock (roll = 90 deg), Controllable around one sequence

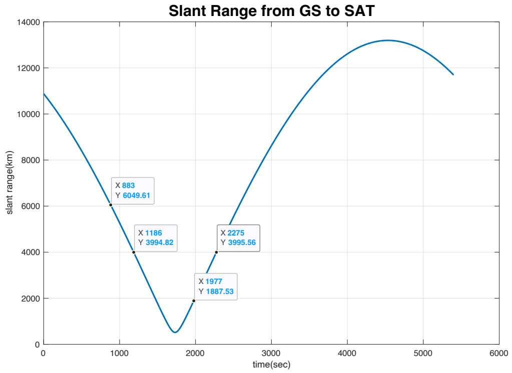
Case Study 1 : Discussion and Conclusion

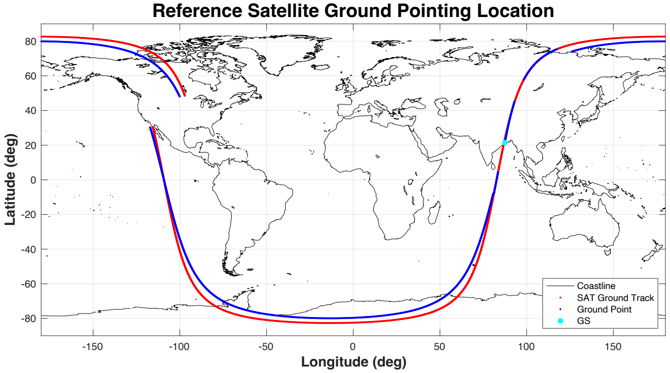
- **Dawn Dusk Orbit & Beta Angle Analysis Result**
  - We could show GMAT simulation result is identical to MATLAB simulation result of beta angle.
  - We could visualize sun vector and orbit plane for selected day throughout 90 days.
  - From the visualization, we could see the angle between orbit plane and sun vector changes, but remains close to orbit normal vector.
- **Sun Pointing Mode Analysis Result**
  - Mainly roll angle changes for different elapsed date, which reflects different beta angle for each elapsed date.
  - We need around 100 seconds to transit from nadir mode to sun pointing mode for each elapsed day environment.
  - But for every case, the gimbal lock is not occurred.
  - Tracking capability is good after the satellite transits to the sun pointing mode.
- **Overall Result**
  - We could show sun-pointing mode is valid for given satellite and controller specification in given orbit.

Case Study 2 : Energy Transmission Analysis

Simulation Setup:







Orbit and Ground Environment Specification

- Epoch: 06/19/2024 00:00:00 – Elapsed Day: 60 days
- Dawn Dusk orbit 6PM LTAN started 3/21/2024
- Ground Powerplant Location: [21.4284 N, 87.4145 E]
- Simulation Duration: 7200 Seconds

Proposed Command

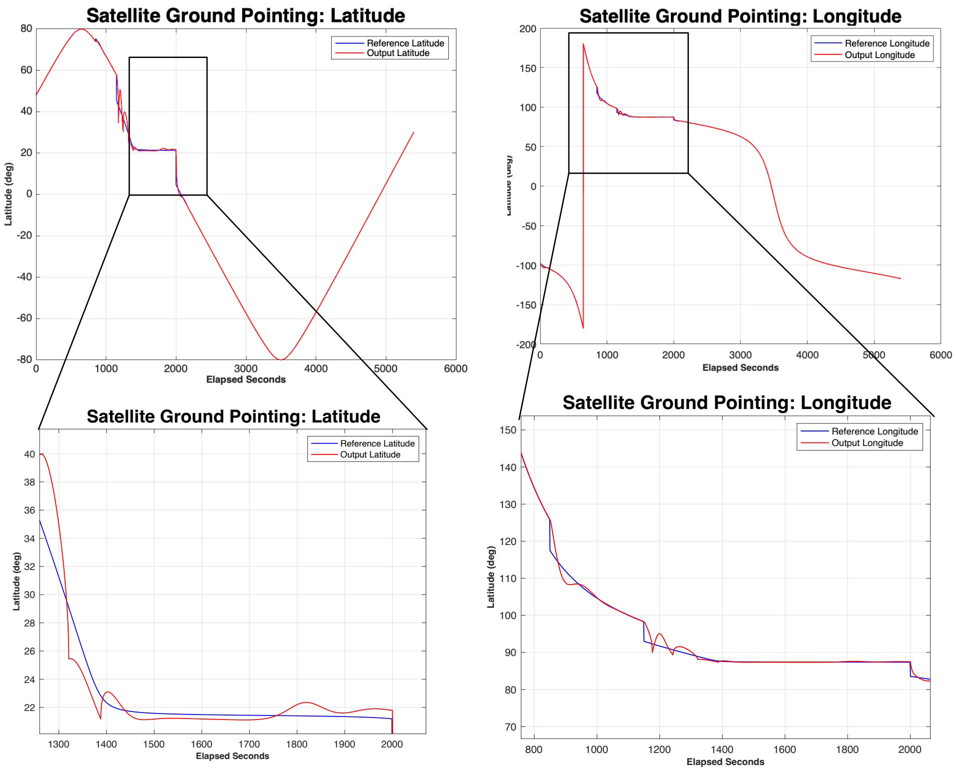
- Start Mode: Nadir Pointing. [1]
- Start – 850 sec: Sun Pointing [3]
- 851 – 1150 sec: Nadir Pointing [1]
- 1151 – 2000 sec: Power Transmission [2]
- 2001 – 2200 sec: Nadir Pointing [1]
- 2201 – end : Sun Pointing [3]

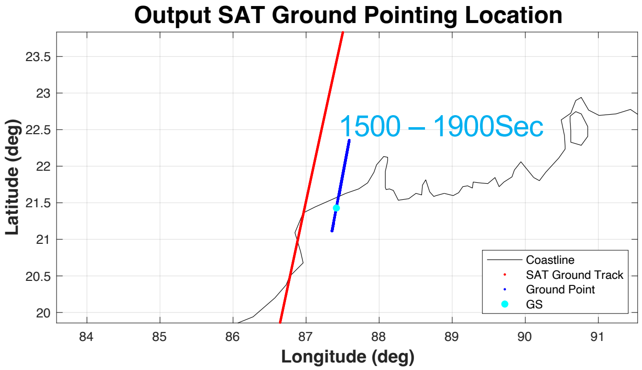
```
% initial operation mode
initial_operation_mode = 1;
% 1: Nadir Pointing Mode
% 2: Energy Transmission Mode
% 3: Sun Pointing Mode

operation_mode_vec(1:850) = 3;
operation_mode_vec(851:1150) = 1;
operation_mode_vec(1151:2000) = 2;
operation_mode_vec(2001:2200) = 1;
operation_mode_vec(2201:end) = 3;
```

Case Study 2-1 : Pointing Accuracy for Given scenario

Simulation Result 1: Pointing Accuracy



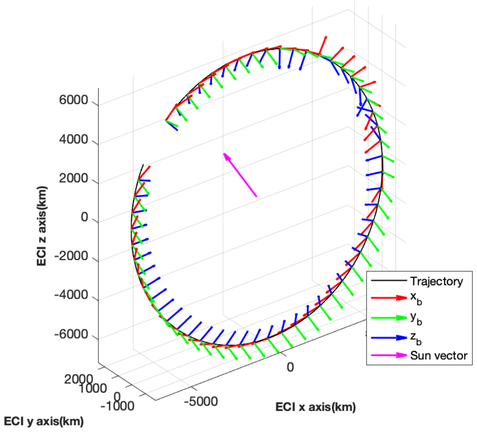


Proposed Command

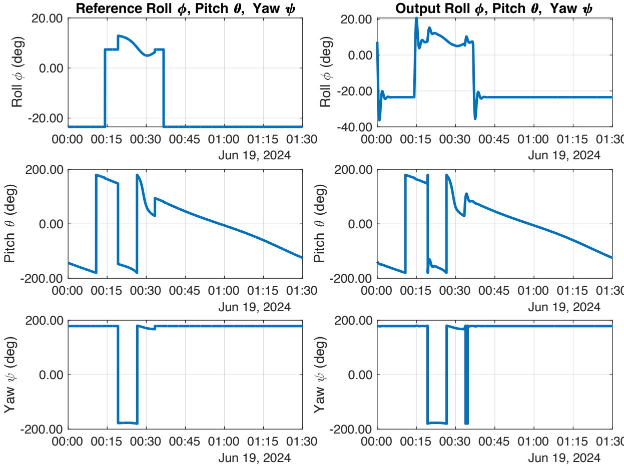
- Start Mode: Nadir Pointing. [1]
- Start – 850 sec: Sun Pointing [3]
- 851 – 1150 sec: Nadir Pointing [1]
- **1151 – 2000 sec: Power Transmission [2]**
- 2001 – 2200 sec: Nadir Pointing [1]
- 2201 – end : Sun Pointing [3]

Case Study 2-2 : Control Capability for Given scenario

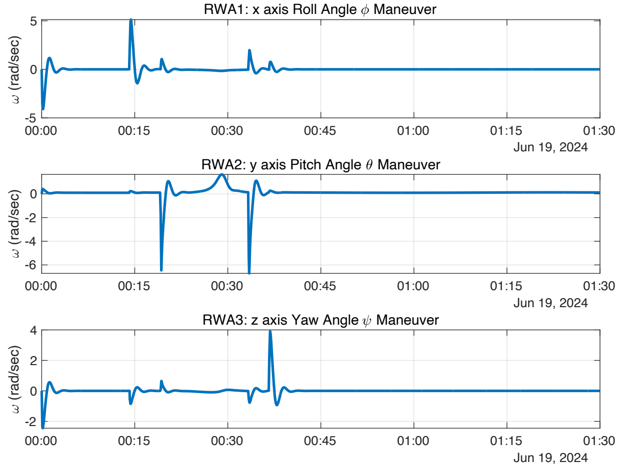
Output Trajectory and Attitude



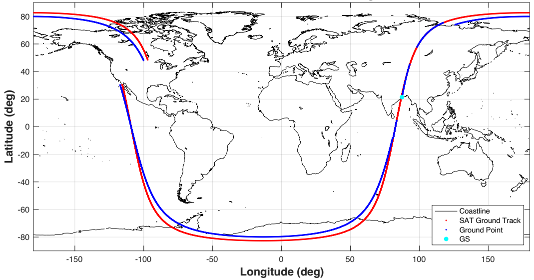
Euler Angle Display



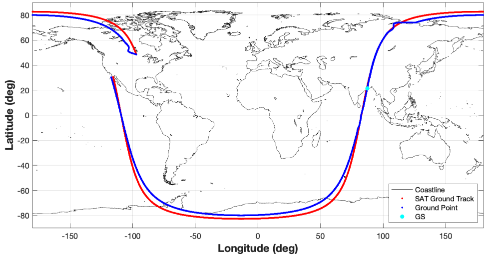
Reaction Wheel Angular Rate Display



Reference Satellite Ground Pointing Location



Output SAT Ground Pointing Location



Command

- Start Mode: Nadir Pointing. [1]
- 00:00:00 – 00:14:10 Sun Pointing [3]
- 00:14:11 – 00:19:10 Nadir Pointing [1]
- 00:19:11 – 00:33:20 Power Transmission [2]
- 00:33:21 – 00:36:40 Nadir Pointing [1]
- 00:36:41 – end : Sun Pointing [3]

Case Study 2 : Discussion and Conclusion

- **Pointing Accuracy Analysis Result**
  - Achieved +/- 0.5 deg pointing error for given of satellite body and controller specification
  - Remaining pointing error can be compensated by sophisticated beam maneuver process
  - Across track error is significantly lower than along track error. Therefore we should concentrate how to improve accuracy for along track error.
- **Control capability Analysis Result**
  - Achieved <5rad/s rotational rate of reaction wheel for all three axis for given energy transmission scenario. The tracking performance after stabilization of mode is good for all 3 modes.
  - Roll angle remains under +/- 50deg for the given scenario, preventing gimbal lock.
  - But, the overshoot in transferring the control mode is large. We should adjust controller gain for lowering the overshoot.
  - Yaw angle and Roll angle does not have significant change, but pitch angle changes continuously for a 3 modes. We should design pitch angle maneuver and control more carefully.
- **Overall Result**
  - In given physical specification of satellite and operation scenario, satellite could both achieve pointing accuracy and control capability.
  - But this specification will be changed, and we have to test simulations in various scenario.

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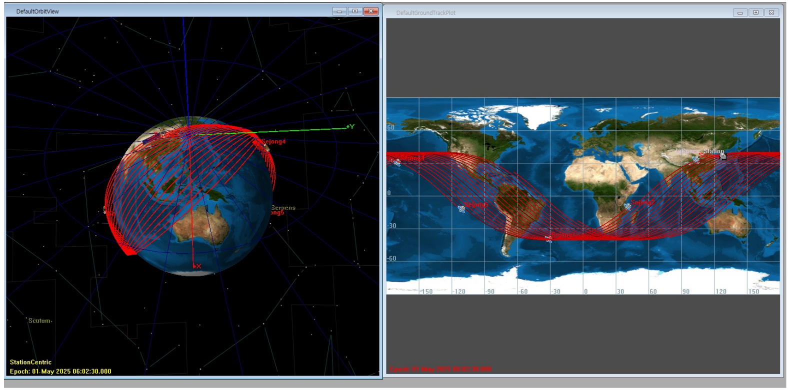
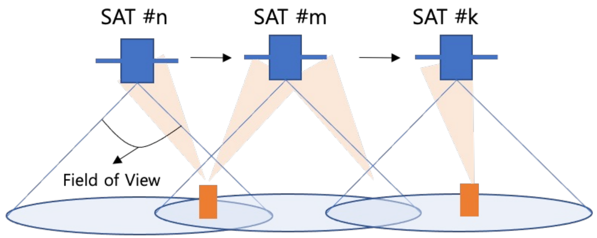
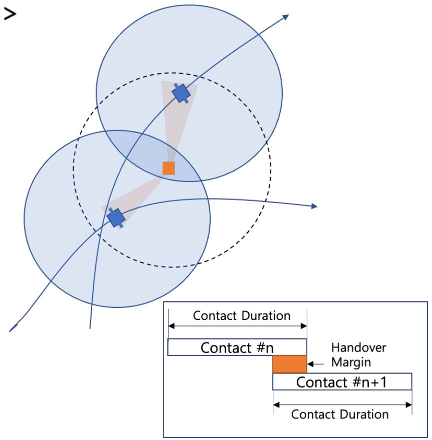
Case Study 3 : Constellation Concept Analysis

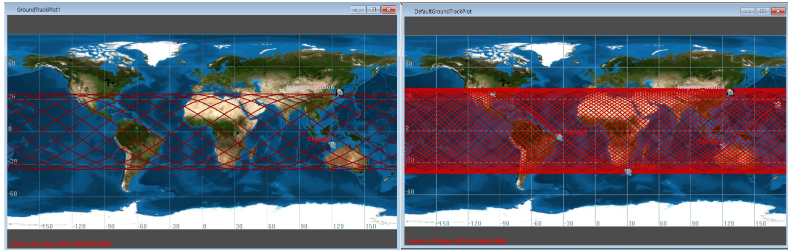


<Satellite Cluster Operation Cluster Operation Concept>



<Handover Process>





- From GMAT, we can see operating multiple satellite in. single orbit can make higher density of orbit, and may make continuous contact stream for certain period.
- Therefore, we can do continuous energy transmission CONOPS using this methodology

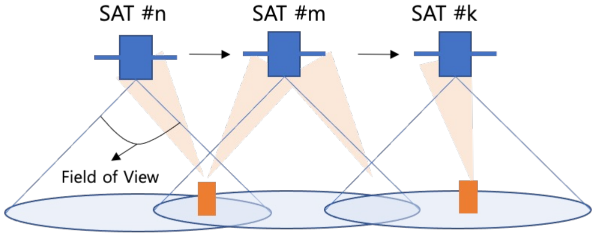
Case Study 3 - 1 : Continuous Contact

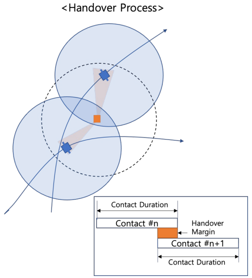
Simulation Parameter Setting

```
startTime = datetime(2024,3,21,0,0,0);
stopTime = startTime + hours(24);
sampleTime = 1; % seconds
sc = satelliteScenario(startTime,stopTime,sampleTime);
% Orbit Settings
semiMajorAxis = 6378000 + 500000;    %m
eccentricity = 1e-5;
inclination = 97.4022;  %degrees
rightAscensionOfAscendingNode = 90; %degrees
argumentOfPeriapsis = 0;     %degrees
trueAnomaly = 75; % Degrees
% Satellite Constellation Settings
sat1 = satellite(sc,semiMajorAxis,eccentricity,inclination,rightAscensionOfAscendingNode,...
    argumentOfPeriapsis,trueAnomaly,"OrbitPropagator","two-body-keplerian","Name","Sat1");
trueAnomaly = 60; % Allocate Different True Anomaly
sat2 = satellite(sc,semiMajorAxis,eccentricity,inclination,rightAscensionOfAscendingNode,...
    argumentOfPeriapsis,trueAnomaly,"OrbitPropagator","two-body-keplerian","Name","Sat2");
trueAnomaly = 45; % Allocate Different True Anomaly
sat3 = satellite(sc,semiMajorAxis,eccentricity,inclination,rightAscensionOfAscendingNode,...
    argumentOfPeriapsis,trueAnomaly,"OrbitPropagator","two-body-keplerian","Name","Sat3");
trueAnomaly = 30; % Allocate Different True Anomaly
sat4 = satellite(sc,semiMajorAxis,eccentricity,inclination,rightAscensionOfAscendingNode,...
    argumentOfPeriapsis,trueAnomaly,"OrbitPropagator","two-body-keplerian","Name","Sat4");
trueAnomaly = 15; % Allocate Different True Anomaly
sat5 = satellite(sc,semiMajorAxis,eccentricity,inclination,rightAscensionOfAscendingNode,...
    argumentOfPeriapsis,trueAnomaly,"OrbitPropagator","two-body-keplerian","Name","Sat5");
trueAnomaly = 0; % Allocate Different True Anomaly
sat6 = satellite(sc,semiMajorAxis,eccentricity,inclination,rightAscensionOfAscendingNode,...
    argumentOfPeriapsis,trueAnomaly,"OrbitPropagator","two-body-keplerian","Name","Sat6");

% Ground Power Plant Site
name = "Ground Power Plant";
minElevationAngle = 15; % degrees
geoSite = groundStation(sc, ...
    "Name",name, ...
    "Latitude", 30.2672, ...
    "Longitude", -97.7431, ...
    "Altitude", 0, ...
    "MinElevationAngle",minElevationAngle);
```

Simulation Result





Source	Target	StartTime	EndTime	Duration	Contact_Margin
SAT 1	AUSTIN	21-Mar-2024 12:53:28	21-Mar-2024 12:59:24	356	
SAT 2	AUSTIN	21-Mar-2024 12:57:24	21-Mar-2024 13:03:16	352	0:02:00
SAT 3	AUSTIN	21-Mar-2024 13:01:20	21-Mar-2024 13:07:07	347	0:01:56
SAT 4	AUSTIN	21-Mar-2024 13:05:17	21-Mar-2024 13:10:56	339	0:01:50
SAT 5	AUSTIN	21-Mar-2024 13:09:16	21-Mar-2024 13:14:45	329	0:01:40
SAT 6	AUSTIN	21-Mar-2024 13:13:15	21-Mar-2024 13:18:32	317	0:01:30

- **Contact Margin = SAT (N) End time = SAT (N+1) Start time**
- We can see continuous contact for certain incidence for 15 degree True Anomaly Difference

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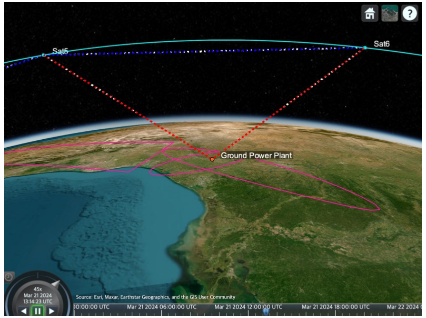
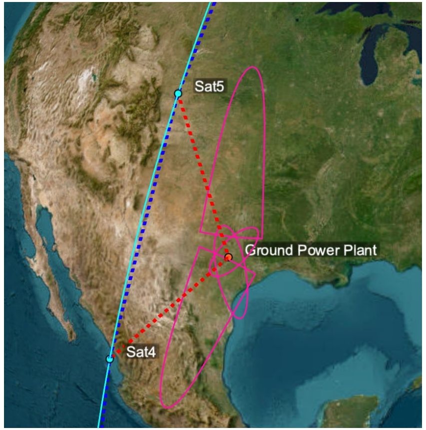
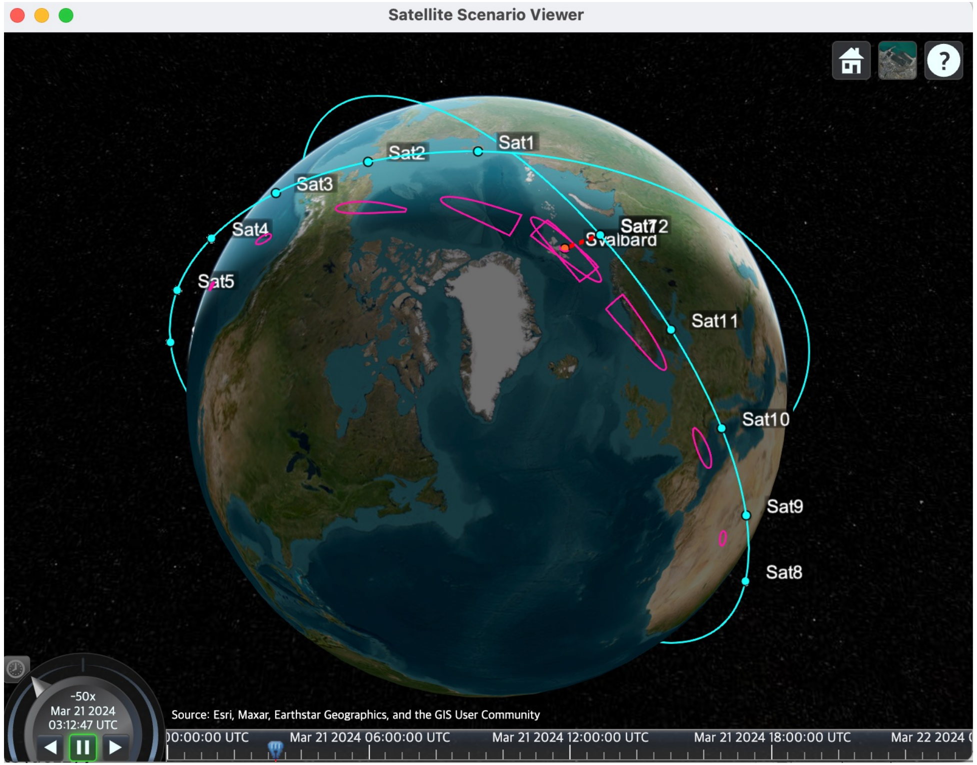
Case Study 3 - 2 : Simulation Visualization







Case Study 3 : Conclusion and Discussion

- **Continuous contact analysis**
  - We could generate contact chart for given scenario from each satellite to each ground stations
  - Allocating satellites for 15 degrees step for true anomaly in same orbit can make continuous contact for certain scenario.
  - In minimum elevation 15 degrees, satellite have up to 300 – 350 seconds contact time. And contact margin is around 100 seconds.
  - Ground station in higher latitude can make more contact per day than ground station in lower latitude.
- **Simulation Visualization result**
  - We could visualize the contact sequence for multiple viewpoints.
  - We could visualize the inter-satellite connection availability for given mission.
  - But adding multiple satellite and multiple ground plants will have more calculation cost and processing time.
  - We could visualize satellites operating in multiple orbits with different RAAN. Which turnout to be good approach for continuous contact in high latitude area.
- **Overall Result**
  - We could show both continuous contact simulation and visualization process in this case study.
  - We should simulate in multiple scenario with various environments. Also design more detailed constellation concept.

VIII. Conclusion and Future Study Topic

- The concept studies for operational environments generated from other sub-topic (Orbit, Energy Transmission, Solar Energy Acquisition) is presented.
- For all concept studies, the operation is successful for given satellite specification and orbit.
- For the pointing accuracy and control capability analysis, we can design better satellite design for lowering the overshoot and response time.
- We could model the constellation concept and contact chart for analyze it, so we can proceed detailed research on this concept.
- In the future, we will quantify how much energy is received and how much energy is transmitted from satellite by given mission scenario.
- Also, we will proposed detailed constellation concept, both for continuous energy transmission to inter-satellite charge technique and transmitting energy to cislunar regime.

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