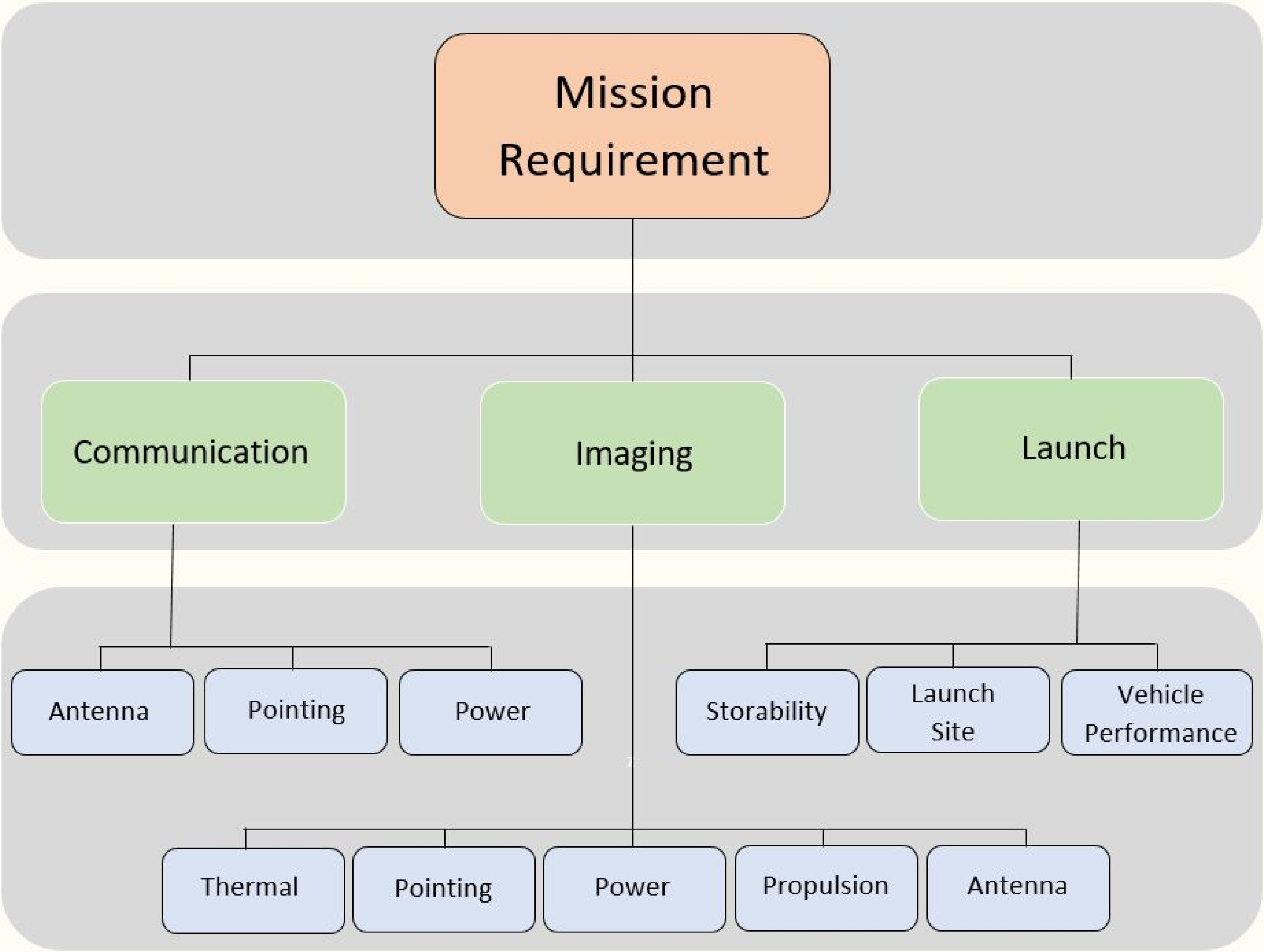
Conceptual Design Review for an Emergency Relief Constellation

Presentation Outline



Emergency Relief Constellation Mission Review

Mission Goals

- Rapid response communications and images of a 500x500 km disaster area

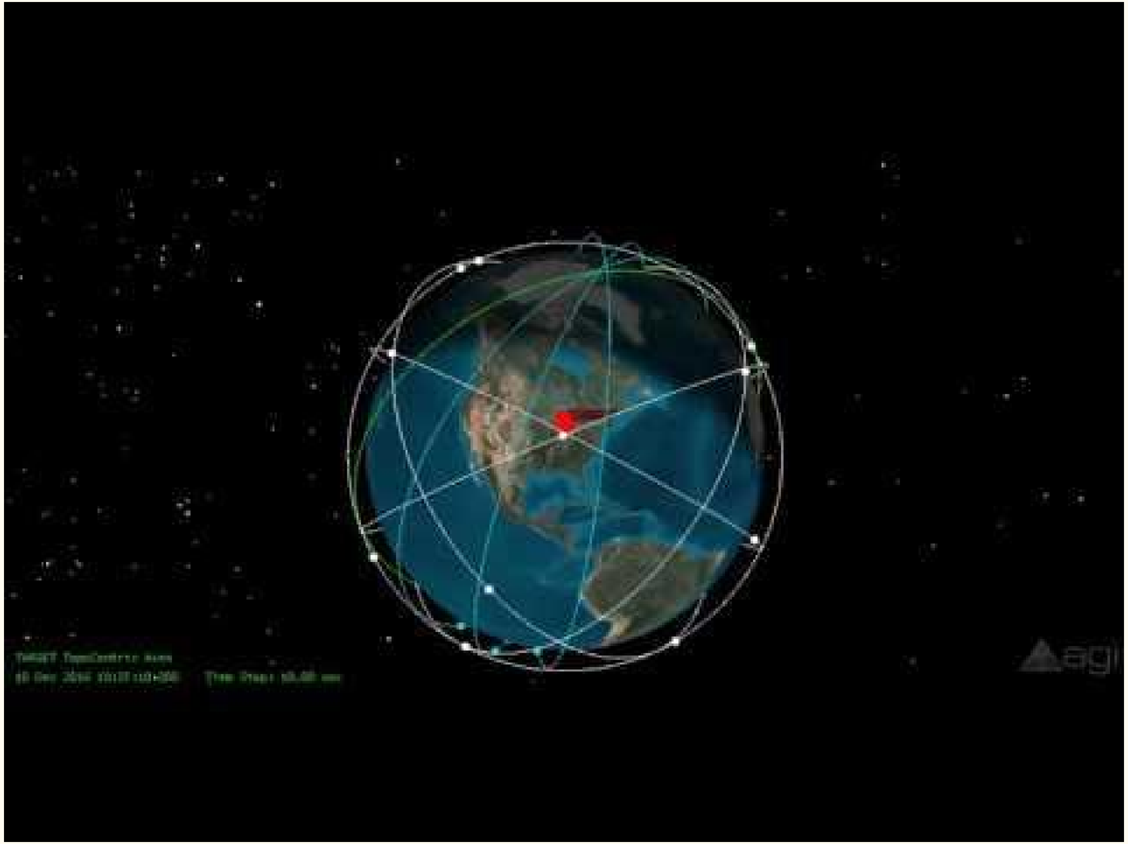
Broad Mission Overview

- Full system must be on standby for a maximum of 5 years
- 25% capability after 12 hours, full capability after 24 hours for 6 months
- 240 total minutes of repeater access/day
- No more than 120 minutes between communication
- 5 meter resolution for thermal IR, near IR, and visible images taken 4x/day

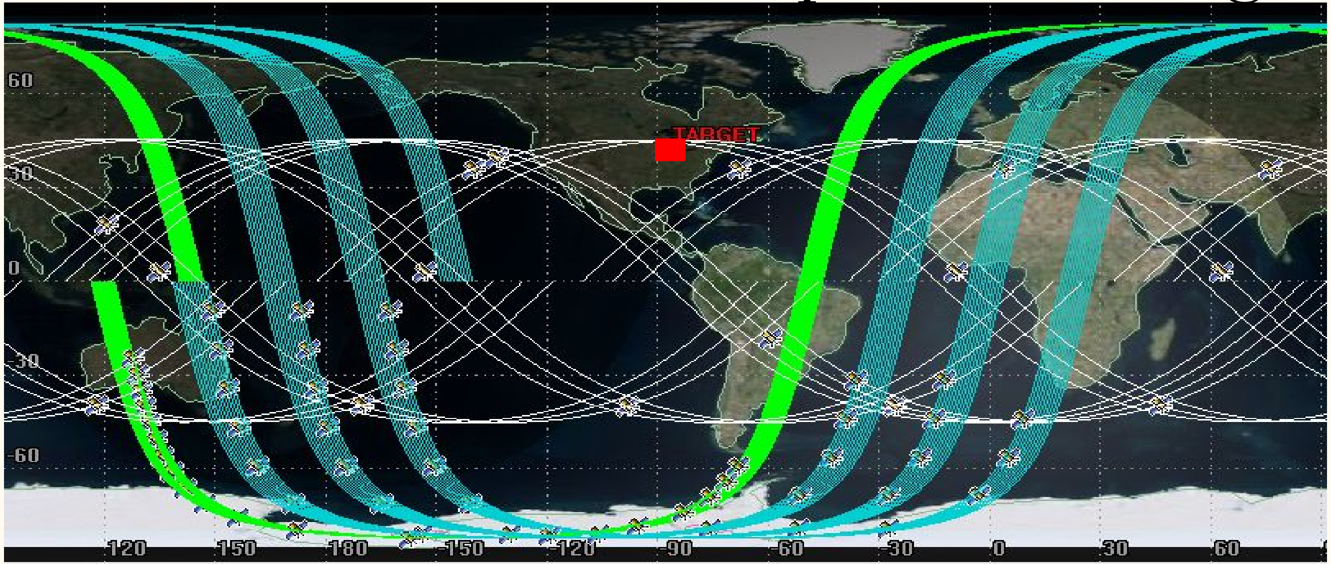
Key Trades and Associated Decisions

Trade	Decision	
	Communications	Imaging
LEO vs. MEO/GEO	LEO	
Circular vs. Elliptical Orbits	Circular	
Variable vs. Invariable Orbits	Variable	
Separate Communications/Imaging vs. Combined	Separate	
Separate Imaging vs. Combined		Combined
Correcting Orbits vs. Non-correcting	Non-correcting	Correcting

Orbits Visualization



Orbital Scheme: Example at 45 Degrees Latitude



White = Communications Satellites

Green = Imaging Satellites (Full Area Photo)

Blue = Imaging Satellites (15% Photos)

Red = Target Area

Communications:

- Altitude: 625 km
- Inclination of orbit based on latitude of disaster

Imaging:

- Altitude: 561 km
- 4 Sun-Synchronous Constellations

Communications Satellites

- Orbit Properties and Numbers of Satellites and Planes

	Best Case	Worst Case
Latitudes (degrees)	0 - 5	30 - 70
Number of Planes	1	5
Number of Satellites	6	16

- Planes and satellites equally spaced
- Number of planes and satellites calculated to meet provided requirements at worst case launch scenario
    - Does not account for redundancy

Number of Planes/Sats

Communications Satellites

- Antenna Type and Information
  - Gain: 3 dB
  - Microstrip Monopole Antenna (MMA)
  - Beam Width: 150 degrees
  - Power: 1.8W per channel
- Satellite Specifications
  - Mass: 10's kg
- Attitude Determination and Control System
  - Nadir Pointing within ~100 degrees

Transmitter Gain Trade Pointing Determination MMA Trade

Communications Satellites: Link Budget

Link Budget	Satellite	Ground
Frequency	0.3 GHz (UHF)	
Antenna:	Microstrip Monopole Antenna (MMA)	Omnidirectional
Beam Width: (degrees)	150	360
Power:	1.8 W	5 W
Gain:	3 dB	0 dB
Noise Temp:	250 K	614 K
Space Loss	175 dB	
Signal to Noise Ratio	13 dB	
Margin	~10 dB	

Imaging Satellites

- Orbit Properties and Numbers of Satellites and Planes:

	Best Case	Worst Case
Latitudes (degrees)	0 - 3	3 - 82
Number of Planes	3	4
Number of Satellites	19	55

- Planes and satellites are spaced accordingly to see the disaster area 4x/day and provide sufficient image overlap
- Number of planes and satellites calculated to meet provided requirements at worst case launch scenario
  - Does not account for redundancy

Many vs Few Trade Daylight Hours

Imaging Satellites

- Sensor and Image Information
  - Swath Width: 29 km
  - 1 km of overlap between images
  - Aperture Lens Diameter: ~100 mm
  - Cost: $100,000's per imaging system
  - Power: ~40 W/imaging system
- Satellite Specification
  - Mass: 10's kg
- Thermal IR
  - Aperture lens diameter to meet 5 m resolution: ~2.3 m
  - Proposed Resolution: ~72 m

Imaging Satellites

- Attitude Determination and Control System
  - Slew up to 12 degrees off nadir
- Propulsion System
  - Micropropulsion needed for orbital maintenance
  - Estimated delta-V required over 6 months: ~60 m/s
- Thermal System
  - Maintain thermal IR sensor temperature
  - Operating Range: -213 ^{o}C to -173 ^{o}C

Imaging Satellites: Link Budget

Average pass time:
5 minutes

Dowlinking for entire pass, data rate: 40 Mbps

Compatible with X-Band independent allocation frequency

Link Budget	Satellite	Ground
Frequency	10.5 GHz (X-Band)	
Antenna:	Patch	Dish
Beam Width (degrees):	16 x 30	Size Dependent
Power:	10 W	
Gain:	16 dB	38 dB
Noise Temp:	250 K	
Space Loss	173 dB	
Signal to Noise Ratio	10 dB	
Margin	10 dB	

Launch Response Time Requirements

- Requirement favors building a launch pad to avoid launch delays from other launches

- Storability: 5 year storage and 12/24 hour response time requirements
  - Several viable options for storable propellants exist
  - Examining payload integration options

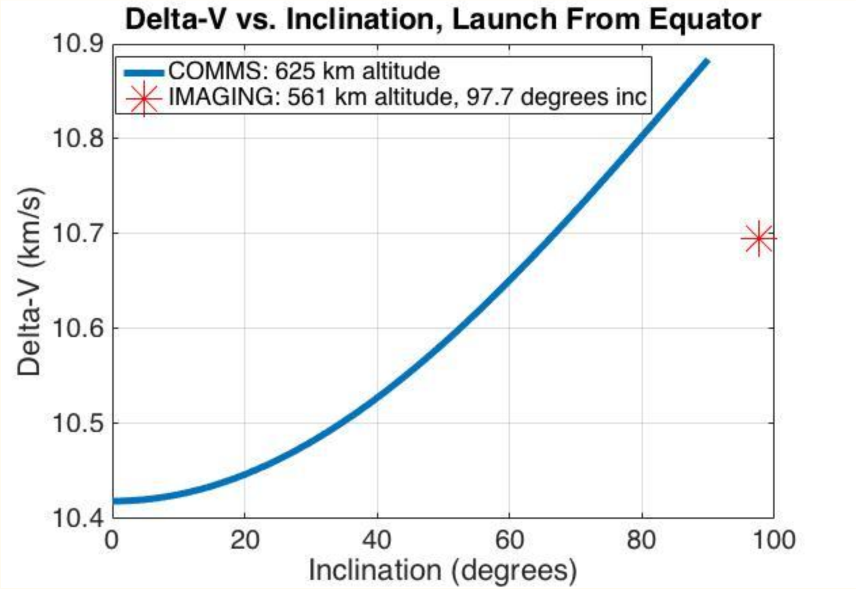
- Phasing Schemes
  - Options include upper stage phasing, satellite micropropulsion phasing, or both
  - Optimize phasing scheme for both response time and Δv

Phasing Chart
Propellant Options

Launch Performance Requirements

- Equatorial launch is favored for completely variable communications orbits

	Communications Satellites	**Imaging Satellites**
Altitude (km)	625	561
Inclination (degrees)	0-90	97.7
Payload Mass Per Launch (kg)	10 - 600	10 - 1900



Moving Forward: Open Trades

- Communications
    - Mobile or fixed ground stations
- Imaging
    - Different types of micropropulsion systems for orbital maintenance
    - Custom vs COTS sensors and camera systems
- Launch
    - Vertical launch vehicle vs. aircraft assisted launch
    - Propellant type
    - Number of stages on launch vehicle
    - Ground operations

Questions?

Slide Repository

Trades Extra Slides

LEO vs. MEO/GEO

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
	A. LEO	• Quick to get to • Accomplished with small satellites • De-orbits in under 25 years	• Higher number of planes/satellites • Quick pass times	**Accepted**
	B. MEO/GEO	• Reduced number of satellites • Lengthy Pass Times	• Expensive • Large satellites • Response time difficulties • Unnecessary for 6 month mission	**Rejected**

Return

Circular vs. Elliptical Orbits

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
	A. Circular	• Little/No orbital maintenance	• Quick passes over target	**Accepted**
	B. Elliptical	• Increased time over target	• High altitudes at apogee • Orbit corrections to maintain apogee	**Rejected**

Return

Variable vs. Invariable Orbits

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
	A. Variable	• Reduces number of orbital planes and allows for fewer launches	• Can cause delays in response time	**Accepted**
	B. Invariable	• Faster response time because orbits do not need to be calculated	• Unable to meet imaging requirements • Greatly increases number of planes	**Rejected**

Return

Separate Communications/Imaging vs. Combined

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
	A. Separate Comms/Imaging	• Reduced complexity satellites • Smaller components • Requirements achieved differently	• More satellites/planes	**Accepted**
	B. Combined Functionality	• Reduced number of satellites	• Large, complex satellites	**Rejected**

Return

Separate Imaging vs. Combined Imaging Function

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
	A. Separate Imaging Functions	• Decreased complexity per satellite	• More satellites required • Increases cost per mission	**Rejected**
	B. Combined Imaging Functions	• Fewer satellites required • Greatly reduced cost/number of launches	• More complex thermal subsystem • Adds size and mass	**Accepted**

Correcting Orbits vs. Non-Correcting Orbits

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
Communications	**A. Correcting Orbits for Comms**	• Longer pass times towards EOL	• Addition of on board propulsion	**Rejected**
	B. Non-Correcting Orbits for Comms	• No need for on board propulsion	• Lower pass times towards EOL	**Accepted**
Imaging	**C. Correcting Orbits for Imaging**	• Maintain daily ground track	• More mass for propulsion system	**Accepted**
	D. Non-Correcting Orbits for Imaging	• No need for on board propulsion	• Drag pulls down altitude • J2 then affects ground track	**Rejected**

Return

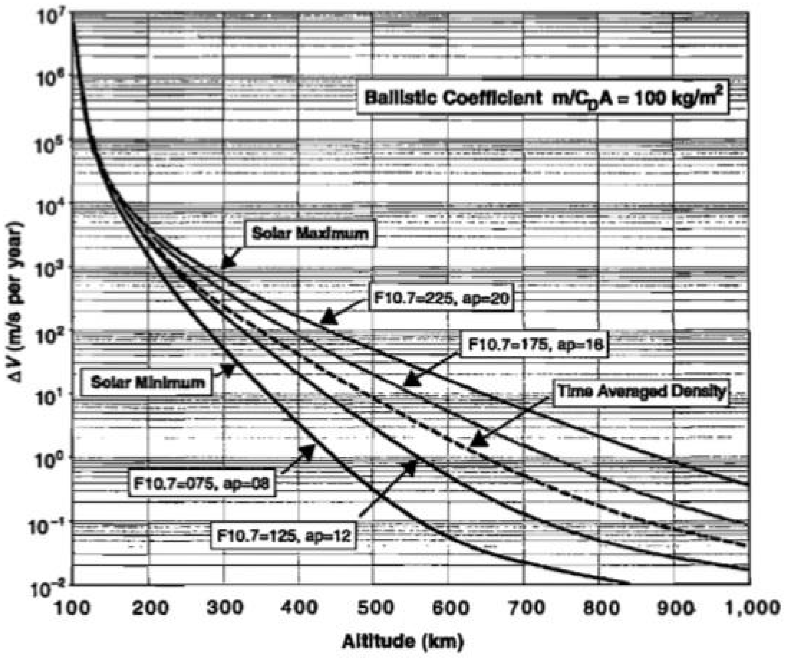
Orbits Repository

Best and Worst Case Latitudes (Communications)

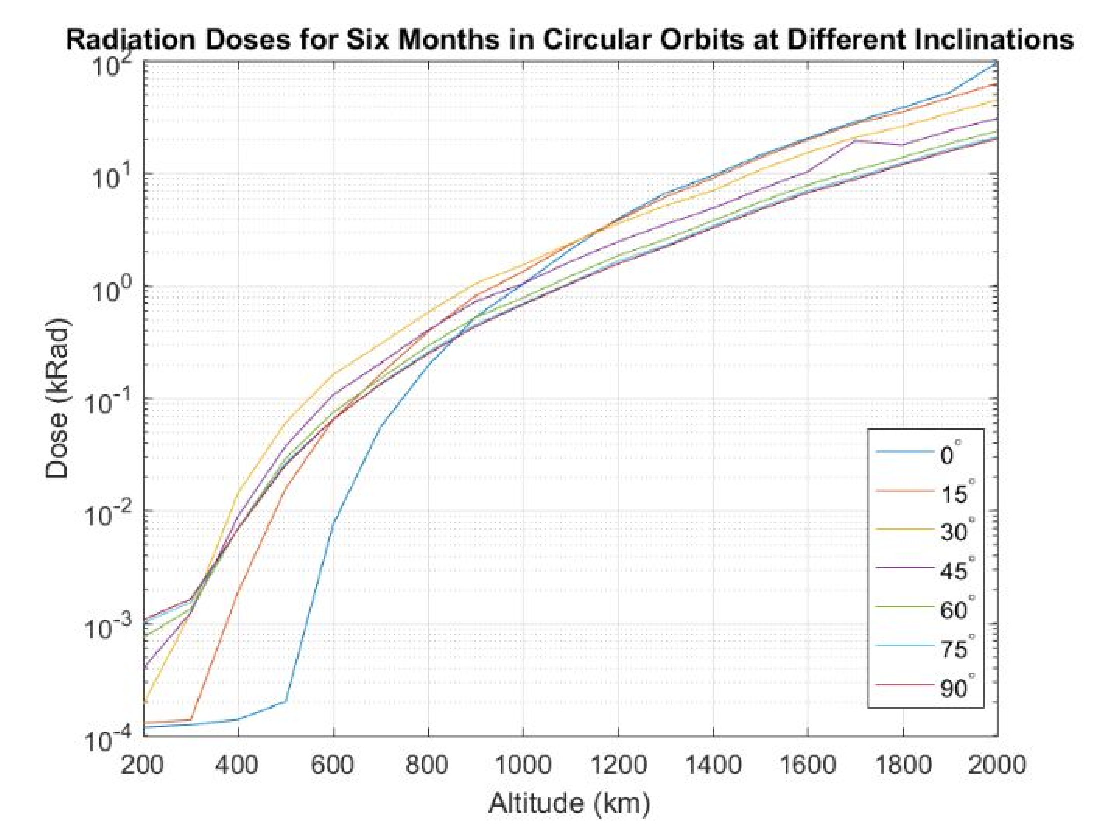
Number of Planes	Number of Satellites	Semimajor Axis (km)	Inclination (degs)	Eccentricity	Argument of Perigee (degs)	Latitude (degs)
1	6	7003	0	0	0	0
1	6	7003	0	0	0	5
3	11	7003	10	0	0	10
5	15	7003	15	0	0	15
5	15	7003	20	0	0	20
5	15	7003	25	0	0	25
5	16	7003	30	0	0	30
5	16	7003	35	0	0	35
5	16	7003	40	0	0	40
5	16	7003	45	0	0	45
5	16	7003	50	0	0	50
5	16	7003	55	0	0	55
5	16	7003	60	0	0	60
5	16	7003	65	0	0	65
5	16	7003	70	0	0	70
4	13	7003	75	0	0	75
4	13	7003	80	0	0	80
3	9	7003	85	0	0	85

Return

Drag Perturbation DeltaV

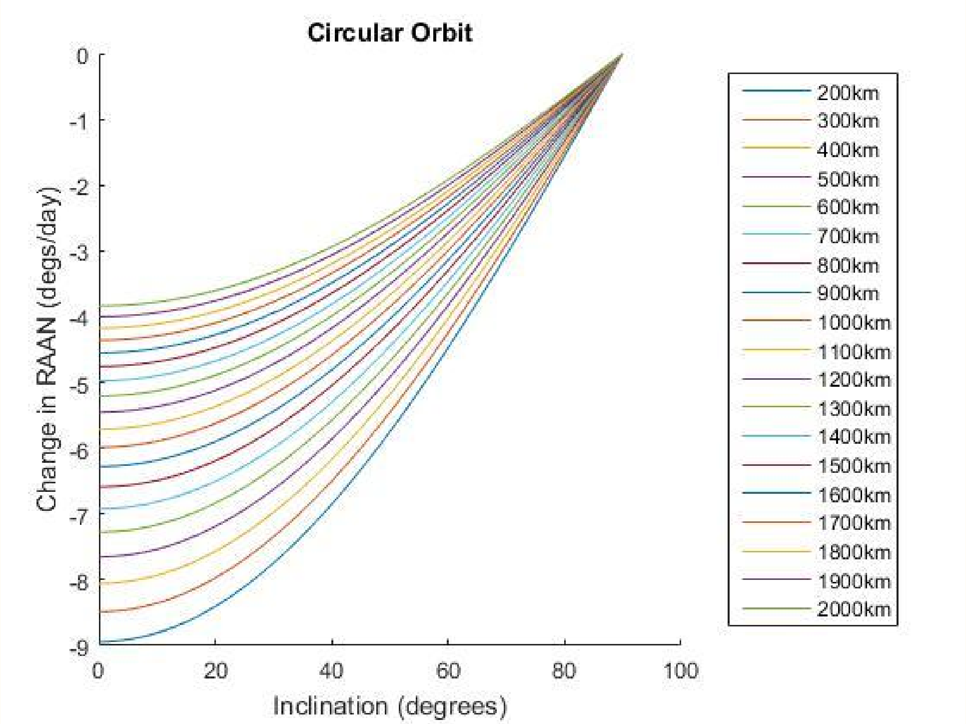


Radiation Exposure

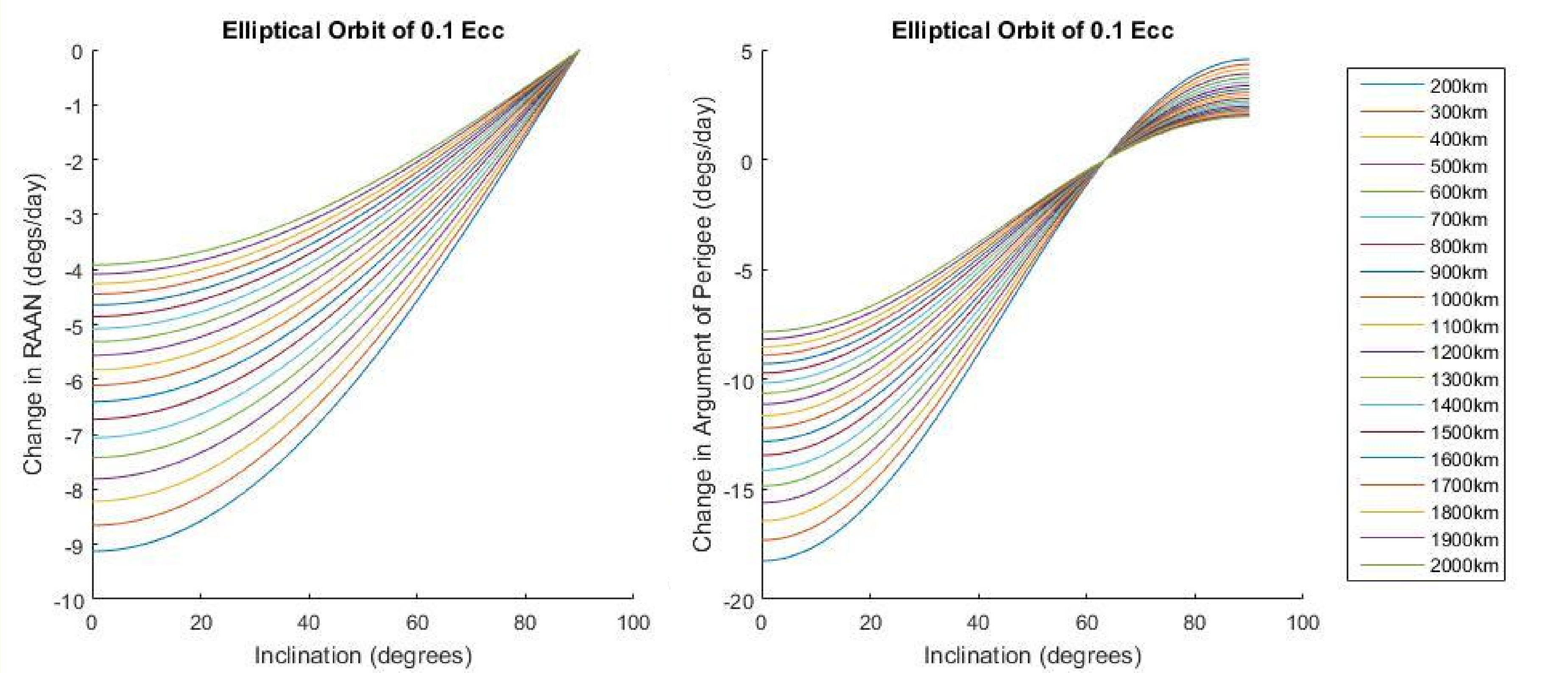


- Dose values are for a spacecraft modeled with 0.7mm of Aluminum shielding.

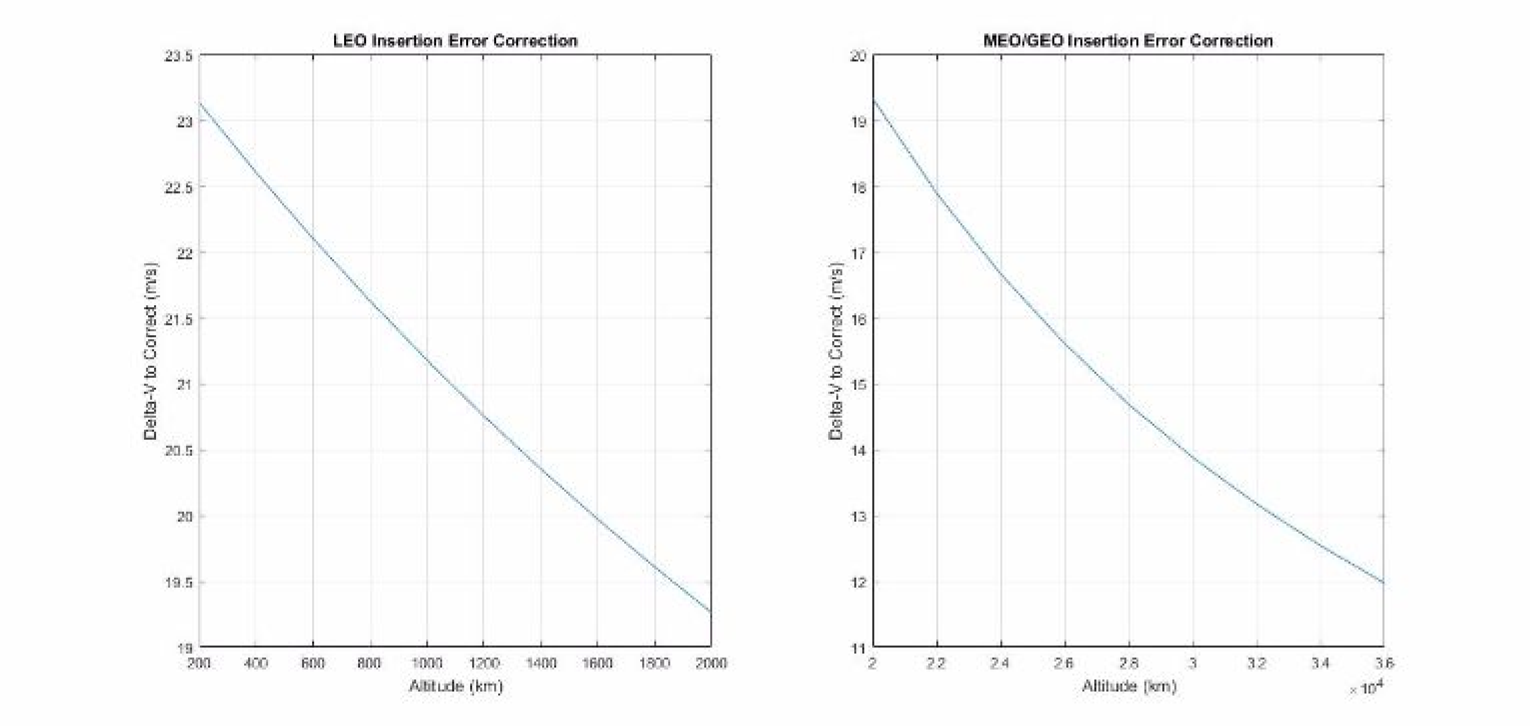
Orbital Perturbations: Circular



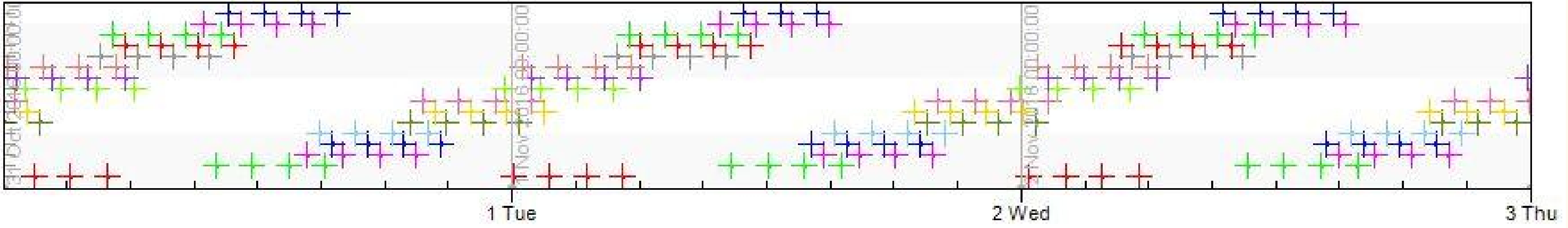
Orbital Perturbations: Elliptical (0.1 ecc example)



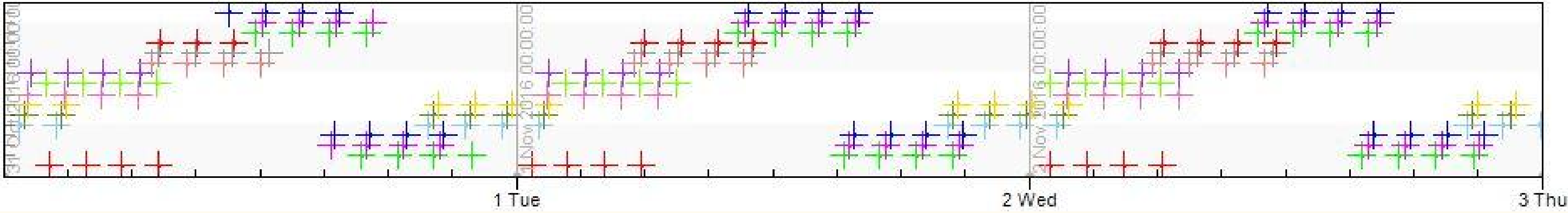
Upper Stage Insertion Correction (Delta-V)



Communications Satellites Coverage Beginning of Life vs End of Life



Initial Coverage of Satellites at a semimajor of 7003 km and inclination of 35° for a latitude of 35°



Coverage of satellites after they've been propagated for 6 months with all the perturbations. Resulted in continuous coverage from BOL to EOL.

Communications Repository

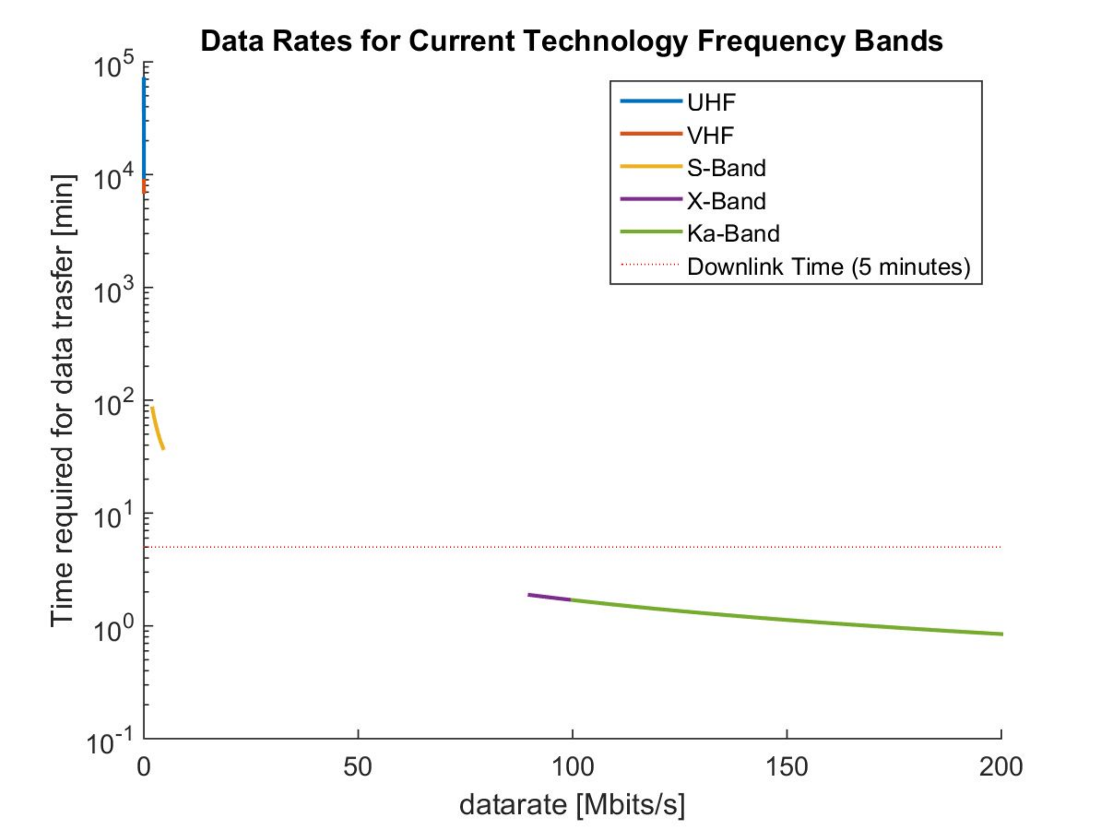
Transmit Repeater Trade (UHF)

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
UHF Repeater	A. MMA	• Low pointing requirements (wide beam) • Non-deployable • Form fitting	• Expensive	**Accepted**
	B. Monopole	• Cost Effective	• Obtrusive • Beam Gap • Complex/ Deployable	**Rejected**
	C. Patch	• Wide Beam • Form fitting	• High Pointing • Expensive	**Rejected**

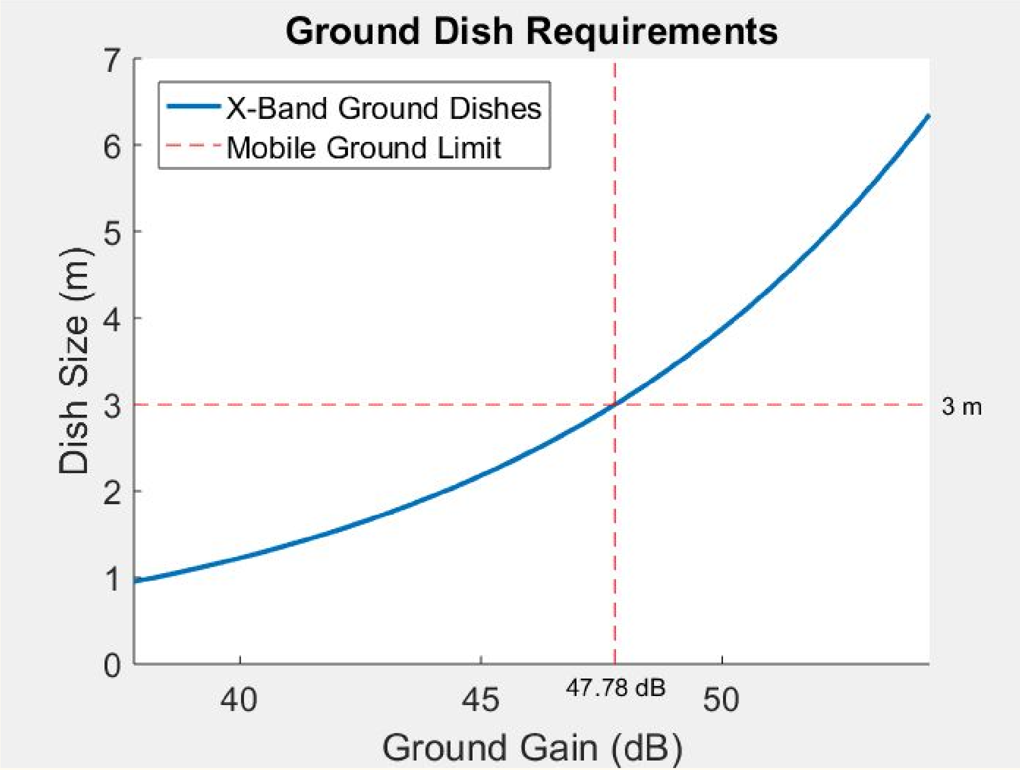
Imaging Downlink Trade

Major Trade Element	Choice(s) Considered	Pros	Cons	Status
Imaging Downlink Frequency	**A. UHF**	Already being used by repeater Cost effective	Very long download time	Does not meet requirements
	B.VHF	Cost effective	Very long download time	Does not meet requirement
	C. S-band		Long download time	Does not meet requirement
	D. X-band	Fast download	Expensive	Proposed option
	E. Ka-band	Fast Download	Expensive Attenuation	Overdesigned for requirement

Data Rates for Data Bands

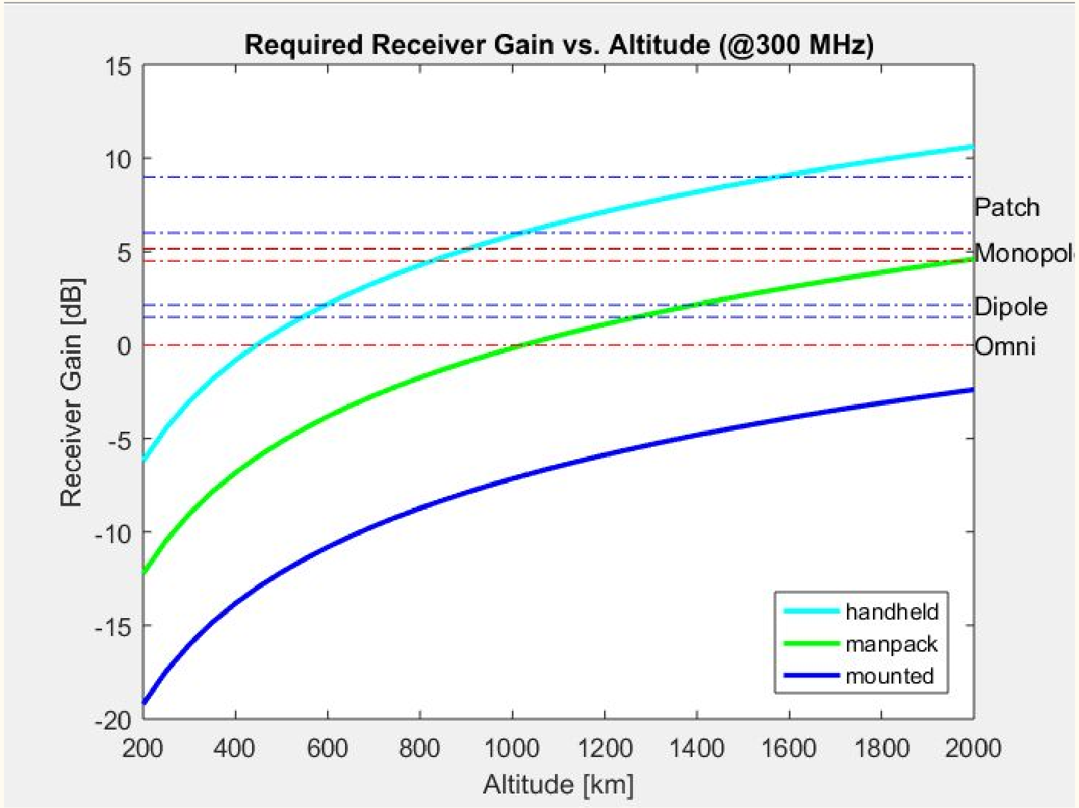


Ground Station Comms (Downlink)



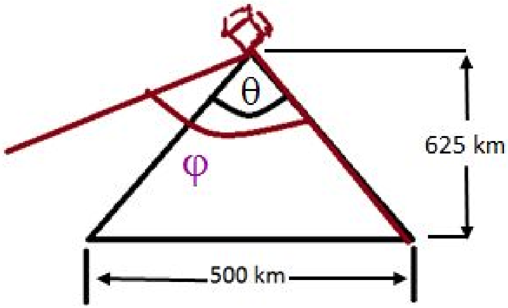
- Mobile limit based on cargo plane size restrictions

Transmitter Gain Trade (UHF)



Return Comms

Pointing Requirement Determination



$$\varphi = 150°$$

$$\theta = 2 * \tan^{-1}\frac{250\ km}{625\ km} = 44°$$

$$Minimum\ Pointing = \varphi - \theta = 106°$$

Imaging Repository

Small vs Large Imaging Satellite

System	Swath Width	# of Sats	Data per Sat per Day	Estimated Cost (imaging system)	Total Cost (imaging system)
10's kg	29 km, Max slew: 32 km	19 in one plane and 12 in each of the other 3 planes total = 55	1.42 GB	$100,000’s	$10,000,000’s
100's kg	68.6 km, Max Slew: 77 km	8 in one plane and 3 in each of the other 3 planes total = 15	4.00 GB	$10,000,000’s	$100,000,000’s

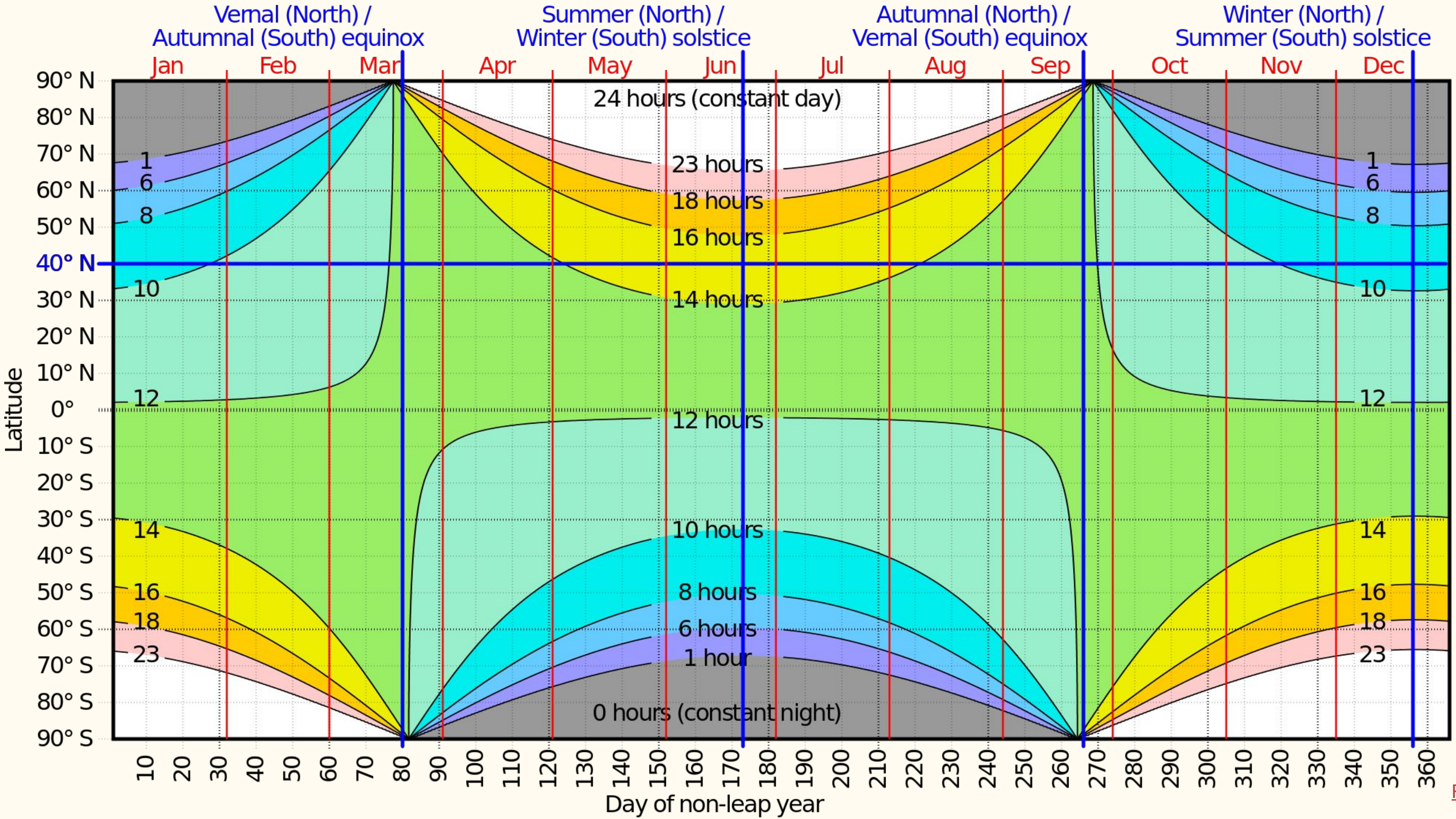
Return

Additional Image Specs

- Pixels per image:
  - Visible: 23.2 MP
  - Near IR: 23.2 MP
  - Thermal: 0.11 MP
- Daylight Hours (Worst Case)
  - 60º Latitude ~ 6 hours
  - 70º Latitude ~ 1 hour
- Cooling System
  - Mass ~ 200g
  - Power ~ 25 W
  - Fits in 3U Cubesat

Return

Daylight Considerations



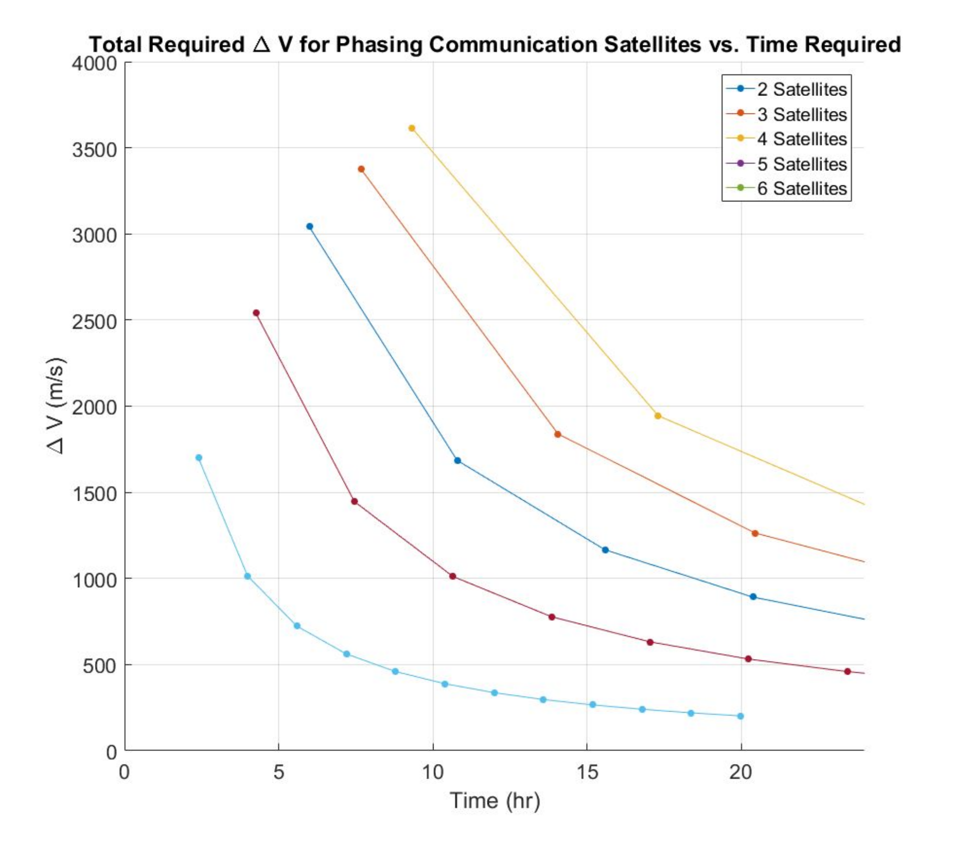
Return

Launch Repository

Propellant Storability

Propellant Type	**Propellant**	**Storability**	**Sea Level Specific Impulse (seconds)**
Solid	Composite HTPB	5-20 yr storage in chamber	280-300
Liquid Bi-propellant (Hypergolic)	Hydrazine/UDM, NTO	Stable Fuel Storage	290-310
Monopropellant	Hydrazine	Over 15 year storage	202-235

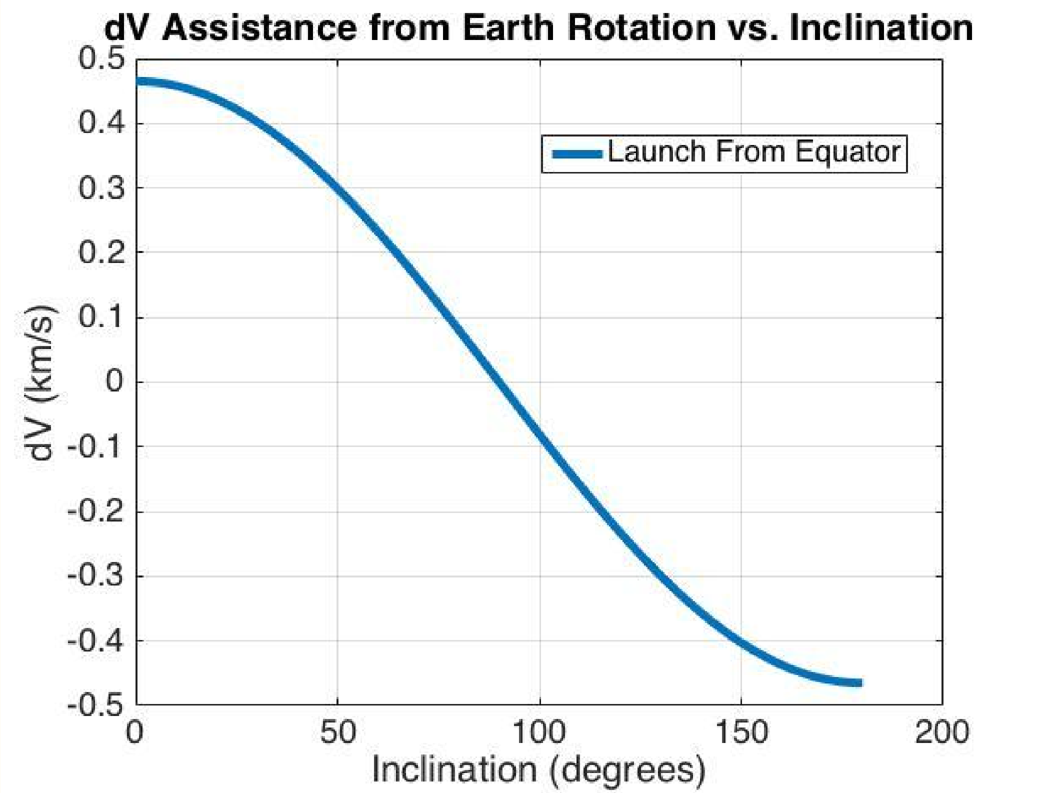
Delta-V for Phasing Maneuvers



- Assuming satellites are released one at a time by a single upper stage that performs the phasing
- Times could be significantly reduced if each satellite had propulsion

Return

Delta-V assistance from Earth’s Rotation



Inclination Ranges from Existing Launch Pads

Launch Site	Location	Average Inclination Range (degrees)
Cape Canaveral	28.5 N, 81.0 W	25 - 55
Vandenberg AFB	34.7 N, 120.6 W	60 - 120
Alcantara, Brazil	2.3 S, 44.4 W	2.5 - 110
Satish Dhawan	13.7 N, 80.2 E	18 - 100
Guiana Space Centre	5.2 N, 52.8 W	5 - 100

Upper Stage Insertion Accuracy (LEO)

	Apogee	Perigee	Inclination
Falcon 9	±10km 3σ	±15km 3σ	± 0.1deg 3σ
Pegasus	±15 km 3σ	±15 km 3σ	± 0.15 deg 3σ
Vega	±15 km 3σ	±15 3σ	± 0.15 deg 3σ
Minotaur IV	± 5 km 3σ	± 5 km 3σ	± 0.1 deg 3σ
Strela	1%	1%	± 0.05 deg