Mission Concept: Emergency Relief Constellation

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Presentation Outline

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- Mission Objective/Requirements
- Mission-Level Trades
- System Architecture
- Concept of Operations
- Communications Constellation
- Imaging Constellation
- Launch Scheme
- Requirements Discussion

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RFP Requirements

Presenter: Nash Reimer

Mission Objective

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Provide recurring repeater access and multi-band images of a customer-designated 500 km x 500 km disaster area. Provide full capability within 24 hours of command time.

Mission Requirements

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Communications

- The system shall provide beyond line-of-sight communications capability to first responders
- The system shall support entire coverage area
- The system shall be compatible with existing UHF communications systems
- The system shall provide repeater capability for 240 minutes/day
- The maximum time without repeater access is 120 minutes
- The minimum communications window is 3 minutes

Mission Requirements

AERO
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Imaging

- Imaging payload shall provide visible and NIR of coverage area with a 5 m resolution
- TIR band images of coverage area with 100 m resolution
- System shall take 1 daylight image of entire coverage area each day and 3 daylight images of 15% of coverage area (determined by customer) daily
  - Above 50 degrees latitude, only one full-coverage image is required daily
- Necessity for TIR imaging will be decided by customer on day of launch
  - If TIR imaging necessary, one additional TIR image of 25% of coverage area (determined by customer) shall be taken each day
- Images must be provided to customer as quickly as possible

Mission Requirements

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Launch/Ground

- The systems shall operate in politically stable locations
- The systems shall comply with applicable U.S. and international regulations
- The systems must store for up to 5 years prior to launch
- The system cannot utilize existing government or military infrastructure

Mission Requirements

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Schedule

- The system shall reach 25% capability within 12 hours
- The system shall have full capability within 24 hours
- The system shall have 95% capability after 6 months at end-of-life
- The system cannot be deployed in orbit prior to disaster call
- The constellation must be disposed of within 5 years of mission completion

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Mission-Level Trades

Mission-Level Trades

Trade #	Option 1	Option 2
1	LEO	MEO/GEO
2	Circular Orbits	Eccentric Orbits
3	Invariable Orbits (Launch)	Variable Orbits (Launch)
4	Combined Communications and Imaging Satellites	Separate Communications and Imaging Satellites
5	Correcting Orbits (Communications Satellites)	Non-Correcting Orbits (Communications Satellites)
6	Correcting Orbits (Imaging Satellites)	Non-Correcting Orbits (Imaging Satellites)

Mission-Level Trades

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LEO vs. MEO/GEO

Major Considerations	Result
• Radiation concerns in MEO/GEO • Satellites can be smaller in LEO • Deorbit in < 5 year requirement • Time expensive to deploy outside of LEO	LEO

Mission-Level Trades

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Circular vs. Elliptical Orbits

Major Considerations	Result
• Eccentric orbits provide longer passes • Requires on-board propulsion to maintain argument of perigee	Circular

Mission-Level Trades

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Invariable vs. Variable Orbits (Launch)

Major Considerations	Result
• Invariable requires global coverage for imaging • Variable reduces number of orbital planes	Variable

Mission-Level Trades

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Combined vs. Separate Communications and Imaging Satellites

Major Considerations	Result
• Coverage and pass time requirements are very different • Reduced complexity in separate satellites	Separate Communications and Imaging Satellites

Mission-Level Trades

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Correcting vs. Non-Correcting Orbits

Major Considerations	Result
• On-board propulsion for orbital maintenance • Specialized orbits • Coverage time	Non-Correcting Orbits (Communications Satellites)
	Correcting Orbits (Imaging Satellites)

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System Architecture

Communications Architecture

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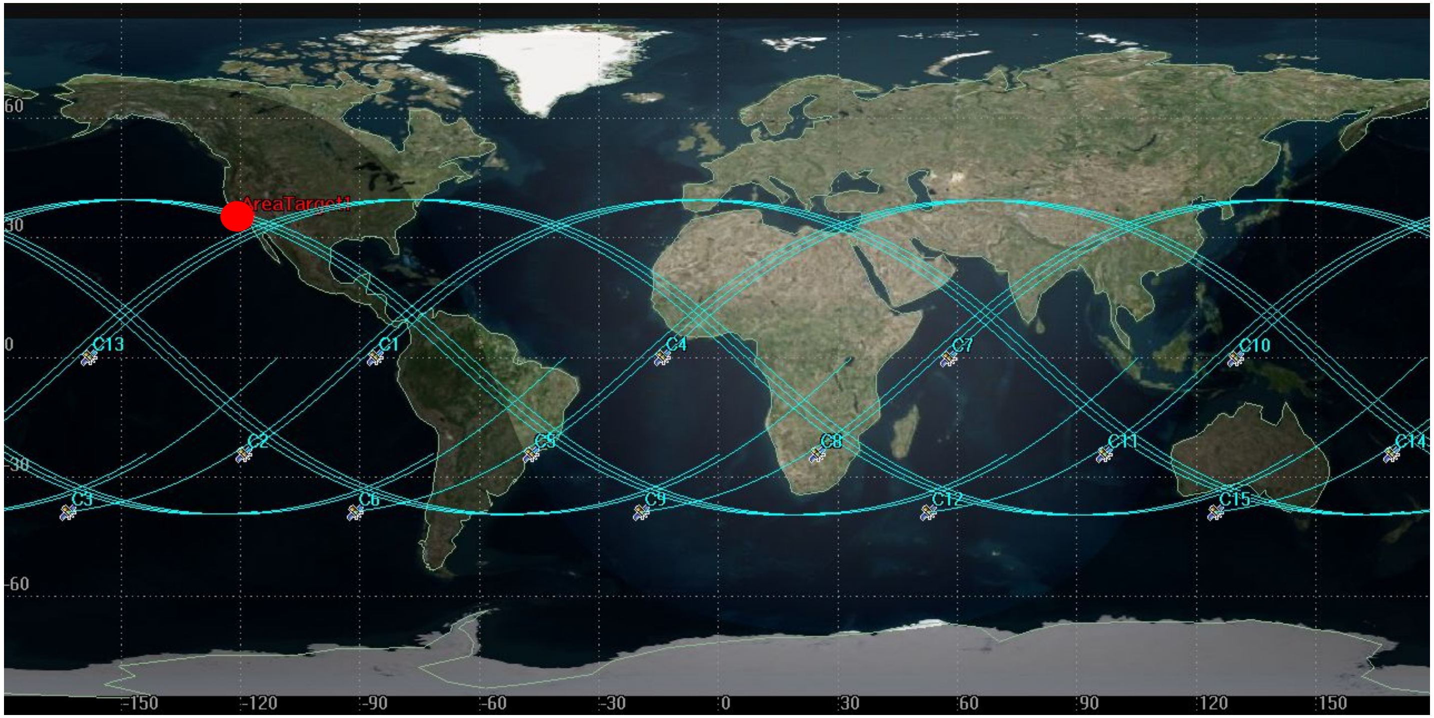
Target Area: San Luis Obispo on July 18th, 2017 at 10am



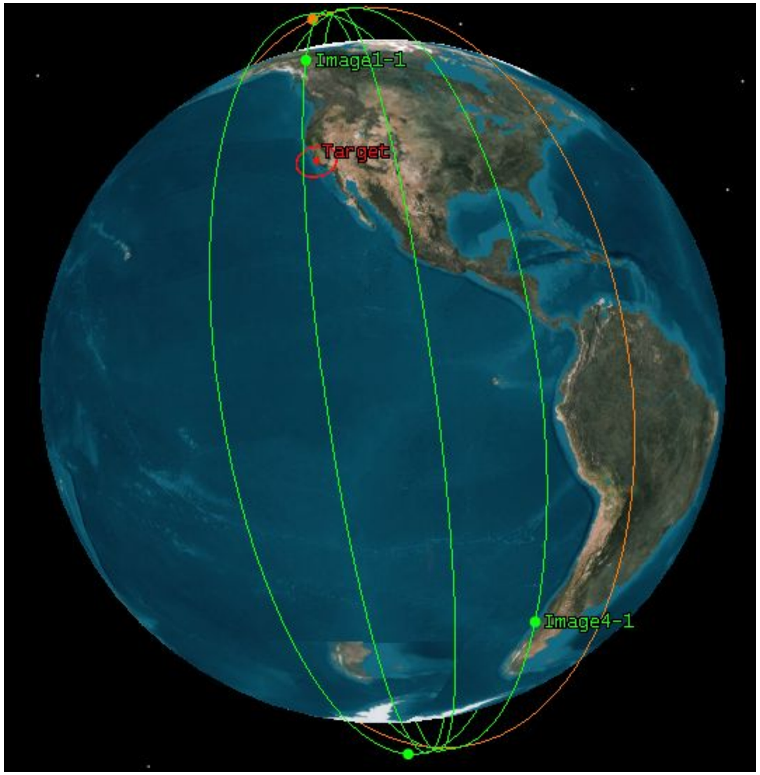
***RED** = Target Area*

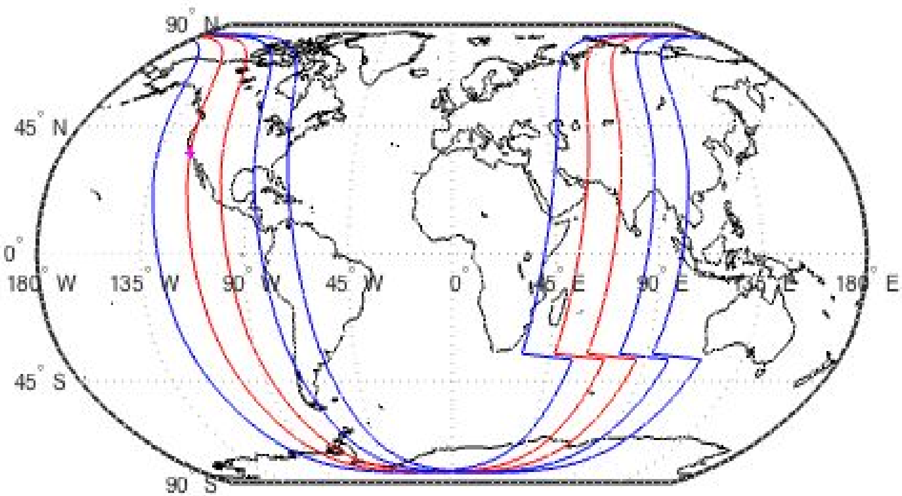
***BLUE** = Satellite Ground Tracks*

- **5** planes, **15** satellites
  - **3** satellites/plane
- Ideal ground station is on equator
- Circular **625 km** altitude, **latitude-inclination matching**
- Planes equally spaced in RAAN
- Satellites spaced 40 degrees apart in true anomaly

Imaging Architecture

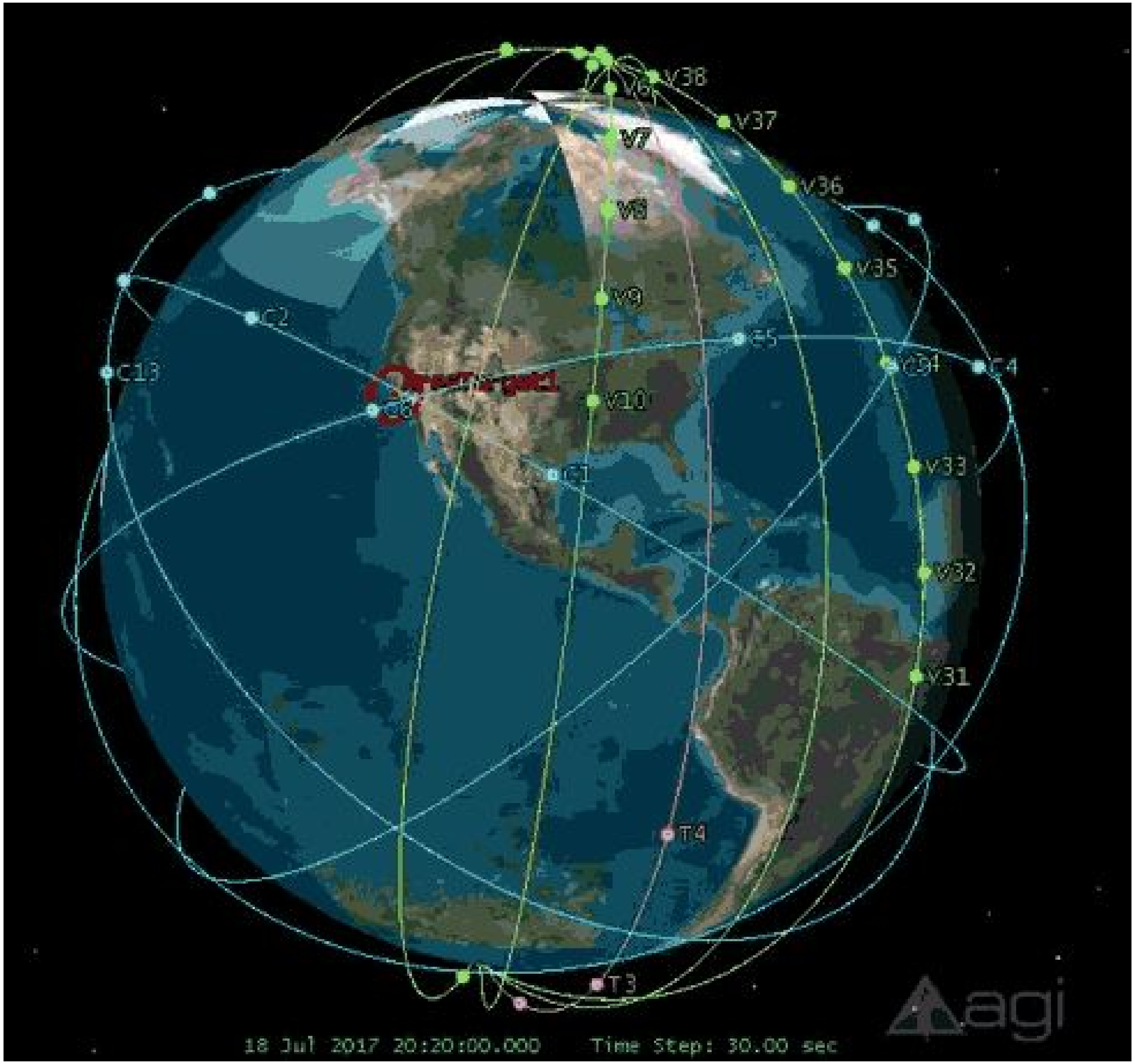
Target Area: San Luis Obispo on July 18th, 2017 at 10am





- **4** VIS/NIR planes
  - 2 cases for satellite numbers: 10 or 20 per plane
- **1** TIR plane, **4** satellites
- Circular **567 km** altitude sun-synchronous orbit
- RAAN spacing based on time between images

System Visualization



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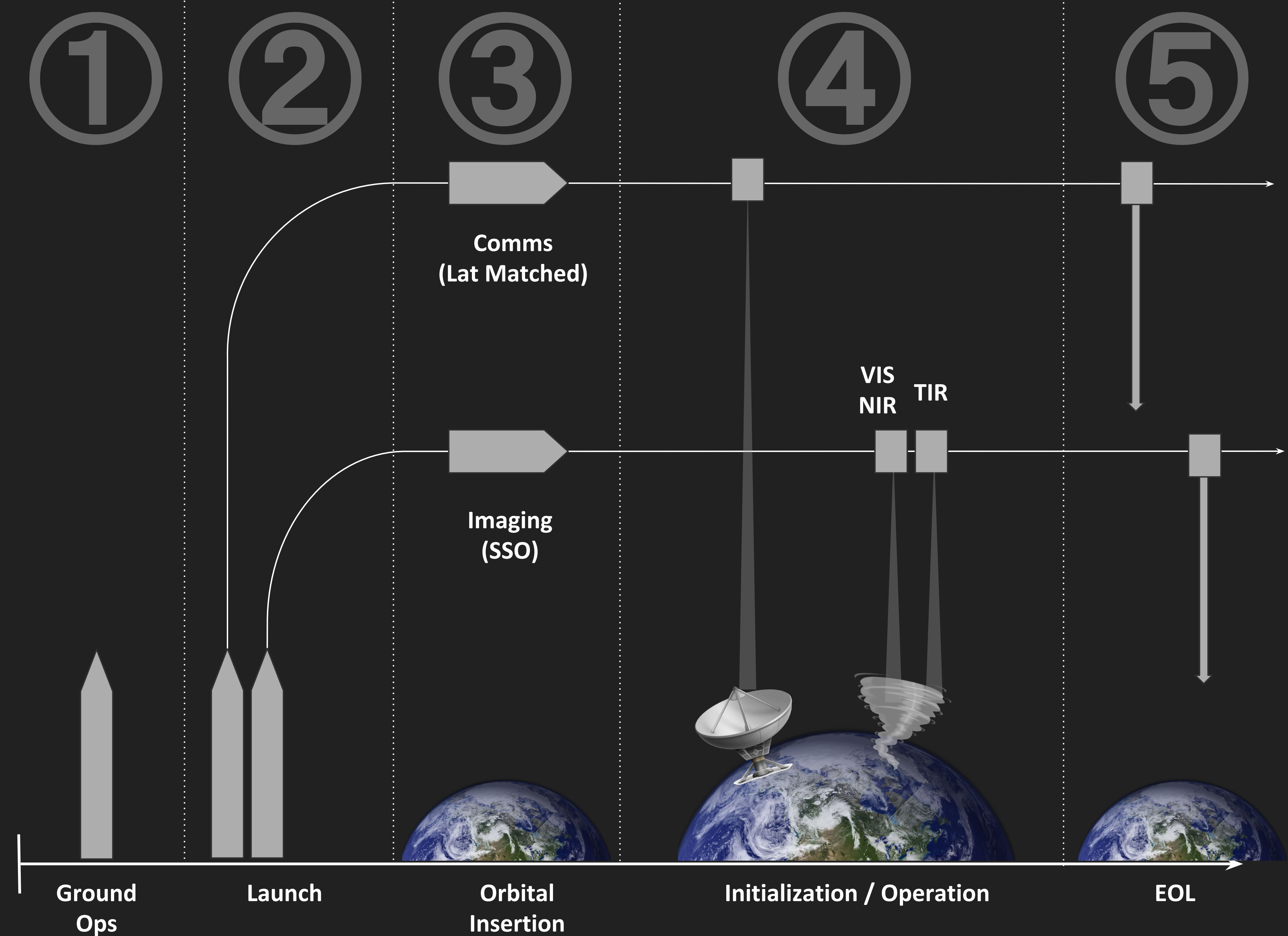
Concept of Operations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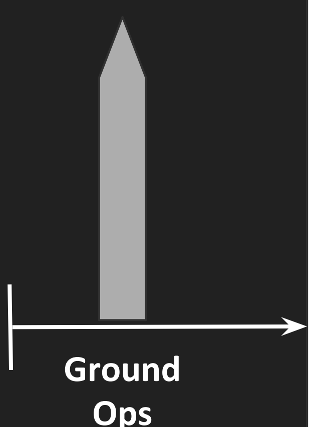
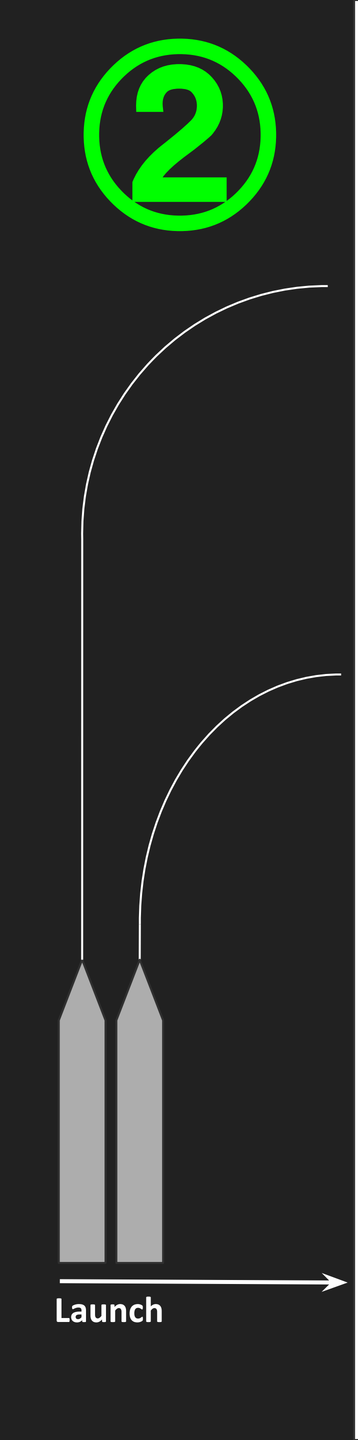
②
③
④
⑤
Comms
(Lat Matched)
VIS
NIR
TIR
Imaging
(SSO)
Ground
Ops
Launch
Orbital
Insertion
Initialization / Operation
EOL

①

Ground Operations

- 5 years minimum storage
- Launch vehicle integration
  - Satellite integration
  - Propellant integration





Launch

- Launch considerations
  - Launch bin identification
  - Launch order
- Different insertion orbits for vehicles
  - Elliptical transfer orbit for communications
  - Circular orbit for imaging

③

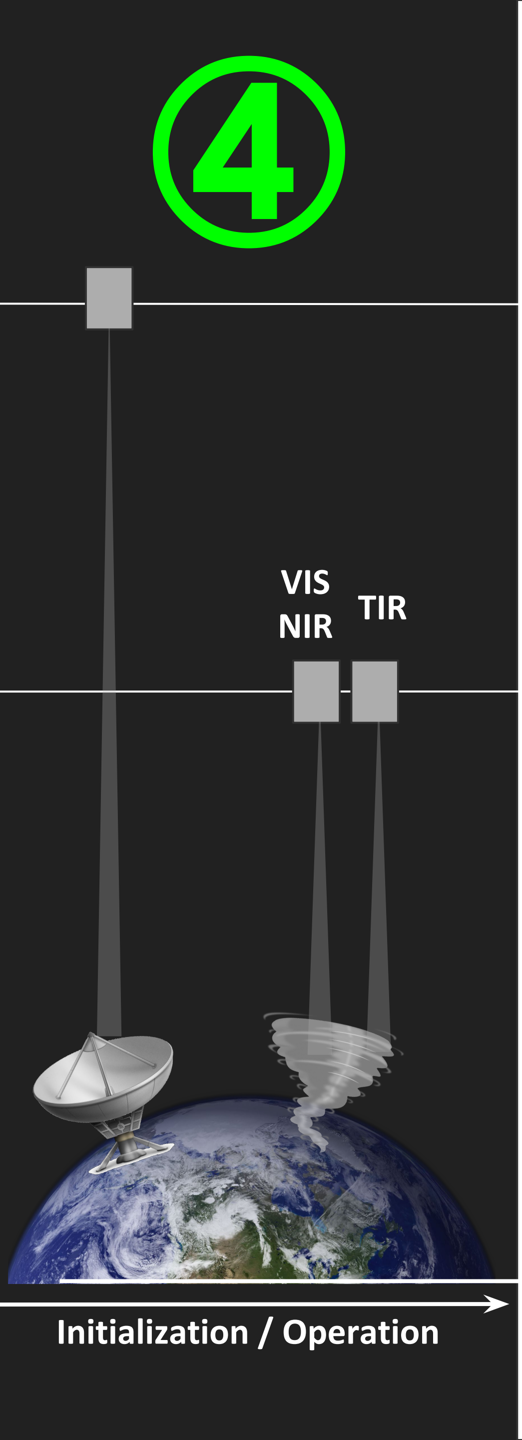
Comms
(Lat Matched)

Imaging
(SSO)

Orbital
Insertion

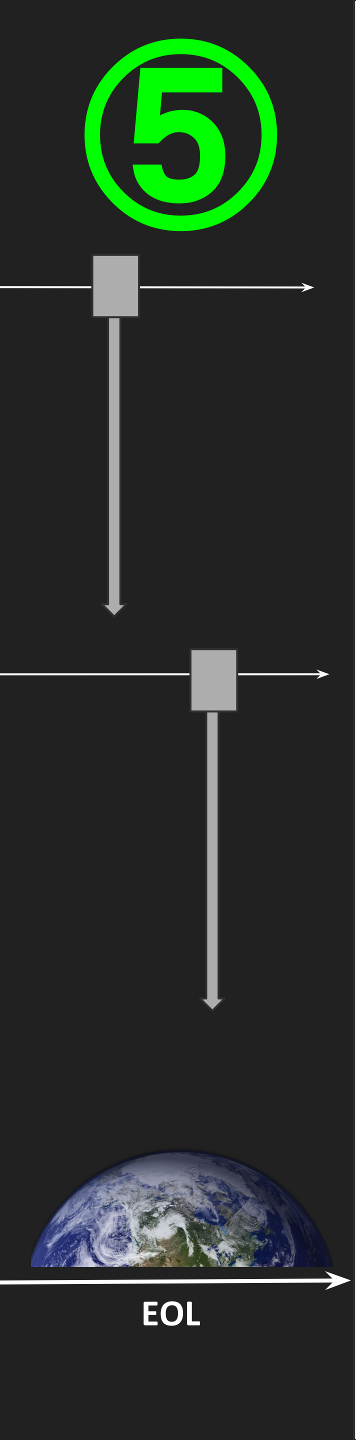
Orbital Insertion

- Phasing into appropriate spacing
  - Single-impulse for communications
  - Two-impulse for imaging



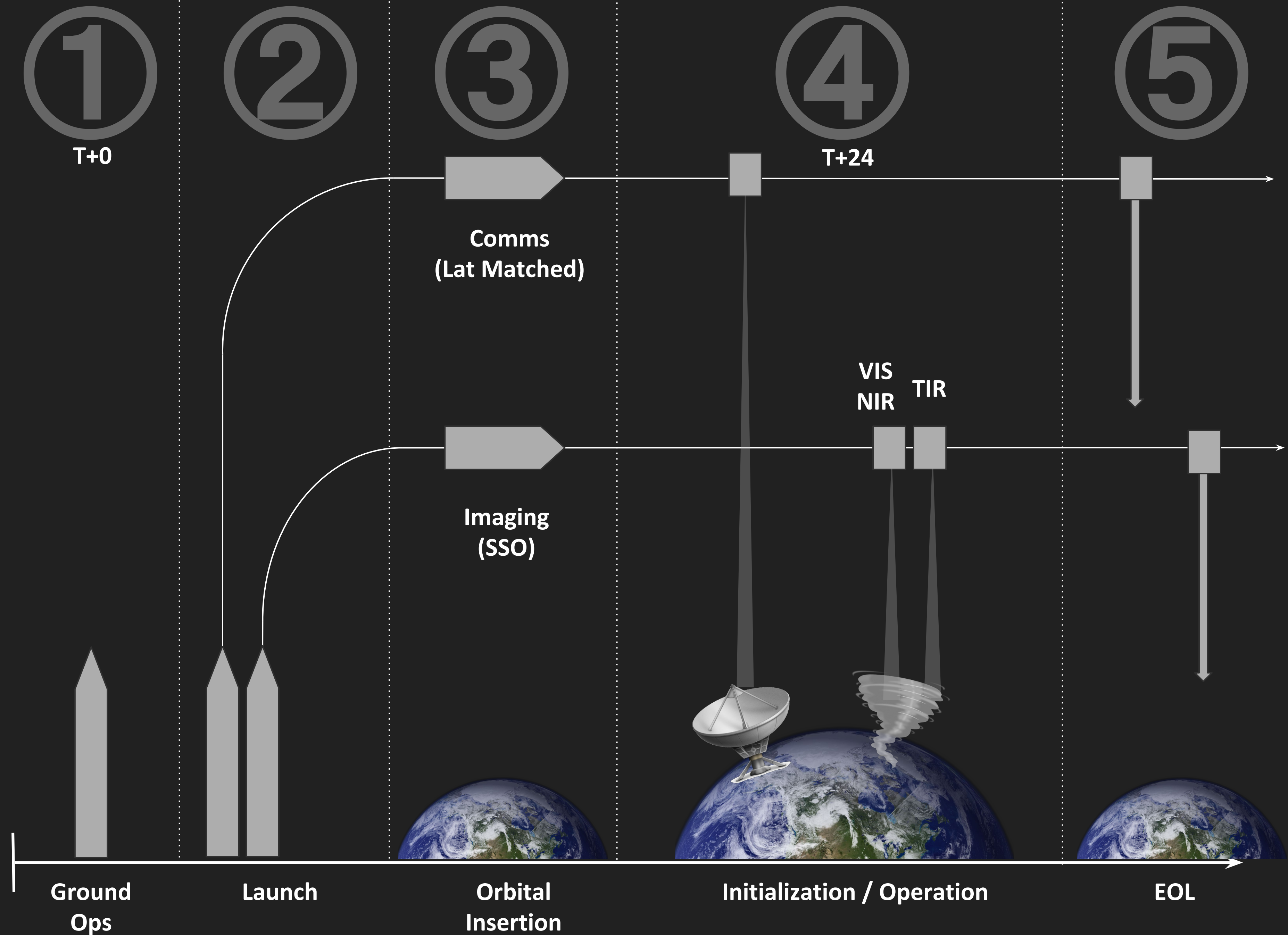
Initialization/Operation

- Satellites conduct daily operations to fulfill requirements
  - Communications provide repeater access
  - Imaging receive commands and image designated area and special requests



End of Life

- Satellites burn to drop altitude and allow deorbiting within the 5 year requirement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T+0
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Comms
(Lat Matched)
Imaging
(SSO)
VIS
NIR
TIR
Ground
Ops
Launch
Orbital
Insertion
Initialization / Operation
EOL

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Communications Constellation

Presenters:
Kian Crowley
Hunter Robinson

Communications Constellation

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Driving Requirements

- The system shall provide repeater capability for 240 minutes/day
- The maximum time without repeater access is 120 minutes

Additional Requirements

- The system shall provide beyond line-of-sight communications capability to first responders
- The minimum communications window is 3 minutes

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Orbital Scheme

Sats/Planes Code

- LEO altitude trade based on gain, ΔV to launch/deorbit, number of planes and satellites

Altitude	Inclination	RAAN Spacing (Between Planes)	True Anomaly Spacing (Between Satellites)	Eccentricity
625 km	Latitude	Equal	40°	0

Latitude Bin	0°-5°, 90°	85°-90°	5°-15°, 73°-85°	15°-73°
No. of Satellites	6	9	12	15
No. of Planes	2	3	4	5

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Phasing Scheme

- Transfer orbit details

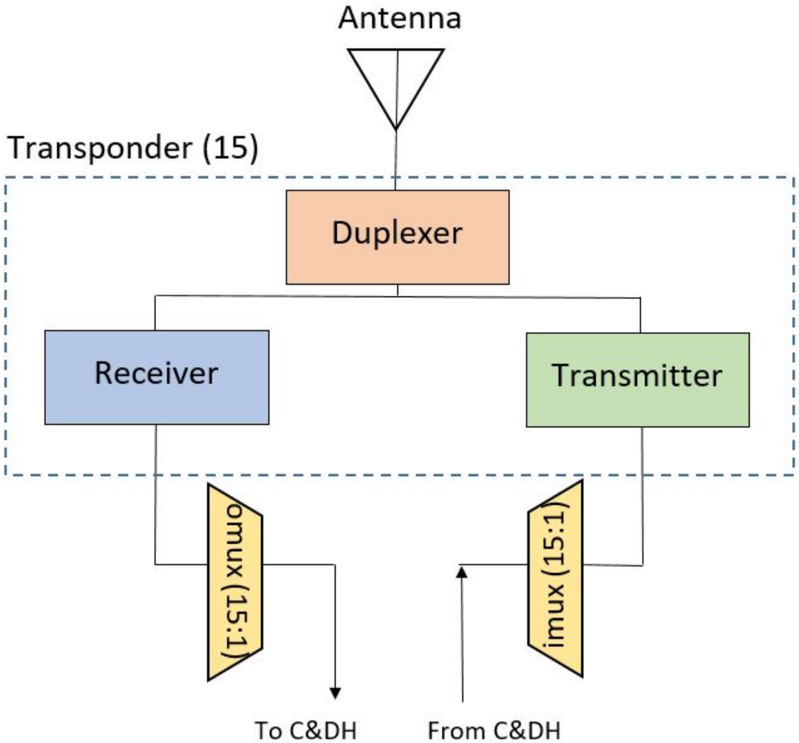
Semi-Major Axis	Eccentricity	Period
7513 km	0.068	1.8 hours

- Worst case phasing takes 5.4 hours
- 252 m/s required for phasing
  - Onboard propulsion deemed necessary
- Thruster accuracy
  - ± 1.7° to insert spacecraft to within 0.001 eccentricity of target orbit
  - Driver for ADC system

Communications Constellation

Payload Design

- First responders using tactical UHF handheld radios
  - Half duplex
- UHF repeater
  - Full duplex
  - 15 transponders
  - Frequency-Division Multiplexing (FDM) implemented



Communications Constellation

Link Budget	Satellite	Ground (First Responders)
Frequency	300 MHz	
Noise Temp	250 K	614 K
Space Loss	175 dB	
Signal to Noise Ratio	13 dB	
Data Rate	9600 bps	
Gain	0 dB	-1 dB
Power (RF)	1.62 W	5 W
Margin	6.5 dB	

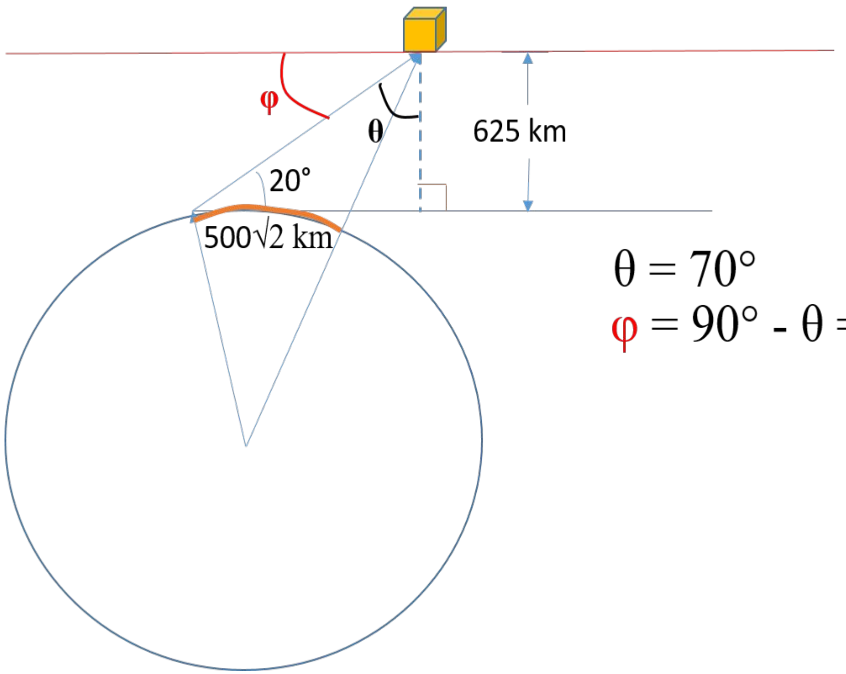
Link Budget

- Decisions:
  - Beamwidth: 180°
    - No slewing required above 140°
  - No. of channels: 15
  - Antenna type trade: OPEN

Communications Constellation

ADCS for Communication

- Nadir pointing
  - Beamwidth allows ± 20° attitude error
  - ADCS trade: OPEN



$\theta = 70°$

$\varphi = 90° - \theta = 20°$

Telemetry, Tracking, and Command

- Use existing payload antenna
- Sending/receiving health packets, coverage schedule, etc.

Communications Constellation

Mass

- Total mass: 13 kg
- Large contributors with margin:
  - Propellant mass: 2.64 kg
  - Batteries: 1.08 kg

Power

- Avg. power: 14 W
- Max power: 150 W
- Large contributors with margin:
  - RF power (including channels): 146 W

Comms Mass Breakdown

Comms Power Breakdown

Communications Constellation

Deorbiting Scheme

- Using propulsion, a double impulse to a lower altitude is required

Deorbit Parameter	Value
Perigee Altitude	500 km
ΔV	68 m/s
Area-to-Mass Ratio	0.007 m^2/kg

- Deorbit mechanism trade: OPEN
  - Considering increasing area

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Imaging Constellation

Presenters:
Michael Salinas
Megan Rund

Imaging Constellation

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Driving Requirements

- The Vis/NIR imaging system shall take:
  - 1 daylight image of entire coverage area each day
  - 3 daylight images of 15% of coverage area (determined by customer) each day

- If TIR imaging is deemed necessary, one additional image of 25% of coverage area (determined by customer) shall be taken each day
  - 100m ground resolution

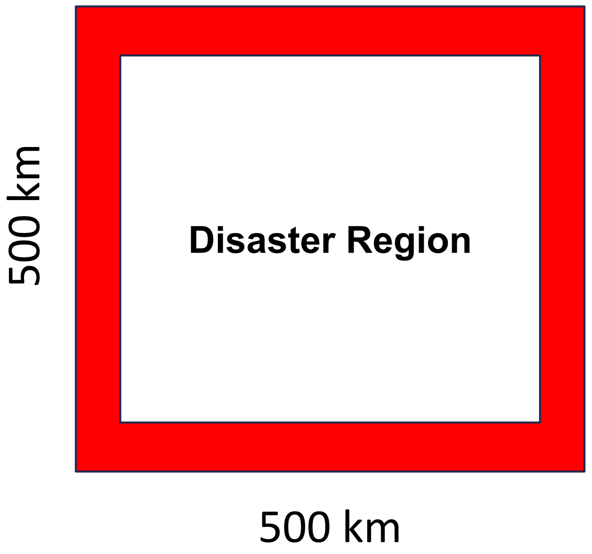
Imaging Constellation

Considerations

- Target area’s geometry undefined by customer
  - Designed for worst case

Decisions

- Full coverage area capabilities 4 times each day
  - Ensures full coverage regardless of geometry



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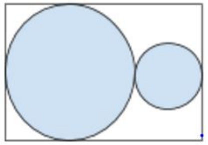
Bus Architecture

- Three general configurations for imaging system:
    1. Same spacecraft, Vis/NIR & TIR
    2. Same spacecraft, Vis/NIR/TIR
    3. Separate spacecraft, Vis/NIR -- TIR

- Decision: separate spacecraft (3)
    - TIR satellites may not launch depending on disaster
    - Simplifies satellite thermal isolation complexity
    - Allows for different imaging control schemes



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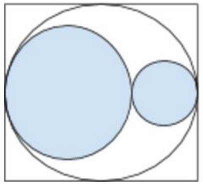

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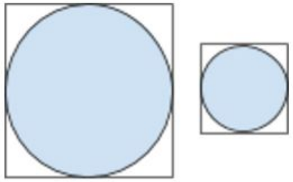
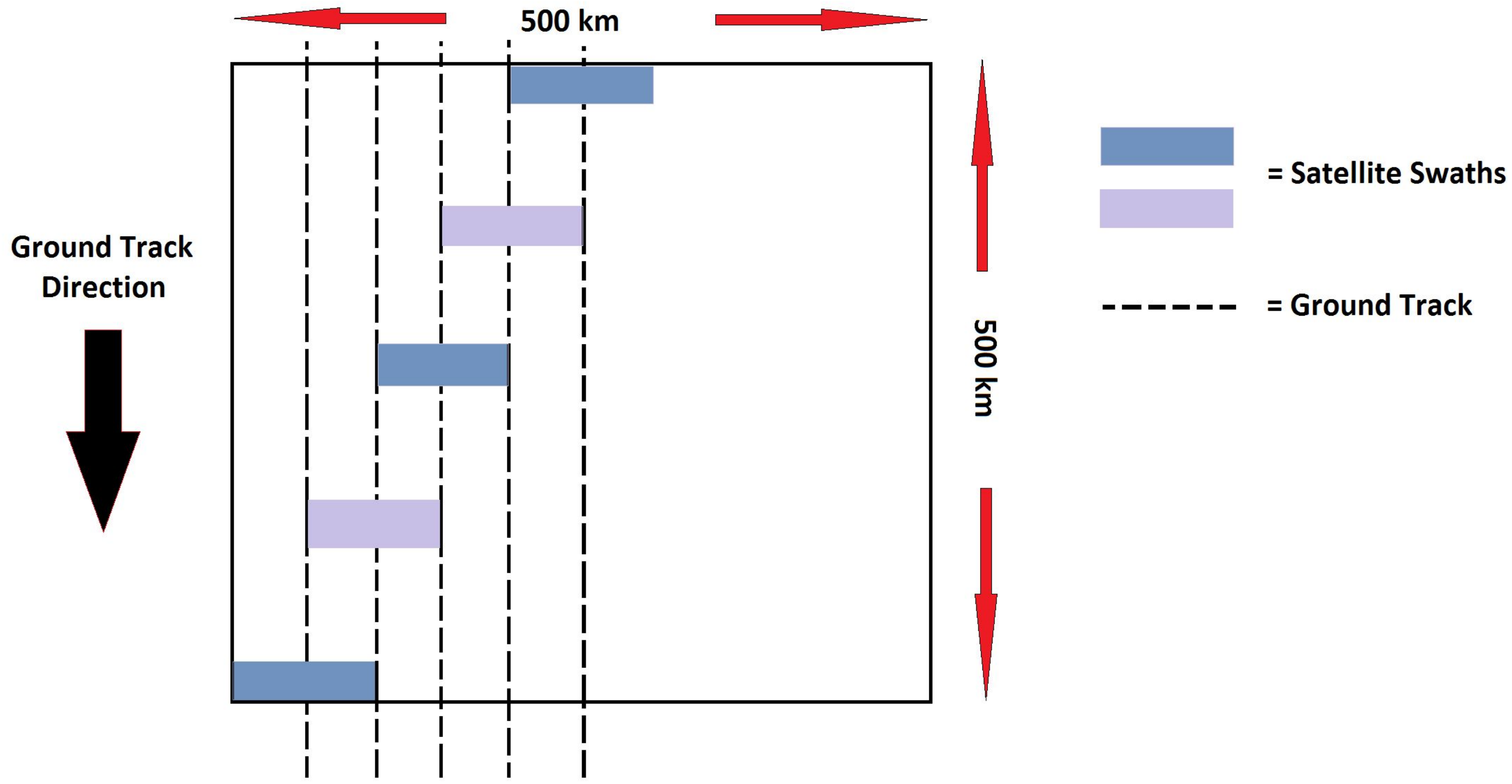


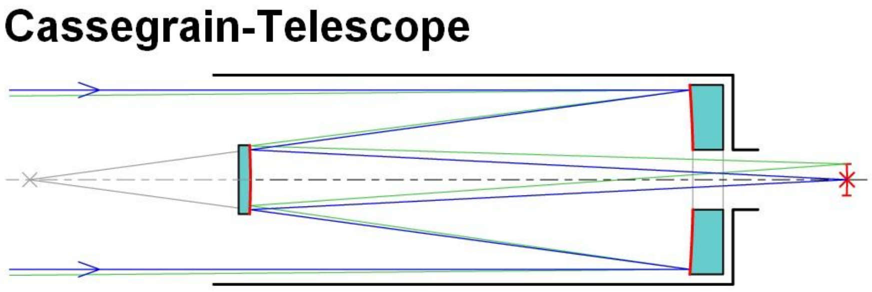
(3)

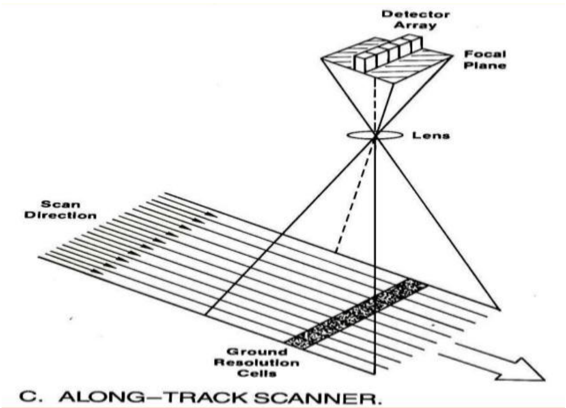
Image Reconstruction Scheme



Payload Imager Type

- Scanner vs. Starer Trade
  - Push-whisk, pushbroom scanners, or a matrix starer
- Decision: Pushbroom
  - Simpler mechanical complexity; less moving components
  - Smaller total amount of detector elements
  - Prevalence of pushbroom sensors already used for imaging large areas





Sensor Type Trade

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Visible/NIR Capability Case Comparison

Imaging Capability Trade

Sats per Plane	10	20
Mass Estimate	215 kg	65 kg
Swath Width	70 km	37 km
Operations Power	80 W	25 W
Aperture	16 cm	16 cm
Focal Length	91 cm	91 cm
Pointing Accuracy	0.185°	0.093°
Max Data Downlink	140 Gbits	70 Gbits

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TIR Capability Investigation

- Optics size significantly decreases with number of satellites

Decision: 4 Satellites

- 4 satellites chosen as balance between launch integration and swath redundancy flexibility
- Phasing difficulty increases as number of satellites increase
- Conops deemed critical factor in satellite number trade

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TIR Satellite Capability

- 4 satellites/plane

TIR Imaging Satellite Characteristics						
Mass Estimate	**Swath Width**	**Operations Power**	**Aperture**	**Focal Length**	**Pointing Accuracy**	**Max Data Downlink**
75 kg	186 km	20 W	7 cm	22 cm	0.44°	70 Gbits

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Orbital Scheme: Visible/NIR

Latitude	0° - 50°	50° - 80°	80° - 90°
Orbit Type	Sun-Synchronous Repeat Ground Track		Polar Repeat Ground Track
Altitude	567 km		554 km
Inclination	97.7°		90°
No. of Planes	4	1	1
No. of Satellites/Plane*	10 Satellites: Wider swath width 20 Satellites: Narrower swath width		

* Variable baseline for concept exploration

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Orbital Scheme: Thermal IR

Latitude	**0° - 80°**	**80° - 90°**
Orbit Type	Sun-Synchronous Repeat Ground Track	Polar Repeat Ground Track
Altitude	567 km	554 km
Inclination	97.7°	90°
No. of Planes	1	
No. of Satellites/Plane	4	

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Phasing Scheme

- Each satellite capable of phasing to correct position with its own propulsion system
- Capability to phase 180° for worst case injection location
- Limits placed on time to phase due to 24 hour operational requirement

Time to Phase	Number of Phasing Orbits	ΔV Required for Each Satellite
6 hours	3	720 m/s

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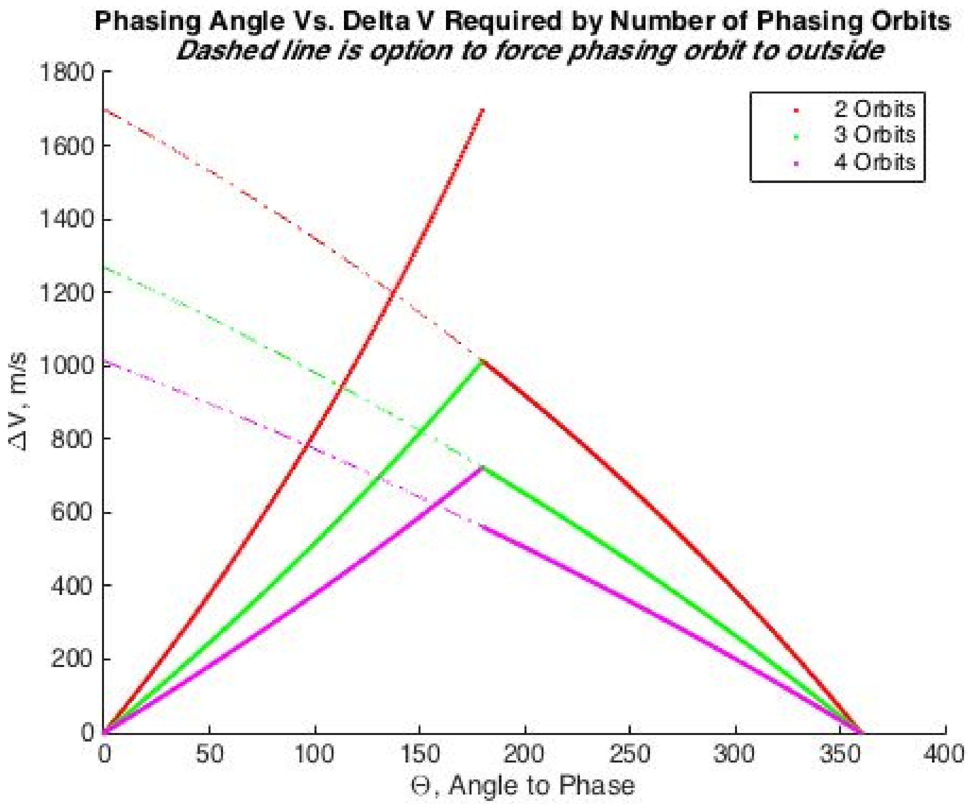
Phasing Scheme: Problems

- Problems with initial phasing plan
  - Some cases require phasing orbits that crash into Earth
  - True anomaly spacing varies drastically based on latitude
  - Maneuver could require $\Delta\theta$ from 0° to 180°
  - Satellite ΔV increases 8 fold
- Possible alternatives
  - Increasing time to phase
  - RAAN spacing
  - Launch vehicle completing phasing maneuvers

Satellite Distribution: Alternatives

- Increase phasing time
  - Need more time after launch
  - Customer needs to provide more time to 100% capability



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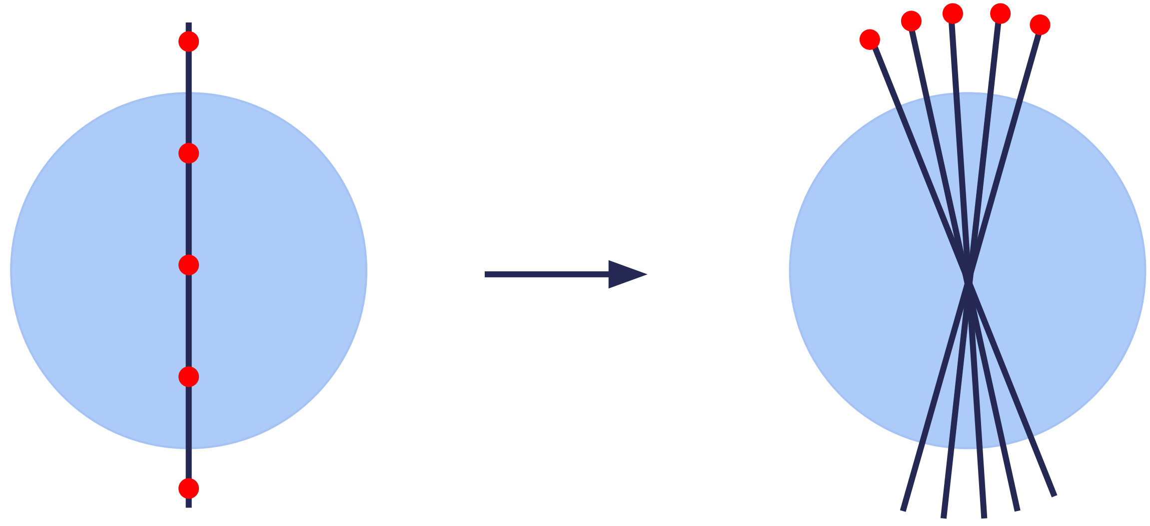
Satellite Distribution: Alternatives

- RAAN Spacing Option
  - Each satellite has its own orbital plane
  - Satellites fly over at one time to take picture of area
  - Launch vehicle completes initial phasing maneuver and RAAN plane changes



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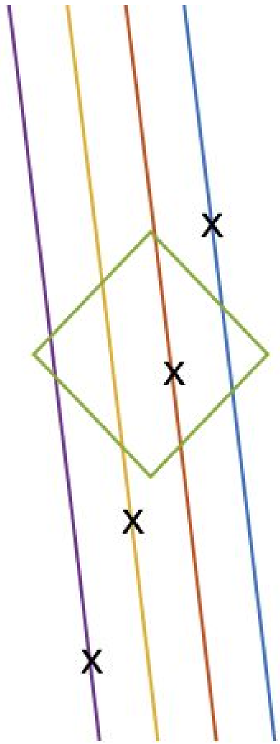
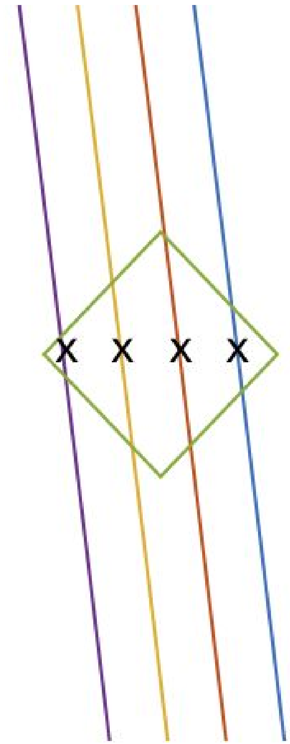
Satellite Distribution: Alternatives



Phasing Option
Same Plane, True Anomaly Spacing



RAAN Spacing Option
Different Planes, RAAN Spacing

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Stationkeeping

- Set a tolerance for drift based on optimizing for lowest total ΔV required for stationkeeping and how far imaging system can deviate from nominal location
- Use two-impulse maneuvers to correct to ideal orbit location when tolerance is met

Drift Tolerance	Frequency of Maneuver	Total ΔV Required for 6 months
300 m	Once per Day	75 m/s

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Deorbiting Scheme

- After 6 months complete a single impulse maneuver to lower perigee into deorbit range.

Perigee altitude after transfer	Time to de-orbit at solar min (SMAD)	ΔV required for transfer
500 km	4.7 years	18 m/s

Imaging Constellation

Satellite Maneuvers Summary

- Satellite distribution after launch
  - Current plan is phasing each satellite, but this is being reconsidered
- On-orbit station-keeping
- De-orbit in 5 years after 6 month lifetime
- ΔV budget

Maneuver	Phasing	Stationkeeping	De-Orbit	Total
Required ΔV	720 m/s	75 m/s	18 m/s	813 m/s

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Launch

Presenter: Ben Kragt

Launch

Driving Requirements

- The system must store for up to 5 years prior to launch
- The system cannot utilize existing government or military infrastructure

Additional Requirements

- The system cannot be deployed in orbit prior to launch
- The necessity for IR imaging will be decided by customer on day of launch

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Major Trades

Trade	Status	Baseline
Launch Sites: Build vs. Use Pre-existing	Closed	Build Launch Site
Launch Type: Air vs. Land vs. Sea	Closed	Land Launch
Launch Vehicle: Design vs. Buy	Closed	Design Launch Vehicle
Propellants	Open	Solid Liquid
Ground Stations: Mobile vs. Stationary	Closed	Stationary Ground Stations

Launch

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Pre-Launch Activities

- Personnel
  - Allocated time for personnel to arrive
- Launch Vehicle
  - Checks
  - Fueling
- Satellite
  - Integration
  - Checks
  - Fueling

Estimated Time to Launch From Command Time

- 6 hours

Launch

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Desirable Latitudes

- Imaging launches: far from equator, into both ascending and descending nodes of the 97° sun-sync orbit
- Communications launches: close to equator, into 0-90° inclination

Locations Evaluated for:

- Political stability (evaluated with fragility index)
- Risk of natural disaster occurring at launch site
- Frequency of rain and stormy weather

Ideal Imaging Launch Sites Found: ***9***

Subset That Work for Comms: ***4***

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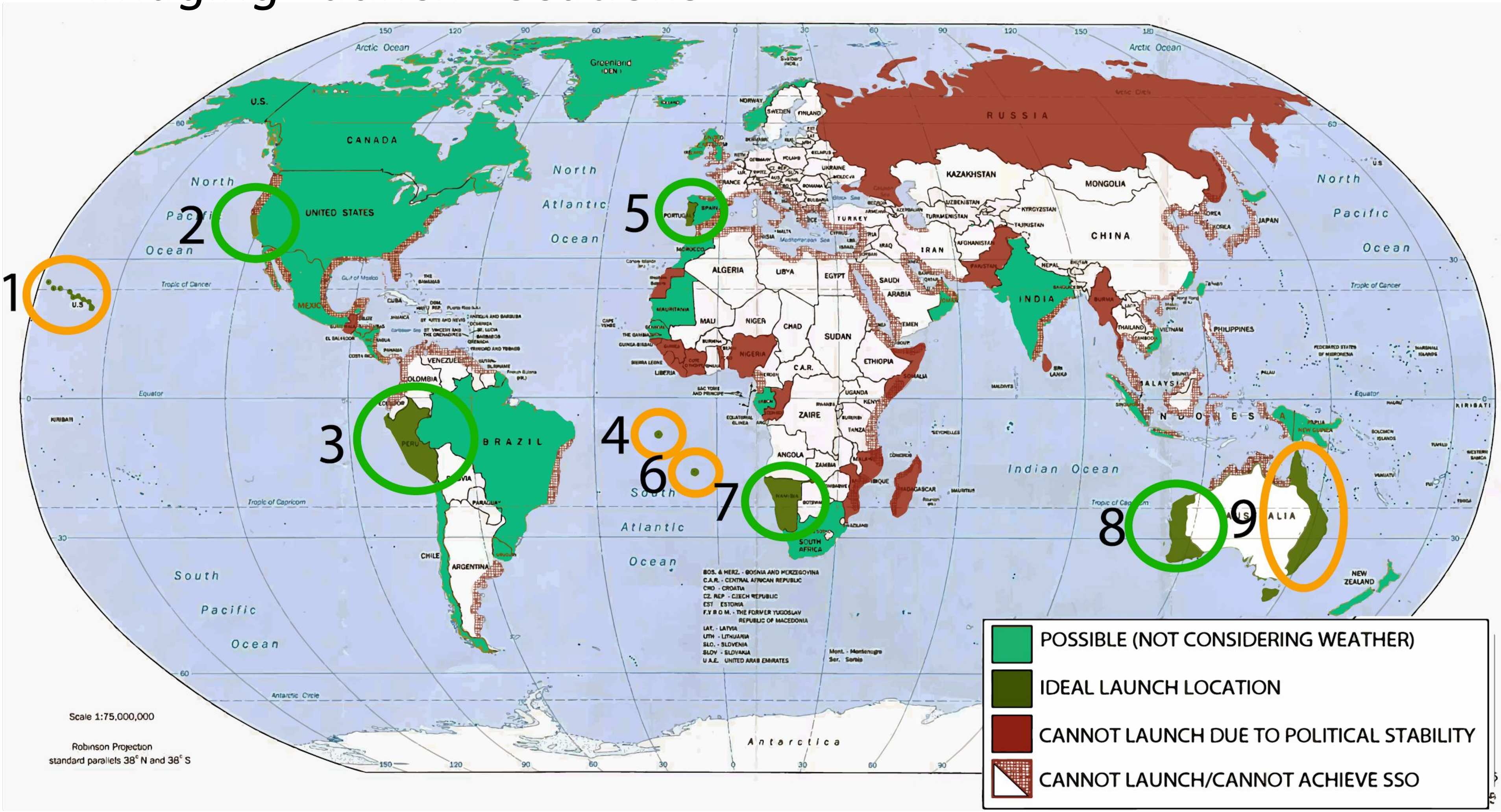
Imaging Launch Locations



Launch

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Customer Requirements

- The system shall reach 25% capability within 12 hours
- The system shall have full capability within 24 hours
- The necessity for IR imaging will be decided by customer on day of launch

Derived Requirements

- Payload Mass
- Payload Volume
- Payload Orbits
- Payload Capability

Launch Derived Requirements

Launch

Current Obstacles

- Imaging and Communications have significantly different payload masses and orbits

Most Important Open Trades

- Single launch configuration vs. multiple configurations for different payloads
  - Strap-on boosters, extra stages, etc.
- Many small launch vehicles vs. few large launch vehicles

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Questions?

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Requirements Discussion

Presenter: Jeralyn Gibbs

Requirements Discussion

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Imaging Additional 15% and Thermal 25% Coverage Area Pictures

- Only asking for clarification
- What is the geometry of the points of interest?
- Are these points of interest the same every day?

95% Capability

- Only asking for clarification
- % of satellites functional?
- % of requirements satisfied?

12 Hour Pushback

Requirements Discussion

25% in 12 hours, Full Capability in 24 hours

- What cases make it difficult to meet these requirements?
  - Specific latitudes require more satellites and therefore more launches than others
  - Specific latitudes also require more phasing of the satellites and therefore more time or fuel
  - Specific times of day leave us waiting for the launch window to reach the launch site
- What would it take to meet these requirements?
  - Trade off between time and cost
  - Tool to determine probability of meeting time requirements
- Our proposal
  - 12 hours only applies to Comms
  - 24 hours extended to 36 hours for 20-30% of cases

Mission Success Tool

Requirements Discussion

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Full Capability in 24 hours

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Slide Repository

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Major Trades

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LEO vs. MEO/GEO

Choice(s) Considered	Pros	Cons	Status
A. LEO	• Quick • Small satellites • De-orbits fast	• High number of planes and sats • Quick pass times	**Accepted**
B. MEO/GEO	• Reduced number of satellites • Lengthy Pass Times	• Expensive • Large satellites • Response time • Excessive for 6 months	**Rejected**

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Circular vs. Elliptical Orbits

Choice(s) Considered	Pros	Cons	Status
A. Circular	• No orbital maintenance	• Quick passes over target	**Accepted**
B. Elliptical	• Increased time over target	• High altitude apogee • Orbit corrections necessary	**Rejected**

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Variable vs. Invariable Orbits

Choice(s) Considered	Pros	Cons	Status
A. Variable	• Reduces number of planes/ launches	• Causes delays	**Accepted**
B. Invariable	• Faster response time • Orbits pre-selected	• Greatly increases number of planes/ sats	**Rejected**

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Separate Communications/Imaging vs. Combined

Choice(s) Considered	Pros	Cons	Status
A. Separate Comms/Imaging	• Less complex satellites • Small components • Different requirements	• More satellites/ planes	**Accepted**
B. Combined Functionality	• Reduced number of satellites	• Large, complex satellites	**Rejected**

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Separate Imaging vs. Combined Imaging Function

Choice(s) Considered	Pros	Cons	Status
A. Separate Imaging Functions	• Decreased complexity per satellite	• More satellites required • Increases cost	**Rejected**
B. Combined Imaging Functions	• Fewer satellites • Reduced cost/ No. of launches	• Complex thermal subsystem • Adds size/ mass	**Accepted**

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Correcting Orbits Vs. Non-Correcting Orbits - COMMS

Choice(s) Considered	Pros	Cons	Status
A. Correcting Orbits	• Longer pass times towards EOL	• Addition of on board propulsion	**Rejected**
B. Non-Correcting Orbits	• No need for on board propulsion	• Lower pass times towards EOL	**Accepted**

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Correcting Orbits Vs. Non-Correcting Orbits - IMAGING

Choice(s) Considered	Pros	Cons	Status
C. Correcting Orbits	• Maintain daily ground track	• More mass for propulsion system	**Accepted**
D. Non-Correcting Orbits for	• No need for on board propulsion	• Drag decrease altitude • J2 affects ground track	**Rejected**

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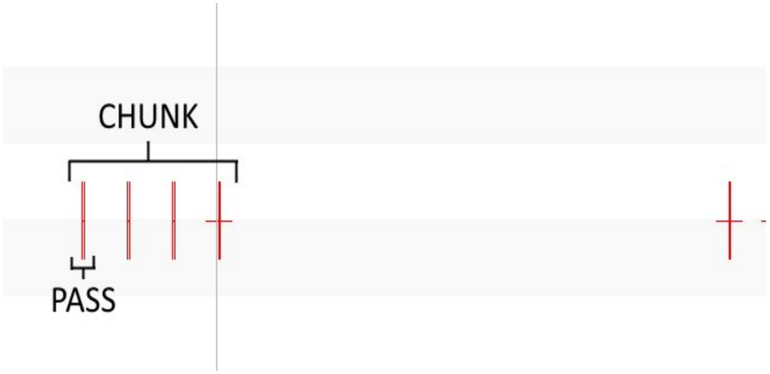
Vehicle Specific Trades

Comms Orbit Determination Code

- The 500x500 km and all COE combinations defined
- Pass = all target area in view (with elevation angle)
- Passes below 3 minutes removed, “chunk” defined
- Check if time between passes in chunk is <120 minutes
  - Satellites added (equal spacing in true anomaly), repeat
- 24 hours/chunk length for continuous daily coverage
  - Planes spaced out equally in RAAN
- Check if total pass time for all sats, all planes <240 minutes
  - Satellites added, repeat



Comms Satellite Altitude Trade

Alt.	800	775	750	725	700	675	650	625	600	575	550	525
Max # Planes	4	4	4	7	5	5	5	5	5	8	8	8
Max # Sats	10	11	12	16	14	14	15	15	16	22	23	25
Gain: (300 MHz)	5.3	5.1	4.8	4.6	4.3	4.1	3.8	3.5	3.2	2.9	2.6	2.2
Area-to-mass	0.43	0.33	0.25	0.18	0.13	0.1	0.07	0.05	0.04	0.03	0.02	0.01
Deorbiting dV (km/s)	0.217	0.204	0.191	0.178	0.164	0.151	0.138	0.124	0.111	0.097	0.084	0.070

Antenna Trade - OPEN

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Antenna	Beamwidth (deg)	Size	Deployment Necessity	Notes
Helix	120.5	3.98E-10 m^3 (Volume)	Yes	
MMA	150		No	Operates in 2-3 GHz.
Patch		10.2 cm	No	Operates in 2-3 GHz
Dipole	90	Small	Yes	
Monopole	90	.25 m (length)	Yes?	Up to 1.5 dB
Omni	360	Small	No	Avg. 0 dB can be -1 dB
Turnstile	180	~18 cm	Yes	Similar to Omni

Propulsion Method Trade - OPEN

										Scenario 1 (2 burns)		Scenario 2 (1 burn + drag sail)		
Make / Model	**Drive Type**	**Prop ellant**	**Engine Mass (kg)**	**Thrust (N)**	**Exhaust Velocity (m/s)**	**ISP (s)**	**Power (W)**	**Mass Flow Rate (kg/s)**	**Assumed Spacecraft Dry Mass (kg)**	**Total Prop Mass (kg)**	**Burn Time: Phase (sec)**	**Burn Time: De-Orbit (sec)**	**Total Prop Mass (kg)**	**Burn Time (sec)**
Aerojet: MR-103	**Mono**	**Hydr azine**	0.33	1	2000	224	13.7	0.0005	12.33	**3.05**	**3641**	**2458**	**1.68**	**3365**
Aerojet: MR-111	**Mono**	**Hydr azine**	0.33	5.3	2208	229	13.6	0.0024	12.33	**2.73**	**678**	**462**	**1.51**	**631**
TRW: MRE-4	**Mono**	**Hydr azine**	0.5	9.8	2134	217	30	0.0046	12.5	**2.88**	**372**	**253**	**1.59**	**346**
Aerojet: MR-106	**Mono**	**Hydr azine**	0.52	30.7	2362	235	49.15	0.013	12.52	**2.58**	**118**	**81**	**1.43**	**110**
Aerojet: R-1E	**BiProp**	**MMH / NTO**	2	111	2775	280	36	0.04	14	**2.42**	**36**	**25**	**1.35**	**34**
Our Ideal Thruster	***Mono***	***Hydr azine***	*Low*	*High*	*High*	*High*	*Low*	*High*	***Add 0.2 kg to Scenario 2 for Dry Mass of Drag Sail + Deployer***					

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Comms Mass Breakdown

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Subsystem	Components	Mass (kg)	Margin (%)	Actual Mass (kg)
ADCS	ACS Package	0.2	50	0.3
Propulsion	Thruster	0.5	25	0.625
	Propellant	3.17	25	3.96
Structures/ Thermal	Frame	5	10	5.5
	Heater	0.01	25	0.02
Power	Batteries	0.72	50	1.08
	Solar Panels	0.5	50	0.75
Comms	Antenna	0.1	50	0.15
	Amplifier/Filter	0.14	50	0.21
C+DH	Computer	0.05	40	0.07

Back: Communications Constellation

Comms Power Breakdown

Subsystem	Components	Power (W)	Margin (%)	Duty (%)	Avg.
ADCS	ACS Package	1.8	50	20	0.54
Propulsion	Thruster	30	50	1	0.45
Structures/ Thermal	Heater	1	25	33	0.4125
Comms	Total RF Power	1.6*4*15	50	5	7.29
C+DH	Computer	0.435	100	100	0.87
	TT&C	1	50	1	0.015

Back: Communications Constellation

Imaging Sat Capability Trade

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Metrics Considered:

- Data Generation
- Sensor Size
- Payload Size
- No. of Satellites
- Complexity
- Data Downlink
- Power Cost
- Pass Utilization
- Mass
- Size
- Power Requirement
- Control Capacity
- Phasing Time
- Phasing DeltaV

Back: Visible/NIR Capability Trade

Sensor Type Trade

	VISNIR				TIR			
Metrics	Weight	Pushbroom	Pushwhisk	Matrix Starer	Weight	Pushbroom	Pushwhisk	Matrix Starer
Dwell Time	0.4	7	6	8	0.5	7	6	10
Mechanical Complexity	0.6	7	5	4	0.7	6	4	3
Pointing Requirements	0.3	7	8	5	0.5	6	9	8
Optical Complexity	0.5	5	6	5	0.4	4	6	4
Cost	0.4	3	4	3	0.4	4	5	3
Smear	0.3	5	4	3	0.6	4	3	5
Reliability	0.7	8	6	6	0.5	8	6	5
Power	0.3	9	8	7	0.3	8	7	6
Useful Data (%)	0.7	7	7	9	0.4	8	8	10
Operational Delay	0.4	8	6	8	0.4	5	4	6
Total		30.7	27.5	27.5		27.9	26.4	27.6

Back: Determining Sensor Type

Spectral Wavelengths

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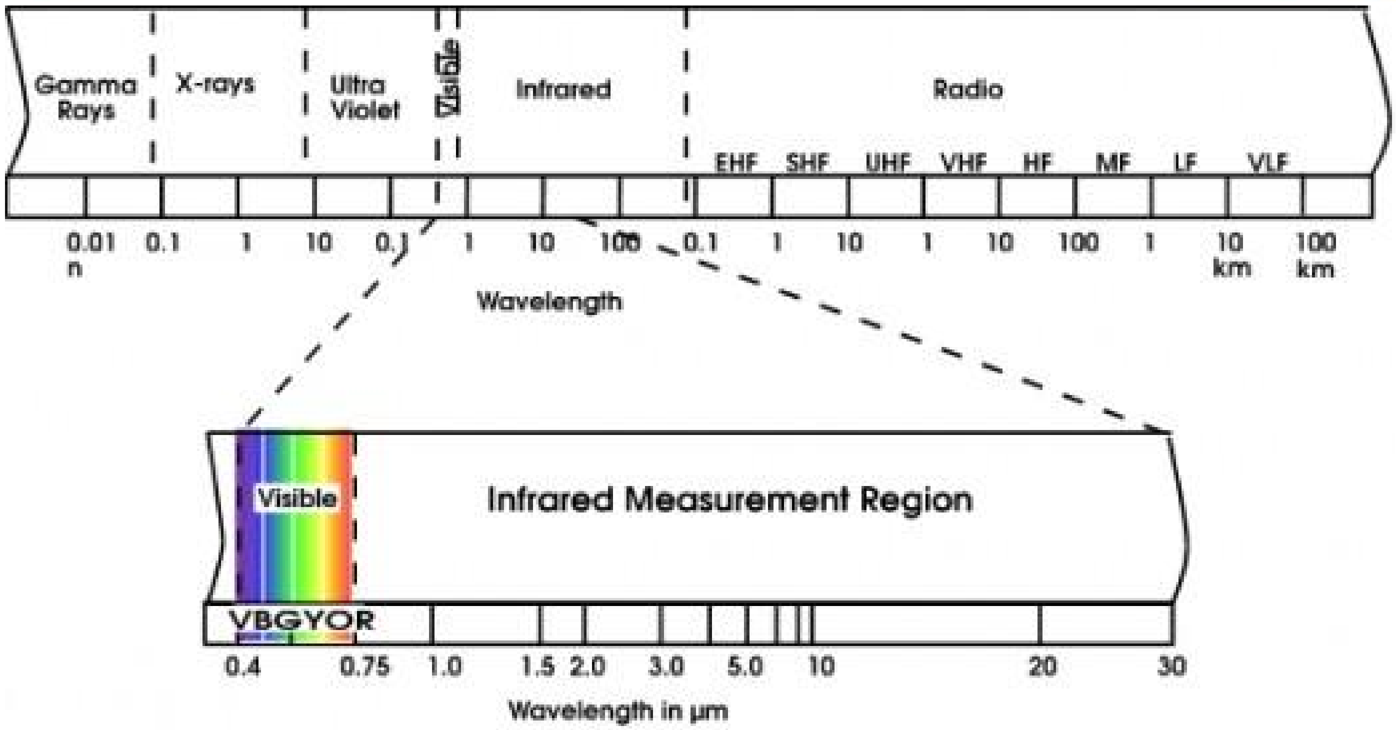

Ground Station Type

Metric	MOBILE	FIXED	WEIGHT	Mobile Total	Fixed total	JUSTIFICATION
Before Delivery:						
Minimize staffing	7	4	0.3	2.1	1.2	lower cost
Storage:						
Ease of storability	8	5	0.3	2.4	1.5	less space
Minimizes maintenance	6	4	0.6	3.6	2.4	building needs more maintenance than truck/suitcase
Disaster Occurs - 24 hours:						
Eases transportation	3	10	0.6	1.8	6	fixed does not need transportation
Minimizes transportation time	3	10	0.8	2.4	8	
Minimizes setup/deployment deployment time	8	9	0.8	6.4	7.2	
Capable of sending signal	5	5	1	5	5	
Minimize preparation time	8	9	0.8	6.4	7.2	
Mission - 6 months:						
Minimizes maintenance	8	7	0.7	5.6	4.9	
Minimizes staff	5	8	0.5	2.5	2.5	
Minimizes time to sending signal to sats	8	4	0.8	6.4	3.2	ability to send 15% cmd
Capable of sending signal	0	0	1	0	0	
End of Mission:						
Ease of disposability	0	0	0.2	0	0	
Totals				**44.6**	**49.1**	

Back: Launch Sites

LV Baseline

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What our **Closed** Trades Determined

- Build our own launch vehicles
- Build our own launch sites
- Land launch

What our **Open** Trades Determined... So far

- Separate launch vehicle configurations for imaging and comms satellites
- HTPB as solid fuel option
- MMH/N2O4 as liquid fuel option

Launch Vehicle: Build vs. Buy

Decision: Build

- LV purchase is unprecedented
- Buying ICBMs is difficult
- Will need a large number and most LV manufacturers don’t have the capability to build that many
- Difficult to buy a launch vehicle and use your own operations system
  - Almost all companies that manufacture LVs require you to use their operating systems
- Building our own LV allows for customization

Launch Site: Build vs. Use Pre-existing

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Decision: Build

- Can't use any government or military infrastructure
  - Eliminates a good number of pre-existing launch sites
- 24 hour requirement means optimal launch locations are limited
  - Only 9 areas that meet our criteria

Pre-Launch Timeline

T-6 hours	Launch Provider Informed of Disaster	
	Personnel Called Out to Launch Site	
T-4.5 hours	Pad Prep Begins	Personnel given 90 min to commute
	Satellite Prep Begins	Payload processing will be mostly complete, only minimal work done right before launch: battery installation, propellant loading, etc. Satellite could possibly already be on adapter, depending on design
	LV Prep Begins	Flight termination system installation, remove before flight items, etc. Vehicle could possibly already be mated to the strongback, depending on launch design.
T-2.5 hours	Satellite Prep Ends	Satellite given 2 hours to prep
	LV Prep Ends	LV given 2 hours to prep, fts usually given a full day, hence why it is given the most amount of time.
	LV Vertical	Accounting for 30 min to get LV vertical on pad
	Pad Clear	Accounting for 1 hour to clear pad and start checks
	LV Checks Begin	
T-1 hour	LV Prop Load Begins	1 hour given to load prop
T-0	Launch	

Back: Pre-Launch Timeline

Air vs. Land vs. Sea Trade

Metric	*Air**	*Land*	*Sea*	*Weight*
Development Cost	**5**	**8**	**4**	**0.6**
Maintenance Cost	**6**	**8**	**3**	**0.6**
Launch Timeliness	**5**	**7**	**3**	**1**
Regulations	**4**	**6**	**8**	**0.4**
Complexity	**4**	**9**	**5**	**0.8**
# launches from each site	**3**	**8**	**7**	**0.4**
Payload Size	**5**	**9**	**8**	**0.7**
People Risk	**6**	**8**	**9**	**0.3**
Launch Location	**8**	**5**	**8**	**0.5**
Total	**26.9**	**40.6**	**29.5**	

**Not possible if high altitude is required*

Back: Pre-Launch Trades

Solid Propellant Trade

Fuel:	Isp (sec)	Density (kg/m^3)	Storability:	Cost/Availability:	Toxicity Level:	Value:
Weights:	0.7	0.7	1	0.7	0.8	
HTPB	260	1854.553615	Good 5+ years	~16 $ / kg	Moderate	18.2
	4	5	6	5	3	
DB	220	1605.434473	NG leaks	Moderate	Bad	10.6
	3	3	2	4	2	
PBAN	260	1771.513901	Good 10+ years	~6 $ / kg	Moderate	18.2
	4	4	6	6	3	
CTPB	260	1771.513901	Good 10+ years	~70 $ / kg	Moderate	16.8
	4	4	6	4	3	

- HTPB was selected for baseline tests due to its performance parameters
- PBAN propellant is the most affordable.
- HTPB has slightly better performance metrics for slightly more cost.

Back: Pre-Launch Trades

Liquid Propellant Trade

Fuel/Ox:	**Isp (sec)**	**Density (kg/m^3)**	Storability:	Cost/Availability:	Toxicity Level:	Value:
Weights:	0.7	0.7	1	0.8	0.8	
MMH/N2O4	280	1.80556	Good storage properties	Very expensive	Bad	15.1
	5	6	5	2	1	
UDMH/N2O4	277	1.140794224	Most stable Hydrazine	Very expensive	Moderate	16.3
	5	4	6	2	3	
Hydrazine/H2O2	269	1.219330855	Worse temperature range	Not used on many engines	Bad	12.7
	4	5	4	1	2	
Hydrazine/N2O4	286	1.195804196	Worse temperature range	Very expensive	Bad	14.1
	6	5	4	2	1	

- MMH/N2O4 was selected for baseline tests due to performance parameters
- MMH/N2O4 has the best performance metrics but is the most toxic
- UDMH/N2O4 is the least toxic of the hydrazine family but has lower performance metrics

Back: Pre-Launch Trades

Launch Derived Requirements

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	Communications	Imaging - Visual/NIR	Imaging - Thermal
Satellite Mass (kg)	13	75 or 215	75
Injection Orbit	625 km Elliptical	567 km Sun-Synch Circular	
Satellites per Plane	3	20 or 10	4
Number of Planes	2-5	4	1

Back: Launch Requirements

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Requirements Alteration Evidence

Tool for Mission Success Probability

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Inputs:

- User selected launch sites
- Time of operations (launch prep, phasing, imaging calibration)
- Number of planes and plane spacing
- Launches per launch site
  - Program does not consider the probability of launch scrubs or failures

Outputs:

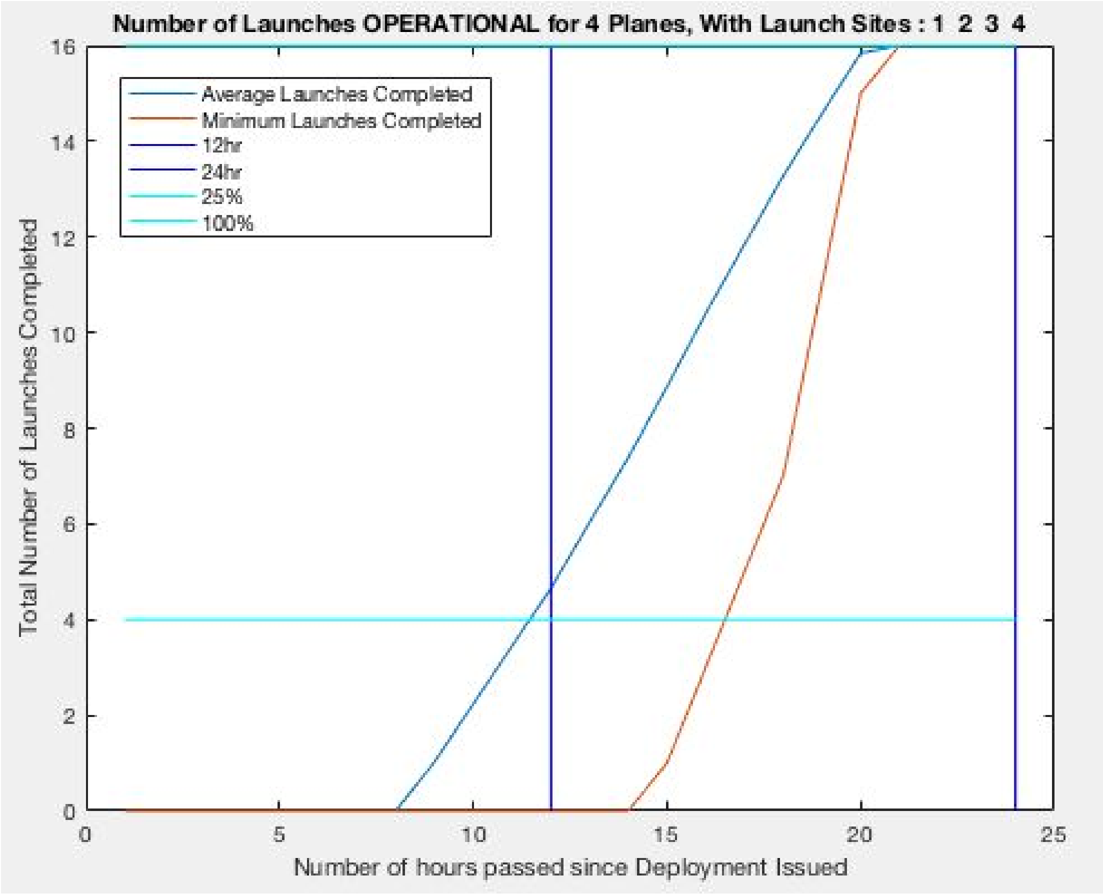
- Probability of success with selected scheme for 25% and 100%
- Average and minimum launches by hour for a user-specified amount of random cases (default 100 trials).

Back: 12 and 24 hour requirements

Output Sample (40 Sat Scheme)

INPUTS: **4** Planes, **3** Sats/LV, **4** Launch sites, **1** Launch per launch site per plane, **6** hours max phasing

Probability of meeting 12hr/24hr requirement based on Launch Prep Time			
	2 hr prep time	4 hr prep time	6 hr prep time
25%/12 hour	51%	38%	0%
100%/24 hour	100%	100%	83%



Back: 12 and 24 hour requirements

12 Hour Pushback

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General findings thus far:

- 12hr/25% capability difficult to achieve even theoretically without 1km/s+ phasing maneuvers.
- 24hr/100% capability is achievable, theoretically, when launch scrubs and failures are not considered.
- **IF (phasing time + launch readiness time) > 10 hours,**
  12hr/25% capability is impossible to reasonably achieve
  24hr/100% capability is often compromised
- **IF (phasing time + launch readiness time) < 3 hours,**
  12hr/25% capability can always be met, theoretically, with at least 4 launch sites and 3 sats per launch vehicle.