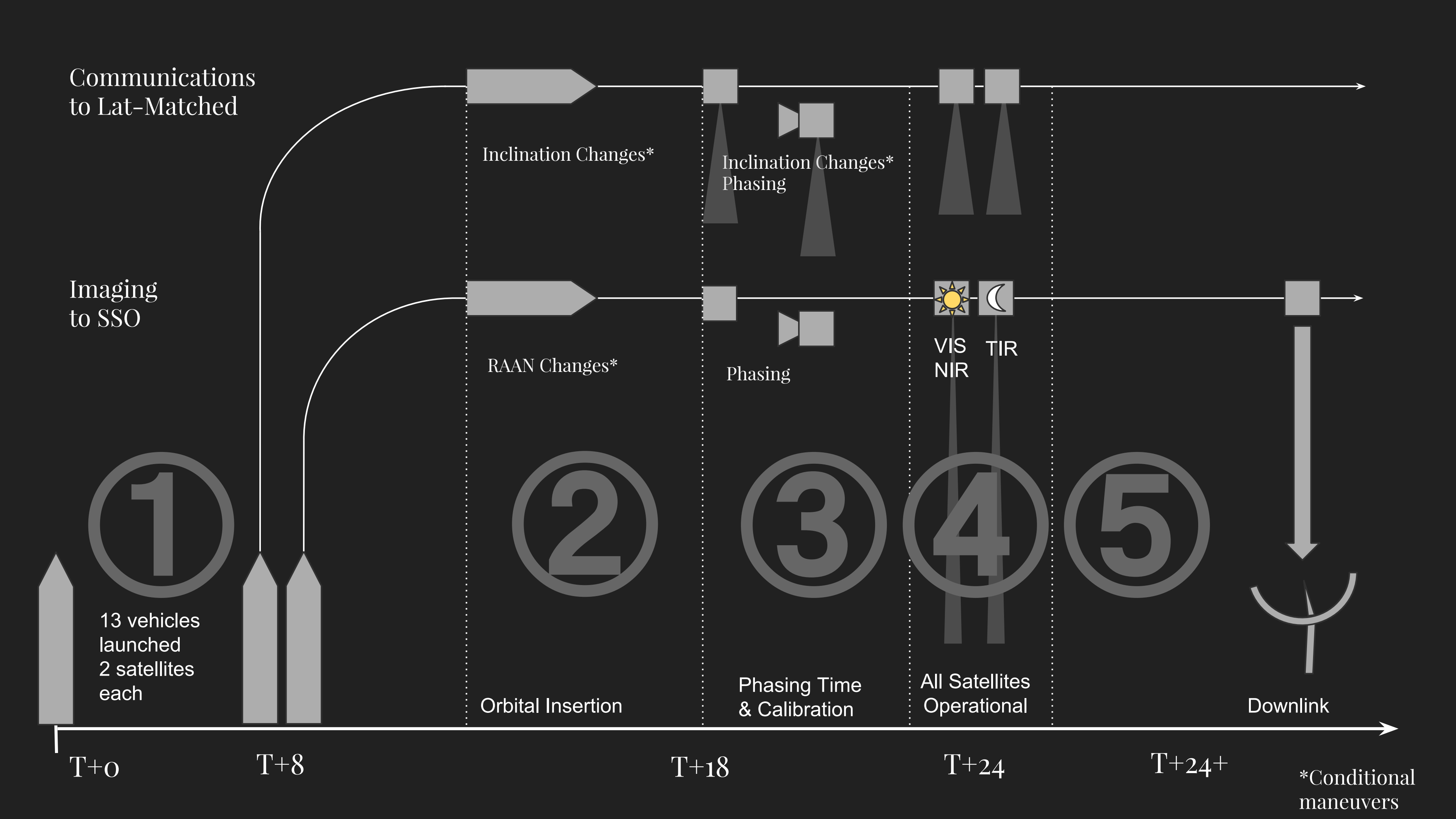
Mission Analysis and Design for Natural Disaster Relief Constellation

AERO 447-02

Mission Architecture

Disaster Occurs!

- Disaster latitude and longitude used to generate necessary information for launch and orbits
- Up to 6 communication satellites in 3 planes
- 10 Visual/Near IR and 10 Thermal IR Imaging satellites in 5 planes
- Preparation begins and launches when ready


Communications
to Lat-Matched
Imaging
to SSO
Inclination Changes*
Inclination Changes*
Phasing
RAAN Changes*
Phasing
VIS
NIR
TIR
1
2
3
4
5
13 vehicles
launched
2 satellites
each
Orbital Insertion
Phasing Time
& Calibration
All Satellites
Operational
Downlink
T+0
T+8
T+18
T+24
T+24+
*Conditional
maneuvers

Early Decisions

Super Trade to refined the options for both Imaging and Communications

1. Many, Small, No On-Orbit Propulsion
2. Many, Small/Med, On-Orbit Propulsion
3. Few, Med/Large, No On-Orbit Propulsion
4. Few, Large, On-Orbit Propulsion

Result of this trade was that imaging needed on-orbit propulsion and communications needed more sats and at lower altitudes than were proposed

The Breakup

Super Trade results lead to a split in Imaging and Communication constellations

- Imaging satellites needed to pass almost directly overhead, where as Communications satellites don’t
- Imaging orbits could meet communication requirements with extra satellites and extra orbital planes
- Drives up satellite size, increases launch requirements, increases satellite complexity and came with no apparent benefits

Orbit Design

- Derived Requirements
  - Imaging:
    - 1000 km altitude limit
    - Repeat ground track
  - Comms:
    - 2900 km Range for UHF
- Other Considerations/Requirements:
    - Launch delta-v
    - Ability to meet 25% after 12 hours and 100% after 24 hours requirements
- Comm Orbit Trade
  - Low Polar, High Polar, Latitude-Matched
    - Winner: Latitude-Matched
- Imaging Orbit Trade
  - Sun-Synchronous, Polar, Lat-Matched
    - Winner: Sun-Synchronous

Imaging Constellation

Orbital Solution for Imaging

- For Latitudes of 0-83º
  - Inclination: 97.7º (Sun-synchronous)
- Special Case for Latitudes > 83º
  - Inclination: 90º (Polar)
- Areas with Limited Daylight at Winter Solstice
  - Locations past ±66º Latitude have no daylight during the winter solstice. Additionally, regions between 63º and 66º have less than 4 total hours of daylight per day
  - This region introduces large gaps between daylight pictures, of up to 20 hours
  - Solution: Nighttime TIR Imaging can reduce gaps to ~8 hours
- Delta-V Budget

Maneuver Type	Phasing	Station-Keeping (6 months)	De-Orbit	Total (w/o margin)
Delta-V (m/s)	723	318	144	1185

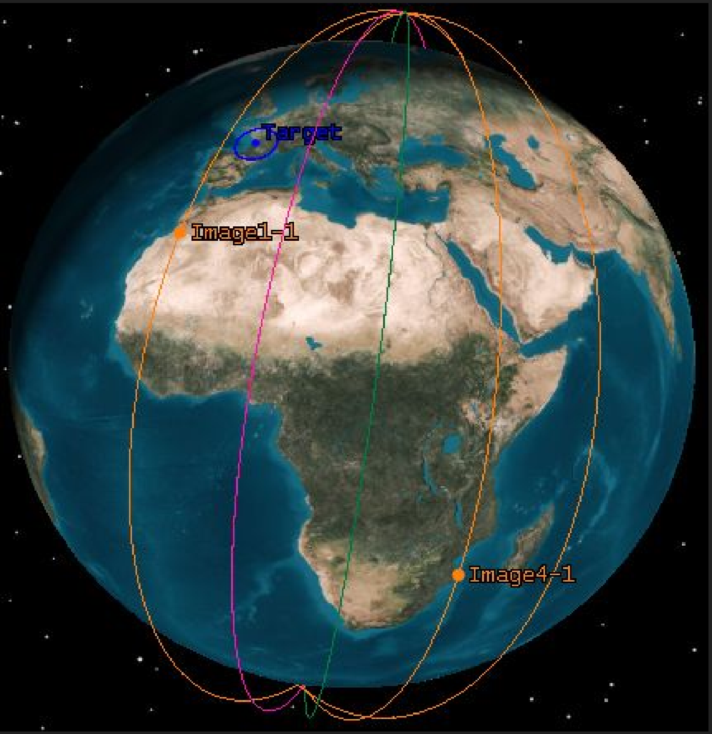
Orbital Solution for Imaging: Planes

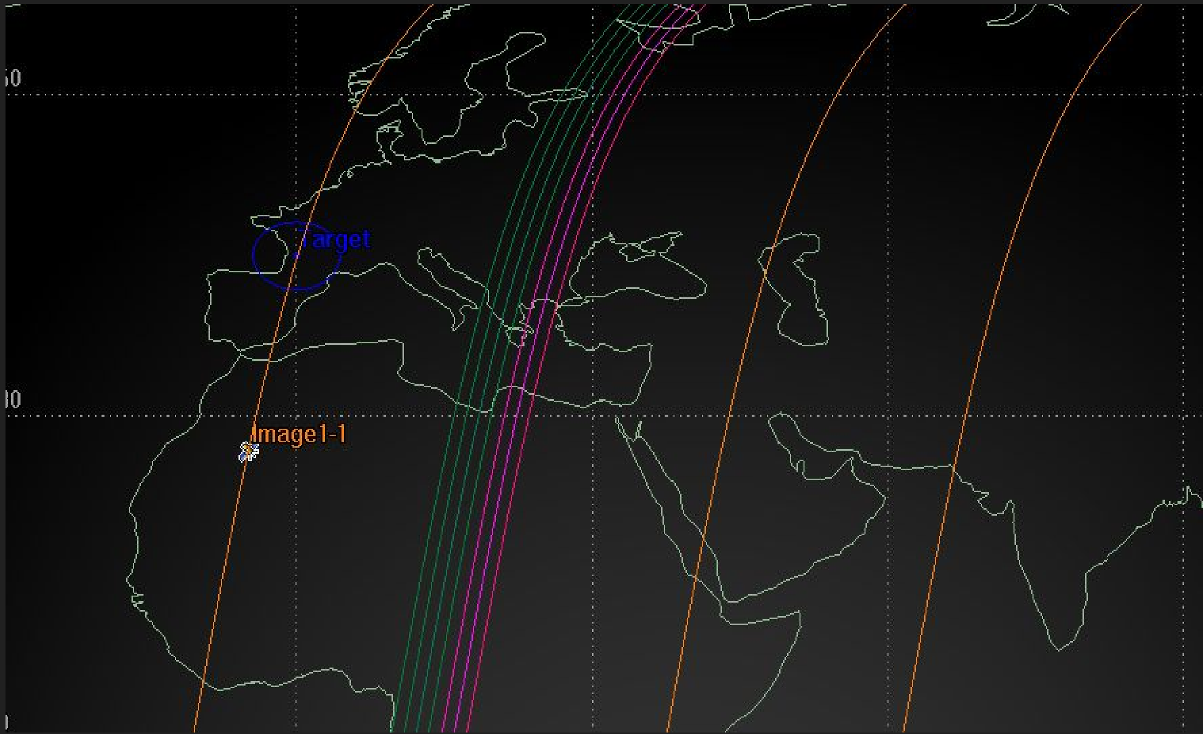
Plane	Auxiliary 1	Base 1	Base 2	Auxiliary 2	Auxiliary 3
Total Number of Satellites per Plane	2	6	8	2	2
Visible/Near Infrared	1	3	4	1	1
Thermal Infrared	1	3	4	1	1
Percentage of Target Area Imaged Per Band	15%	100%		15%	15%
RAAN of Plane *	Ωº	Ω+15º	Ω+30º	Ω+45º	Ω+60º

* Dependent on Disaster Location. Spacing shown for > 4h of Daylight

Orbital Solution for Imaging

- Altitude: 560.92 km (Repeat Ground Track, 15 revs to repeat)
- Sun-Synchronous





Imaging Major Design Decisions

- Satellite Pass Capability
  - The area each satellite captures in a single pass over area
- Separate Satellites for VIS/NIR and TIR Spectrums
  - Each band has different effects on optics design
- Altitude
  - The chosen orbit affects optics, control, pass time, and number of satellites
- Type of Imaging Method
  - Which imager type is best for the ground area’s geometry

Imaging Scheme

	Visible/Near Infrared (VIS/NIR)	Thermal Infrared (TIR)
Imaging Method	Pushbroom	Matrix Starer
Optics Size (Aperture/Focal) (m)	0.4 / 1.3	1.8 / 3.1
Field of View (km)	53.3 (swath width)	3.8 x 3.8
Imaged Area per Satellite (km^2)	~37500	~37500
Spectral Wavelength Bands	6	2
Total Data Captured per Pass (Gb)	193	82
Operating Temperature Range (°C)	-10 to 40	-200 to -50

5 meter resolution will be met with both systems at a max off nadir angle of 32 degrees

Requirement Considerations

Thermal Spatial Resolution Requirement

- Change from 5 m to 15 m significantly decreases design complexity

	5 m Resolution	15 m Resolution
Focal Length (m)	3.1	0.9
Aperture Diameter (m)	1.8	0.5

- Using resampled quality to meet requirements would decrease size and cost
- Thermal spacecraft size would then be more like the Visible/ NIR spacecraft

Satellite Area Capture Capability Trade

Options:

- Less than 15% of total area per pass
- 15% of total Area
- Greater than 15% of total area

Selected: 15% of total area in one pass

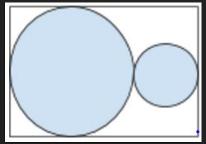
Driving Metrics: Increasing Area...

- Number of satellites **- ...decreases** number of satellites needed
- Sensor size **-** ...**increases** sensor size
- Pass Utilization **-** ...**increases** unnecessary data collected per pass

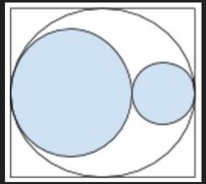
Visible/Near IR and Thermal IR Separation

Options:

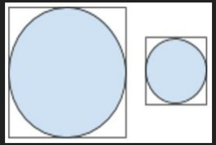
1. Same Spacecraft, Separate Sensors



2. Same Spacecraft, Integrated Sensor



3. Separate Spacecraft



Selected: Separate Spacecraft

Driving Metrics: Increasing Separation...

- Sensor/Optic Size - ...integrated **increases** aperture size; others do not change
- Dwell Time - ...**decreases** dwell time
- Temperature Control - ...**decreases** thermal isolation and cost
- Complexity - ...**decreases** complexity; less development for optics and easier pointing

Feasible Imaging Method Comparison

Options (relative motion):

- Pushbroom (minimum)
- Push-whisk (moderate)
- Matrix Starer (maximum)

Selected: Pushbroom for VIS/NIR

Driving Metrics: Increasing Motion...

- Pass Utilization **- ...decreases** unnecessary data collection
- Dwell Time - ...**decreases** dwell time
- Complexity **- ...increases** mechanical complexity; optical complexity is worst for push whisk and best for matrix starer
- Reliability **- ...decreases** reliability

Key Differences Between VIS/NIR and TIR

1. Pointing Requirement - Harder to point the larger sensor

2. Operational Delay - Less slewing delay because sensor sizes are larger

3. Smear - Less slewing means less smearing

Selected: Matrix Starer for TIR

Imaging Communications System

- Maximum Data: 193 Gbits per satellite

- Transmitter Data Rate: 500 Mbps
  - Total Downlink Time: 6 min 40 sec

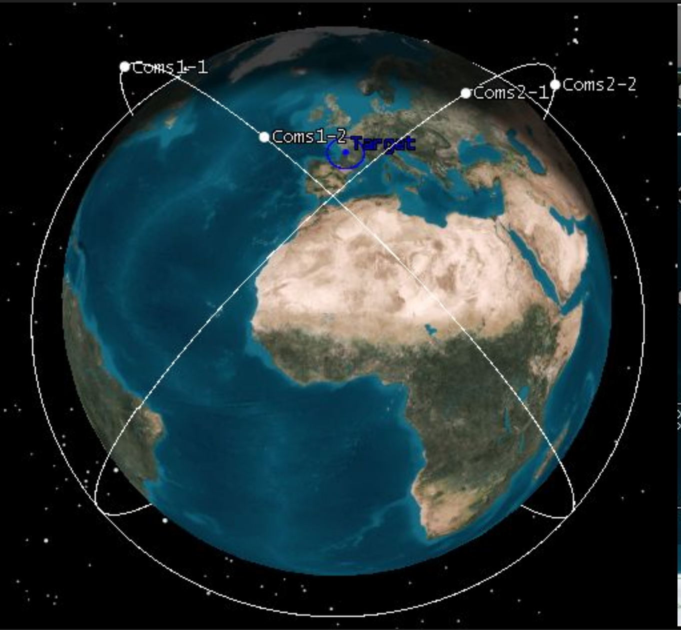
- Downlink Frequency: X band
  - based on current transmitter technology capabilities

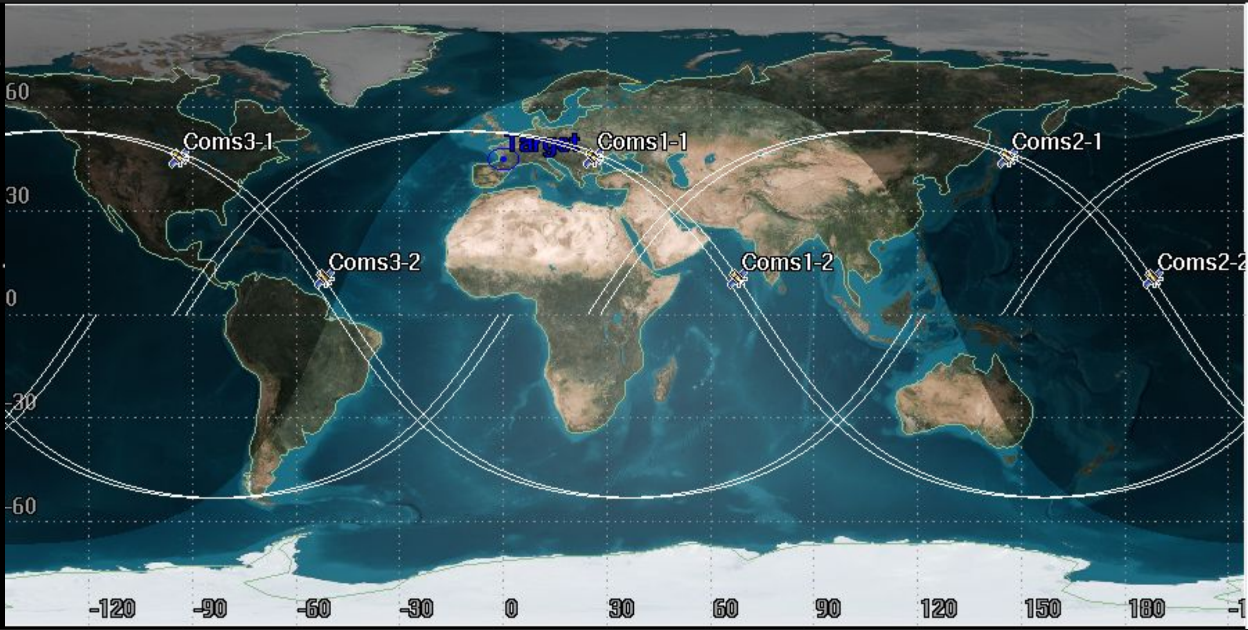
- Ground Stations :
  - Worst case: 10
  - Mobile ground stations preferred

Communications Constellation

Orbital Solution for Communications

- Altitude: 887.7km (14 revs to repeat)
- Latitude Matching: Orbit inclination determined by coverage location latitude





Orbital Solution for Communications: Planes

- Minimum elevation angle: 15º
- Maximum slew angle: 58º

Target Latitude	Inclination	Number of Satellites	Number of Planes	Total Pass Time	RAAN Spacing of Planes
0-7º	0º	2	1	280 min	n/a
7-15º	0º	4	2	250 min	180º
15-60º	~Lat+8º	6	3	300 min	120º
60-75º	~Lat+8º	4	2	260 min	180º
75-83	90º	4	2	250 min	180º
83-90º	90º	2	1	280 min	n/a

Orbital Solution for Communications: Delta-v

Communications constellation will have delta-v budget for three types of maneuvers:

- Phasing: Second comm sat phases to 50º relative true anomaly from first sat.
  - 8 hours for phasing
- Station-Keeping: corrects altitude/inclination changes for 6 months.
- De-Orbit: Must de-orbit 25 years after mission according to regulation.

Maneuver Type	Phasing	Station-Keeping (6 months)	De-Orbit	Total (w/o margin)
Delta-V (m/s)	178	217	230	625

Repeater Communications System

- Repeater Satellite Antenna infrastructure derived from ground radio capability

- Utilizes 1-5 W UHF ground handheld radios with AFSK encoding

- Antenna Type : Helical Antenna
  - Better for UHF range
  - Wider beamwidths with lower gain
  - Lighter, simpler design, deployable

Parameters	Units	Values
Beamwidth	deg	44
Antenna Diameter	m	0.18
Antenna Length	m	0.80
Power to close link	W	1.55
Signal to noise ratio	dB	23.71

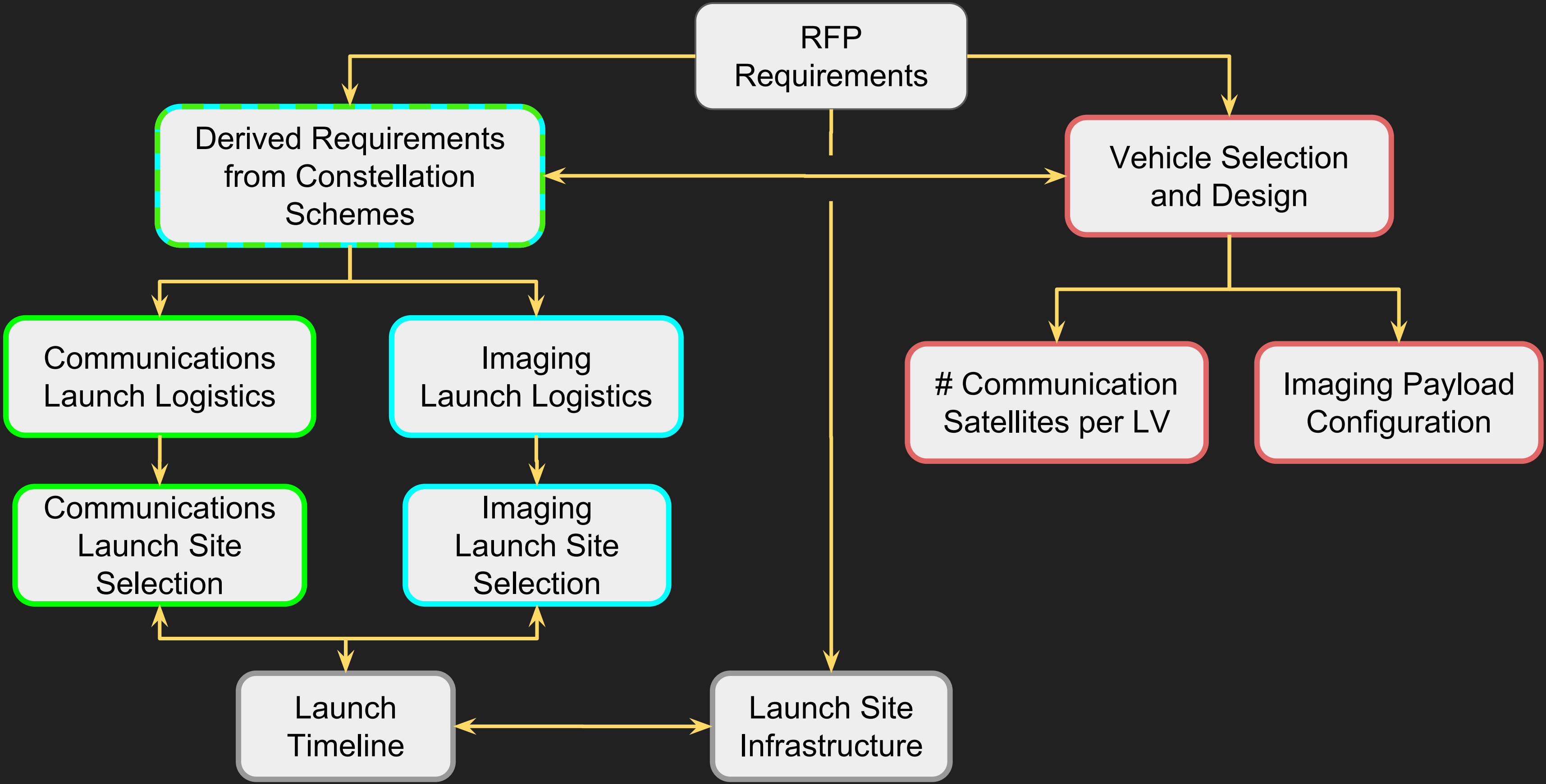
Repeater Communications System

- Comms satellites will make use of transponders for “channeling”
  - Multiple channels allows many first responders to use the comms system at once

- Comms satellite will require slewing
  - 58° max slew angle

- Communication Time Warning Scheme
  - Propagation of orbits for comms satellites will be delivered to first responders before deployment
  - Dedicate a channel to a tone system which alerts users to communication windows (warning tone/ping)
    - Constant tone to alert first responders of communications window, then a warning tone during last minute of communications

Launch System Flowdown



Launch Considerations

Build over Buy*

- Unprecedented Launch Window
- Launch Vehicle Customization
- Component Purchases Still Considered

* Complete launch vehicle without launch services

Land Launch over Air or Sea

- Launch Timeliness
- Cost
- Complexity

Launch Logistics

Imaging Satellites

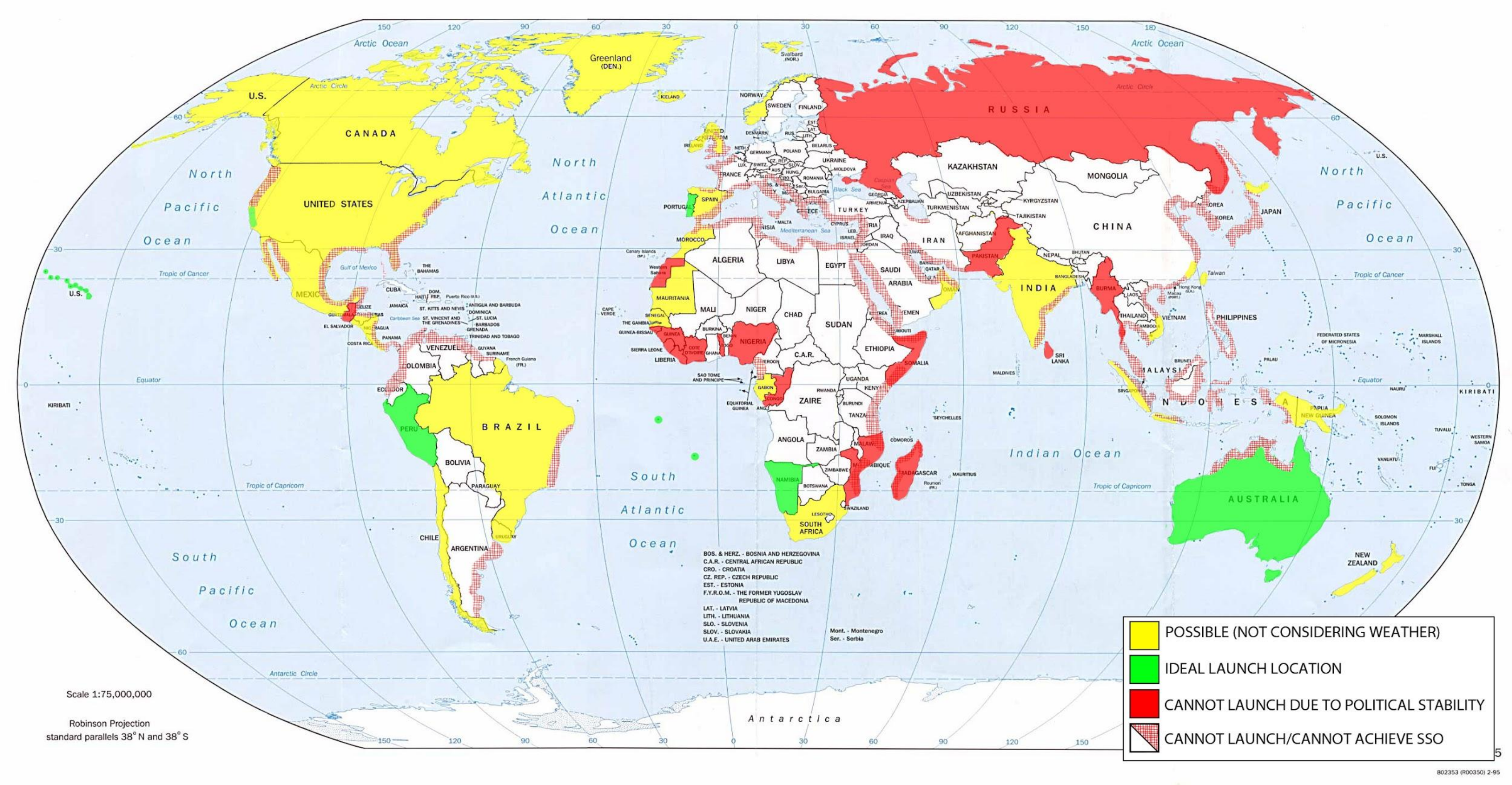
- 5 launch sites
- ≥ 2 launch vehicles each (redundancy not yet determined)
- 0-20% of imaging satellites operational at 12 hours

Communication Satellites

- 2 launch sites
- 2 launch vehicles each (potentially at same launch sites as imaging sites)
- ~50% of communications satellites operational at 12 hours

Total	
Minimum # of launch vehicles	14
# of launch sites	5-7

Launch Locations (Imaging)



Launch Timeline

Launch Prep Activities

- Personnel to Launch Site
- Pad prep
- Satellite prep
- LV prep

Comms Launch Constraints

- Can launch as soon as the pad is ready
- Max time between 1st and last launch: 8 hrs

Imaging Launch Constraints

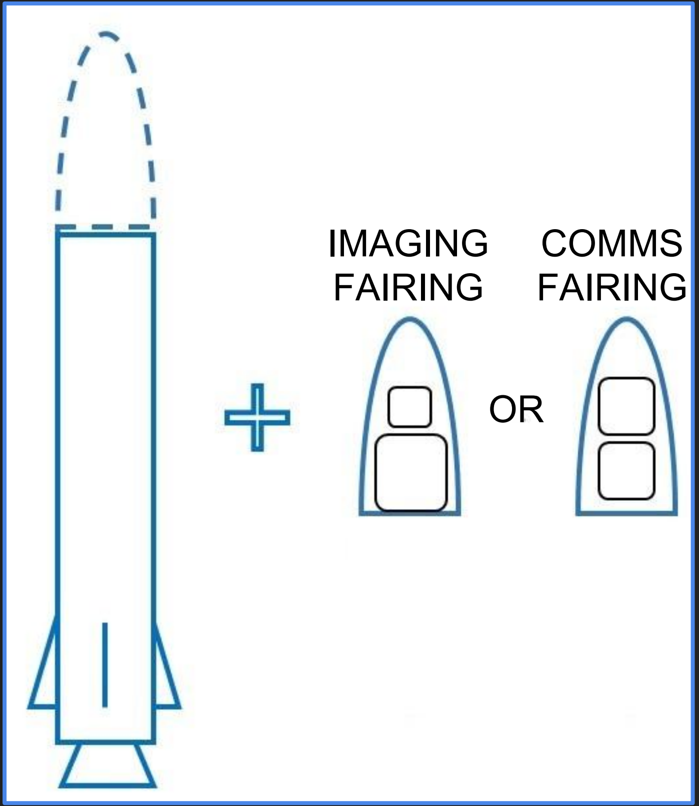
- Ideally launch when the plane passes over the launch site
- Max time between 1st and last launch: 10 hrs

Phasing Information

- Comms sat phasing time: ~ 8 hours
- Imaging sat phasing time: ~ 6 hours

Preliminary Launch Vehicle Configuration

- One configurable launch vehicle will be capable of supporting the imaging mission and the communications mission
  - 1 TIR & 1 VIS/NIR on each imaging launch vehicle
  - 2 communications payloads on each communications launch vehicle



Sketch to show fairings - not to scale

Launch - Moving Forward

- Phasing using launch vehicle vs. on-orbit satellite phasing
- Vehicle design (staging, propellant type, payload size constraints, etc.)
  - 5 year storage requirement will affect usable propellant types
- Launch infrastructure and operation requirements

Path Forward for Whole System

- Update Mission Architecture to reflect recent changes to the RFP
- Begin to develop on the system level as well as the subsystem level
- Refine Timeline
- Optimize design for best possible performance with current derived requirements

Questions?