Exploration Research and Technology Programs

Ground Systems & Mission Operations

July 13th, 2023

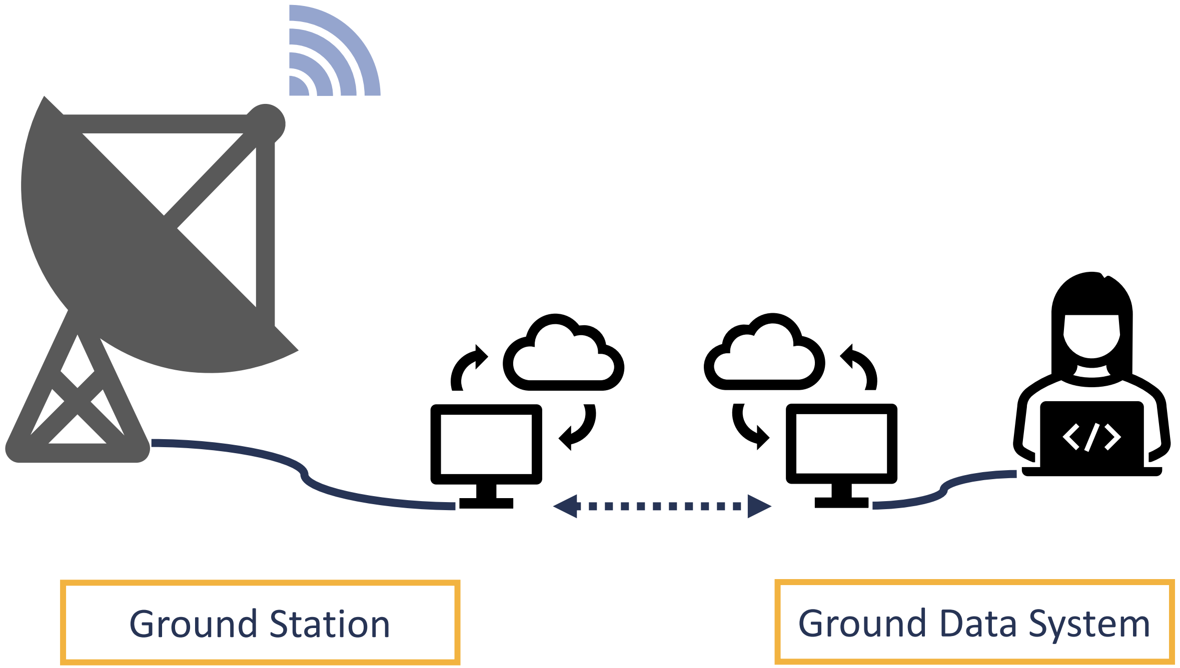
Josh Undlin

Ground System

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

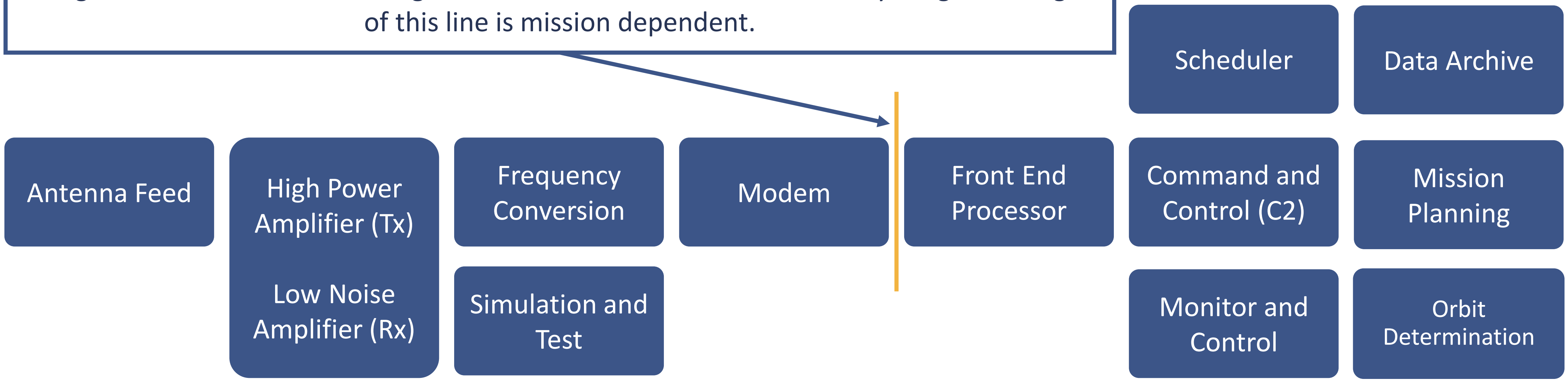
Ground Components

- Two primary subsystems
  - Ground Station(s)
    - May be your own or commercial
    - Includes radio(s), antenna(s), rotor, etc.
    - Heavily intertwined with satellite communications system
    - Influences link budget
  - Ground data system
    - Your command, control, and telemetry interface
    - Operator facing tools
    - Front end processor
    - Includes computer(s), networking equipment, displays, software tools, etc.
    - Directly links to your ground station via network
  - Additional ground subsystems could include:
    - Payload ground (i.e. optical ground terminal)
    - Space comm networks (i.e. Iridium)



Ground System Components

Many possible configurations, this shows one simplified example. Yellow line designates general break between Ground Station and Ground Data System. This line may also designate the networked link to ground stations around the world. Everything to the right of this line is mission dependent.



To satellite

Most of these boxes are now software applications

To operator

Ground Stations

- Build your own
  - Not too difficult for UHF
  - Somewhat more difficult/expensive for S-band, but still doable
  - Kits available from a variety of vendors
  - Limited to one station
    - Maintenance issues heavily impact mission
    - Fewer passes than multiple distributed stations
- Utilize ground station service providers
  - Mature, capable services that add value
    - Ksat, Atlas, Amazon, Viasat, Satnogs, and Xplore Major Tom.
  - Wider variety of stations around the world for more passes
  - Assistance with frequency licensing and ground station testing
  - Costs vary and may be more expensive than building your own
    - Cost for using service as a whole
    - Setup cost for each ground station used
    - Cost for time using network
    - Many companies offer university discounts

A DIY ground station kit from Alen Space with S-Band and UHF capabilities

Atlas Space S-Band ground stations. Generally Ground station services will provide larger/more capable ground stations than in-house options available to universities

Ground Data System

- Ground data system provides single interface to entire ground system:
    - Command Database
    - Telemetry Database
    - Payload Data
    - Operator Interface Tools
    - Automation
    - Alarming
    - Packet framing
    - Error correction (Viterbi, Reed-Solomon)
    - Telemetry processing/display
    - Encryption/decryption
    - Operation Records (i.e. anomalies, shifts)
- Can be fancy or simple
    - Commercial products
    - Python scripts

AFRL Image

Keep in mind: Data ≠ Information

References

- Kratos White Paper on Ground Systems for Small Sats - https://www.spacefoundation.org/wp-content/uploads/2019/07/Prechtel-Matt-Smallsat-Ground-Systems-a-C2-to-RF-Integrated-Approach.pdf
- Software Defined Radio Sampling basics - https://pysdr.org/content/sampling.html

Questions?

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

Mission Operations

UNP In review…

Experiment plan → **CONOPS** → Mission Operations → End data product

Concept of Operations (CONOPS)

- Describes how the Mission will achieve the objectives including Flight, Ground, and Information Systems
- How does the project get data or carry out the mission to satisfy stakeholders?
- Can be broken into four major elements (see SMAD):
  1. Data delivery
  2. Communications architecture
  3. Tasking, Scheduling, and Control
  4. Mission Timeline
- If the Experiment Plan describes the data and tasking that need to be done, the CONOPS address how that data is created, sent to the ground, and the timeframe it is done within

Notes:

- CONOPs means different things to different people
- CONOPs depends on the missions, and is how to do your mission
- ***The thing that matters is ability to execute from the document***

CONOPs – Just one way to do it

I. Phases – *experiment objectives*
   I. LEOPS
      I. Initialization
      II. Checkout
      III. Payload calibration/characterization
   II. Nominal Ops
      I. Experiment A
      II. Experiment B
      III. Experiment C

II. Modes – *state of spacecraft*
   I. Survival
   II. Safe
   III. Operational

- There are different ways to organize your mission
- "Modes" and "Phases" are often used; the important thing is common vernacular within a team and communicated outward
- In this case
  - "phases" describes intended objective fulfillment
  - "modes" describe vehicle state
- The key is that you have to describe **both**

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

CONOPs – Example Experiment A

I. Phases – *experiment objectives*
   I. LEOPS
      I. Initialization
      II. Checkout
      III. Payload calibration/characterizati
   II. Nominal Ops
      I. Experiment A
      II. Experiment B
      III. Experiment C

II. Modes – *state of spacecraft*
   I. Survival
   II. Safe
   III. Operational

Experiment A

Description: Baseline Mission Data Collect, completion correlates to minimum mission success criteria

Requires 5 data collects for complete data set for fulfillment of success criteria (based on analysis and stakeholder input)

Assumes mission has a site track data collect (i.e. imager)

CONOPs – Example Experiment A, Single Instance

Exploration Research and Technology Programs

Experiment Mode Description

Entrance and exit criteria

These four blocks are not all inclusive; your document needs to have further detail

Objectives
& End data products
(may be in experiment plan)

State/vehicle action definition

CONOPS – Example Experiment A Single Snapshot

Experiment A CONOPS Description

- *Satellite is in operational mode*
- *Operator schedules data collect for selected target*
- *Vehicle does data collect for specific target*
- *Data downlink to ground station*

Experiment Entrance Criteria	Experiment Exit Criteria
Vehicle is in a healthy* state	All experiment data is downlinked
Desired Target is identified	Schedule is executed, complete
Vehicle is in operations mode	Fault scenarios -> safe mode

Experiment Objectives:

- Experiment Collect
- Experiment Data Downlink

Desired Data Product:

- Single pass data collect w/time stamp
- GPS correlated

Operational Mode State				
Subsystem	Power State	State	Data Type	Data resolution
EPS	ON		Telemetry	1 Hz
CDH	ON		System state	1 Hz
TT&C	ON		Telemetry	1 Hz
ADCS	ON	Fine point	Telemetry	1 Hz
GPS	ON		Telemetry	1 Hz
Payload	ON		Telemetry & Mission data	10 Hz

In review…

Experiment plan → CONOPS → Mission Operations → End data product

Concept of Operations (CONOPS)

- Describes how the Mission will achieve the objectives including Flight, Ground, and Information Systems
- How does the project get data or carry out the mission to satisfy stakeholders?
- Can be broken into four major elements (see SMAD):
  1. Data delivery
  2. Communications architecture
  3. Tasking, Scheduling, and Control
  4. Mission Timeline
- If the Experiment Plan describes the data and tasking that need to be done, the CONOPS address how that data is created, sent to the ground, and the timeframe it is done within

Notes:

- CONOPs means different things to different people
- CONOPs depends on the missions, and is how to do your mission
- ***The thing that matters is ability to execute from the document***

In review…

Experiment plan → CONOPS → **Mission Operations** → End data product

- Mission planning
- Vehicle tasking
- Plan/pass/task execution
- Data Downlink
- Data processing

BUT WHY DO I CARE NOW?

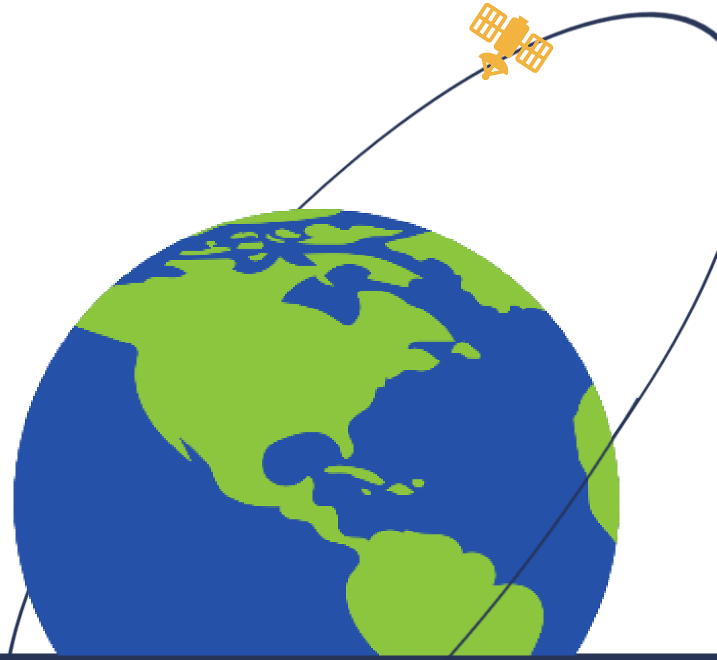
1. You are ALREADY making assumptions about ops (whether you know it or not)
2. To understand what information I need in the end, which I need to design in
3. To understand what tools I need to execute
4. To maintain ability to understand satellite behavior and provide solutions on orbit

UNP CONOPS – Example Experiment A

Exploration Research and Technology Programs

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft stores data → Downlink data → Data Analysis

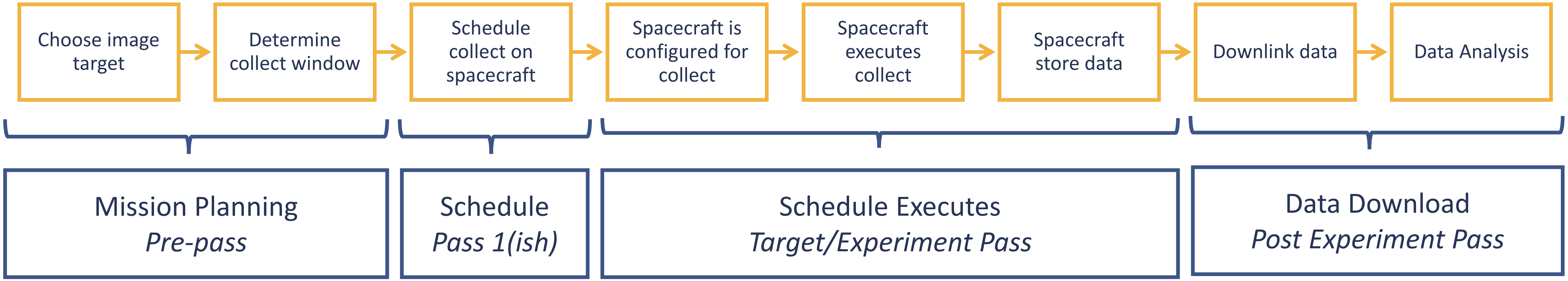
Seems simple at a high level, but **there is a lot of detail.**



Things to consider…

- Operations Cadence
  - How often are you running experiments? (and what are the drivers?)
    - High tempo vs low-manned (nominal mission plan for each phase)
    - How long do things actually take?
  - Mission Planning
    - Phase planning -> weekly(ish) plan -> daily/shift(ish) plan -> pass plan

UNP CONOPS- Example Experiment A



UNP CONOPS- Example Experiment A

Exploration Research and Technology Programs

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft store data → Downlink data → Data Analysis

Mission Planning *Pre-pass*	Schedule *Pass 1(ish)*	Schedule Executes *Target/Experiment Pass*	Data Download *Post Experiment Pass*

<u>Pre-experiment planning occurs on many levels</u>

- What are the criteria for evaluating appropriate target (length of pass, staffing, etc.)
- What tools are needed for determining collect window?

Weekly Plan (strategic)	Daily Plan (tactical, does not mean day-of)
What objective am I trying to meet? • Identify target • Figure out window – time, appropriate command sets, goals	• Specific pass plan • Assessment per vehicle data • Create schedule (before pass) & review

UNP CONOPS- Example Experiment A

Exploration Research and Technology Programs

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft store data → Downlink data → Data Analysis

Mission Planning *Pre-pass*	Schedule *Pass 1(ish)*	Schedule Executes *Target/Experiment Pass*	Data Download *Post Experiment Pass*

Building a Schedule

- Tool Dependent – consider mission needs
- Priority of telemetry and commanding requires consideration!
  - SOH telemetry matters (vehicle safety)
  - Command Sequencing (handling dropped commands, schedule subsystems back on before off, etc.)
- Steps pre-collect
  - System configuration (power states, telemetry data rate and storage, attitude commanding/slew, etc.)
  - How long will vehicle configuration take? How long can system budgets handle it?
- State to return to/end of pass

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

UNP CONOPS- Example Experiment A

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft store data → Downlink data → Data Analysis

Mission Planning
Pre-pass

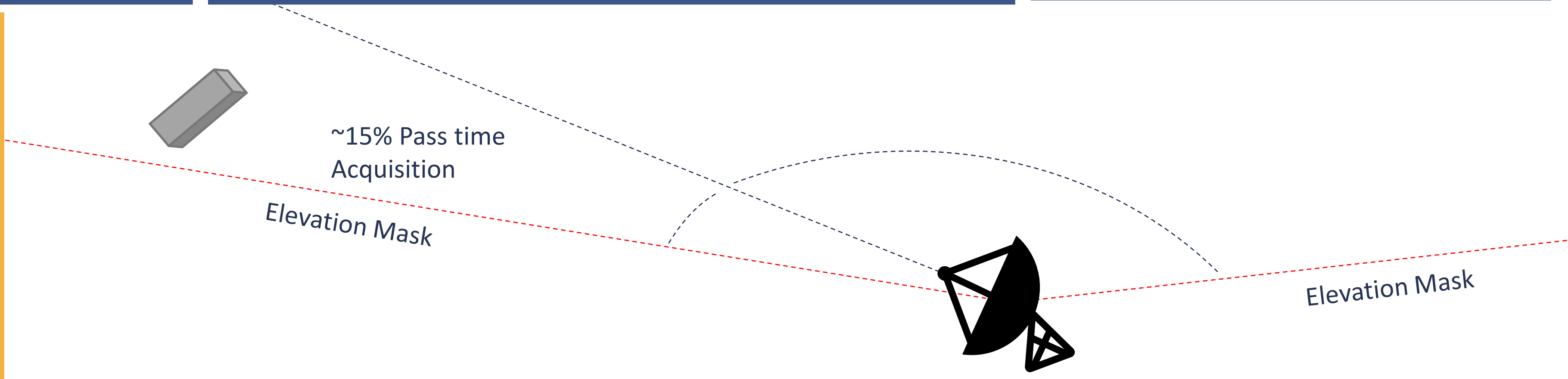
Schedule
Pass 1(ish)

Schedule Executes
Target/Experiment Pass

Data Download
Post Experiment Pass

<u>Things to consider</u>

- Always assess **state of health** at the beginning of every pass
- Signal strength/quality of link
- How will you know that your command has been received/executed?



UNP CONOPS- Example Experiment A

Exploration Research and Technology Programs

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft store data → Downlink data → Data Analysis

Mission Planning
Pre-pass

Schedule
Pass 1(ish)

Schedule Executes
Target/Experiment Pass

Data Download
Post Experiment Pass

Things to consider

- Always assess **state of health** at the beginning of every pass
- Signal strength/quality of link
- How will you know that your command has been received/executed?

Side note on State of Health:

- How will you know health of your vehicle?
- Be intentional regarding beacon content.
- Suggested telemetry
  - Vehicle state, EPS switch states, thermal, attitude states, +

How will I know the vehicle is in safe mode and how it got there?
(putting a pin in anomaly resolution for now…)

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

UNP CONOPS- Example Experiment A

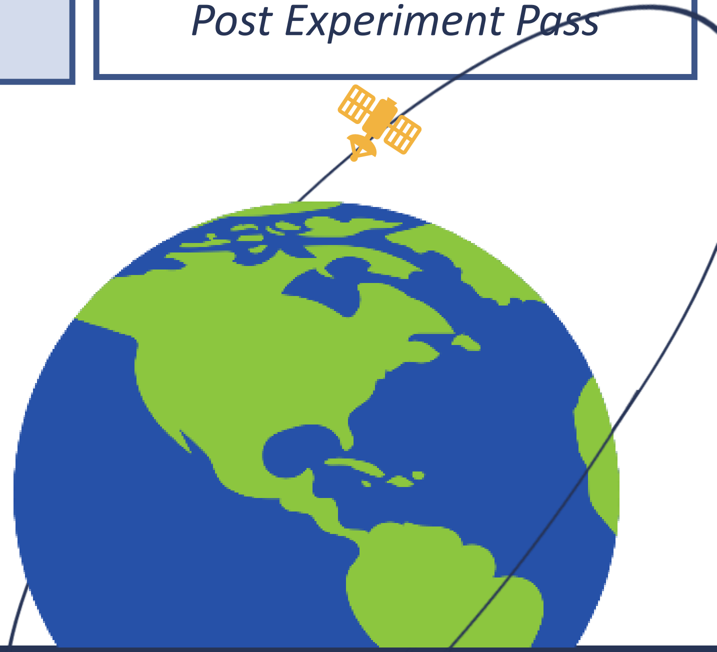
Exploration Research and Technology Programs

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft store data → Downlink data → Data Analysis

Mission Planning *Pre-pass*	Schedule *Pass 1(ish)*	Schedule Executes *Target/Experiment Pass*	Data Download *Post Experiment Pass*

Things to consider

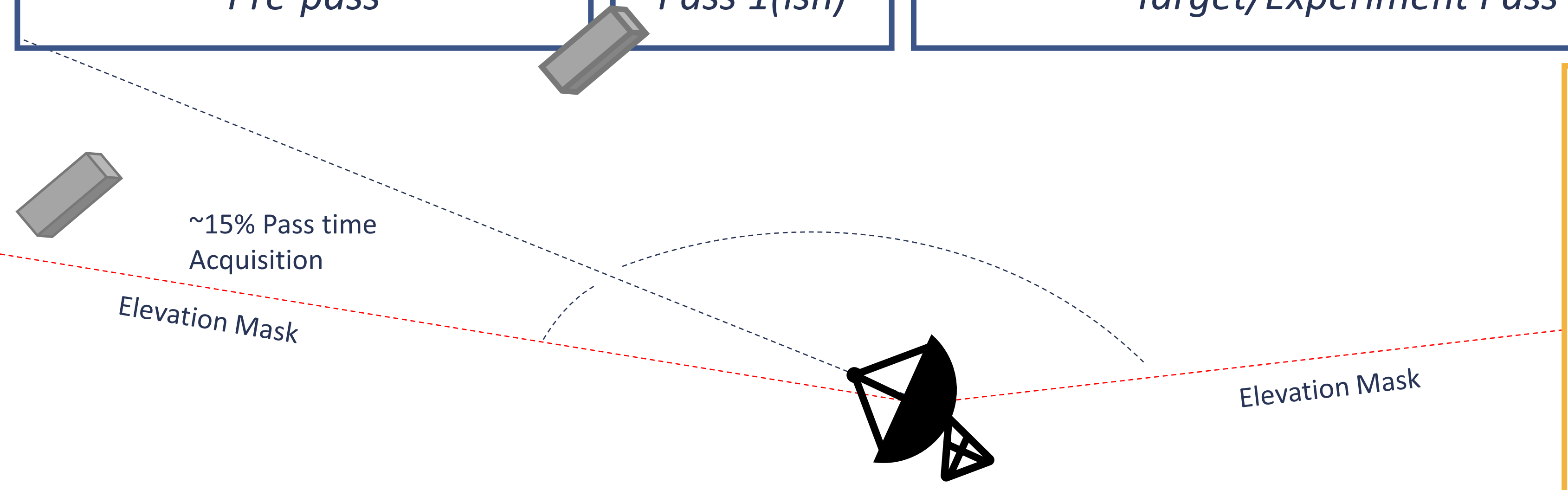
- In theory, this is the easiest part
- Unique for every mission
  - Might not be pass-based, might be multiple
- Consider if you will have any live commanding during the pass
- State to return to/end of pass



CONOPS- Example Experiment A

Choose image target → Determine collect window → Schedule collect on spacecraft → Spacecraft is configured for collect → Spacecraft executes collect → Spacecraft store data → Downlink data → Data Analysis

Mission Planning	Schedule	Schedule Executes	Data Download
Pre-pass	*Pass 1(ish)*	*Target/Experiment Pass*	*Post Experiment Pass*

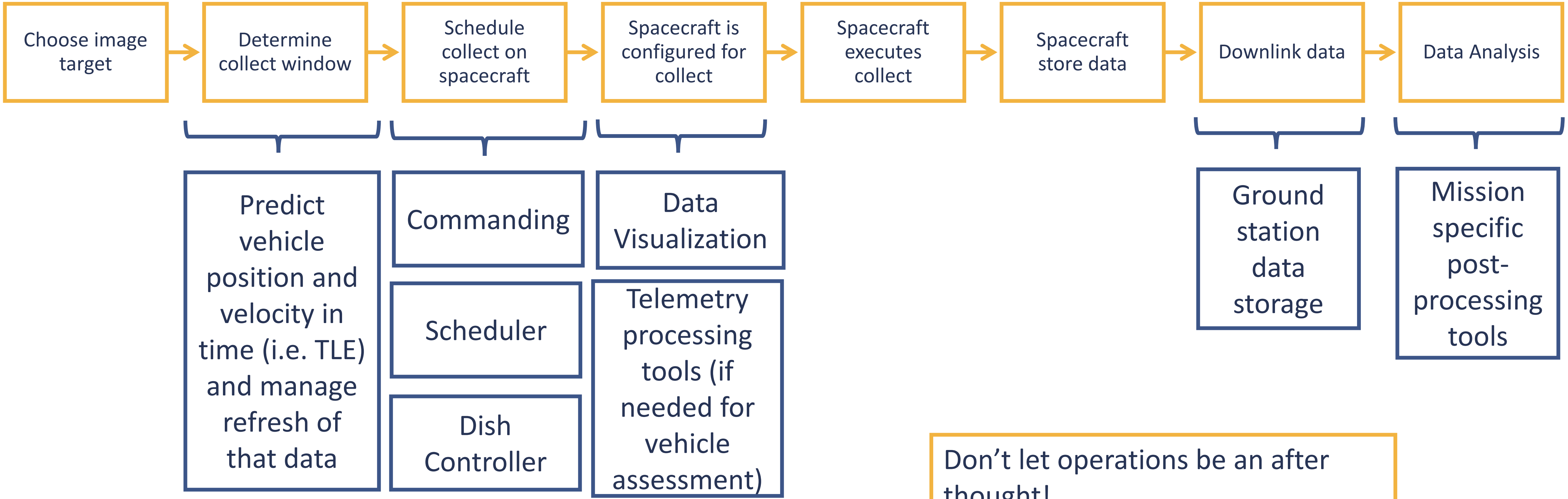


<u>Things to consider</u>

- Always assess **state of health** at the beginning of every pass
- Pass/data priority?
- Data downlink file system (how are you going to ask for the data?)
- Consider analysis tools and time sensitivity
- Likely multi-pass

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

CONOPS- Example Experiment A



Don’t let operations be an after thought!

Approved for public release; distribution is unlimited. Public Affairs release approval AFRL-2023-4526

Anomaly Resolution

Most CubeSats that launch and have an immediate, mission-ending problem
11% DOA, 6.2% Early Loss (Dr. Swartwout's database)

Plan for things to go wrong, and figure out what you need in the vehicle to fix it

1. Assessable anomalies with active problem solving
   - Telemetry to consider – Thermal, power, attitude, …. Figure out how to fix it
2. Anomalies you can't control… how does the vehicle recover? (fault scenarios)
   - Watchdog timers
   - Subsystem resets
   - Example: no-valid uplink reset

Approved for public release; distribution is unlimited. Public Affairs release approval
AFRL-2023-4526

UNP Application - SHARC

Problem: Satellite power negative (contrary to power analysis) upon start up

Indication of problem: State of charge telemetry, MPPT input telemetry

Cause: Solar panel failure on primary sun-pointing axis

Solution: reconfigure sun-safe mode primary axis for pointing

Key take aways

1) Configurability

2) Pre-uplink testing

Misc. Best Practices

- **Safe mode**
  - Design satellite for survival in a tumble
  - Design a mode (i.e. safe or sun-safe) so the vehicle can happily live indefinitely (think holidays, anomaly resolution, etc.)
- Perspective- reassess your CONOPS and assumptions from operator view point
- Test on the ground with as representative of a ground system as possible

Things you'll eventually need to think about…

- Teaming
  - Satellite Control Authority
  - Roles and Responsibilities
- Flight Rules
- Training
- Planning (specifics)
  - Review process
  - Operations cadence
  - End-data user interface
- Facilities and User Interfaces

Key Take-Aways

- Consideration of operations in design phase matters
  - Assumption validation
  - Catch missing pieces
  - Hooks in the system for anomaly resolution

The problems you create now will not be a problem until later… and you might not be there to provide a solution

Questions?