VIRGINIA TECH

VT Spaceflight Infrastructure Improvements

Fall 2018

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Introduction

Dr. Jonathan Black

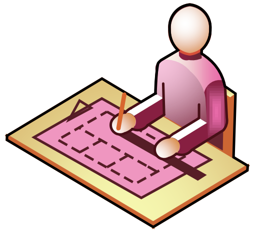
Spacecraft Engineering at Virginia Tech

Stephen Noel

Research Faculty

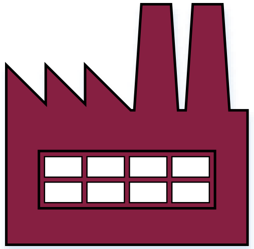
The Big Picture

Virginia Tech Space Mission Life Cycle



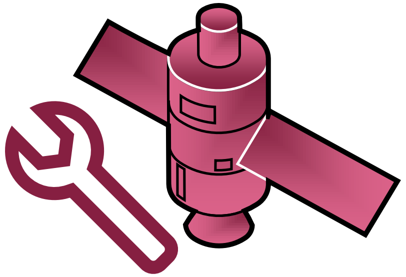
CONCEPT AND DESIGN

- Requirements Definition
- Conceptual Design
- Design Reviews
- Modelling and Simulation



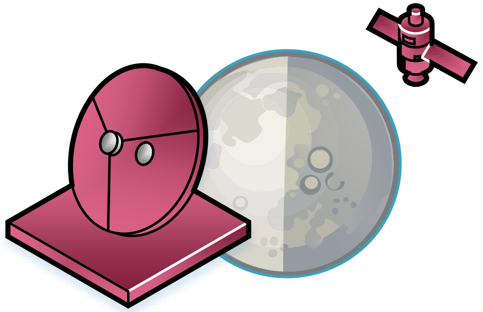
PLANNING & FABRICATION

- Prototyping and Testing
- Licensing
- Test and Ops Planning
- GSE Development



INTEGRATION AND TESTING

- Environmental Testing
- End-to-end Testing



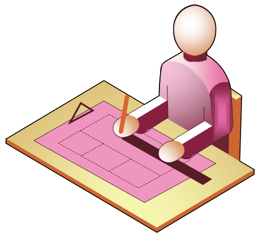
MISSION OPS

- Health and Safety Monitoring
- Command and Control

Current Capabilities

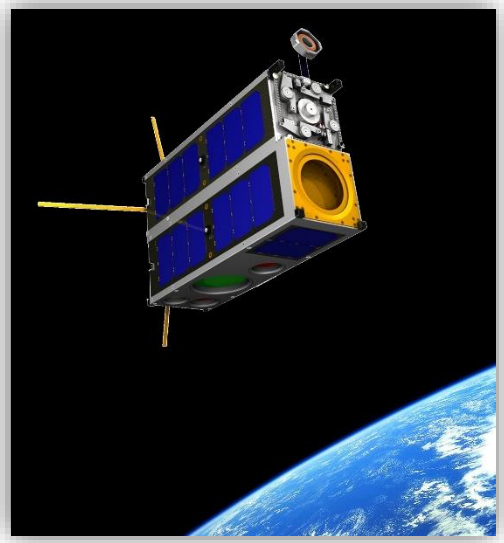
LEGEND:

- Strong capabilities and/or experience
- Experience - room for improvement
- Need for growth/capability



CONCEPT AND DESIGN

- Requirements Definition
- Conceptual Design
- Design Reviews
- Modelling and Simulation



LAICE 6U CubeSat

- Experience in NASA design approach
- AOE senior design teaches strong systems engineering skills
- Templates and examples available from previous projects like:
  - LAICE
  - HokieBus
  - SharkSat

NEED: Reusable, flexible mission planning resource

- **Usually custom-built for individual missions**
- Most simulation needs at this phase are:
  - Science access time
  - Power budget/management simulation
  - Lifetime analysis
  - Ground station access analysis

Current Capabilities

LEGEND:

- Strong capabilities and/or experience
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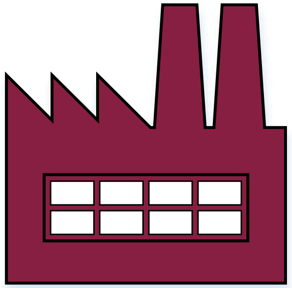
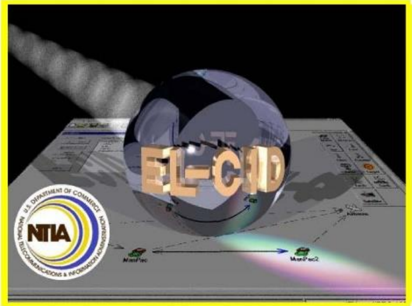
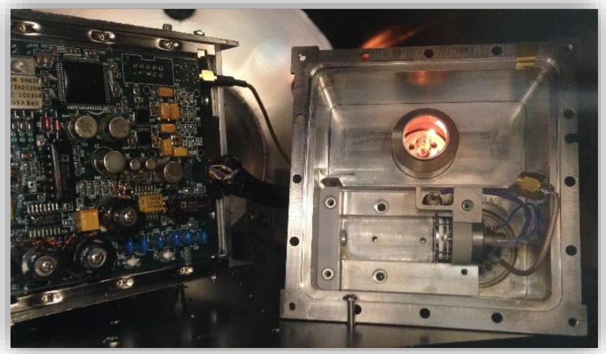


PLANNING & FABRICATION

- Prototyping and Testing
- Licensing
- Test and Ops Planning
- GSE Development



FCC Experimental Licensing



LAICE LINAS payload testing

Orbital Debris Assessment Report (**ODAR**)

NEED: Central command/control and logging resource for subsystem testing

NATIONAL INSTRUMENTS LabVIEW

- **Custom-built for individual missions**

Current Capabilities

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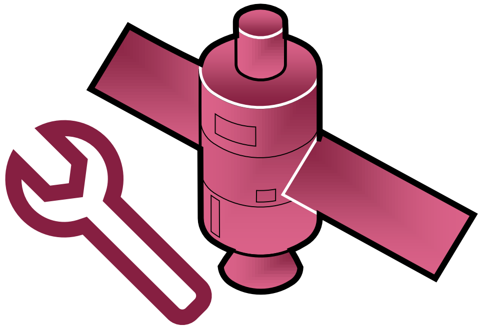


LEGEND:

- Strong capabilities and/or experience
- Experience - room for improvement
- Need for growth/capability

INTEGRATION AND TESTING

- Environmental Testing
- End-to-end Testing

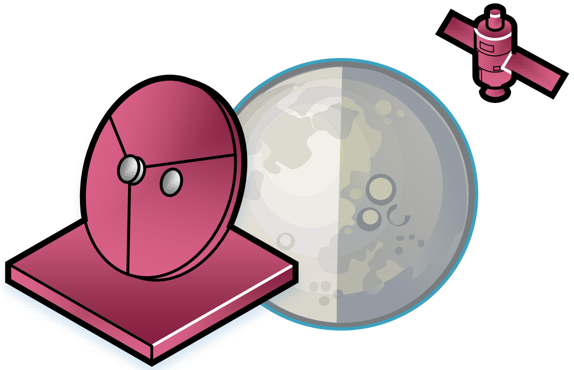
NASA cFS core Flight System

NATIONAL INSTRUMENTS LabVIEW

NEED: Reusable and scalable flight software

NEED: Central command/control and logging resource for subsystem testing

Current Capabilities



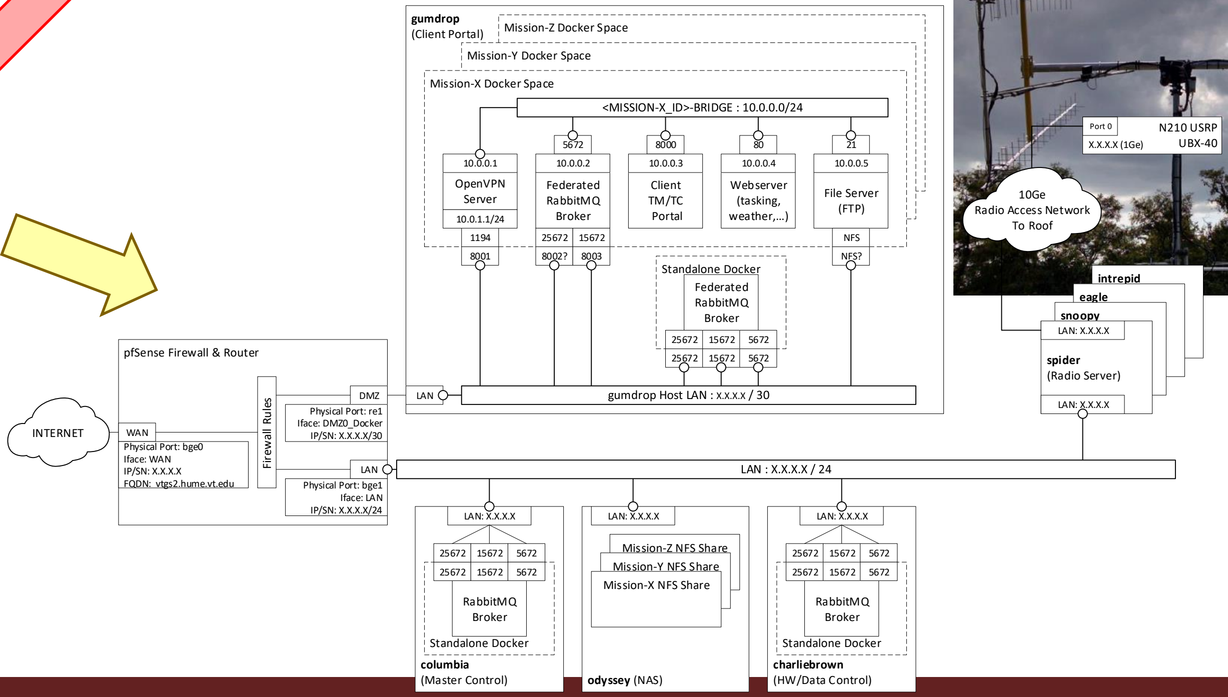
MISSION OPS

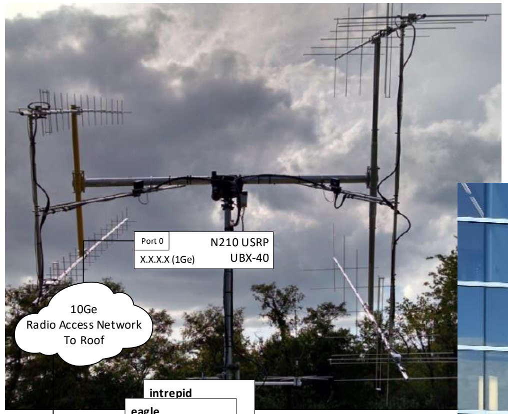
- Health and Safety Monitoring
- Command and Control

NEED: Health & safety monitoring and situational simulation

LEGEND:

- Strong capabilities and/or experience
- Experience - room for improvement
- Need for growth/capability



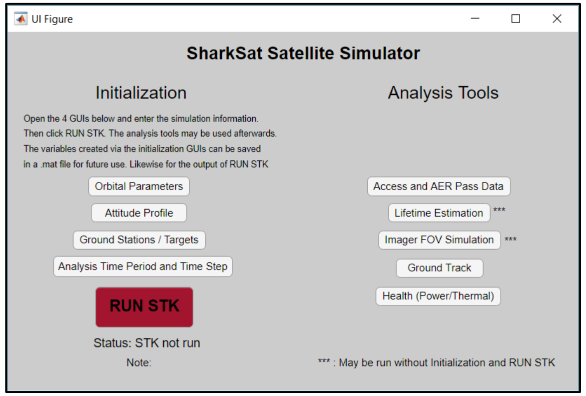


Summary of Needs

HOW WE'LL ADDRESS THESE NEEDS:

NEED: Reusable, flexible mission planning resource

NEED: Health and safety monitoring and situational simulation



NEED: Reusable and scalable flight software

NASA cFS core Flight System

NEED: RF channel simulator for injecting realistic Doppler shift and path loss in satellite pass simulation

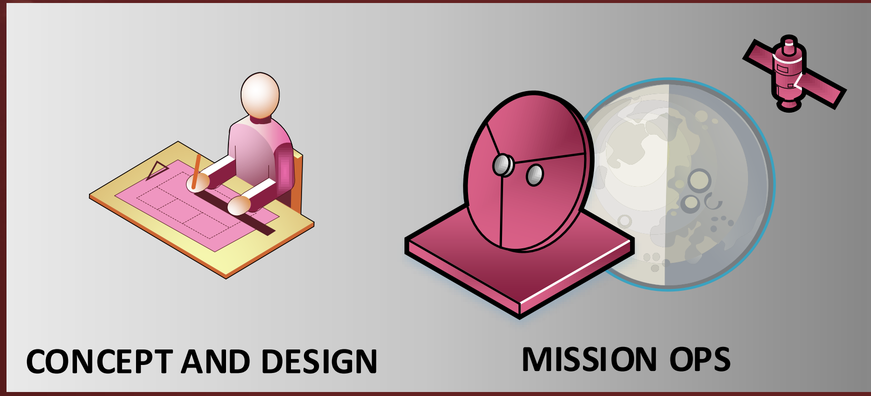
RF Channel Simulator

NEED: Central command/control and logging resource for subsystem testing

COSMOS

Modeling and Simulation

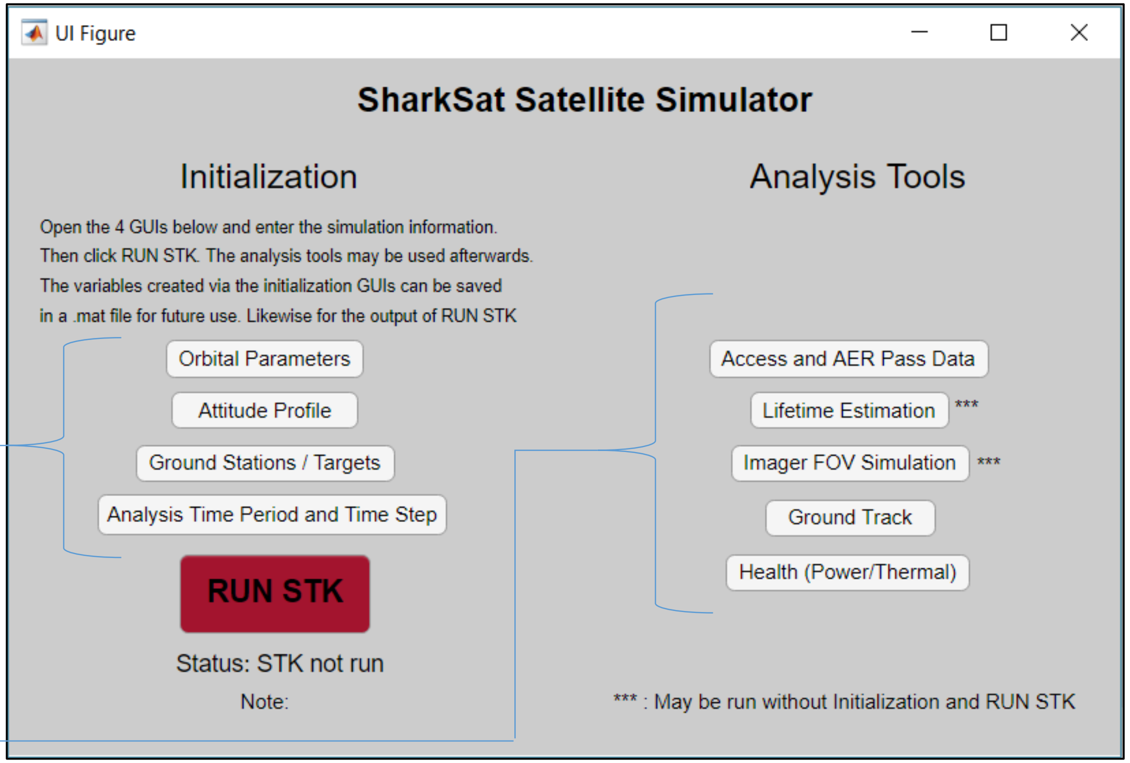
Jeremy Ogorzalek
Graduate Student



Modeling and Simulation

<u>All GUI-based Matlab code that interfaces with STK</u>

Main Screen:



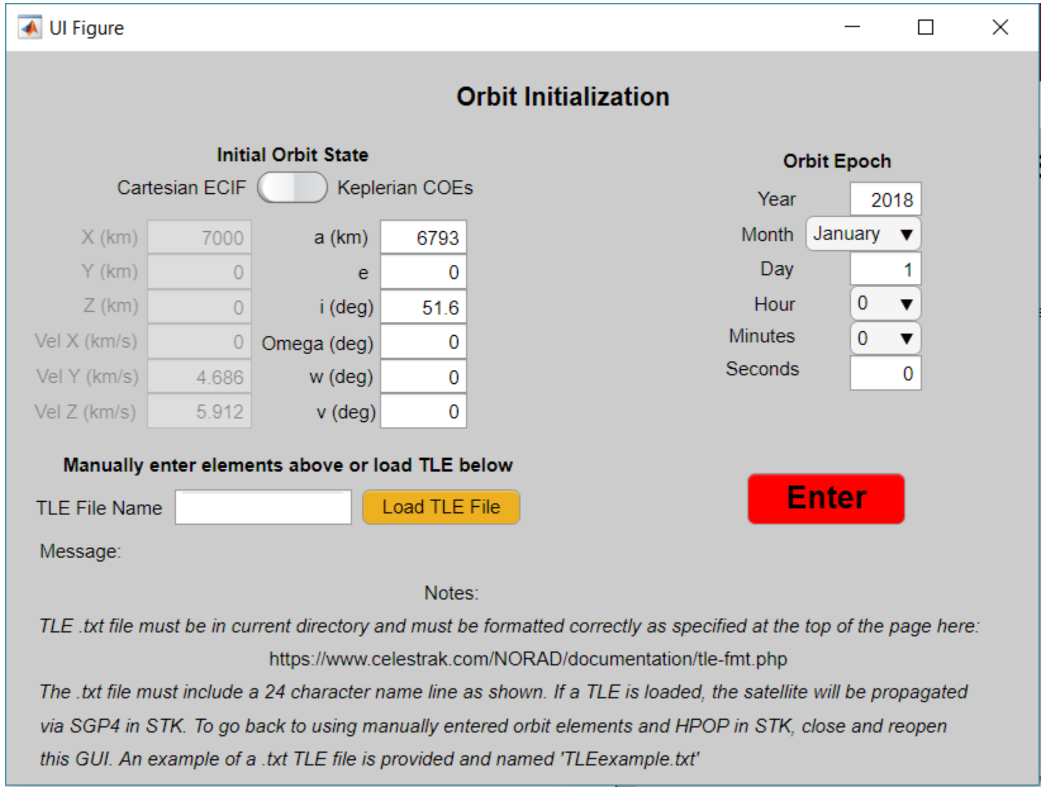
User never has to interact with command line or with STK, they simply press buttons and enter values in GUIs

- User inputs satellite and scenario properties

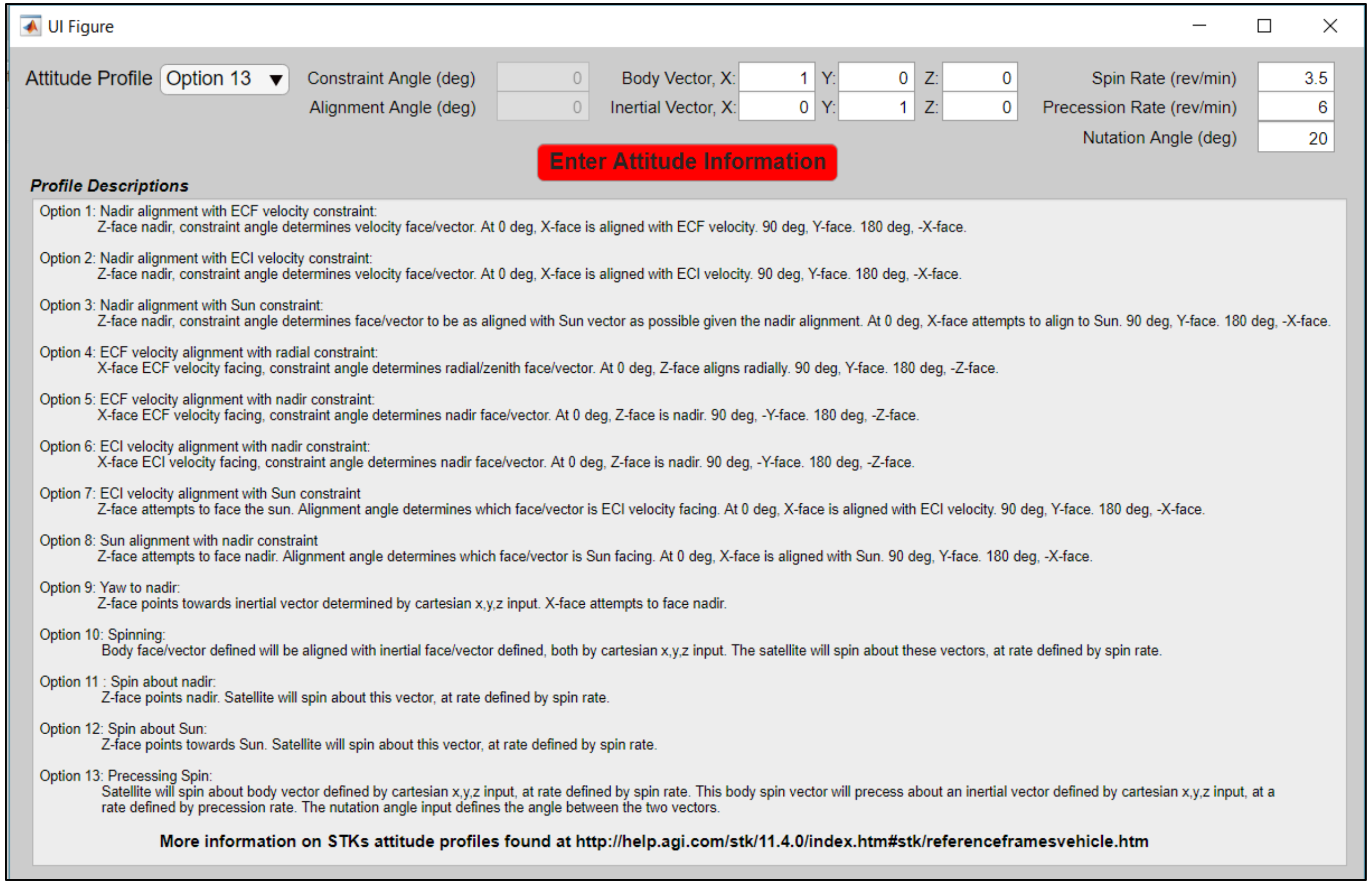
- A variety analysis tools are available for visualizing and understanding the health and operations of your spacecraft

- Outputs can be exported for further analysis

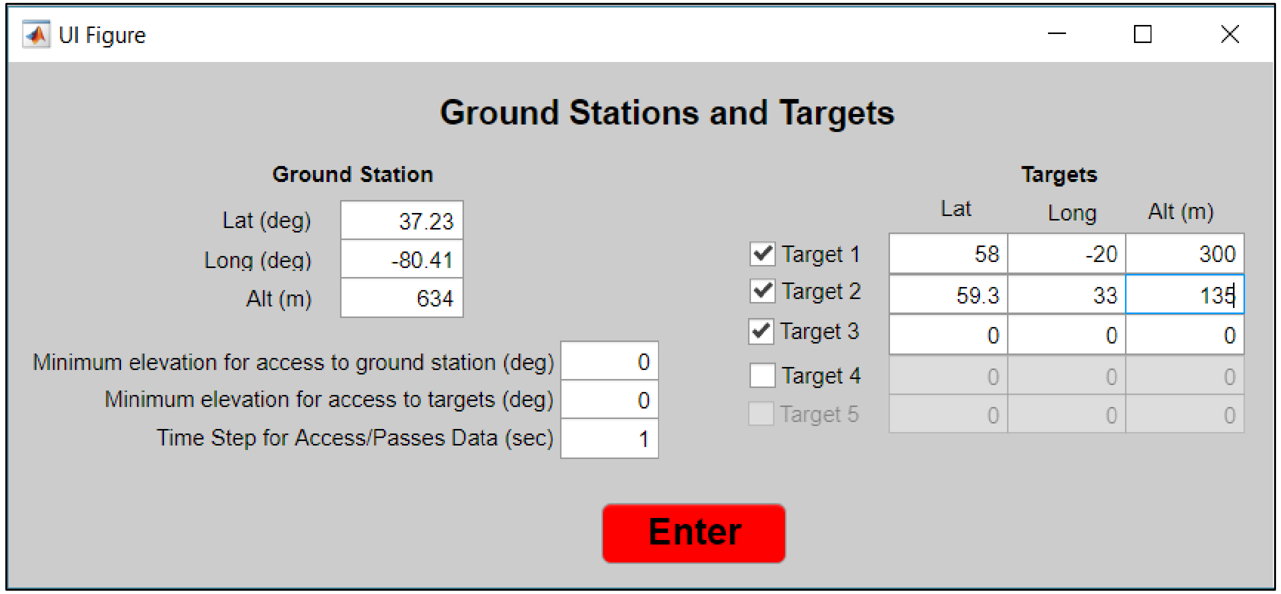
- Initialize orbit with Cartesian or Keplerian elements
- Can also load and use TLE text file



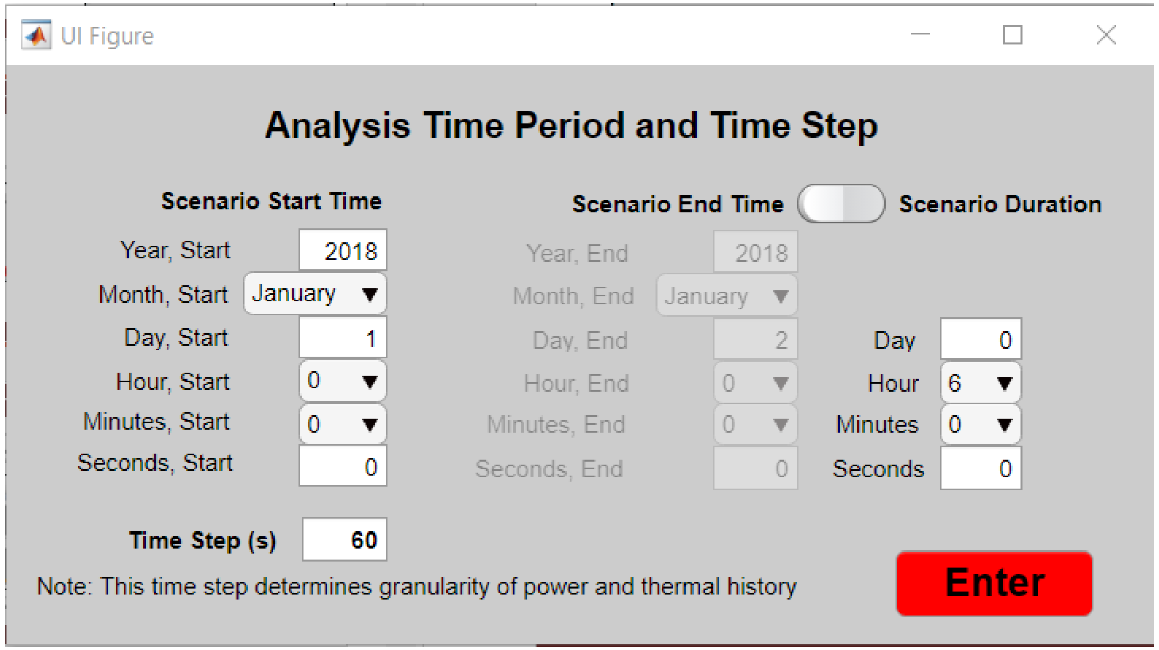
- Select from a number of attitude profiles and declare relevant parameters from constraint angles to nutation rates



- Specify a ground station, as well as up to 5 targets by their latitude, longitude, and altitude
- Ground station and targets can have different access elevation constraints

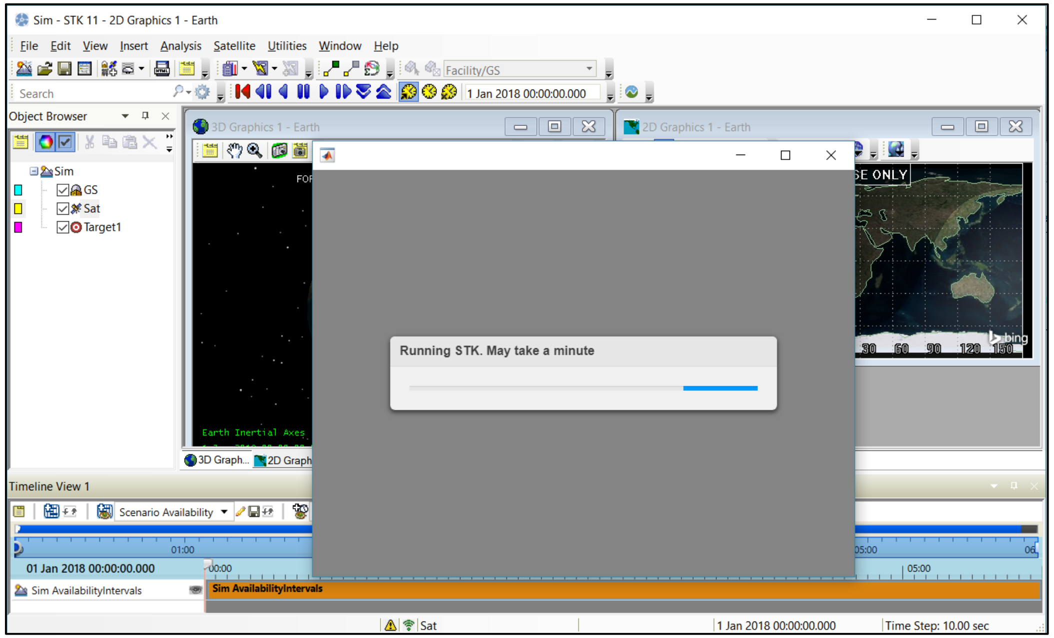


- Define the time period you wish to analyze and the time step
- End date can be defined by a date or by a time from start



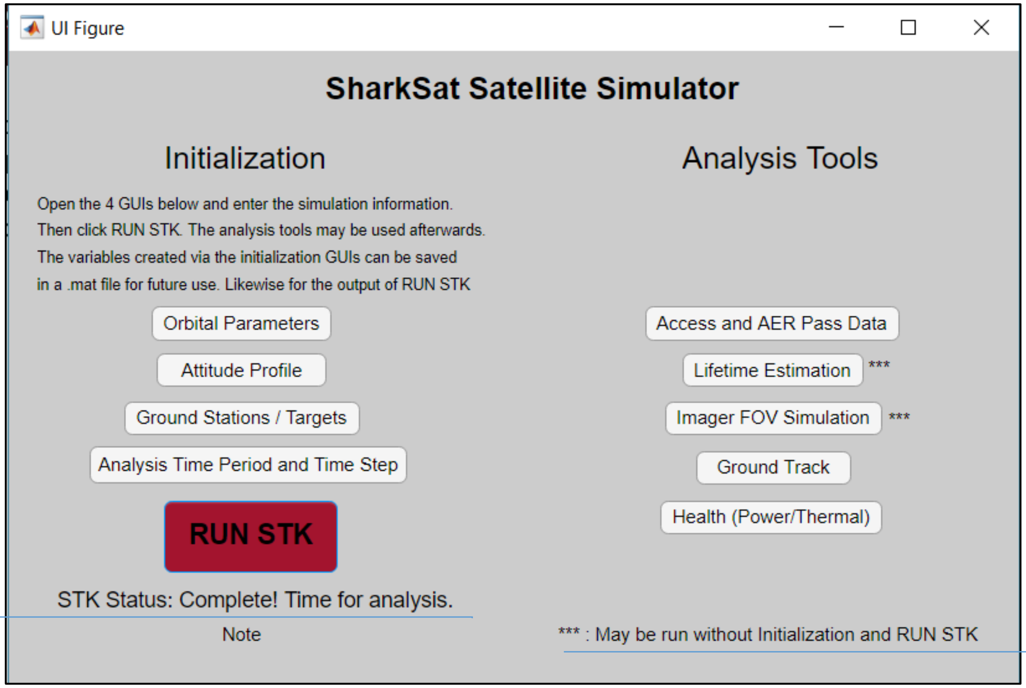
Modeling and Simulation

- After all initialization parameters have been input, STK can be run with the push of a button
- From STK, Matlab receives mission geometry (vectors between satellite, Sun, and Earth, in several coordinate systems) and access information



- Alternatively, all initialization parameters an/or the output from STK can be stored as an .mat Matlab data file and loaded at a later time to avoid having to repeat the process

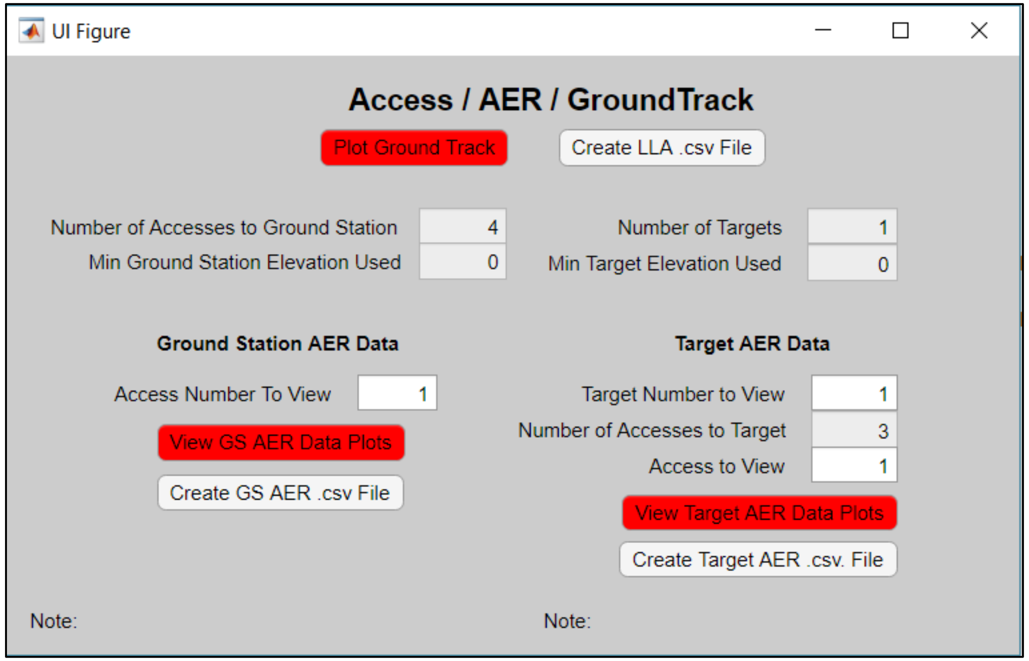
- Once STK is done running (or inputs/outputs from previous run are loaded from .mat file), the analysis tools can be used

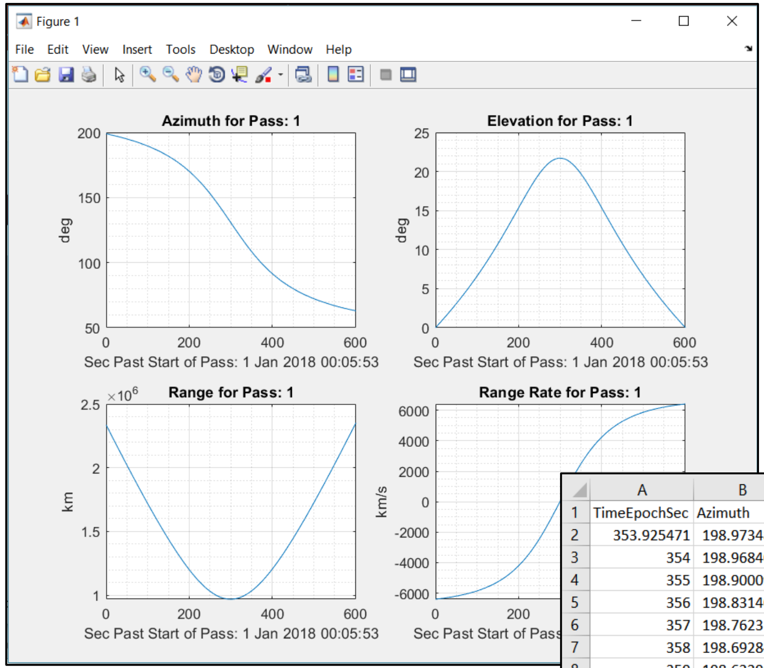


- Note that some of the tools can be used without initialization and/or running STK, but the user will need to supply some information

Modeling and Simulation

Analysis Tool: Access, Azimuth, Elevation, Range for Passes





	A	B	C	D	E
1	TimeEpochSec	Azimuth	Elevation	RangeM	RangeRateMpS
2	353.925471	198.9734851	0.000260276	2335890.195	-6396.656842
3	354	198.9684092	0.004570396	2335413.477	-6396.430094
4	355	198.9000973	0.062472805	2329018.716	-6393.369997
5	356	198.8314017	0.12050787	2322627.031	-6390.276761
6	357	198.7623192	0.178676445	2316238.456	-6387.150058
7	358	198.6928468	0.236979388	2309853.025	-6383.989554
8	359	198.6229811	0.295417563	2303470.771	-6380.794912
9	360	198.5527189	0.35399184	2297091.728	-6377.56579
10	361	198.4820569	0.412703094	2290715.932	-6374.301843
11	362	198.4109919	0.471552205	2284343.417	-6371.002721
12	363	198.3395204	0.530540058	2277974.219	-6367.66807
13	364	198.2676391	0.589667546	2271608.373	-6364.297529
14	365	198.1953445	0.648935563	2265245.916	-6360.890737
15	366	198.1226332	0.708345012	2258886.884	-6357.447325
16	367	198.0495018	0.767896801	2252531.313	-6353.96692
17	368	197.9759466	0.82759184	2246179.242	-6350.449145
18	369	197.9019641	0.887431049	2239830.706	-6346.893618
19	370	197.8275508	0.947415351	2233485.745	-6343.299953
20	371	197.752703	1.007545674	2227144.397	-6339.667756
21	372	197.6774169	1.067822951	2220806.701	-6335.996632

- Displays number of accesses to the ground station as well as to each individual target

- User selects which access to analyze (unable to select an invalid pass)

- Can plot Azimuth, Elevation, Range, and Range rate for selected pass, or export as .csv

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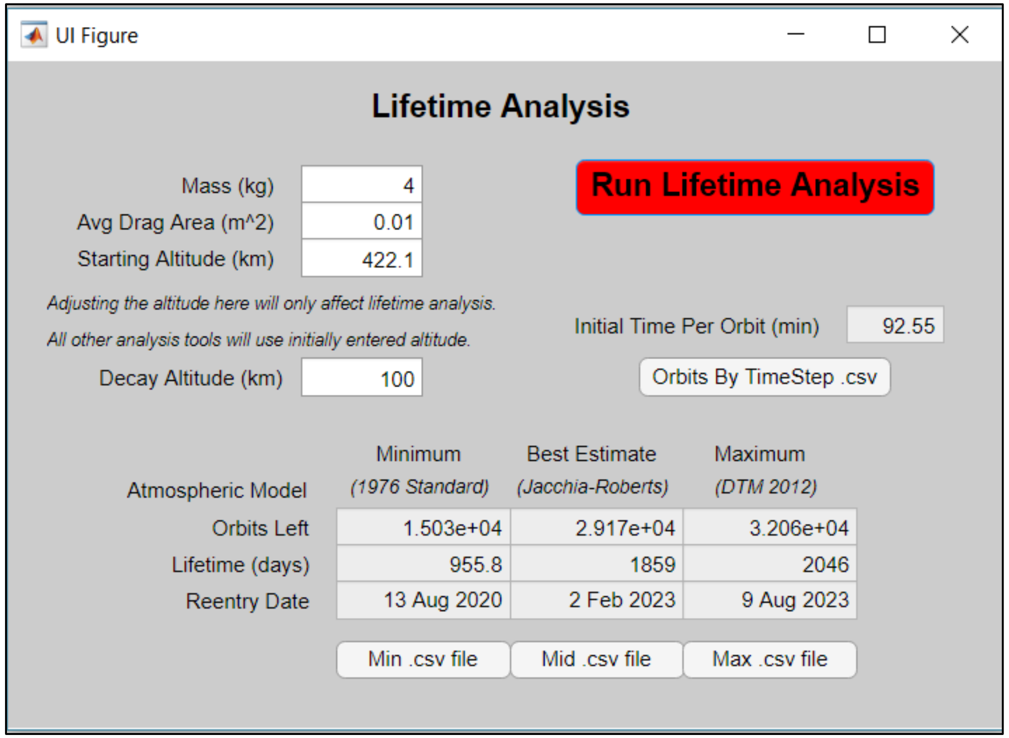
Analysis Tool: Lifetime Estimation

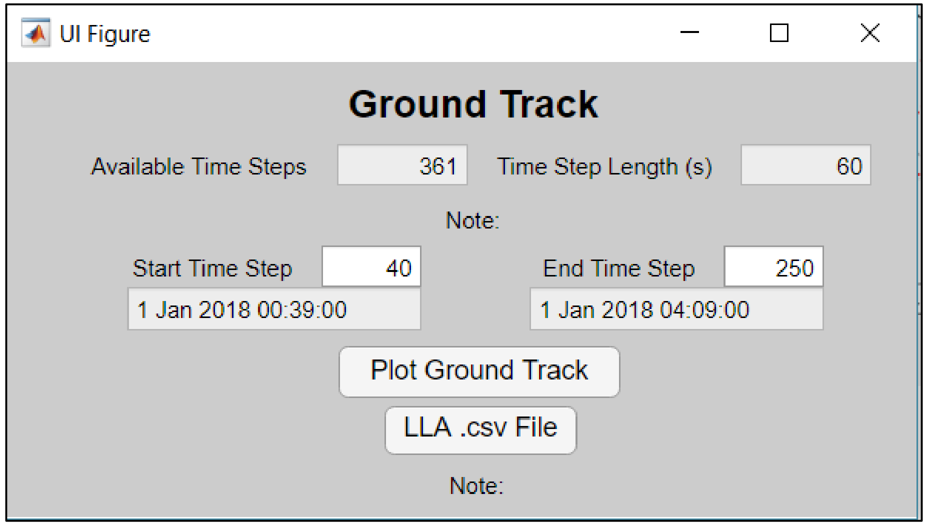


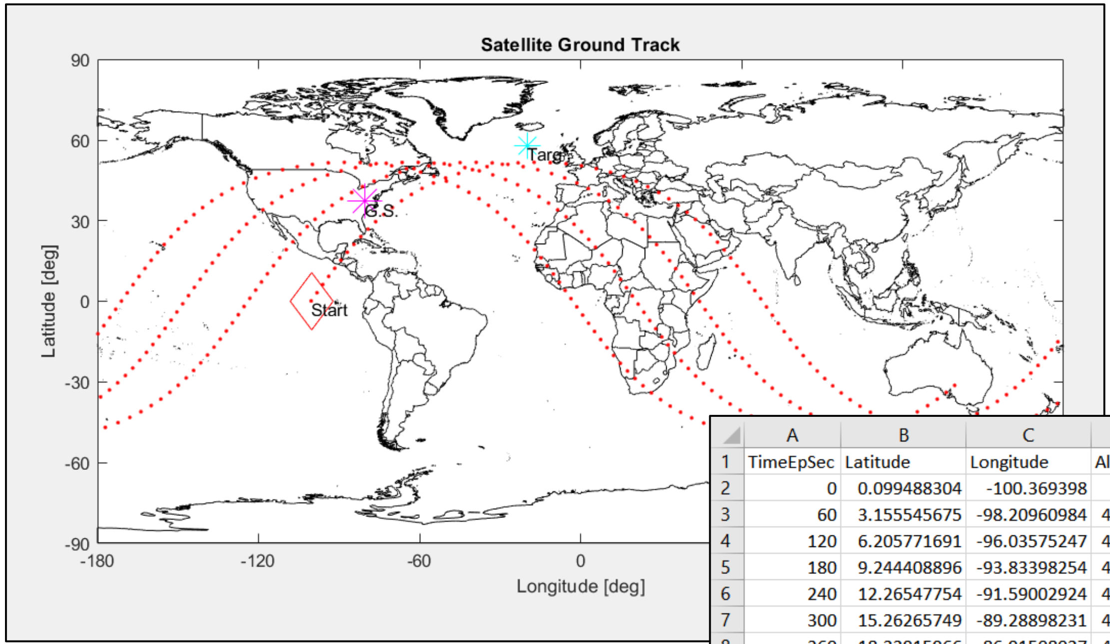
- User sets Mass, Drag Area, and Decay Altitude threshold
- Starting altitude is automatically imported from Orbital Parameters (but can be changed by the user to compare the difference in results)
- 'Run Lifetime Analysis' runs STK and calculates lifetime data using three separate atmospheric models
- Data can be exported in two formats: by orbit, and by time step

	A	B	C
1	TimeUTCG	TimeEpSec	Orbits
2	1/1/2018 0:46	2783.723947	0
3	1/1/2018 2:18	8336.779515	1
4	1/1/2018 3:51	13889.83419	2
5	1/1/2018 5:24	19442.88714	3
6	1/1/2018 6:56	24995.93836	4
7	1/1/2018 8:29	30548.98786	5
8	1/1/2018 10:01	36102.03564	6
9	1/1/2018 11:34	41655.08168	7
10	1/1/2018 13:06	47208.126	8
11	1/1/2018 14:39	52761.16859	9
12	1/1/2018 16:11	58314.20946	10
13	1/1/2018 17:44	63867.24859	11
14	1/1/2018 19:17	69420.28598	12
15	1/1/2018 20:49	74973.32165	13
16	1/1/2018 22:22	80526.35558	14
17	1/1/2018 23:54	86079.38777	15
18	1/2/2018 1:27	91632.41823	16
19	1/2/2018 2:59	97185.44695	17
20	1/2/2018 4:32	102738.4739	18
21	1/2/2018 6:04	108291.4992	19
22	1/2/2018 7:37	113844.5227	20

	A	B
1	TimeEpSec	OrbitsAtTimeStep
2	0	0.010767985
3	60	0.021535969
4	120	0.032303954
5	180	0.043071938
6	240	0.053839923
7	300	0.064607907
8	360	0.075375892
9	420	0.086143876
10	480	0.096911861
11	540	0.107679845
12	600	0.11844783
13	660	0.129215814
14	720	0.139983799
15	780	0.150751783
16	840	0.161519768
17	900	0.172287752
18	960	0.183055737
19	1020	0.193823721
20	1080	0.204591706

Analysis Tool: Ground Track





	A	B	C	D	E
1	TimeEpSec	Latitude	Longitude	AltitudeKM	
2	0	0.099488304	-100.369398	415.003064	
3	60	3.155545675	-98.20960984	415.0450725	
4	120	6.205771691	-96.03575247	415.1622572	
5	180	9.244408896	-93.83398254	415.3518058	
6	240	12.26547754	-91.59002924	415.6092043	
7	300	15.26265749	-89.28898231	415.9283852	
8	360	18.22915966	-86.91508027	416.3018752	
9	420	21.15758283	-84.45150357	416.7209242	
10	480	24.03975216	-81.88018153	417.1756497	
11	540	26.86653676	-79.18162902	417.6552254	
12	600	29.62764474	-76.33483939	418.1480981	
13	660	32.31139713	-73.31727478	418.6421896	
14	720	34.90448547	-70.10501574	419.1250784	
15	780	37.39172527	-66.67315663	419.5842037	
16	840	39.75582878	-62.99656153	420.0071254	
17	900	41.97723589	-59.05111915	420.3818173	
18	960	44.03406257	-54.81564041	420.6969347	
19	1020	45.90224849	-50.2745029	420.9420296	
20	1080	47.55600449	-45.4210245	421.1077362	

- Can plot and export data for entire scenario time period

- Alternatively, can select specific period to analyze by selecting a start and stop time step

Modeling and Simulation

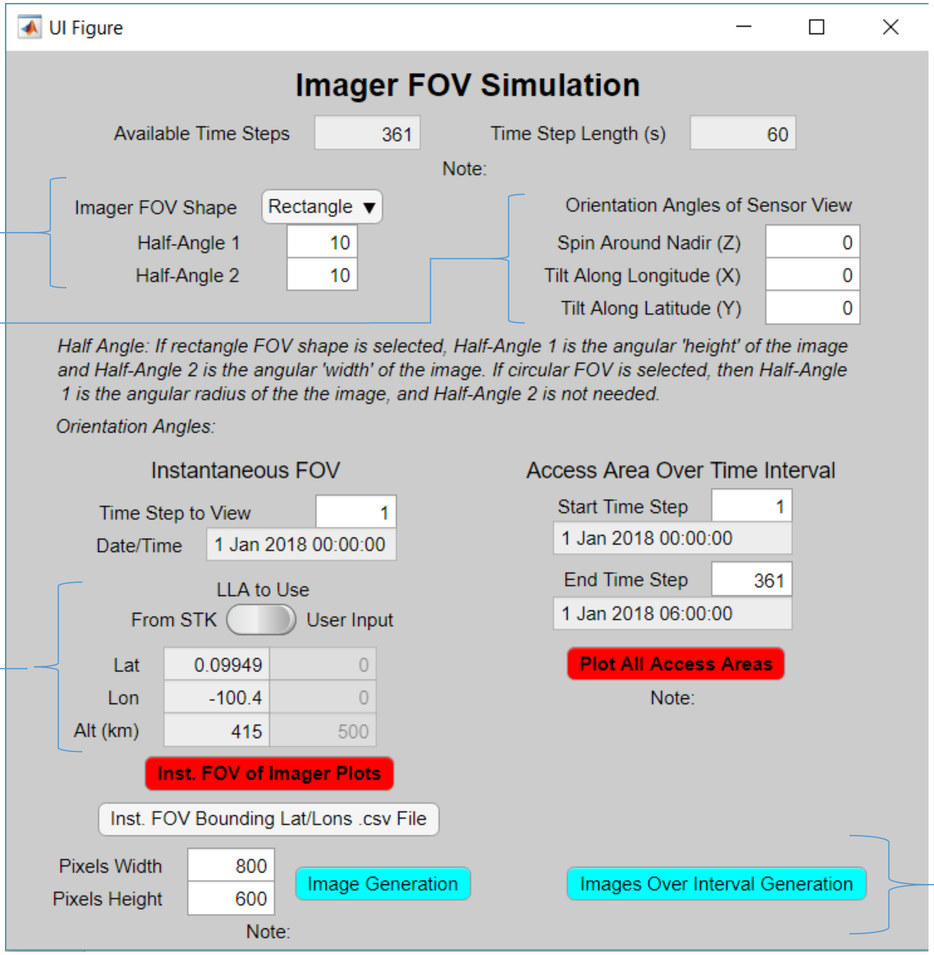
Analysis Tool: Imager Simulation and Image Generation

- User defines imager shape and FOV

- User defines imager boresight orientation via three Euler angles

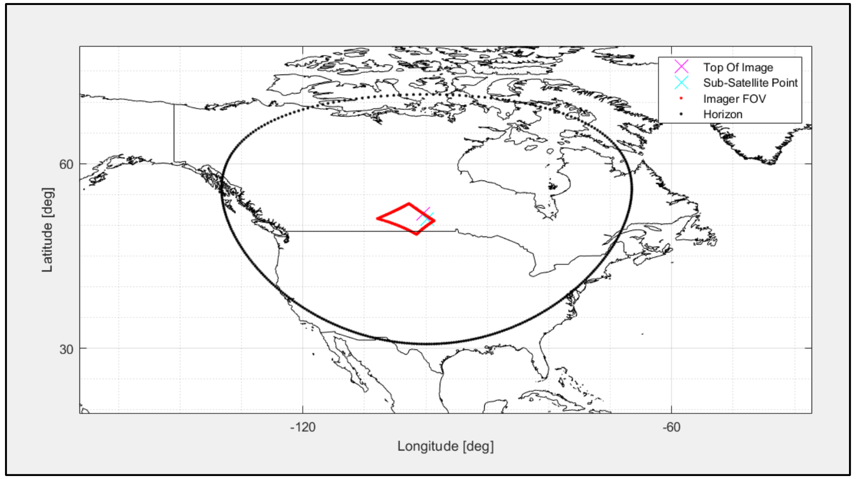
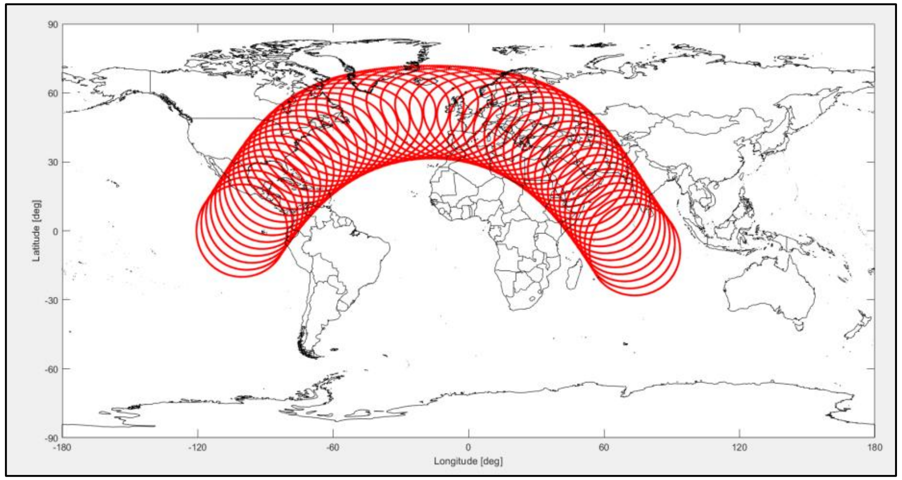
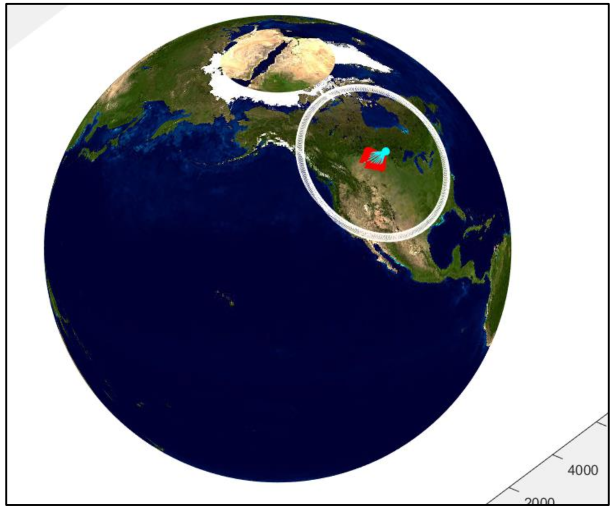
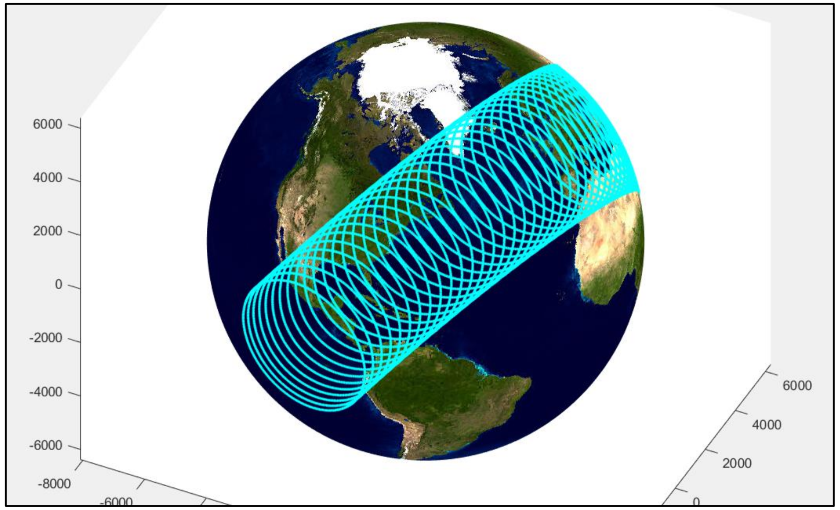
- Selecting a time step will automatically load the associated lat, lon, alt, but user can alternatively supply custom values

- 2D and 3D visualization of imager FOV can be generated for both one instantaneous time or over a time interval



- Given pixel dimensions, realistic images can be generated via STK

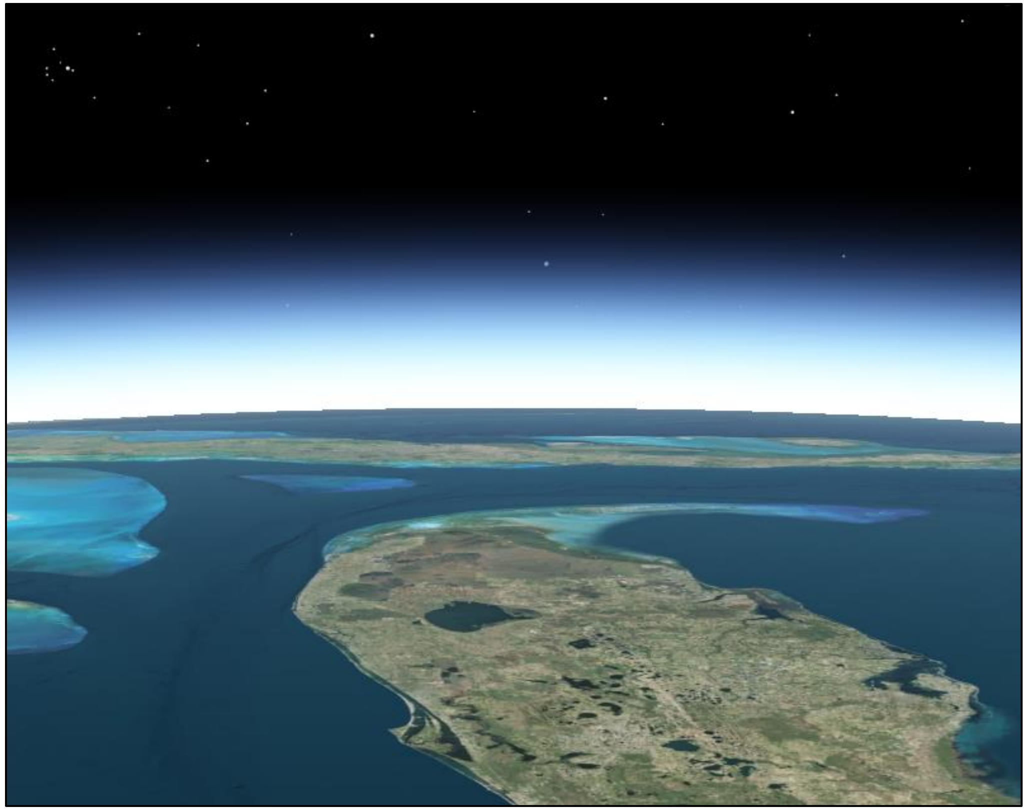
Modeling and Simulation

	Instantaneous Imager FOV and Access Area	Time Interval Access Area
2D		
3D		

Modeling and Simulation

Simulated Imager Data

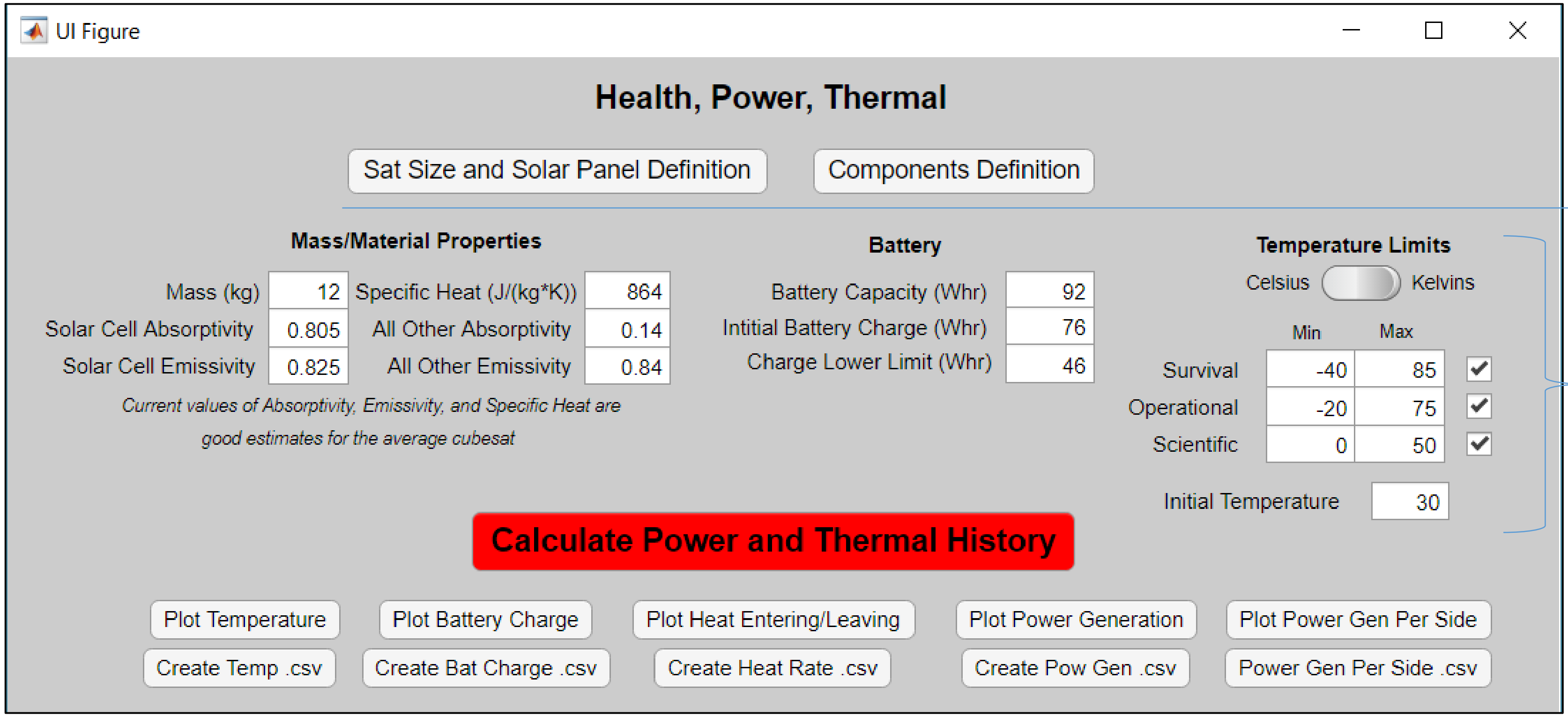
LLA: [37, 81, 400km], Euler Angles: [30º, 0, 0]



LLA: [37, 81, 400km], Euler Angles: [70º, 0, 180º]

Modeling and Simulation

Analysis Tool: Health, Power, and Thermal

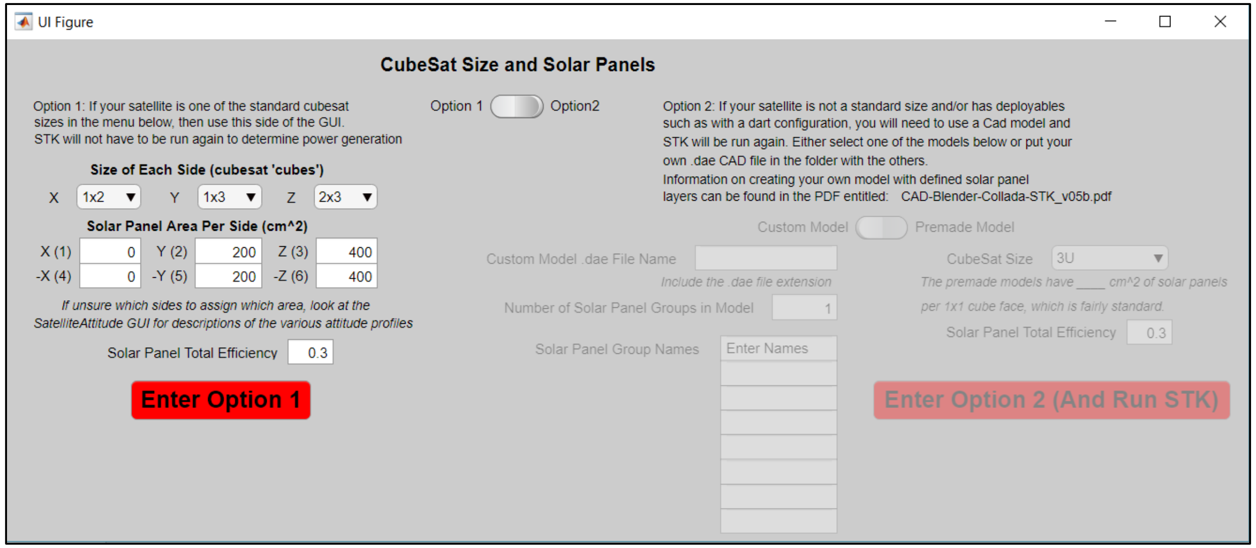


- Two other GUI's are opened to define size and solar panels, as well as component power usage profiles

- User inputs material properties, as well as battery and temperature limit information

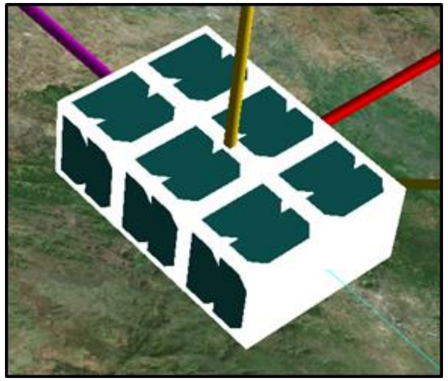
- Once all properties are set, and Calculate Power and Thermal History is pressed, various data can be plotted and/or exported to a .csv file

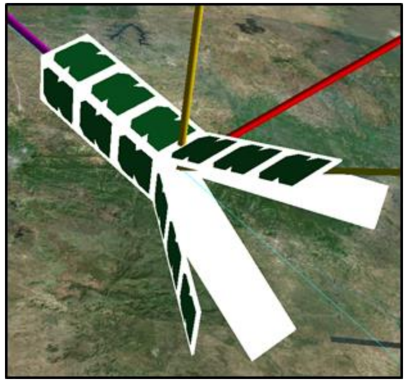
Modeling and Simulation

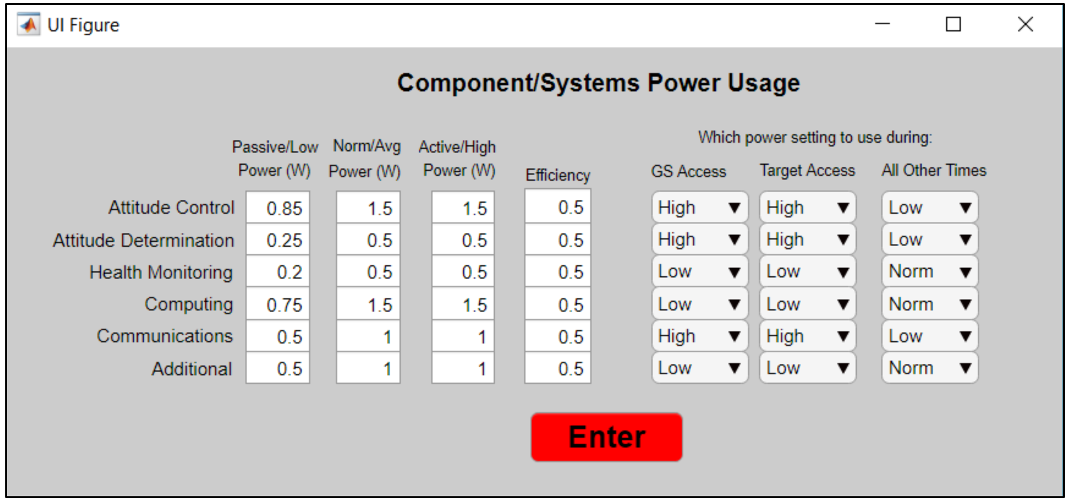


- Satellite size, shape, and solar panel coverage can be defined manually

- Alternatively, a CAD model (either custom or one of the standard provided models) can be imported and analyzed in STK





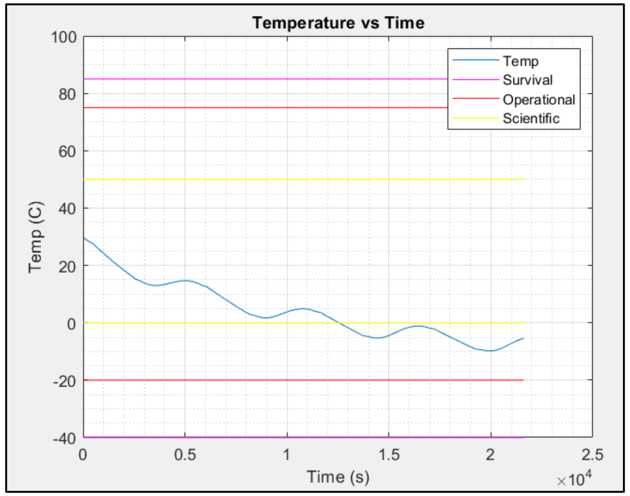


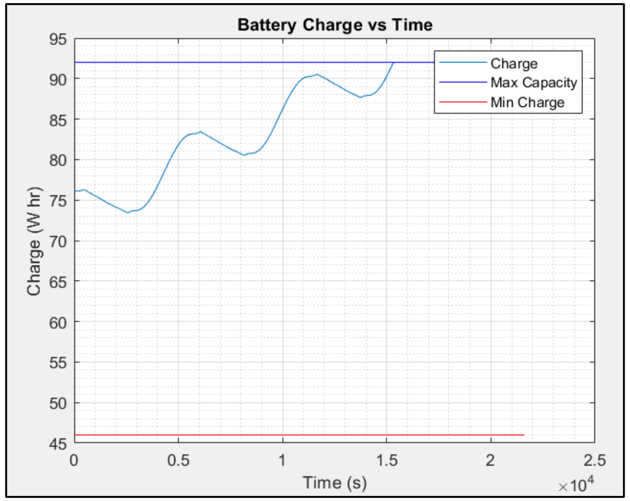
- For a variety of common satellite components, various power levels and efficiency can be entered

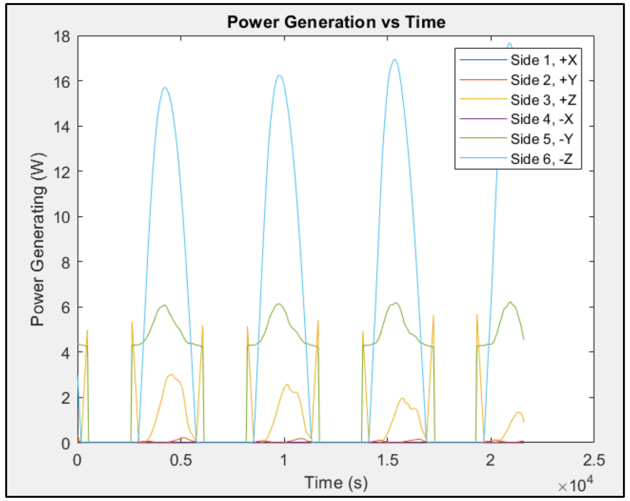
- User can determine which power level is used at what time depending on access to ground station and targets

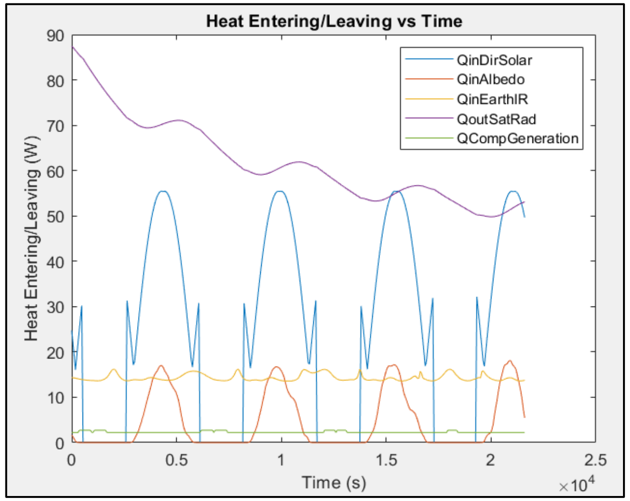
Modeling and Simulation

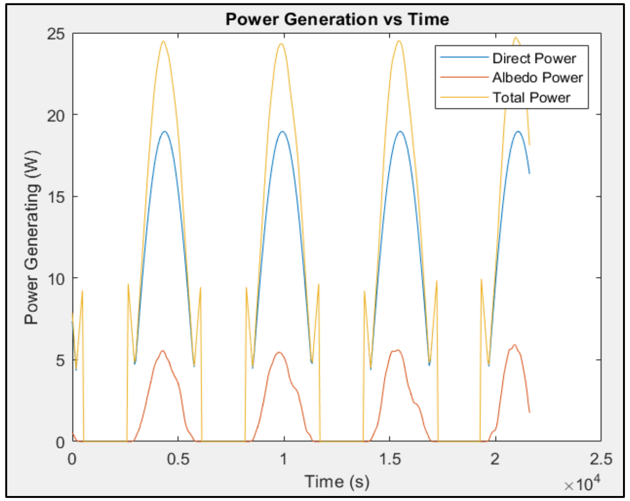
Example Plots from Health, Thermal, Power Tool



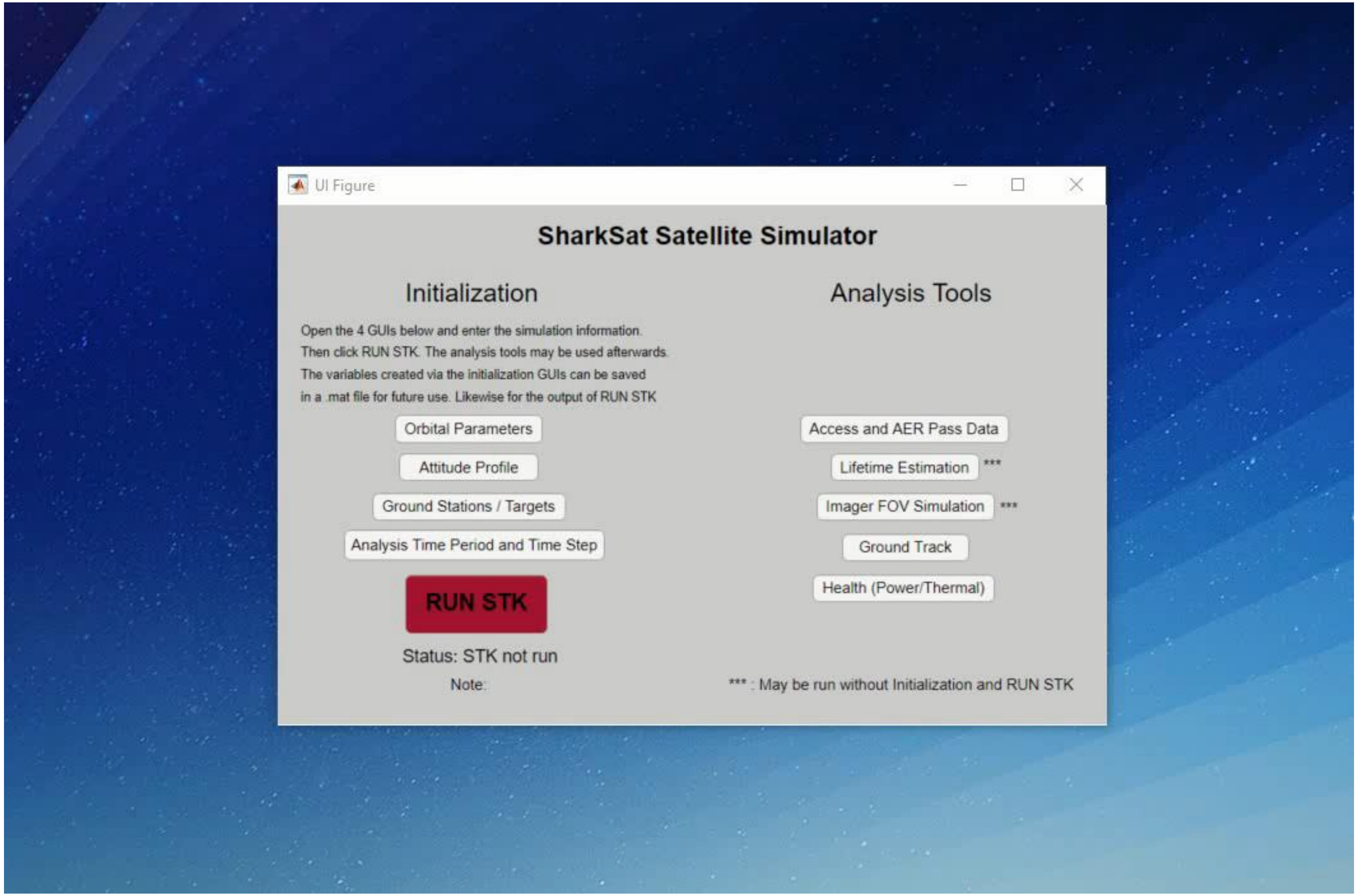








Demonstration Video



Modeling and Simulation Future Work

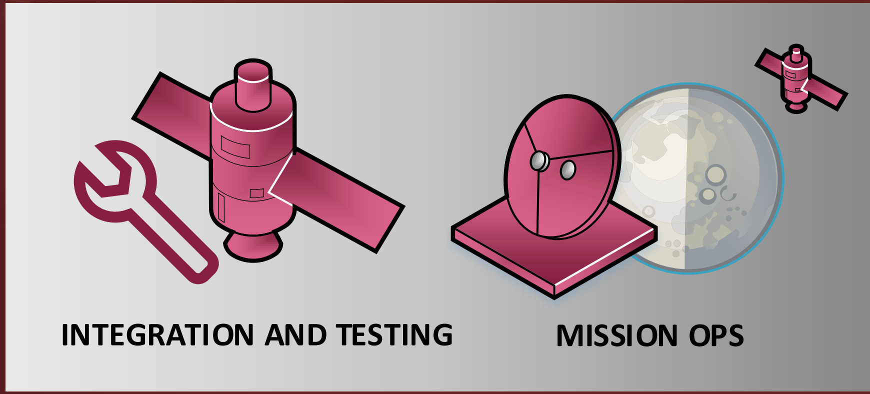
- Continue to add functionality and analysis tools, including:
  - Determining percentage of Earth coverage over a given time period
  - Taking series of photos over a given time period
  - Ability to use attitude history from STK in imager simulation
  - More error handling / warning features
- Create more standard cubesat configuration CAD models to be used in simulator
- Have it used and tested to find bugs and get feedback on improvements
  - Add additional relevant science mission evaluation modules

VIRGINIA TECH™

NASA core Flight System

Josh Smoot

Graduate Student



NASA core Flight System Overview

- Software framework for flight projects and embedded systems
- Platform and project independence
  - Runs on Linux, RTEMS, and vxWorks 6
  - core Flight System (cFS) applications are reusable between varying hardware
- Requires more computational resources than typically available on low power microcontrollers
- Applications can be developed in a desktop environment and easily be ported to flight computer without modification

Source: https://coreflightsystem.org

Mission Independence

- cFS consists of four layers of software
  - Operating System Abstraction Layer (OSAL)
  - Platform Support Package (PSP) layer
  - core Flight Executive (cFE) layer
  - Applications layer

- OSAL and PSP are configured such that cFE and applications run identically on varying hardware and OS
  - Board support packages contained in OSAL can be built for most systems
  - Applications can be developed for one flight computer and then reused for a mission with similar needs utilizing different hardware

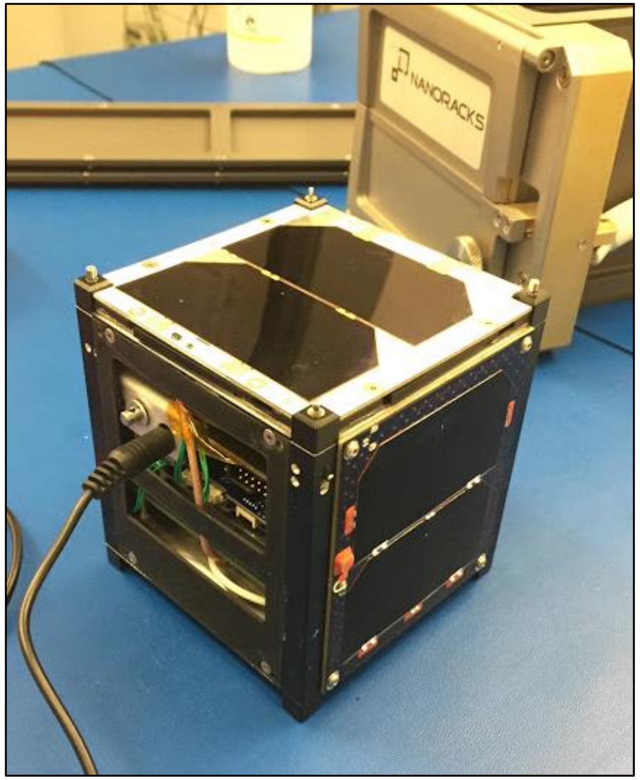
core Flight System on Raspberry Pi

- Raspberry Pi (RPi) boards are low cost and have sufficient resources to run linux and cFS
    - Peripherals can be easily connected
- RPi comes in multiple form factors
    - Development on standard Model 3B+ boards
    - Deployment on the Compute Module 3
- cFS runs on RPi with slight modifications to NASA OSAL and PSP distributions
- Image of RPi with cFS build can be cloned for multiple students to develop applications simultaneously

Source: https://www.raspberrypi.org/products/compute-module-3/

core Flight System Comparison

	NASA core Flight System	Virginia Cubesat Constellation Flight Software, developed at Space@VT
Hardware	Runs on many systems, x86 and ARM	Developed for MSP430 microcontroller onboard 1U cubesat
Operating Systems	Multi platform: Linux, RTEMS, and vxWorks 6	Includes real time operating system in build
Applications	Large cFS codebase, applications can be made for specific purpose and reused	Drivers for new components can be easily integrated into flight software
Portability	Applications developed for one mission can be easily reused on any machine with OSAL and PSP implemented	Development required to implement VCC code on another system



Future Work with core Flight System

- FlatSat testing environment
  - Set up multiple benchtops with hardware emulating what is typically used for cubesat missions with cFS implemented
  - Applications to operate a mission’s flight components can be developed and tested in the FlatSat environment and then easily ported to mission hardware
- Interfacing cFS on RPi with ground system to send and receive telemetry
  - NASA ASIST or COSMOS
- cFS deployment on high altitude balloon flight or cubesat mission

RF Channel Simulator

Seth Hitefield

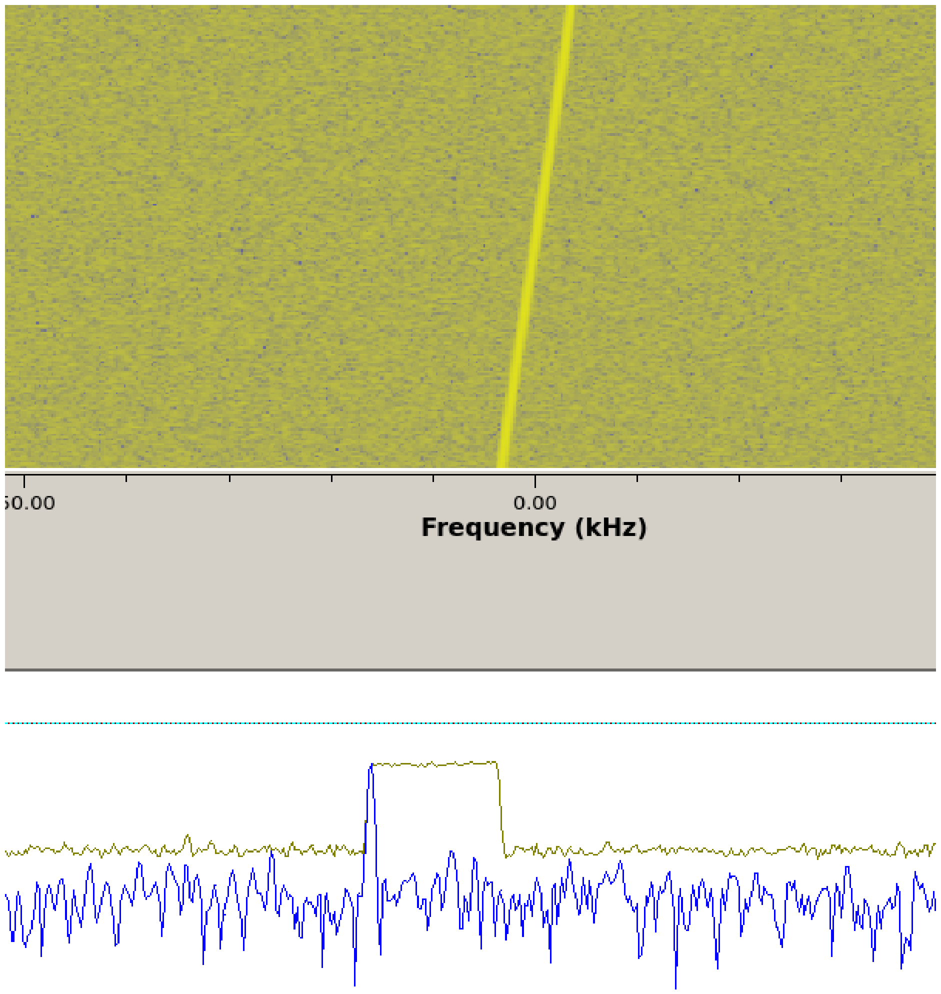
Graduate Student

VIRGINIA TECH

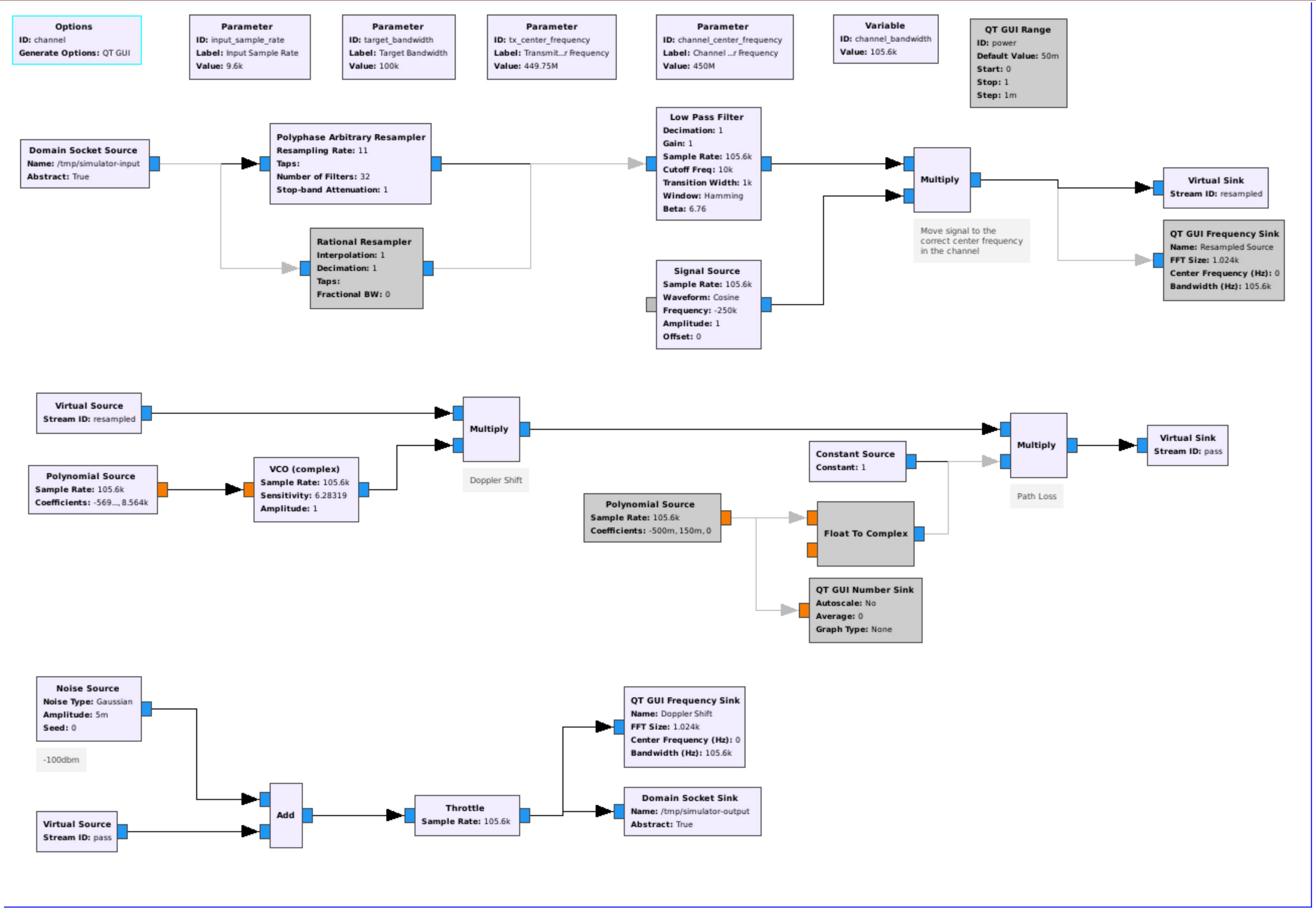
INTEGRATION AND TESTING

GR-Simulator

- GNU Radio based channel simulator
  - Simulates RF channels for different satellites/passes
  - All software defined or hardware in the loop
  - Uses TLEs to generate estimated doppler shift for selected pass or uses external doppler input
  - Data can be fitted to Logistical curve for smooth shift
  - Created several new GR blocks for per-sample simulation of path loss and doppler shift for the pass
  - Virtual hardware blocks for interfacing between the transmitter and receiver flowgraphs and channel simulator

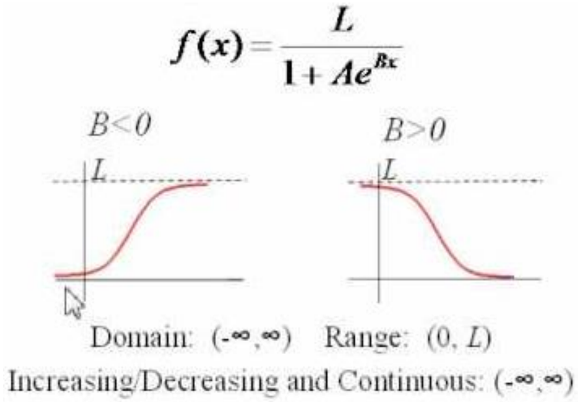


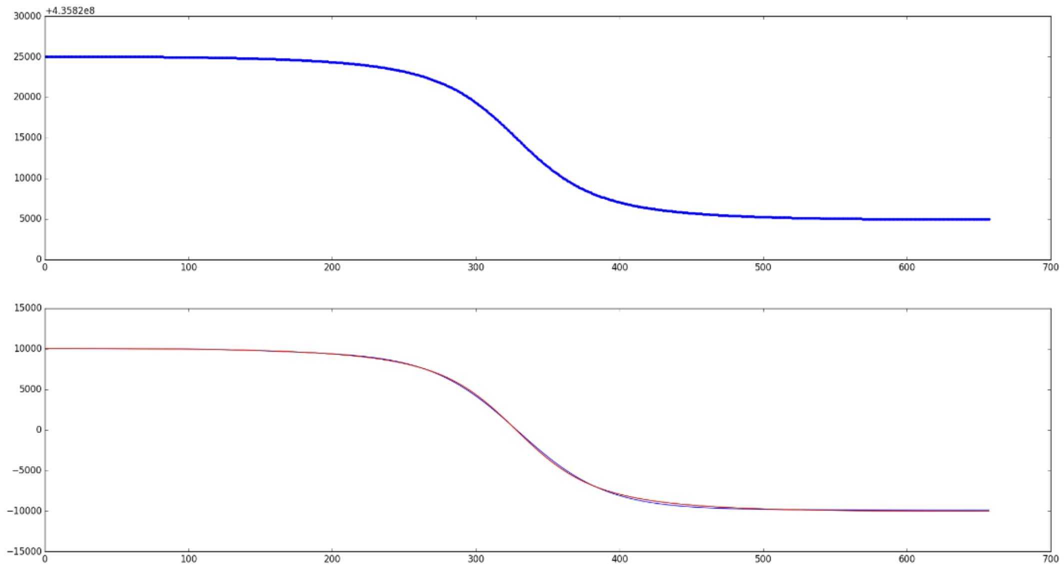
GR-Simulator

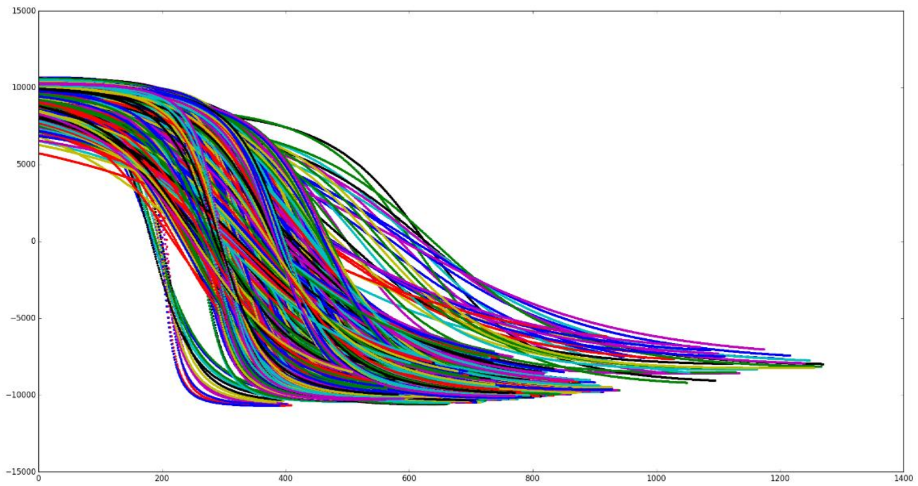


Curve Fitting

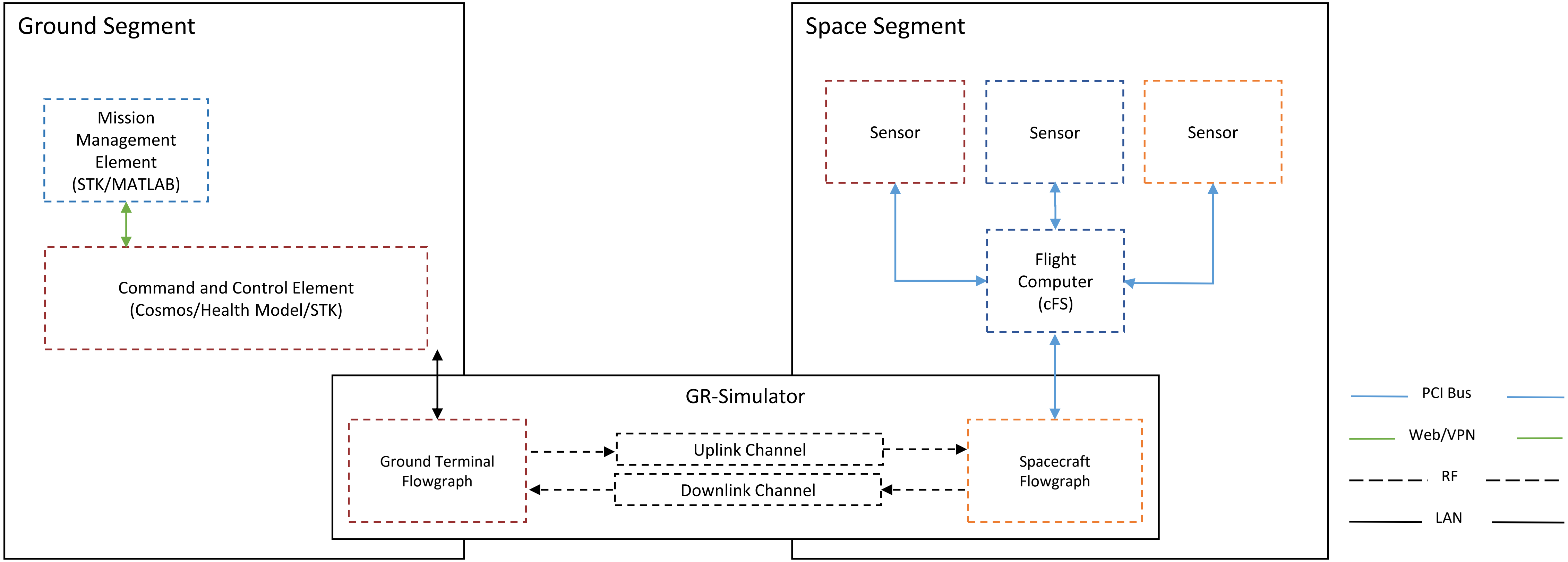
- Simulation of the Doppler shift and path loss for an orbital pass
  - Logistical functions
  - Curve fitting generated from 1 second time steps
  - Smooth (continuous) shift over the entire pass



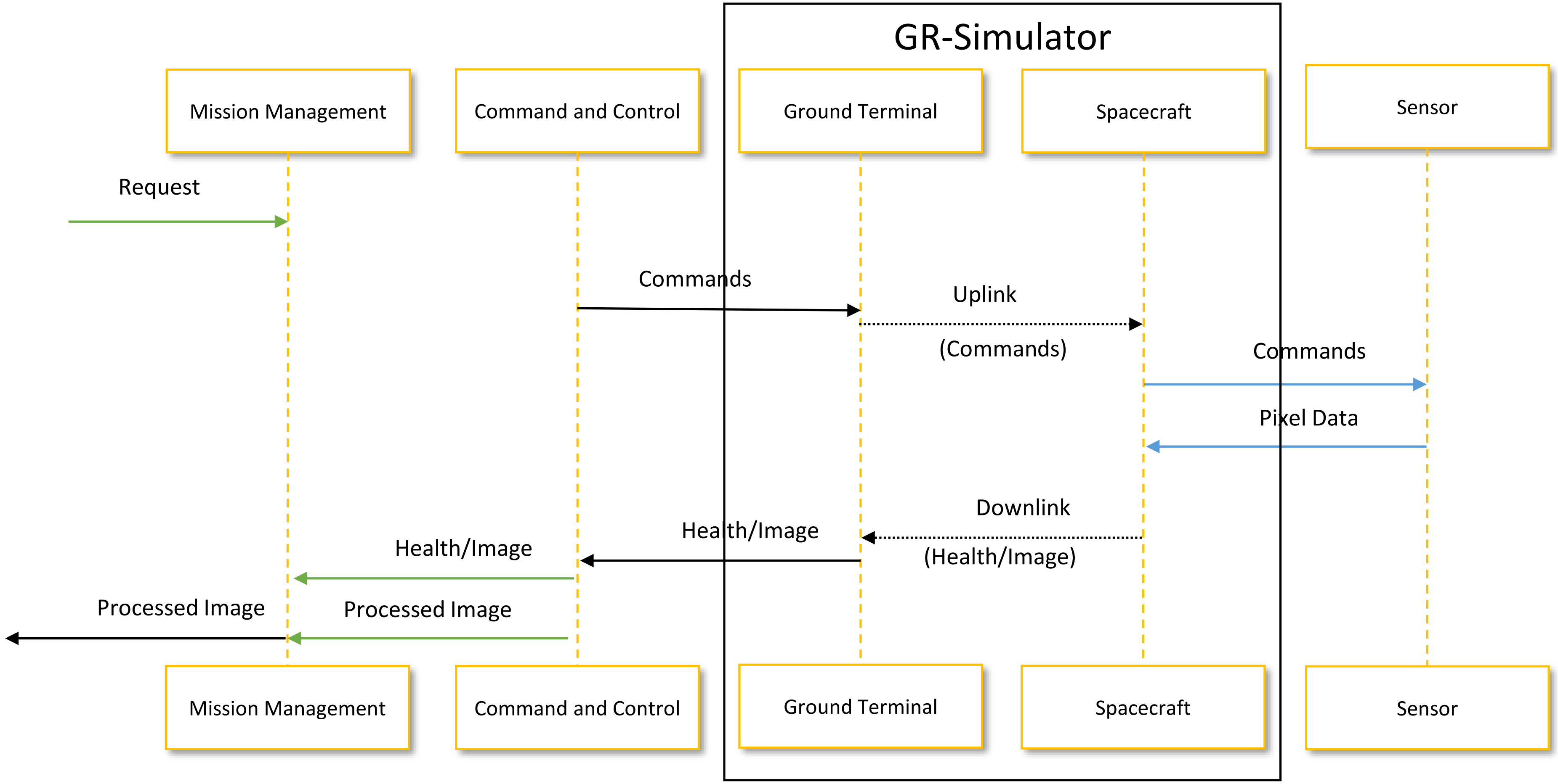




Representative Mission System Diagram



Timeline Diagram



Future Work

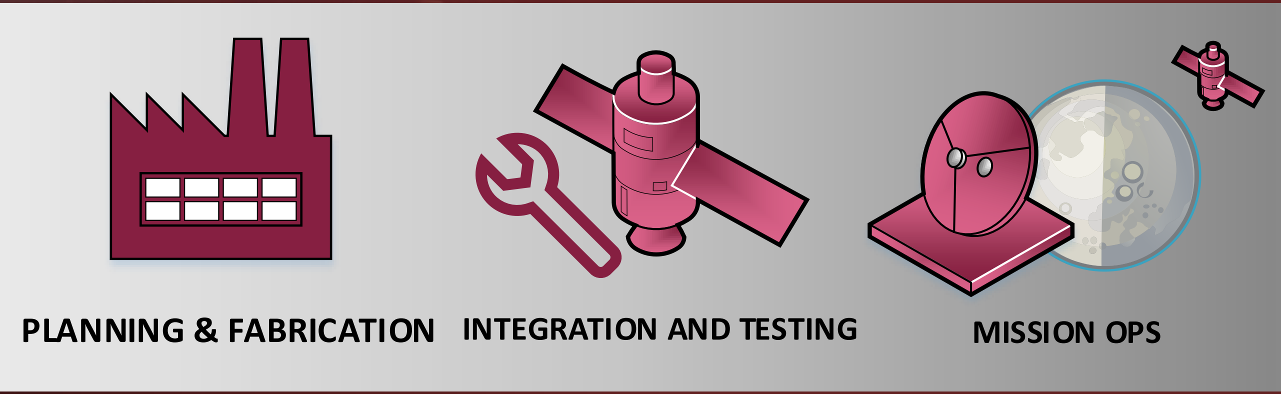
- Add a user interface for controlling the simulator
  - Allows user to select specific satellite/pass and visualize channel
- Setup the simulator for handling over-the-air testing on a test bench
- Ability to schedule different passes and execute on demand

Validate with HIL testing using flatsat, ground station, and cloud computing

COSMOS

Gavin Brown

Undergraduate Student



COSMOS Overview

- Open source software by Ball Aerospace.
- A command and control system for test and operations made up of 15 customizable applications.
- Can:
  - Send commands
  - Visualize & extract data
  - Write automated procedures
  - Monitor telemetry
  - Review logged information
- Ruby is used to create and customize applications and procedures.
- Cross platform: Windows, Linux, Mac OSX.
- Used by NASA, Lockheed Martin, Ball, & many others.

COSMOS Block Diagram

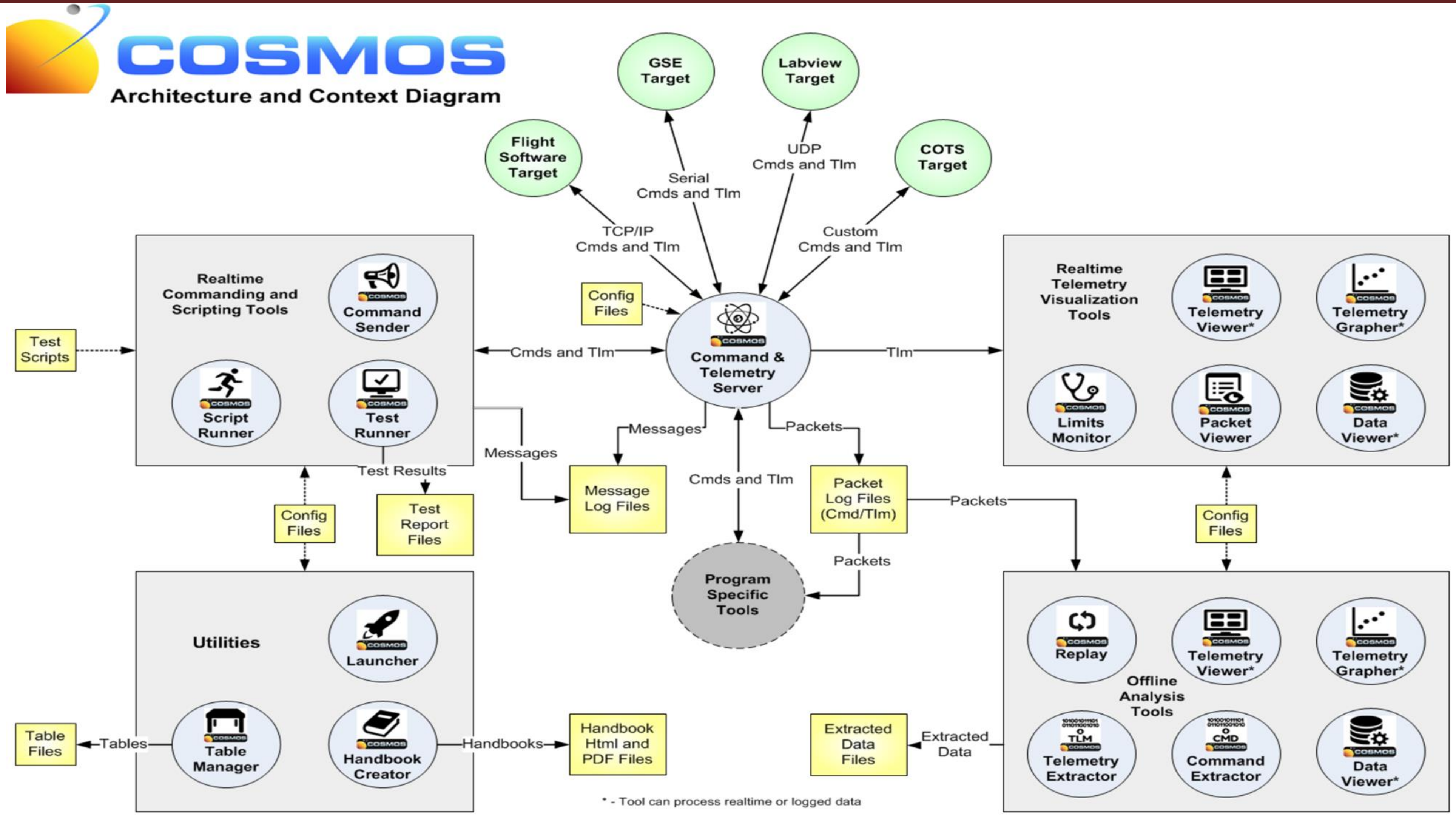
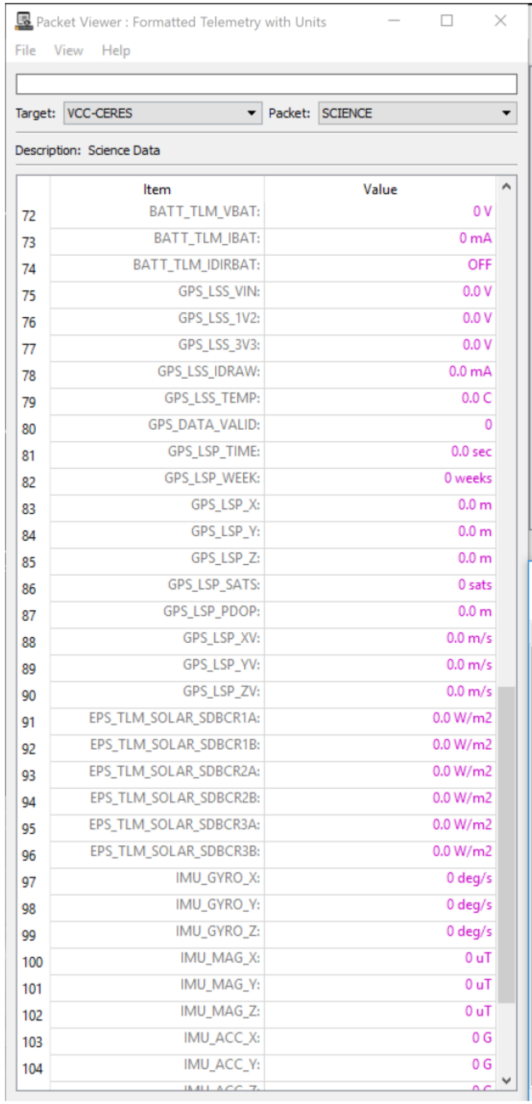
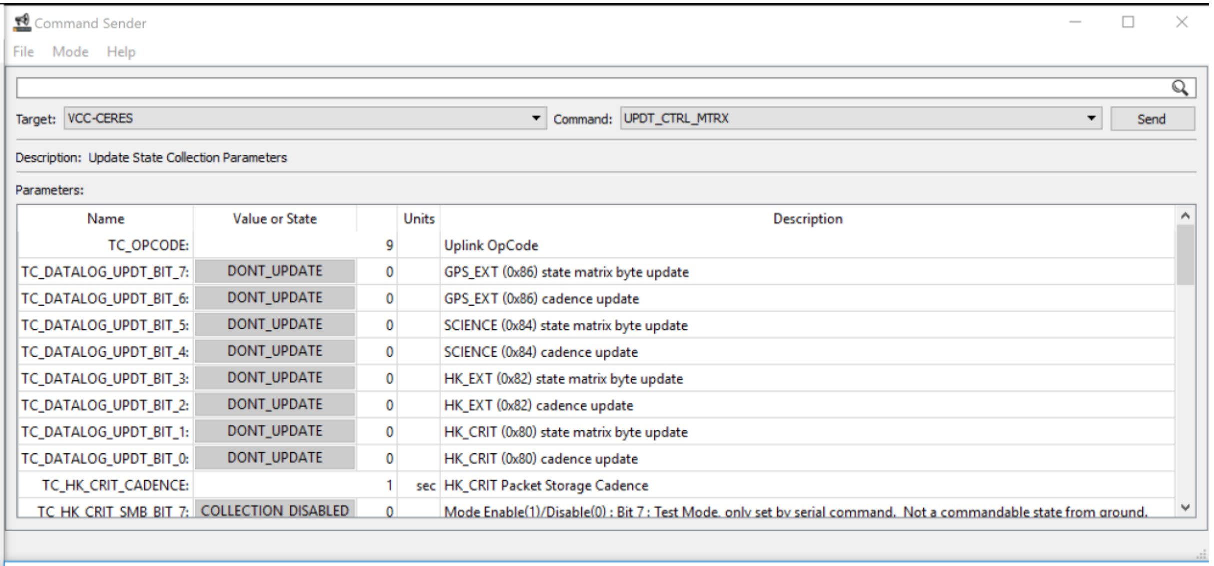


Image Ref: https://github.com/BallAerospace/COSMOS

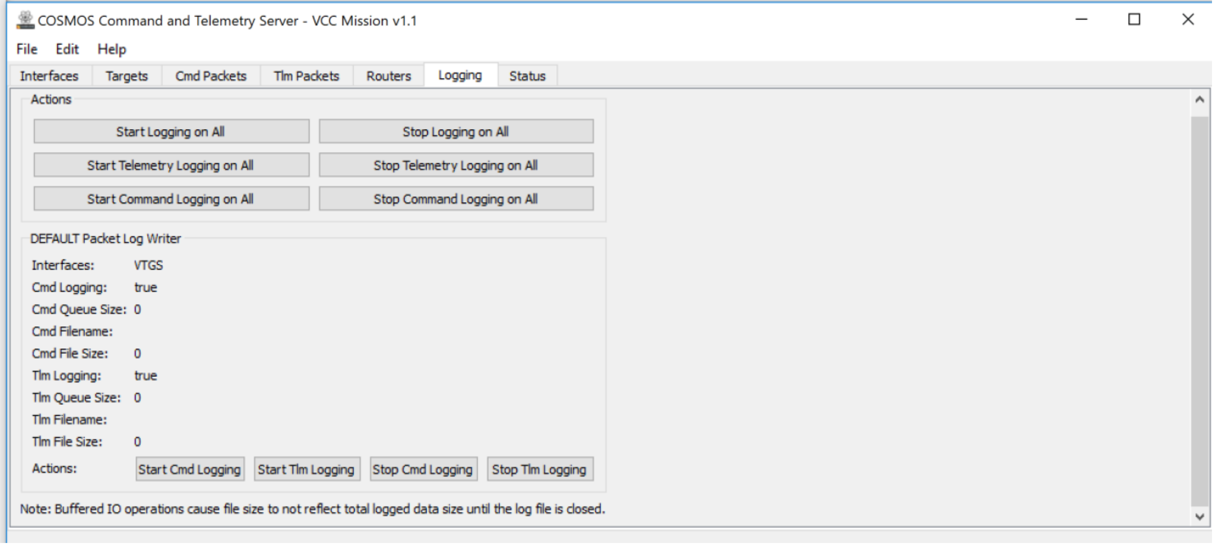
COSMOS Basic Tools

Packet Viewer





Command Sender

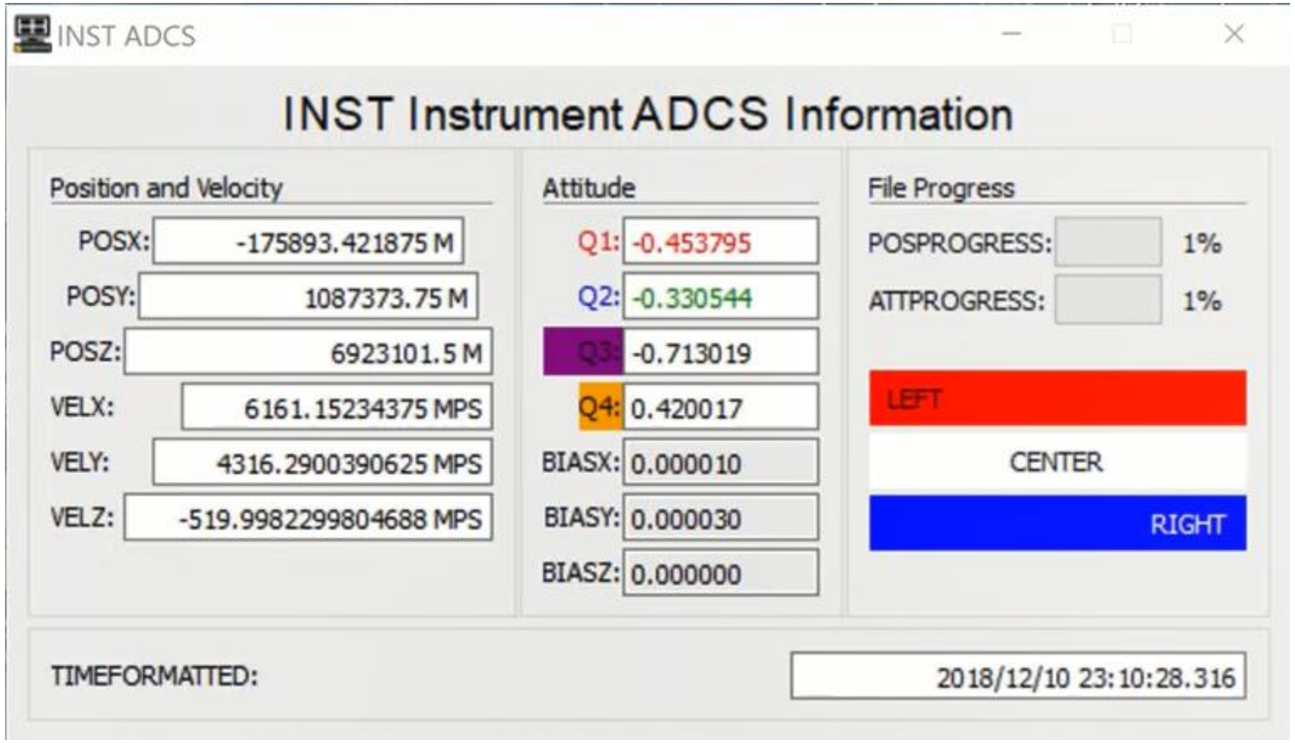


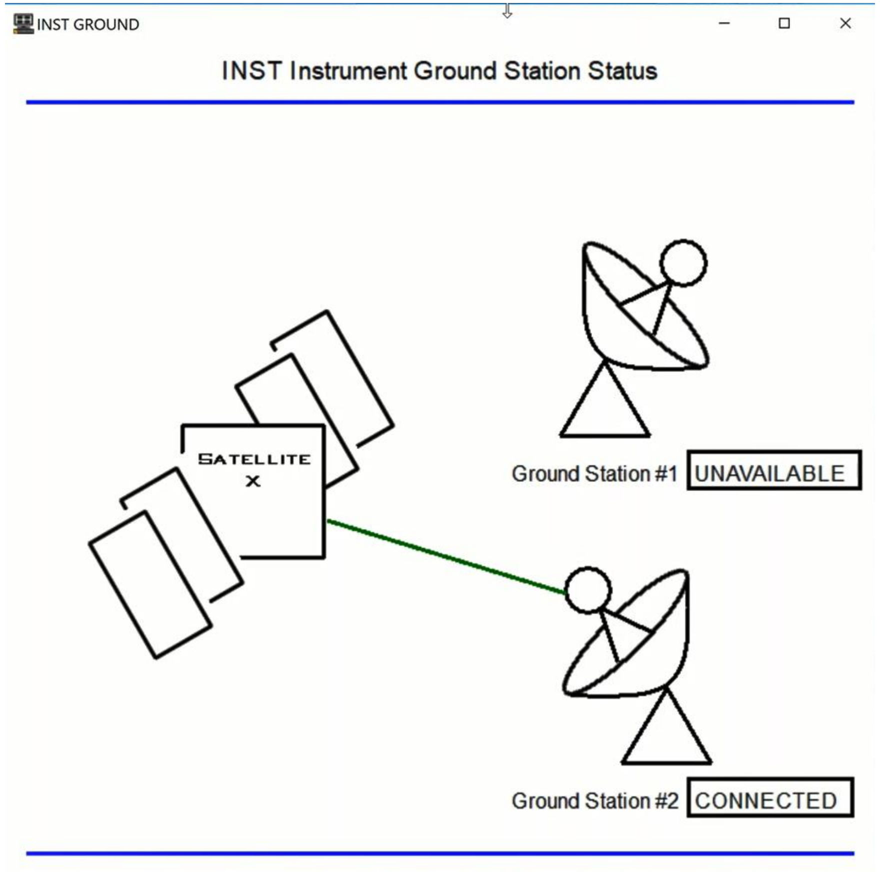
Command & Telemetry Server

Demonstration Video

COSMOS: Future Work

- Telemetry Screens
- Autonomous Operation through Command Sequences





Images from Ball Aerospace COSMOS Demo.

VIRGINIA TECH™

VT Ground Station Commercial S-Band Addition

Zach Leffke

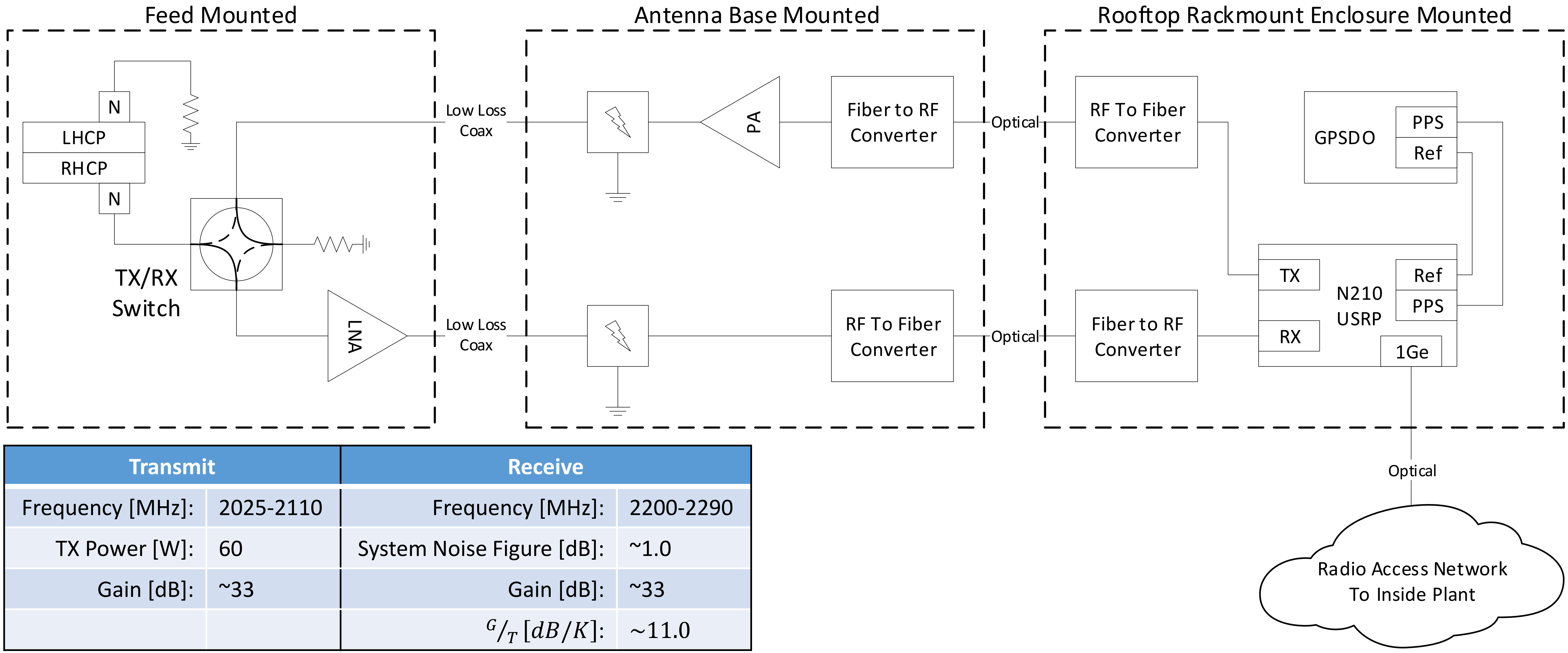
Research Faculty

MISSION OPS

Key Features

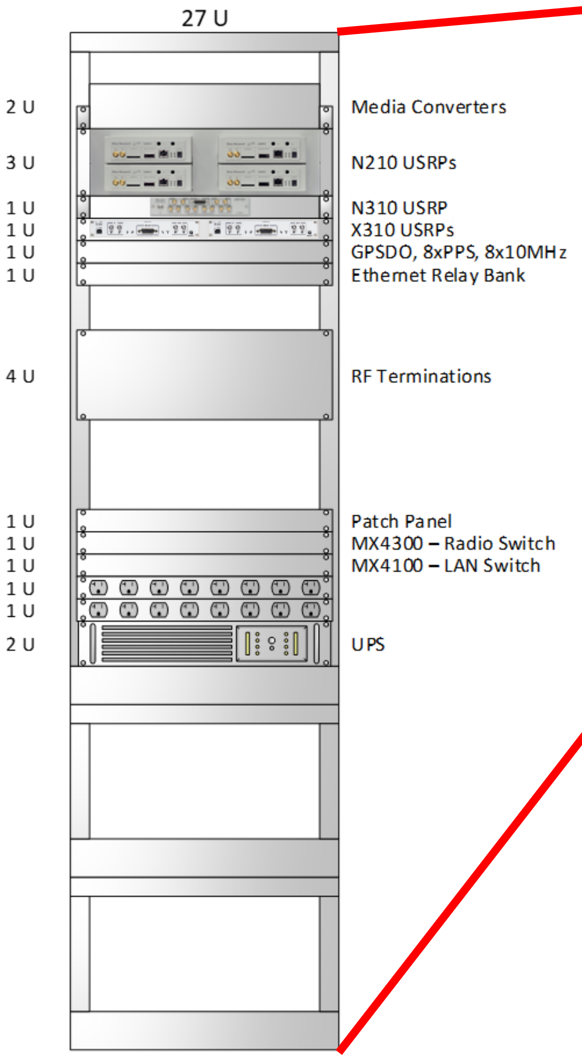
- 2.4m Parabolic Antenna (prime focus dish)
- Mounted on high end precision tracking pedestal
- Stepped Septum Feed (RHCP/LHCP)
- S-Band Frequency Allocations
    - Compatible with commercial/federal licensing
- Roof mounted on secure facility (no unrestricted physical access)
- Secure access operations center
- Software Radio based signal processing (GNU Radio)
- GPS Disciplined Oscillator for timing and accurate frequency reference
- Custom, antenna mounted, RF Front End
- Excellent lightning protection network
- Customer data access through secure VPN connection (real time and historical)
- Estimate installation spring/summer 2019, operational fall semester 2019.

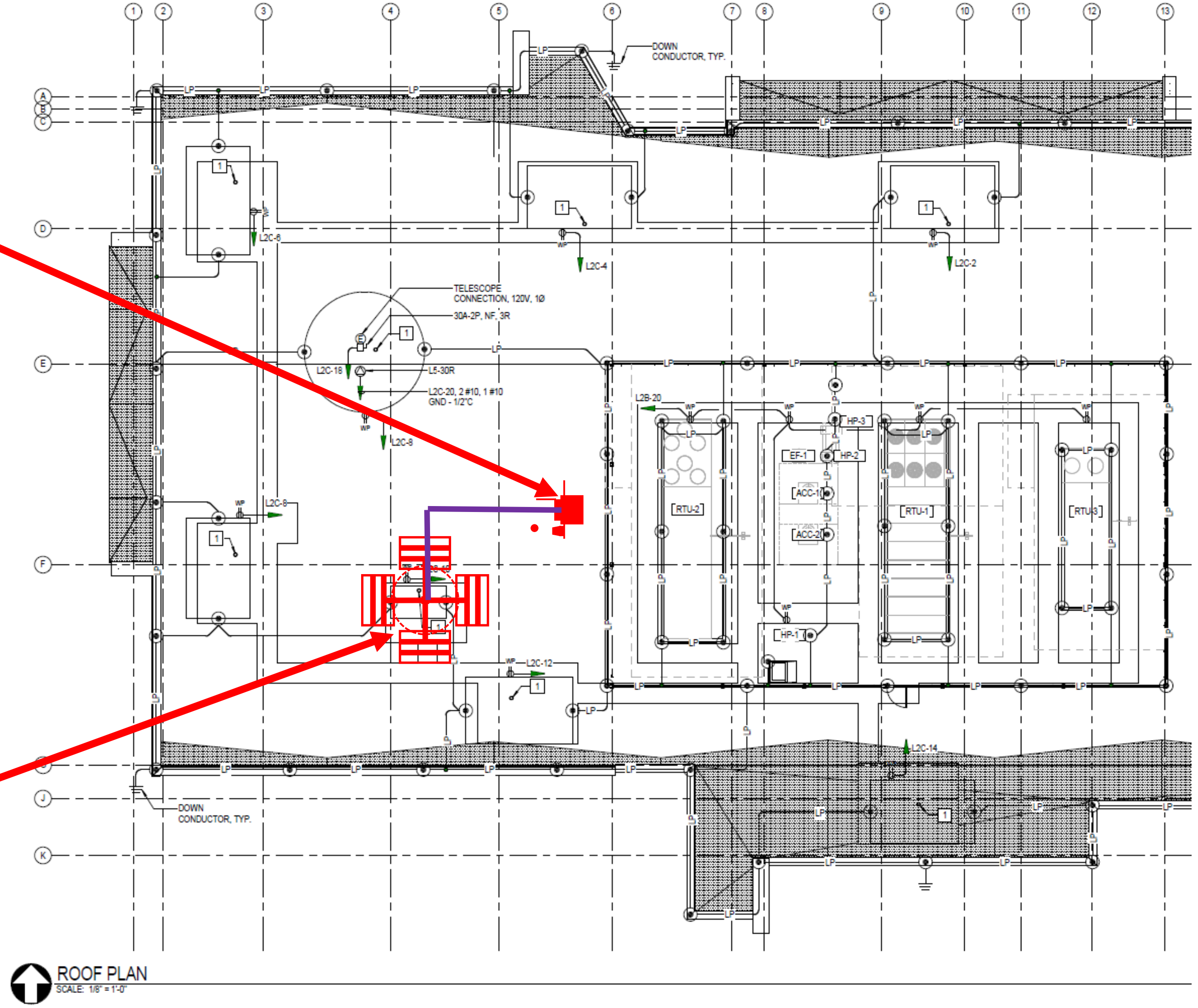
RF Block Diagram & Simplified Characteristics



Transmit		Receive	
Frequency [MHz]:	2025-2110	Frequency [MHz]:	2200-2290
TX Power [W]:	60	System Noise Figure [dB]:	~1.0
Gain [dB]:	~33	Gain [dB]:	~33
		G/T $[dB/K]$:	~ 11.0

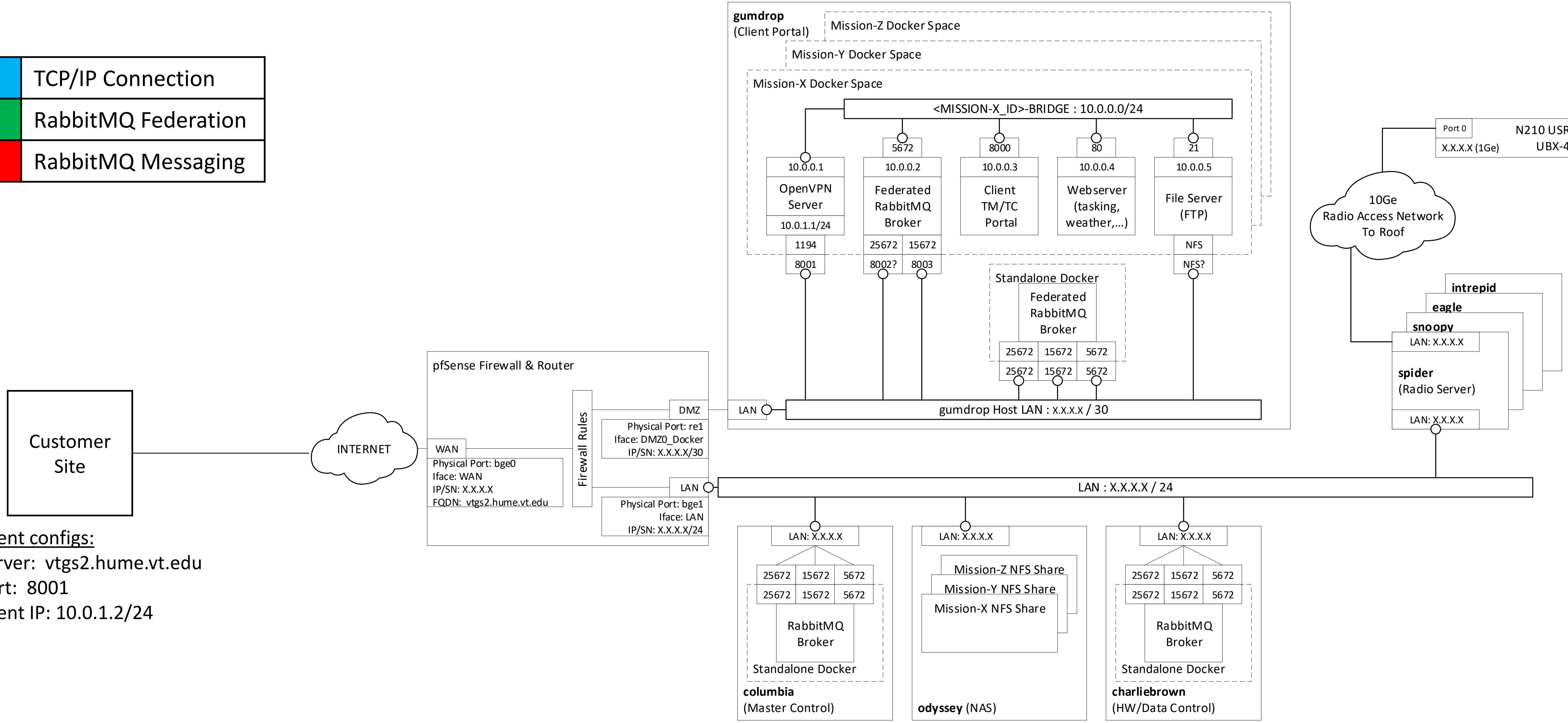
S-Band Ground Station Rooftop Layout





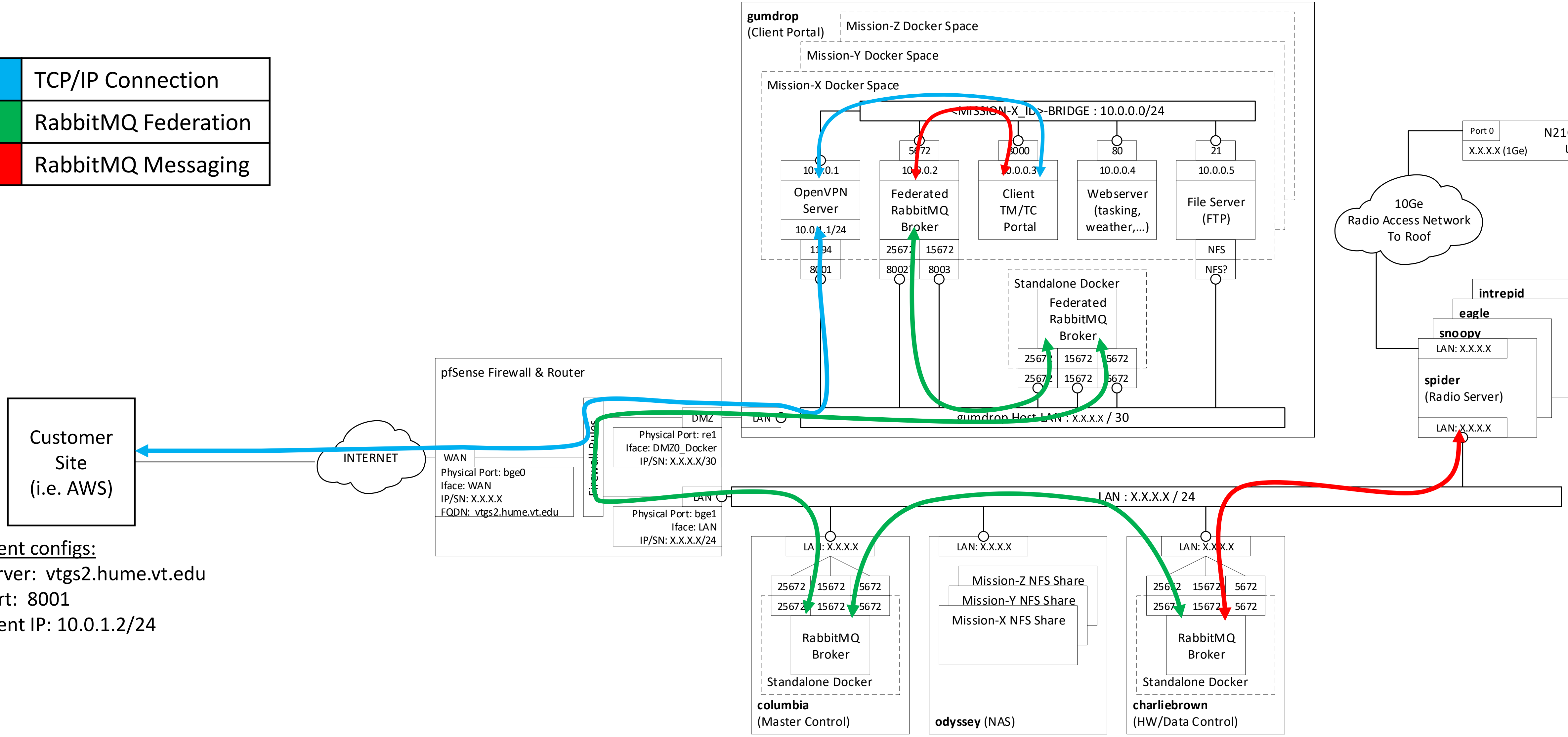
Customer Data Access

(blue)	TCP/IP Connection
(green)	RabbitMQ Federation
(red)	RabbitMQ Messaging



Client configs:
Server: vtgs2.hume.vt.edu
Port: 8001
Client IP: 10.0.1.2/24

Customer Data Access – ex. Real Time Streaming



Client configs:

Server: vtgs2.hume.vt.edu

Port: 8001

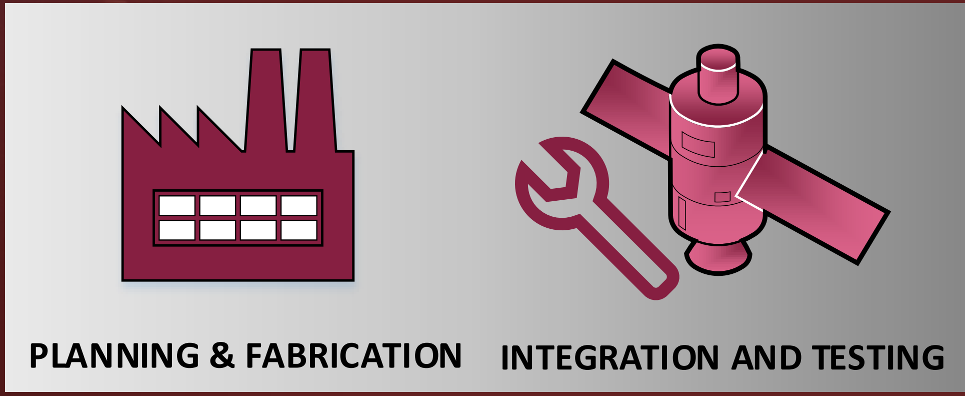
Client IP: 10.0.1.2/24

VIRGINIA TECH™

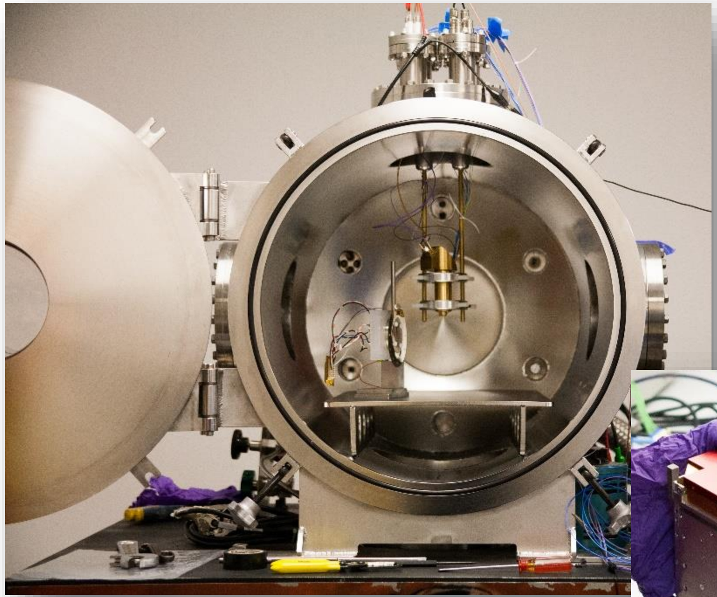
Laboratory Facilities

Stephen Noel

Research Faculty



Overview



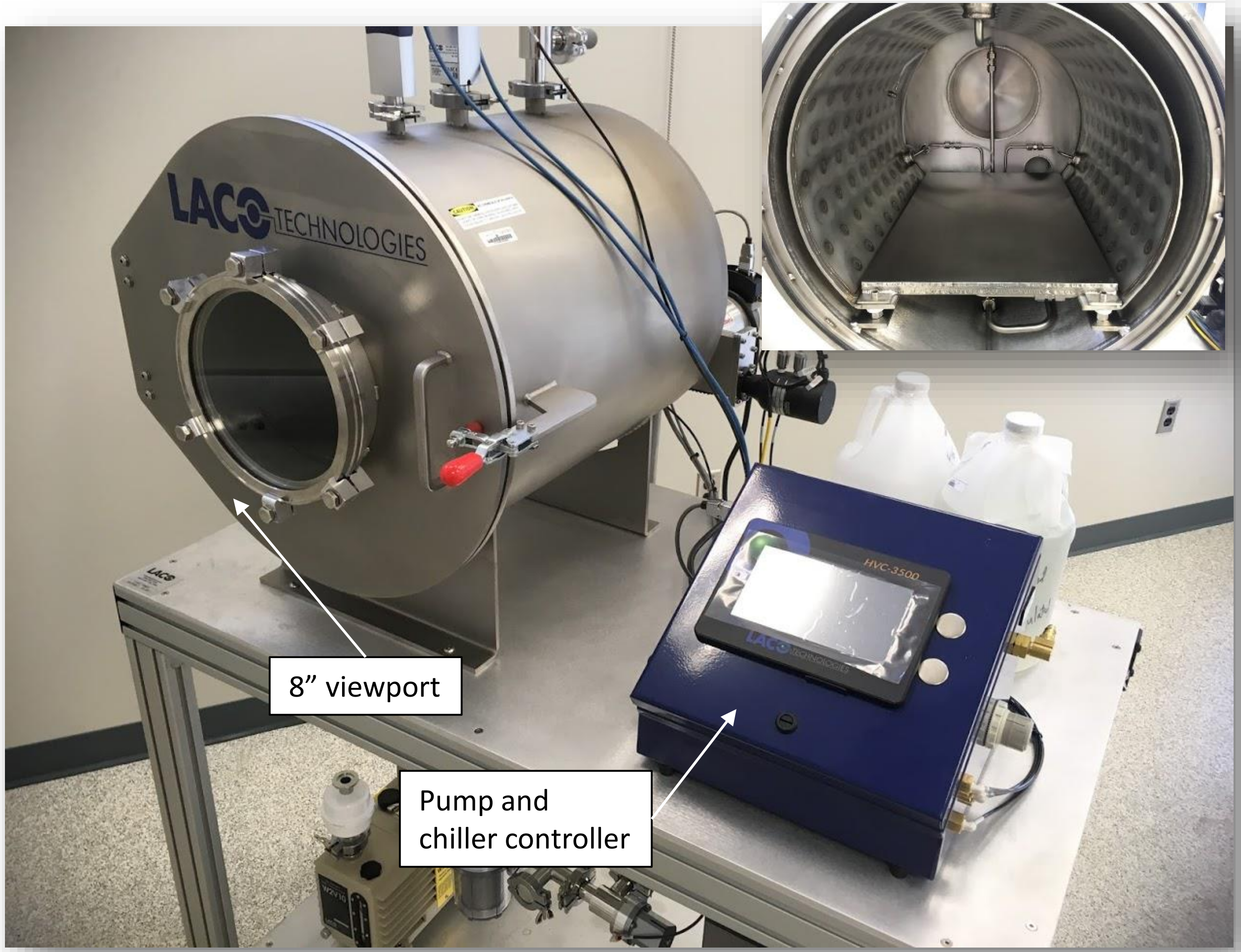
- VT facilities used for buildup and verification testing of LAICE 6U CubeSat payload
- VSGC VCC satellite constellation program (1U)
- Procedures based on NASA standards
- Pick-and-place & solder re-flow oven for PCB assembly
- Contamination control
  - 4 laminar flow benches
  - Class 10,000 capable clean room
- ESD mitigation
  - Anti-static mats, ground-straps, ESD lotion, and ground-strap testers
  - ESD-safe tools
- 5 vacuum chambers of various sizes
- Small machine shop for prototyping
- CubeSat-compatible air bearing platforms
- Hot-filament ion source

VT Clean Room

- **Specs:**
  - Capable of ISO 7 (Class 10,000) classification
- **Status:**
  - **Upgraded September 2018**
    - New ESD smocks, dirt mats, and control procedure
  - Currently configured for flight board assembly (pick and place)
  - Can be re-configured for more bench space
  - Assembly of LAICE CubeSat payload performed here
  - VCC USIP 1U CubeSat assembly performed here

Virginia Tech TVAC

Interior View

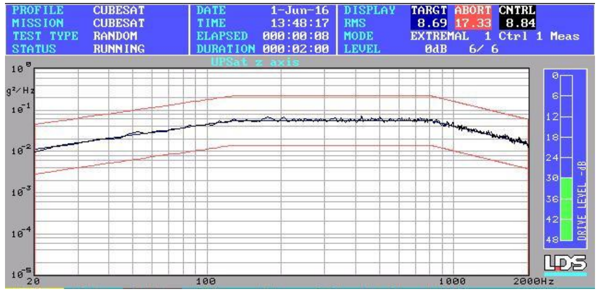


- **Specs:**
  - Sized for 6U CubeSat form factor
  - Minimum pressure: **< 5 x 10-7 Torr**
  - **-45 to 200°C**
  - Digital controller for valves and chiller operation; programmable recipes
  - Fluorocarbon-based chiller fluid pumped through platen and shroud for thermal control
  - Built in 2017

Shaker Table (Potential Future Asset)

- **Specs:**
  - 5000 lbf-in Sine and Random
  - 95g sine peak, 50g random acceleration
  - 78.7 in/sec max velocity
  - Usable frequency range up to 3000 Hz
- Capable of current NASA workmanship, acceptance, and qualification levels
- **Requires:**
  - **Control system design**
  - **Hearing PPE**
  - **GUI development**
  - **Power and compressed air hookups**

LDS V850 Shaker

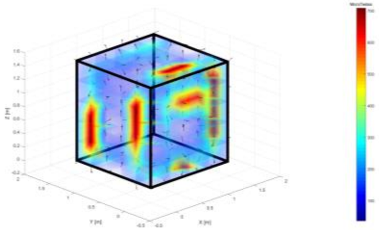


LDS SPA-K Amplifier

CubeSat Testbed – Simulations Lab

- CubeSat air bearing
  - Sized for up to 6U CubeSat mounting
  - ±15˚ tilt angular flexibility
  - Auto balancing (coming soon)
  - Maximum mass 136 kg
  - VectorNav VN-100 IMU
  - Carbon fiber mounting plate
- Helmholtz cage
  - 1.5m x 1.5m x 1.5m
  - Automated calibration routine in development
  - Integrated GUI with STK for hardware-in-the-loop orbit simulation
  - At least ±2 Gauss (200 µT) in all three axes
  - Verifying uniformity and performing upgrades Spring 2019

CubeSat Attitude Control Simulator (CSACS)



VT Helmholtz Cage

Status and Future Work

- Spring 2019
  - Configure air bearing for 1U and 3U form factors
  - CSACS procedures
  - Install shake table
- 2019 and beyond…
  - Goals:
    - Space@VT fully functional end-to-end CubeSat assembly and testing facility
    - Fee-for-service opportunities
    - Leverage laboratory and experience in upcoming CubeSat proposals

Retain more aspects of satellite design, assembly, testing, and operations at Virginia Tech!

Future Work

Stephen Noel

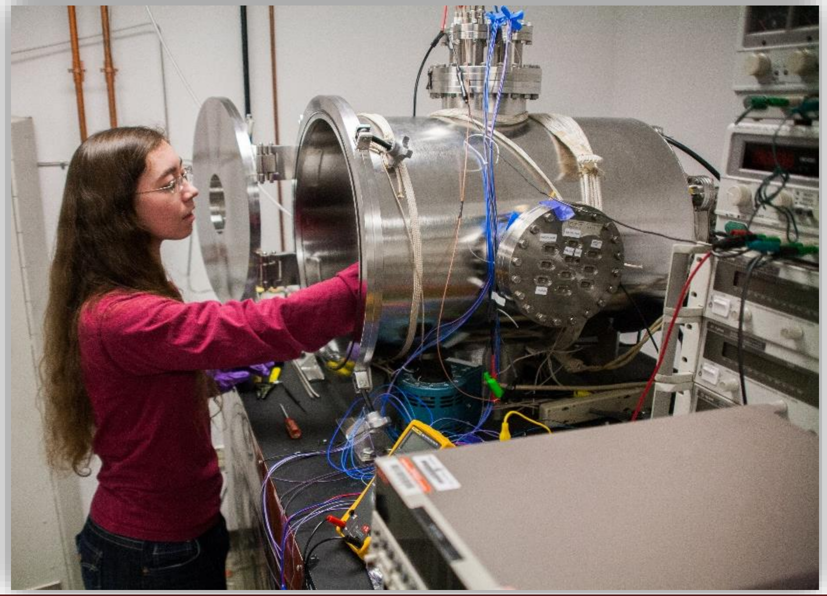
Overall Status

- Most of the resources are not fully operational yet
  - Requires additional people time and continual financial investment
- If we want to someday take on a full CubeSat mission (payload, bus, and ground elements) we need to invest in this kind of infrastructure **before the mission gets awarded**
- None of this would be possible without student effort (funded and unfunded)
  - Need a trained and highly motivated student workforce
    - Crucial to planning for future success in CubeSat missions
  - Don't throw the students into a satellite hardware mission without any background and faculty oversight

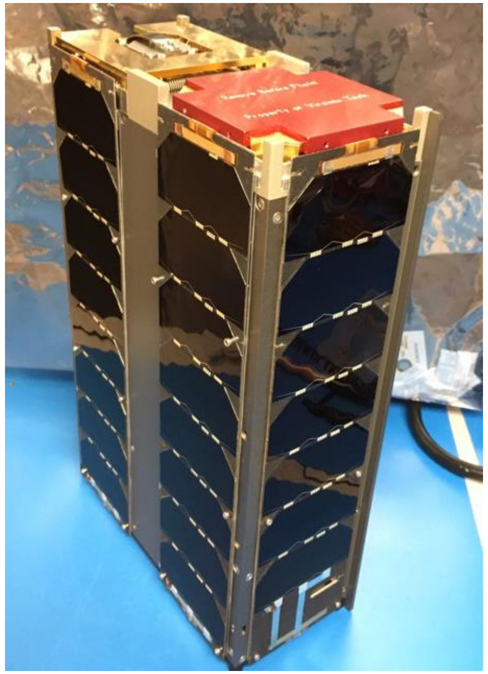
Persistent investment and effort needed from students and faculty to build this infrastructure

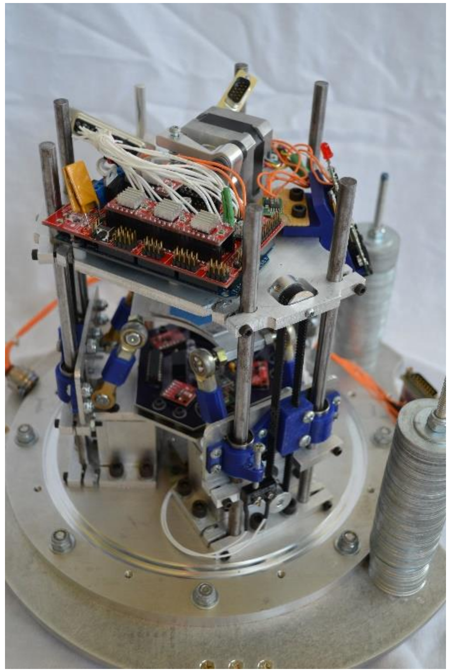
Educational Skills

- Soldering for survivability – NASA standards
  - Hand-soldering best practices
  - Solder joint inspection and cleaning
  - Pick and place and solder reflow oven training
- Electronics prototyping and debugging
  - Coding on Raspberry Pi’s, Arduino, etc.
  - FPGAs and microcontrollers
  - Schematic design, layout best practices, fabrication and assembly
  - Harness design, fabrication and documentation
- General lab test equipment training
  - Power supplies, oscilloscopes, multi-meters, current sensors
- Vacuum chamber best practices
- Clean room training
  - Flight component handling and cleaning
- Staking, potting, and conformal coating procedures and best practices
- ESD control
- Machine shop training
  - Drill press, CNC, drop saw

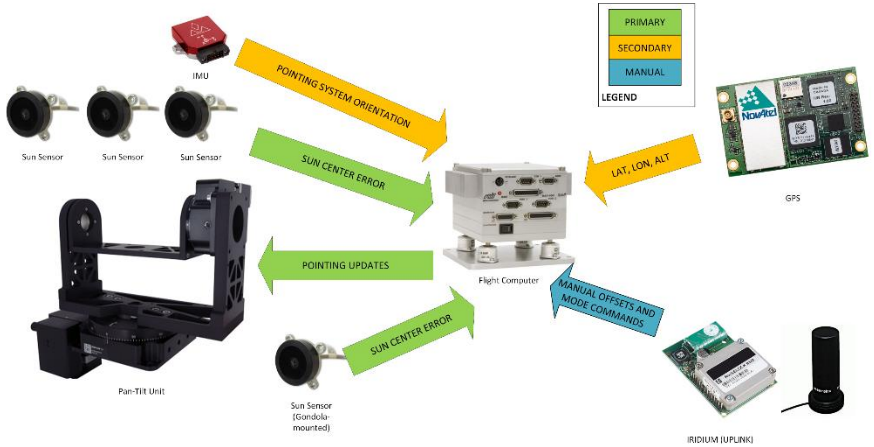


Projects

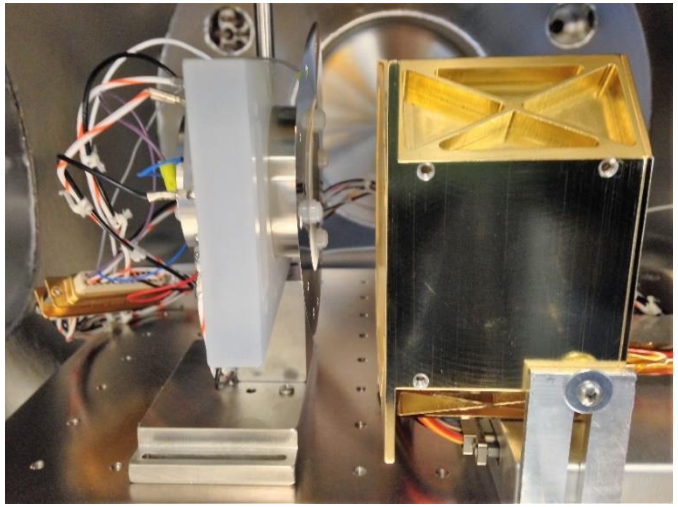

LAICE 6U CubeSat

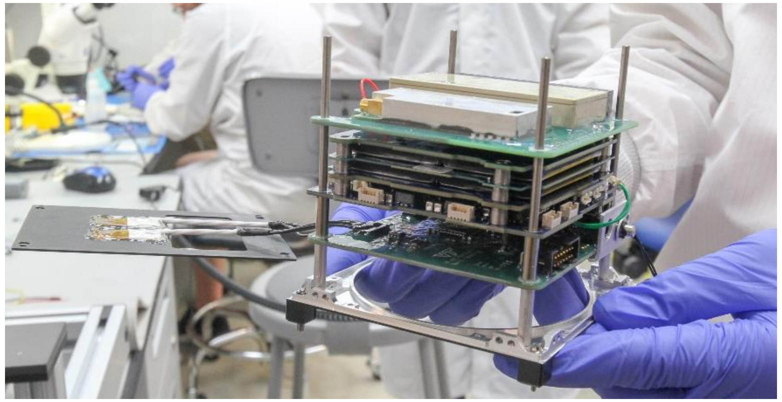

RockSat-X sounding rocket payload


GLO instrument pointing platform for high altitude balloons



Payload design / systems engineering


GRIDS Instrument validation with hot filament ion source


VCC CubeSat assembly

Future Work for VT Spaceflight Programs

- Flat-sat implementation of SharkSat/HokieBus
  - NASA core flight system (embedded processors)
  - Simulated channel with SDRs
  - COSMOS for ground station simulation
  - ADCS
  - Telemetry sensors
  - Smallsat power systems
- Facilities
  - Expand lab capabilities for development and testing
  - Expand VTGS capabilities
- Secure containers for resilient Smallsat subsystems
- Autonomous optimization for robust Smallsat tasking
- Distributed and heterogeneous network communications
  - Cross-links
  - Mesh networks

COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH

Thank you for your support!

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VIRGINIA TECH

Space @ Virginia Tech
Center for Space Science and Engineering Research

Relevant Links and Publications

- Links:
  - VTGS GitHub
  - Space@VT Lab GitHub Organization
  - Space@VT Documentation Cloud (access by request only)

- Publications:
  - VTGS Overview (IEEE Aerospace)
  - “Implementation of an actor framework for a ground station” (IEEE Aerospace)