Long Range Endurance Platform, Systems Engineering and Payload

California State University, Los Angeles

College of Engineering, Computer Science and Technology

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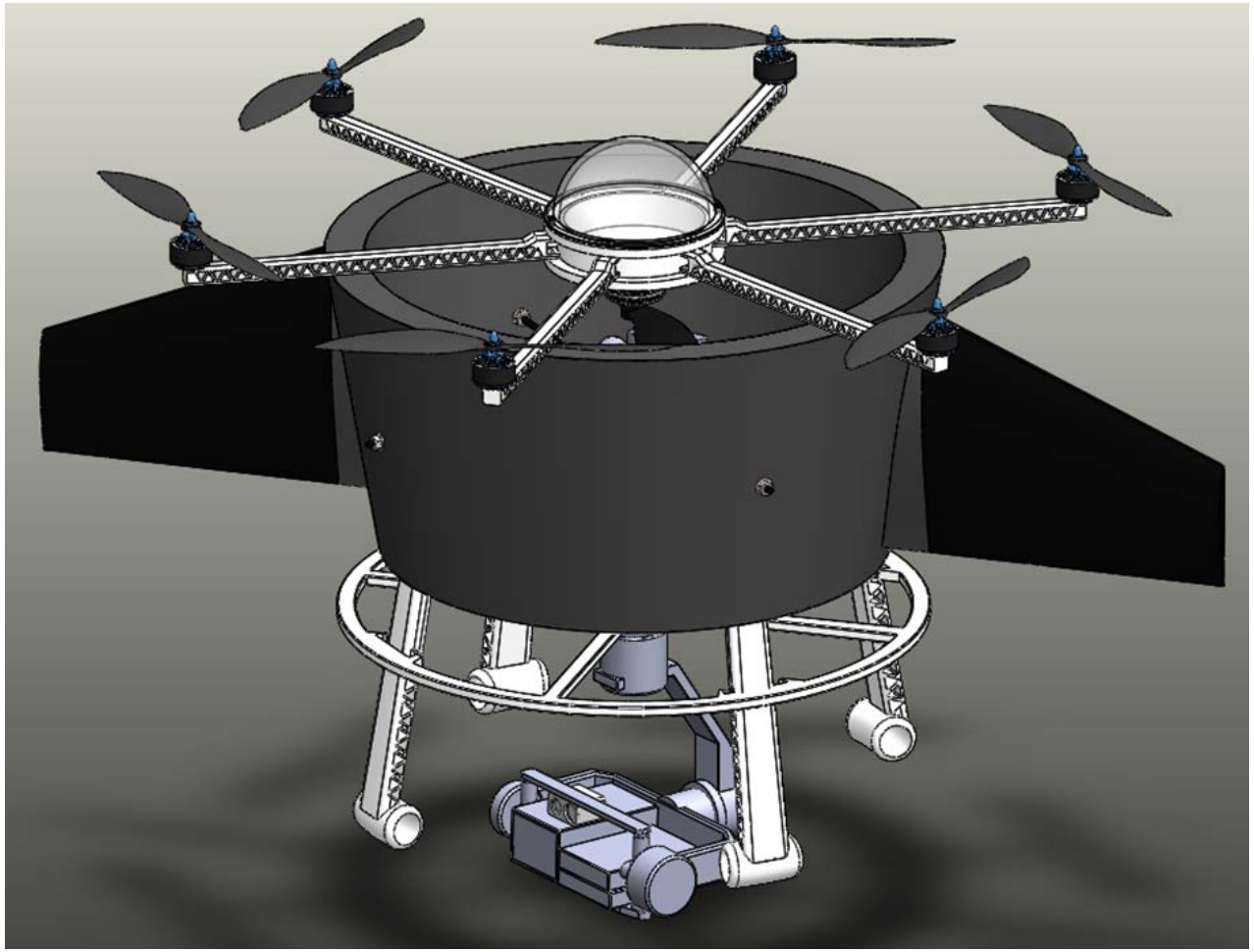
Advisor: David Scholler

Client: The Aerospace Corporation, Dr. Alyson Yarbrough

Agenda

1) What is Systems Engineering?
2) Requirements
3) Regulations
4) Missions
5) Sensors
    1) Lower Payload Bay Configuration
    2) Cameras
    3) LIDAR
    4) Particulate Sensor
    5) CO2 Sensor
6) Telemetry Tracking and Control
    1) Transmitter and Receiver
    2) Antenna
    3) IMU
7) Conclusion

Sub teams-Responsibilities

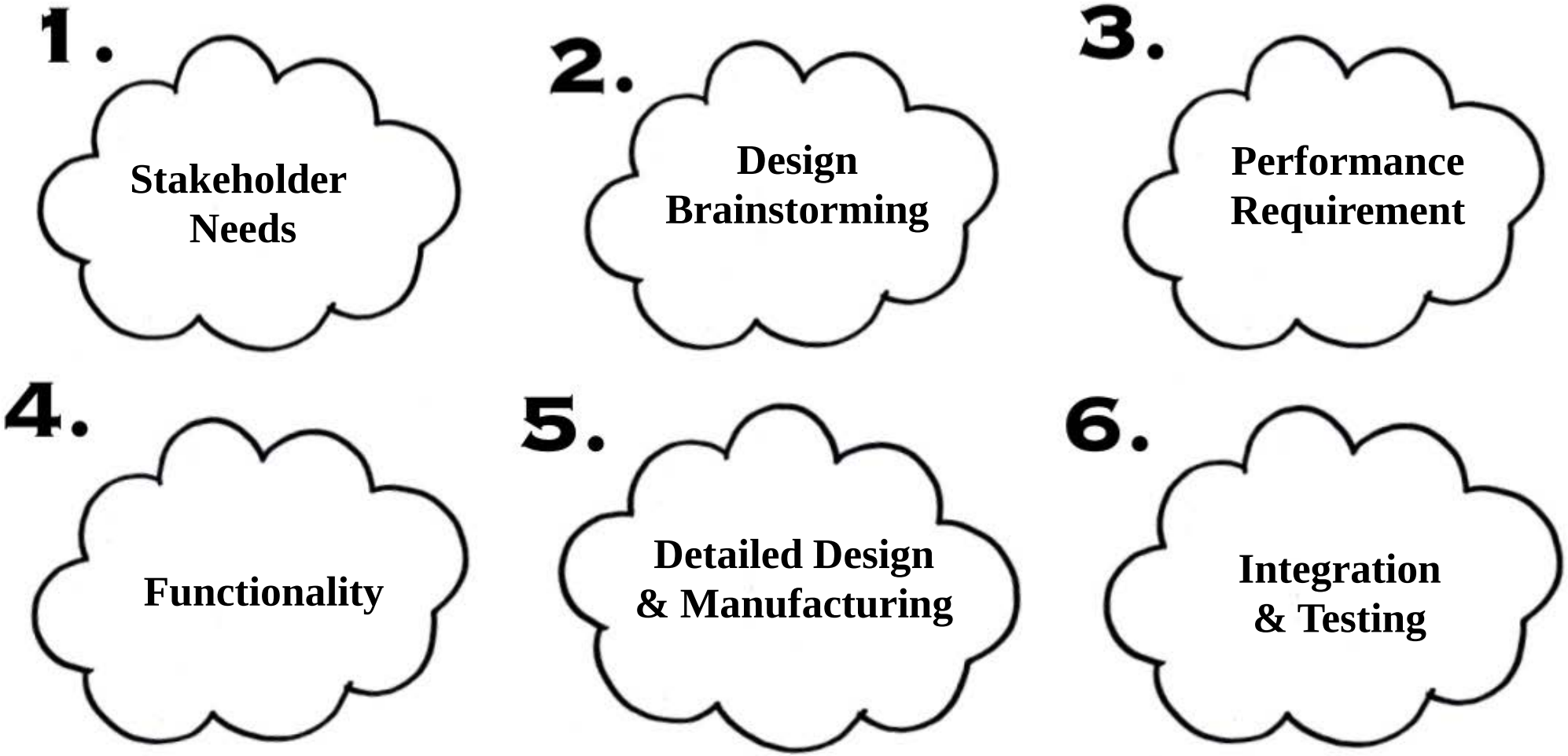


- Systems Engineering and Payload
  - Tracking Telemetry and Communication, Sensors, Payload Design and Analysis
- Structures
  - Design and Analysis of UAV structure
- Powertrain
  - Design and Analysis of UAV powertrain
- Flight
  - Design and Analysis of Propellers, Wings, and Flight characteristics

What is Systems Engineering?

- How can we successfully complete this project in the most efficient way possible?
- Approaching a complex problem and breaking it down to smaller tasks.
- Communicate the objectives, requirements, and constraints for the team
- Coordinating the project as it progresses
- Does the result meet the stakeholder’s expectations?

What is Systems Engineering?



Mission Requirements

Mission Profile Requirements

General UAV Requirements

From Aerospace Corporation:

- Must maintain physical parameters given by the client's design
- Must have capacity to assess particulate emissions from marine vessels/ vehicles
- UAV must maintain at least an 8+ hour fight time
- Maintain duty cycle (60% sensing, 20% landing, 20% taking off)
- Be utilized in other port related missions (infrastructure inspection, security, emergency services)
- Real-time data recovery and assessment

Regulations

Government Regulation to operate UAV over 55lbs– FAA

- Register the UAV

Waivers to apply to

- Night flying Waiver § 107.29 – Daylight Operations is required if flying past sunset.
- Anti - collision lights that meet visibility for at least 3 statue miles is needed for filing Waiver 107.29
- Waiver § 107.31 – Visual Line of Sight Aircraft Operation
- Waiver § 107.33 – Use a visual observer without following all visual observer requirements

Regulations



Waivers to apply to - Continuation

- Waiver § 107.35 – Operation of Multiple Small UAS
- § 107.145 – Operations Over Moving Vehicles
- Waiver § 107.39 – Operation Over People
- Waiver § 107.51 – Operating limitations for Small Unmanned Aircraft if need to surpass speed of 100mph or fly above 400ft

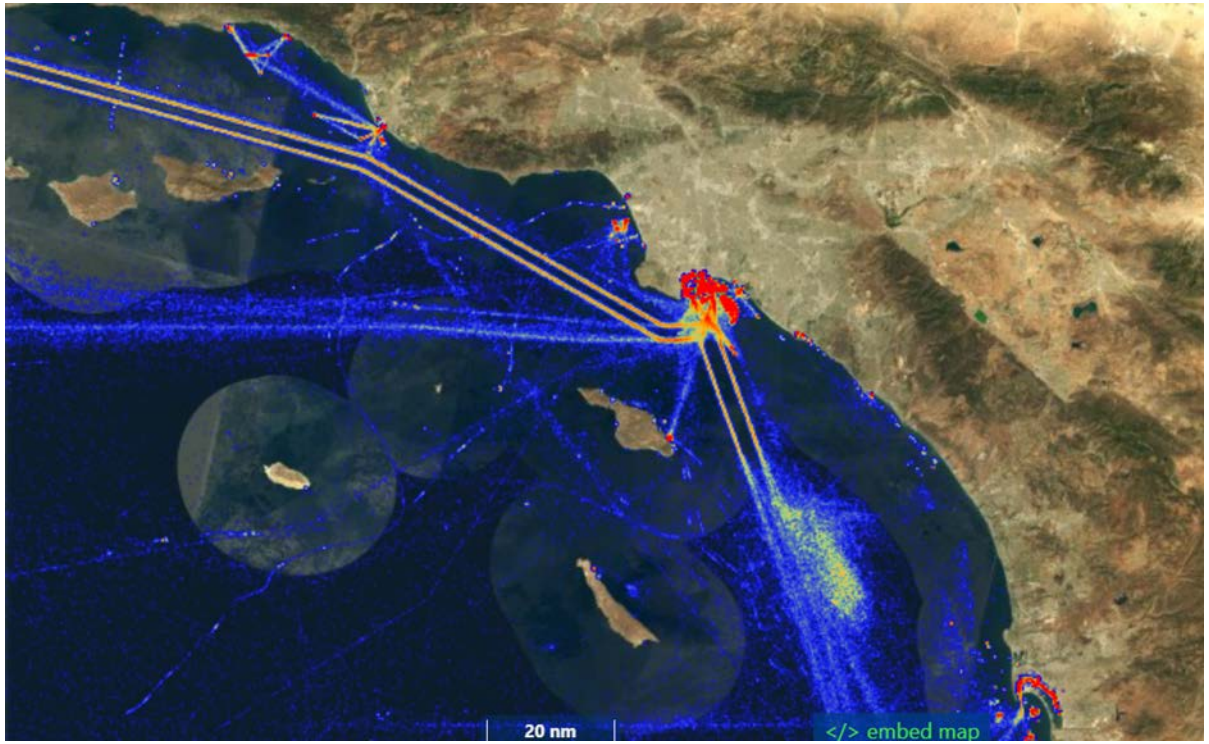
Mass Budgets

Team	Assigned (%)
Systems	20 lbs (20%)
Structure	20 lbs (20%)
Power Train	50 lbs (50%)
Flight	10 lbs (10%)

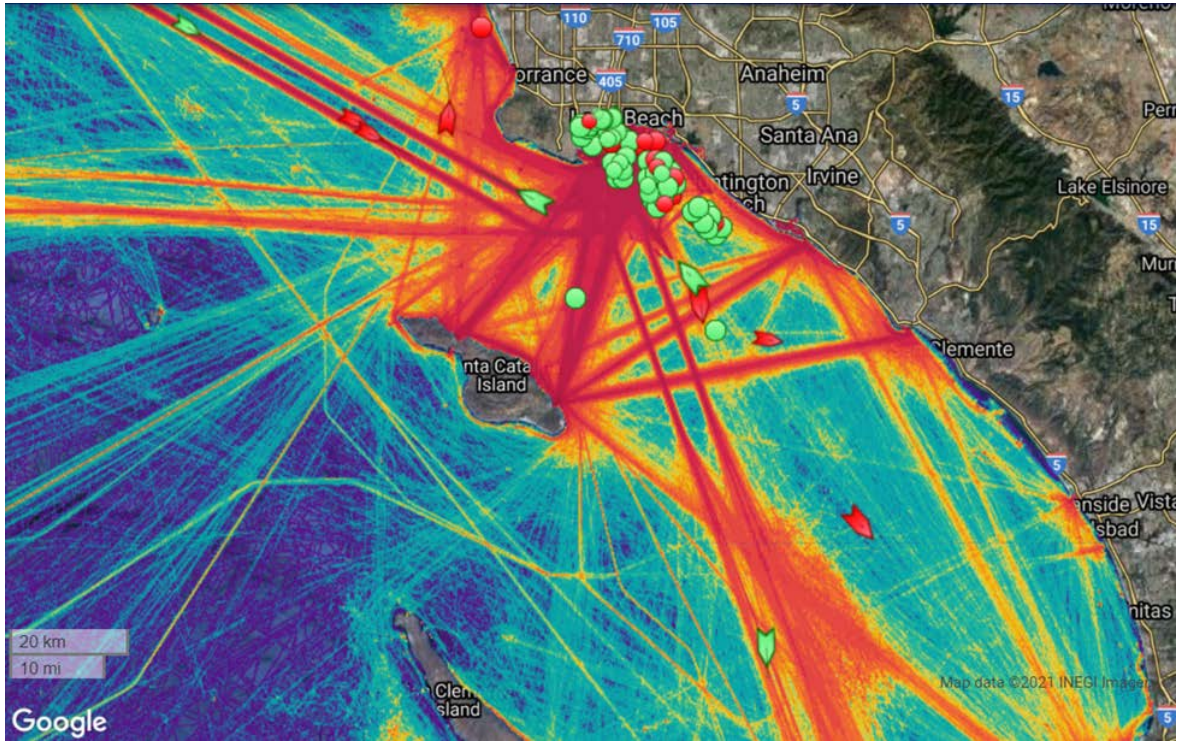
Cost Budget

Team	General Description	Forecasted Expense
Systems	Sensors	$7,060.00
	Gimbal	
	Camera	
Structure	Supports/Polyurethane	$4,500.00
	Screws	
	Carbon Fiber Sheets & Rods	
Power Train	Engine & Battery Packs	$6,663.00
	Electric Motors	
	Fuel	
Flight	Propellers	$600.00
	Wings	

Port Mission



Density Map with Marine Highways: Courtesy of Marine Traffic

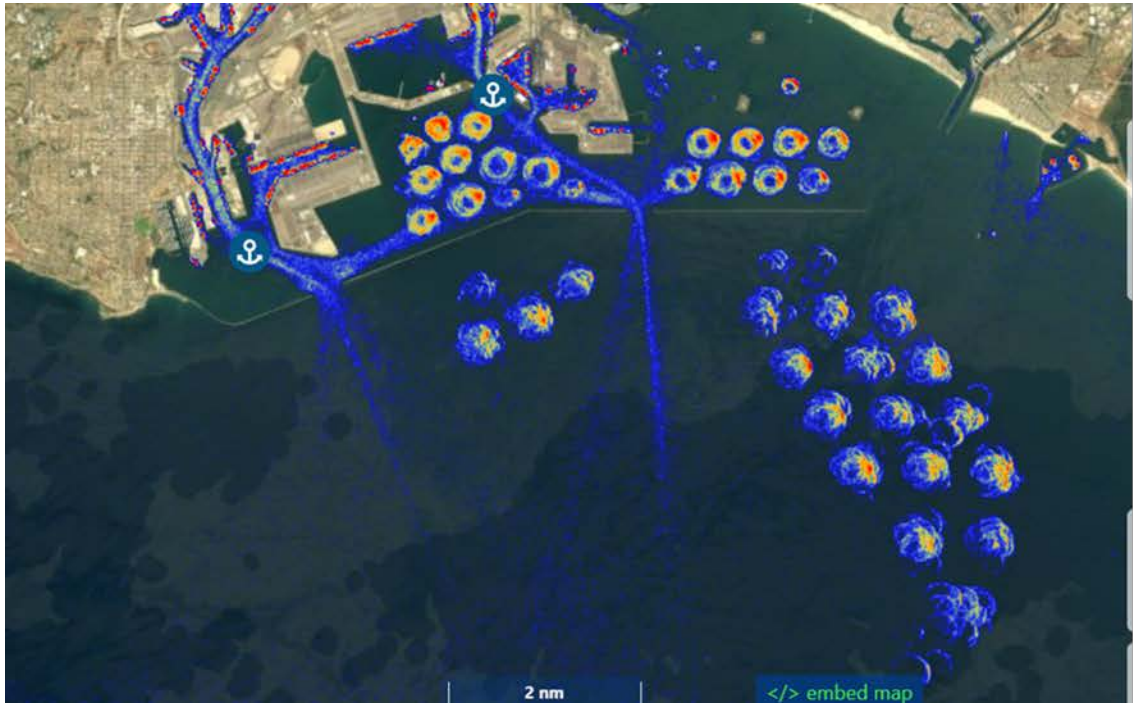


Density Map with Ship Locations: Courtesy of Vessel Finder

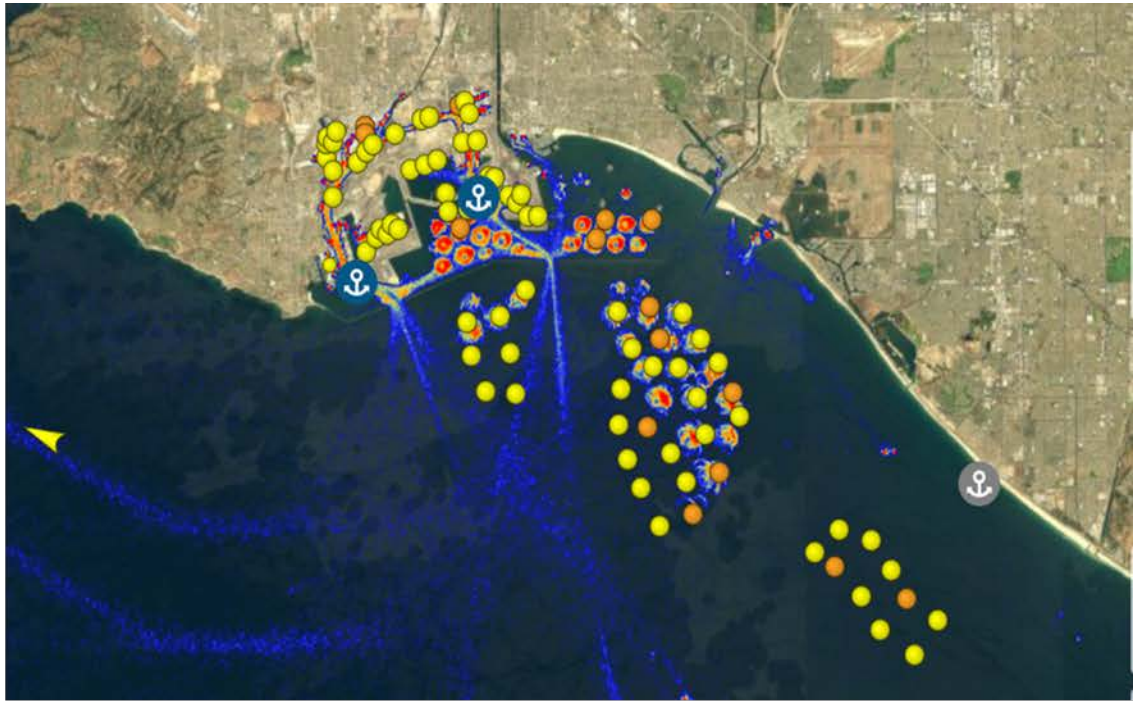
North-South and East-West Passages Visible in density maps.

All Cargo, Container, and Freighter Ships enter ports from TWO locations

Port Mission



Density Map with Anchorage Locations (2019): Vessel Tracker



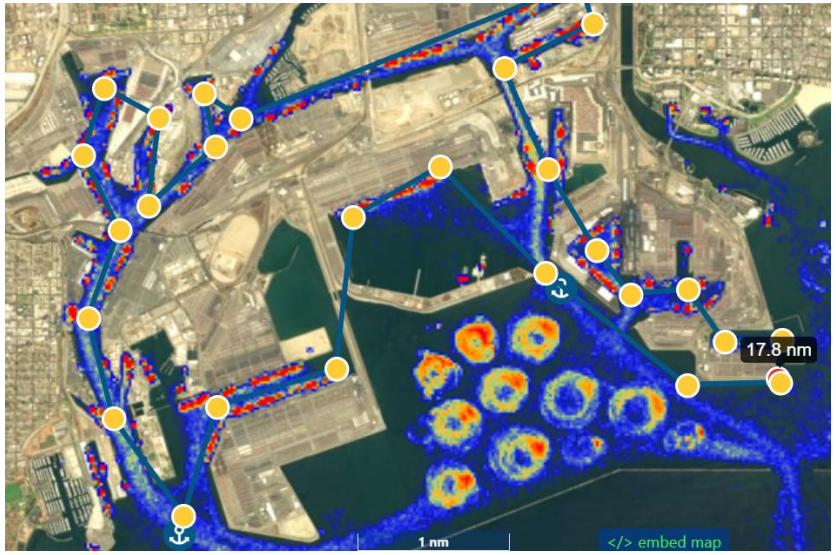
Density Map with Live Ship Locations (03/15/21): Vessel Tracker

Ships wait at Anchorage to be let into port.

Port backlog due to Covid 19, extra Anchorages set up.

Over 1 week waiting period as of February 2021

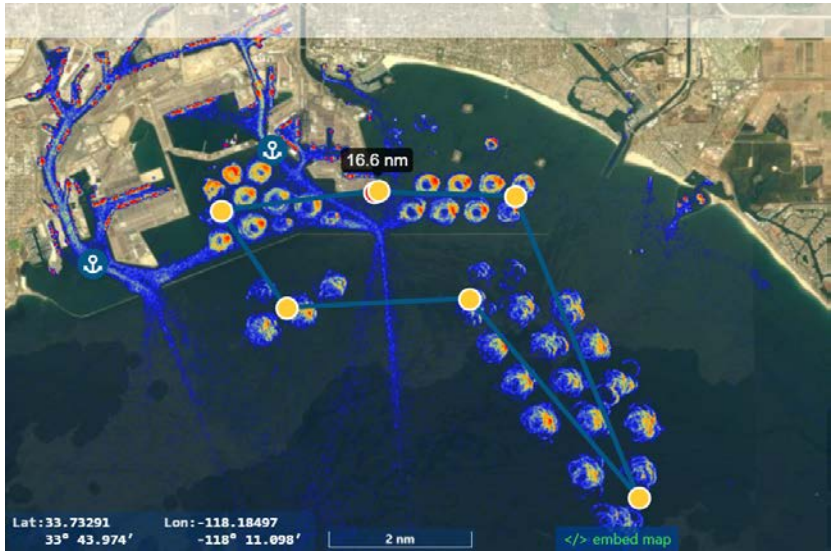
Missions



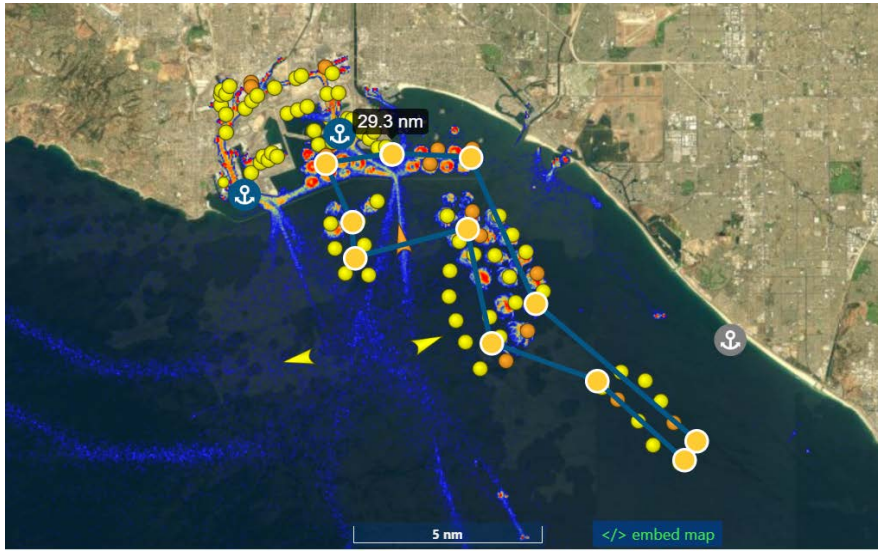
Dock Inspection: Average Distance 17.8nm



Passage Monitoring: Average Distance 19.5nm



Anchorage Inspection: Average Distance 16.6nm



Anchorage Inspection(extended): Average Distance 16.6nm

Port Mission

Mission	Dock Inspection	Passage Monitoring	Anchorage Inspection	Anchorage Inspection (Backlog)
Cruise Time (min)	42.7	46.8	39.8	70.3
Hover Time (min)	25	5	15	55
Total Flight Time (min)	67.7	51.8	54.8	125.3
Total Distance (nm)	17.8	19.5	16.6	29.3

Missions – Primary and Secondary

	Components			
Missions	Camera	Sensors	LIDAR	Lighting
Marine Vessel Emission Detection	Optical Thermal	Particle GPS	Yes	No
Port Security, Surveillance, and Reconnaissance	Optical Thermal	SWIR GPS	Yes	Spotlight
Port Emergency Services	Optical Thermal	Laser Fluro CO_2	Yes	Spotlight Indicator
Wildfire Detection	Optical Thermal	Particle CO_2 GPS	Yes	NA
Infrastructure Inspection	Optical Thermal Wide lens	Laser Fluro	Yes	NA

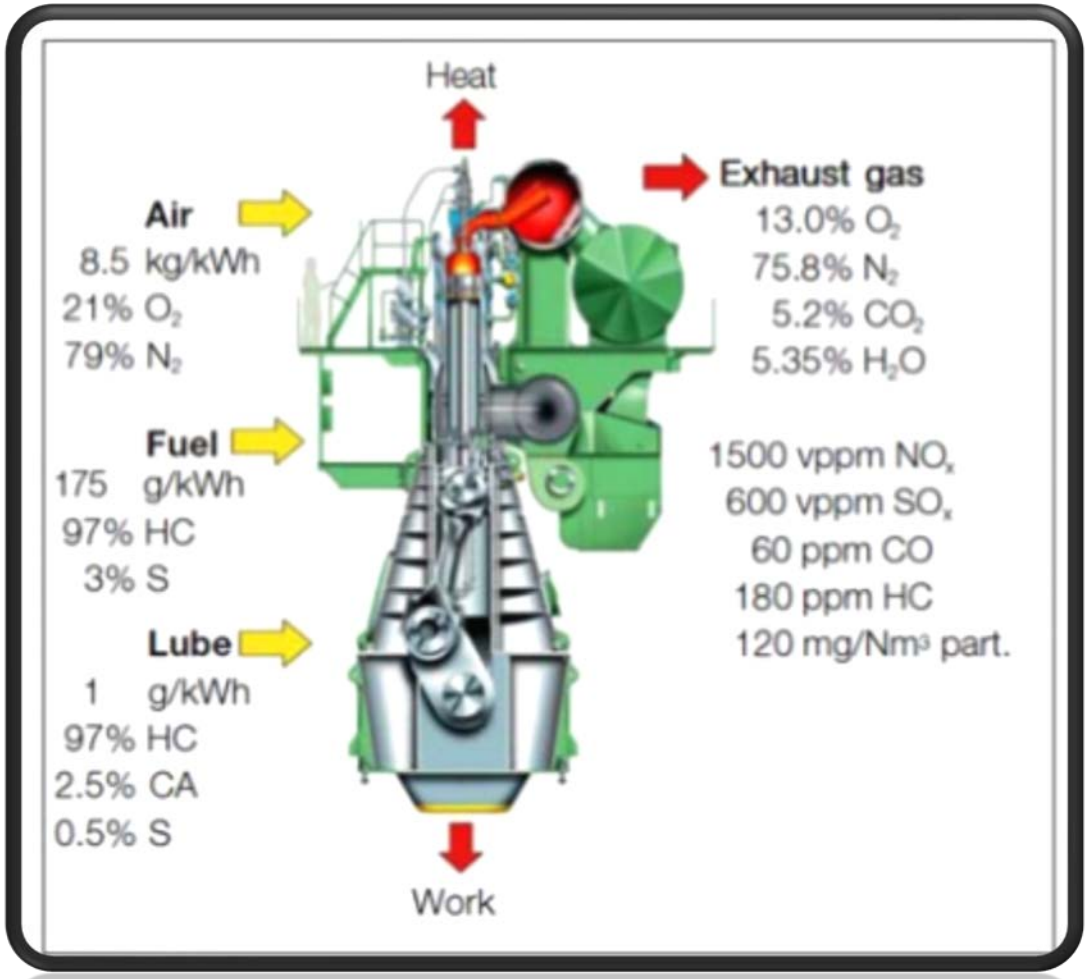
Mission – Emission Analysis

Composition of Vessel Exhaust

- Oxides of Nitrogen (NO_x): creates ozone
- Oxides of Sulphur (SO_x): create acidification
- Carbon Dioxide (CO_2): is a 'greenhouse' gas

→ Southern CA has a speed restriction of 12 knots for vessels within 20 miles of coast

- Carbon Monoxide (CO): product of incomplete combustion
- Hydrocarbons (HC): gas, soot and additional particulates



Mission – Emission Analysis

Composition of UAV Exhaust (Wankel Rotary Engine)

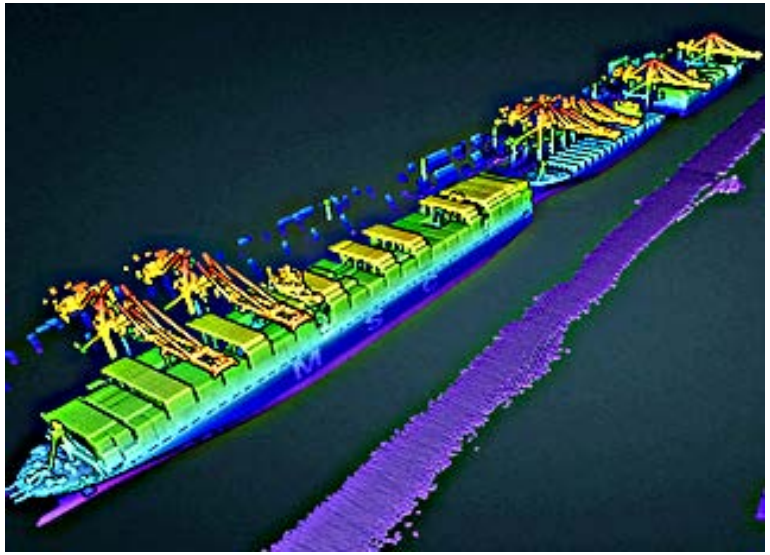
- Higher Nitrogen oxide (NO_x) emissions compared to other UAV engines
- Low Sulphur oxide (SO_x) emissions
- Higher Carbon Dioxide (CO_2) emissions
- Utilizes regular unleaded gasoline (~10 ppm of SO_x, 30 ppm for No_x)
- Power - 22 kW / 29.9 hp @ 6000 rpm



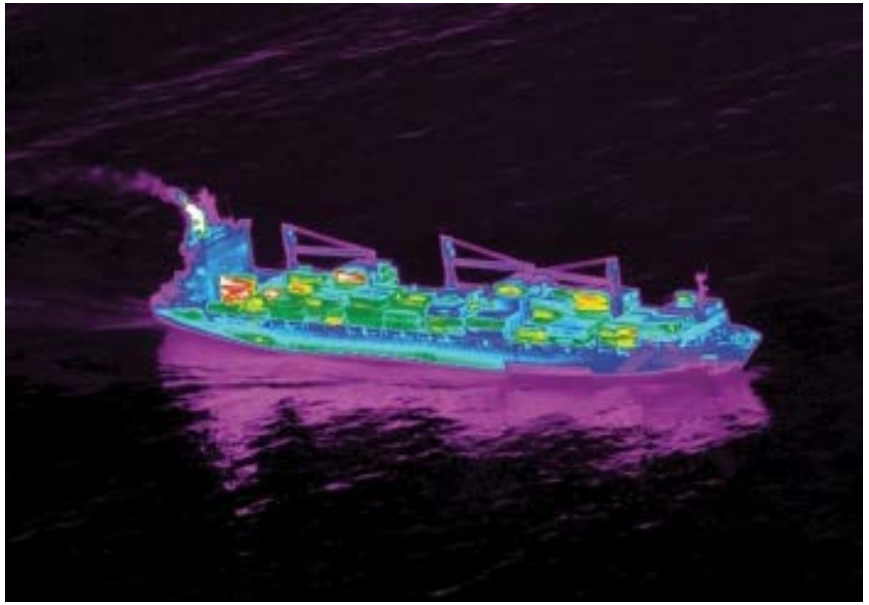
Sensors

Sensors required to fulfill mission requirements

- Optical and Thermal Imaging Camera
- LIDAR Light Detecting and Ranging sensor
- Particulate Emission Detection Sensor
- CO2 Emission Detection Sensor



LIDAR imaging of docked cargo ships

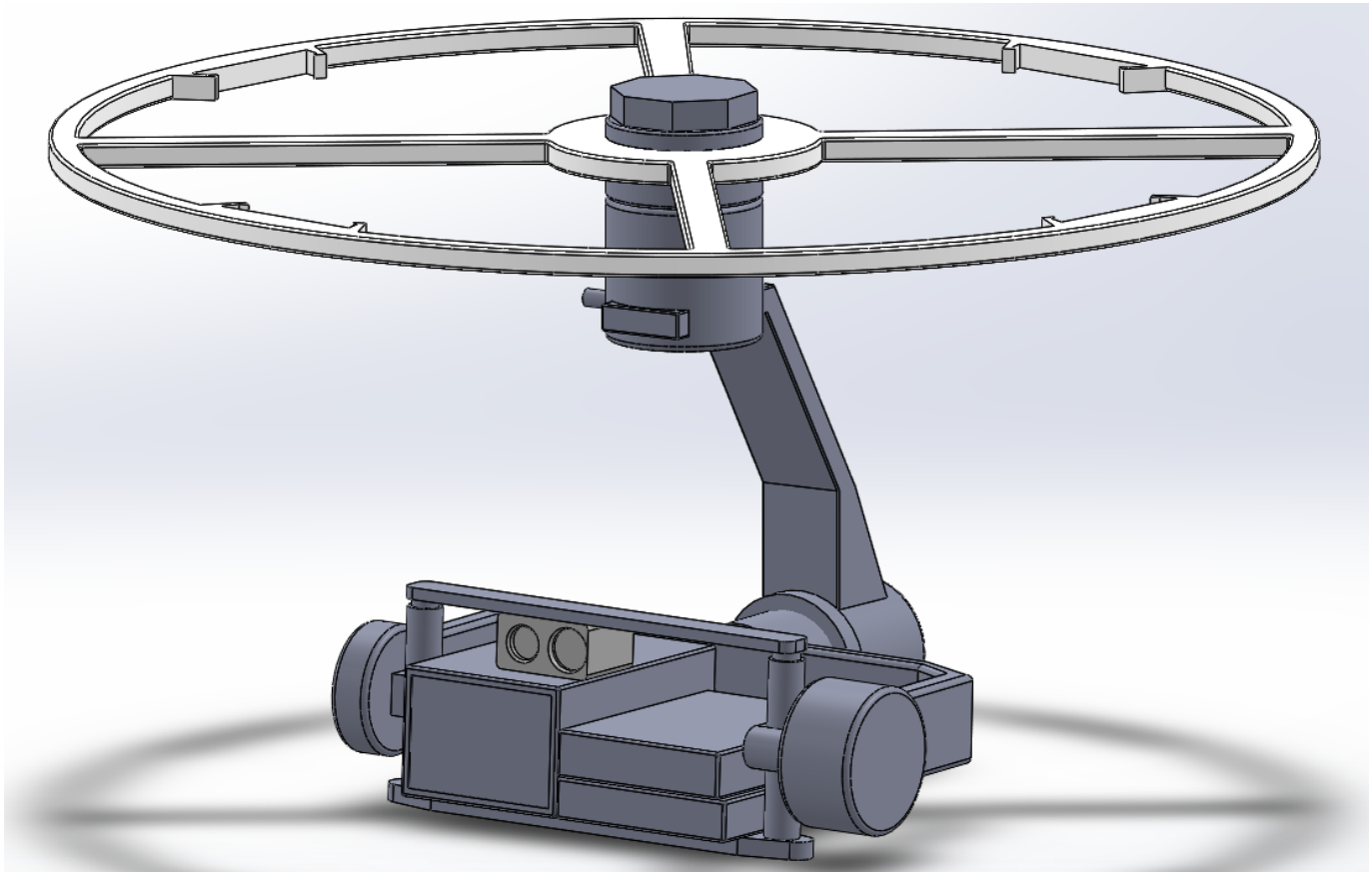


Thermal Imaging of Cargo Ship at sail



Exhaust plume from Container Ship

Sensors - Lower Sensors Bay



Lower Sensors Bay CAD model with Sensors Suite

Payload - Camera

- Thermal and HD images
    - Pre-integrated thermal module
- Suitable for locating and identifying subjects in low light conditions
- Low profile design
    - Flexible positioning
    - SWaP for longer air-time



FLIR Hadron

Sensors – LiDAR S3

- Light Detection and Ranging
    - a remote sensing method that utilizes lasers to measure elevation data at a very fast rate.



- Key Advantages
    - Best used for wide area mapping
    - Long range of 150 m
    - LiDAR system has the strong capability to examine both natural and man-made environments without sacrificing high accuracy and precision.
    - Low cost
    - Light weight and compact

Sensor - LiDAR

How it works

- LiDAR emits laser pulses and measures the time it takes from the moment the pulse leaves the scanner, reflects off a detected object and return to the scanner.

- Airborne LiDAR data system
    - LiDAR Unit – Scans the large geographical area from side to side
    - GPS – tracks the altitude and location of the aircrafts and is vital to attain accurate elevation data.
    - IMU – tracks the orientation allowing high accuracy of the position of the pulse
    - Computers - Gather the elevation data as the Lidar unit scans the surfaces

Sensor - LiDAR

Equations that will be used to determine

- Distance

$$\frac{(\boldsymbol{Travel\ Time})(\boldsymbol{Speed\ of\ Light})}{\mathbf{2}}$$

- Ground Elevation

(Altitude) - (Distance)

Sensors – Particulate and CO_2

What is a Particulate Sensor/Counter?

- Three types: Infrared, Beta Attenuation, Laser scattering
- Laser scattering -utilizes laser diffraction to count particles and determine their size
- How it works
    1. A laser beam strikes a particle, the beam's light is scattered
    2. Sensor detects the intensity and angle of the beam after passing through the particulate-laden air
    3. An algorithm determines how many particles were in the sample and their size

What is a CO_2 Sensor?

- Three types: NDIR, Electrochemical, Metal oxide semiconductor
- NDIR - utilized specific wavelengths of light to measure amount of CO_2 in air
- How it works

1. Air enters the sensor
2. Sensor will activate a light set at one of the specific wavelengths for CO_2; Other side will hold a receptacle that will measure how much light makes it across
3. Once light is activated, any CO_2 in air sample will absorb the beams of light

➢ <u>The more CO_2 that is present, the more light that will be absorbed</u>

Sensors - Particulate



Aeroqual S500 (sensor only)

- Designed for real-time surveying of common outdoor air pollutants
- Interchangeable sensor heads (one monitoring system for +5 pollutants)
- Sensor heads utilize active fan sampling, which increases measurement accuracy



Prana Air PM2.5 Sensor

- Laser-based scattering principal w/ advanced algorithms
- Fully calibrated digital output for particle number and mass concentration values
- 10 yr. life w/ continuous operation of 24 hours/day



ExTech VPC300 Particle Counter (sensor only)

- Six particle size channels
- Stores up to 5000 records (data, time, counts, etc.)
- Intended for tasks involving traffic related emissions

Sensors - CO_2





K33 ELG Sensor

- Low-Power consumption (can be reduced to less than 52 µA)
- Maintenance free
- Sensor life of +10 yrs.

Kele Senva Outside Air CO_2 Sensor

- Auto-calibration feature available
- Internal heater for reliable outdoor operation
- 15+ yr. life expectancy on CO_2 sensor

TT&C – Government Regulations (FCC)

- FCC rules and regulations found in Title 47 of the Code of Federal Regulations (CFR).
    - 6 47 CFR § 97.215. 7 – Transmitter frequencies. $16,000 fine.
    - 47 CFR § 97.301(a) - Drone accessories regulation that limits transmitter power to 1Watt.
    - 47 CFR §97.215(c)- Violators may be subject to substantial monetary fines



TT&C - Transmitter and Receiver

- How it works
  - Our System Design

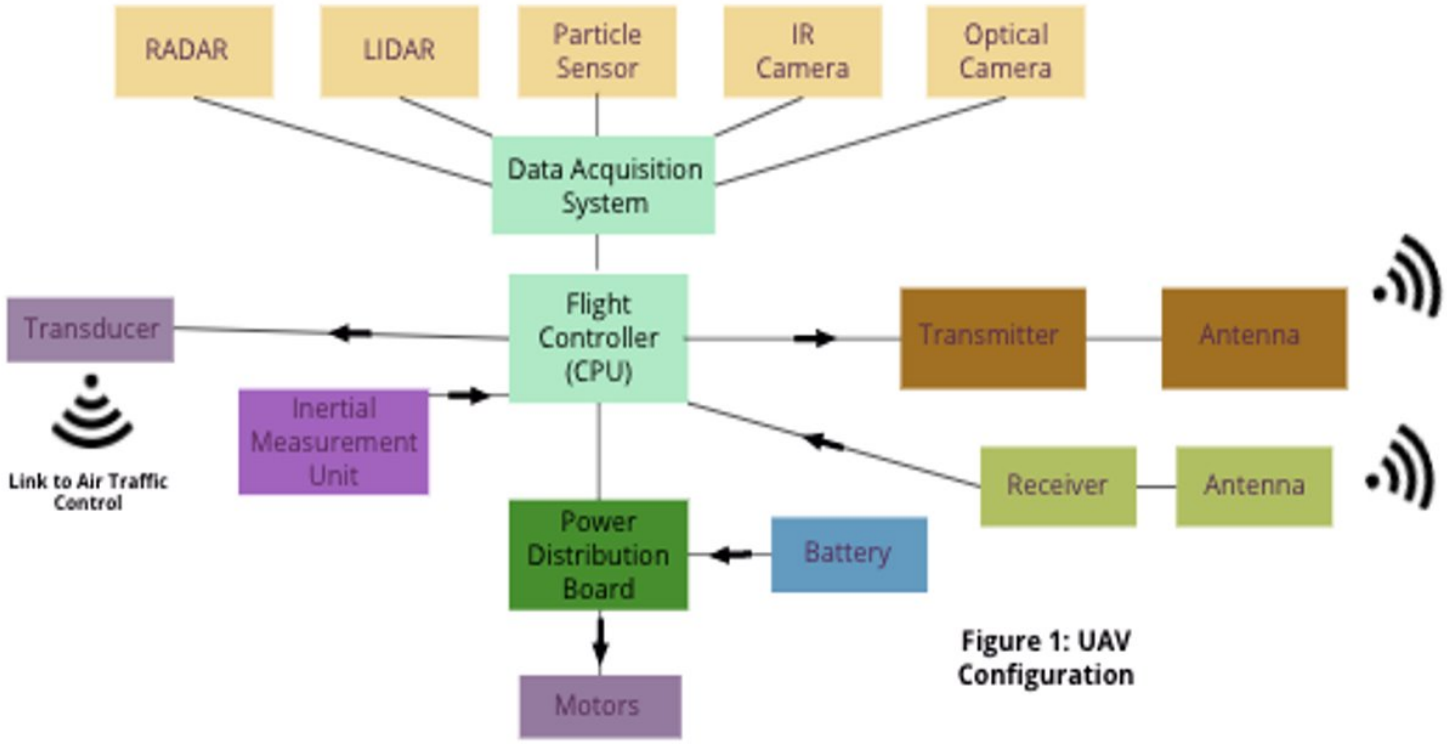


Figure 1: UAV Configuration

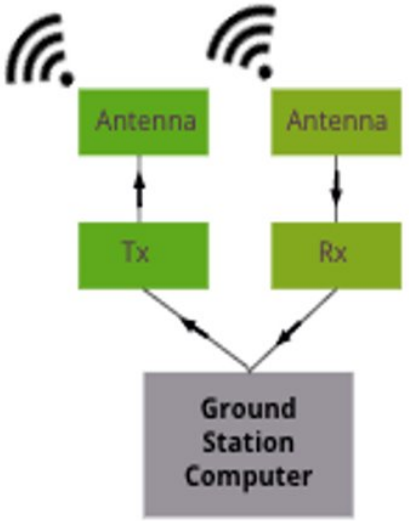
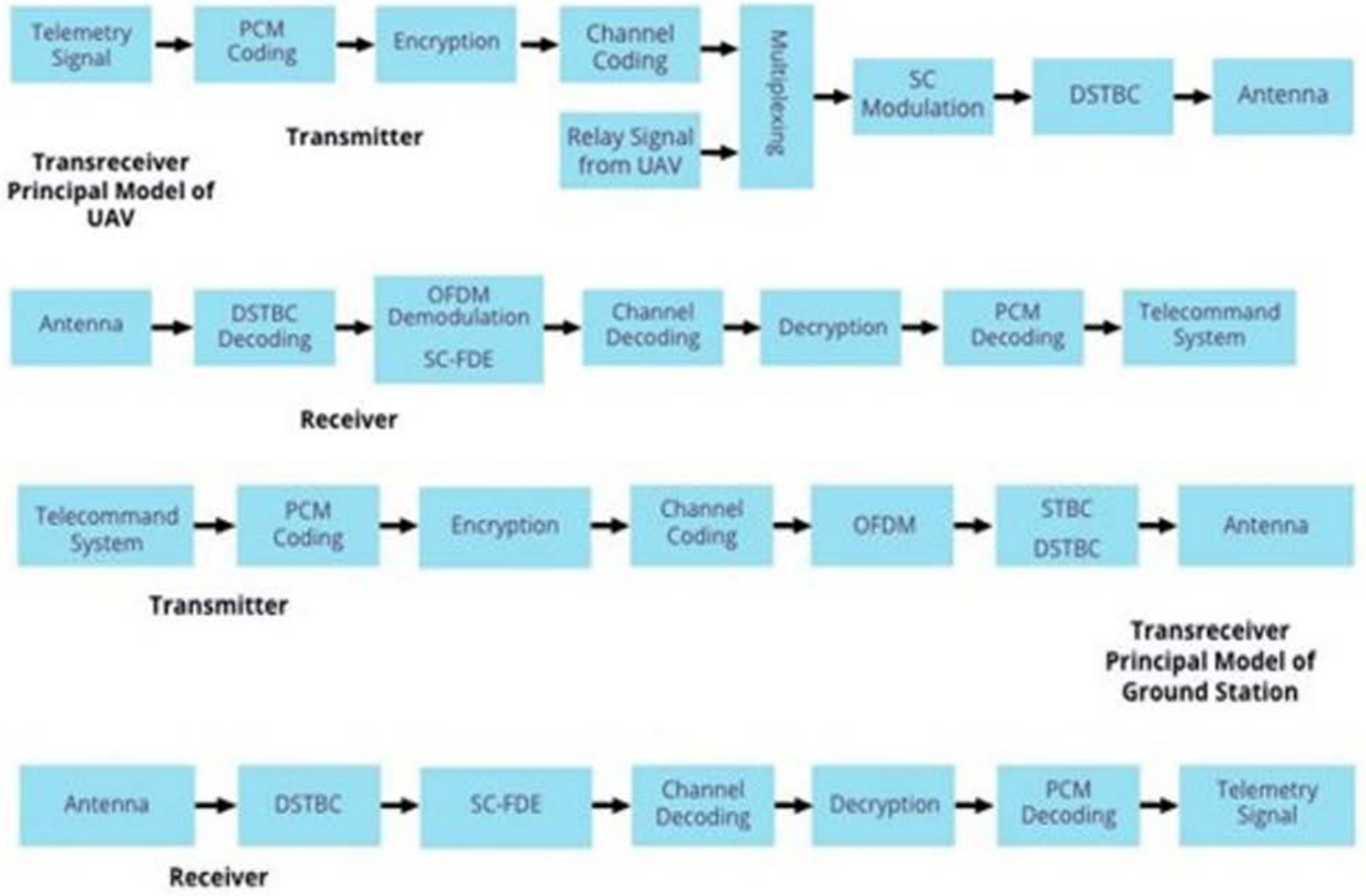


Figure 2: Ground Station Configuration

TT&C - Transmitter and Receiver



TT&C

- System Changes
  - Frequency: 928MHz rather than 2.4GHz
- Capabilities
  - Entire System Included
  - 100 km (62.137 miles) LOS
  - Small and lightweight
  - Emergency power supply
  - Multiple payload interface

    Possibilites
  - Single Antenna
  - Dead-reckoning, flight and navigation without GPS

Central Processing Unit



Pitot Tube Mini



GPS Unit Mini



Onboard Telemetry Unit Mini



Servo drive SD3



Link Analysis

- What is link analysis?
    - The analysis of power gains and losses that our system experiences while our signal travels from the transmitter to the reciever.
- Why is this important?
- Variables used in analysis
    - Frequency
    - Center Frequency
    - Wavelength
    - Bandwidth

Frequency (Hz)	Center Frequency (Hz)	λ (cm)	Bandwidth (Hz)
928 MHz	912 MHz	30 cm	26 MHz

Link Analysis – Calculation Results

Distance (mi)	Power Received (dBW)	Thermal Noise Power (dBW)	Signal-to-Noise Ratio (dB)	Eb /N0 (dB)
5 mi	-85.6 dBW	-129.2 dBW	43.65 dB	58.1 dB
10 mi	-91.6 dBW	-129.2 dBW	37.64 dB	51.8 dB
15 mi	-95.1 dBW	-129.2 dBW	34.1 dB	48.1 dB
20 mi	-97.6 dBW	-129.2 dBW	31.6 dB	45.7 dB
30 mi	-101.1 dBW	-129.2 dBW	28.1 dB	42.2 dB
40 mi	-103.6 dBW	-129.2 dBW	25.6 dB	39.7 dB