# Long Range Endurance Platform, Systems Engineering and Payload

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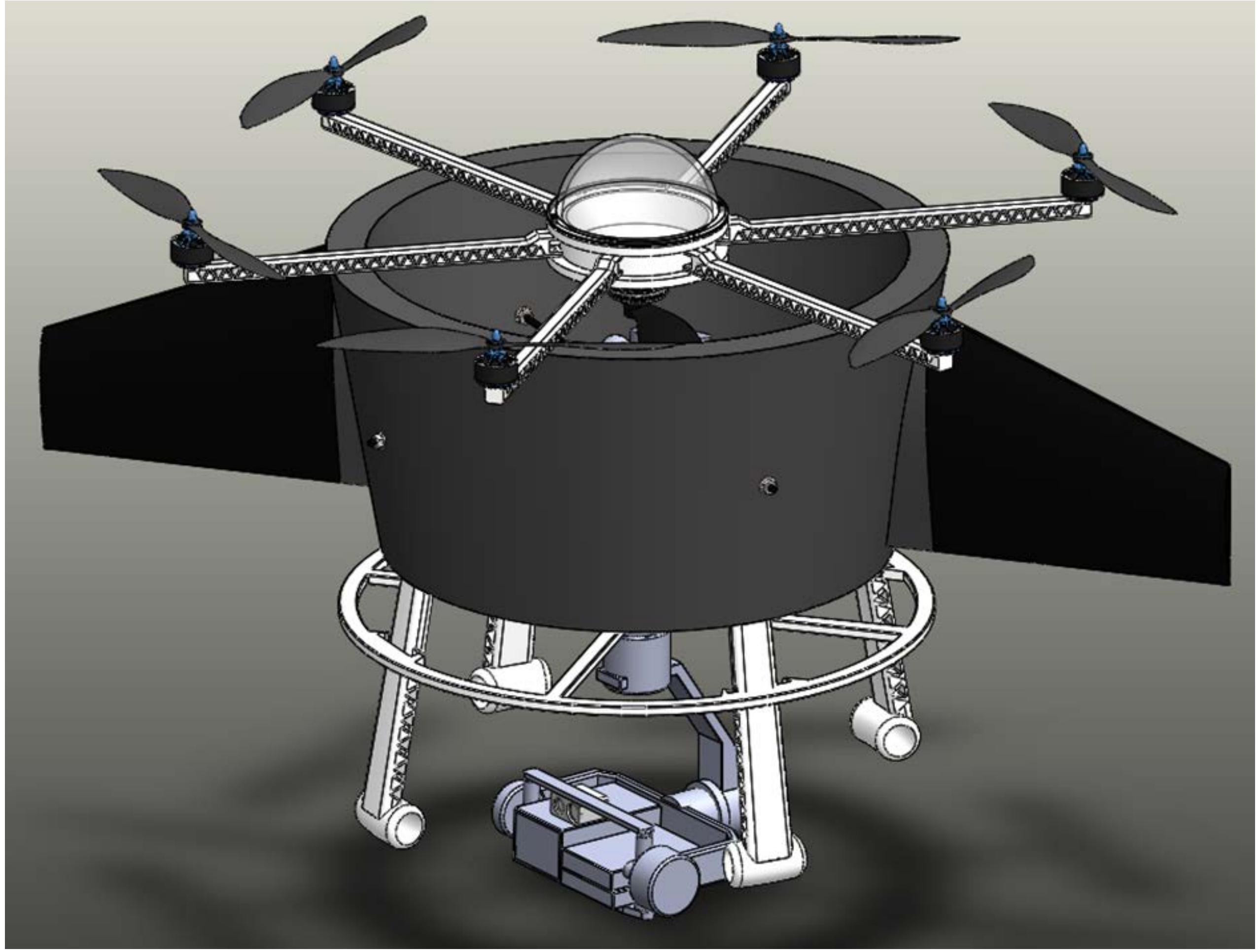
Client: The Aerospace Corporation, Dr. Alyson Yarbrough

# 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) $CO_2$ Sensor
6) Telemetry Tracking and Control
    1) Transmitter and Receiver
    2) Antenna
    3) IMU
7) Conclusion

# Sub teams-Responsibilities

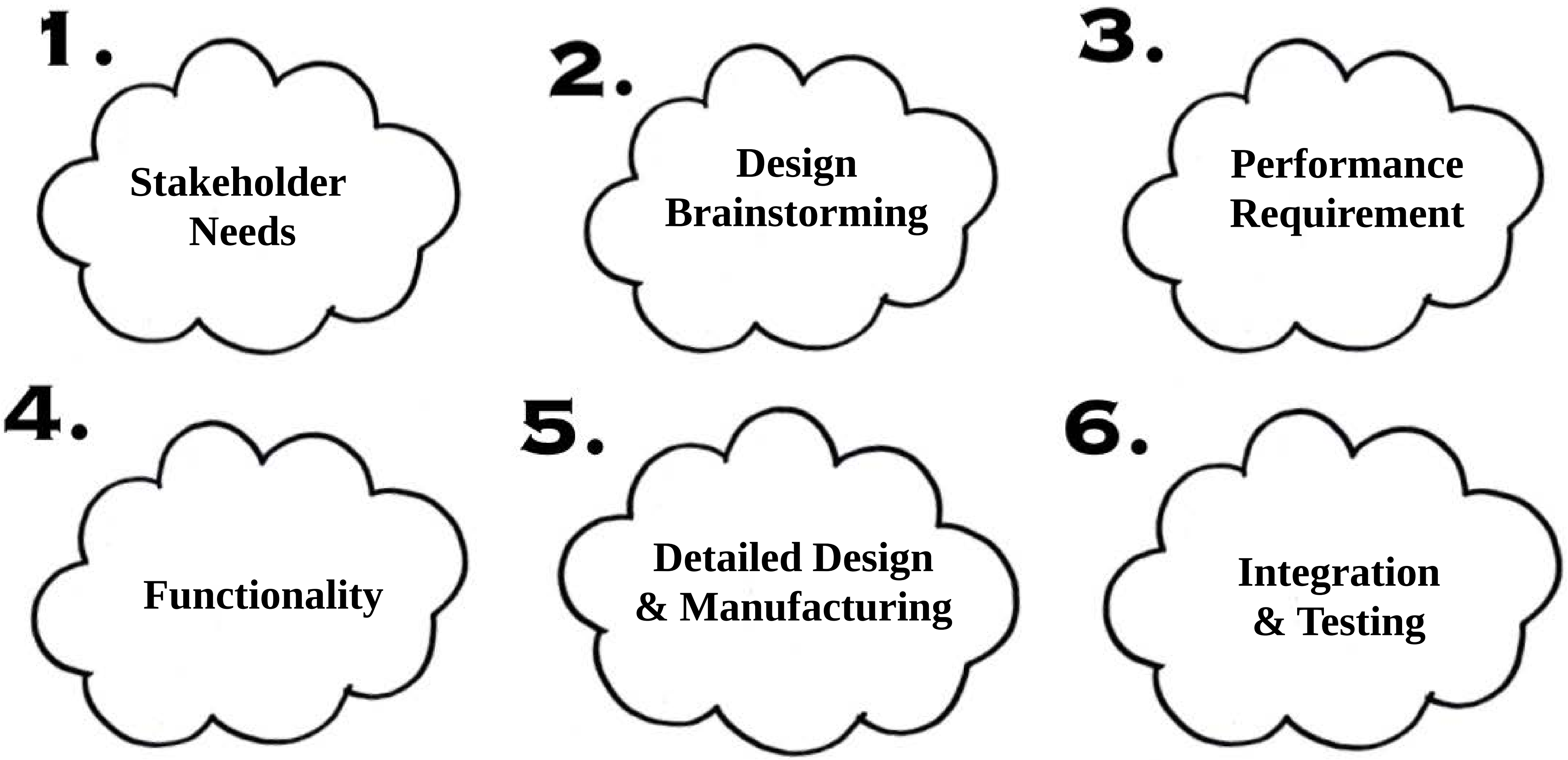


- Systems Engineering and Payload
  - Tracking Telemetry and Communication, Sensors, Payload Design and Analysis
- Structures
  - Design and Analysis of UAV structure
- Powertrain
  - Design and Analysis of UAV powertrain
- Flight
  - Design and Analysis of Propellers, Wings, and Flight characteristics

# 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

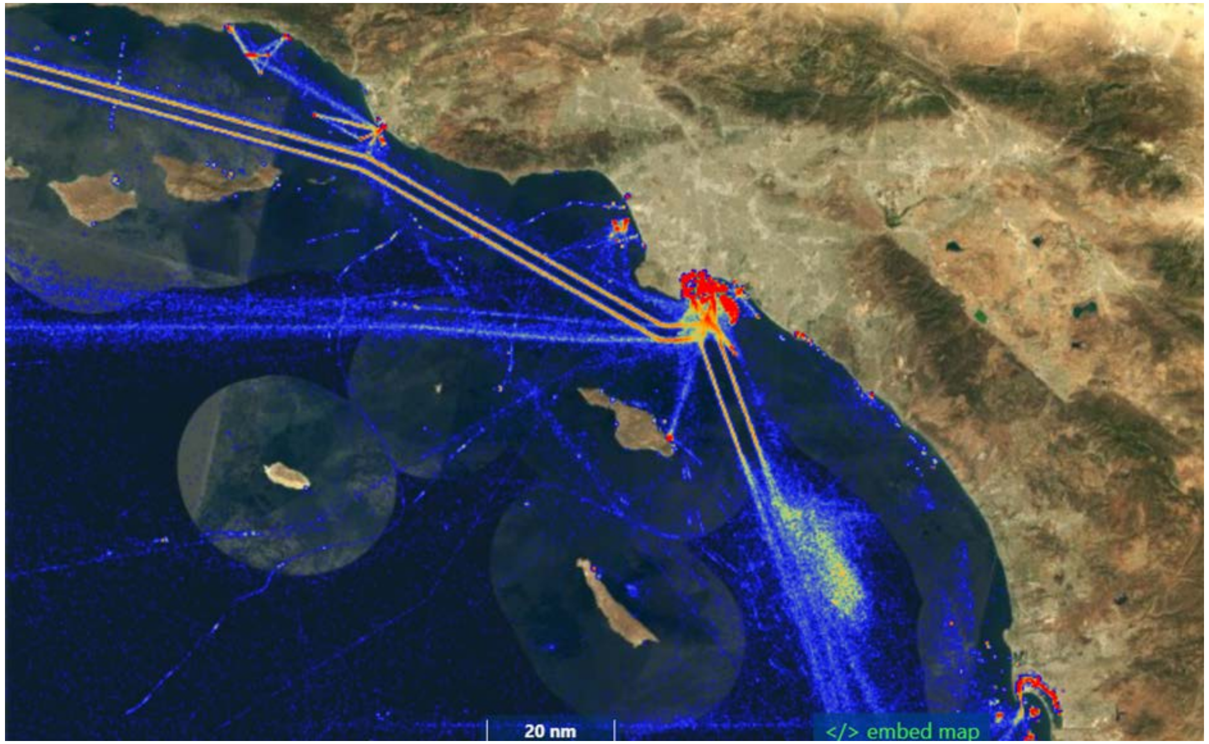
# Mass Budgets

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

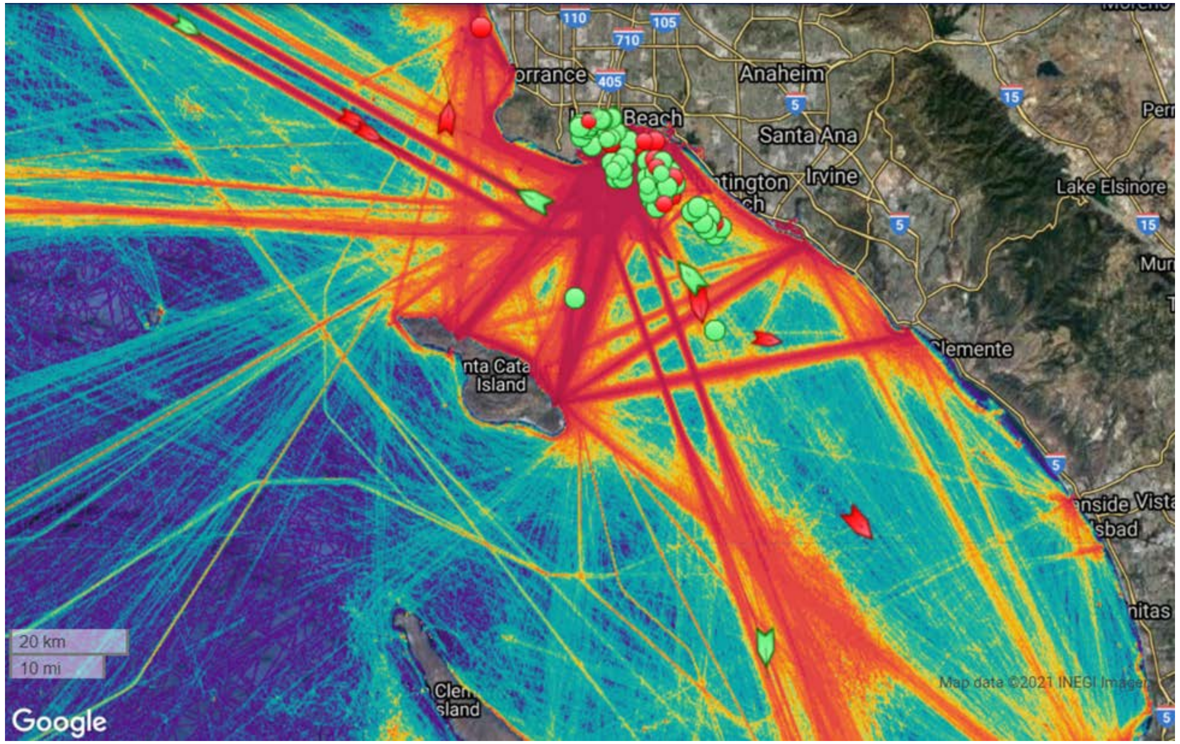
# Cost Budget

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

# Port Mission




Density Map with Marine Highways: Courtesy of Marine Traffic

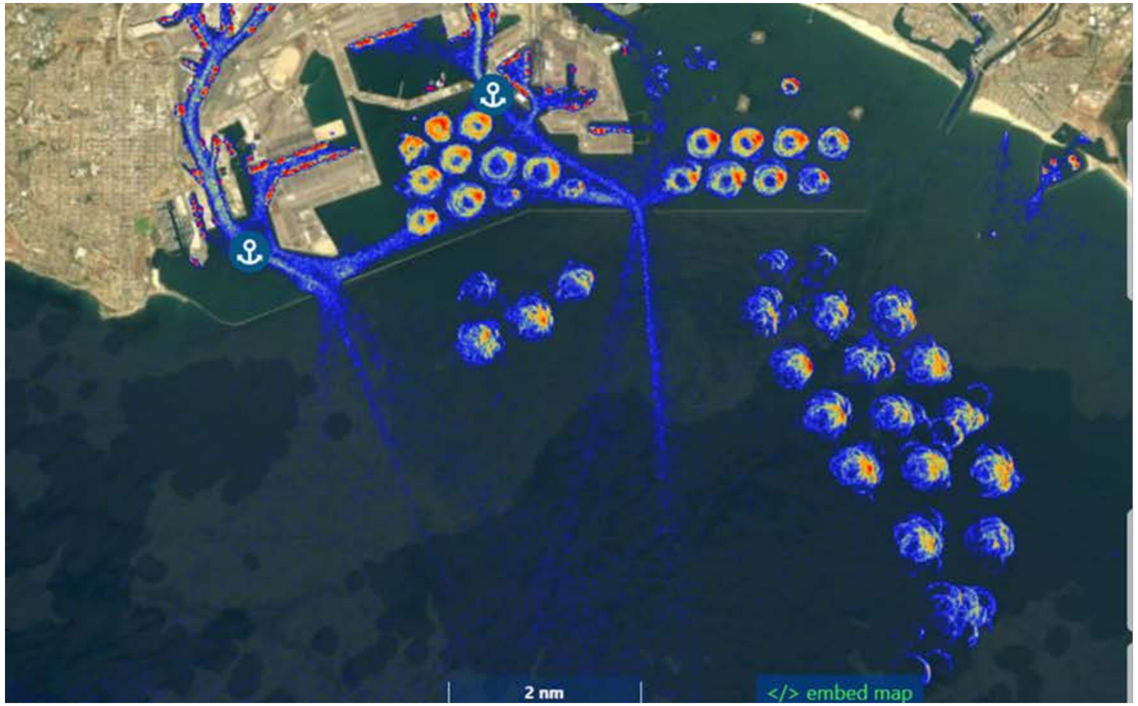



Density Map with Ship Locations: Courtesy of Vessel Finder

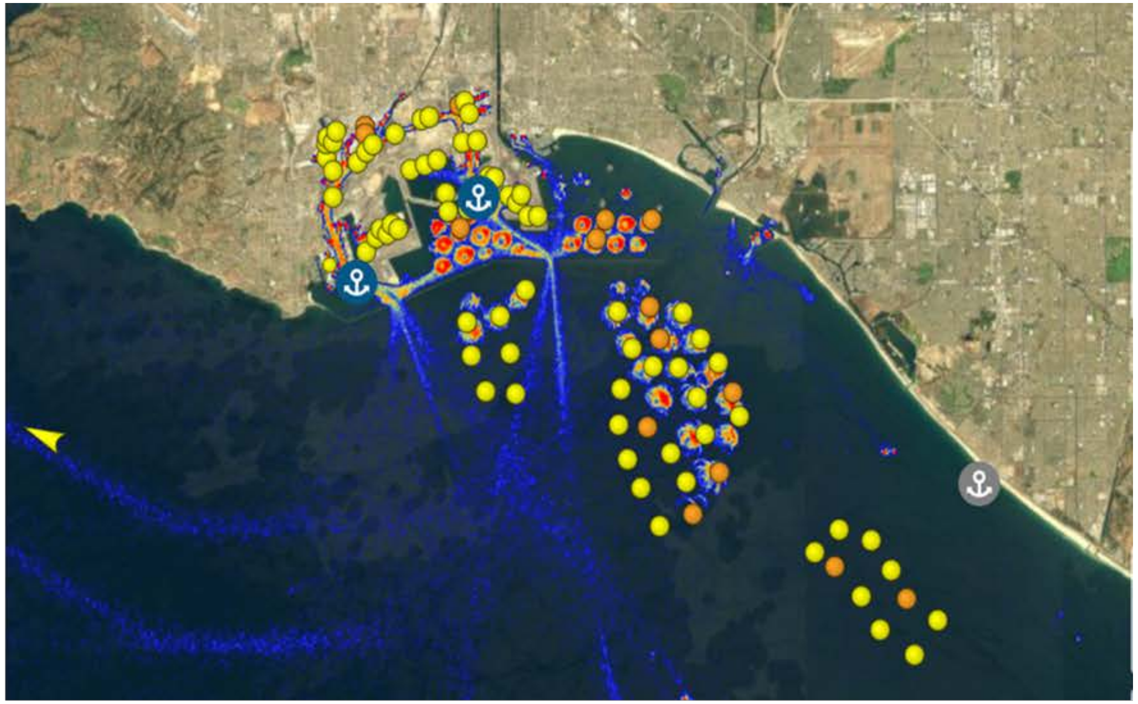
North-South and East-West Passages Visible in density maps.

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

# Port Mission




Density Map with Anchorage Locations (2019): Vessel Tracker



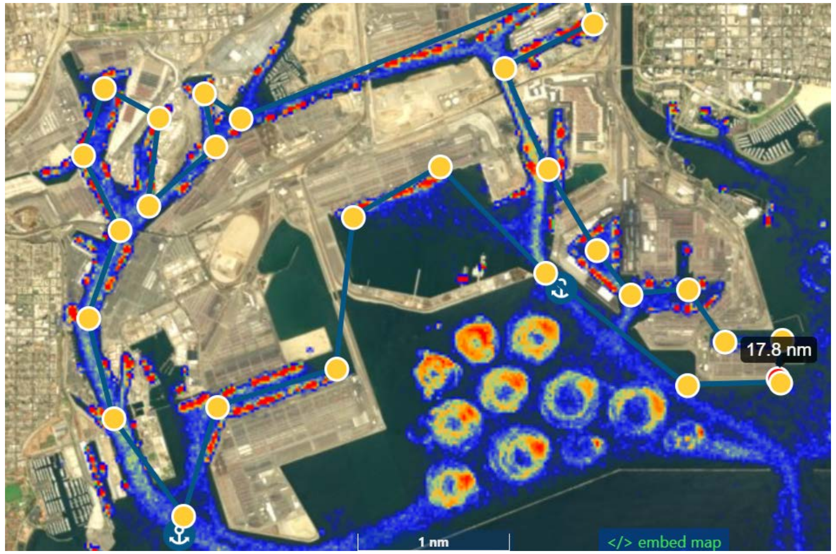
Density Map with Live Ship Locations (03/15/21): Vessel Tracker

Ships wait at Anchorage to be let into port.

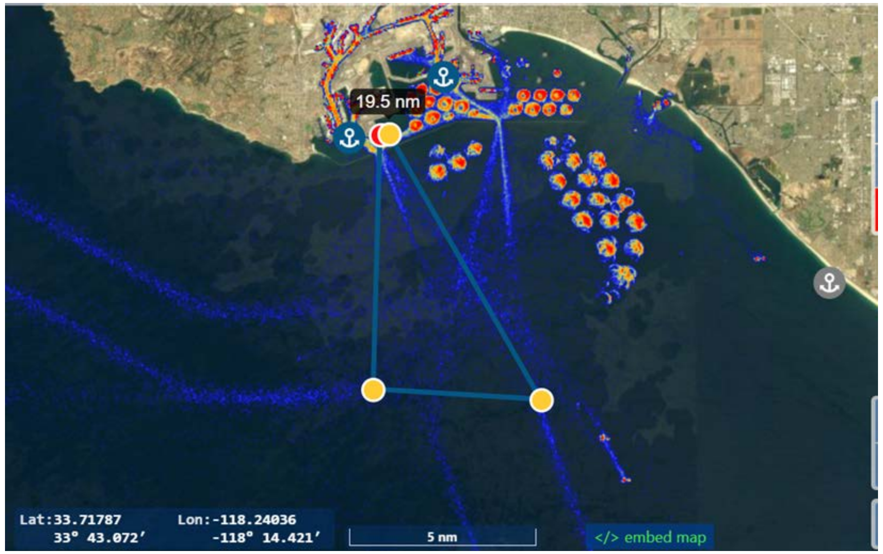
Port backlog due to Covid 19, extra Anchorages set up.

Over 1 week waiting period as of February 2021

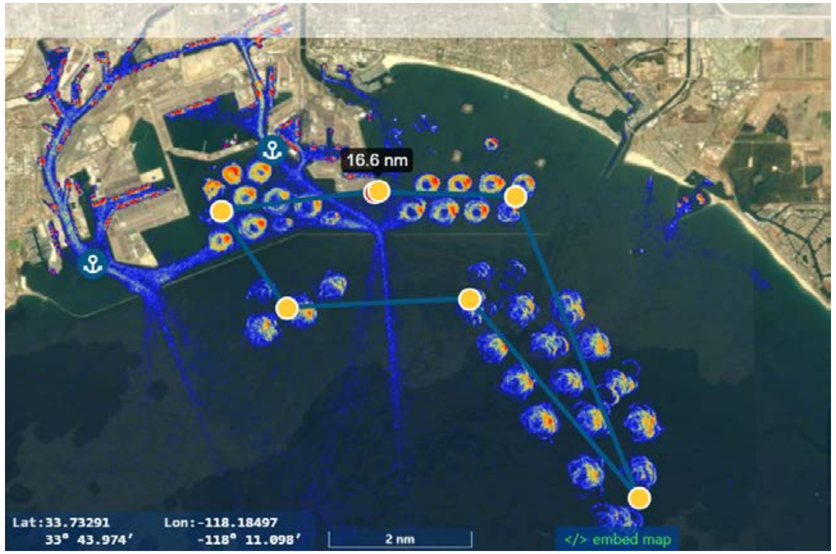
# Missions



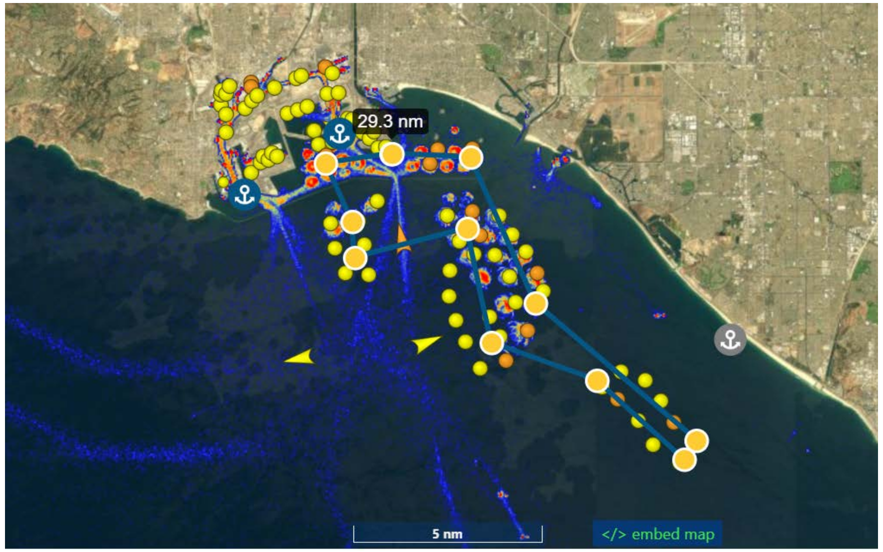

Dock Inspection: Average Distance 17.8nm




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<br>Thermal | Particle<br>GPS | Yes | No |
| Port Security, Surveillance, and Reconnaissance | Optical<br>Thermal | SWIR<br>GPS | Yes | Spotlight |
| Port Emergency Services | Optical<br>Thermal | Laser Fluro<br>$CO_2$ | Yes | Spotlight<br>Indicator |
| Wildfire Detection | Optical<br>Thermal | Particle<br>$CO_2$<br>GPS | Yes | NA |
| Infrastructure Inspection | Optical<br>Thermal<br>Wide lens | Laser Fluro | Yes | NA |

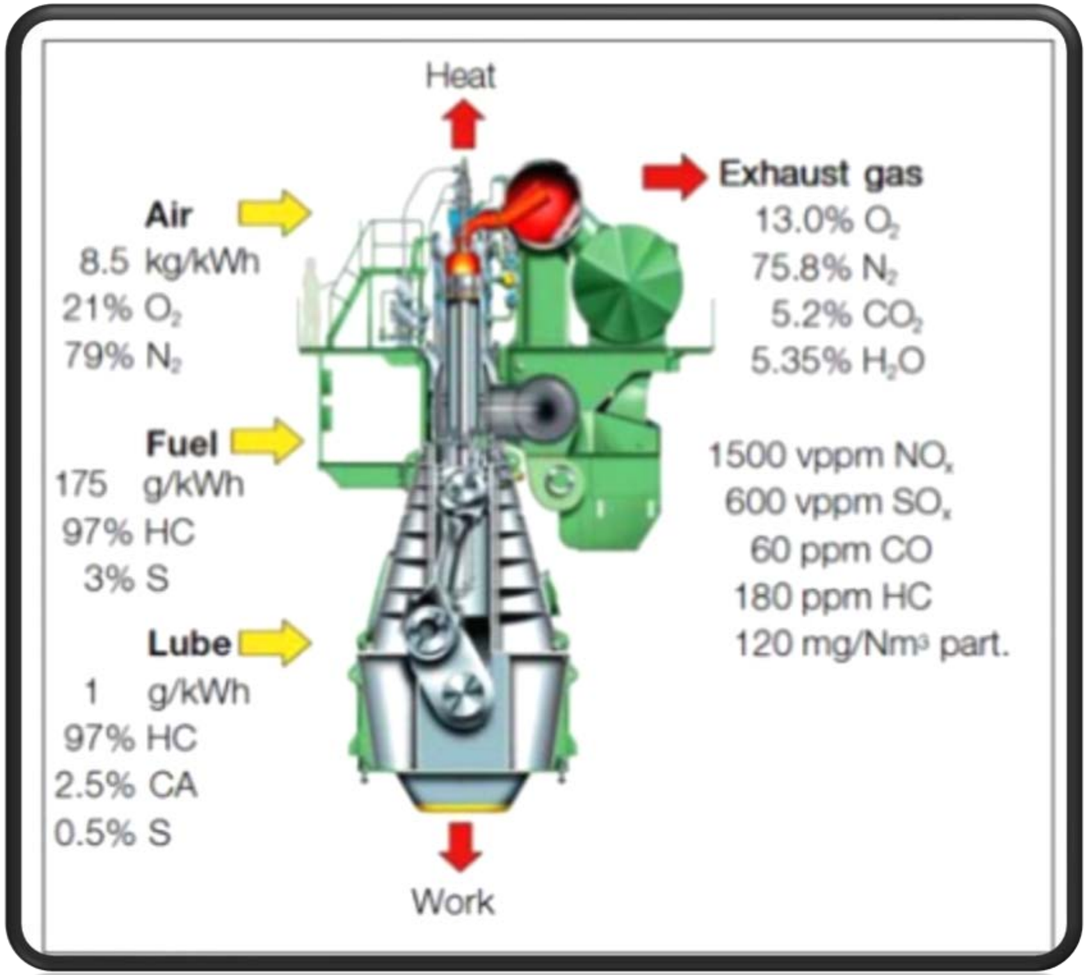
# Mission – Emission Analysis

## <u>Composition of Vessel Exhaust</u>

- 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

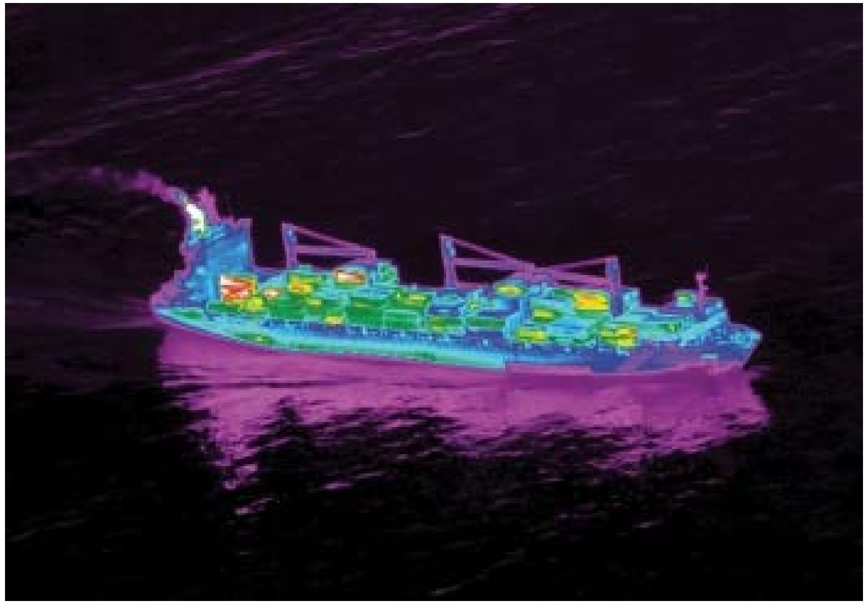
<u>Composition of UAV Exhaust (Wankel Rotary Engine)</u>

- 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

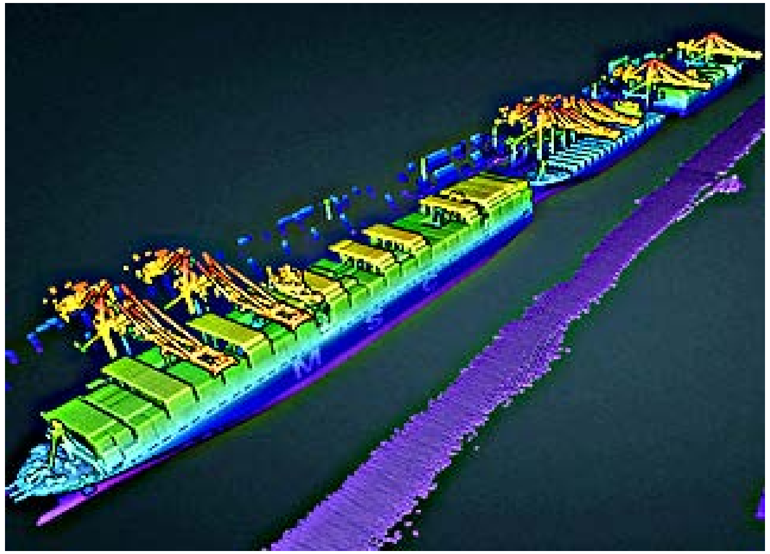
# Sensors

Sensors required to fulfill mission requirements

- Optical and Thermal Imaging Camera
- LIDAR Light Detecting and Ranging sensor
- Particulate Emission Detection Sensor
- $CO_2$ Emission Detection Sensor



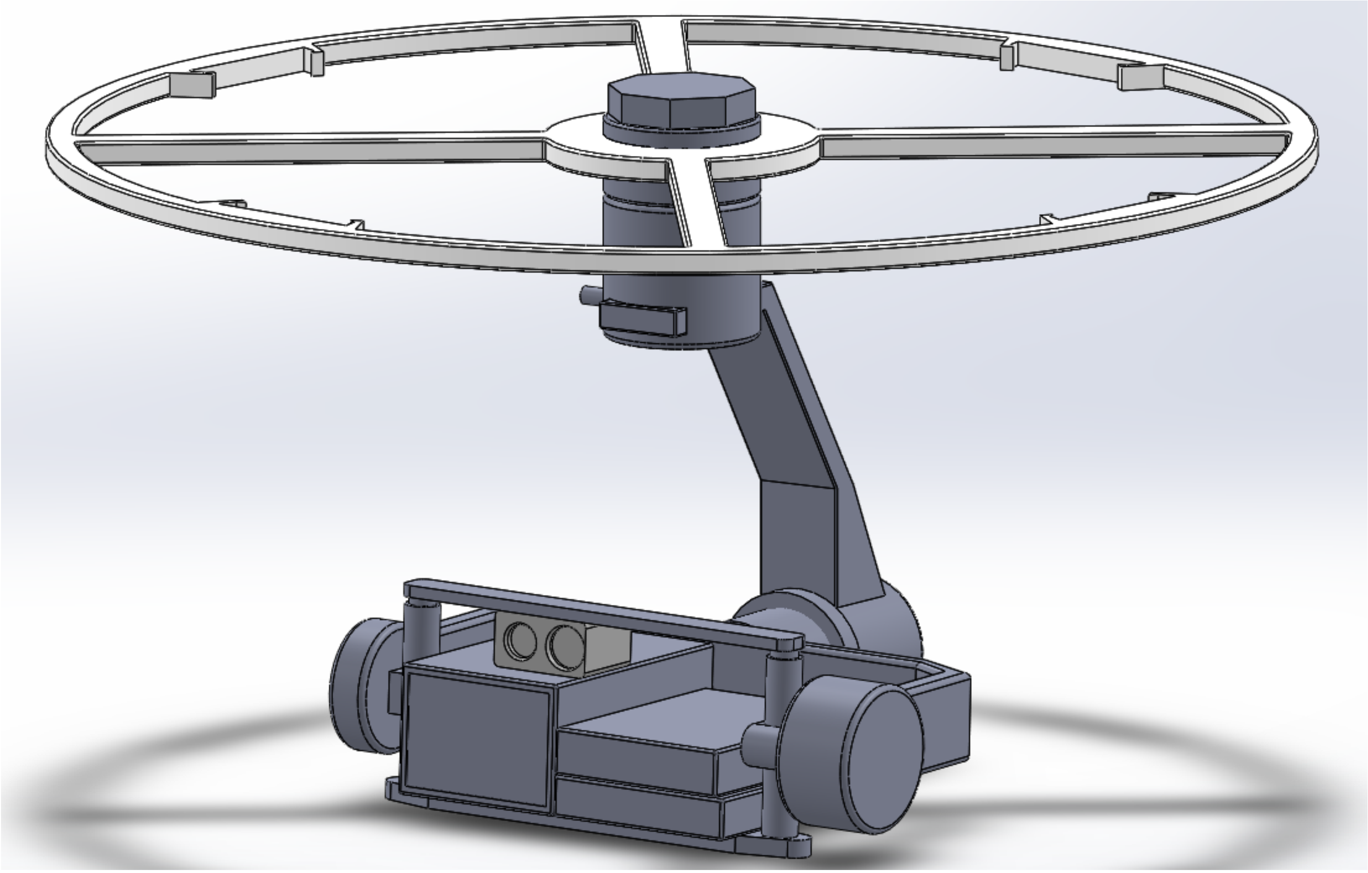
*Thermal Imaging of Cargo Ship at sail*



*LIDAR imaging of docked cargo ships*

*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

- <u>Distance</u>

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

- <u>Ground Elevation</u>

***(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

➢ The more $CO_2$ that is present, the more light that will be absorbed

# Sensors - Particulate

| | | |
|---|---|---|
|   |   |   |
| Aeroqual S500 (sensor only) | Prana Air PM2.5 Sensor | ExTech VPC300 Particle Counter (sensor only) |
| • Designed for real-time surveying of common outdoor air pollutants<br>• Interchangeable sensor heads (one monitoring system for +5 pollutants)<br>• Sensor heads utilize active fan sampling, which increases measurement accuracy | • Laser-based scattering principal w/ advanced algorithms<br>• Fully calibrated digital output for particle number and mass concentration values<br>• 10 yr. life w/ continuous operation of 24 hours/day | • Six particle size channels<br>• Stores up to 5000 records (data, time, counts, etc.)<br>• 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

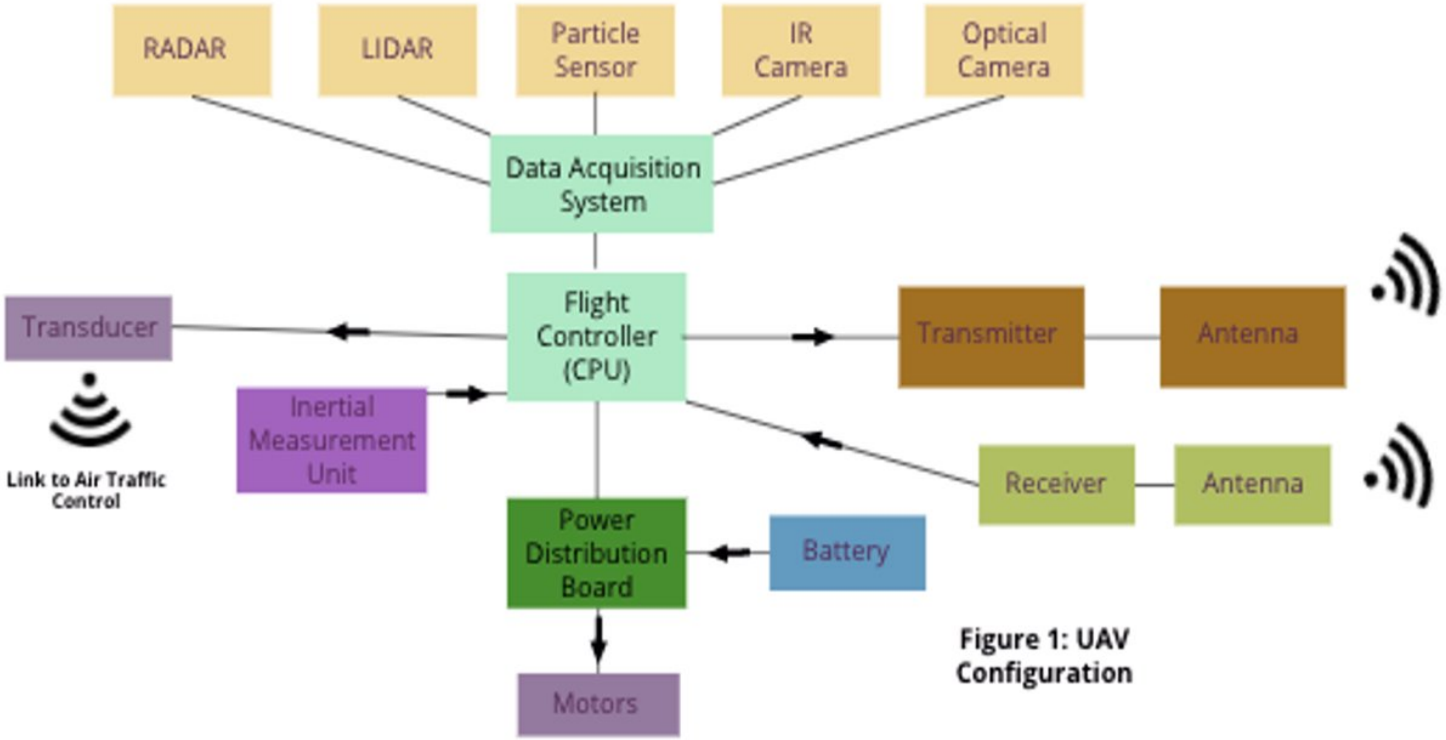



Figure 1: UAV Configuration

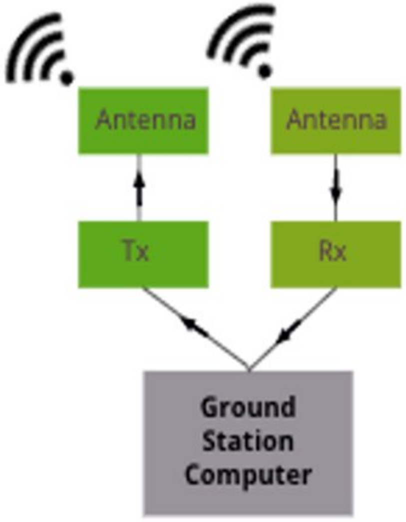
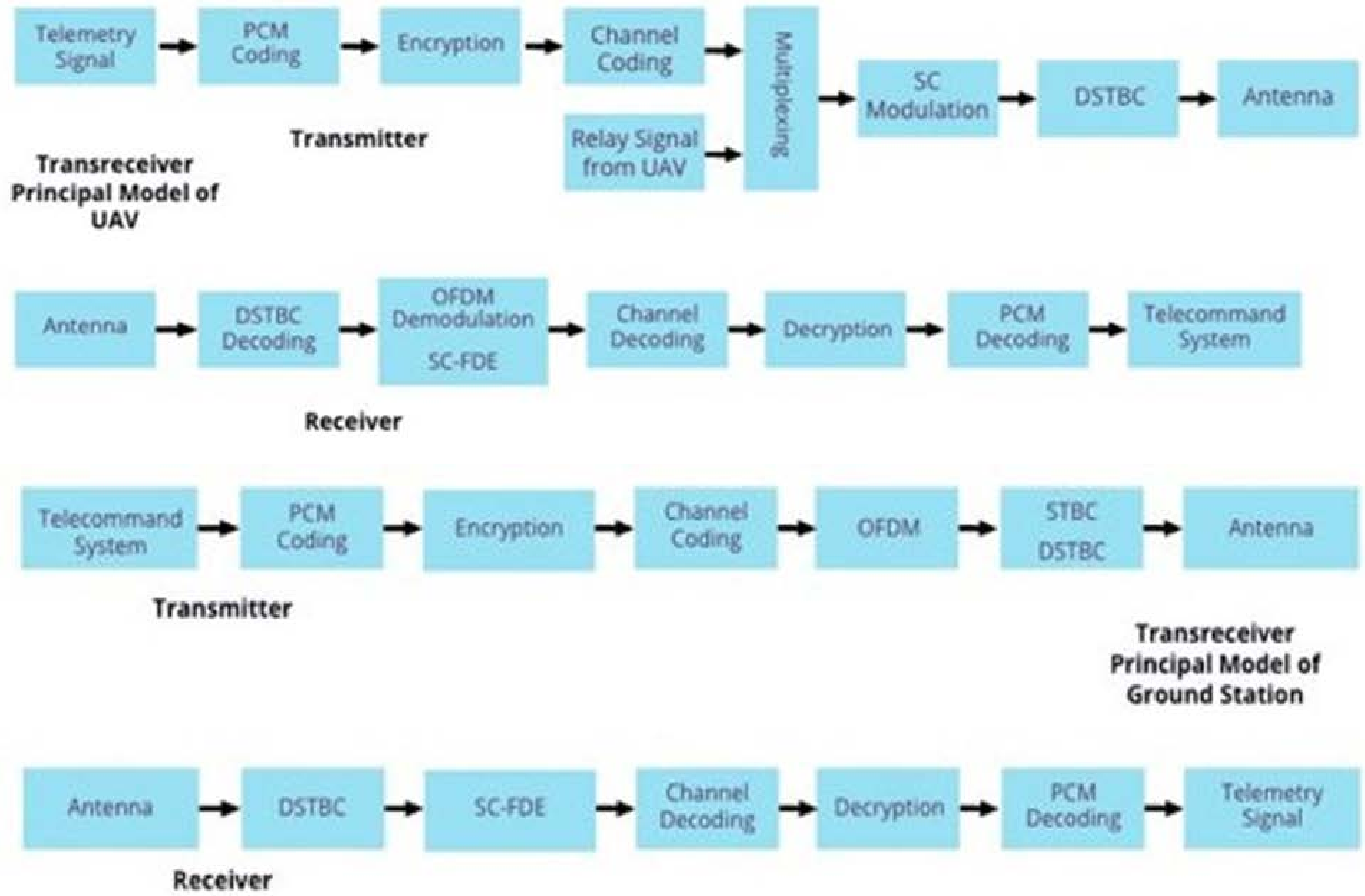



Figure 2: Ground Station Configuration

# 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

# 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 |