Yellow Jacket Swarm Counter Unmanned Aerial System

Project Presentation

Presented by: Parth Patel

April 13, 2026

Project High Level Overview

Role:

- Designed and built the interceptor drone entirely. (Ideation, CAD, manufacturing, controls, testing)
- Now, lead 6-person team where I direct the hardware and manufacturing while integrating with SDEs

Timeline

- Last semester: Physical interceptor
- This semester: Drone Detection System
- Aim to reach TRL 6 by April

Program:

- Georgia Tech Create-X Team 7, Interstellar Foundry

Customers:

- DoW, DIU Open Solicitation, Army FUZE Program, SBIR/STTR

DEPARTMENT OF DEFENSE
DEFENSE INNOVATION
UNITED STATES OF AMERICA

ARMY
FUZE

atdc
GEORGIA TECH®

SBIR · STTR
America's Seed Fund

The Threat · Why Now

"Peace cannot be kept by force; it can only be achieved by understanding." — **Einstein**

Low-RCS, Low-Altitude

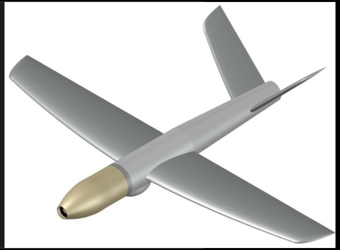
Commercial drones fly under legacy radar thresholds and Small cross-sections evade S-band sensors designed for aircraft.

Sustainment Cost

Current COTS counter-drone solutions cost $50K–$500K per node. Cannot scale to protect dispersed DoD infrastructure.

Fixed-Wing Gap

Fixed-wing interceptors lack agility to track quadcopters making abrupt evasive maneuvers at 25+ mph in close engagements.



OUR SOLUTION

Sub-$1,000 modular ground station

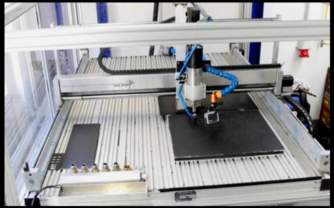
- NVIDIA Jetson Nano edge computing
- FMCW radar + CV sensor fusion
- Kalman filter → eliminates false positives
- 3× autonomous quadcopter interceptors
- Waterjet CF frames → < $280/unit
- < 15 min deployment on ISV/JLTV

Georgia Tech Create-X · DIU PROJ00656

UAV Interceptor · Manufacturing Approach

HARDWARE SPECS

Frame	450mm quad · waterjet-cut carbon fiber · 3D-printed mounts
Motors	2204 2300KV brushless x 4 per airframe
Props	5" balanced props · optimized for 80+ km/h intercept
Flight Ctrl	Matek F405 running ArduCopter firmware
Comms	ESP32 WiFi MAVLink telemetry to ground station
Cost	~$280/unit · ~$1,617 total for 3 swarm C-UAS
Weight	< 10 lb deployable ground station
Deploy	< 15 min setup



DESIGN FOR MANUFACTURABILITY

Waterjet-Cut CF Frames

2D DXF files → waterjet table. Minimal downtime. Consistent tolerance ±0.005"

3D-Printed Mounts & Arms

PETG/ABS mounts for motors, ESCs, sensors. Rapidly iterate design.

COTS Avionics Stack

Matek F405 + ESP3: proven, in-stock, programmable. No defense foundry lead times. ATO-streamlined.

Cost Scalability

Tier 1: ~$280/unit MVP.
Tier 2 (6-25): Low-Rate Production.
Tier 3 (26-100+): mass manufacturing.

Flight Physics · Design Rationale

PROPULSION PHYSICS

Hover condition:

4T = mg | T = (1/2)rho*A*v_i^2

T_total ~120 N, mass=0.280 kg -> T/W = 43.7

Drag at 80 km/h (22 m/s):

F_drag = (1/2)*rho*Cd*A*v^2

= (1/2)(1.2)(0.4)(0.04)(22)^2 = 4.7 N

Kinetic impact energy at intercept:

KE = (1/2)*m*v_rel^2

Head-on closing @ 44 m/s: KE ~ 271 J

Stress in CF frame (motor mount):

sigma_vm = sqrt(sigma^2 + 3*tau^2)

FEA: 48 MPa at mount holes, FS > 12

DESIGN CHOICES

450mm frame selection

Longer moment arm -> torque per RPM gain. Larger props -> efficiency. Tradeoff: agility vs. 250mm race frame. Intercept geometry prioritizes speed over maneuverability.

2204 2300KV motor selection

High KV -> high RPM at 3S -> fast prop speed -> agility. T/W >4 at hover. >75% thrust reserve for intercept acceleration from 0 to intercept < 3 sec.

3K twill CF plate (3mm)

sigma_UTS ~600 MPa. Waterjet-cuttable with +/-0.005" tolerance. Consistent cross-section vs. hand-layup. Safety factor >12 at motor mounts under crash load.

Polycarbonate guards over CF-PLA

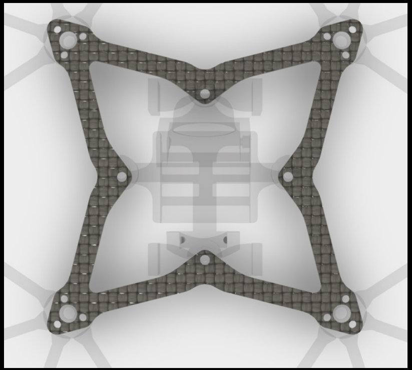
CF-PLA: 220N peak load but catastrophic brittle fracture. PC: 150N but plastic deformation. Failure MODE trumps failure LOAD for attritable interceptors. Must survive, not just endure.

Interceptor Design · CAD Modeling

Airframe: 450mm quadcopter configuration. Waterjet-cut carbon fiber main plate (3K twill weave, 3mm thickness). CAD modeled in Fusion 360. 3D-printed PETG motor mounts and camera bracket assembly.

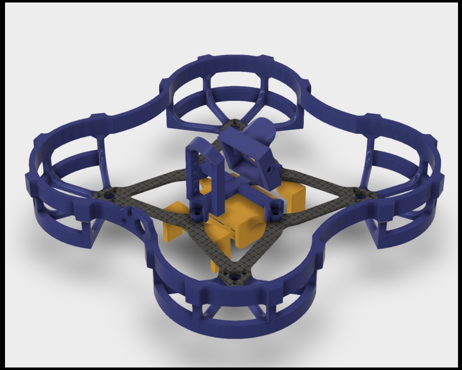
Propulsion: 2204 2300KV brushless motors × 4, 5" balanced propellers, optimized for 80+ km/h intercept.

Flight Control: Matek F405 running ArduCopter 4.3. ESP32 MAVLink telemetry bridge. Coordinated engagement vectors uplinked from ground station via Python API.

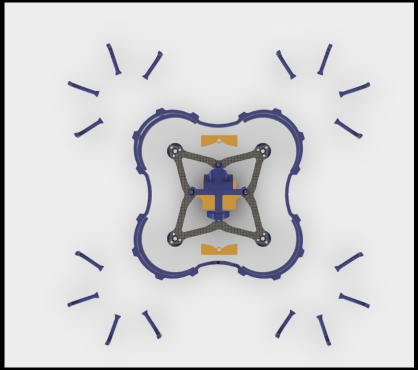


CF Frame (top view)
Waterjet DXF → waterjet table

Payload + Camera Mount
3D-printed PETG



Full Assembly: CF frame (gray) + guards (blue) + mounts (gold)



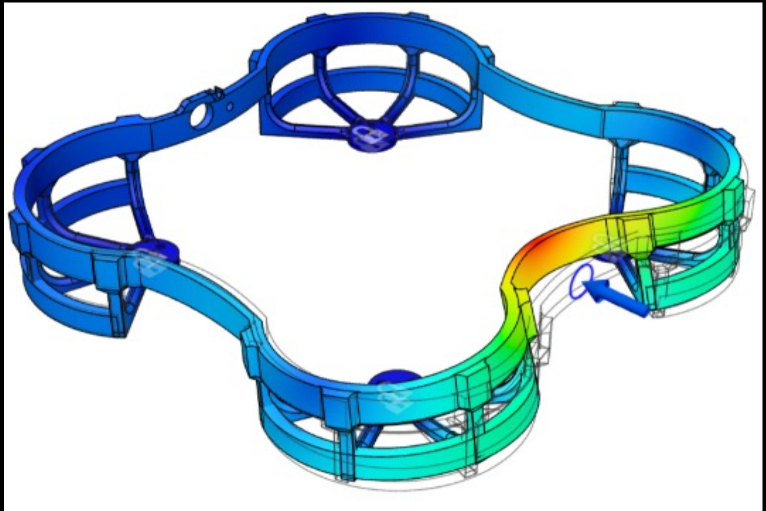
Full Assembly Exploded View

Material Selection · Structural FEA

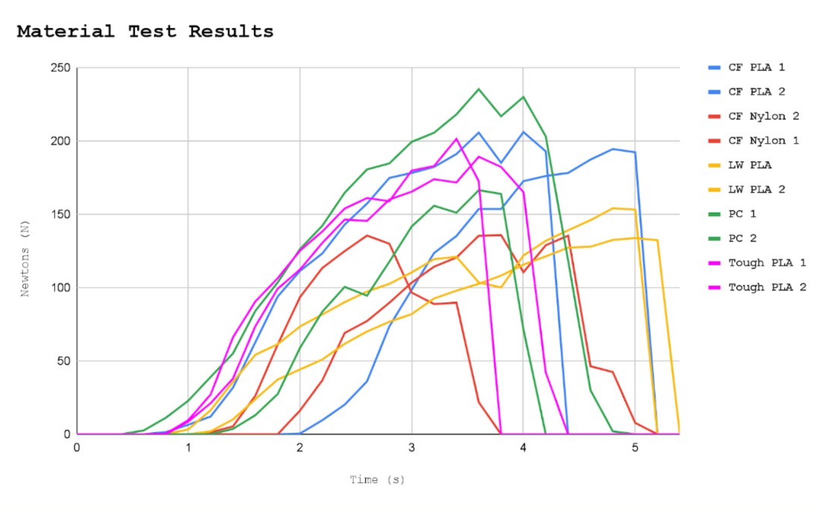
Test Campaign: 10 prop guard specimens across 5 filament types (PETG-CF, CF-PLA, CF-Nylon, LW-PLA, Polycarbonate) loaded to failure under axial compression. Peak load plotted over time to characterize both maximum strength and failure mode (brittle fracture vs. progressive deformation).

Key Finding: CF-PLA achieved peak loads exceeding 220N but fractured catastrophically. Polycarbonate showed the best post-failure behavior (plastic deformation rather than shattering), selected as primary material for guards.

Von Mises Stress: $\sigma_{vm} = \sqrt{\sigma_\theta^2 + \sigma_{ax}^2 - \sigma_\theta \cdot \sigma_{ax}}$



ANSYS FEA: Prop guard structural analysis
Von Mises stress distribution under axial compression load.



Material test result: Force (N) vs. time (s) across 10 specimens.

Physical Build Setup

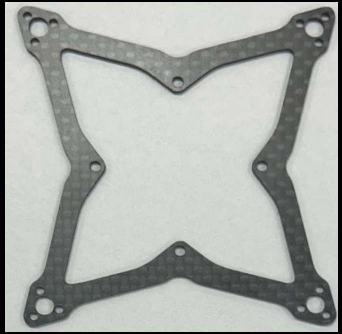
Carbon Fiber Main Plate: 2D DXF exported from Fusion 360 and cut on a waterjet table (±0.005" tolerance).

- **Challenge:** delamination with carbon fiber (piercing in scrap material, using lower pressure)

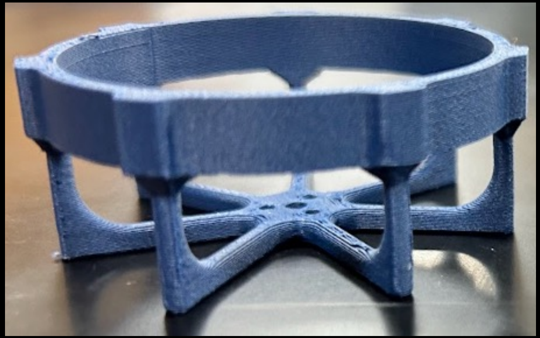
3D-Printed Components: Motor mounts, prop guards, and camera brackets printed in PETG and polycarbonate using Bambu Lab X1 Carbon. Iterated across 5 revs to achieve target budget and impact resilience.

- **Challenge:** Difficulty with polycarbonate (requires high enclosure temps to prevent warping)

Assembly Budget: ~$280/interceptor. Total 3-unit CUAS: ~$1,617.



Waterjet CF frame (physical part)

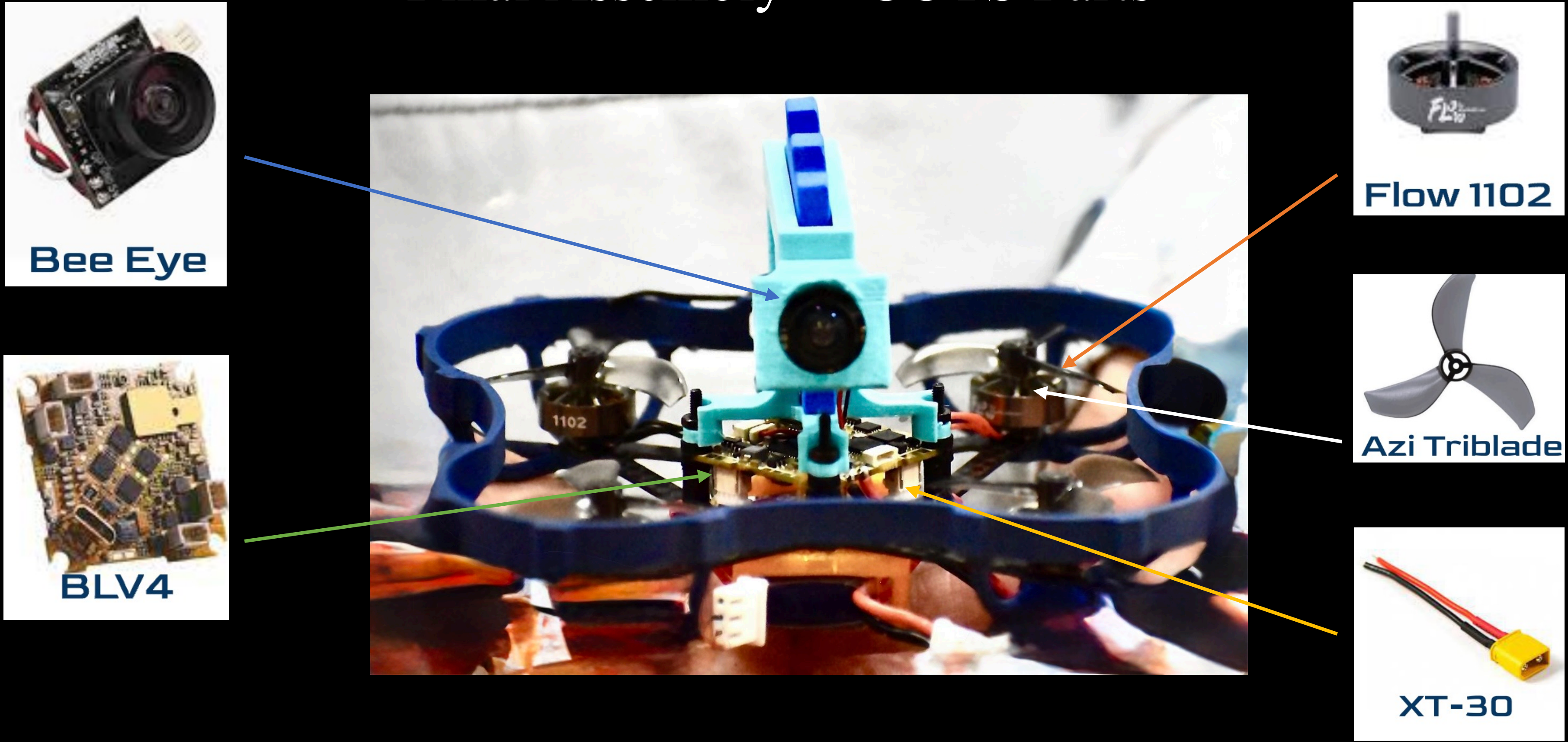


3D-printed motor guards

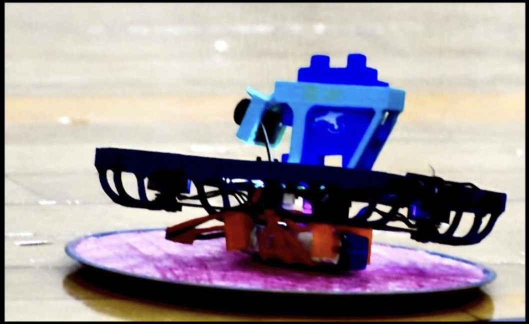
3D-printed prop guards

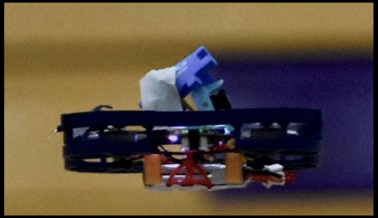
Camera/Payload mount finished part

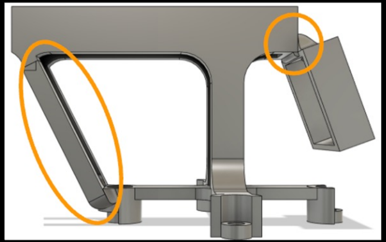
Final Assembly · COTS Parts



Initial Flight Testing







Upon Testing, realized the camera mount was not strong enough, so decided to add structural supports to the camera mount itself.

Failures · Adjustments

Camera mount collapsed in flight

Vibration + thrust reversal loads not in single post design.

PID oscillations / unstable hover

ArduCopter defaults tuned for large/stiff frames; sub-300g frame has different inertia tensor.

Prop guard CF-PLA: brittle fracture in crash

CF-PLA 220N peak but catastrophic shatter; debris hazard, system unflyable.

Camera FOV missed target in terminal intercept phase

Level-mounted camera; approach from above geometry requires forward down FOV.

3-point triangulated PETG mount, silicone damping grommets.
Design for dynamic loads, not static geometry. Verify with first principles

Tuned PIDs from scratch; notch filter at 200Hz; Blackbox logging.
Never assume firmware defaults work. Tune methodically.

Tested 5 materials; selected PC (150N, plastic deformation, re-flyable).
Failure MODE > peak strength.
Ductile failure > Tensile Strength

-15 deg angled mount; recalibrated YOLO bounding box coordinates
Model engagement geometry in 3D first. Kinematic analysis before hardware.

Detection System Architecture

01

Primary Detection

RADAR

24 GHz FMCW
K-band Doppler
Range + velocity
≤20 dBm emission

→

02

Secondary Tracking

OPTICAL

OAK-D Pro stereo
Hikvision 8MP
Angular precision
Object classification

→

03

Edge Compute

JETSON

NVIDIA Jetson Nano
60+ TOPS, 7-25W
YOLOv8 inference
No cloud dependency

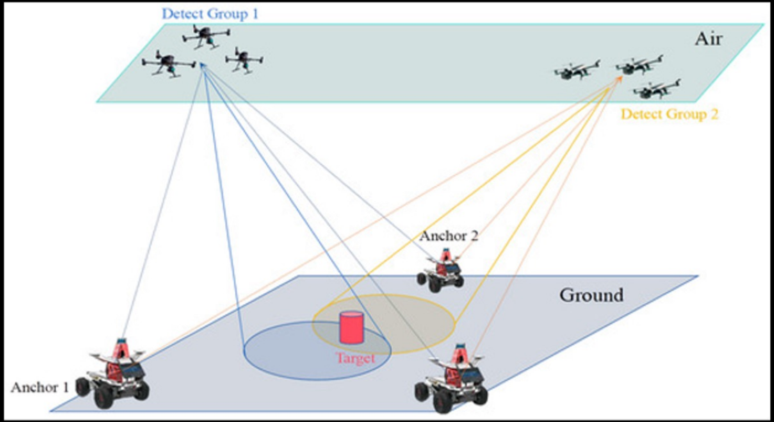
→

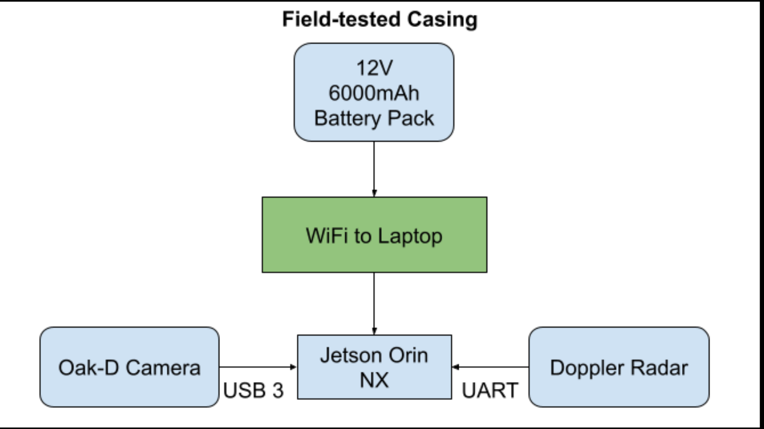
04

Sensor Fusion

HANDSHAKE

Kalman filter
Fuses radar + optics
Elim. false positives
Locks Group 1/2 sUAS





Sensor Fusion Physics · Kalman Filter

The math that locks Group 1/2 targets while eliminating birds and weather clutter

RADAR DETECTION

Doppler frequency shift:

$$f_D = 2v_r \cdot f_c / c$$

Radar range equation:

$$R = [(P_t \cdot G_t \cdot G_r \cdot \lambda^2 \cdot \sigma) / ((4\pi)^3 \cdot S_{min})]^{(1/4)}$$

FMCW range resolution:

$$\Delta R = c / (2 \cdot B) \quad \text{where } B = \text{bandwidth}$$

Velocity resolution:

$$\Delta v = \lambda / (2 \cdot T_{CPI})$$

f_D: Doppler frequency shift, v_r: Relative velocity, f_c: Carrier frequency, c: Speed of light, R: Target range, P_t: Transmit power, G_t: Transmit antenna gain, G_r: Receive antenna gain, λ: Wavelength, σ: Radar cross section, S_{min}: Minimum detectable signal, ΔR: Range resolution, B: Bandwidth, Δv: Velocity resolution, T_{CPI}: Coherent processing interval

360° Azimuth Coverage **10 Hz** Update Rate

KALMAN FILTER FUSION

State prediction:

$$\hat{x}_{k|k-1} = F \cdot \hat{x}_{k-1} + B \cdot u_k$$

Covariance prediction:

$$P_{k|k-1} = F \cdot P_{k-1} \cdot F^T + Q$$

Kalman gain:

$$K_k = P_{k|k-1} \cdot H^T \cdot (H \cdot P_{k|k-1} \cdot H^T + R)^{-1}$$

State update:

$$\hat{x}_k = \hat{x}_{k|k-1} + K_k \cdot (z_k - H \cdot \hat{x}_{k|k-1})$$

$\widehat{x_{k|k-1}}$: Predicted state estimate, F: State transition model, z_k: Measurement vector, $\widehat{x_{k-1}}$:: Previous state estimate, B: Control input model, u_k: Control vector, $P_{k|k-1}$: Predicted covariance estimate, Q: Process noise covariance, K_k: Kalman gain, H: Observation model, R: Measurement noise covariance, $\widehat{x_k}$: Updated state estimate

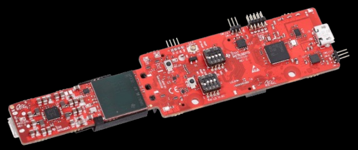
<5 mrad Az/El Error **50 mph** Vehicle Track Speed

Hardware Subsystems

Radar (Tiered Scaling) → **Optical Suite** → **Edge Processing** → **Tactical Footprint**

Radar (Tiered Scaling)

TI IWR6843AOPEVM (~$220) for high-speed DSP and >50m tracking.



Optical Suite

Highly compatible with **OAK-D Pro** (RGB/stereo depth) or

Edge Processing

NVIDIA Jetson Nano delivers localized, cloud-independent **AI (60+ TOPS)** on a highly efficient **7-25W power draw.**

Tactical Footprint

Sub-10 lb modular design supports under 15-minute deployment on ISV, JLTV, FMTV, and HEMTT platforms.

Software Subsystems

GNSS-Denied Navigation → **Spectral Stealth** → **Cybersecurity**

GNSS-Denied Navigation

Converts 2D pixels to 3D map coordinates using OpenCV and SLAM to localize threats without GPS.

Spectral Stealth

Air-gapped serial communication and passive optics ensure maximum EMI robustness and low physical/spectral signatures.

Cybersecurity

Architecture strictly complies with **DOD Instruction 8510.01 (RMF)** to streamline the Authorization to Operate (ATO).

INTERSTELLAR FOUNDRY

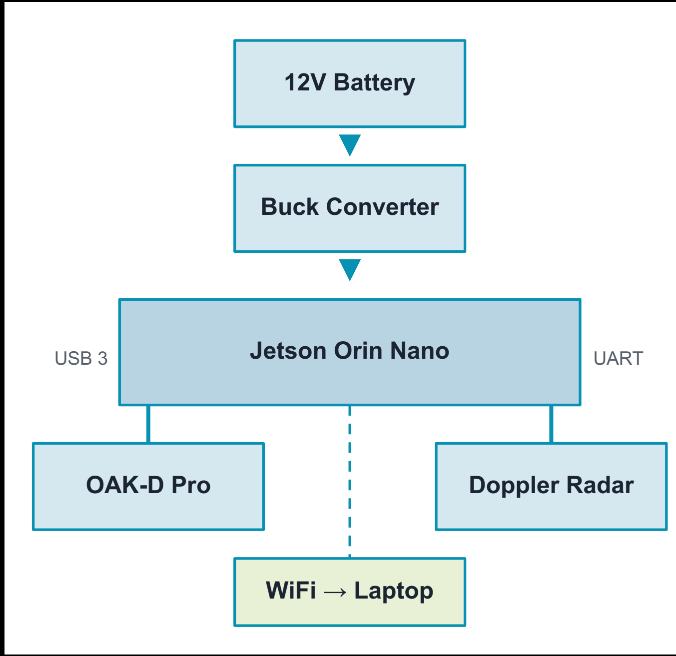
BILL OF MATERIALS

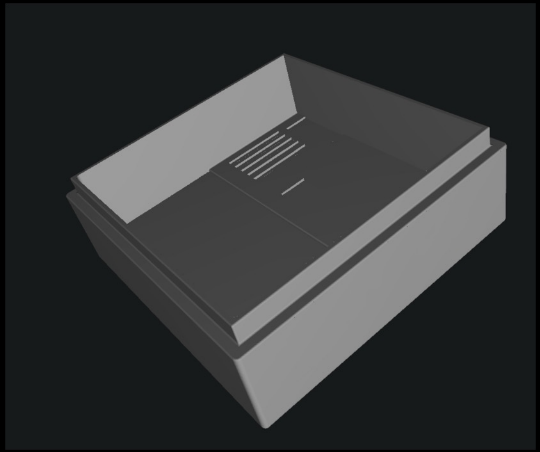
Component	Supplier	Cost
OAK-D Pro Camera	Neobits	$302.19
Jetson Orin Nano	Amazon	$245.00
12V 6000mAh Battery	Fat Tire House	$65.00
mmWave 24GHz Radar	DFRobot	$65.90
DC Converter + Cables	Amazon	$48.05
CQ Robot Radar x 2	Amazon	$31.98
TI IWR6843AOPEVM	DigiKey	$208.86
Power Supply	Amazon	$69.99
Test Drones (x4)	Amazon	$196.94
Tax + Software Tools	Various	$257
TOTAL		$1,547.18

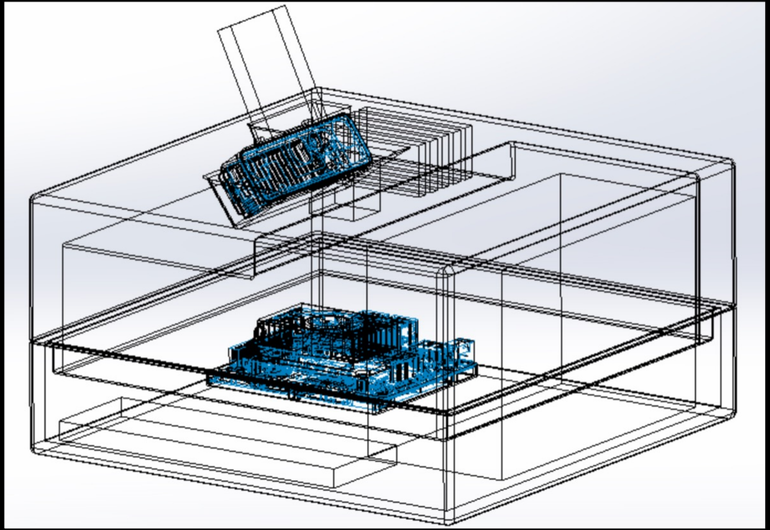
Total Dev. Cost: $1,547.18

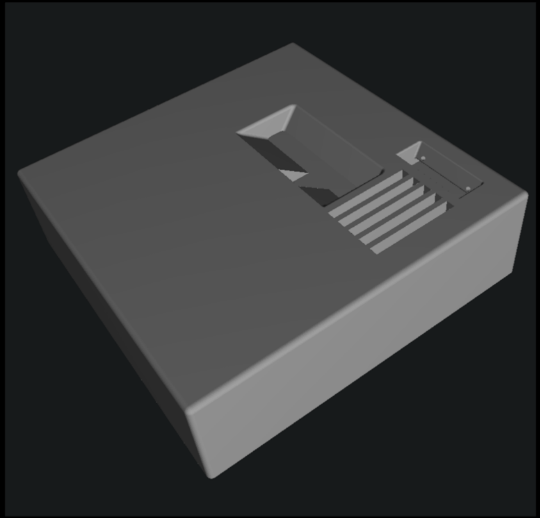
- Core hardware: $914/device

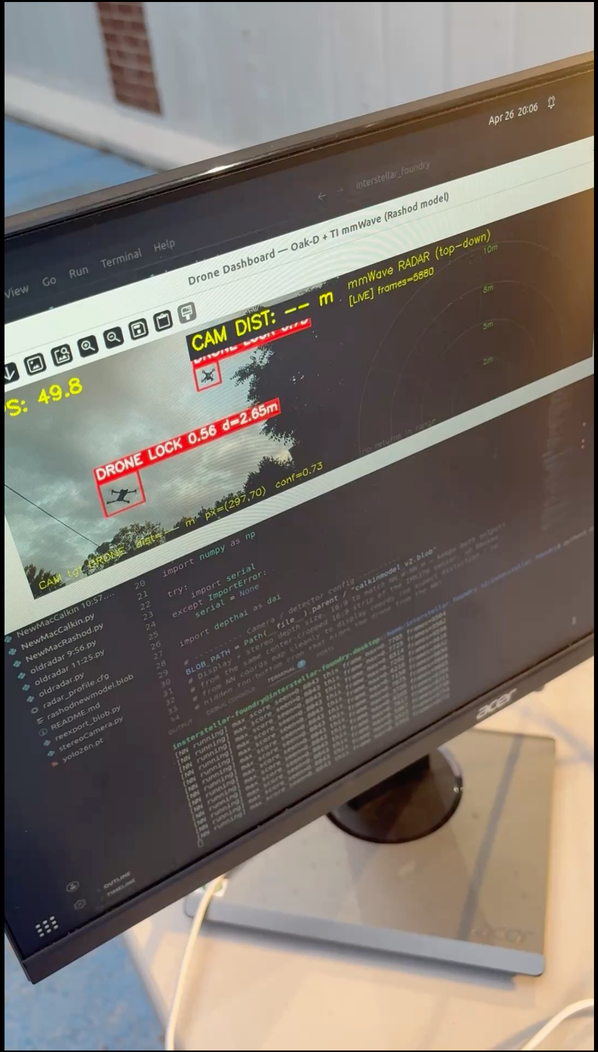
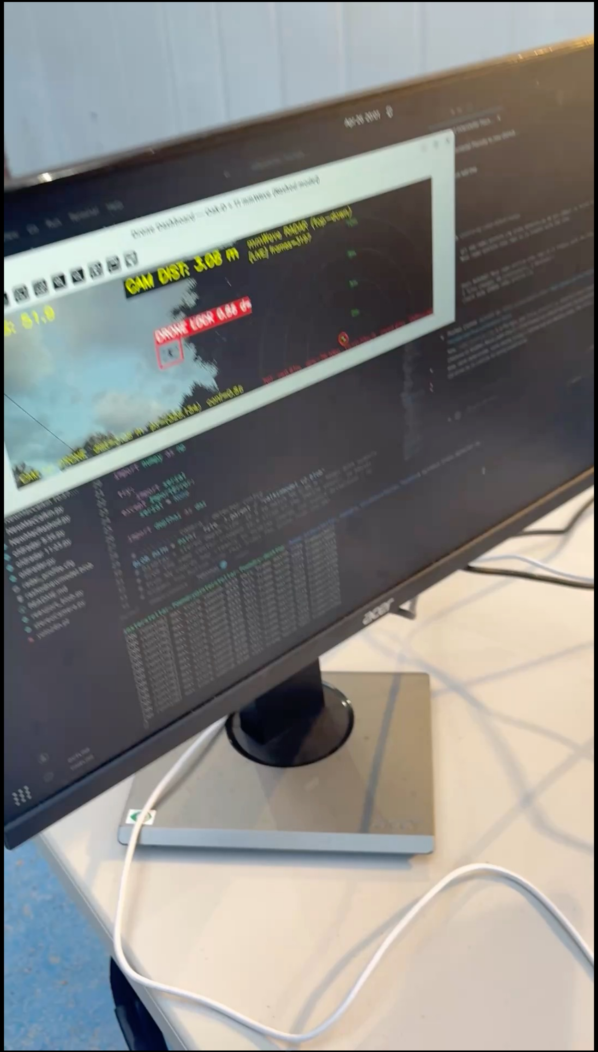
Hardware Schematic



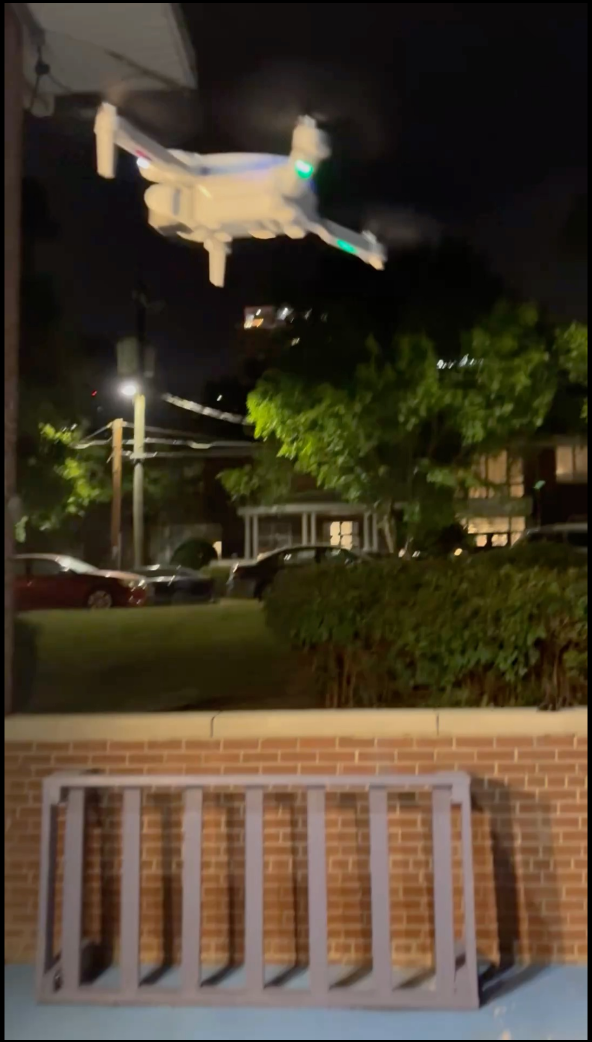




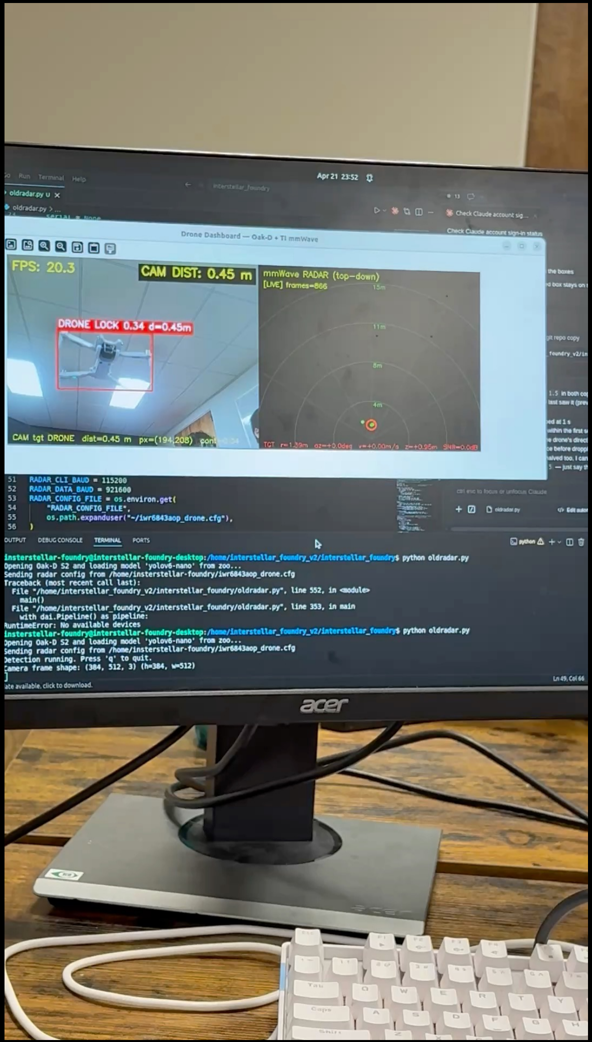



Apr 26 20:06
interstellar_foundry
View Go Run Terminal Help
Drone Dashboard — Oak-D + TI mmWave (Rashod model)
CAM DIST: -- m
mmWave RADAR (top-down)
[LIVE] frames=5880
DRONE LOCK 0.56 d=2.65m
conf=0.73
import numpy as np
try:
import serial
except ImportError:
serial = None
import depthai as dai
NewMacCalkin.py
NewMacRashod.py
oldradar.py
radar_profile.cfg
rashodnewmodel.blob
README.md
reexport_blob.py
stereoCamera.py
yolo26n.pt
acer

CAM DIST: 3.08 m
mmWave RADAR (top-down)
DRONE LOCK
acer

CAM DIST: 15.24 m
FPS: 20.2
acer



ZBT



Apr 21 23:52
Drone Dashboard — Oak-D + TI mmWave
FPS: 20.3
CAM DIST: 0.45 m
mmWave RADAR (top-down)
DRONE LOCK 0.34 d=0.45m
CAM tgt DRONE dist=0.45 m px=(194,208)
RADAR_CLI_BAUD = 115200
RADAR_DATA_BAUD = 921600
RADAR_CONFIG_FILE = os.environ.get(
"RADAR_CONFIG_FILE",
os.path.expanduser("~/iwr6843aop_drone.cfg"),
)
OUTPUT DEBUG CONSOLE TERMINAL PORTS
insterstellar-foundry@interstellar-foundry-desktop:/home/interstellar_foundry_v2/interstellar_foundry$ python oldradar.py
Opening Oak-D S2 and loading model 'yolov6-nano' from zoo...
Sending radar config from /home/insterstellar-foundry/iwr6843aop_drone.cfg
Traceback (most recent call last):
File "/home/interstellar_foundry_v2/interstellar_foundry/oldradar.py", line 552, in <module>
main()
File "/home/interstellar_foundry_v2/interstellar_foundry/oldradar.py", line 353, in main
with dai.Pipeline() as pipeline:
RuntimeError: No available devices
insterstellar-foundry@interstellar-foundry-desktop:/home/interstellar_foundry_v2/interstellar_foundry$ python oldradar.py
Opening Oak-D S2 and loading model 'yolov6-nano' from zoo...
Sending radar config from /home/insterstellar-foundry/iwr6843aop_drone.cfg
Detection running. Press 'q' to quit.
Camera frame shape: (384, 512, 3) (h=384, w=512)
acer

Engagement Logic · Swarm Software

GROUND STATION SOFTWARE

Python / OpenCV
Real-time video processing pipeline

HB100 Doppler
Velocity + range primary detection

Kalman (FilterPy)
Multi-target tracking + fusion

YOLOv8 inference
Jetson-accelerated classification

PyQt6 UI
Operator display / engagement cue

ENGAGEMENT LOGIC

Target acquired
Dual-sensor confirm → lock

Primary dispatch
Lead interceptor → head-on vector

Flankers launch
2 flankers on diverging intercept

Abort logic
Flankers abort if primary scores kill

Re-engage
Missed intercept → re-cue loop

MVP SUCCESS CRITERIA

Dual-sensor detect
Both radar AND camera confirm

80+ km/h targets
Intercept at full speed

3 simultaneous launches
Coordinated swarm execution

Kinetic contact
Physical intercept confirmed

< 15 min deploy
From packed to combat ready

Business Case · Current Market

The gap: low-cost, high-lethal, mass-producible C-UAS at scale

TIERED ROM PRICING

TIER 1 1-5 units

$500-$1,000/node

Prototype / evaluation

TIER 2 6-25 units

LRIP pricing

Low-rate initial production

TIER 3 26-100+ units

Mass manufacturing

Full contract scale

MARKET CONTEXT

$4B+

C-UAS global market by 2030

~$500K

Avg. legacy sensor node cost

<$1K

Our node cost is 500× cheaper

Group 1/2

Primary threat is underserved

Thank you!

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