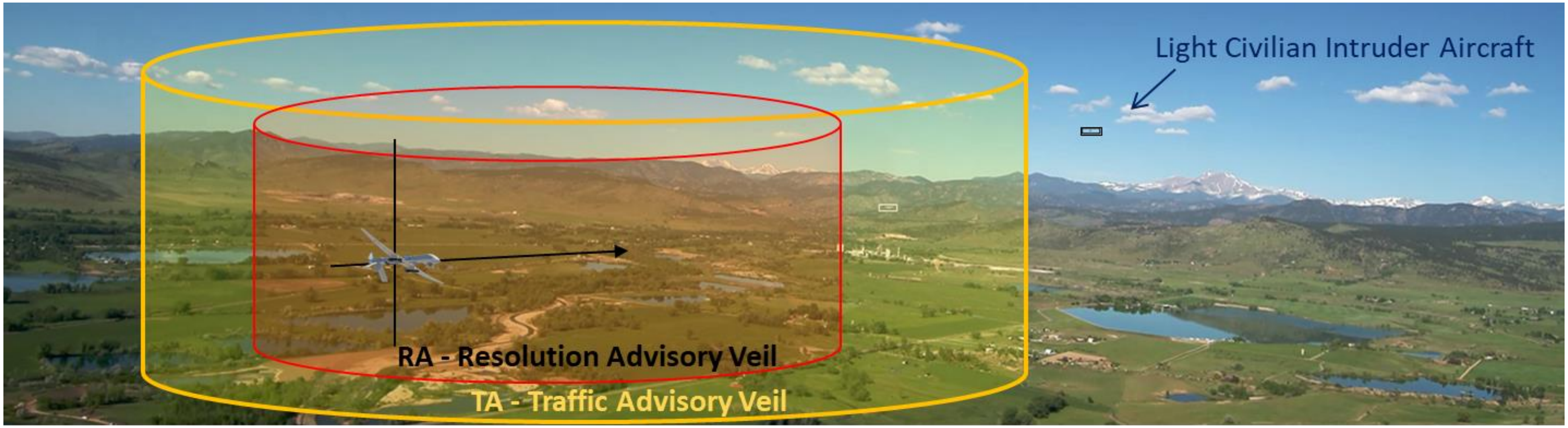
Using GPUs in the Development Of Airborne Collision Avoidance



GTC 2019 Topic: S9216

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Operational Prototype for "Sense & Avoid" Technology (OPSAT)

- Project Summary
  - Began June 2016. Ends May 2019
  - Sponsored by United States Air Force
  - Goals:
    - Provide a passive "See and Avoid" capability for USAF aircraft

      (Primary Target: MQ-9 Remotely Piloted Aircraft (RPA))
    - Provide a low-power, low weight, small volume "See and Avoid" capability for unmanned and manned aircraft
    - Contribute to the suite of technologies needed to integrate Unmanned Air Systems into the National Air Space
    - Begin FAA NORSEE Certification process and Commercialization

Current USAF Contract

See and Avoid Technology for Unmanned Air Systems (UASs)

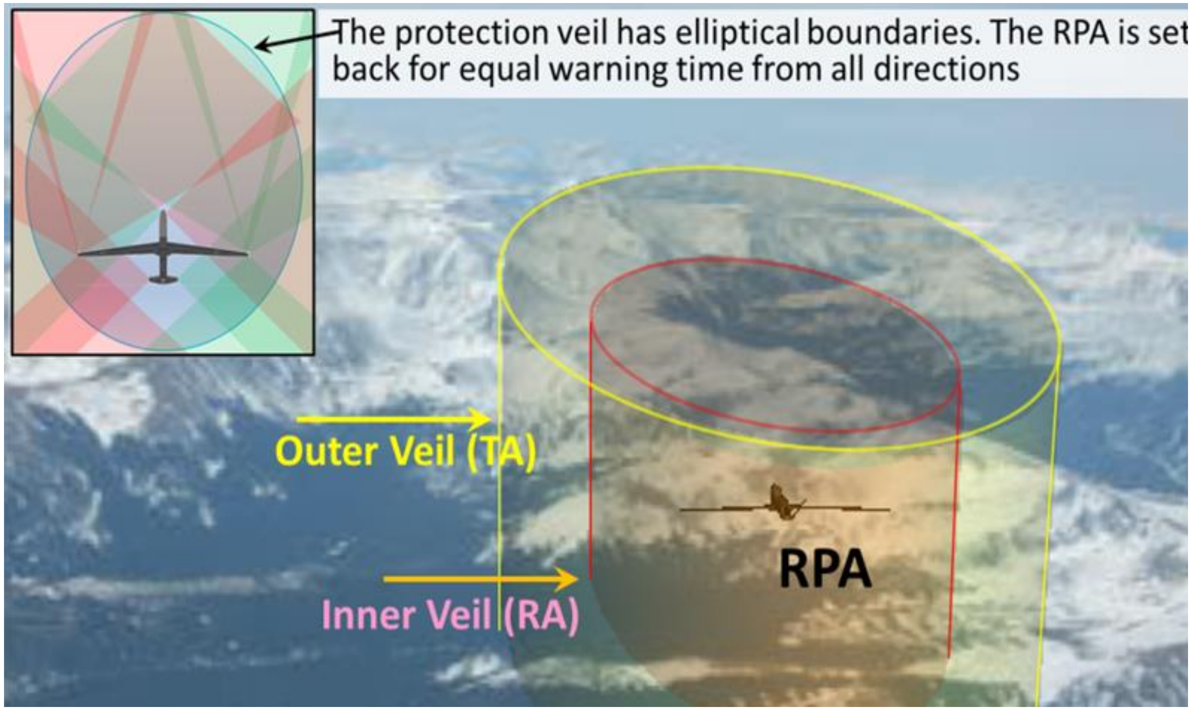
- Federal Aviation Regulations (FAR) 91.113 (b)

"When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, ***vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.*** "

- Managed by Air Force Flight Test Center, Edwards AFB, CA
- *Increases safety & situational awareness for unmanned/manned aircraft*

Program Description

- Create a miniature passive, low weight , low cost see-and-avoid capability to facilitate the integration of UAS into the National Air Space. System defines a Traffic Advisory (TA = be informed) veil, and a Resolution Advisory (RA = avoid traffic!) veil.
- Goal to implement 360° capability using miniature, high performance video cameras and Deep Neural Nets, with mono & stereo-vision-based detection, tracking and avoidance of intruders.

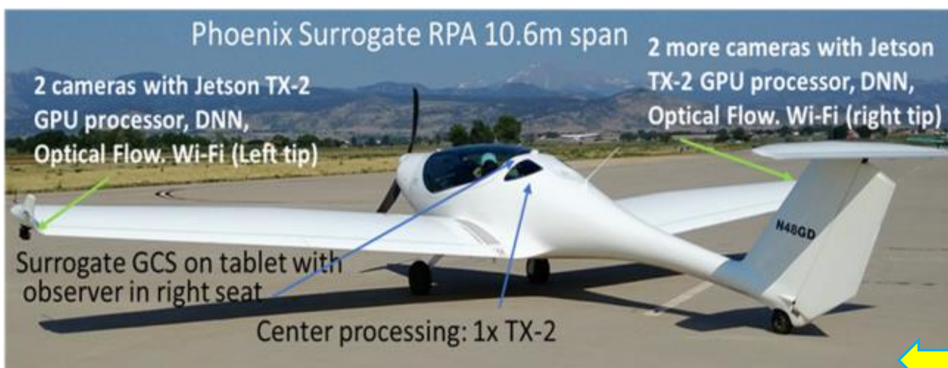


Technology

Intruder 1 C172RG Climbing out of KLMO 1250m ahead

Intruder 2 – Unknown type on wide left base to KLMO

Flight Tested Passive Sensing of light civilian Intruder Aircraft. Developed from actual, verified flight data. Integrates aerodynamic modeling with deep learning and physics based, real-time, 3D model of ownship dynamics. Compensates real-time aeroelastic deflections.



Close up of OPSAT Self Contained Prototype Wing Unit

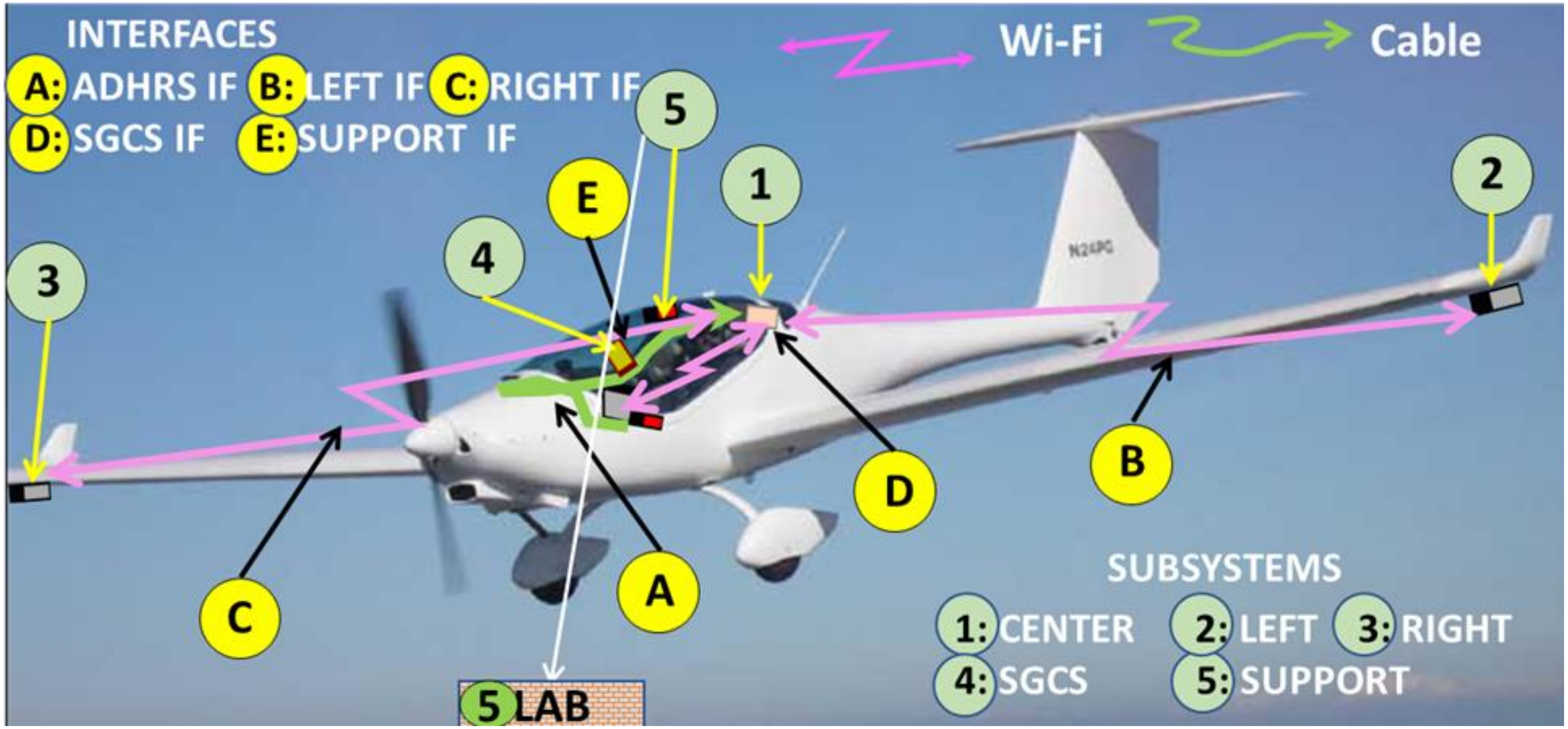
OPSAT on Phoenix

PPI and VSI display with Unsafe (RED) and Safe (green) Vertical Speed command ranges to avoid Intruder(s). Current VS is the yellow bar in the VSI

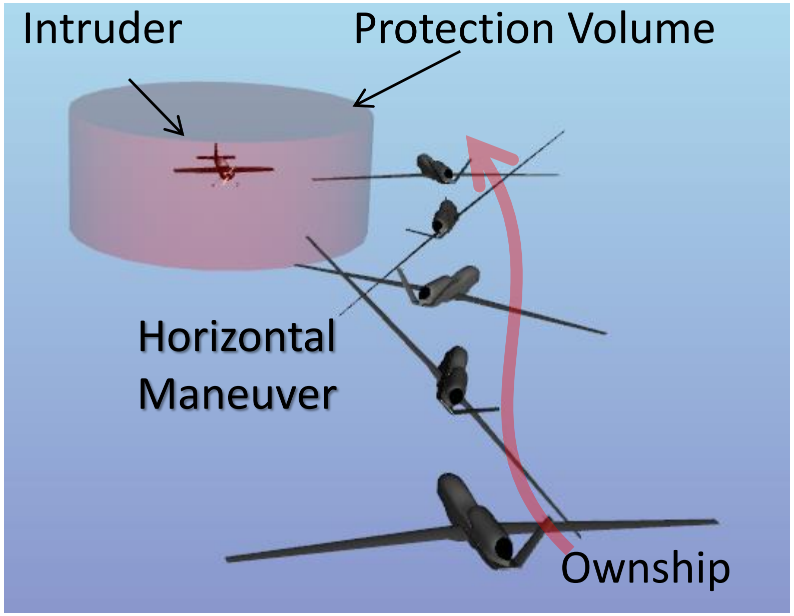
OPSAT Subsystems

Left, Right and Center subsystems shown in transport case (left), and mounted to aircraft wing (right)

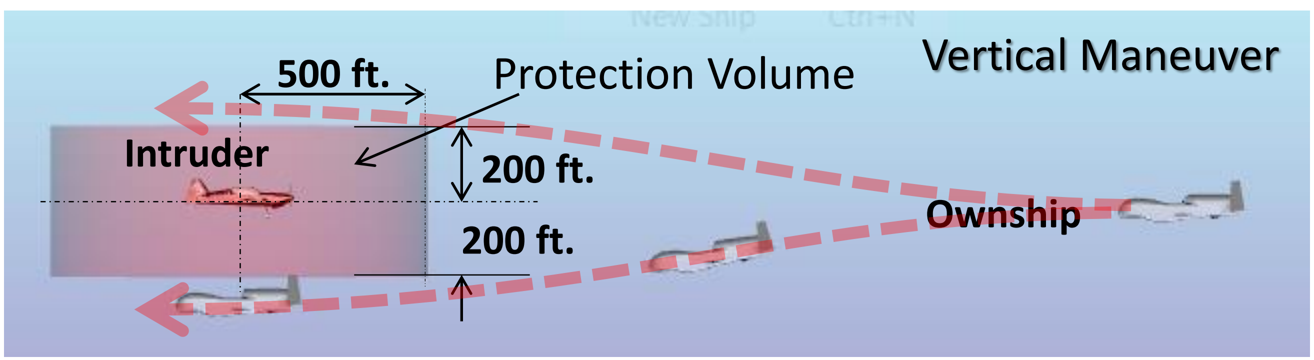
Testbed Installation



Collision Avoidance

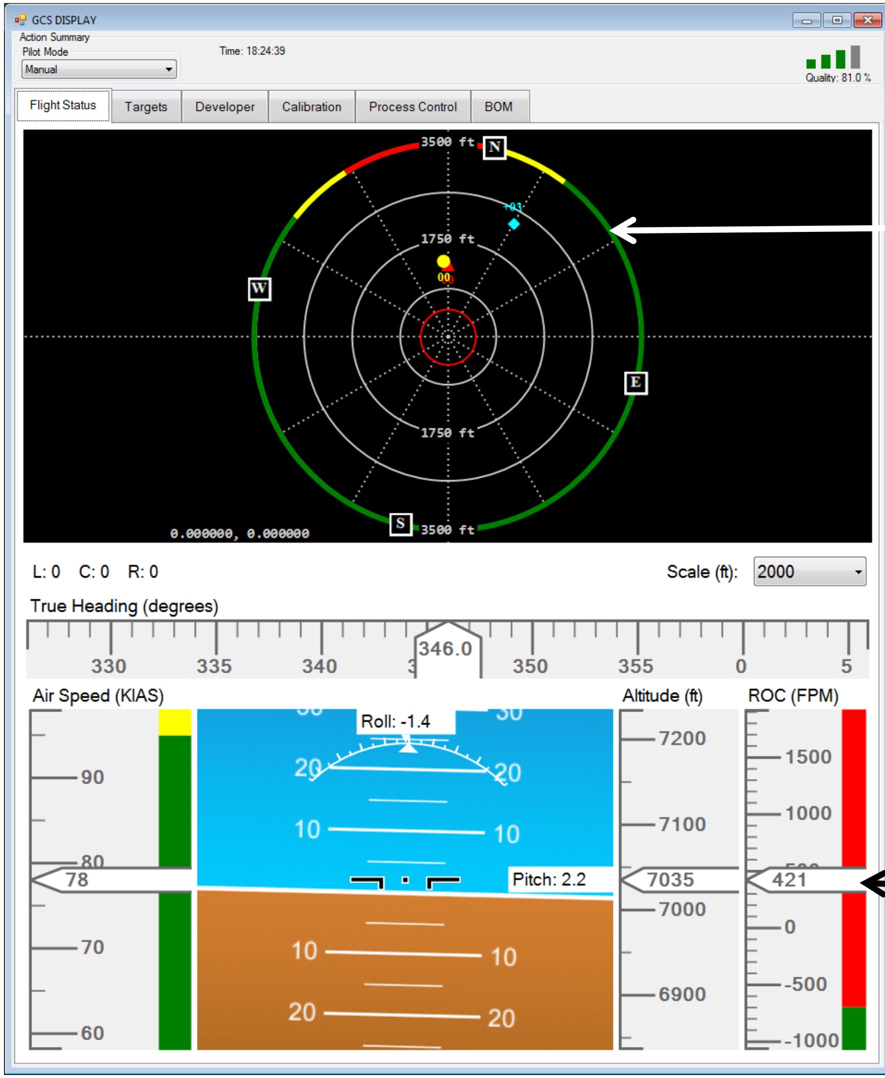


<u>Vertical and lateral avoidance</u>. This is how the next-generation Airborne Collision Avoidance System (ACAS) will work, resolving difference between FAR 91.113 (horizontal avoidance) and ACAS standard (vertical avoidance). <u>Current implementation</u>: FAR compliant avoidance maneuver(s) updated (for each closest approach in case of multiple intruders).



For all maneuvers maintain 1000 ft. (300 m) terrain clearance

PPI Display



Lateral Avoidance
(indicates need to turn in
safe direction indicated
by green portion of outer ring

Red triangle= intruder ground truth
Yellow circle = OPSAT intruder position
(yellow circle indicates potential collision)
Blue diamond= OPSAT position of another Intruder (not instrumented) Blue diamond Indicates this intruder is not a threat.

Vertical Speed Indicator
(indicates need to reduce speed to 60 knots to descend 1,000 ft.)

See & Avoid: A Unique Approach

- Passive sensing of Intruder aircraft
- Developed from actual, verified flight data
- Interfaces with existing avionics and COTS sensors
- Integrates aerodynamic modeling with deep learning
- Designed for multiple uses and low cost
  - UAS Detect and Avoid
  - Increased Safety & Situational Awareness for manned aircraft
  - Drone detection during vulnerable flight stages
- To be accepted through flight test

Jetson GPU Integration

Integration of Jetson TX-2 System:

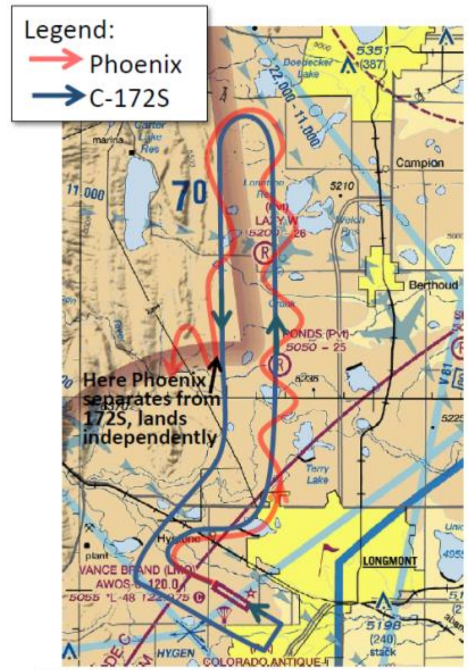
- Custom heat sinks keep the Jetsons cool while testing at the airfield.
- Twin fan units were also installed for increased airflow, and wingtip-mounted housing has “NASA Scoops” for cooling by airflow.
- System interfaces with the host aircraft (or UAS) Air Data and Heading / Attitude Reference System (ADAHARS).

Test Flights

- Monthly (or more frequent) test flights
  - Test current code improvements
  - Collect training data
  - Test recognition against a variety of aircraft
  - Test avoidance code on different collision courses
- Complete system installed on the Phoenix aircraft
  - System is temporary and installed for each flight test
  - Must be recalibrated at every installation
- All aircraft are instrumented with GPS loggers to obtain true target location
  - One to three instrumented intruder aircraft fly during each flight test
- Aircraft typically flown for 1 hour

Sample Flight Plan

- Flight planning crucial for program success
  - Validates software
  - Data capture in real environment
  - Video to refine DNN training and post flight analysis
  - Results often affect system architecture or software



Phoenix follows C172 by 800 to 3000 ft., 200 ft. below, 200 ft. above, and level when offset to side. Phoenix breaks if lost sight of C172. VFR Flights observing all FARs.

Preliminary flight plan for Thursday, September 13, 2018 (finalized at pilots' conference 0845 at KLMO)

Aircraft:

Lead C172 N52221

Camera Phoenix N48GD (Graham Beasley)

Flights from KLMO:

2 x ~ 25 min flights from Longmont KLMO

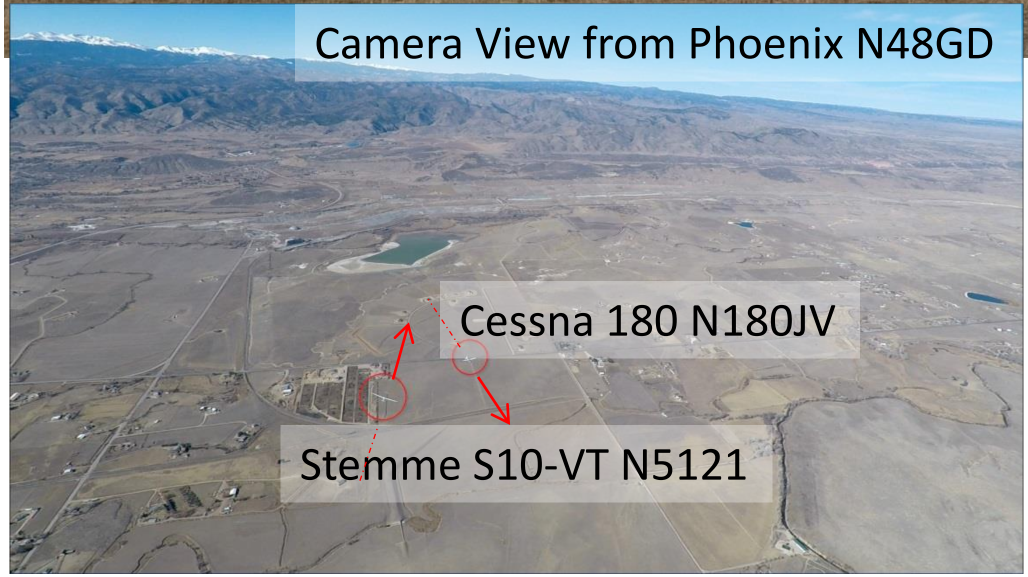
There will be a 15 minute break between flights for camera database re-load into Phoenix, otherwise flights are identical as shown. C172 lands briefly at KLMO after 2nd flight to retrieve Nano flight recorders supplied by Pathfinder.

Air-to-Air Frequency (North of KLMO until separation): Likely 123.3, as agreed by pilots. Frequency change calls by Phoenix.

KLMO = Longmont, CO Airport

A Flight Test with 3 Aircraft

Aircraft readied for flight test at Vance Brand Airport, Longmont, CO



Flight tests and data collection flights conducted from Longmont Vance Brand Field (International Civil Aircraft Organization designator = KLMO) and at Apple Valley airport, CA (KAPV)

DNN Implementation

- Modified DetectNet
- Trains to 500-1000 epochs
  - 500: Starting point for usable nets
  - 1000: Gross results are similar to a net trained to 500, but further training offers bounding box refinements
- Turned off random training image augmentations due to poorer results when tested in flight

Unique Program Challenges

- Calibration
- Aircraft Detection (especially in clutter)
- Accounting for Elastic Deformation of the Aircraft
- Target matching in a crowded airspace
- Profiling & projecting ownship dynamics to assign proper resolution advisory
- Data Synchronization (during lab testing & development)
- Hardware selection
  - Features / Performance
  - Compatibility
  - Cost

Camera Pair Snapshot

__RIGHT FORWARD CAMERA__
Video image and results of Deep Neural Net (DNN) image recognition in a recent test flight

__LEFT FORWARD CAMERA__
Same scene, same time, different camera. Cameras form a “virtual pair”, enabling stereo distance estimation of the intruder.

Current Results

OPSAT tracking two intruders

Boxes surrounding the aircraft are a visual aid only.

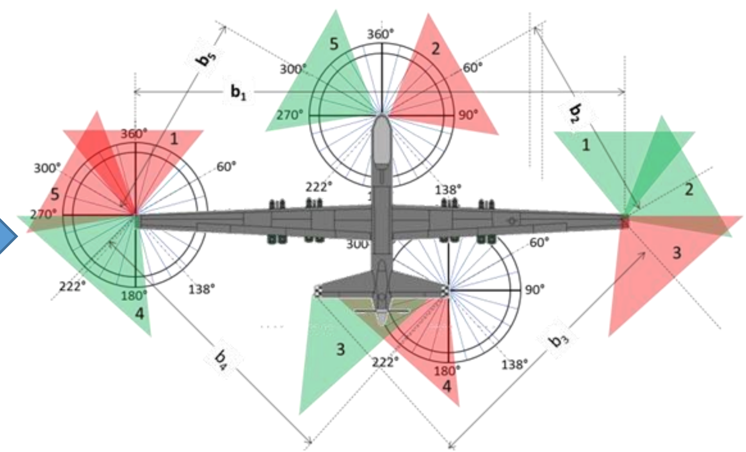
DNNs generate a bounding box but these are too small to see in the Figure

OPSAT in Action

Switch to video clip of OPSAT in Action:

- Shows images of left and right camera pairs
- Shows the Pilot Plan Position Indicator (PPI) Display

OPSAT OBJECTIVE SYSTEM



Lessons Learned

1. Limit DNN to recognizing broad categories: "this is an aircraft or an ultralight" or a "helicopter, or balloon, or parachute," to avoid overtraining.
2. Elastic deformation of the airframe critically impacts distance estimates and must be accounted for in the software.
3. Early deployment of "flying brassboard" critical to development effort.
4. Frequent flight tests key to both software and hardware development as well as data collection.
5. 3-D printed plastic housings worked well for functional prototypes.

Future Development

- Current Target detection up to 3000 ft.
- Small footprint and power requirement of TX2 is perfect for development and proof of concept
  - Moving to newer hardware
    - Improved GPU SoC for decreased inference time (e.g. Xavier)
    - Higher resolution camera for increased detection distance
      (Considering current USAF requirement)
    - Multi-camera system to support 360° tracking
- Integration into actual aircraft for one-time calibration and use of on-board power when system is installed.

Point of Contact

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