Pilot Visual Detection of Small Unmanned Aircraft Systems

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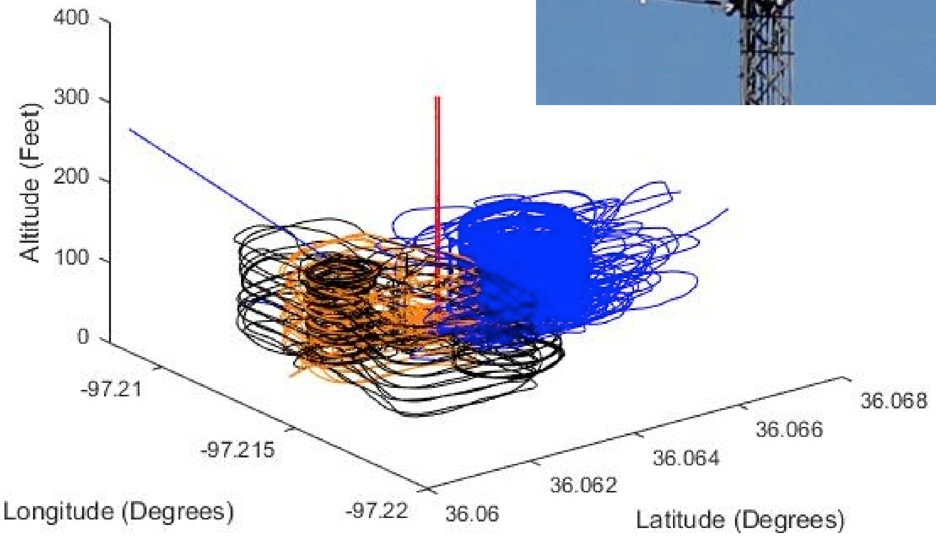
NSF CLOUD-MAP

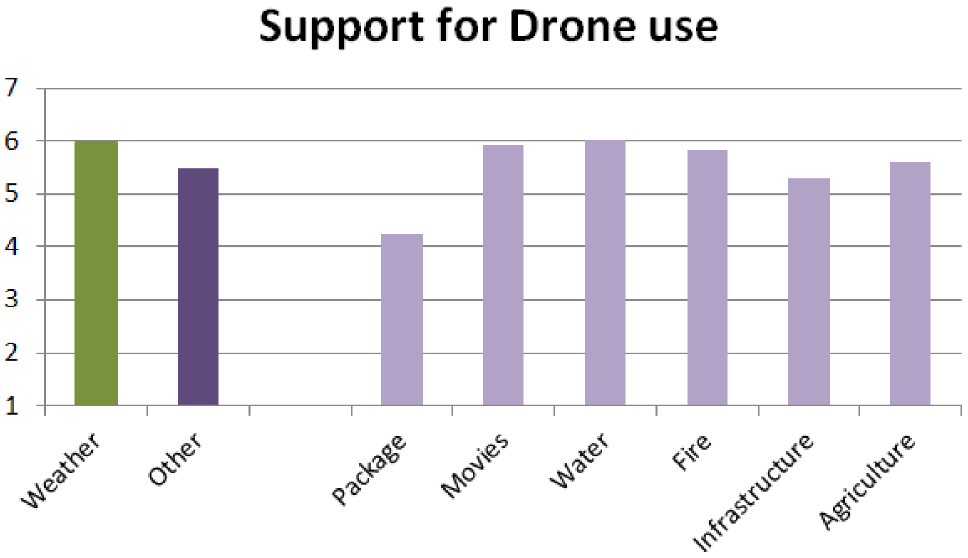
- Developing UAS and protocols for weather measurement
- 2016 Campaign
  - *4 teams – 3 flight days*
  - *>60 participants*
  - *20 systems*
  - *241 separate flights*
  - *25 hrs. total flight time*



CLOUD-MAP Policy Findings

- You can call a drone whatever you want without changing people's support
  - UAS, UAV, aerial robot, drone
- Support does not seem to vary by characteristics
  - Autonomy and other
- Framing matters, for now
  - Say it is to avoid harm, not to approach benefits
- Purpose matters
  - And interacts with time, political leanings, and actor using the drone…
- Trust matters…
  - People currently are rather "forgiving" and allow "trust brokerage" processes to operate

It doesn't matter what they look like…



Pilot Visibility of UA - Problem

- Integrating manned & unmanned systems into the NAS
  - Collision risk
  - No established separation criteria
  - No UAS transponder requirement
  - Effective and reliable SAA not yet developed
  - "Mark II eyeball" only current, reliable method of detecting UA
- Anecdotal evidence indicates increasing airspace incursion trend
- Little experimental data exists to baseline effectiveness of UAS visual detection

"A Review of Research Related to Unmanned Aircraft System Visual Observers," DOT/FAA/AM-14/9, Williams & Gildea, 2014

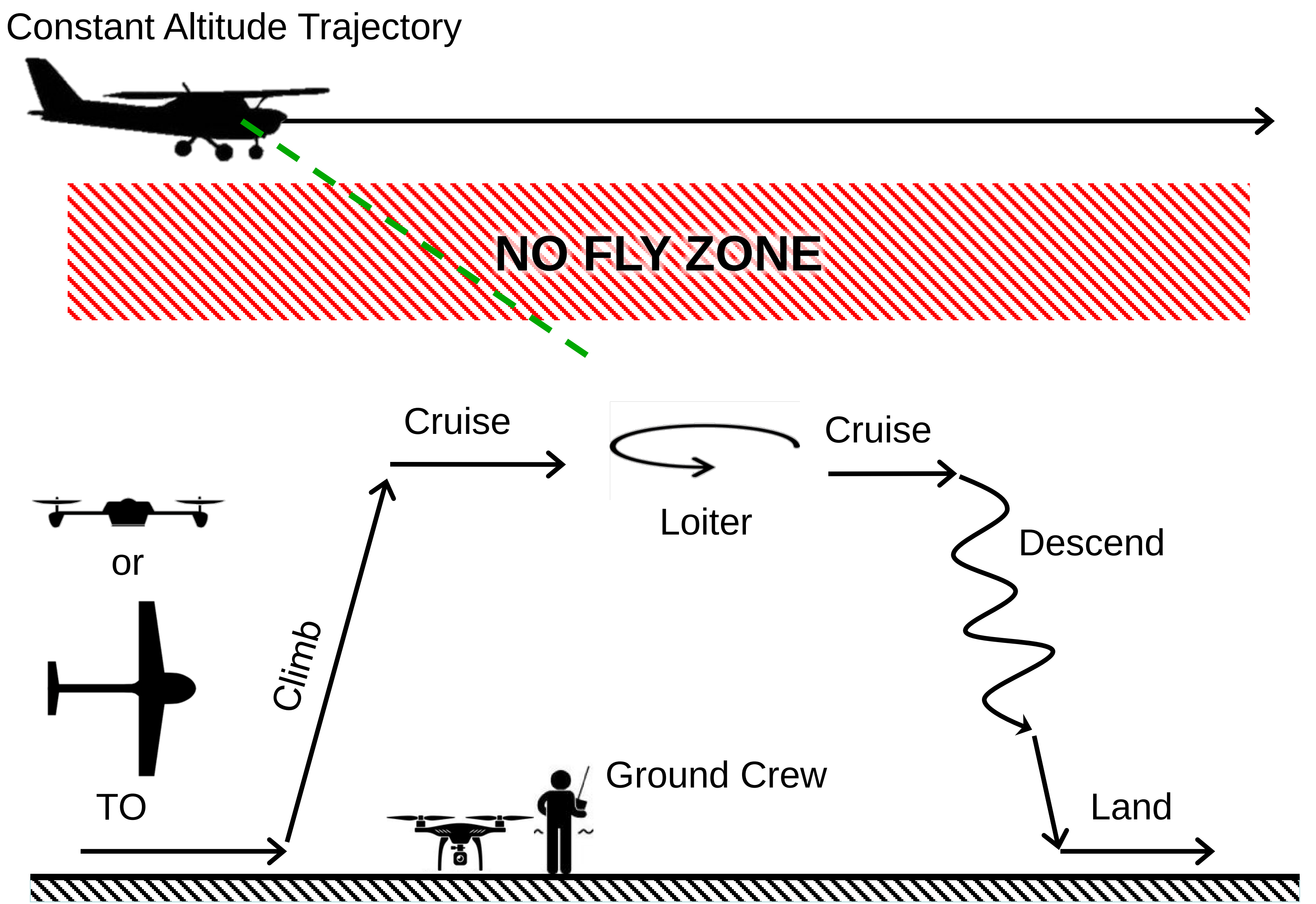
Purpose

- Determine visibility distance at which an aware pilot can detect SUAS under VMC
- Evaluate available pilot reaction time, based on closure rate
- Determine appropriateness of pilot evasive maneuver selection, based on visual convergence perception
- Evaluate pilot's ability to determine UAS threat level (size, distance, speed)
- Establish pilot visibility benchmarks for sUAS encounters under VMC
- Develop research vectors for spin-off studies
  - UAS color schemes
  - Lighting selection or patterns
  - Electronic Detect, Sense & Avoid systems
  - Transponder systems

Project Phases

- Phase I – Pilot visibility baseline; ADS-B used as safety device for SA
- Phase II – Impact of passive UA configuration (color, size, navlights) on detection as well as meteorological conditions (time of day)
- Phase III – ADS-B used with and without additional navigational aids
- Phase IV – ADS-B used with additional pilot support (voice cues, HUD)
- Phase V – ADS-B with automatic collision avoidance

Mission Profile



Manned Aircraft

- Cessna 172
- Airspeed:
  - Max Cruise (SL): 126 kts
  - Maneuvering: 88-102 kts
  - Stall (Flaps up, Power Off): 53 kts
  - Stall (Flaps Down, Power Off): 48 kts

- Operating Altitude: S -14,000
- Endurance: >4 hrs
- Fuel: AVGAS (56 gal total/53 gal usable)
- Control Method: Manual/No AP
- Sensors: EO (Mounted),
  G-1000 GPS/WAAS
- Altimeter Source: GPS/barometric
- Altimeter Datum: MSL

Unmanned Aircraft

RMRC Anaconda

Type	FW
GTOW [lb]	15
PW [lb]	5
Span [ft]	7
Powerplant	Electric
Vcruise [kts]	40
TO/L	Runway

3DR IRIS+

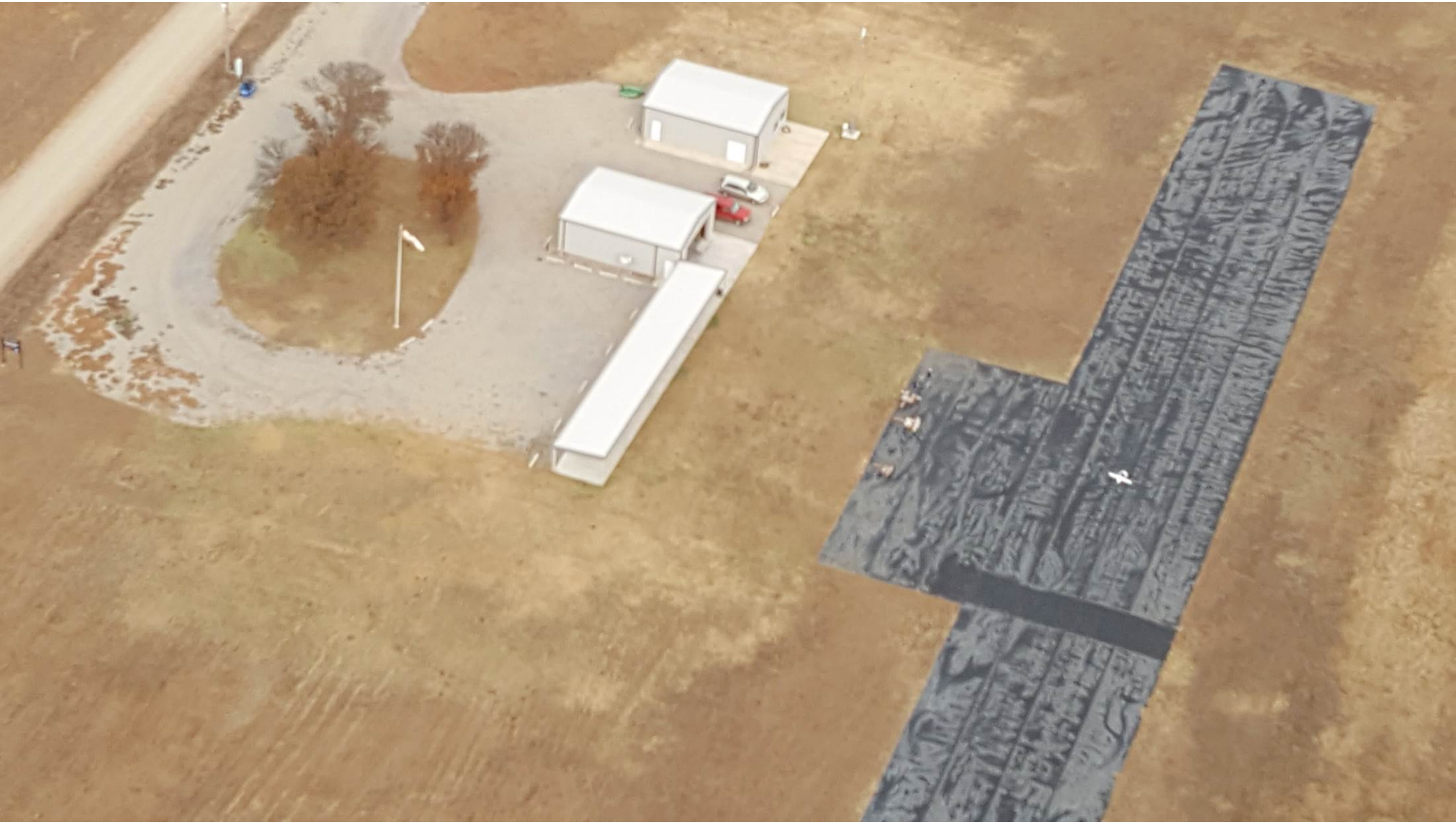
Type	RW
GTOW [lb]	2
PW [lb]	1
Span [ft]	1.8
Powerplant	Electric
Vcruise [kts]	20
TO/L	VTOL

- Equipped with Pixhawk autopilot, 2.4 GHz manual Tx, 915 MHz AP control, real time telemetry to GCS, Nav Lights, and ADS-B Tx/Rx

OSU UA Flight Station

- Main runway is 600 feet long and 60 feet wide with 400 foot cross runway; flight area is 1 mile by 1 mile, though most flights occur within the ¼ mile by ¼ mile SW quadrant of the section
- Within Class G airspace and approved FAA COA

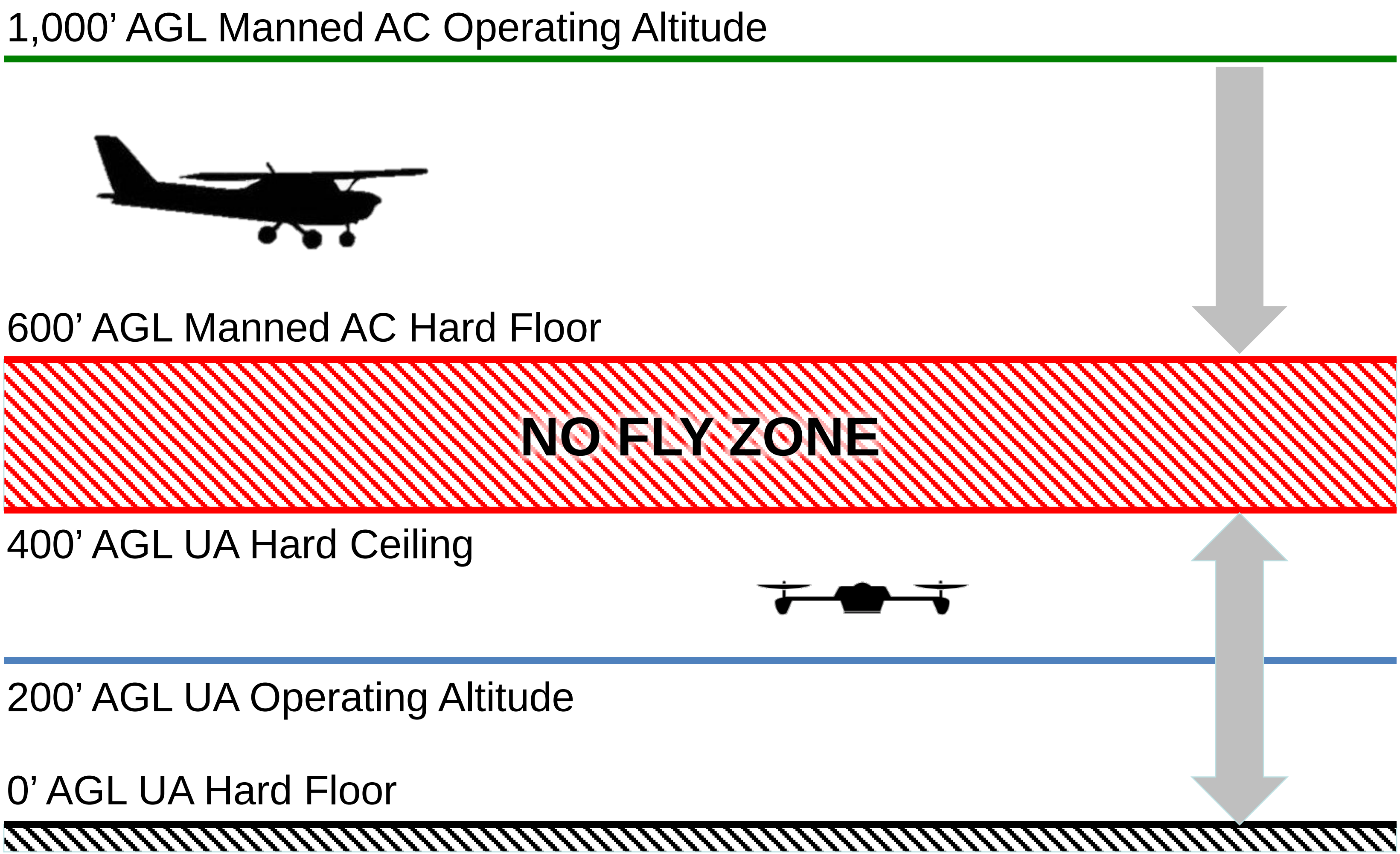
Aerial View (FW UA On Ground Hold)



Safety Assurance

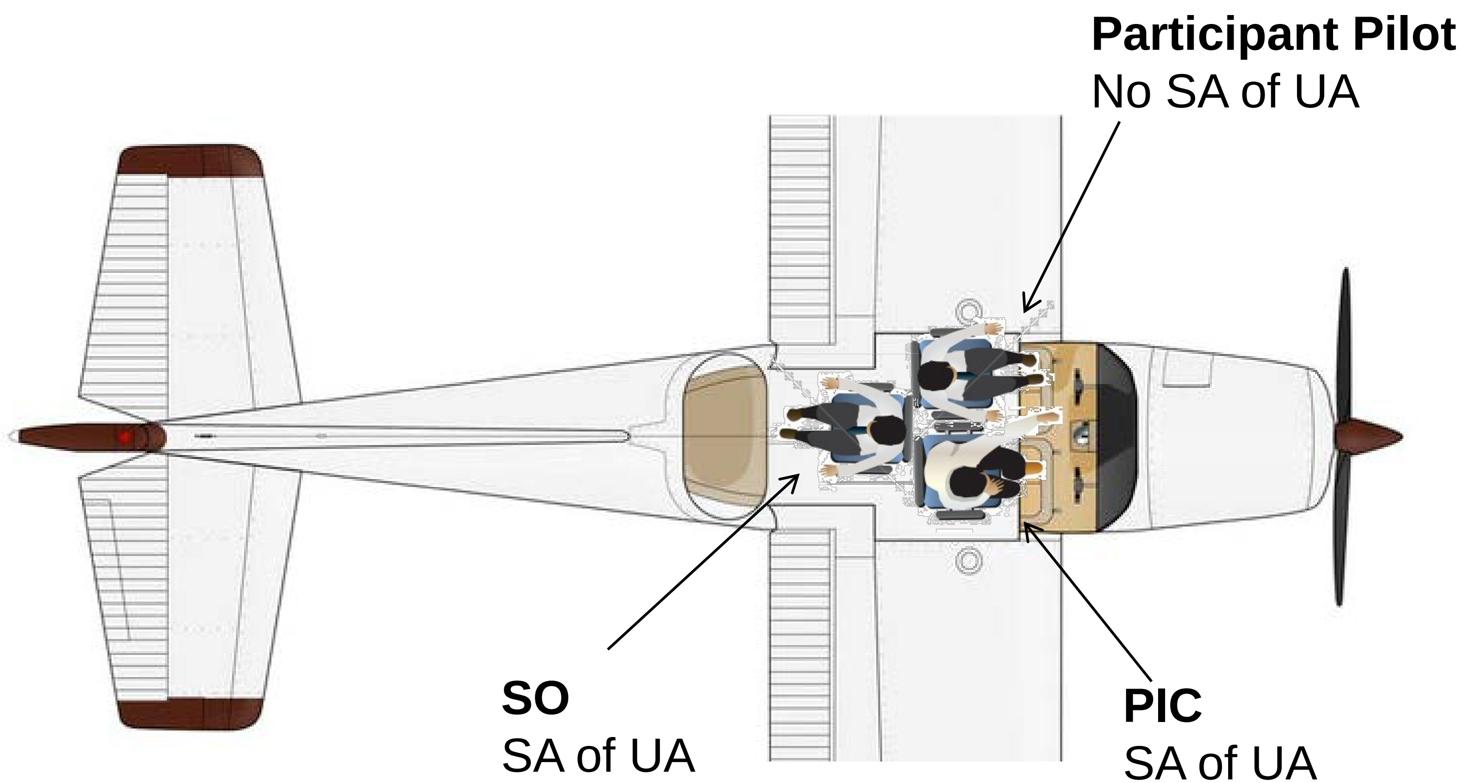
- Manned AC and UAS crew with constant SA regarding both aircraft at all times
- Aircraft tracked via ADS-B and displayed on EFB (UA) and UA GCS
- Manned AC
  - 2 qualified pilots on AC; one PIC, other for UA SA; participant pilot serving as test subject (UA spotter)
- UA
  - 2 qualified pilots on ground with 1 UA operator
  - VOs for spotting
- Constant communication between crews with clear commands for emergency procedures

Altitude De-Confliction Plan



Constant communication between PICs and VOs, along with ADS-B

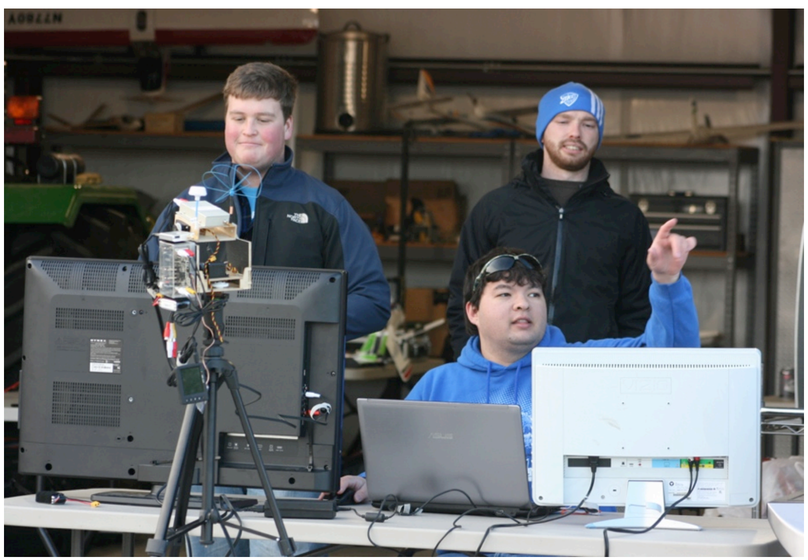
Manned Aircraft Arrangement

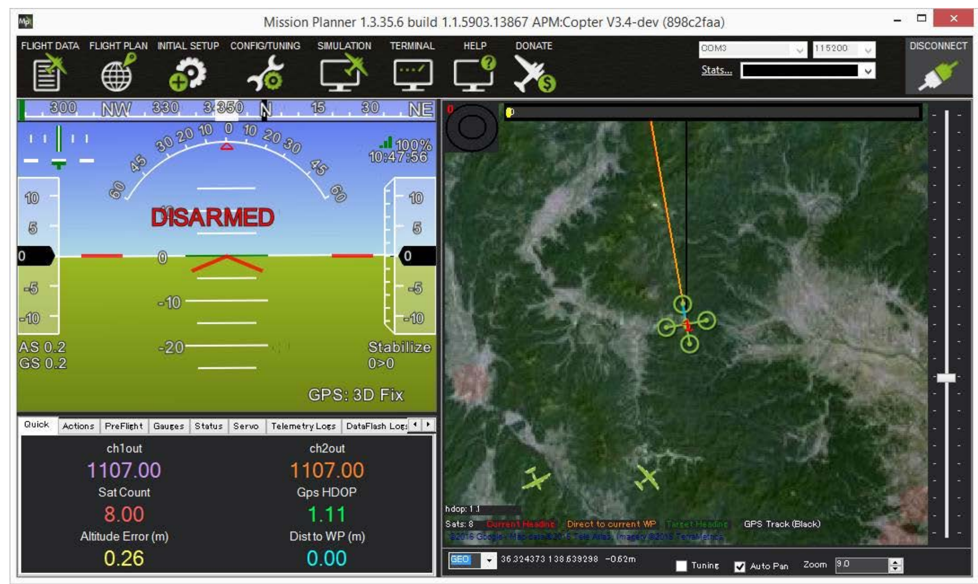


PIC
    CFI, with ATP Rating
Participant Pilot
    Private Pilot or higher
Safety Observer (SO) and Test Director
    Private Pilot or higher (Tracks UAS via ADS-B on EFB)

UAS Crew Roles and Tasks

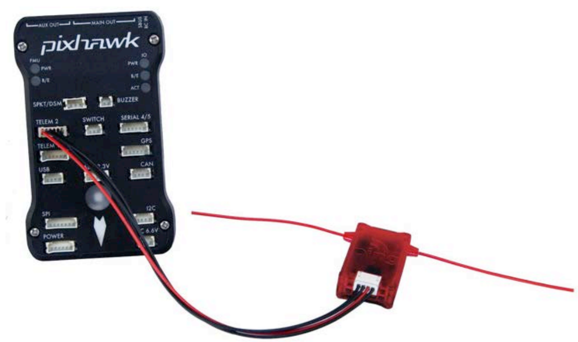
Role	Operational Tasks	Non-operational Tasks
Flight Director	ATC comms, flight safety, maintain sterile cockpit	Communication, mission planning, logistics,
Vehicle Operator (PIC)	Aircraft control, flight planning	Vehicle maintenance
Visual Observer (VO)	Spotter, communication	Maintenance, safety and security, GCS



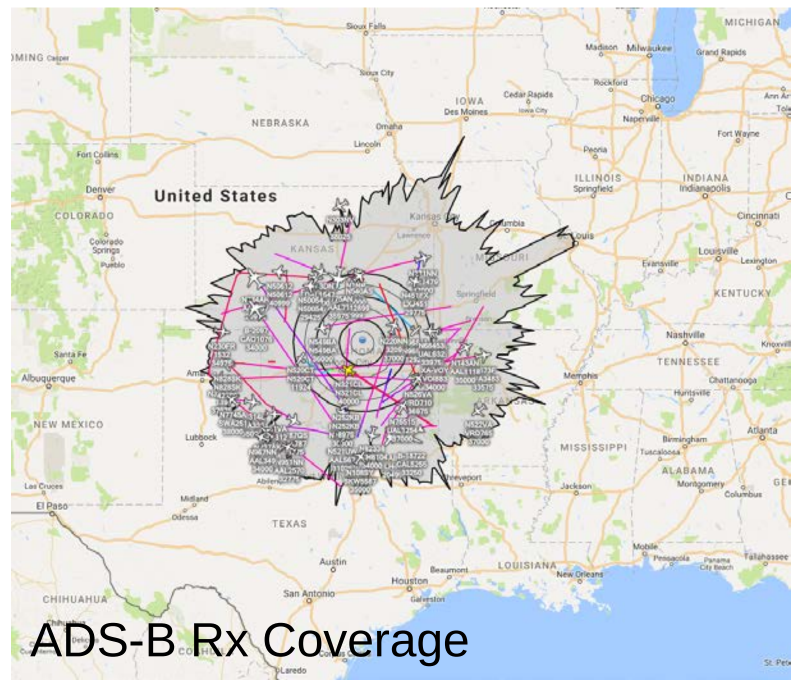


ADS-B

- Utilized uAvionix Ping ADS-B Tx/Rx solution
- Transmits and receives from UAS to GCS
- Automated collision avoidance capability
- Recently implemented on Precision Hawk platforms



Specification	Ping
Size (mm)	25x28x22mm
Weight	4grams
Fail Safe TX power	0.5W
1090ES RX Range	20miles
978UAT RX Range	30miles
978UAT TX range	7miles
Power	4-12V 100mW



ADS-B Rx Coverage

Go/No Go Criteria

- UAS
  - Airworthiness OK
  - Handheld Communication OK
  - Visual Safety Observers (Minimum manning)
  - Autopilot/control systems operational
- Aircraft
  - Airworthiness OK
  - Communications system functioning
  - Navigation/G-1000 operational
  - Fuel >3 hrs
- External Factors
  - Weather below of established minimums
  - Factor traffic operating IVO test area
  - Other safety factors determined by Flying/UAS pilots

Weather Limitations

- Ceiling
  - >3000'
  - NMT SCT (4/8) cloud cover
  - No clouds <1,200
- Wind
  - Not to exceed AC operational limits
- Visibility
  - 6+ SM
  - No visibility-limiting conditions (mist, fog)
- Other conditions
  - No precipitation
  - No convective activity
  - No reported turbulence

Phase I Test Subject Demographics

Flight	Age Bracket	FAA Pilot Certificate(s)	Medical Certificate	Reported Vision	Vision Correction
1	60-65	ATP	2nd Class	20/20	Corrected
2	20-25	CFI/MEI	1st Class	Unknown	Unknown
3	20-25	CFI/MEI	1st Class	20/20	Corrected
4	<20	PPL w/ IR	1st Class	20/20	Corrected
5	20-25	CPL	1st Class	20/20	Uncorrected
6	<20	PPL	3rd Class	20/20	Corrected
7	20-25	CFI/CFII	1st Class	20/20	Uncorrected
8	20-25	ATP	1st Class	20/20	Corrected
9	20-25	CPL	2nd Class	20/20	Uncorrected
10	20-25	PPL w/ IR	3rd Class	22/20	Corrected
11	20-25	CPL	2nd Class	Unknown	Unknown
12	20-25	CFI/CFII	1st Class	20/20	Uncorrected
13	20-25	ATP	1st Class	20/20	Uncorrected
14	20-25	CFI	3rd Class	20/20	Uncorrected
15	20-25	CFI/CFII	3rd Class	20/20	Uncorrected
16	20-25	CPL	1st Class	Unknown	Unknown
17	20-25	PPL w/ IR	3rd Class	20/20	Corrected
18	20-25	CPL	3rd Class	20/20	Uncorrected
19	25-30	CFI/CFII/MEI	1st Class	20/20	Corrected
20	20-25	CFI/CFII	1st Class	20/20	Uncorrected

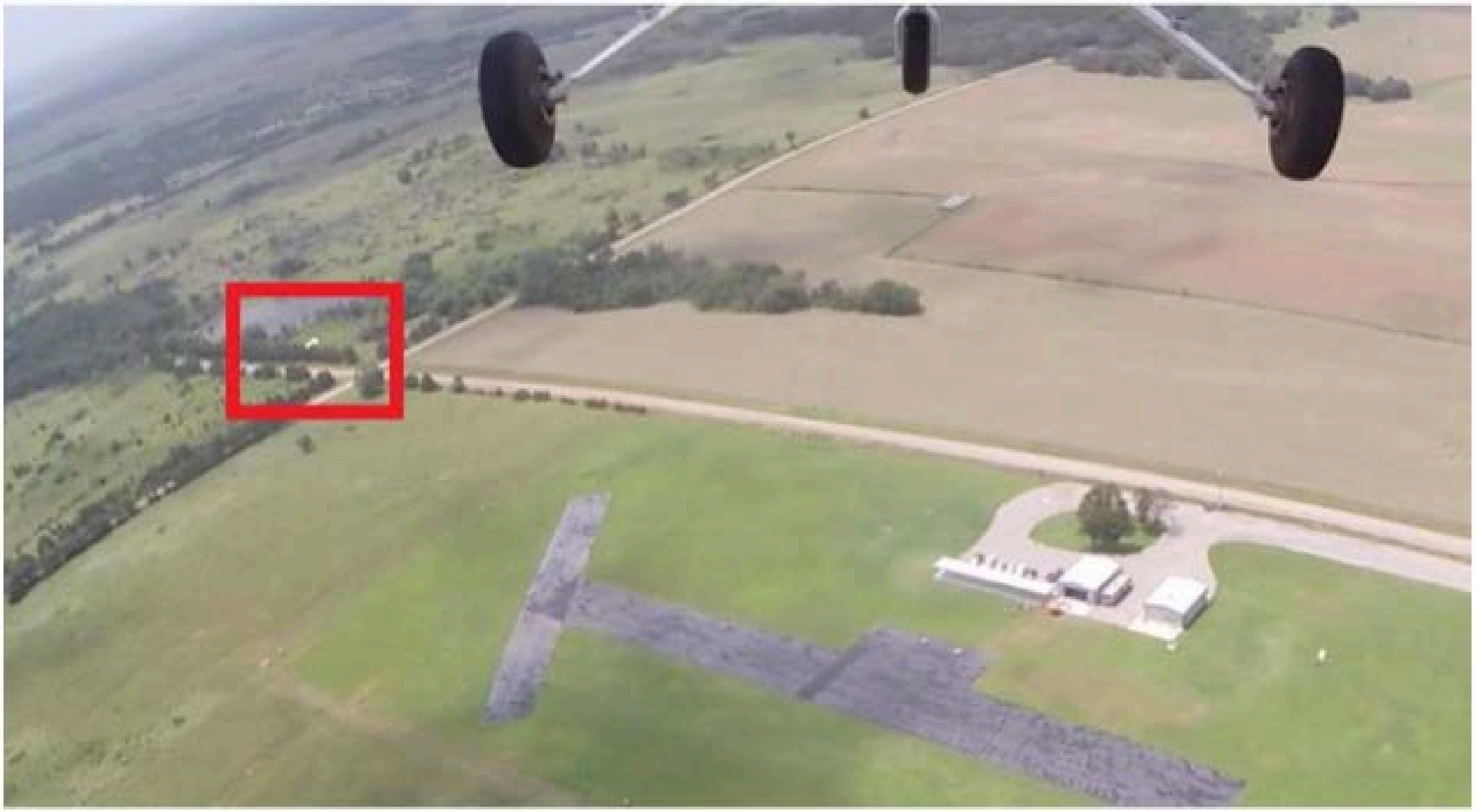
Note: (PPL = Private Pilot License; IR = Instrument Rating; CPL = Commercial Pilot license; CFI = Certified Flight Instructor; CFII = Certified Flight Instructor-Instrument; MEI = Multi-Engine Instructor; ATP = Airline Transport Pilot). All commercial pilots and above were instrument rated. Vision correction indicates if participant medical certificate required wear of corrective lenses.

Encounter Vignettes

- Intercept 1: Control Scenario in which no UA was launched
- Intercept 2: Hovering RW UA on port side of aircraft course
- Intercept 3: Hovering RW UA on starboard side of aircraft course
- Intercept 4: RW UA transitioning from port to starboard side
- Intercept 5: RW UA transitioning from starboard to port side
- Intercept 6: Fixed-wing UA orbiting on head-on aspect relative to aircraft course

FW Encounter

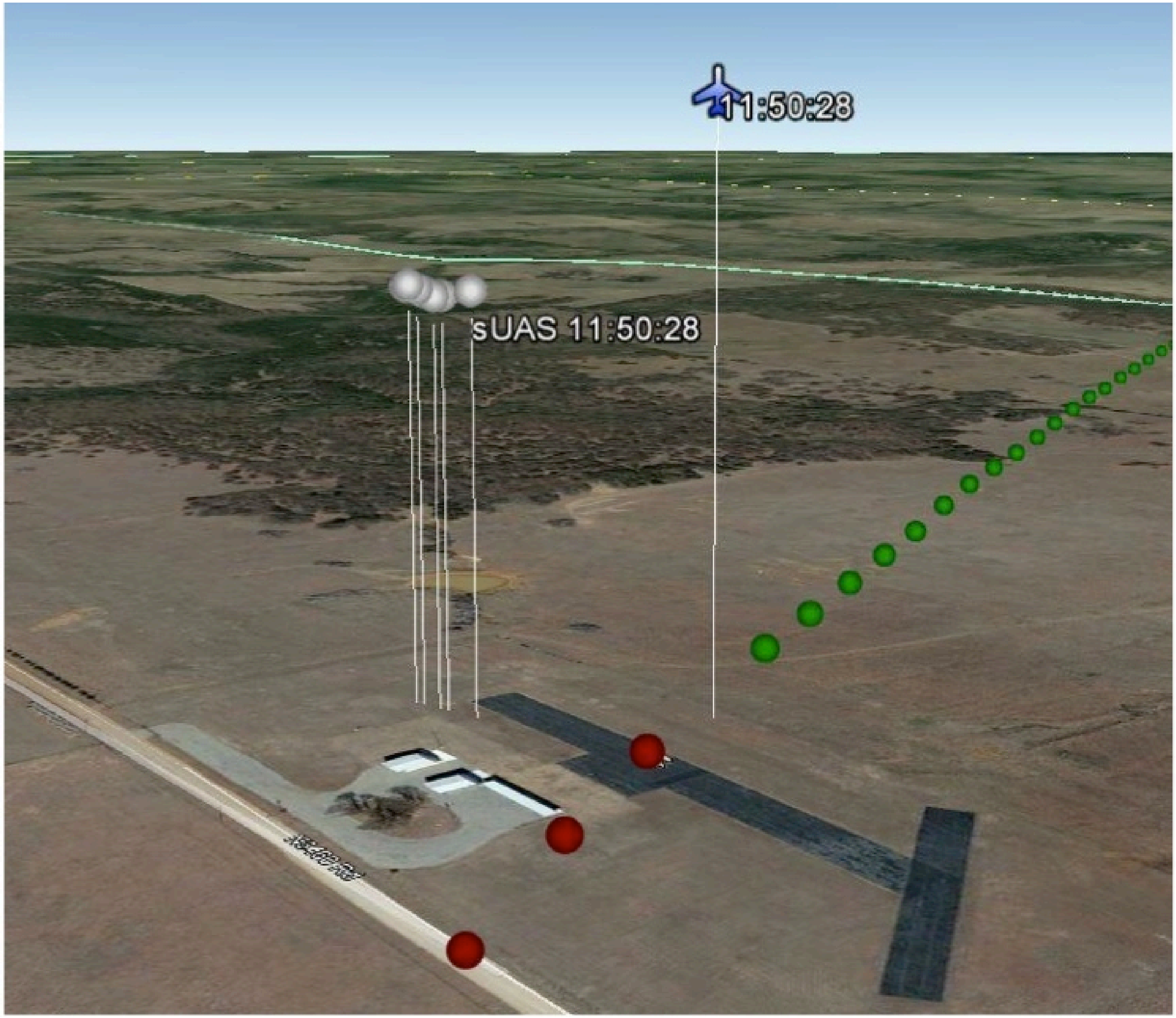
FW Encounter



RW Encounter

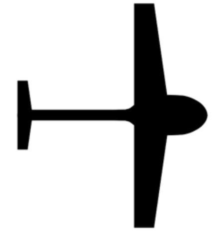
Bird Encounter

RW Encounter – Closest Detection



FW Encounter – Furthest Detection

Distance Estimates

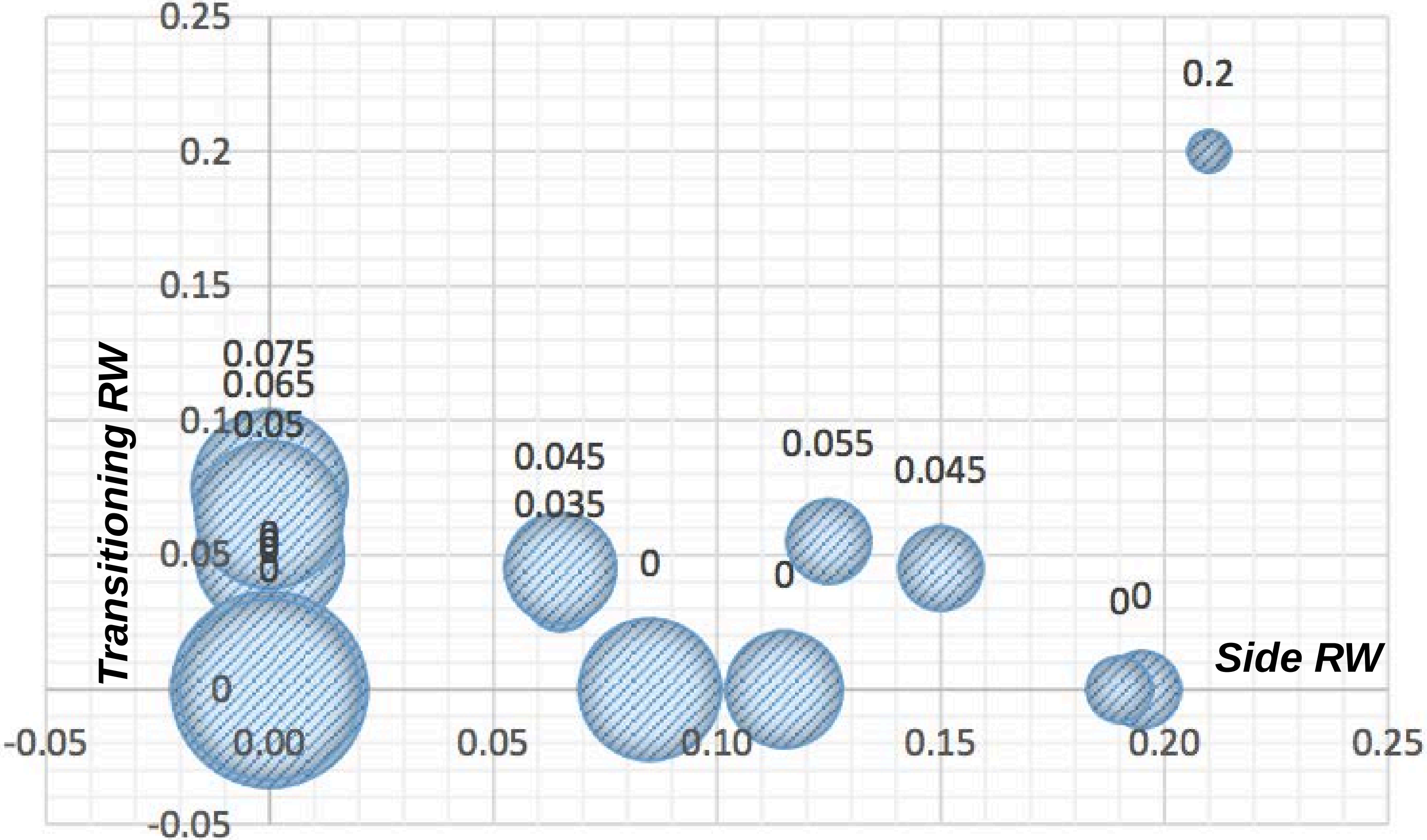
  

	2			3			4			5			6		
Flt	Act	Est	Δ	Act	Est	Δ	Act	Est	Δ	Act	Est	Δ	Act	Est	Δ
1				.39	.50	-.11							.22	0	.22
2	.17	.25	-.08										.72	.50	.22
3													.98	1.50	-.52
4	.08	.04	.04	.15	.095	.06							.49	.095	.40
5	.31	.25	.06	.07	.25	-.18							.16	.25	-.09
6				.08	1.0	-.92				.06	1.0	-.94			
7										.10	.125	-.03	.79	.25	.54
8	.34	.25	.09	.08	.125	-.05	.19	1.4	-1.21	.21	1.8	-1.59	.07	.095	-.03
9				.07	.057	.01	.05	.047	0				N/A	.152	N/A
10	.09	.09	0	.14	.076	.06									
11				.13	.057	.07				.07	.019	.05	.19	0	.19
12	.11	.25	-.14	.19	.75	-.56	.09	.25	-.16				.26	.25	.01
13	.13	.08	.05	.12	.19	-.07	.11	.057	.05				.26	.114	.15
14													.61	.379	.23
15				.13	.057	.07	.09	.028	.06				.45	.076	.37
16	.13	N/A	N/A	.28	.75	-.47				.18	.5	-.32			
17							.15	.19	-.04				.86	.095	.77
18										.13	.038	.09	.78	N/A	N/A
19													1.36	1.0	.36
20													1.17	.25	.92

Observations Can Be Deceiving

Results

RW Detection Rates: 26-58% (higher for station UA)
FW Detection Rates: 84%



Results

- **Size estimation error** – participants poorly estimate the size and distance of the UA from the aircraft
- **Parallax error** – despite being aware of the positive vertical separation, several participants reported still perceiving the UA to be in such proximity that they felt a collision was imminent
- **Paint scheme** – UA color has a large impact on detection
- **Wing flash** – fixed wing maneuvering vehicles are much easier to see due to the large wing and banking maneuver
- **Reaction time estimation error** – Contrary to the telemetry data, most participants reported they could avoid a UAS collision

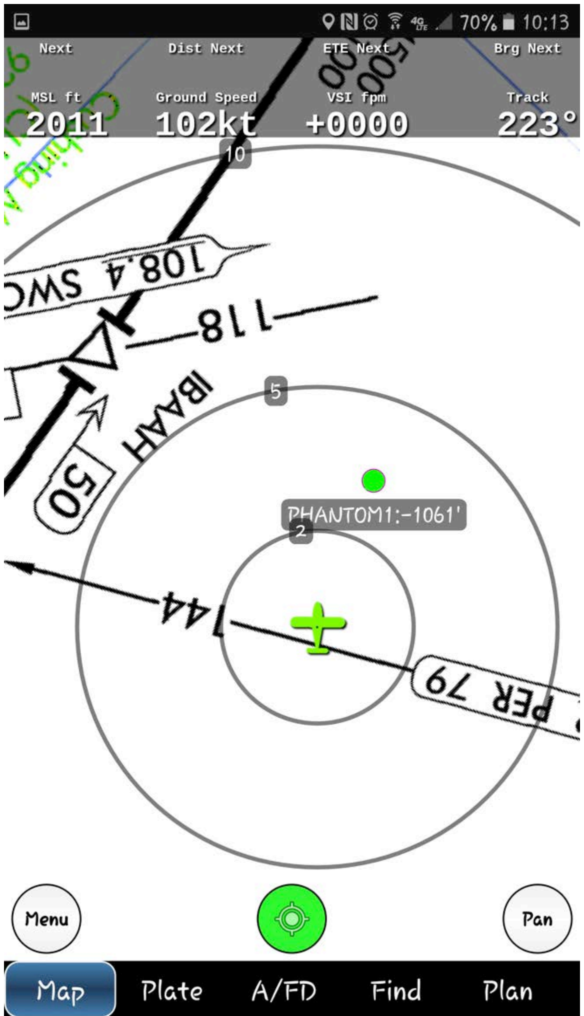
Platform	Detection Distance	Speed	Available Reaction Time
Anaconda	0.493 SM	115.08mph (100 kts)	15.42 seconds
Iris	0.10 SM	115.08mph (100 kts)	3.12 seconds

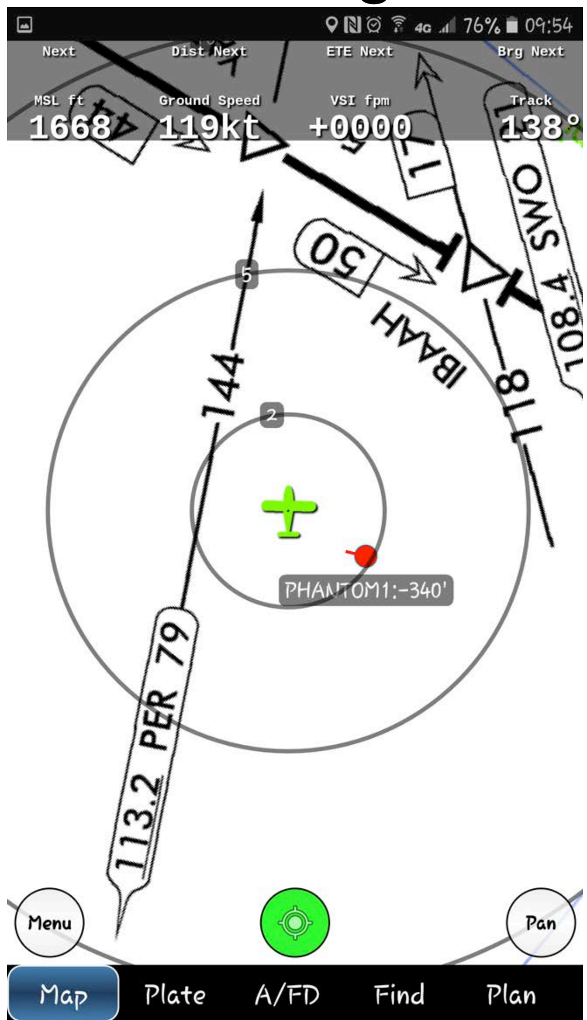
Recommendations for VMC Detection

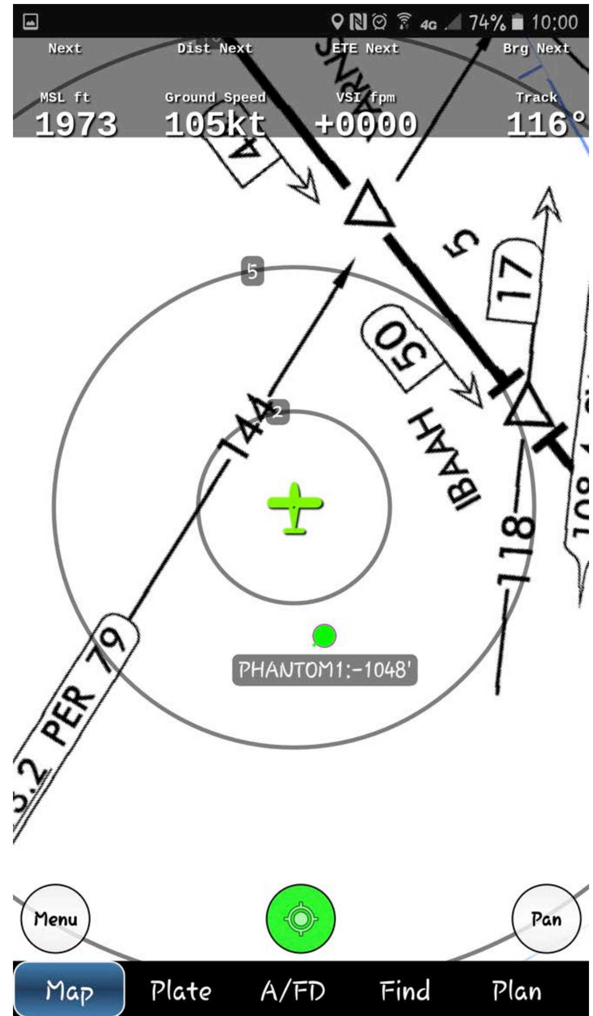
- **Full-range scanning.** Full-range scanning is critical to ensuring safety in the visual environment (see AC 90-48D, *Pilots' Role in Collision Avoidance)*
- **Enlist others to assist in UAS detection.** Enlist the aid of other crewmembers or passengers to assist in UAS visual detection by putting more eyes on more sky, particularly in areas proximate to UAS operations.
- **Realize the limitations of vision.** It is important to understand the physical limitations of vision as a mechanism of collision detection. Visual illusions such as the aforementioned parallax error and size estimation error can lead to poor aeronautical decision-making regarding UAS avoidance and evasion.
- **Do not delay evasion.** The study results indicate pilots are consistently poor at estimating UAS distance. The authors recommend pilots actively maneuver to avoid or evade close encounters with UAS platforms, provided the maneuver can be performed without compromising flight safety.

ADS-B Visibility Tests

- uAvionix Ping Rx/Tx connected to EFB
- Provides distance, bearing, and altitude of UA





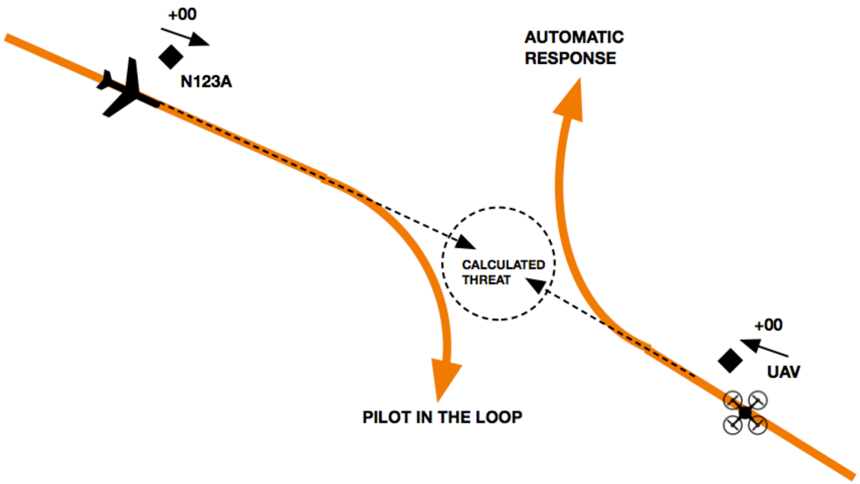


Preliminary ADS-B Comments

- **Operability** Simple installation and operation; low SWAP did not significantly reduce endurance.
- **Peace of mind** It sounds contrary, however knowing that a target is observed (either by sight or by sensory equipment) is reassuring.
- **Knowing where to look** Pilots commented on how important it was to know where the target was in relation to the flight path.
- **Type of UA** Is it a rotor wing or a fixed wing? Can be differentiated on ADS-B Tx. Helps pilot in predicting the UA capabilities and movement as well as what to look for.

Planned Future Efforts

- The study has many limitations, so the next steps will be in addressing these short comings, including
  - UA configuration (color, size, navigation aids)
  - Meteorological conditions (viz., time of day)
- Effect of ADS-B on detection rate and distance estimation will be a primary focus
  - EFB
  - Voice cues
  - HUD
- Automatic collision avoidance on UA



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- Marc Hartman, Pilot
- Taylor Mitchell, USRI Research Engineer

Supplementary Information

Manned AC Crew Roles & Responsibilities

- PIC
  - Solely responsible for operation of aircraft
  - Weather Call
  - Safety
  - Communications with ATC/Tower
- Participant Pilot
  - Research subject
  - Visually locates UAS
    - Reports sighting
    - Indicates perception of collision threat (yes, no)
    - Indicates avoidance maneuver (climb or descent; right/left turn)
- Safety Observer
  - Aid PIC in safe operation of aircraft
  - Navigation, visual detection of other aircraft or threats
  - Emergency procedures assistance
  - Tracks UAS via ADS-B on EFB (all Phases)

Communication Flow

Flying Pilot Communications	**UAS Pilot Communications**
1. Inbound to the hold - 10 minutes out.	Acknowledge
2. Established in the box	Acknowledge
3.	Box open, report Point I
4. Box open, report Point I	Acknowledge
5. Crossing Point I	Approved into the Box. Intercept initiated. Report once in the Box.
6. Cleared into the Box. Will report.	
7. Aircraft is in the Box.	Acknowledge
8. Aircraft over Center Point (CP)	Aircraft merged with UAV.
9. Aircraft exiting Box.	Box Closed, UAV transiting altitude.
10. Established in the (West/East) hold	(Repeat from Sequence #3)

Pilot Communications Setup

Flying Pilot Communications	**UAV Pilot Communications**
COM 1: •123.4 Air-to-Ground Coordination •121.5 Emergency Frequency COM 2: •123.50 Local (SWO) CTAF •135.725 Local ASOS NAV: 108.4 VORTAC Handheld Radio •Emergency B/U for 123.4 (Knock-it-Off call)	Handheld Air-to-Ground Radio •123.4 Air-to-Ground Coordination •121.5 Emergency Frequency Ground Radio •Coordination frequency for visual observers (as required)

Participant Qualifications

- Flying Pilot
  - Commercially-certificated, with Instrument Rating
- Experimental Pilot
  - Private Pilot or higher
- Safety Observer
  - Private Pilot or higher

Ground Control Station

- Field Transportable Communications Link
  - Pelican Case iM2590
  - Custom Front Panel
  - DVR Capture of Displays
  - 120 VAC with distributed power (DC 12V)
  - USB communication protocol
- Primary Display
  - 1 x Semi-Rugged Panasonic Toughbook (CF53)
    - Waypoint Navigation and Control
- Secondary Display
  - 2 x 11" LCD
    - Attitude and Telemetry
    - FPV streaming from aircraft

Data Collection

- Aircraft data collected via mounted Contour HD EO Camera
  - E/O (visual) recording
  - Time-stamped GPS location
  - Auditory Recording via microphone to Experimental Pilot
- Location Data
  - Recorded via Contour HD
  - Aircraft backup may use Bad Elf BT GPS
  - UAS will use proprietary software or Bad Elf BT GPS