Using Aircraft-Deployed Low Altitude UAS in Tropical Cyclones: Testing in 2009 and plans for 2010-11

Joseph Cione NOAA/Hurricane Research Division

Nancy Ash NOAA/AOC

Intergovernmental Hurricane Conference

Savannah, Georgia

March 1, 2010

Coyote Specifications

Parameter	Value (U.S.)	Value (Metric)
Maximum Gross Takeoff Weight (MGTW)	14 lbs	6.4 kg
Nominal Mission Takeoff Weight (NMTW)	12 lbs	5.4 kg
Nominal Mission Endurance	1.5 Hours	
Motor	Brushless Electric Motor	
Airspeed (Cruise @ NMTW)	50 kts	93 kph
Airspeed (Dash - level flight @ NMTW)	75 kts	140kph
Airspeed (Max. Endurance @ NMTW)	45 kts	83kph
Airspeed (Stall @ NMTW)	38 kts	70kph
Airspeed (VNE @ NMTW)	100 kts	185kph
Navigation	GPS	
Service Ceiling	25,000 feet	7,610 meters
Payload (EO)	Sony FCB-IX10A EO Camera	
Payload (IR)	BAE SCC500, Uncooled IR	
Command and Control Radio (C2)	Up to 2 Watt, Discrete/Frequency Agile, Military Band / ISM Band Radio Modem (TX/RX)	
Command and Control Radio Range	20 nm, Line of Sight (LOS)	36 km, Line of Sight (LOS)
Video Transmitter	2 Watt (optional 5W), S-Band FM Video TX With Optional 19.2kbps Data Carrier	
Video Transmission Frequency Range	2.20-2.39 GHz	
Video System Range	20 nm, LOS	36 km, LOS
Payload Capacity	Up to 5 lbs	Up to 2.25 kg
Onboard Power	12V, 200Wh	
Propulsion	13x13 Foldable Propeller	

advanced ceramics research

3292 East Hemisphere Loop • Tucson, Arizona 85706
T: 520.573.6300 • F: 520.573.2057 • www.acrtucson.com

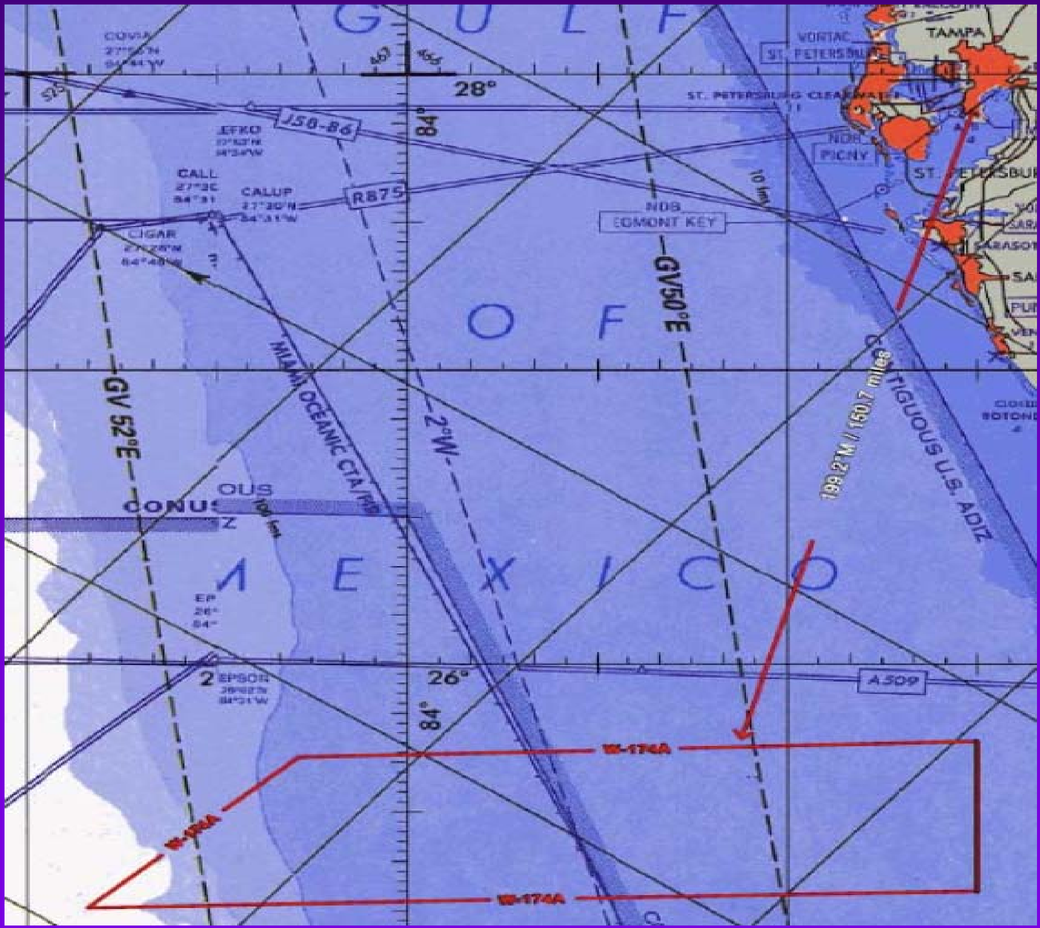
050620

Demonstration 2009

Coyote launched from free-fall sonobuoy chute

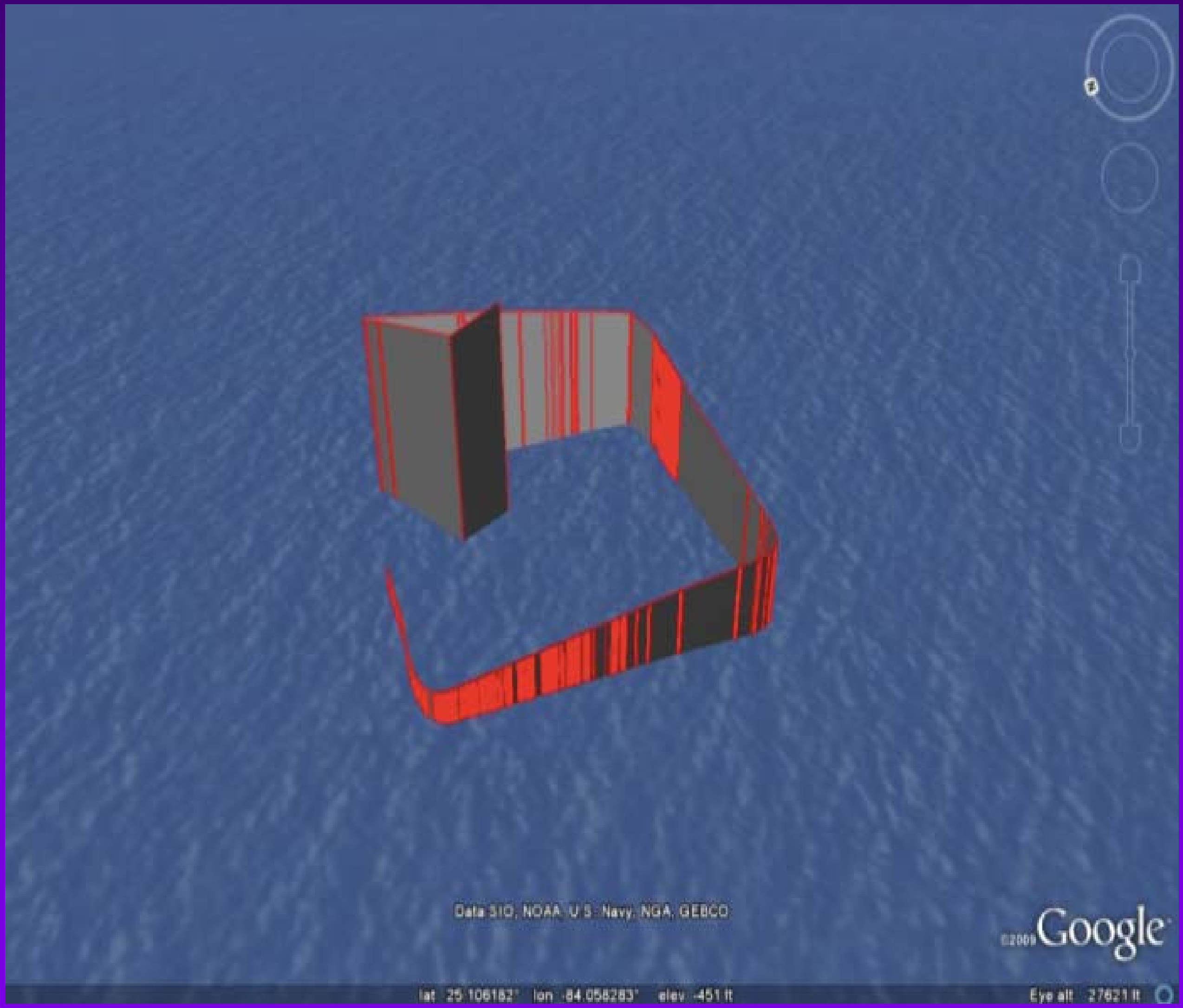
Demonstration 2009

Approved Airspace



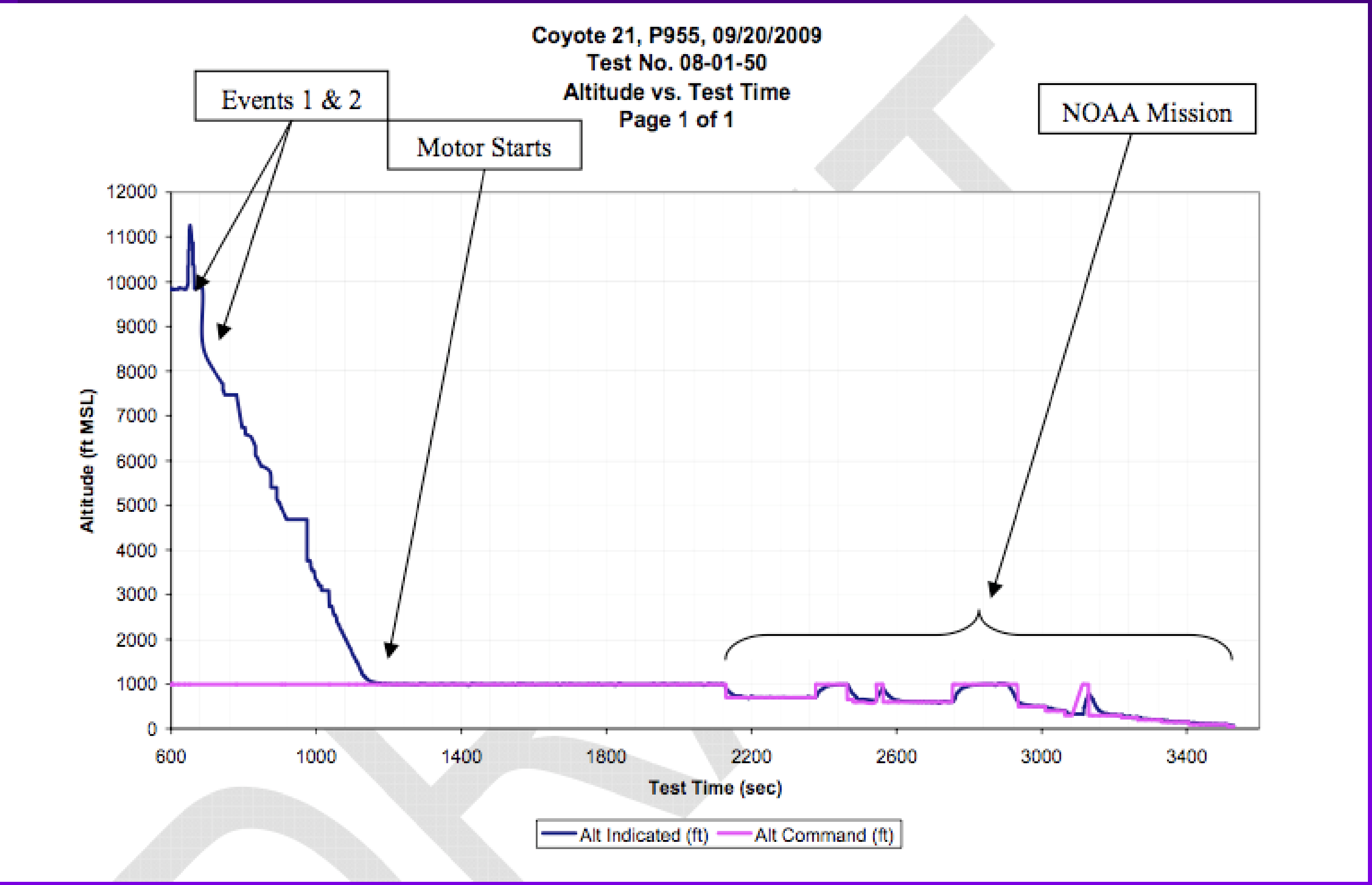
Demonstration 2009

Flight Profile



Demonstration 2009

Flight Profile



Coyote UAS Test Flight 090920I Summary….

- **Coyote Flight 9/20/2009 Into Warning Area 174 (NW of Key West)**
- **Mission Plan: Launch, command & control Coyote using NOAA P-3 aircraft**
- Three Coyote UAS were brought onboard the manned aircraft. The plan was to deploy two UAS with the third to at as a back up.
- Science team members. Cione, Uhlhorn, Lorsolo (HRD); Ash (AOC); Corcoran, Osbrink (BAE Systems)
- Mission Synopsis: Takeoff: 930am local out of MacDill Air Force Base
- ~1030am: First Coyote deployed. Parachute malfunction resulted in fast fall. First UAS test release was unsuccessful.
- Coyote 2: BAE had problems with initialization. Effort aborted.
- ~1230pm: Began initializing Coyote #3.
- **Third (and final) Coyote UAS launch was a success.** Release time ~1pm local
- Operational plan: Fly UAS within a 3mi x 3 mi 'box pattern'. Coyote deployed from P-3 @10,000ft . Before activating the UAS' (electric) motor remotely, the Coyote was required to establish 5,000 ft separation with 43. **After several minutes of controlled glide descent, the Coyote was fully operational @5000ft. Coyote continued descent to 1,000ft. The remainder of the flight consisted of repeated ascending and descending controlled soundings between 600-1000ft. The last 5-10 minutes of the flight included control stair-step descent from ~600ft UAS down to ~64ft.**
- 4 GPS sondes were released during the 50-minute UAS test flight. The last drop occurred as the UAS was at ~100ft altitude. 5000 ft vertical/3-5min horizontal separation was maintained. The P-3 conducted 'multiple spirals' centered on the Coyote 3mi x 3mi boxed flight plan below. (Planned) 'lost comms' checks worked as expected.
- **Post-mission observations/lessons learned:**
- BAE's difficulty in obtaining timely UAS pre-flight initialization. Still, it was the 1st time BAE operated/worked with P-3/AOC personnel. Improvement is expected next time.
- **Weaker than expected P-3/UAS in-flight communications.** After speaking with BAE engineers, they are confident gain can be greatly improved with a stronger antenna/receiver system. BAE says they already have a fix for this and expect no issues going forward.
- **Short battery life.** The 50minute duration will be dramatically increased once a shorter pre-flight routine is established. Reducing/eliminating 'up soundings' would also increase duration. BAE also feels that increased battery power (for enhanced duration) is very possible and should not be a major issue going forward.

2010-11 Objectives

1. Improve Communications Range *(Iridium/ NavAir RF transmitter/ amplifier and improved C2 antenna)*
2. Improve UAS endurance *(battery)*
3. Integrate met sensors onto Coyote *(GPS sensors/mistsonde board)*
4. Instrument bench testing
5. Pre-season UAS-manned flight test/cross comparisons
   (likely winter/spring 2011…)
6. Test UAS in Tropical Cyclone conditions *(P-3/UAS mission)*
   (likely summer/fall 2011…)

Airspace Options (Pre-season 2011 test flight)

1. UAS systems checkout and instrument cross comparison flight

   -*Recover Coyotes*

Options:

Primary: AVON MOA

Backups: Kennedy Space Center, Wallops Island

AVON MOA

RESTRICTED
R-2901 A & B
R-2901 E
R-2901 C
R-2901 G
R-2901 I
AVON EAST MOA
AVON SOUTH MOA
MARIAN MOA
LAKE PLACID MOA
BASINGER MOA
MACDILL AFB AUX (AGR)
N

Airspace Options (in-storm 2011 mission)

1. Fly UAS using P-3 launch, command and control
2. UAS instrumented with GPS sensors *(PTHU capable)*

   -<u>Do not</u> recover Coyotes

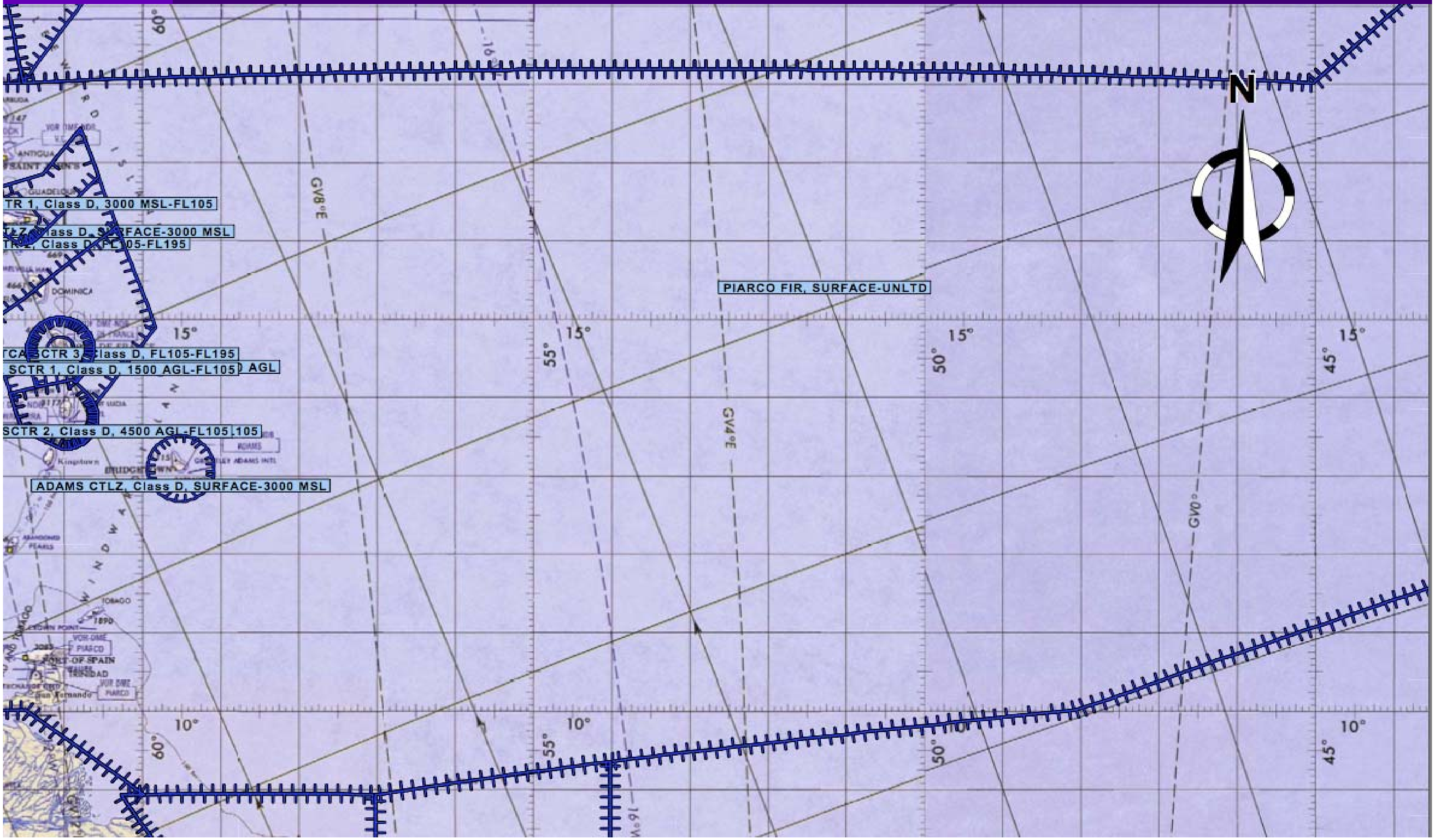
Options:

Piarco *(Barbados or possibly St. Croix deployment)*

Wallops/Navy controlled airspace *(east coast US)*

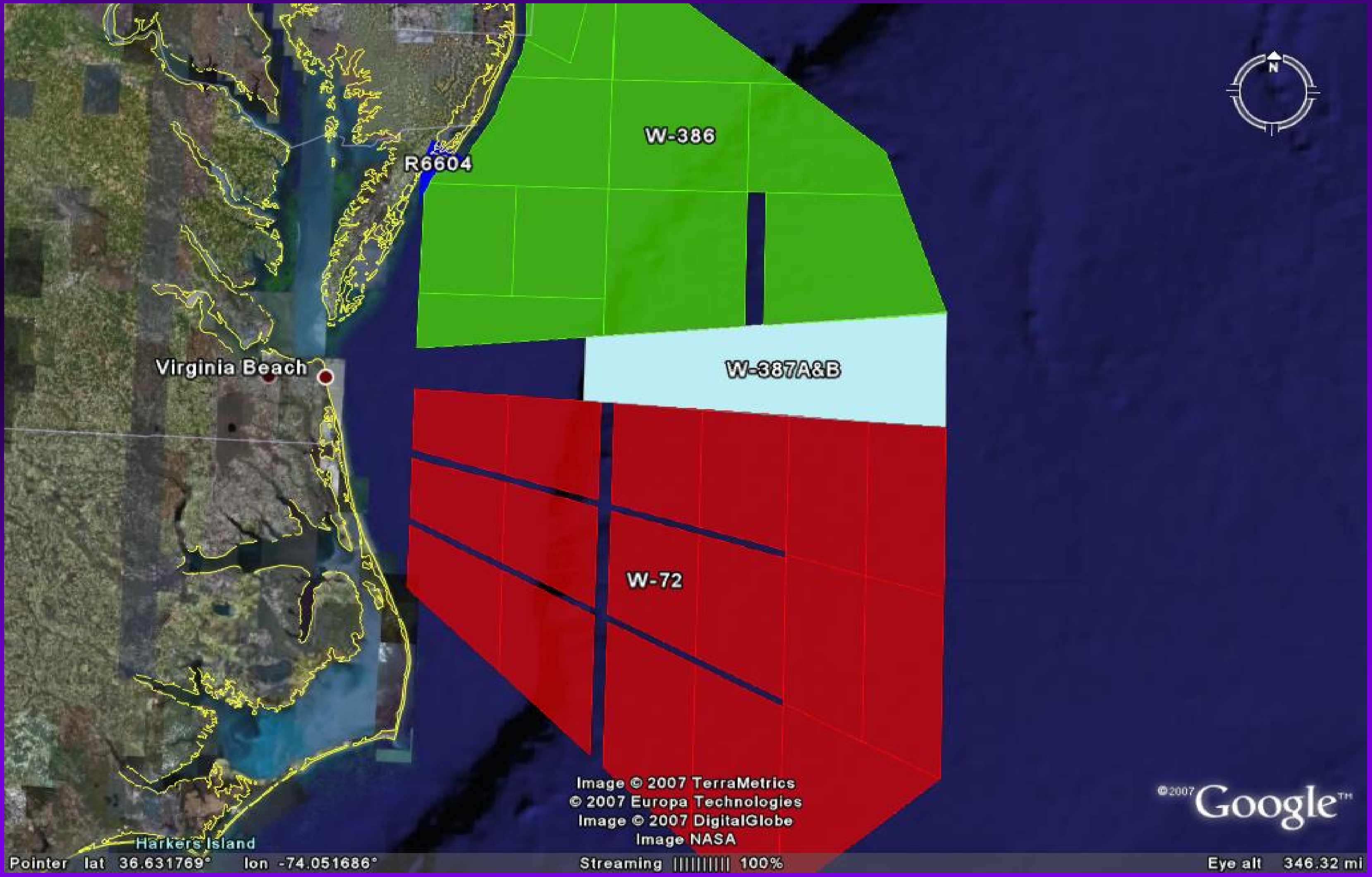
Gulf of Mexico warning areas

Barbados and PIARCO



W-168 and W-174

Wallops



W-386
R6604
Virginia Beach
W-387A&B
W-72
Harkers Island
Image © 2007 TerraMetrics
© 2007 Europa Technologies
Image © 2007 DigitalGlobe
Image NASA
©2007 Google
Pointer lat 36.631769° lon -74.051686°
Streaming |||||||||| 100%
Eye alt 346.32 mi

Primary Low Altitude UAS Tropical Cyclone Mission Objectives

- **Fill critical data gaps. Provide observations from an important region of the storm that is very difficult (and dangerous) to observe.**
  - **Provide high resolution near-surface observations (PTHU)-**
  - **Ensure real-time data availability -**
    - **To NHC/EMC (and other interested operational centers)**
- **Fully demonstrate the UAS' overall capabilities in a variety of conditions within a hurricane environment.** ***Including operations at very low altitudes ($\leq$200ft)***
- **Leverage NOAA's P-3 manned aircraft to further enhance the utility of UAS-Hurricane missions (e.g. launch, command and control from existing NOAA manned assets)**

Coyote UAS in-storm Demo open questions….

- **2011:** **Can the UAS survive (and adequately perform) in a hurricane environment?**

  This includes (but is not limited to) assessing the UAS' effectiveness with respect to to in-storm survivability; 2-way communications and data transmission; flight duration (≥1.5h); and quality of measurements (PTHU).

- **Beyond 2011:** **Additional options, flexibility and improved capabilities?**

  i. In-storm release of multiple UAS?
  ii. Multiple command and control aircraft and/or deployment vehicle options?
  iii. Significant (4h+?) increase in UAS flight duration? ***(Battery, airframe enhancement?)***
  iv. Significant increase with respect to UAS-to-command aircraft separation/range?
  v. More payload possibilities? ***(Sophisticated and/or higher quality sensors, additional payload space and/or carry capacity?)***

Coyote TC-UAS Mission Possibilities…

EYE SOUNDING/LOITERING/EYEWALL EXPERIMENTS-

Research objectives:

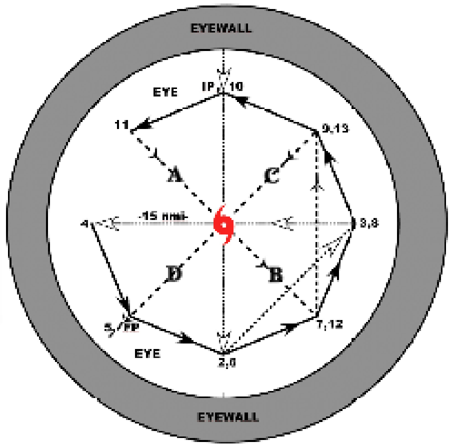
- **Improve understanding of TC eye/eyewall heat, moisture and momentum exchange processes;**
- **Continuously monitor TC intensity with the possibility of capturing a rapid intensity change event.** ***(This particular module, for 2010, would be a proof-of-concept only mission since capturing TC intensity change would require multiple back-to-back Coyote UAS launches.)***

Mode of UAS transport: As the “launch, command and control” P-3 conducts orbits within the eye at altitude (10,000ft), the Coyote UAS would initially be deployed in the eye and then circumnavigate ($r \leq 50$km) the hurricane eyewall. For the TC monitoring/intensity change module, the UAS would provide PTHU profile and near surface data within the hurricane eye.

Potential operational benefits?

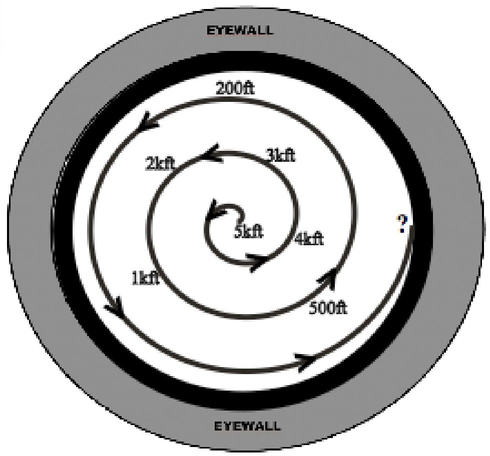
1. **Unique -continuous- measurements of near-surface winds in the eyewall. Should potetnially help NHC better estimate ‘maximum surface wind speed’.**
2. **Possible early detection of a rapid intensity change process as ‘loitering’ in the eye takes place.**

Coyote UAS - P3 Mature Hurricane Eye Module



P-3 FLIGHT PATTERN

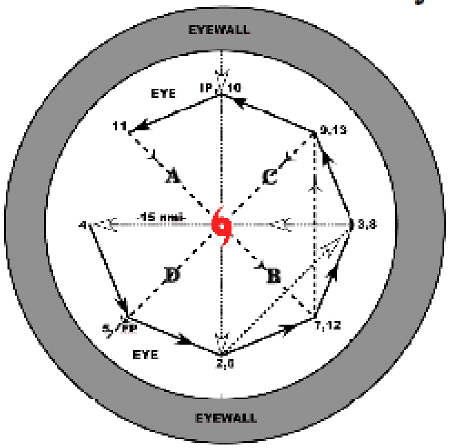
The P-3 approaches from the north at an altitude of 10,000ft, penetrates the eyewall into the eye, and performs a figure-4 (dotted line) in the eye. **Midway during leg 3-4 the Coyote UAS is released.** The P-3, remaining at 10,000ft, circumnavigates the eye in an octagon pattern and conducts another figure-4 rotated 45 degrees from the original (dashed line). Flight duration for this module should be close to 1 hour. An add-on ~45 minute duration module may also be conducted. This optional module would initiate where the preceding module ended (point 'FP'). The P-3 would proceed counterclockwise, repeating points 6-13 and completing the pattern once again at point 'FP'. **14 Dropsonde releases** should be conducted during the primary 1h module at the following locations: IP;2-5;7;9;11;A-D and midway during legs IP-2 and 13-FP. In addition, **9 AXBT launches** should be conducted at points 4 through 11 and midway during leg 11-12. (Note: except for AXBT drop at point 4, it is acceptable to launch all remaining 8 AXBT probes during the optional 45 minute second module.)



COYOTE UAS FLIGHT PATTERN

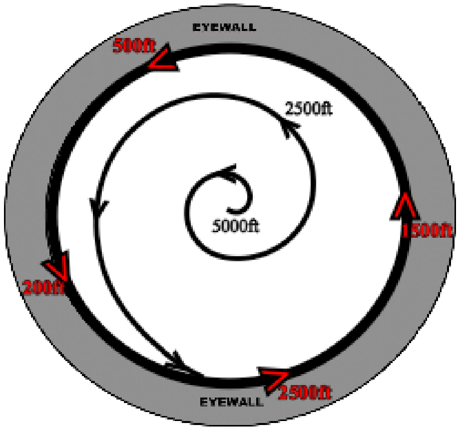
Midway during P-3 leg 3-4, the Coyote UAS is released at 10,000ft altitude. The Coyote UAS proceeds to glide (unpowered) in a downward counterclockwise spiral to an altitude of 5,000ft. **At 5000ft, the UAS motor is started and the Coyote continues its counterclockwise descent in 1000ft increments.** At each interval (4kft,3kft,2kft,1kft), the UAS maintains altitude for 3 minutes prior continuing its counterclockwise, radially expanding with decreasing altitude, spiral descent. After 3 minutes at 1000ft, the Coyote descends to 500ft and remains at this altitude for 3 minutes. **The UAS continues to descend in 100ft increments down to 200ft, maintaining altitude for 3 minutes at each level.** The remainder of the flight is conducted at 200ft until battery power is fully expended and the UAS reaches the ocean surface. (Note: If full descent to 200ft is achieved and the UAS has sufficient battery power to continue, **an optional 'eyewall penetration' module may be considered** if conditions present themselves. Prior to any attempted UAS eye-eyewall penetration, the Coyote should ascend from 200ft to a (minimum) altitude of 500ft.)

Coyote UAS - P3 Mature Hurricane Eyewall Module



P-3 FLIGHT PATTERN

The P-3 approaches from the north at an altitude of 10,000ft, penetrates the eyewall into the eye, and performs a figure-4 (dotted line) in the eye. **Midway during leg 3-4 the Coyote UAS is released.** The P-3, remaining at 10,000ft, circumnavigates the eye in an octagon pattern and conducts another figure-4 rotated 45 degrees from the original (dashed line). Flight duration for this module should be close to 1 hour. An add-on ~45 minute duration module may also be conducted. This optional module would initiate where the preceding module ended (point 'FP'). The P-3 would proceed counterclockwise, repeating points 6-13 and completing the pattern once again at point 'FP'. **14 Dropsonde releases** should be conducted during the primary 1h module at the following locations: IP;2-5;7;9;11;A-D and midway during legs IP-2 and 13-FP. In addition, **9 AXBT launches** should be conducted at points 4 through 11 and midway during leg 11-12. (Note: except for AXBT drop at point 4, it is acceptable to launch all remaining 8 AXBT probes during the optional 45 minute second module.)



COYOTE UAS FLIGHT PATTERN

Midway during P-3 leg 3-4, the Coyote UAS is released at 10,000ft altitude. The Coyote UAS proceeds to glide (unpowered) in a downward counterclockwise spiral to an altitude of 5,000ft. At 5000ft, the UAS motor is started and the Coyote continues its counterclockwise descent to 2500ft. **The UAS maintains 2500 ft altitude and continues its outward counterclockwise spiral until it reaches the hurricane eyewall.** Once the Coyote penetrates and stabilizes **within the hurricane eyewall, the UAS begins a step-decent pattern from 2500ft down to 500ft** (while maintaining altitude for 3 minutes at each level). After reaching and maintaining 500ft for 5 minutes begin a steady decent down to 200ft within the eyewall. **Maintain 200ft altitude within the hurricane eyewall until battery power is fully expended and the UAS reaches the ocean surface.**

Discussion: Low Altitude Observing Strategies….

Intergovernmental Hurricane Conference

Savannah, Georgia

March 1, 2010

General Guidelines for
for Low Altitude UAS Hurricane Missions

- **Ensure safety**
- **Fill an existing critical low altitude data void in hurricanes**
- **Complement and support NOAA's existing research & operations**
- **Minimize mission and regulatory 'risk' (increase the likelihood for success)**
- **Minimize Cost**

LALE TC UAS CONOP comparison

Land-launched vs. Air-deployed

- *Execution of a low altitude UAS TC flight mission…pros and cons*

First up…

Common to both CONOPS

Pro:

1. Fill existing critical low altitude data void in tropical systems (significant benefit to both research and operations)
2. Ensure safety (No need for low level manned flight in hurricanes below 5kft)
3. All UAS operations now fall within NOAA's existing ORM (risk management)
4. Potential to expand coverage exists now (multiple UAS/storm)

Con:

1. Limited payload capability (power/weight/endurance issues)
2. Limited instrumentation options (cost ceiling- given 'expendable' nature of platform)
3. Regulatory risk (land-based has higher risk but air-deployed still has some exposure)

LALE TC UAS CONOP comparison

Land-launched vs. Air-deployed

Execution of a low altitude UAS TC flight mission…pros and cons

Land-launched:

Pro:

1. **No ‘Mothership’ required**
2. **Obtain observations 100’s of miles from TC in addition to inner core**

Con:

1. **To date, restrictive range limitations exist (~500mi 1-way). Mission execution determined by TC position relative to a fixed UAS deployment location.**
2. **Significant ingress and egress mission failure risk. (Flight into and out of the storm comprise ≥70% of UAS mission time.)**
3. **Significant regulatory risk. (FAA is especially leery of ‘fair weather’ ingress/egress portions of the proposed flight)**
4. **Operations require very early deployment of the launch team, often days before an inherently uncertain event. (increased mission failure risk)**
5. **Very high cost in dollars and in time. Consistent successful execution of this conop requires several pre-position deployment sites and teams. Large travel and labor costs including multiple site surveys and months of planning to coordinate. A myriad of logistical issues need to be addressed (including but not limited to: lodging, ITAR import/export regulation, securing required national and international airspace clearances, operator clearances, local media requests, etc).**
6. **Operations potentially involve a complex chain of (required) real-time communication (e.g. ground-based UAS operators, mission scientists, manned aircraft personnel, national/international airspace operators, CARCAH)**

LALE TC UAS CONOP comparison

Land-launched vs. Air-deployed

Execution of a low altitude UAS TC flight mission…pros and cons

Air-deployed:

Pro:

1. If manned aircraft is within operational range of a TC, so is the UAS.
2. No ingress/egress mission or regulatory risk.
3. No need to establish on-the-ground mission assets or team pre-deployments (reduced mission risk, cost)
4. Aircraft command and control results in streamlined communications (reduced overall mission risk)
5. Leverage of existing NOAA hurricane field operations infrastructure including manned assets (AoC, HRD) and aircraft instrumentation (P-3 launch, command and control, P-3 communications, data, and expendable deployment systems)
6. Potential for significant overall cost and personnel savings (pre-season: minimal logistics set-up time and cost; in-season operations: reduced travel and labor costs)

Con:

1. If manned aircraft is out of operational range, so is the UAS. (Mothership dependent)
2. To date, limited endurance/range capability (restricted storm coverage/UAS)