## 2024 NOAA/AOML/HRD Hurricane Field Program - APHEX

## MATURE STAGE EXPERIMENT
*Science Description*

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**Experiment/Module:** Research In Coordination with Operations Small Uncrewed Air Vehicle Experiment (RICO SUAVE)

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**Requirements:** Categories 1–5

**Plain Language Description:** This experiment will leverage NOAA's P-3 aircraft to deploy uncrewed assets into regions of the TC environment that are unsafe for crewed operations. The experimental goals are to improve physical understanding, situational awareness, and ultimately, operational forecasts of TC track and intensity. It is believed that observations from these unique platforms will improve basic understanding and enhance forecaster situational awareness. Detailed analyses of data collected from these small drones also have the potential to improve the physics of computer models that predict changes in storm intensity.

**Mature Stage Science Objective(s) Addressed:**

1) Test emerging (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne and surface measurements in mature hurricanes. These measurements include improved three-dimensional representation of the hurricane wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds and underlying oceanic conditions [*APHEX Goal 2*].
2) Collect observations targeted at better understanding internal processes contributing to mature hurricane structure and intensity change [*APHEX Goals 1, 3*].

**Motivation:** Reducing the uncertainty associated with TC intensity forecasts remains a top priority of NWS/NHC. In addition to NOAA's operational requirements (sampling surface wind and thermodynamic structure), developing the capability to regularly fly low-altitude small uncrewed aircraft systems (sUAS) into TCs helps to advance NOAA research by allowing scientists to sample and analyze a region of the storm that would otherwise be impossible to observe in detail (due to the severe safety risks associated with crewed reconnaissance). It is believed that such improvements in basic understanding are likely to improve future numerical forecasts of TC intensity change. Over time, projects such as this, which explore the utilization of unconventional and innovative technologies in order to more effectively sample critical regions of the storm environment should help reduce this inherent uncertainty. Coordination with uncrewed ocean surface vehicles (e.g., saildrones) in a hurricane, if the opportunity arises, will enable unique collocated measurements of the upper ocean, air-sea interface, and atmospheric boundary layer from autonomous vehicles.

**Background:** The Area-I Altius 600 is an electric-powered sUAS that has 3-4 h of endurance with a maximum 190-n mi range (in clear air conditions). The aircraft has a wingspan of 8.3 ft and a gross weight of 25-27 lbs. Once airborne, the sUAS collects in-situ measurements of pressure, temperature, relative humidity (PTHU), and remotely senses sea surface temperature. In 2023 the Altius was upgraded to have a new multi-hole pressure port probe capable of measuring turbulent wind quantities. In some ways, the Altius 600 sUAS is similar to the GPS dropwindsonde since both observing platforms are air-deployed and both use identical (Vaisala RD41) meteorological payloads. However, unlike the dropsonde, the Altius 600 can target specific areas within the storm circulation in detail (both in the horizontal and in the vertical). Furthermore, observations from the Altius 600 are continuous (~5 Hz) and long-duration (hours versus minutes) which gives scientists an extended look into important turbulence-scale thermodynamic and kinematic processes that regularly occur within the near-surface TC boundary layer (Cione et al. 2016, Cione et al. 2020). The Altius 600, when operated within a hurricane environment, will provide a unique observation platform to observe the low-level atmospheric boundary layer and sea surface environment in great detail.

An additional sUAS (Black Swift Technologies S0) is also expected to be available during the 2024 HFP. The endurance for the S0 was recently tested to ~1.5h. Range tests are ongoing but the final values are expected to be similar to values observed using the Altius platform. This smaller sUAS (3 lbs, 3ft wingspan) will also measure pressure, temperature, and humidity (PTHU), remotely sensed sea surface temperature, and wave height using a laser. Wind velocity and atmospheric turbulence measurements will also be available using this aircraft.

**Goal(s):** This module aims to collect PTHU observations within the high-wind-speed eyewall and boundary-layer inflow regions of mature hurricanes. A primary goal is to provide real-time wind velocity data to improve operational situational awareness (RMW, VMax). An equally important, albeit longer-term goal, is to improve basic understanding of a sparsely sampled, yet critically important region of the TC where turbulent exchanges of heat, moisture, and momentum with the ocean and eye-eyewall interfaces regularly occur. These observational data will also be used to evaluate model performance as it relates to boundary-layer thermodynamic and kinematic structure and ocean response.

**Hypotheses:**

1. 360-degree depictions of hurricane boundary-layer RMW and VMax at multiple altitudes are possible by conducting sUAS eyewall orbit missions by strategically synchronizing the prevailing wind direction with sUAS heading.
2. Accurate depictions of the TC thermodynamic and kinematic inflow layer (100-1500 m) are possible using strategically deployed dropsonde and sUAS observations and can yield information about important physical processes that control TC intensity.

3. Deriving the vertical profile of turbulence information at hurricane-force wind speeds is feasible with the specifically-designed P-3 and sUAS flight patterns.
4. Eye loitering, TC center fixes, and eye-eyewall sampling are possible using sUAS.

**Objectives:**

1. Eyewall module: Make sUAS High Density Observations (HDOBs) available in near real time to NHC; Report estimates of RMW and Vmax at multiple altitudes and azimuths to NHC in near real time. In post-storm mode, conduct analyses comparing sUAS atmospheric and SST eyewall observations with operational analyses and forecast fields from HWRF and HAFS. All sUAS data collected will be available in AirOPS (AOC's P-3 situational awareness visualization tool). For data assimilation calibration purposes, flying in the same storm at varying categories within the range 1-5 is strongly preferred.
2. Inflow module: Make sUAS HDOBS available in near real-time to NHC and EMC. In post-storm mode, compare sUAS boundary-layer thermodynamic and kinematic radial structure (including SST) with numerical equivalents to improve TC boundary layer parameterizations and ocean response in HWRF and HAFS. Also, use sUAS HDOBS to improve our understanding of the role of downdrafts in determining TC intensity as well as the turbulent structure of the boundary layer.
3. sUAS inflow-layer turbulence module: Make sUAS HDOBS available in near real-time to NHC and EMC. In post-storm mode, retrieve the vertical profile of eddy viscosity at hurricane-force wind speeds using the sUAS and dropsonde observations. This information is crucial for improving boundary-layer parameterizations used in NOAA's hurricane forecast models.
4. Center fix/Eye-Eyewall module: Make sUAS HDOBS available in near real time to NHC and EMC. Report center fix estimates to NHC in near-real time. In post-storm mode, compare sUAS-boundary layer thermodynamic and kinematic and SST structure within the eye and eye/eyewall interface with numerical equivalents to improve boundary-layer parameterizations and ocean response in HWRF and HAFS.
5. Video Capture module: Capture video from a SUAS to see what conditions are in place in the lower atmosphere in TCs.
6. Saildrone Overflight module: Make sUAS HDOBS available in near real-time to NHC and EMC. In post-storm mode, compare sUAS boundary-layer thermodynamic and kinematic radial structure (including SST) with data from saildrone overflights to improve our understanding of coupled air-sea interactions as well as enhanced coupled data assimilation.

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**Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information):**

### P-3 Pattern #1: sUAS Eyewall Circumnavigation

This P-3 module can be conducted using any pattern that maximizes azimuthal eyewall coverage and will collect flight level, TDR, dropsonde, streamSonde, AXBT, and SFMR observations for sUAS comparison and validation. The P-3 pattern should maximize eyewall sampling and penetration count. Dropsondes, SST-capable dropsondes, and AXBTS (10-15 total) will be deployed in locations that are collocated with sUAS under flights.

### P-3 Pattern #2: sUAS Inflow

With the ideal sUAS inflow module starting in the upshear-left quadrant, the ideal P-3 pattern starts with a radial penetration from the downshear-right to the upshear-left quadrant. After release of the sUAS, the P-3 flies a similar flight path as the sUAS but at a higher altitude, where dropsondes, SST-capable dropsondes, streamSondes, and AXBTS (10-15 total) will be deployed every 30 degrees in azimuth in locations that are collocated with sUAS under flights. The P-3 will then continue its standard flight pattern and collect flight level, TDR, CRL, dropsonde, AXBT, and SFMR observations for sUAS comparison and validation. This pattern is designed to study the effects of downdrafts on the hurricane boundary layer which are persistent in the principal rainband in the left-of–shear quadrants (Riemer et al. 2010) whose effects have been recently shown to be height-dependent (Wadler et al. 2021). Flying the inflow module, mimics what the P-3 flew in Hurricane Bonnie (1998) and presented in Wroe and Barnes (2003).

### P-3 Pattern #3: sUAS inflow-layer turbulence Module

sUAS is released from P3 in hurricane conditions, typically within the core region of mature hurricanes. Prior to the beginning of the stepped descent mode of sUAS in the inflow layer, the ideal P-3 flight pattern is “zig-zag” such that its radial penetration can be slowed down to allow the sUAS to keep up with the P-3. A dropsonde is released from P-3 at the beginning of each flight leg, with a total of 7 dropsondes required. This pattern is designed to derive the vertical profile of eddy viscosity at hurricane-force wind speeds to fill in the gap of observations and to improve the PBL parameterizations in high-wind conditions (Chen et al. 2021; Chen 2022).

### P-3 Pattern #4: sUAS Center Fix/Eye Loiter/Eye-Eyewall Sampling Module

This P-3 module can be conducted using any pattern that maximizes inner core coverage and will collect flight level, TDR, dropsonde, streamSonde, AXBT, and SFMR observations for sUAS comparison and validation. Dropsondes, SST-capable dropsondes, and AXBTS (10-15 total) will be deployed in locations that are collocated with sUAS under flights.

### P-3 Pattern #5: Video Capture Module

There will be one sUAS equipped with video capturing technology. The sUAS will be released in the eye, similar to with P-3 Pattern #4. Once the sUAS does a low-level center fix, it will go to the eyewall. To obtain full motion video (FMV) the P-3 needs to stay within 20 nm range of the sUAS. Thus, the suggested flight pattern is for the P-3 to do circles within the eye while the sUAS is sampling. Alternatively, the P-3 may do center fixes to compare with what the sUAS is measuring. Also, if the storm structure is appropriate, the P-3 can perform short radial legs into the eyewall similar to the NESDIS Ocean Winds module.

**P-3 Pattern #6: Saildrone Overflight Module**

The sUAS is released similarly to either an inflow module or an eyewall module. The drop location for the sUAS is a semicircle away (i.e. directly upwind) from the saildrone, with a preferred distance that gives the sUAS time to establish stable communications with the P-3 and descent to a low altitude. The sUAS will attempt to directly overfly the saildrone at a low altitude. Additionally, the P-3 will overfly the saildrone, preferably as close in time as possible as the sUAS. At this time, the P-3 will deploy as many expendables as possible (especially a possible mass streamsonde deployment). After the overflight, this P-3 module can be conducted using any pattern that maximizes inner core coverage and will collect flight level, TDR, dropsonde, streamSonde, AXBT, and SFMR observations for sUAS comparison and validation. Dropsondes, SST-capable dropsondes, and AXBTS (10-15 total) will be deployed in locations that are collocated with sUAS under flights. Further, if it is estimated that the sUAS battery and conditions permit a circumnavigation of the TC with a second saildrone overflight, the saildrone/sUAS/P-3 overflight would be conducted again.

**Links to Other Mature Stage Experiments/Modules:** The RICO SUAVE Experiment can be flown in conjunction with following *Mature Stage* experiments and modules: *Boundary Layer* and *Air-Sea Interactions, Coordination with Ocean Assets (CHAOS), Eye-Eyewall Mixing, Gravity Wave, Convective Burst Structure and Evolution, Rainband Complex Survey, Surface Wind Speed, and Significant Wave Height Validation, TC Diurnal Cycle, Synoptic Flow, NESDIS JPSS Satellite Validation, ADM-Aeolus Satellite Validation, and NESDIS Ocean Winds*.

**Analysis Strategy:** The analysis of these data includes two components: understanding hurricane boundary layer structure and potential improvements to hurricane prediction that sUAS observations can provide. Existing working groups are currently analyzing sUAS data and are focused on two main areas: boundary layer turbulence and thermodynamics, and observing system experiments (OSEs). Data from these sUAS missions can resolve small-scale features and physical processes that can then be compared and contrasted with similar boundary layer representations from multiple numerical models (HWRF, HAFS, CM1). In addition, research involving OSEs and observing system simulation experiments (OSSEs) will be used to help quantify the impact of sUAS observations and help optimize sUAS resources by comparing observing strategies generated from a Nature Run.

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