MODULE DESCRIPTION

3. GALE UAS Eye/Eyewall Module

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Primary IFEX Goal: 2 - Develop and refine measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment

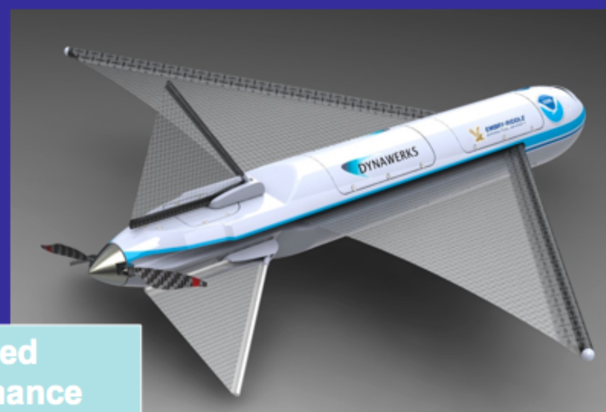
Why UAS?

The interaction between the ocean and the hurricane is important, complex, and not well handled in current observing systems and models. Specifically, the hurricane depends on the ocean to supply the necessary heat and moisture to form and maintain the system. The detailed process by which a storm 'draws heat' from the ocean and ultimately converts it into kinetic energy (i.e. strong winds) is very complex and is currently not well understood. This lack of understanding is primarily due to the limited availability of detailed observations within the storm near the air-sea interface. The amount of heat and moisture extracted from the ocean is a function of wind speed, ocean temperature, atmospheric temperature, pressure and humidity. Accurate measurements of these variables are required, yet exceedingly difficult to obtain due to the severe weather conditions that exist at the ocean surface during a hurricane. A limited array of surface buoys make in-situ measurements in this region spotty at best, while direct measurements at very low altitudes using NOAA and Air Force hurricane hunter manned aircraft is impossible due to the severe safety risks involved. Nevertheless, for scientists to dramatically improve our understanding of this rarely observed region, detailed, continuous observations must be obtained. To this end, an aggressive effort to utilize low level unmanned aerial systems (UAS) designed to penetrate and sample the violent low level hurricane environment would help fill this critical data void. Such improvements in observation and understanding would likely lead to significant advancements in the area of hurricane intensity prediction. Enhancing this predictive capability would in turn reduce the devastating impact hurricanes have on our Nation's economy and more importantly help save countless lives.

GALE UAS

GALE is an aircraft platform that is currently under development by Embry Riddle Aeronautical University in close cooperation with the Dynawerks Corporation (http://www.dynawerks.com/index.html). The intended deployment vehicle for the GALE is the P-3 Orion. The GALE is a small electric-powered unmanned aircraft with 1-2 hour endurance and is capable of carrying a 1-2lb payload. The GALE can be launched from a P-3 sonobuoy tube in flight, and terrain-permitting, is capable of autonomous landing and recovery. The GALE is supported is capable of supporting multiple aircraft operations. GALE's control station will be onboard the deployment aircraft (i.e. P-3), allowing for in-air command and control after launch. The GALE, when deployed from NOAA's P-3's within a hurricane environment, will provide a unique observation platform from which the low level atmospheric boundary layer environment can be diagnosed in great detail. In many ways, this UAS platform be considered a 'smart GPS dropsonde system' since it is deployed in similar fashion and will be able to carry a comparable meteorological payload (i.e. lightweight sensors for P, T, RH, V). Unlike the GPS sonde however, the GALE UAS can be directed from the NOAA P-3 to specific areas within the storm circulation (both in the horizontal and in the vertical). Also unlike the GPS dropsonde, GALE observations are continuous in nature and give scientists an extended look into important thermodynamic and kinematic physical processes that regularly occur within the near-surface boundary layer environment. GALE UAS operations also represent a potentially significant upgrade relative to the more traditional "deploy, launch and recover" low altitude UAS hurricane mission plan used in the past. By leveraging existing NOAA manned aircraft assets, GALE operations significantly reduces the need for additional manpower. The GALE concept of operations also reduces overall mission risk since there is no flight ingress/egress. This fact should also help simplify the airspace regulatory approval process. Specifications associated with the GALE UAS are illustrated in Figure 3-1.

Gale UAS



Performance Attribute	Estimated Performance
Mission Weight	8.0 lbm
Cruise Speed	42 kts
Dash Speed	110 kts
Stall Speed	22 kts
Mission Endurance	60 minutes

Figure 3-1. GALE Unmanned Aerial System Specifications.

Relevance to NOAA

In recent years, an increasing number of hurricanes have impacted the United States with devastating results, and many experts expect this trend to continue in the years ahead. In the wake of Katrina (2005), NOAA is being looked at to provide improved and highly accurate hurricane-related forecasts over a longer time window prior to landfall. NOAA is therefore challenged to develop a program that will require applying the best science and technology available to improve hurricane prediction without placing NOAA personnel at increased risk. UAS are an emerging technology in the civil and research arena capable of responding to this need.

In late February 2006, a meeting was held between NOAA, NASA and DOE partners (including NOAA NCEP and NHC representatives) to discuss the potential for using UAS in hurricanes to take measurements designed to improve intensity forecasts. The group came to a consensus around the need for a UAS demonstration project focused on observing low-level (<200 meters) hurricane winds for the following reasons:

- Hurricane intensity and track forecasts are critical at sea level (where coastal residents live)
- The hurricane's strongest winds are observed within the lowest levels of the atmosphere
- The air-sea interface is where the ocean's energy is directly transferred to the atmosphere
- Ultimately, low-level observations will help improve operational model initialization and verification
- The low-level hurricane environment is too dangerous for manned aircraft

The potential importance of low-level UAS missions in hurricanes is further emphasized by the findings of the Hurricane Intensity Research Working Group established by the NOAA Science Advisory Board. Their recommendation is that:

"Low and Slow" Unmanned Aircraft Systems (UAS) have demonstrated a capacity to operate in hurricane conditions in 2005 and in 2007. Continued resources for low altitude UAS should be allocated in order to assess their ability to provide in situ observations in a critical region where manned aircraft satellite observations are lacking.

This effort is in direct support of NOAA's operational requirements and research needs. Such a project will directly assist NOAA's National Hurricane Center better meet several of its ongoing operational requirements by helping to assess:

The strength and location of the storm's strongest winds
The radius of maximum winds
The storm's minimum sea level pressure (which in turn may give forecasters advanced warning as it relates to dangerous episodes of rapid intensity change)

In addition to these NOAA operational requirements, developing the capability to regularly fly low altitude UAS into tropical cyclones will also help advance NOAA research by allowing scientists to sample and analyze a region of the storm that would otherwise be impossible to observe in great detail (due to the severe safety risks involved associated with manned reconnaissance). It is believed that such improvements in basic understanding are likely to improve future numerical forecasts of tropical cyclone intensity change. Reducing the uncertainty associated with tropical cyclone intensity forecasts remains a top priority of the National Hurricane Center. 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.

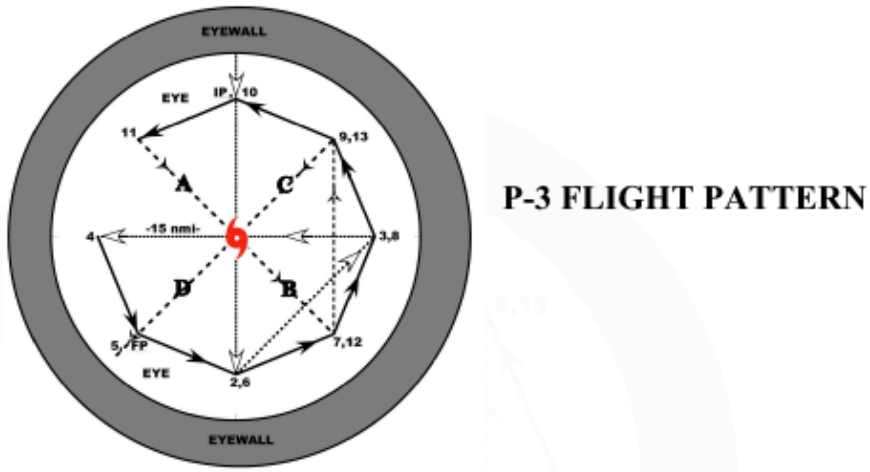
This HRD field program module is designed to build on the successes and strong momentum from recent UAS missions conducted in 2005 and 2007 as well as successful P3-UAS test flights in 2009. As part of this effort, any UAS data collected will continue to be made available to NOAA's National Hurricane Center in real-time.

Mission Description

The primary objective of this experiment is further demonstrate and utilize the unique capabilities of a low latitude UAS platform in order to better document areas of the tropical cyclone environment that would otherwise be either impossible or impractical to observe. For this purpose, we will be using the GALE UAS. Since the GALE will be deployed from the manned P-3 aircraft, no UAS-specific forward deployment teams will be required. Furthermore, since the GALE is launched using existing AXBT launch infrastructure, no special equipment is required beyond a 'ground' control station GALE operators will have onboard the P-3. The target candidate storm is a mature hurricane with a well- defined eye. Furthermore, since the P-3 will have to operate within the eye, daylight missions will be required so as to maintain P-3 visual contact with the eyewall at all times. This capability will have the dual positive effect of minimizing experimental and safety risks. The immediate focus of this experimental module will be to test the operational capabilities of the GALE UAS within a hurricane environment. Besides maintaining continuous command and control links with the P-3, these flights will test the accuracy of the new MISTSONDE meteorological payload (vs. observations taken from dropsondes released near the UAS). The UAS will be tested to see if it can maintain altitudes according to command. In addition, the GALE UAS will attempt to fly at extreme altitudes (as low as 200 ft) in low (eye) and high (eyewall) wind conditions within hurricane environment. The longer-term goal for this UAS platform is to assist scientists so they can better document and ultimately improve their understanding of the rarely observed tropical cyclone boundary layer. To help accomplish this, the UAS will make detailed observations of PTHU at low altitudes within the hurricane eye and eyewall that will then be compared with multiple in-situ and remote-sensing observations obtained from manned aircraft (NOAA P-3 and AFRES C-130) and select satellite-based platforms. In addition, a primary objective (but not a 2012 requirement) for this effort will be to provide real-time, near-surface wind observations to the National Hurricane Center in direct support of NOAA operational requirements. These unique data will also be used in a 'post storm' analysis framework in order to potentially assist in the numerical and NHC verification process.

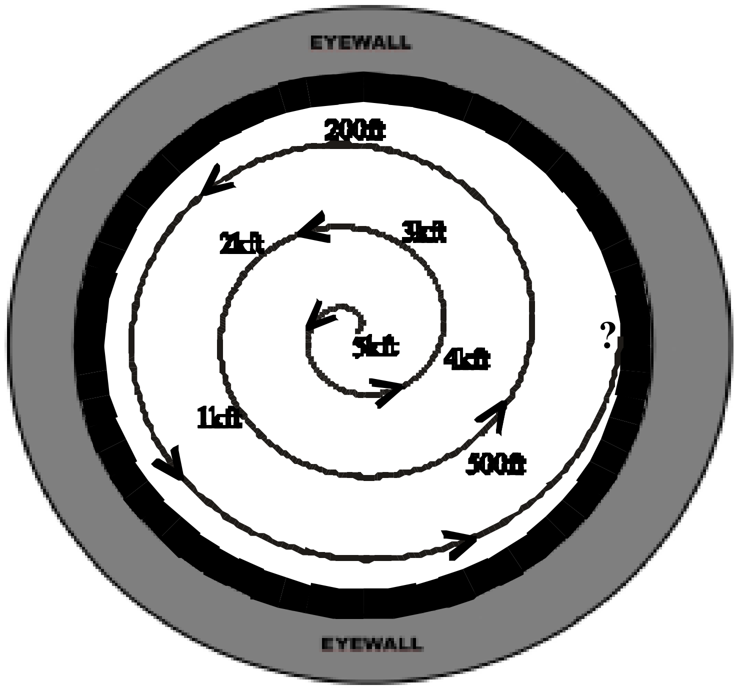
For this experiment, NOAA P-3 flight altitude will be at 10,000 ft at all times. Ideally both modules (~1.5h each) would be conducted on the same manned mission. The eye-only module would be conducted first, followed by the eye-eyewall UAS module. The P-3 flight pattern is identical for both eye and eye-eyewall UAS modules. GPS dropsonde and AXBT drop locations are also identical for each UAS module. AXBT and GPS drop locations are explicitly illustrated in the flight plan below. UAS deployment on leg 3-4 is also identical for both modules. UAS operational altitude will be entirely below 5,000 ft. UAS motor will not be activated until an altitude of 5,000 ft is met. The UAS will be conducting a controlled, spiral glide (un-powered) decent from 10,000 ft to 5,000 ft.

Gale UAS - P3 Mature Hurricane Eye/Eyewall Module



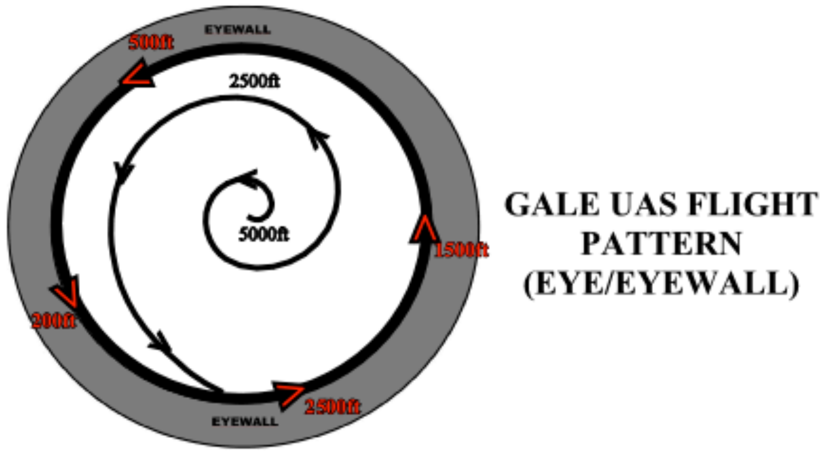
The P-3 approaches from the north at an altitude of 10,000ft, penetrates the eyewall into the eye, and performs a figure-4 (dotted line) in the eye. **Midway during leg 3-4 the Gale UAS is released.** The P-3, remaining at 10,000ft, circumnavigates the eye in an octagon pattern and conducts another figure-4 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.)

Figure 3-2a. P-3 Pattern for GALE UAS eyewall/eye module.



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

Figure 3-2b. GALE UAS pattern (eye only).



Midway during P-3 leg 3-4, the Gale UAS is released at 10,000ft altitude. The Gale UAS proceeds to glide (un-powered) in a downward counterclockwise spiral to an altitude of 5,000ft. At 5000ft, the UAS motor is started and the Gale 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 Gale 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.**

Figure 3-2c. GALE UAS pattern (eye/eyewall).