UAS Activities at Lamont-Doherty Earth Observatory of Columbia University

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R/V Falkor – October/November 2016
All UAV flights took place here, in international waters.
UAS from Ships (Latitude HQ-60B)

Combines vertical takeoff and landing (VTOL) capabilities of a quadrotor and the speed and range of a fixed-wing (FW) aircraft
Latitude HQ-60B

<table>
<thead>
<tr>
<th>HQ-60B</th>
<th>Aircraft built</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total flights</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Total flight time</td>
<td>&gt;80 hrs</td>
</tr>
<tr>
<td></td>
<td>Max demonstrated launch weight</td>
<td>105 lbs</td>
</tr>
<tr>
<td></td>
<td>Max demonstrated recovery wind</td>
<td>31 kts</td>
</tr>
<tr>
<td></td>
<td>Max demonstrated endurance</td>
<td>22.5 hrs</td>
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103 lbs gross weight
12-18 hours endurance
8-12 lbs payload
UAS from Ships

- No runway needed
- Portable
- Shipboard operation demonstrated
- Pusher engine – required for gas and aerosol measurement
- Nose cone payload
Shipboard Operation – Confined Area Launch and Recovery

- Standard configuration provides 3 minutes VTOL, at 75ft transition height.
- 30-45 seconds required for each launch and recovery event
- 2 min reserve

- Obstacle height: 50ft
- Landing accuracy: ±15ft
- Lateral launch/recovery area clearance: ±25ft
- Obstacle clearance height can increase with increased VTOL battery mass. 150 ft. transition altitude costs ~2.5 hours fixed wing endurance
UAS from Ships – Operational Limits

- **Range**: Operations were limited to daytime and line of sight (5 nm).

- **Altitude**: Operations range up to 5000 ft. (self-determined)

- **Wind and Sea State**: Operations were limited to wind speeds less than 20 knots.

- **Clouds and Visibility**: Operations were limited to visual line of sight and class E airspace weather minimums (3 statute miles flight visibility and 500 ft below any clouds).
UAS from Ships – Hover Test
UAS from Ships – Launch
UAS from Ships – Return Transition and Landing
UAS from Ships – Flight Summary

- **Tucson Integration:**
  - 2 Total Flights (3 hours)
  - 1 Functional Check Flight (FCF)
  - 1 with Radiation Payload

- **Falkor Cruise:**
  - 17 Total Flights (30 hours)
  - 11 Flights with Payloads (23 hours)
    - RAD, ATOM, VNIR payloads
    - Nominally < 3 hours
  - 3 Hover Tests
  - 3 FCFs
• 5 successful hover flights

• 10 successful flights with vertical take off, switch to fixed wing flight, and vertical landing.

• Successful flights were conducted with takeoff 45 off the port into the wind.

• Demonstrated the ability to operate the HQ technology from a ship with limited deck space.

• Demonstrated the ability to operate the HQ technology from a ship under 10 – 18 kt wind speed conditions.
UAS from Ships – Lessons Learned

• Pitch and roll of the deck posed a less significant challenge than anticipated.

• High Wind (>25 knots) posed a problem... the large steel structure of the ship was significant enough to cause a significant transitional turbulent boundary layer over the aft deck that made manual operation difficult.

• Solution: More powerful VTOL engines as well as dGPS for automated take off and landing.

• Latitude Engineering has increased the VTOL system control authority (power, responsiveness) for future operations... currently on HQ-90. More to come.

• Autonomous VTOL will require the addition of the dGPS system... future R/V Falkor Cruise in December 2019.
UAS Payload Development

BASE payload allows for quick change between sensor payloads.
## UAS Payloads

Table 1: Implemented science payloads and applications

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<td>Drone-Deployed Micro-Drifters with launcher for in-flight ejection of up to four micro-dropsonde packages. The DDµD measures temperature, pressure, and relative humidity as it descends through the atmosphere. Once it lands on the ocean’s surface, it deploys a string of sensors that measures temperature and salinity of the upper 2-3 meters of the ocean at fifteen minute intervals for up to two weeks as a buoy. The ocean sensors on the DDµD collect and store data and then transmit the data back to the UAS on subsequent flights from up to 10 miles away.</td>
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*also included upward- and downward-looking pyrometers (8-14 µm) to measure narrow field-of-view (FOV) skin SST and ice-surface temperature.

Sea Ice Radar Development – Built on experience from IcePOD at LDEO
Ocean Cooling Due to Rain

Mean ΔT:
- before rain: 0.10 ± 0.02 °C
- during rain: 0.15 ± 0.03 °C
- heavy rain: 0.20 ± 0.06 °C
- after rain: 0.14 ± 0.03 °C
UAS Payload Development

BASE payload allows for quick change between sensor payloads.

$U_{10} = 7 \text{ m} \cdot \text{s}^{-1} – 10 \text{ m} \cdot \text{s}^{-1}$ from West

Flight001 RAD UAV Payload visible image taken 28 Oct 2016, 0624 UTC
LDEO UAV-based shortwave albedo shows good agreement with classical values of ~0.6 for open ocean (Payne 1972)

Comparing downwelling irradiance from LDEO UAV-based to LDEO ship-based measurements shows the two data sets broadly track

Differences in UAV-based vs ship-based shortwave downwelling measurements highlight ship-based errors introduced by superstructure
Comparing downwelling irradiance from LDEO UAV-based to LDEO ship-based measurements shows the two data sets broadly track.

Note a decrease in both up- and down-welling longwave irradiance at higher altitude.

Differences in UAV-based vs ship-based longwave downwelling measurements highlight ship-based errors introduced by superstructure.
Hyperspectral Payload Development

BASE Payload

VNIR Module

NIR Module

![Diagram of BASE Payload](image)

![Diagram of VNIR Module](image)

![Diagram of NIR Module](image)

**Case 1 water, Chl = 1**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Total at Sensor Radiance $I_s$ [W m$^{-2}$ sr$^{-1}$ nm$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m</td>
<td>0.00</td>
</tr>
<tr>
<td>300 m</td>
<td>0.02</td>
</tr>
<tr>
<td>500 m</td>
<td>0.04</td>
</tr>
<tr>
<td>1000 m</td>
<td>0.06</td>
</tr>
<tr>
<td>10,000 m</td>
<td>0.00</td>
</tr>
<tr>
<td>30,000 m</td>
<td>0.00</td>
</tr>
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</table>
Blue copepods evolved predatory camouflage to be same as peak ocean color.

Current Directions – R/V Falkor

- Cruise from R/V Falkor in the Northwest Australian Continental Shelf
- Payloads developed for Manta UAS will be integrated onto Latitude Engineering HQ-60.
- Airborne surveys of the Sea Surface Microlayer from Latitude UAVs as well as in situ measurements of the SSM chemistry and biology from catamaran, drifters, and buoys.
- Measurements: ocean surface gravity-capillary wave spectra ($O(1-0.001)m$) using LIDAR and polarimetric imaging; complete chemical and biological quantification and characterization of the biogenic slicks from autonomous catamarans; and quantification and characterization of the near-surface ocean temperature, salinity, TKE dissipation rate, and currents from a drifting spar buoy and in the mixed-layer from autonomous sub-surface profiling.
Current Directions – R/V Falkor

Dense internal wave field

- Effects of biogenic slicks on albedo, near-surface heat flux, diurnal warm layer processes and mixing.

(Top) True color image captured by the Landsat satellite on November 17, 2014, of the coast of Northwestern Australia, east of Point Samson. (Bottom Left) 30 m resolution chlorophyll map obtained from the Landsat data. The high albedo from the dense surface slicks trigger the cloud mask (white). (Bottom Right) MODIS Aqua map of chlorophyll for the same day.
Current Directions – R/V Falkor

Trichodesmium
a) *Trichodesmium* sp. abundance as the number of normalized bacterial 16S rRNA genes (Normalized Reads) in manual samples taken at 04:15 UTC (15 Oct 2016) from 1m below the surface, the surface skin and surface slick. Note that the skin sample was collected between the surrounding banded slicks, and cannot be considered as a “clean” skin layer. b) Micrograph of sampled colonies of *Trichodesmium* sp. Scale bar represents 50µm.
Surfactants (Sta 4&5, Timor Sea)

Start Time: 00:42:49 UTC

Station 4 10/15/16

Polarimeter
Current Directions – R/V Falkor

Trichodesmium
Trichodesmium

Current Directions – R/V Falkor

Trichodesmium
Enhancements to HQ-90B for Ship Deployment

1. **Complete autonomous takeoff and landing from ships.** This project provides a considerably safer and more reliable VTOL operation. Integration of Novatel ALIGN dGPS system for automated VTOL takeoff and landing. Dual dGPS system determines aircraft heading. Additionally, the ground station on the ship uses the ALIGN system to send the vehicle data including the ship’s heading and heave. The precise relative position data achieved with a dGPS solution allows the vehicle to autonomously land on a moving platform at sea.
Enhancements to HQ-90B for Ship Deployment

2. **Dual- (Multi-) UAV aircraft flight operations.** For most scientific applications, multiple aircraft are required for both varied payload deployment as well as variable temporal spatial scales to be observed. The primary required element is the integration of long-range mesh network radios and antennas.

3. **Long-range capability (50+ nm) with high bandwidth data link** for real-time mission control and tasking. This obfuscates the need for Iridium at distances up to 50 nm. Long-range mesh radios are much faster, more robust, more reliable, and less expensive than total Iridium costs (both modem hardware and data service charges). It further allows for:
   a. Mother aircraft at high altitude to provide relay link to a squadron or fleet of UAVs to fly a greater distance (over 100 nm) from ship.
   b. Mother aircraft at high altitude to provide relay link to a squadron or fleet of UAVs flying at low altitude.
Bridging the Scientific and Indigenous Communities to Study Sea Ice Change in Arctic Alaska

Christopher Zappa (LDEO), Andy Mahoney (UAF), Alex Whiting (NVK), Sarah Betcher (FNF)
Sea Ice is Thinning
Consequences of Sea Ice Change
Understand sea ice dynamics and how it is changing with a warming climate

Bridge scientific & indigenous knowledge to study changes in sea ice that will lead to predictive models for:
  - Sea ice loss
  - Impact on ocean life
  - Impact on land mammals
Indigenous knowledge is “a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation” (ICC Alaska 2015).
## Project Objectives

<table>
<thead>
<tr>
<th>Science</th>
<th>Improve understanding of the mechanisms, impacts, and implications of sea ice retreat in the Arctic for the global science community and local stakeholders</th>
</tr>
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<tbody>
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<td>Community</td>
<td>Develop partnerships between scientists and local residents to increase the capacity of local communities to address their research needs</td>
</tr>
<tr>
<td>Legacy</td>
<td>Document the progress of the project as a potential model for future community-based collaborative science endeavors in the Arctic</td>
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Community-based research design

- Begins with community engagement
- Before research questions have been defined
- Ensures our observing plan meets our science, community, and legacy goals
Village of Kotzebue

[Map of the area around Kotzebue, Alaska, showing the village's location in Kotzebue Sound, along with nearby locations such as Cape Lisburne, Point Hope, and Shishmaref.]
Highest HQ wind launch to date: 31 knots
Expected launch/recovery wind limitation: ~30 knots, on the nose.
No crosswind limitation. HQ automatically negotiates crosswind up to max wind limitation
Max rain demonstrated to date: 0.25 inch/hour
Max demonstrated WMO sea state capability: 5
Flight into known icing (FIKI): Under Development

**HQ-90 AIRFRAME SPECIFICATIONS**

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<th>PARAMETER</th>
<th>PERFORMANCE</th>
<th>VALIDATION METHOD</th>
</tr>
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<tbody>
<tr>
<td>Line of Sight Range</td>
<td>60 Nautical miles nominal*</td>
<td>Flight Test</td>
</tr>
<tr>
<td>Maximum Endurance</td>
<td>20+ hours</td>
<td>Flight Test**</td>
</tr>
<tr>
<td>Mission Speed</td>
<td>40kts</td>
<td>Flight Test</td>
</tr>
<tr>
<td>Payload</td>
<td>12-20lbs</td>
<td>Flight Test</td>
</tr>
<tr>
<td>Max Gross Takeoff Weight</td>
<td>105lbs</td>
<td>Flight Test</td>
</tr>
<tr>
<td>Design Operational Altitude</td>
<td>15,000ft.</td>
<td>Design Goal</td>
</tr>
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* with wave relay
**Longest flight to date is 22.5 hours with 6lb payload and 5 hours fuel remaining on landing
HQ-90 Airframe Endurance / Payload Tradeoff

**Graph Details:**
- **Axes:**
  - **X-axis:** Endurance (Hrs)
  - **Y-axis:** Mass (Lbs)

- **Lines:**
  - **Blue Line:** Fuel Mass (lbs)
  - **Red Line:** Payload Mass (lbs)

- **Legend:**
  - HQ-90 Design Point

- **Legend Description:**
  - FUEL MASS (lbs) and PAYLOAD MASS (lbs)

**Graph Note:**
- The graph illustrates the tradeoff between fuel mass and payload mass over the range of endurance from 4 to 24 hours.

**Design Point:**
- The design point is marked on the graph indicating the optimal balance between fuel and payload mass for a specific endurance duration.

**Conclusion:**
- Understanding the tradeoff helps in optimizing the design for extended endurance missions while managing fuel and payload requirements effectively.
BASE payload allows for quick change between sensor payloads.
## UAS Payloads

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Sea Ice Radar Development – Built on experience from IcePOD at LDEO
Kotzebue Temperatures

UAS: Maximum Temperature 100.4F and Minimum Temperature -4F

The daily low (blue) and high (red) temperature during 2013 with the area between them shaded gray and superimposed over the corresponding averages (thick lines), and with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile). The bar at the top of the graph is red where both the daily high and low are above average, blue where they are both below average, and white otherwise.
UAS in Kotzebue – Operational Limits

- **Range:** Operations were limited to daytime and line of sight (~2 nm) within the 10 nm LOS COA.

- **Altitude:** Operations range up to 4000 ft. (LOS COA)

- **Wind:** Operations were limited to wind speeds less than 20 knots.

- **Clouds and Visibility:** Operations were limited to visual line of sight and class E airspace weather minimums (3 statute miles flight visibility and 500 ft below any clouds).
UAS in Kotzebue – Takeoff
UAS in Kotzebue – Flight Summary

- **Tucson Integration:**
  - 7 Total Flights (3 hours)
  - 2 Functional Check Flight (FCF) with Hover Test
  - 5 Flights with Payloads (2 hours)
    - ATOM, RAD, VNIR, DDuD payloads

- **Warm Springs OR Flight Testing:**
  - 5 Total Flights (9 hours)
  - 2 Functional Check Flight (FCF) with Hover Test
  - 3 Flights with Payloads (6.5 hours)
    - ATOM, RAD, VNIR payloads

- **Kotzebue IOP:**
  - 12 Total Flights (30 hours; 5-hour Max)
  - 9 Flights with Payloads (25 hours)
    - RAD, ATOM, VNIR, MET payloads
  - 3 FCFs
“Imaging” Payload
- Thermal Camera
- Visible Camera
- Surface Height (Laser)
- Sky & Surface Temperature
“Hyperspectral” Payload

- Hyperspectral Camera
- Up- & Down-looking Spectrometers
- Sky & Surface Temperature
"Atmospheric" Payloads
- Solar & Longwave Radiation
- Visible Camera
- Sky & Surface Temperature
- Air Turbulence
- Pressure
- Humidity
- Air Temperature
UAS in Kotzebue – Accomplishments

- 24 Total Successful Flights (42 hours) with HQ-90B
- 17 Successful Flights with payloads.
- Flights were conducted with takeoff directly into the wind.
- Demonstrated the ability to operate the HQ technology autonomously.
- Demonstrated the ability to operate the HQ technology in cold weather conditions.
"Imaging" Payload

- Thermal Camera
- Visible Camera
- Surface Height (Laser)
- Sky & Surface Temperature
Seal Detection

May 8 2018
Seal Detection

Visible

Thermal
Equatorial Pacific Air-Sea CO2 Exchange Experiment
R/V Araon
QUESTIONS?