NASA Airborne Hurricane Research

• Recent Experiences – TCSP
• Future Platform Assessments
Overview

- Tropical Cloud Systems & Processes (TCSP) Campaign Overview
- ER2: high-altitude platform for TCSP
- TCSP Highlights
- Hurricane Over-flights - ER2 Pilot Observations
- Aerosonde UAV – Ophelia penetration
- Future Platforms
Tropical Cloud Systems & Processes (TCSP): Mission Overview

An Earth Science field research investigation sponsored by the Science Mission Directorate of the National Aeronautics and Space Administration (NASA).

Field phase: conducted during the period July 1-27, 2005 out of the Juan Santamaria Airfield in San Jose, Costa Rica

Research Objectives:
• Tropical cyclone structure, genesis, intensity change, moisture fields and rainfall
• Satellite and aircraft remote sensor data assimilation and validation studies pertaining to development of tropical cyclones
• The role of upper tropospheric/lower stratospheric processes governing tropical cyclone outflow, the response of wave disturbances to deep convection and the evolution of the upper level warm core.

Airborne Platforms:
• 12 NASA ER-2 science flights, including missions to Hurricanes Dennis and Emily, Tropical Storm Gert and an eastern Pacific mesoscale complex that may possibly have further developed into Tropical Storm Eugene.
• The P-3 aircraft from the NOAA Hurricane Research Division (HRD) flew 18 coordinated missions with the NASA research aircraft to investigate developing tropical disturbances.
• Aerosonde uninhabited aerial vehicle flew 8 surveillance missions.
# NASA ER-2

## Capabilities

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>Above 70,000 Feet</td>
</tr>
<tr>
<td>Range</td>
<td>6000+ Nautical Miles</td>
</tr>
<tr>
<td>Duration</td>
<td>10+ hours</td>
</tr>
<tr>
<td>Speed</td>
<td>410 knots (467 mph)</td>
</tr>
<tr>
<td>Payload Capacity</td>
<td>2600 lbs</td>
</tr>
<tr>
<td>Payload Power</td>
<td>36Kw</td>
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</tbody>
</table>

## Special Modifications & Facilities

- Q-bay instrumentation area & payload pallets (pressurized)
- Wing-mounted instrumentation pods (pressurized)
- Nose instrumentation area (pressurized)
- Zenith and nadir viewing capability
- Navigation data recording system
- Nadir Video Camera system
- Facility Sensors (film-based cameras, multi/hyper spectral scanners)
- Aerosol Particle Sampler Systems
- Dropsonde delivery system
- IRIDIUM Voice and Data Line; REVEAL
TCSP ER-2 Instrument Payload

- High Altitude MMIC Sounding Radiometer (HAMSR)
- Microwave Temp. Profiler (MTP)
- ER-2 Doppler Radar (EDOP)
- Cloud Radar System (CRS)
- MODIS Airborne Simulator (MAS)
- Advanced Microwave Precipitation Radiometer (AMPR) Lightning package (LIP) REVEAL

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TCSP: Noteworthy milestones of the 30-day mission:

• Rapid genesis of Hurricane Dennis.
  • In a region of the Caribbean where such dramatic development is rare. The storm's pressure dropped 12 millibars in two hours. Researchers hope data from Dennis will help improve understanding of this "rapid deepening" phenomenon.

• Re-generation of Hurricane Dennis
  • As a powerful Category 4 -- passed over Cuba 's mountainous terrain, severely disrupting its well-defined eye and weakening it to a Category 2 hurricane. When it re-emerged over warm waters north of Cuba, the storm quickly regained its former strength and intensity.

• Birth of Tropical Storm Eugene.
  • Observed while monitoring a narrow Pacific region called the "Inter-Tropical Convergence Zone"

• Recording of the entire lifespan of Tropical Storm Gert
  • The ER-2 and P3 Orion flew five back-to-back missions enabling the team to monitor the entire lifespan of Gert, which developed from an elongated area of low-pressure or "trough" off the Yucatan coast. The ER-2 also investigated the impact of Mexican mountain ranges on Gert as the storm made landfall.

• Hurricane Emily overflight
  • ER-2 over-flew the most powerful hurricane of its “career” while studying the borderline Category 4-5 Hurricane Emily. Recorded frequent lightning, unusual in hurricanes, and captured startling Doppler radar imagery of Emily, including "eye wall" storms rising to rarely observed heights of above 60,000 feet.
“Indeed, the electric fields above Emily were among the strongest ever measured by the aircraft’s sensors over any storm.”

"We observed steady fields in excess of 8 kilovolts per meter," says Blakeslee. "That is huge--comparable to the strongest fields we would expect to find over a large land-based 'mesoscale' thunderstorm."
Hurricane Emily – ER2 Flight Track, 17 July 2005
ER2 Pilot Observations

• Hurricane Dennis (Cat 1):
  – Little or no turbulence; stable air mass at 65,000 feet.
  – Observed actual formation of the “eye”.

• Hurricane Emily (Cat 5):
  – Pronounced turbulence up to 68,000’.
  – Wild fluctuations in outside air temperature.
  – Winds in excess of 60 knots at 65,000’.
  – Eyewall cloud tops estimated between 62,000 & 63,000 feet.
  • Filled with severe lightning.
  – Lesson Learned: sacrifice endurance for altitude.

NASA Dryden Flight Research Center
# Aerosonde Mark 3 Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Weight, wing span</th>
<th>27-30 lb, 10 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>24 cc, 1.2 kw, fuel injected using premium unleaded petrol</td>
<td></td>
</tr>
<tr>
<td>Navigation</td>
<td>GPS</td>
<td></td>
</tr>
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</table>

## Operation

<table>
<thead>
<tr>
<th>Staff for Launch and Recovery</th>
<th>3 people: Controller, Technician, Pilot/Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staff for Flight Operations</td>
<td>1 Person for up to 3 aircraft</td>
</tr>
<tr>
<td>Ground Equipment</td>
<td>Proprietary Staging Box, personal computer (laptop), GPS antenna, aviation and local communications radios</td>
</tr>
<tr>
<td>Flight</td>
<td>Fully autonomous, under Base Command</td>
</tr>
<tr>
<td>Launch and Recovery</td>
<td>Launch from car roof rack (catapult option), land on belly, Autonomous or with pilot</td>
</tr>
<tr>
<td>Ground &amp; air communications</td>
<td>UHF or Satcoms (Iridium) to Aerosonde, VHF to field staff and other aircraft, internet to command center and users.</td>
</tr>
</tbody>
</table>

## Performance

| Speed, Climb                  | 18 – >32 ms\(^{-1}\), Climb >2.5 ms\(^{-1}\) at sea level |
| Range, Endurance with no additional payload | >1800 miles, >30 h |
| Altitude Range               | Up to 20,000 ft (medium weight) |
| Payload                      | Maximum 5 lb with full fuel load |

## Standard Instrumentation

| Temperature, Pressure, Humidity, Wind | 2 Vaisala RSS901 Sondes for temperature, pressure and humidity, and a proprietary wind system. |

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**Table 1. Specifications of Mark 3 Aerosonde UAV**

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![Image of Aerosonde Mark 3](image-url)
"Hurricane researchers at the NOAA Atlantic Oceanographic and Meteorological Laboratory in Miami, Fla., marked a new milestone in hurricane observation as the first unmanned aircraft touched down after a 10-hour mission into Tropical Storm Ophelia, which lost its hurricane strength Thursday night. The aircraft, known as an Aerosonde, provided the first-ever detailed observations of the near-surface, high wind hurricane environment, an area often too dangerous for NOAA and U.S. Air Force Reserve manned aircraft to observe directly."
Payload

- Two Vaisala RSS901 Sondes
  - Pressure
  - Temperature
  - Humidity
- KT11 Infrared Pyrometer
  - Sea Surface Temperature
- Winds Derived from Aerosonde
  Proprietary Algorithm
Aerosonde Operations

Inbound

NOAA WP-3D Stepped Frequency Microwave Radiometer (SFMR) Surface winds in light blue, Aerosonde winds in black, buoy winds in dark blue.

Outbound

Eye
Ophelia Flight Facts

• 10.1 hours flight duration
• 2500 ft transit inbound to, and outbound from eye
• Over-flew buoy for SST comparison on Inbound leg at 2 altitudes
• Spiral down to 1200 ft conducted in the eye
• Measured 75 kt winds in NE quadrant
Hurricane Research - Future Platforms

- **Global Hawk:**
  - Max Altitude: 65,000 feet
  - Ability to withstand conditions encountered over Emily still being assessed.
    - Climb profile not designed to maintain max altitude
    - Stability in such dynamic atmospheric conditions - uncharacterized

- **ALTAIR:**
  - Max design altitude: ~52,000 feet.
    - Max demonstrated: 45K on 18 hr mission

- **Predator-B:**
  - Max design altitude: ~50,000 feet
    - Max demonstrated: 40K on 24.5 hr mission

Penetration and over-flight capabilities still being assessed for ALTAIR and Predator-B.

Endurance of Global Hawk and Predator/ALTAIR make them **ideal** for Cyclogenesis studies.