Air-sea interaction measurements with the Controlled Towed Vehicle (CTV)

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Office of Naval Research

In memory of Carl Friehe, UC Irvine

Reynolds' Fluxes and Coefficients

$$\boldsymbol{\tau} = -\rho(\overline{uw}\boldsymbol{i} + \overline{vw}\boldsymbol{j}) = \rho C_{d10} U_{10}^2$$

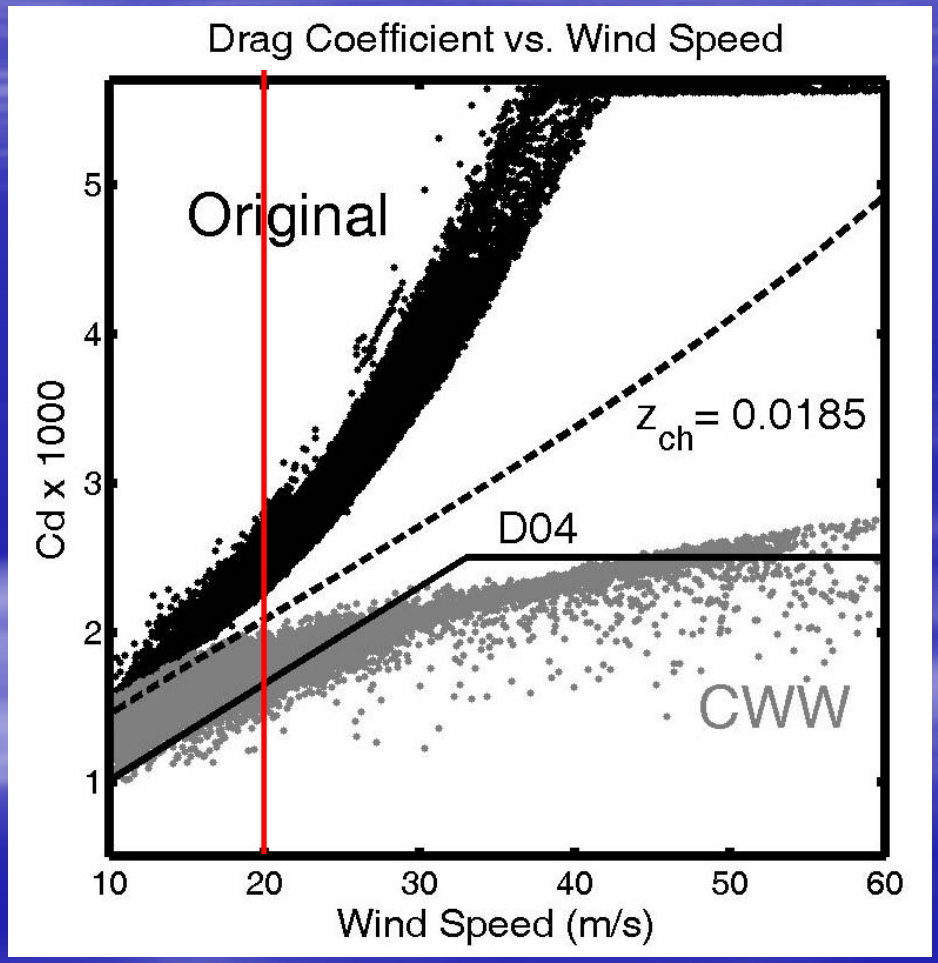
$$H_s = \rho C_p \overline{w\theta} = \rho C_p C_H U_{10}(\Theta_s - \Theta_{10})$$

$$E = \overline{w\rho_v} = C_E U_{10}(\rho_{vs} - \rho_{v10})$$

$$H_l = h_{fg} E$$

High Wind Conditions

Various Model Results – c/o Tetsu Hara URI

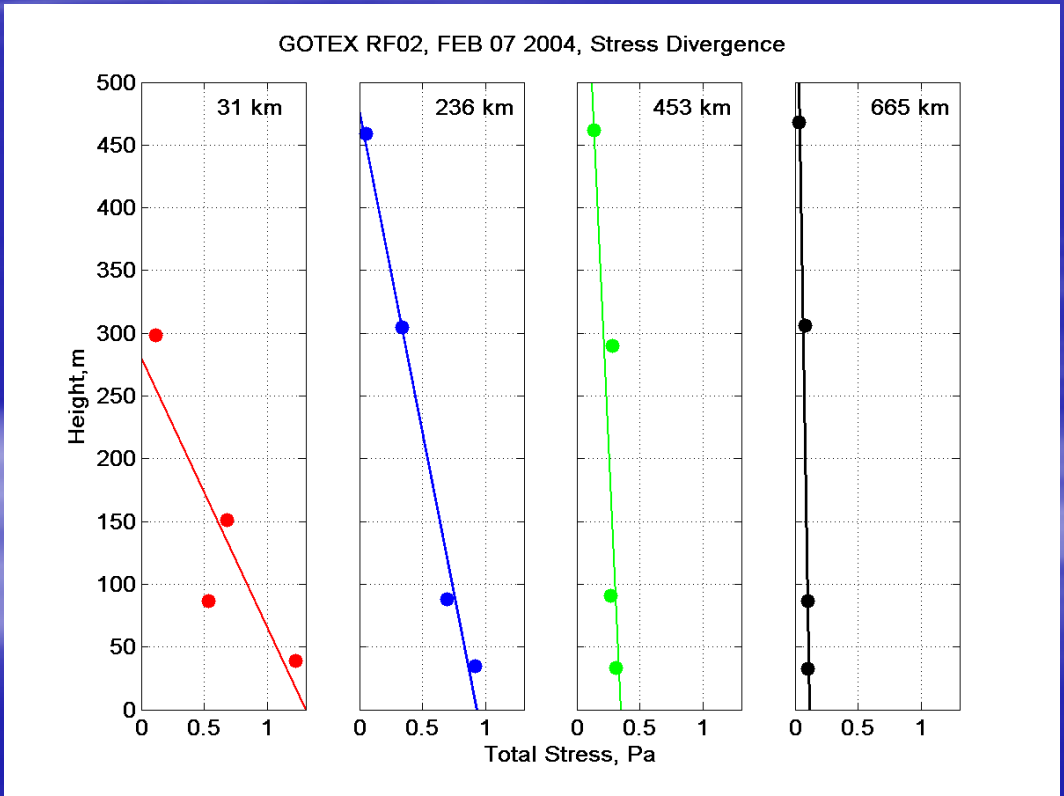


Above ~20 m/sec, mostly models or inference.

Waves

Stress Divergence

Stress Divergence in developing BL gap outflow in the Gulf of Tehuantepec, Mexico Feb 7, 2004 (Aircraft used is the C130 from NCAR.)



- Lowest flight level for most research aircraft is ~30 m, thus data need to be extrapolated to the 10-m reference height
- Monin-Obukhov similarity theory applies to the constant-fluxes surface layer and profiles functions used were obtained from overland data (Kansas Experiment 1968)
- 30 m may be above surface layer in some BL flows such as developing gap outflow close to shore or very stable BL as in CBLAST-Low
- Simultaneous measurements from two levels

Flux Platforms for Fair to Moderate Weather

Buoy: 10m
Ship: 14m
Aircraft: >33m

Motivation

- Air-sea flux parameterizations require in-situ turbulence and mean measurements at 10m above the sea.
- Data at high winds are lacking: buoys and ships inadequate; aircraft >33m.
- Wind stress in hurricanes is needed to improve “intensity” forecasts.
- Stress Divergence. Extrapolate means to 10m.
- CTV can operate at ~10m while tow aircraft is safely above.

Controlled Towed Vehicle (CTV) Goals

1. Measure surface fluxes of momentum (stress), sensible heat, water vapor (latent heat) and trace gases (CO_2) **near the ocean surface** in all conditions, especially high to hurricane strength winds. (Canonical measurement height is 10 meters.)

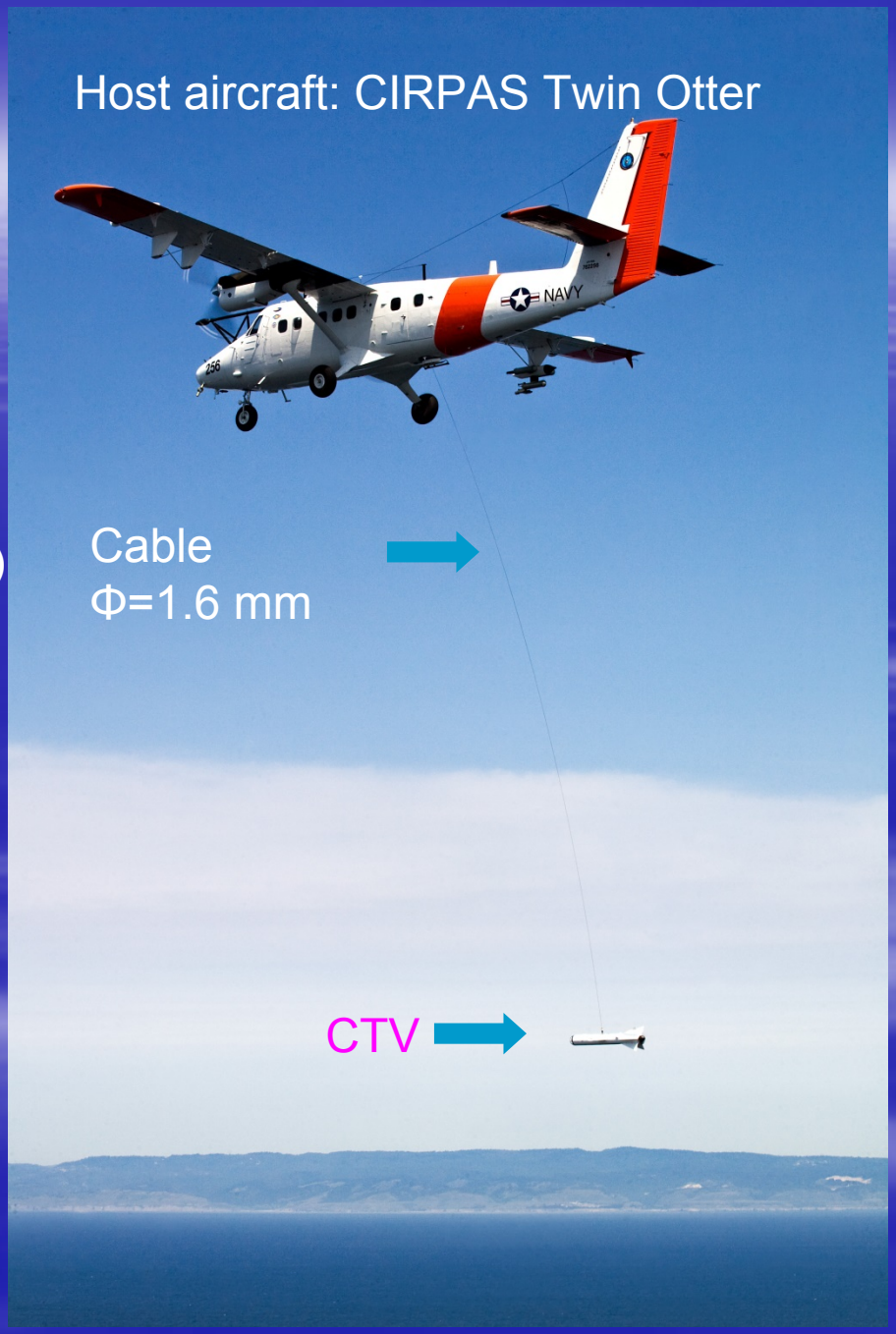
2. Profile the boundary layer for determination of mean and turbulent variations, e.g., wind profile, flux divergences for model verification.

3. Aircraft are suitable platforms due to their mobility (large spatial coverage) and ability to fly in high winds, but are limited to > 33 m (some much higher). It is desirable to extend their reach nearer the surface without compromising safety.

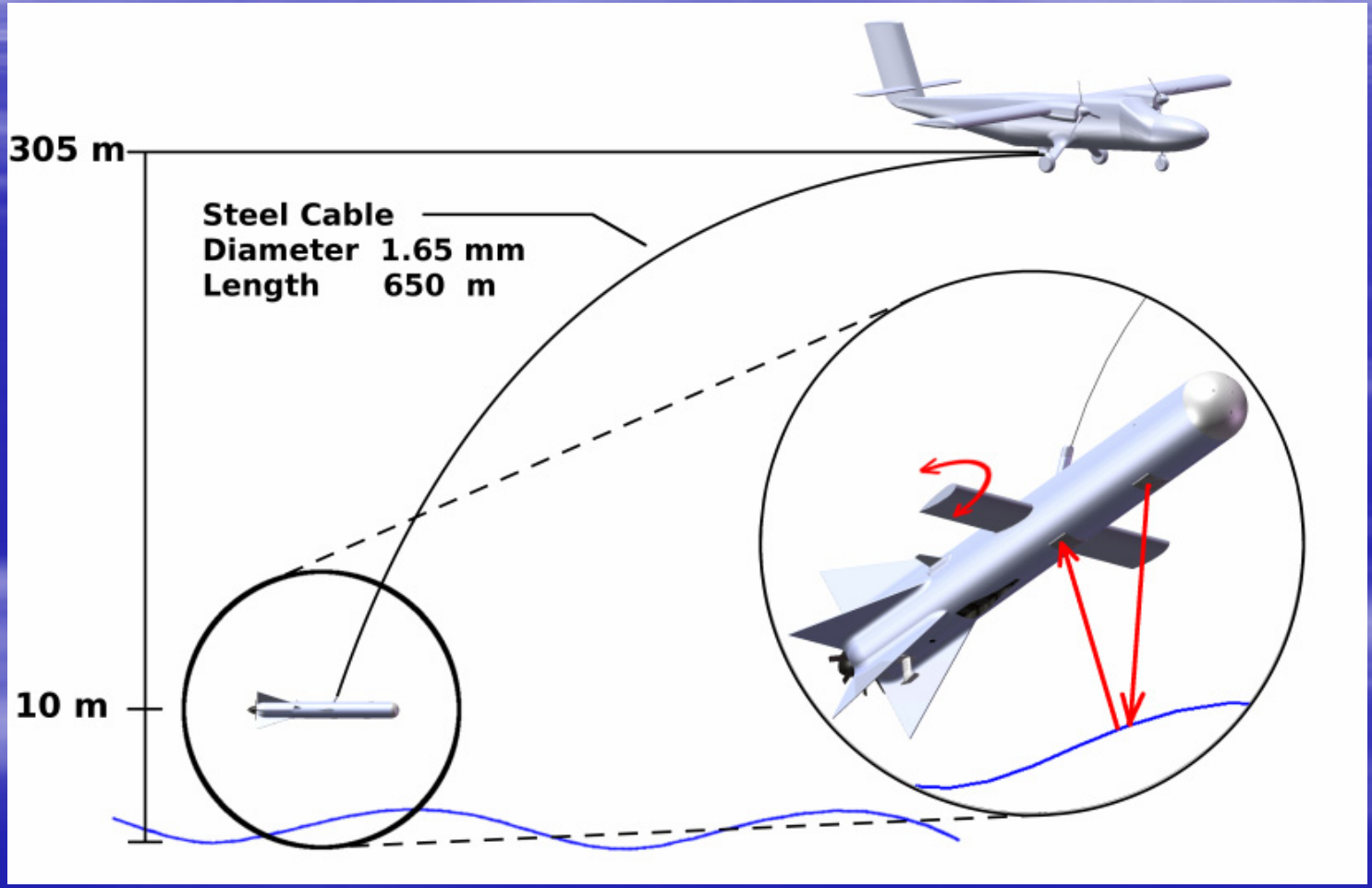
4. Radar-height controlled target drones are proven technology and are readily adaptable for scientific measurements and can "fly" **as low as 10 meters**.

Choice of platform in Inhospitable Ocean Environment

1. Buoy – few, fixed-point, motion
2. Ship – slow, motion, flow distortions
3. Aircraft – mobile, low altitude limit
4. Unmanned Aerial Systems (UASs, ex-UAVs) – small payload, underpowered)
5. Modify existing towed target drone technology for controlled height over the sea while tow aircraft is safely above.



Concept of the Controlled Towed Vehicle

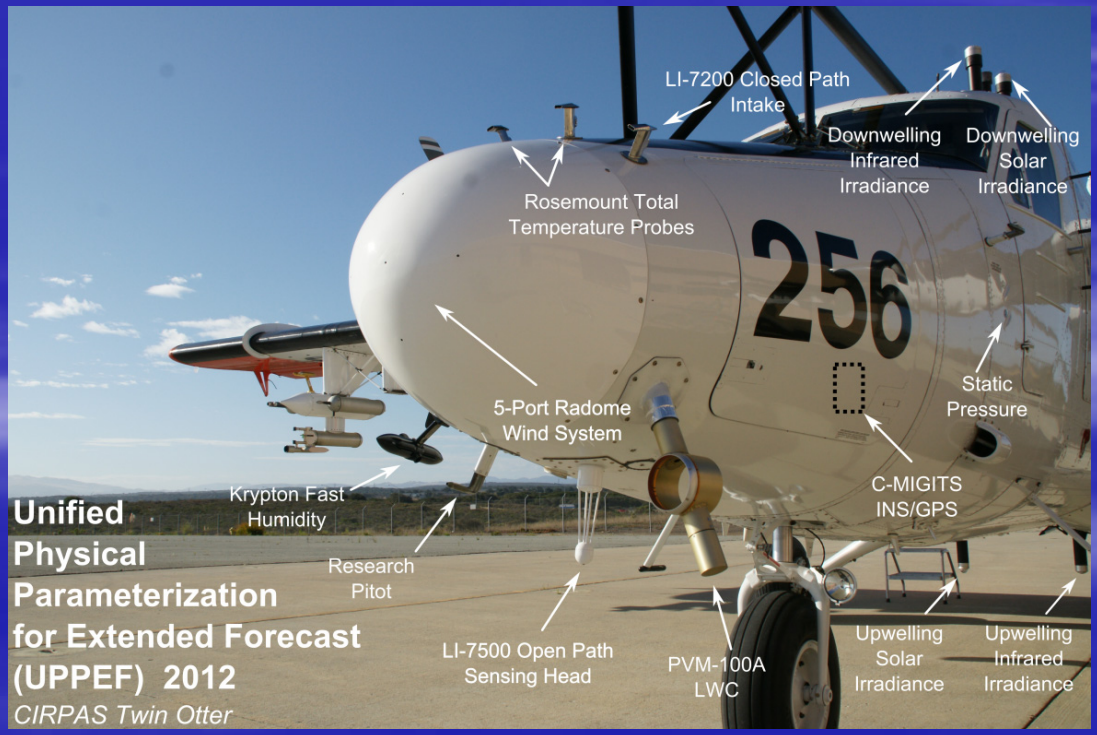


Requirements

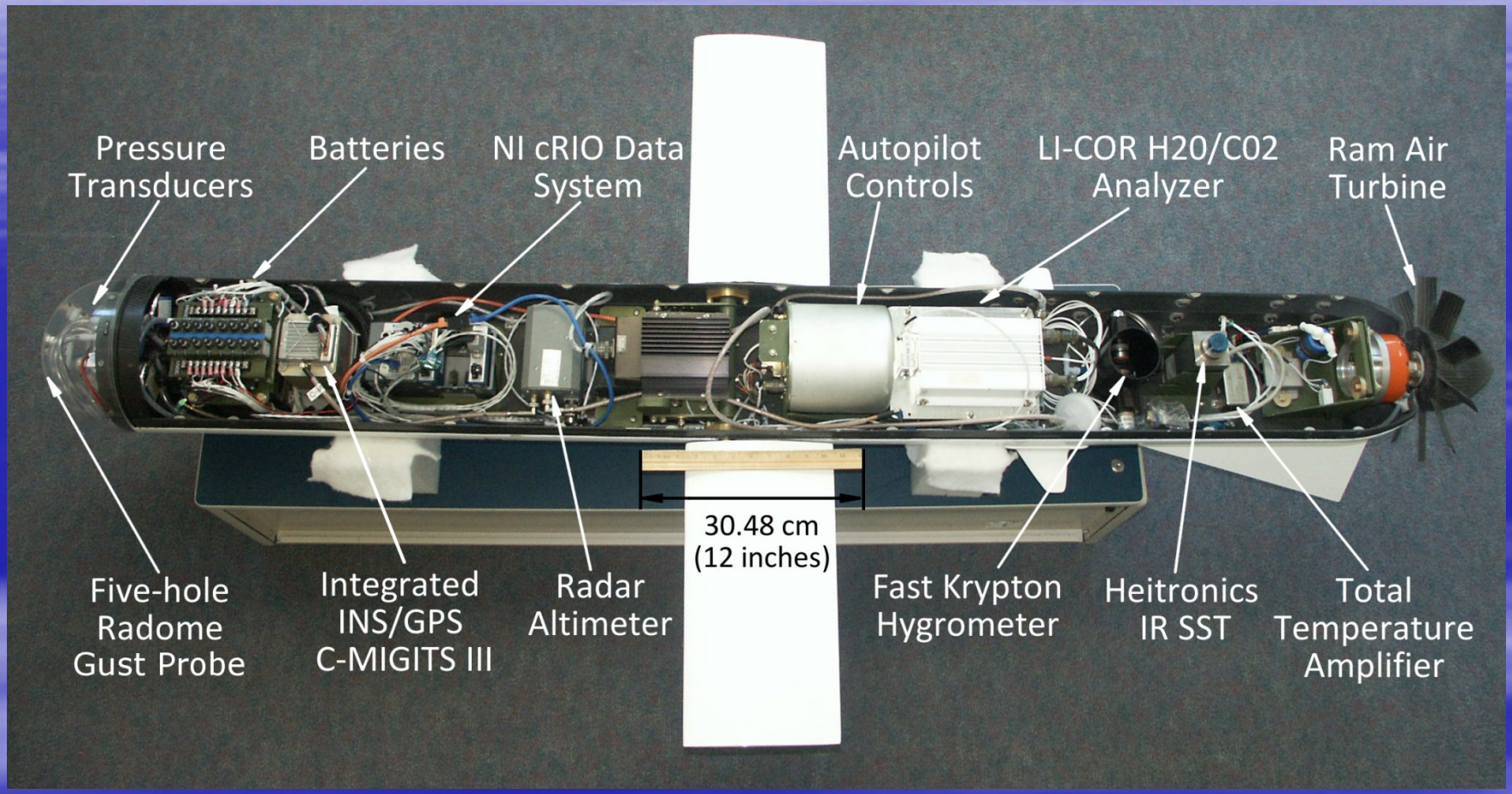
1. Mean and fluctuating 3-component winds, U,V,W, motion corrected
2. Mean and fluctuating temperature and humidity
3. Sea surface temperature (IR)
4. Platform motion, altitude, navigation, GPS time.
5. BW: DC to ~50Hz for co-variances and inertial sub-ranges

CIRPAS Twin Otter Aircraft

Note: Relative airspeed vector from 5-port radome pressures, i.e., in-situ “Cobra Probe.” Navigation, motion, angles from GPS/Inertial

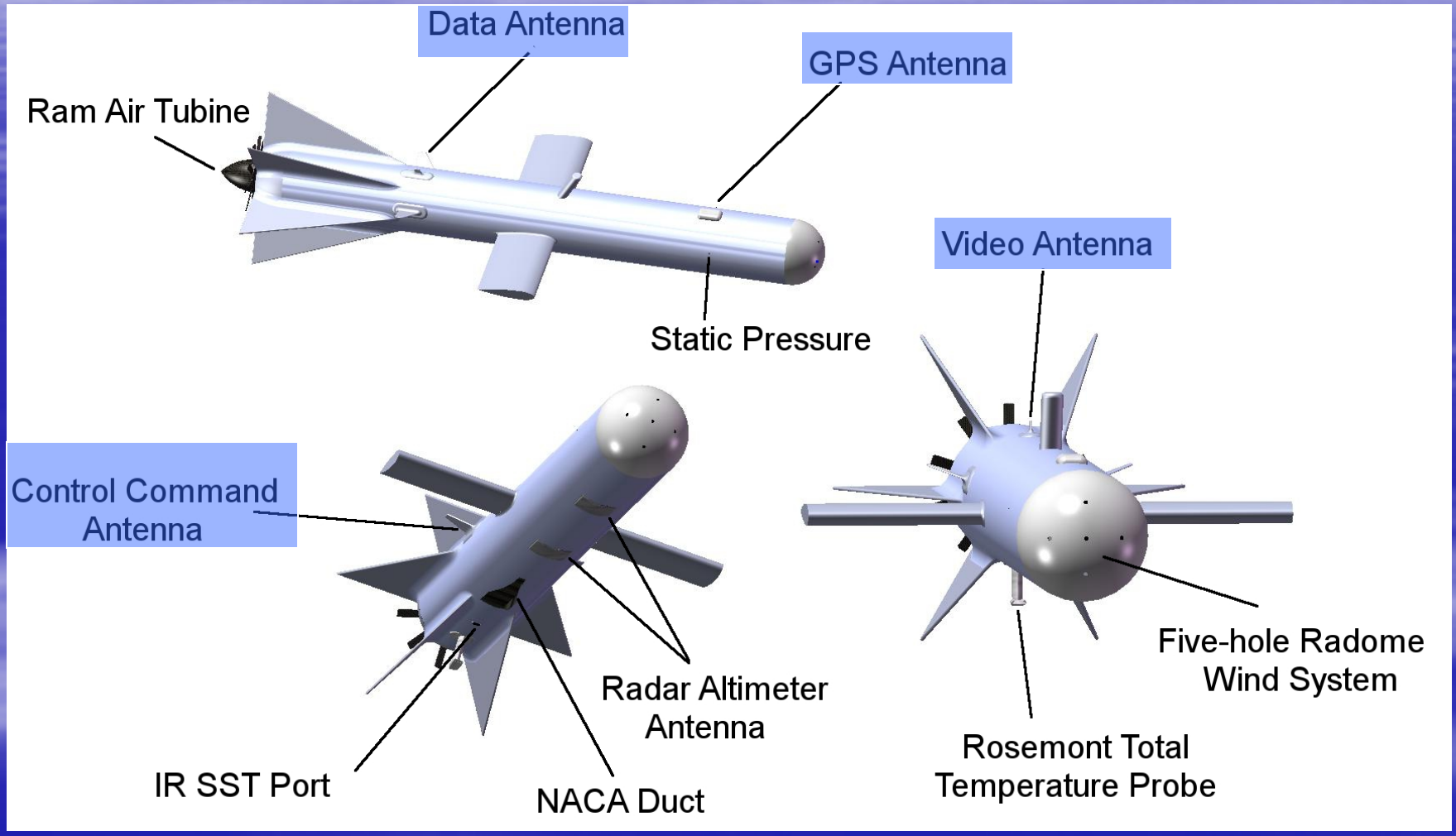


Instruments Layout

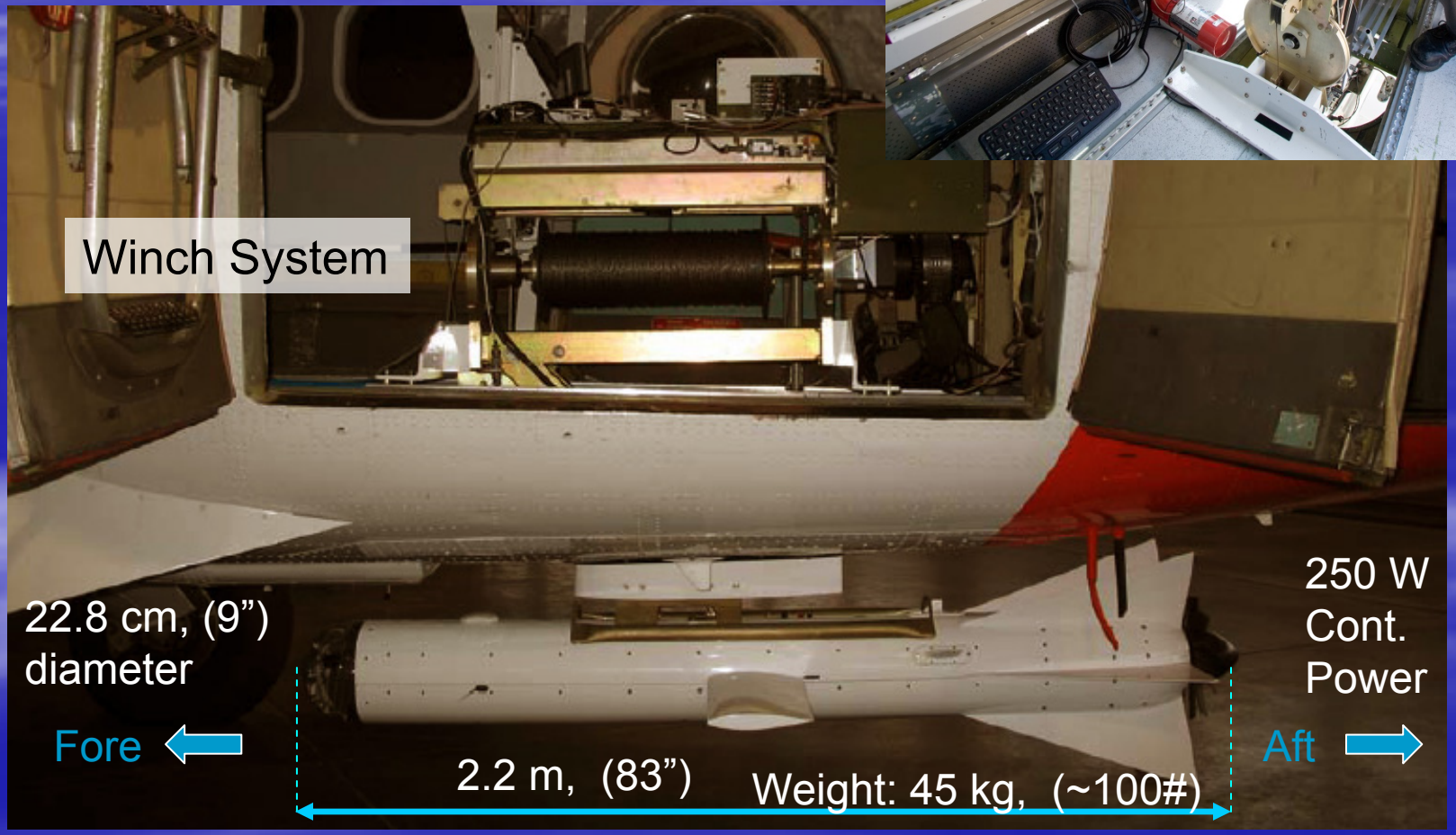


Mass=45 kg; D=0.23 m; L=2.2m; P=250 W

Instruments and Systems

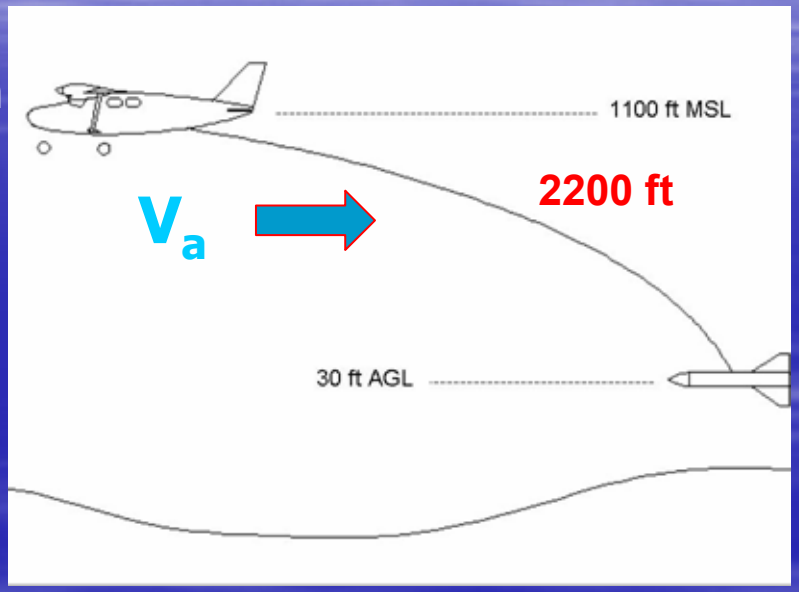


CTV on CIRPAS Twin Otter



How Safe is the CTV?

1. Cable "natural" lift: when enough cable is reeled out its resultant lift force balances the weight of the CTV and prevents it from going further down. **The active control system has to be engaged** to pitch down the wings forcing the CTV further down to the commanded height. **If malfunction, wings auto-set to neutral→ CTV CLIMBS.**



2. Weak link on the CTV end of the cable breaks when cable tension is too high

3. Automatic cable cutter switches on flight deck and at CTV control station

4. Manual cable cutter nearby winch system

5. Video from CTV nose camera and from downward-looking aircraft camera

6. Twin Otter radar detects ships, obstacles…

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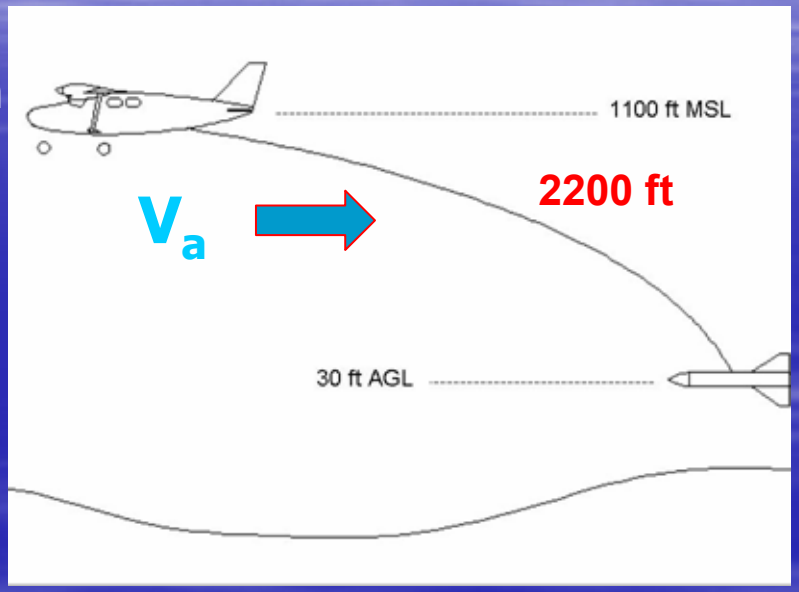

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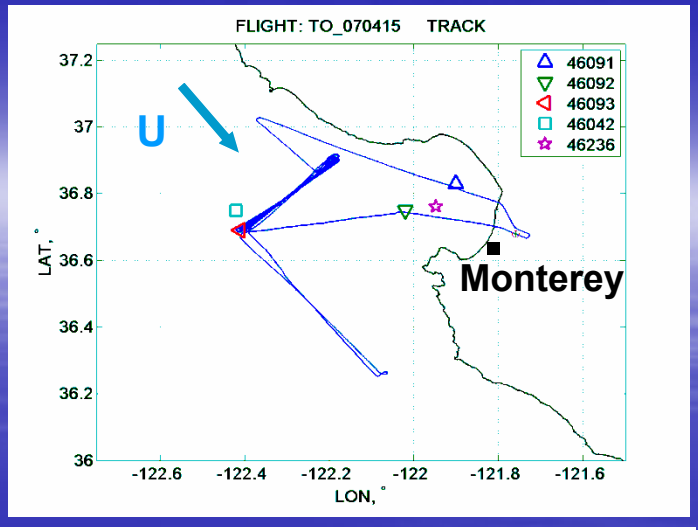
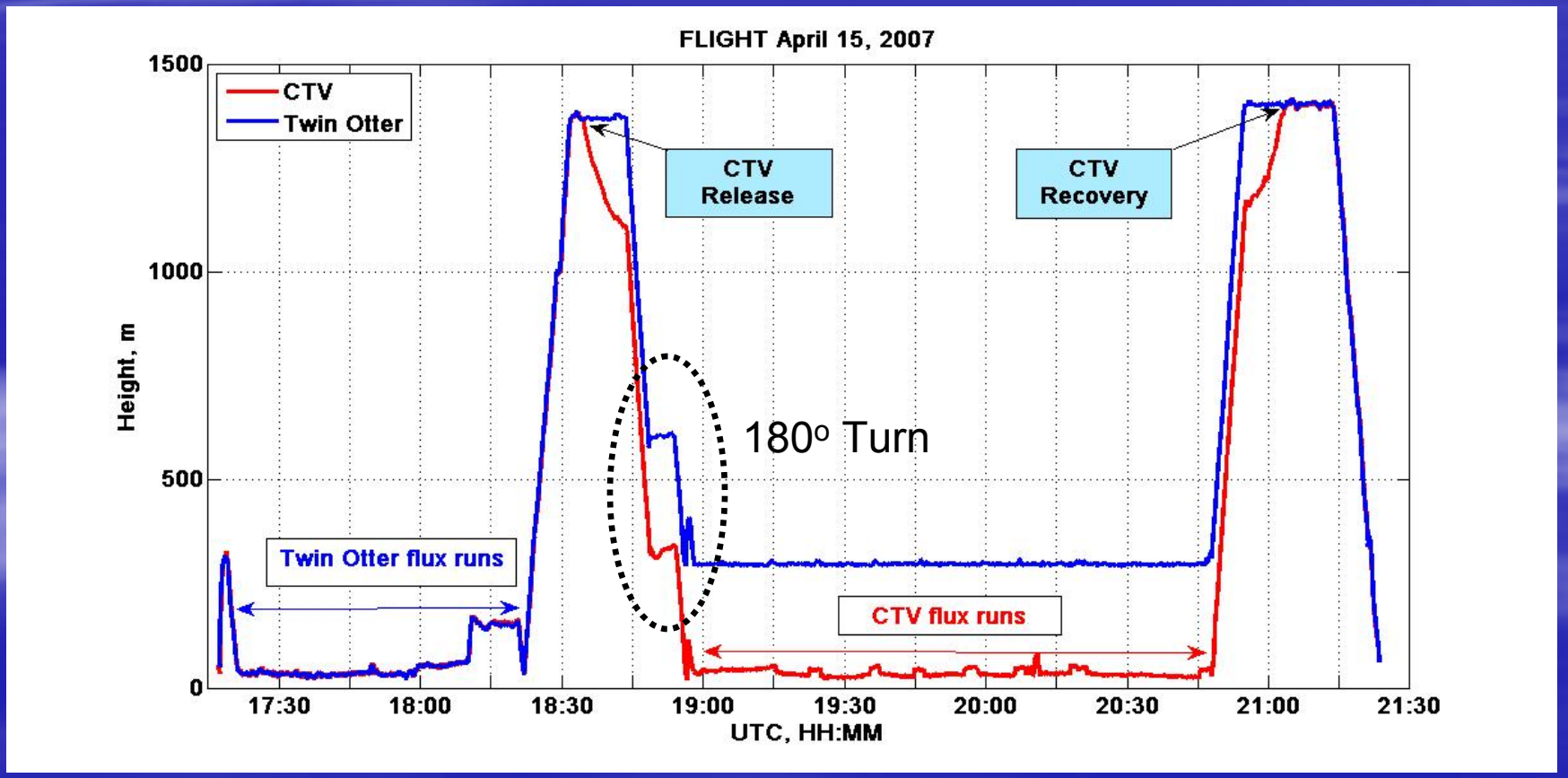
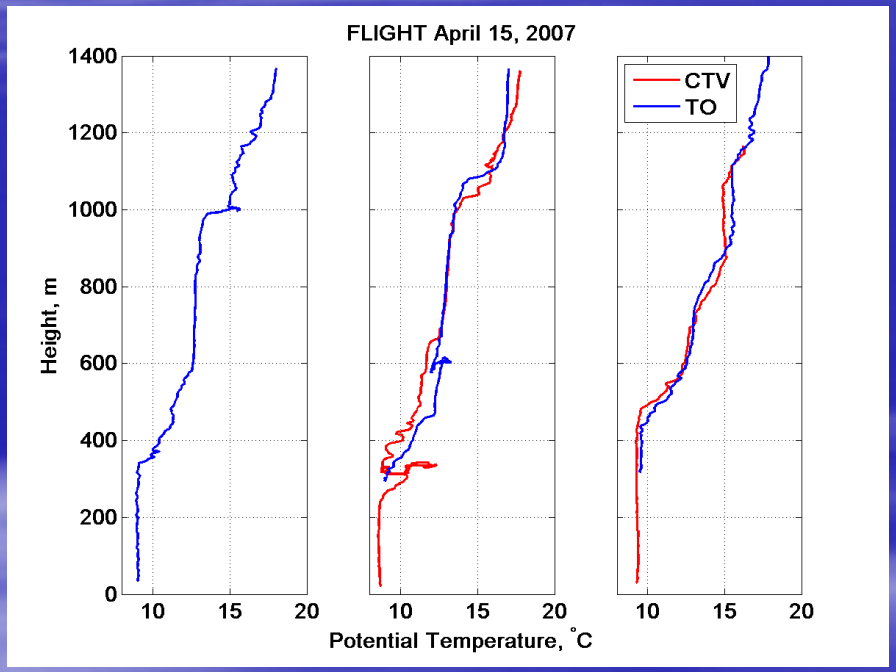
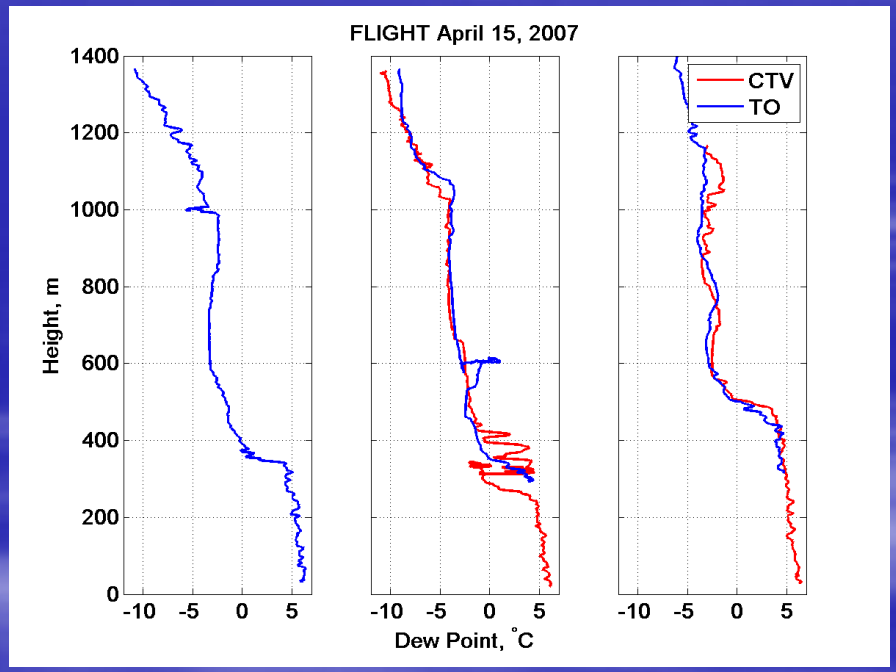
Flight of April 15, 2007



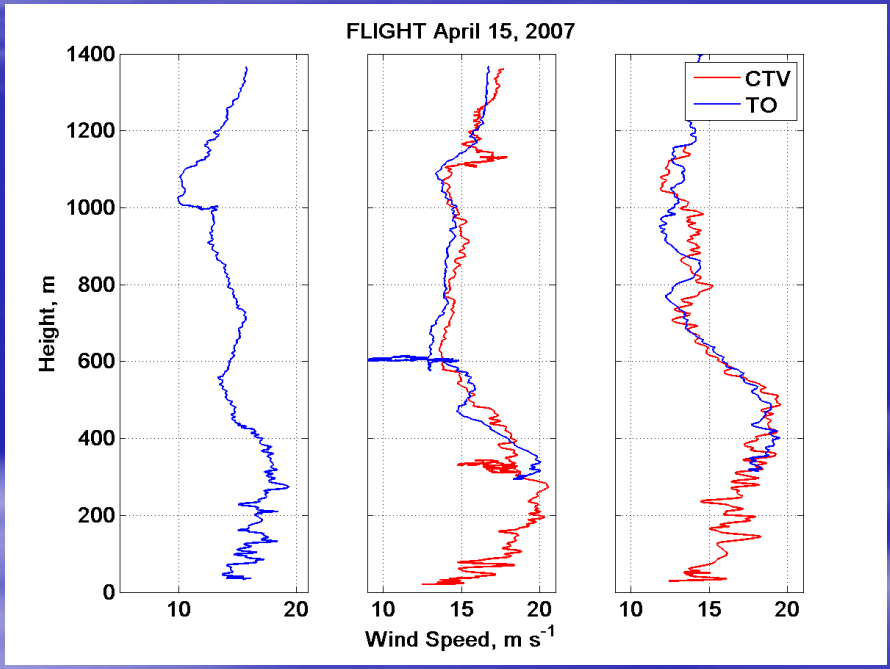


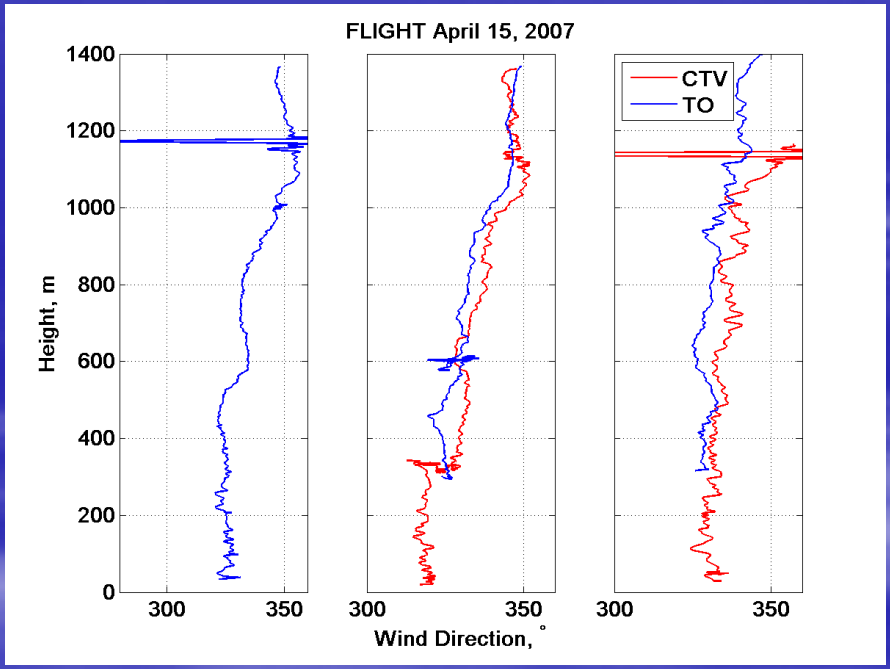
Temperature and Dewpoint Profiles





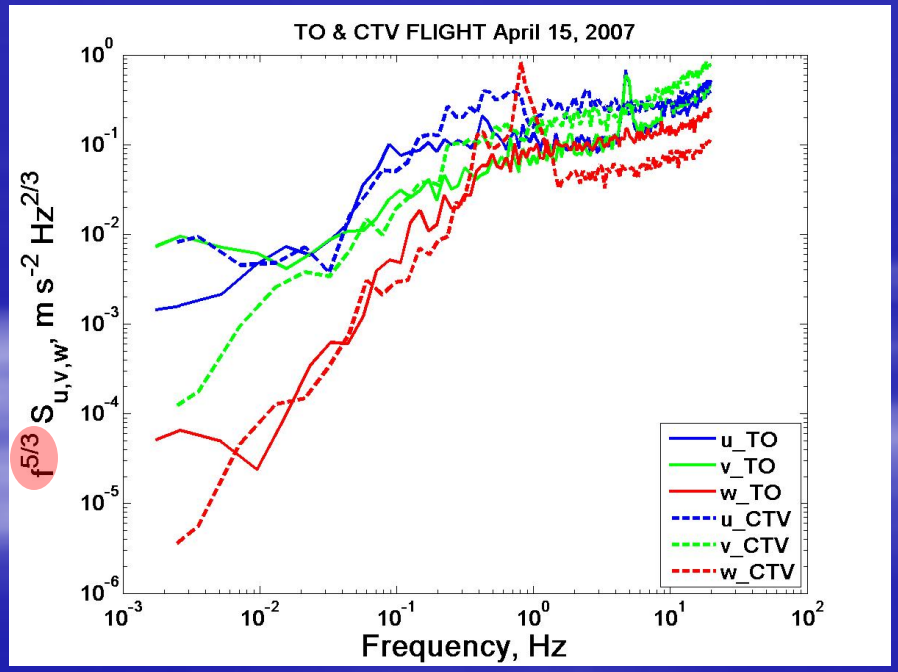
Wind Speed and Direction Profiles



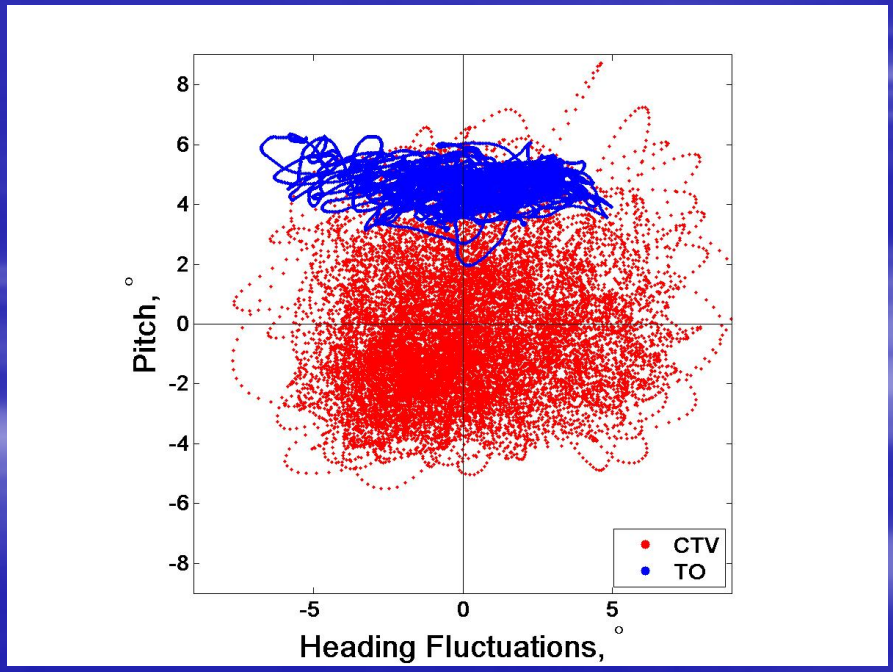


Wind Component Spectra (5/3-moment) and Platform Motions

Wind Spectra



Attitude



Improved Control System

Piccolo SL Autopilot
(Cloud Cap Technology)

100 waypoints saved in autopilot

3 axis gyroscopes. 300 deg/sec

3 axis acceleration. 6g

Transponders, Secondary Comms Radios, Iridium SatComm, TASE Gimbals, Servo PTZ gimbals, Magnetometers, Laser Altimeters, Payload Passthrough, RTK GPS

Vin: 4.5 – 28 volts

Power: 4 W (typical including 900 MHz radio)

Size: 130 x 59 x 19 mm (5.1 x 2.34 x 0.76 inches)

Weight: 110 grams (3.9 oz) with 900 MHz radio

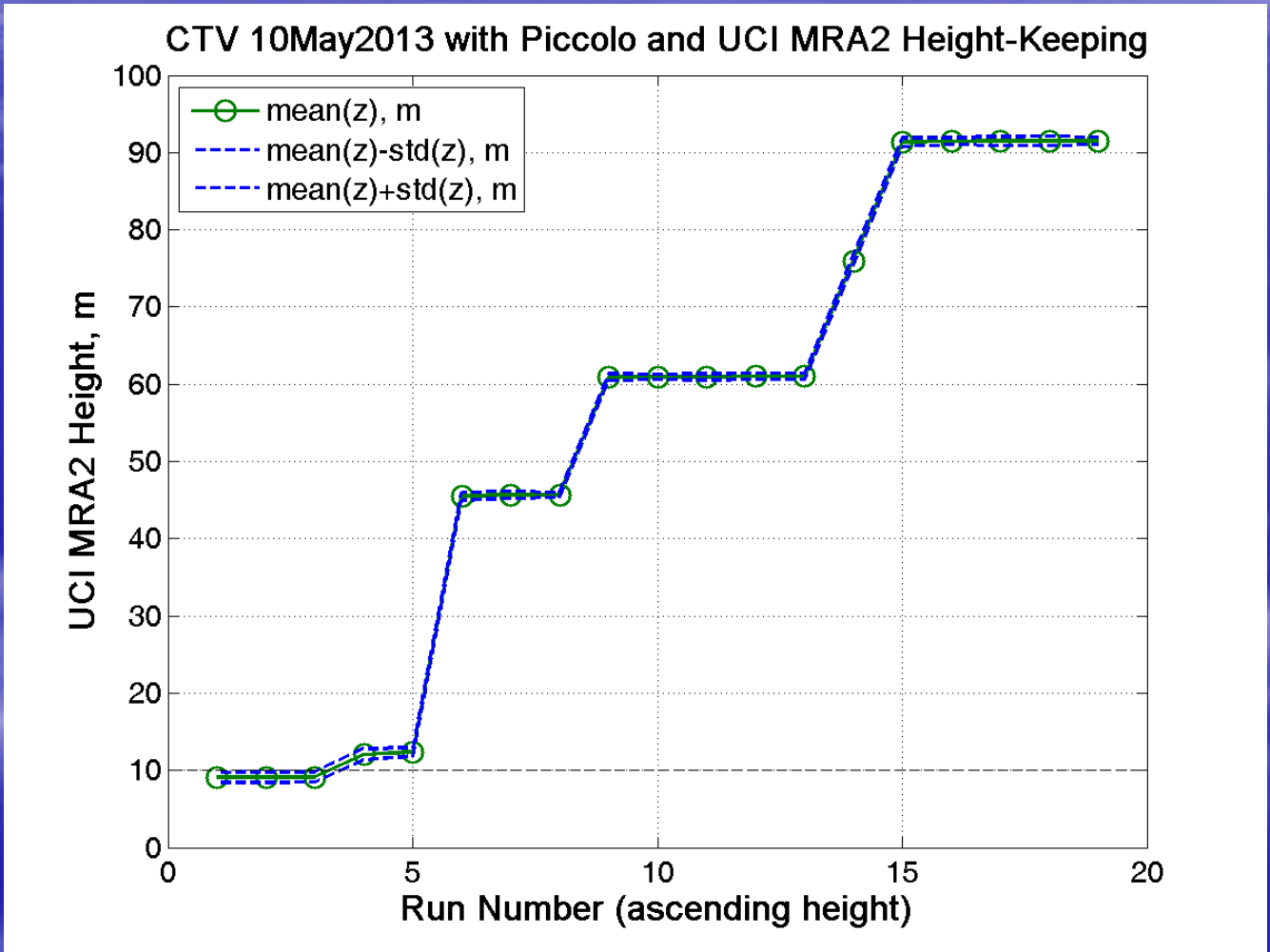
Operating Temperature: -40C to +80C (calibrated Range, no case)

Miniature Radar Altimeter
(Roke Manor Research, LTD)

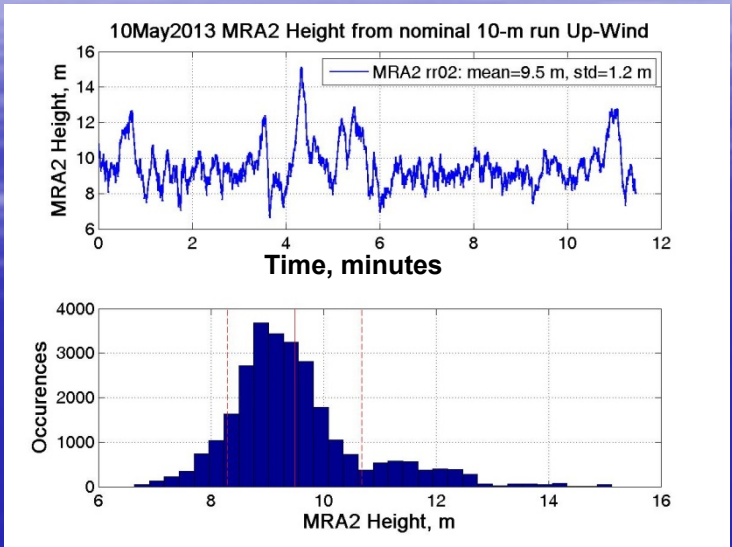
MRA Type 2 – system specification

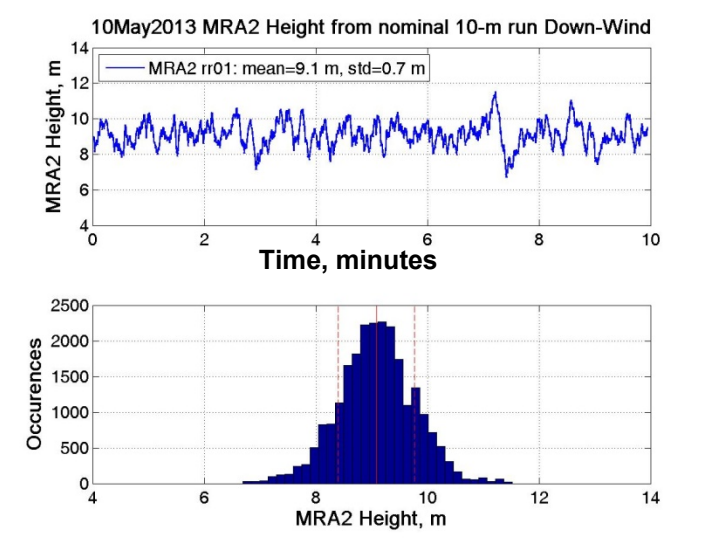
Altitude	
Nominal Range	0.2 to 100m
Resolution	
Default	0.02m
Physical	
Length	140 mm
Width	75 mm
Height	46 mm
Weight	400g
Integrated antenna dimensions	
Length	12.6 mm
Width	8.6 mm

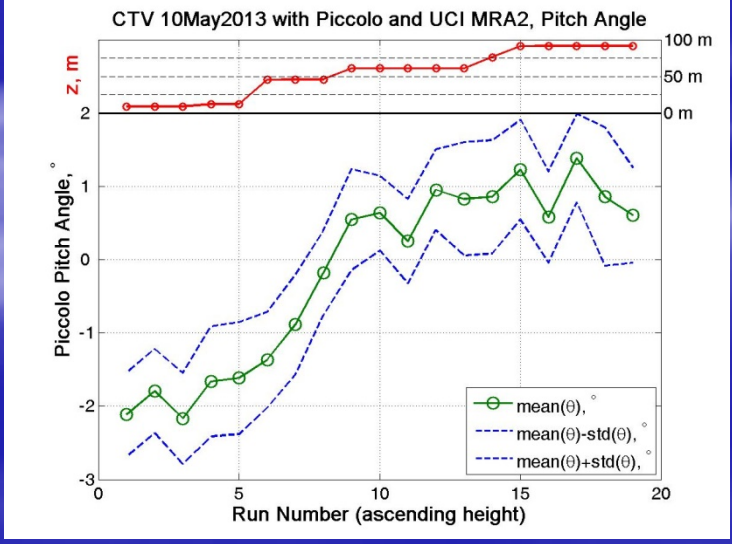
Height-Keeping Performance

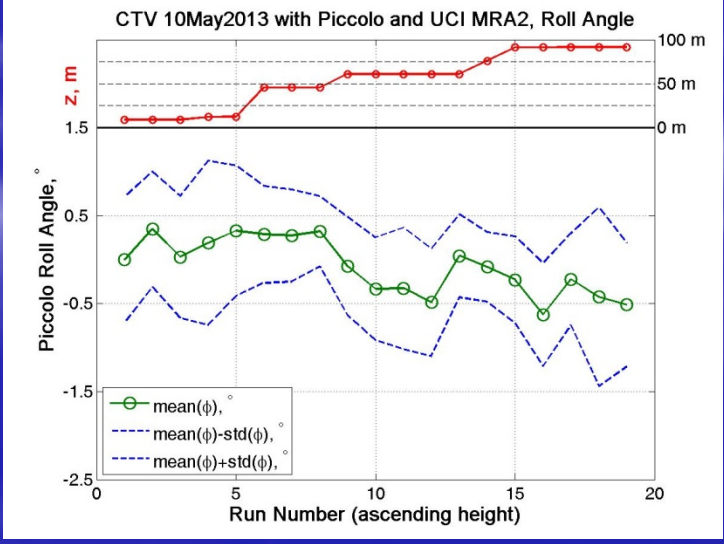


Height-Keeping Performance (continued)



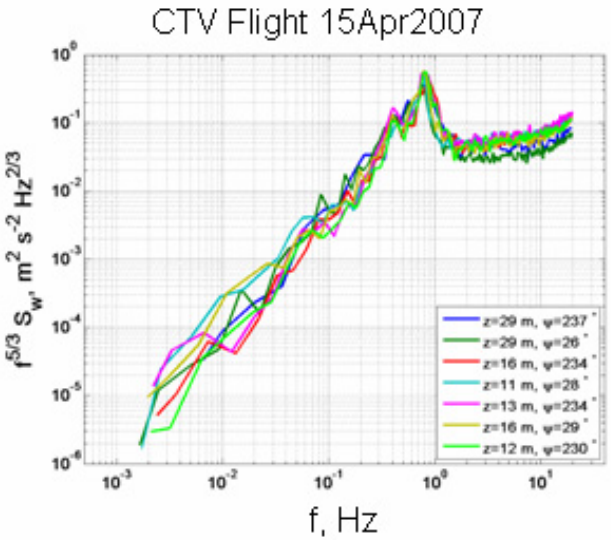


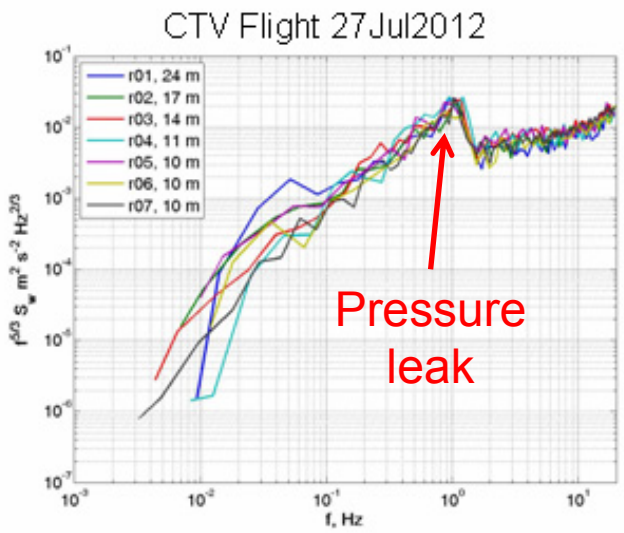




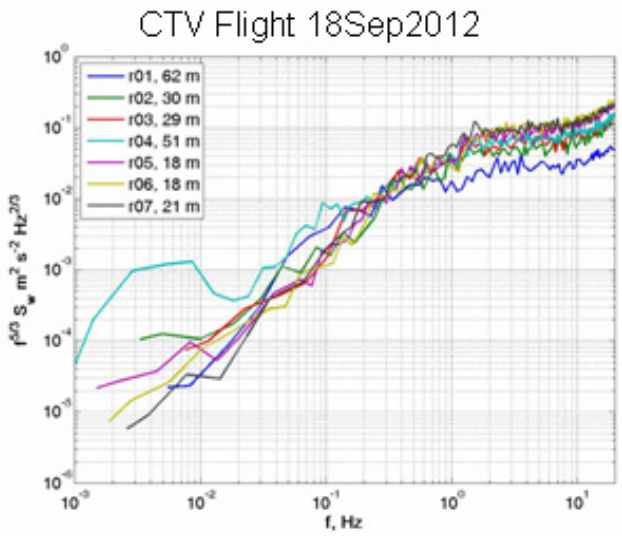
Improved Vertical Wind Spectra

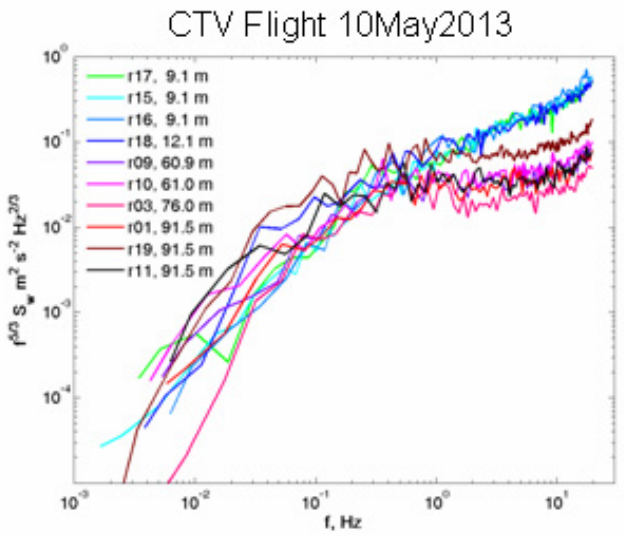
Control: Original (Meggitt)





Control: Piccolo + AGL laser





Control: Piccolo + Radar MRA II

Piccolo + AGL laser Control

Conclusions

- Towed target drone technology was successfully adapted to the CTV to obtain critical turbulence measurements near the ocean surface.
- A new control system allows very reliable and stable control as low as 9m
- Problems in vertical wind spectra with original control system are solved
- CTV has had approximately 90 cycles-140 hours without mishap.
- CTV has more space, power and payload compared to most UAVs (UASs)
- Simultaneous measurements obtained from tow aircraft higher above.

UCIrvine
University of California, Irvine

Z-Axis Zivko Aeronautics Inc.

NPS Praestantia per Scientiam

ONR Office of Naval Research

Future Work

- Resolve issue with CTV nose camera video link that transmits live images to flight deck and operator (this worked back in 2007 and 2008)

- Will participate with the CTV in the NPS Coupled Air Sea Processes and EM ducting Research (CASPER)

- CTV can be readily adapted to larger tow aircraft (such as the NCAR C-130 and NOAA WP-3D)

- Other sensors can be added or substituted – atmospheric chemistry, aerosols, radiative transfer, volcanic emissions, waves, etc.

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