On the Use of Low-Cost Unmanned Aircraft Platforms as Part of a System To Determine Short-Term Electromagnetic Propagation Characteristics in the Surface and Boundary Layers

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Key Point *We have developed a low-cost (~ $10K) unmanned aircraft system useful for near-surface (< 300 m AGL) observations. Initial analysis from Fall 2010 flights reveals structure that can go undetected by other sensors, such as sub-km horizontal structure as well as vertical structure in temperature and moisture fields that has implications for effective use of radar and other systems relying on EM propagation.*

Motivation

As part of work underway at the University of North Dakota (UND) to develop sense-and-avoid technologies for Unmanned Aircraft Systems (UAS) operations, we have been investigating the utility of low-cost UAS platforms equipped with atmospheric state variable (temperature, pressure, humidity) instrument payloads for near-surface and boundary-layer observations.

Such observations are valuable for a variety of purposes. Here, we are concerned about the potential of these observations to characterize the near-surface/boundary-layer electromagnetic (EM) propagation environment. Characterization of the EM propagation environment is important for several reasons relevant to the management of airspace capacity. First, the presence of surface-based or mixed layer ducting layers can potentially interfere with air-ground communications for aviation. Second, the presence of ducting layers can lead to misinterpretation/obscuration of aircraft positions as observed by tracking radars since the ducting layers substantially impact radar beam propagation. The resulting sub-optimal tower-aircraft communication and radar tracking necessitate wider separation (in space and time) between incoming and outgoing aircraft given the potential for reduced reaction times for both traffic controllers and pilots. Therefore, the ability to characterize the EM propagation environment in real- to near-real time, as well as provide nowcasts (0-3 hours) of the propagation environment (via assimilation of observations into a numerical forecast model) is important as it can provide controllers more time to implement strategies designed to manage periods of reduced capacity.

In addition, current work at UND is focused on improving sense-and-avoid technologies for UAS, as a means of providing a pathway towards enhanced airspace access for such unmanned systems. This work involves both Automatic Dependent Surveillance Broadcast (ADS-B) transponders and a system of Ganged Phased Array Radars (GPARS; see Johnson et al. 2011, poster 337, for details) as input to a Risk Mitigation System intended as a decision support tool for UAS operations in unrestricted airspace. Analyses and forecasts of the EM propagation environment are expected to be an important component of such a system since they would help to determine optmal radar scan strategies.

The UAS Platform and Payload

UAS Platform Characteristics

Although Light UAS platforms (< 150 kg weight) are much more widely available than was the case a decade ago, there are very few platforms for atmospheric measurements that are economical to deploy on an extended basis as would be desired for measurement campaigns in support of airspace management. One of the goals of this project was to determine the feasibility of utilizing a low-cost off-the-shelf airframe with locally- developed (as a project for students of UND's Unmanned Aircraft Systems Engineering Center (UASE)) payload incorporating commercial off-the-shelf atmospheric sensors for temperature, humidity, pressure and particle counts. The airframe selected for the project, the Telemaster Senior (shown in the accompanying figure), is technically considered a model aircraft and was obtained at a cost of slightly over $3K from a Hobby Lobby outlet.

Telemaster Senior Specifications

- *Wing Span: 7.8 ft (2.38m)*
- *Length Nose-to-Tail: 5.3 ft (1.62m)*
- *Flying Weight: 10.5 lb. (4.76 kg)*
- *Maximum Payload: 7 lb. (3.18 kg)*
- *Cruise Speed: 20 kt (10.3 m/s)*
- *Operating Ceiling: 1200 ft (365.8m)*
- *Endurance: 1 hour*
- *Propulsion: Axi Brushless Motor*
  - *✓1700 W , 12.5 lb (5.67 kg) thrust*
- *Power: 22.2V LiPO batteries*
- *Navigation: MicroPilot Autopilot with Global Positioning System link*
- *Communication: 2.4GHz datalink*
- *Launch and Recovery: Conventional takeoff and landing*

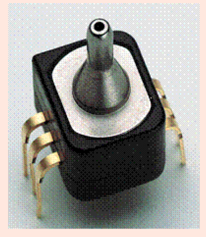
The Telemaster Senior Airframe (with pilot console) on the Test Field at Camp Grafton South, ND

UAS Payload

Left: View of payload mount location and expanded exterior view of payload.

Right: Interior view of payload.

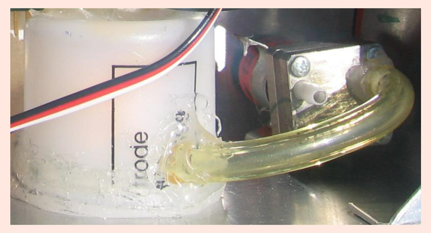
Payload Major Components



Pressure Sensor Omega PX40-15G5V

Temperature/RH Sensor Vaisala HMP50

Optical Particle Counter Met One 9012



Particle Counter Pump /Chamber Clark 15317

GPS Unit Trimble Condor

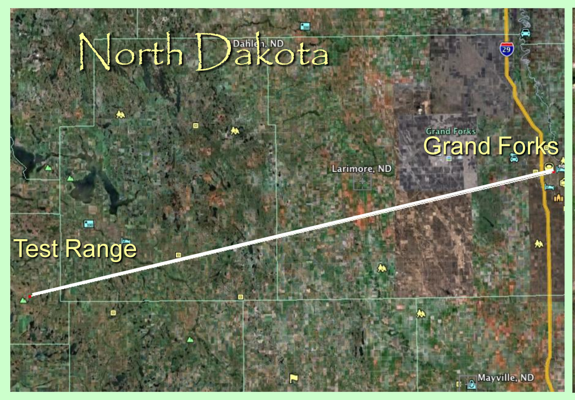
PIC Microcontroller

Murata DC-DC Power Board

The payload operates as a self-contained system on the airframe. It is light-weight (2.3 lb/ 1.04 kg) and is contained within an aluminum EMI shielded housing. Data is collected at a frequency of 1 Hz with 10-bit resolution. Variables collected include ambient temperature and relative humidity, ambient pressure, particle counts within six size bins, and GPS position for redundancy with the GPS contained within the MicroPilot Autopilot. Data can be easily retrieved using a portable UPS drive.

Test Range and Missions

All flight missions to date have taken place at the UND Center for UAS Research, Education and Training Flight Test Range. As illustrated in the left figure below, the Range is located approximately 75 miles (120.7 km) west-southwest of the UND campus, within the North Dakota National Guard's Camp Grafton South facility. The Test Range consists of approximately 15 km^2 within Restricted Airspace Area R5401. As can be inferred from the right figure below, terrain is gently rolling (approximately 35 m maximum elevation difference from ridge tops to basin low points) with a flat runway area composed of groomed prairie grasses. All takeoffs and landings are from this grass runway area.



Location of the Test Range utilized for the Telemaster missions, relative to Grand Forks, ND. Image generated using Google© Earth.

Close-up Google© Earth plan view of the Camp Grafton South Test Range, from an eye altitude of 1.5 km

View, looking southeast from a ridge top to the northwest, of the grass runway area of the Test Range.

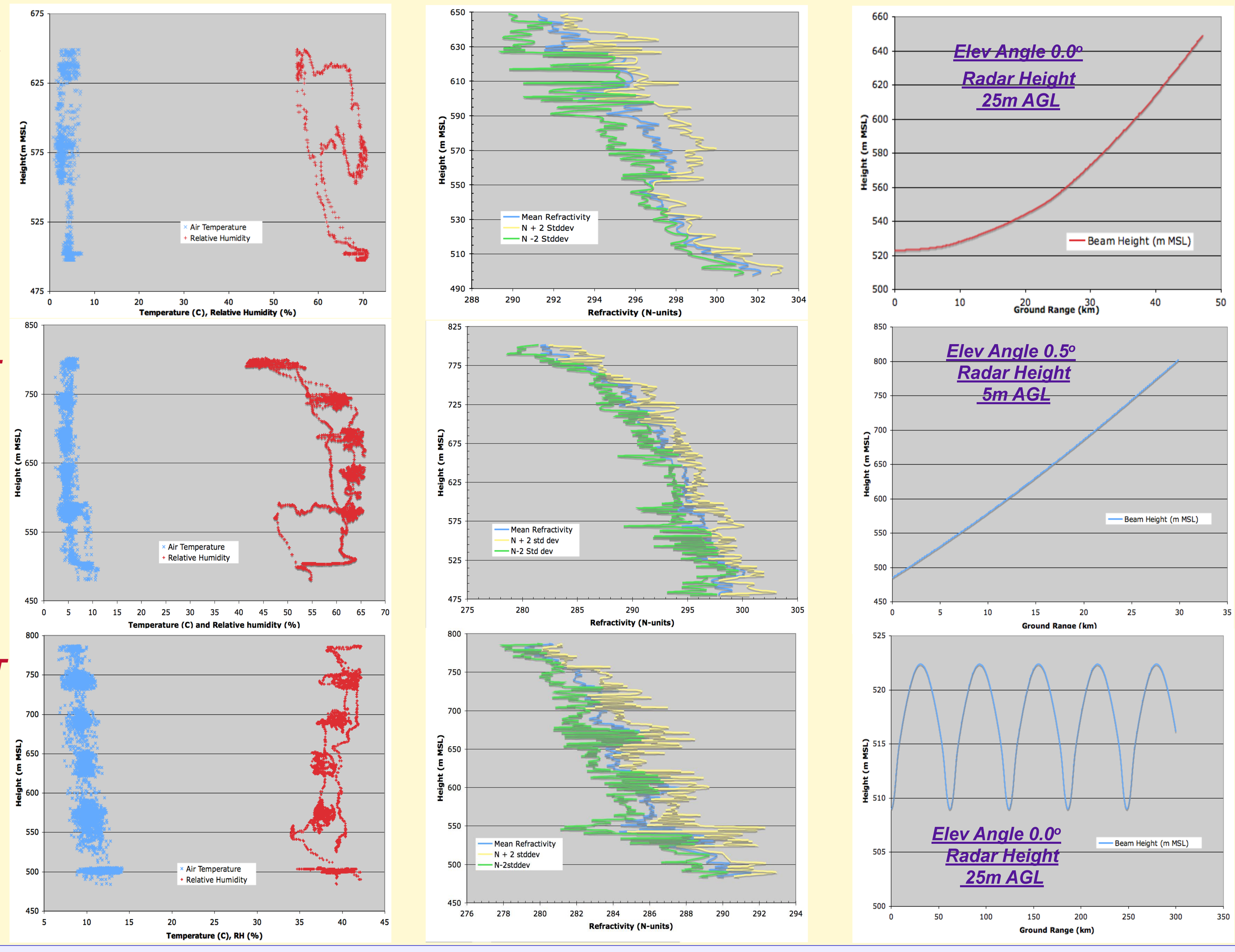
In 2010, the Telemaster UAS platform was flown on three mission days: 10 August (2 flights); 6 October (4 flights); and 5 November (3 flights). The 10 August flights were basic test flights to determine the viability of the platform, but the pressure sensor was not yet functional though temperature, humidity and GPS data were obtained. The 6 October flights and 5 November flights included a functioning pressure sensor, but the 6 October flight observations are relatively noisy due to issues with the microcontroller, which resulted in a redesign of the primary electronic board to solve this problem. Quality control (QC) of the 6 October dataset is continuing. Calibration and QC of the cleaner 5 November dataset is complete ; this dataset is presented in this poster.

Sample Results and Discussion: The 5 November 2010 Dataset

Sample results from the 5 November 2010 Telemaster Flights are presented below. The three flights on this date commenced at 1036, 1152 and 1513 Central Daylight Time, allowing for sample of different stages in the development of a well-mixed boundary layer on this clear-to-partly cloudy day (Cloud cover increased as the day progressed, but will still limited to only scattered cumulus). In future work, data from these flights (as well as the 6 October flights) will be assimilated into short-range (3 hr) simulations with the WRF Modeling System (e.g., Skamarock et al., 2008) to evaluate the potential benefit of these observations to forecasts of the EM propagation environment within eastern North Dakota. The diagnostics computed below, however, are quite interesting in their relationship to the results of Johnson et al., (2011, adjacent poster).

T/RH Profiles | *Mean Refractivity N & ±2σ* | *EM Ray Propagation*

1036 CDT / 1152 CDT / 1513 CDT



Analysis Methodology

As the flight track for each flight consisted of a stacked series of 'X' patterns at several levels, with slant ascents between each level (plus a final descent into the landing), mean profiles of the state variables are derived and used to compute mean refractivity plus a standard deviation around that mean. Ray propagation paths are computed, following Johnson et al. 2011, for the mean refractivity profile as well as profiles characterized by values +/- 2σ from the mean.

Discussion

The data from the test flights provided a variety of EM propagation environments in the near-surface boundary layer, as seen from the figures on the left. Slight subrefraction, normal propagation, elevated ducts and surface-based ducts all occurred with the observed mean refractivity profile. Allowing for observational errors with the $\pm 2\sigma$ modifications to the N profiles also, in some cases, changed the EM propagation environment from ducting conditions to normal propagation and occasionally to subrefraction. Ducting conditions were observed with assumed radar heights at both 5 and 25 m above ground level, for elevation angles of 0.0° and 0.5°. The presence of the near-surface ducts supports the results of the WRF-based N climatology of Johnson et al. (2011), which suggested a larger occurrence of such low level ducts than had been obtained from previous studies utilizing radiosonde observations as the primary data source.

Acknowledgements

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