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MODIFICATION OF AN AIRBORNE GUST PROBE FOR HURRICANE BOUNDARY LAYER RESEARCH

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1. INTRODUCTION

Estimates of fluxes using bulk methods such as the COARE algorithm from buoy measurements under weak and moderate winds have been shown to agree reasonably well with direct measurement of surface fluxes of heat, moisture and momentum in the marine boundary layer (Fairall et al., 1996; 2003). However, these algorithms are based on measurements in winds ranging up to roughly 20 m s^{-1}. Extending to higher wind speeds requires extrapolating into a range for which very few direct measurements exist. Obtaining direct measurements of surface fluxes in higher wind regimes is quite complicated. Ship-borne measurements become very difficult due to increased motion of the ship and the complexity of flow distortion. Likewise, aircraft measurements require flying near the ocean's surface in high winds and strong turbulence. Measurements are further complicated as high wind conditions are often associated with storms that produce precipitation that can interfere with the instruments.

Despite these difficulties, a major component of the ONR-sponsored Coupled Boundary Layer Air-Sea Transfer (CBLAST) Hurricane program is to obtain measurements of the turbulent transfer of heat, moisture and momentum in the marine boundary layer under strong winds conditions (> ~20 m s^{-1}). A NOAA P3 research aircraft was employed to fly boundary layer legs in dry slots of hurricanes to obtain these measurements.

In this paper we present the evolution of an airborne gust probe, originally designed and used to measure surface fluxes from small research aircraft in light to moderate winds over land and water.

2. P3 GUST PROBES FOR CBLAST

The NOAA P3 has two Rosemount 858 gust probes mounted near the front of the fuselage, just aft of the cockpit. A nose radome system is also mounted on the aircraft. Results from data collected with the nose-radome in TOGA-COARE suggest that it provides: (1) accurate winds (to 0.4 m s^{-1}) with an even greater degree of precision and (2) a higher frequency response than the Rosemount probe (Khelif et al., 1999).

As part of CBLAST, a NOAA/ARL-designed "Best" Aircraft Turbulence (BAT) probe was added to the suite of already existing gust probes. The BAT probe is designed to mount on a boom that extends well beyond the nose of the aircraft (Fig 1). The benefit of such a design is to reduce errors in measurement due to flow distortion caused primarily by lift-induced upwash

Fig 1: BAT probe mounted on NOAA P3 research aircraft. The probe protrudes roughly 4-5 m in front of the fuselage nose.

(Crawford et al., 1996). However, a tradeoff to making measurements on an extended boom is the possible introduction of noise due to probe arm vibration.

3. BAT PROBE

The BAT probe (Crawford and Dobosy, 1992; Hacker and Crawford, 1999) evolved as an airborne gust probe to obtain high frequency measurements of wind and temperature from research aircraft. The BAT measures the pressure distribution over a hemisphere. These data are then used to determine a three dimensional wind velocity with respect to the probe. This technique is nearly identical to the techniques employed using the once commercially available Rosemount 858 probe and the modified nose radome.

The BAT probe differs from the other P3 gust measuring systems not only by its mounting location but also in the philosophy that is employed to obtain all of the measurements necessary to determine wind velocity. The BAT utilizes a nine-hole hemisphere as opposed to the standard 5-hole design. The additional ports are pneumatically averaged to provide a reference pressure, from which the static pressure can be determined. This alleviates the need for using static pressure ports near the rear of the aircraft. Further, A GPS antenna and accelerometers are mounted directly on the BAT for determining ground relative probe velocity. Built-in air temperature sensors complete the measurement suite. All of the measurements are made on the probe itself, alleviating possible errors associated

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with translating measurements from one portion of the aircraft to the probe's location.

4. BAT INSTALLATION ON THE P3

In summer 2002, the BAT was installed on the NOAA P3. Initial flight tests conducted under fair weather conditions indicated that the BAT was operating properly and raw data from the probe matched measurements from the other gust probe devices.

4.1 Modifications: Back-Flushing

The installation on the P3 required modifications to the probe due to contamination of the pressure ports by rain. Early in the design, it was determined that flux measurements would be possible only between rain-bands. To keep the ports clean while flying through rain a back-flushing system was devised. A small positive pressure was applied to all of the ports, near the sensors. The resultant flow of air out of the ports acts to flush water that gets trapped in the ports or pneumatic lines. Tests of the back-flush system during flights in 2002 and 2003 indicate that ports could be cleared in 2-3 minutes after flying through moderate rain. Hurricane research flights in 2003 reveal more time is needed to clear the ports after flying through heavy rain, 5-10 minutes after penetrating the eyewall are typical.

4.2 Modifications: Aluminum Hemisphere

Prior to the P3 install, previous BAT installations were all on aircraft of composite construction (fiberglass). For this reason, and to keep weight at a minimum, BAT probe construction historically has been fiberglass or carbon fiber. During the 2002 hurricane season, a carbon fiber version of the BAT hemisphere suffered severe damage during a flight in moderate rain (Fig 2). The impacts from water drops at the relatively high flight speeds of the P3 (> 100 m s^{-1}) caused significant erosion on the face of the sphere. A re-design of the sphere using a gel-coat was flown roughly one week later in moderate rain and showed improved results. However, a third re-design using machined aircraft aluminum was performed during the 2002 hurricane season. Unfortunately, even with a turn around time of two weeks, there were no CBLAST flight hours left in the 2002 season. Test flights between the 2002 and 2003 season and hurricane flights during the 2003 season with the aluminum sphere indicate that the aluminum design is resistant to erosion while maintaining the integrity of the measurement.

4.3 Modifications: Water drain

Initial hurricane flights in 2003 revealed intermittent problems with the electronics contained within the hemisphere. Although the BAT operated nearly flawlessly on the first flight, the electronics were becoming less reliable with each subsequent flight. It was determined that water was intruding into the sphere through vent holes in the center port. A re-design of the drainage system from the vent holes encased the entire center port in a chamber that drained to a vent at the base of the BAT. This re-design took roughly one week to manufacture with a turn-around fast enough to reinstall prior to flights in Hurricane Isabel.

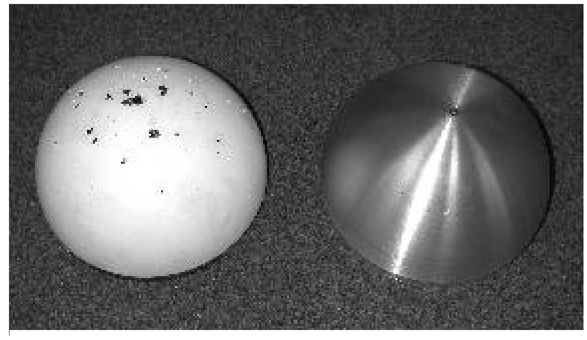

Fig 2: Carbon-Fiber BAT hemisphere (left) damaged from impact of raindrops in TS Eduardo, Aluminum BAT hemisphere (right) to replace original composite sphere.

Measurements from flights in Isabel indicated that water intrusion was no longer a problem.

5. FUTURE PLANS

The remaining modification is to replace the carbon fiber cone housing with an aluminum cylinder. The housing sits behind the hemisphere and is susceptible to erosion but to less of a degree than the hemisphere. A proto-type all-aluminum BAT was designed and manufactured in early 2004 for the British Antarctic Survey.

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