A Note on VHF Backscatter from Turbulence in the Upper Troposphere

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1. Introduction

Safe pilotage of jet aircraft is occasionally threatened by encounters with high-altitude turbulence. Present turbulence forecasts are synoptic in nature and fail to supply timely, fine-grain information for individual flight paths. Present airborne weather radars, employing wavelengths of 1–6 cm, detect particulate backscatter from rain drops, hail, snow, and cloud droplets, and occasionally, sharp air mass boundaries (ΔN -jumps) but fail to detect clear air turbulence. This note introduces a radar technique for turbulence detection by non-particulate backscatter, and gives preliminary test results.

2. Tropospheric sounding

Radio waves have been employed for vertical sounding of the troposphere (Friend, 1949). Short waves, ($\lambda < 10$ cm) of interest primarily for detection of precipitation (particles) have received major attention in the development of weather radar. Long-wave sounding

of atmospheric turbulence and flight verification was first described by Friend (1939).

Radioscattering by the atmosphere is the basis of a very widespread and useful mode of radio propagation. Several divergent views of tropospheric radio scattering at low levels (< 2 km) are current (JTAC, 1960); the Booker-Gordon theory (Booker and Gordon, 1950) can be used to estimate the scattering coefficient (radar cross section per unit volume) of turbulent air. For this purpose we use dielectric fluctuation data obtained by airborne refractometer and apply it to the Booker-Gordon formula for backscatter ($\theta = 180^\circ$) from large-scale ($2\pi l > \lambda$) turbulence:

$$\sigma_{180^\circ} = \frac{1}{32\pi l} \left(\frac{\Delta \epsilon}{\epsilon} \right)^2.$$

From the airborne refractometer (Crain, 1955) a typical value of spatial dielectric fluctuation is

$$\frac{\Delta \epsilon^2}{l} \sim 10^{-14} \text{ m}^{-1}$$

FIG. 1. Turbulent backscatter calculated from Booker-Gordon Theory.

FIG. 2. 75 Mc path profile cross section.

FIG. 3. Echo power vs. maximum wind shear.

whence

$$\sigma_{180^\circ} \sim 10^{-16} \text{ m}^{-1}.$$

For the experiment to be described, the scattering angle is 110° , and the $14/3$ power law (Ortwein, 1961) gives a scattering cross section of

$$\sigma_{110^\circ} \sim 10^{-15} \text{ m}^{-1}.$$

Prevailing theories fail to correlate σ with wind speed or its variance, a situation which is intuitively unsatisfactory in the high-wind-shear region of the upper troposphere.

Turbulent backscatter calculated from Booker-Gordon theory is given in Fig. 1 for $\theta = 180^\circ$ and for various turbulent 'scales' and radio wavelengths. While all eddy sizes (scales) of turbulence may occur, there is a certain range of scales most critical to the operation of jet aircraft. These relate to the aircraft wingspan,

air speed and lowest structural flexing modes, a range of say 3–300 meters.

3. Backscatter experiment

A bistatic¹ radar experiment has been in operation near Seattle since October 1963, employing upward-directed beams sharing a common volume in the region of maximum jet stream and turbulence activity (Fig. 2).

The operating frequency is 75 Mc ($\lambda = 4$ m). Direct transmitter-receiver leakage, normally a problem in CW radar, is controlled by a nulling-antenna phase-shifter arrangement. Transmitter power is 100 watts, and receiver bandwidth 50 cps, so the system dynamic range, limited by cosmic noise, is 200 db. Received signal amplitudes are recorded on a 24-hr basis. Upper-air information is obtained from the U. S. Weather Bureau rawinsonde station at Olympia, Washington. Due to the prevailing winds, the mean balloon position at 10-km altitude is 50 km southwest of the radar common volume.

During "normal" quiet days no backscatter signal is observed, and the recorded level is that due to galactic noise. Occasional large bursts (10–50 seconds) due to aircraft passing through the common volume are observed. Meteor trails, although outside the common volume, give measurable responses (1–10 seconds) due to their very large radar cross sections. During times of upper-level turbulence (wind shear > 4 knots per thousand feet) strong noise-like radar echoes are obtained. These persist from 1 to 8 hours as jet fronts pass overhead. Steady layer-type echoes, previously reported by Friend (1949), are also observed. At the receiver site, located on an exposed hilltop, little or no correlation of echo strength with surface wind is observed. On clear nights, unusually strong twinkling is observed simultaneously with strong radar echoes. A regression diagram relating the apparent variance (ratio of 10%–90% exceedance levels) of received radar power to maximum wind shear is shown in Fig. 3. Recorder smoothing effects must be removed to obtain absolute variance.

It is planned to continue the bistatic recordings through the winter 1964–65, and to assemble a pulsed vhf monostatic radar for turbulence sounding next winter.

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¹ Radar transmitter and receiver separated geographically.