Horizontal displacement of simulated cloud particles by the propeller of an aeroplane

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1. INTRODUCTION

Measurements of cloud particle size and charge made from a single engine, propeller-driven aircraft have been criticized* on the basis that the natural particle population samples may have been contaminated by liquid water or ice particles sprayed centrifugally from the propeller. If this were to occur, the charges and sizes of sprayed particles probably would be quite different from those of the natural particles and therefore, unless some means of rejecting the modified particles were used, any such measurements would be suspect and of little value in characterizing the properties of natural cloud particles.

We were associated with W. Gaskell, A. J. Illingworth and J. Latham of UMIST in their coupled measurements of precipitation particle sizes and charges in Florida and New Mexico during the 1976–1979 period. In their work, the U.S. Navy ONR 'special purpose test vehicle for atmospheric research', (the SPTVAR 1) airplane was equipped with an induction ring and a shadowgraph instrument which were mounted on the port wing. The SPTVAR 1 is a single-engine aircraft with a 200 hp Lycoming engine and a Hartzell, 3 bladed constant-speed propeller. The length of each blade is about 0.97 m. The propeller arc was about 2.6 m ahead of the intake to the UMIST particle measuring instrument which was between 1.94 m and 2.00 m outboard from the aircraft centre line in its various installations.

On research flights, SPTVAR 1 is usually operated so that it has a true airspeed ranging between 40 and 50 m s$^{-1}$. The propeller tip speed typically is of the order of 250 m s$^{-1}$ at the cruise rotation rate of 2500 rpm.

The measurements reported by Gaskell et al. (1978) from SPTVAR 1 flights indicated that some of the precipitation particles carried charges near the Rayleigh limit and much larger than can be easily explained using the polarization-induction charging mechanisms. This result has been privately challenged as a possible artefact arising from cloud particles sprayed from the propeller.

To test the validity of the undisturbed droplet collections by Gaskell et al., we have carried out a simple test with the SPTVAR 1 on the ground.

2. PROCEDURE

On 2 October 1981, under an overcast sky (air temperature 18 °C with a relative humidity in excess of 90% and frequent rain showers), we positioned SPTVAR 1 on a taxiway at Socorro Airport (altitude 1453 m) so that the aircraft faced into the 2 m s$^{-1}$ wind from the south. The aircraft was elevated above the earth about 0.2 m and was anchored firmly to its ground transport dolly. On the ground at both sides of the aircraft, we placed sheets of cotton cloth that had been soaked in a saturated solution of sodium carbonate and then dried in the sun. The southern edges of the sheets were 0.5 m south (ahead) of the plane of the propeller; the northern edges of the sheets were under the wings, about 1.5 m north (behind) of the propeller arc. The sheets extended to a distance of 5 m starting at a distance of 1.8 m from the centre line of the aircraft and were held in place by rocks round their edges.

For the first part of the test, an indicator solution of 1% phenolphthalein in ethanol was used. The aircraft engine was started, warmed up for 4 min and then operated at 2500 rpm, simulating cruise conditions at an altitude of 7 km.

*We became aware of the specific criticism made by Levin and Dye (1982) only after completing the work reported here.
Initially, the indicator solution was injected for 30 s into the propeller in a fine stream from a chemical wash bottle held 2 m ahead of the rotating propeller. A spray cloud of solution formed at the propeller and a venturi-shaped cloud aft of the propeller could be seen by observers to the side but no ‘centrifuging’ of the droplets was apparent. Inspection of the sheets showed none of the tell-tale red colour that was immediately produced when a drop of the indicator solution was placed on an outer corner of the sheet.

In the second part of the test, the engine was again run up to 2500 rpm and 30 cc slugs of the solution were thrown in from 2 m ahead of the propeller. Again all of the debris exhausted in the propeller back-wash and no red spots could be seen on any of the sheet.

Larger quantities (250 cc at a time) of the liquid indicator were then thrown onto the propeller with identical results as before: the windscreen bubble covering the cockpit was drenched but no traces of spray could be detected on the sheets.

Rain began to fall so that we picked up the sheets before they became wet. During the shower, we experimented with the indicator and established that, even in small droplets, it readily reacted in contact with the alkaline sheets and produced an intensely coloured spot.

The possibility that surface tension effects would allow the impinging liquid to be sheared too easily from the propeller before it was accelerated up to centrifuging speeds was then considered. Some of the indicator was diluted about 100 to 1 with distilled water. This, of course, precipitated the phenolphthalein into a milky white water solution. Although the test spot colours now were pink and much less intense than before, the diluted solution was still effective as a droplet indicator. After the rain, we repeated parts 2 and 3 above with the diluted solution and the propeller rotating at 2500 rpm. The results were the same as before with no evidence being found of particles being centrifuged off the propeller.

Finally, a Stryfoam cup containing about 150 cc of diluted solution was thrown onto the rotating propeller from 2 m in front. The cup was quickly broken by the propeller but it and its contents were all blown backwards in a spray with no outward motion being observed in the debris.

3. DISCUSSION

From these observations, it appears to us that cloud and precipitation particles, engulfed by a rotating propeller on a moving aircraft, have little chance of being deflected in a direction that is perpendicular to the line of flight. This unexpected finding suggests that ingested particles impacting on the propeller are sheared off before they are accelerated laterally up to the local velocity of the propeller. As a result, they are caught in the local air flow and do not acquire any significant velocity components to the side.

These results also indicate to us that the measurements of Gaskell et al. (1978), at altitudes below that of the 0 °C isotherm, were not vitiating by the placement of their instrument relative to the propeller of the SPTVAR 1.

A different flow regime may occur when supercooled liquid droplets freeze on impact with the propeller and there accrete. If accreted ice were allowed to build up on the propeller, it would acquire the local velocities and then could be centrifuged off either by release after application of heat to the propeller de-icing equipment or by the mechanical stresses imposed by the propeller rotation. In the worst case, we should expect that these particles could be released tangentially with laterally-directed velocities of up to 250 m s⁻¹.

The horizontal trajectories for such particles have been computed by Levin and Dye (1982) and others. These computations indicate large lateral excursions for centrifuged particles such that propeller modified and centrifuged particles could reach the inlets of instruments at all positions along the 9 m length of the SPTVAR 1 wing.

Our pilot (J. W. Bullock) operates the aircraft under an 'anti-icing program' with the periodic application of heat to the neoprene-covered boots on the leading edge of the central portions of the propeller, commencing before the aircraft enters the clouds. With this procedure, appreciable ice does not collect on the propeller, but melts and (the pilot believes) is sheared off and blown to the rear. However, we have no measurements on the nature and trajectories of any particles that have been released from the propeller during its flight through super-cooled clouds.

To minimize possible contamination in the cloud particles measured during studies at low temperatures, we plan to place the next particle size and charge measuring instrument out as far on
the wing spar as possible (a distance of 4-6 m) and then to place a vertical slab of Teflon between the propeller and the particle measuring instrument. In this manner we expect to intercept any propeller-modified particles moving laterally ahead of the instrument intake and thereby be able to sample undisturbed cloud particles.

ACKNOWLEDGMENTS

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REFERENCES


Reply to A. J. Illingworth and J. Latham by Z. LEVIN and J. E. DYE

We welcome the reply of Drs Illingworth and Latham to our comment regarding the possibility of contamination of the charge/size measurements of Gaskell et al. (1978) and Christian et al. (1980). Some comments which we have regarding their reply are as follows:

1. The measurements of Gaskell et al. (1978) were made at temperatures from +1 to +4°C. Because of the finite time required for melting, it is likely that particles found at these temperatures will contain some ice. Indeed, observations made during COPE in Montana, where cloud base temperatures are similar to those reported by Gaskell et al. (1978), on at least one occasion showed some ice to be present at temperatures as warm as +8°C. Thus, the measurements of Gaskell et al. (1978) still may be in question.

2. It is not at all clear that particles impacting on the face of the propeller will not receive the required radial velocity. For graupel only a fraction of the velocity would be needed to place them in a trajectory past the charge size instrument. If we assume the propeller has an average width of 10 cm the volume of possible particles swept out by the face is approximately 3 times the volume swept out by the 1 cm thick rotating blade assumed by Illingworth and Latham. Additionally, since most of the particles will acquire only a small fraction of the maximum velocity, it seems reasonable to expect that they will be redistributed close to the propeller. Assuming the particles to be uniformly redistributed over a 5 m radius, as Illingworth and Latham have done, is likely to be a significant underestimate of the particle flux near the instrument.

3. The assumption that the particles follow a straight line path from the propeller to the sensor overestimates the angle of approach of the particles. As pointed out in our original comment our concern is more with the particles several hundred microns in diameter. For these the angle of approach may be significantly less, especially when their initial radial velocities are only a small fraction of the maximum.

In view of the numerous uncertainties associated with determining the path which individual particles may follow, it is difficult to know how severely or if the measurements reported by Gaskell et al. and Christian et al. were affected by contamination. Experiments such as those reported by Moore et al. (1982) are important for further understanding of this problem. Hopefully, this discussion will lead investigators to take some care in the placement of particle measuring devices on aircraft.

Reply to Z. Levin and J. E. Dye by A. J. ILLINGWORTH and J. LATHAM

Drs Levin and Dye are quite correctly concerned that particles of several hundred microns diameter, highly charged after impact with the propeller may subsequently pass through the induction ring. We accept that any particles of this size could have such a trajectory. The measure-
ments in question are the simultaneous charge and size measurements shown in Figs. 12 and 14 of Christian et al. (1980) and Fig. 8 of Gaskell et al. (1978). We examine again the possibility that these coincidence measurements are of particles which have interacted with the propeller.

All the coincidences presented in Christian et al. (1980) are for particles of diameter \( \geq 1 \) mm which are therefore not suspect. Figure 8 of Gaskell et al. (1978) has 11 coincidences with \( d = 0.5 \pm 0.3 \) mm. The other eighteen are for larger particles. These eleven events comprise a small proportion of the total number of coincidences recorded, and when regard is given to the predominance of liquid precipitation, and the small estimated increase in flux, then it seems that at most one or two could be due to propeller interference. We therefore feel that the major conclusions of the paper are unaffected.


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1. INTRODUCTION

Johns et al. (1981) presented a numerical model and simulated the storm surge of November 1977 on the east coast of India. The results from their numerical model imply that major storm surges occurred over a 1200 km stretch from Pondicherry to Contai (Fig. 1). They mentioned that the results of their model agreed with observations but they did not present any observations.

Johns et al. gave the results of their model at five locations: Pondicherry, Kavali, Divi,