Development and Use of an Airborne Air Marker for Atmospheric Research

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ABSTRACT

Common motor oil is injected into the exhaust manifold of an aircraft where it is vaporized, and then mixes into the cold outside air to condense into a dense oil fog. This air marking technique has been used in atmospheric research activities to visually track or maintain contact between research aircraft in flight, and to track seeded plumes and air parcels.

1. Introduction

Natural air motion has been studied by observations of the behavior of smoke from both man-made and naturally occurring, stationary sources. Scorer (1958) and Sutton (1957) both used smoke plumes for qualitative observation work on natural eddy formations and plume dispersion rates. Woodcock and Wyman (1947) expanded the use of the smoke techniques by emitting smoke plumes from low flying aircraft and ships in their studies of convection over the ocean. Loesser dropped pyrotechnic smoke devices from a helicopter in order to trace low level air motions (Chamberlin *et al.*, 1957). Observations of the diffusion of smoke plume from continuous sources on the ground are compared to theories of diffusion by Gifford (1968).

This report is a survey of the experiences that the authors have had with a simple air marking technique as well as some suggestions on future applications of the method in atmospheric research.

2. Marking device necessary

As the airborne instrumentation and sampling systems approached operational readiness for a wave-cloud flight program in the fall of 1966, a need for an air parcel trajectory device became very pressing. Tests with two aircraft in flight, one to distribute seeding material and the other to sample the seeded plume in cloud, demonstrated that it was not only hazardous to fly in close proximity in lee-wave conditions, but also that valuable research time was repeatedly lost in regaining visual contact between the two aircraft.

Positive, repeated interceptions of seeded plumes proved to be very difficult when guidance to their location was available only from the ground via radar tracking. The collected data were at best questionable, and quantitative interpretation of the experiment was impossible.

It was felt that a "smoke" dispenser on the seeding aircraft would nearly eliminate the visual sighting problem between the aircraft, and would also permit out-of-cloud practice of plume interceptions. These anticipations were verified.

3. System choice

During the investigation of the available techniques, pyrotechnic devices were rejected early for several reasons: they cannot conveniently be fired and shut off at will; they are dangerous to handle in and around aircraft, and cannot be installed without elaborate safety precautions; and official approval is problematic. The limited performance of the aircraft available would also be further impaired through the added aerodynamic drag of mounting racks and other exterior fixtures. Inquiries into various other methods of aerial marking devices revealed that the U. S. Forest Service (1963) has made an extensive evaluation of an airborne "smoke" generating system for use in forest fire control. An evaluation was also made by the U. S. Army Aviation Test Activity (1963).

The subsequent evaluation of potential systems showed that a device using a liquid agent seemed preferable. It is the most convenient to operate for its size, and the specific "smoke" output is close to three times that of a system using a solid media of equivalent weight.

A Forest Service unit was seen in operation and a comparable unit was designed. It was manufactured by Fallon Air Service and installed in the seeding aircraft, a Cessna 206, in February 1967.

4. Design characteristics

Fig. 1 shows schematically the method by which the oil fog is generated and dispersed from the seeding air-

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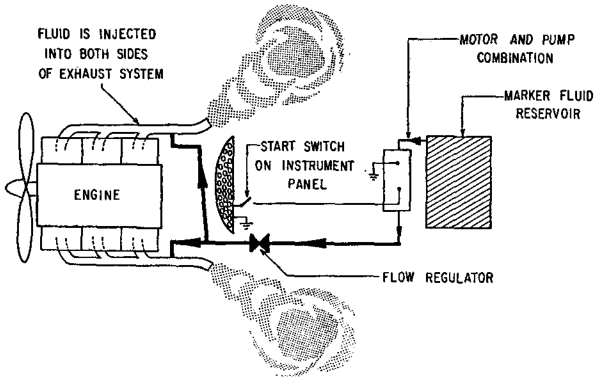

FIG. 1. Schematic of oil fog device.

craft, while Fig. 2 shows the installation of the reservoir and pump in the Cessna 206 behind the forward seats. This location permits operation of the unit by either pilot or observer during flight. A 12 V dc pump motor is driven by a heavy duty storage battery independently of the aircraft electrical system. This extra battery was found to be necessary, since the starting current momentarily exceeds 100 A and running current is about 40 A in cold conditions. The aircraft electrical system was not capable of handling this additional load. The 20-liter reservoir contains oil for 2.5 min of continuous running or about 150 one-second bursts. The empty weight of the total system was held to 30 kg for ease of removal and service. Common automotive non-detergent motor oil SAE 5 was used.

5. Operational characteristics

Operation of the "smoke" generator does not measurably affect the performance of either the aircraft or its power plant, although the exhaust noise is muffled significantly. No changes have appeared on the engine instruments, nor have the FFA routine inspections revealed any adverse effects.

Upon the advice of the Forest Service maintenance officials who had experienced repeated clogging of the injection nozzles, the Desert Research Institute unit nozzles were inspected at frequent intervals during the testing phase. There has been no evidence of local hot spots, carbon accumulations, or other deposits anywhere in the injection system or the engine exhaust system. This may be due to a more favorable location for the nozzles than was used on the Forest Service installation.

Small amounts of smoke enter the cabin during operation, but not at a level hazardous to the occupants of the cabin, nor is it enough to prevent the pilot from performing his duties. The path by which the smoke enters has not been determined.

When the unit is subjected to very cold environments for several hours, it is necessary to preheat the oil to 100–125F to decrease the viscosity of the oil for easier pumping and vaporization through the nozzles.

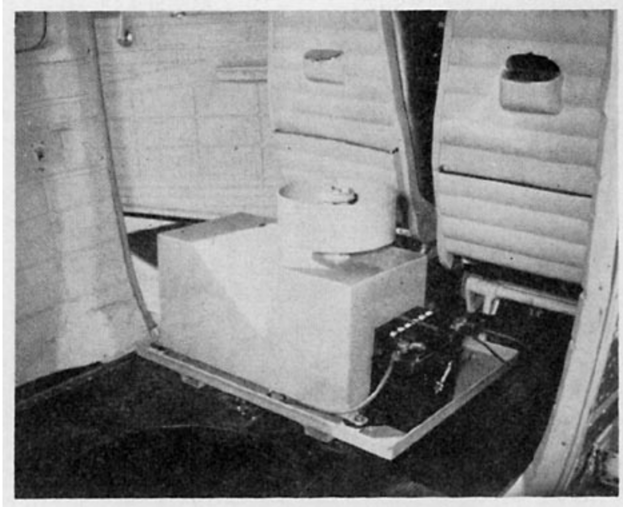

FIG. 2. Location of the oil injector in the cabin of the Desert Research Institute Cessna 206.

6. Properties of the plume

The oil is pumped from the reservoir through the nozzles with an injection pressure of 45–50 psi. There it vaporized and, when cooled by the outside air, condenses into a dense white oil fog. About 3 sec after leaving the aircraft the plume becomes about 20 m in diameter, corresponding to the size of the tip vortices generated by the aircraft. Looking back from the aircraft a mustache-shaped plume with two converging symmetrical swirls is readily apparent. This dissolves in about 10 sec into a cylindrical-shaped plume whose further diffusion is primarily dependent upon the local atmospheric turbulence and convection.

The fog appears to be bluish-white in color. There has not yet been any need for other colors, since the puffs or trails distinguish themselves well against all encountered backgrounds, even clouds. Fig. 3 shows the oil fog viewed from above.

FIG. 3. Smoke about 3 min old seen from above over Reno, Nev.

FIG. 4. The plume at 10,600 ft above the photographer just after dispersal upwind and 1200 ft below the wave cloud (photo by John Hallett).

FIG. 6. Plumes immediately after ejection from aircraft over a dry lake.

The bluish-white color of the fog indicates that the droplets' sizes are in the submicron range and rather uniform. To test for the possible presence of a few larger particles, samples were taken with both the Squires' rod particle sampler (at the belly of the Cessna) and with a continuous Formvar particle sampler (in a Beechcraft flying behind the Cessna). No particles were observed larger than 1 μ, which is the limit of resolution of the data. This implies that the presence of the oil fog in a cloud will not interfere with these droplet sampling techniques.

7. Uses of the oil fog

Questions were raised early as to the dispersion rate of the plume. Figs. 4 and 5 show the plume in laminar flow at 15,200 ft MSL.

The first photograph was taken immediately after ejection; the aircraft is moving to the right. The second, taken one minute later, shows the ultimate extent of the plumes width. Thereafter, the plume was seen to bend as it entered the updraft, proceed under the cloud, whose base was at 16,500 ft MSL, and continue downwind without subsequent dispersion until it was lost from sight 30 min later.

In moderately convective air the plume is a useful visible tracer for about 10 min. In strong convection at ground level it is limited to 1–$1\frac{1}{2}$ min of useful life. A measure of this lifetime is shown on Figs. 6, 7 and 8, taken 30 sec apart. In highly turbulent situations, such as those encountered around roll clouds, the fog can be seen for about 15 sec.

Unlike ballons and chaff, oil fog shows the true trajectory of the original air parcel. With it we have measured the fall velocity of chaff and calibrated a computer in a radar to record the approximate tra-

FIG. 5. The plume at maximum width 1 min later than FIG. 4 (photo by John Hallett).

FIG. 7. Same as Fig. 6 except 30 sec later.

FIG. 8. Same as Fig. 6 except 60 sec later.

jectory of an air parcel while tracking the chaff. As two coordinated M-33 radars followed the Cessna 206, "smoke" and chaff were released from it simultaneously. One radar continued to track the aircraft, while the other switched to the chaff. At 1-min intervals the aircraft was flown through the smoke puff and the position change between the smoke and the chaff was measured. One radar set was then programmed to compute the fall distance of the chaff for any given time and add this distance to the indicated altitude of the chaff.

Thus, in the absence of strong wind shear, the chaff can be used to predict the true position of an air parcel. Simultaneous use of both chaff and smoke allows both visual tracking and radar tracking of the air parcel. Inside the cloud, the calibrated radar determines the parcel trajectory and increases the possibilities of interception of the plume by the instrumented aircraft. Outside the cloud, the pilot of the aircraft has visual reference to the position of the seeded plume.

In another experiment very small rates of vertical air velocity were measured by circling the aircraft back to the plume and recording accurately the elapsed time and the altitude change.

8. Conclusions

The airborne marking device described here is a convenient, economical solution to several needs in air trajectory tracking. It has several advantages over conventional tracking devices, such as chaff or balloons, in that it can easily be positioned in the air, a large quantity of "marker" can be carried, it is inexpensive in operation, and it is highly visible. It should be useful in diffusion and convection studies as well as in larger scale air motion analyses.

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