The Use of Jet Aircraft Engines to Dissipate Warm Fog

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ABSTRACT

This paper describes a pilot study carried out to determine the feasibility of using the heat and mixing properties of jet engine exhaust to evaporate fog from an aircraft runway. It was found that visibilities can be raised from less than 1000 ft to well over a half mile in less than 5 min.

1. Introduction

Supercooled fogs have been dissipated for a number of years by initiating the ice-crystal process through seeding with a refrigerant, such as dry ice, or with ice-forming nuclei, such as silver iodide. Some of these techniques are now in routine operational use at military and commerical airports (Appleman, 1968; Beckwith, 1968). As yet, however, despite extensive testing, no operational technique currently exists for dissipating warm fog ($T>0$C). The two most promising approaches involve 1) the dispensing of hygroscopic material from an aircraft or a ground-based blower to absorb the fog droplets, and 2) the use of heat to vaporize the fog drops. The first technique is currently under study by a member of commercial companies and governmental agencies with as yet very limited success. The second approach was taken by the Air Weather Service (AWS) in Project Warm Fog.

The first operational application of heat for fog-dissipation purposes took place in England during World War II. A crude system, called FIDO, used gasoline ignited alongside the runway. Apparently some success was obtained. A more refined post-war system was designed using clean-burning, high-pressure fuel-oil burners. The installation cost of an adequate system, however, has been estimated at some millions of dollars, so its installation would necessarily be limited to high-use permanent airports. Furthermore, its efficiency is low due to off-runway heat losses, and its effectiveness has been questioned under moderate-to-strong wind speeds.

Several groups have considered the possibility of using jet engines stationed alongside the runway as the heat source. This approach has several advantages. Not only would the engines provide the necessary heat, they would also provide the turbulent energy required to mix the hot exhaust with the foggy air over the runway. The use of engines eliminates the requirement for high-pressure fuel pumps, pipes, wiring, and other costly features of the refined FIDO system. Obsolete jet engines with fuel tanks would be adequate for fog-dispersal purposes. For routine operational use, the engines could be located underground and vented toward the runway.

For simplicity in its pilot study, AWS decided to make use of locally available jet aircraft, rather than engines mounted on stands, to serve as the heat source. A number of Military Airlift Command C-141 four-engine jet aircraft were available at Travis AFB, Calif., a base which is seriously affected by warm fog.

2. Heat requirements for warm-fog dissipation

Category I requirements for aircraft landings call for a ceiling of 200 ft and a visibility of 2400 ft. In Project Warm Fog a critical clearing zone 1000 m long, 100 m high, and 100 m wide was assumed, giving a volume of 10^7 m^3. The fog liquid-water content was taken as 0.5 gm m^{-3}, a rather high value. Thus, it would be necessary to vaporize 0.5×10^7 gm of liquid water to clear the fog completely, requiring about 3×10^9 cal of heat.

In addition to the heat required to evaporate the fog droplets, the air must be warmed sufficiently to hold the resulting vapor (0.5 gm m^{-3}). Another major factor is the water vapor produced by combustion of the jet fuel; each gram of fuel burned produces about 1.4 gm of water vapor. In Project Warm Fog, 16,000 lb (7257 kg) of fuel was consumed in each test (see Section 3), producing about 10^7 gm water vapor or 1 gm m^{-3}. Assuming an initial temperature of 5C and a saturation water vapor content of 6.8 gm m^{-3}, the air must be heated to a temperature of 8C to hold the final vapor content of 8.3 gm m^{-3}. Allowing a margin of 0.5C above equilibrium conditions, the 10^7 m^3 of air can be heated the necessary 3.5C with the expenditure of 10^{10} cal. The total heat required to both evaporate the fog droplets and warm the air is therefore about 1.3×10^{10} cal.

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3. Heat and turbulence generated by a C-141 aircraft

Fig. 1 is a diagram of the temperature and velocity profiles in the wake of a stationary C-141 aircraft. When run at military-rated thrust (MRT), each of the four engines uses about 200 lb of fuel min^{-1}. Each gram of fuel produces 10^4 cal of heat. Thus, four C-141 aircraft burn a total of 16,000 lb of fuel in a 5-min test, yielding 7.3×10^{10} cal, a factor 5–6 times greater than required to clear the critical volume under zero wind-speed conditions. A 5-min test period was selected to represent very light winds. (A 1-kt wind at a 45° angle to the runway would replace the critical volume over the runway at 5-min intervals.) A stronger cross wind would require a greater heating rate. The safety margin provided in the test allowed for stronger winds, loss of heat outside the critical volume, etc.

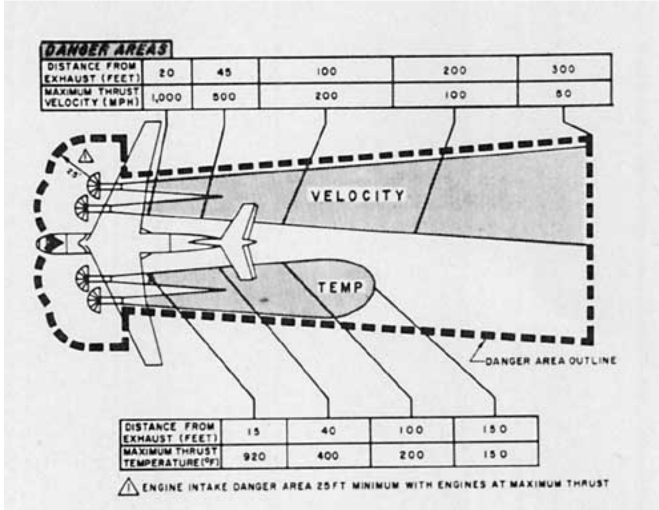

FIG. 1. Temperature and velocity profiles in a C-141 exhaust.

4. Test procedure

Travis AFB is located at the western edge of the Sacramento Valley. It has two parallel runways, each 11,000 ft long and 300 ft wide. The test was run before sunrise in a dense fog on 23 January 1968. Four C-141 aircraft were parked one behind another at intervals of 750 ft along the center line of the runway as shown in Fig. 2. Each nose wheel was chocked to prevent aircraft movement during the high power settings and to reduce strain on the brakes. For each test the power setting was simultaneously increased on all engines to MRT and held for 5 min. Three such tests were run between 0650 and 0715 PST, with 5-min breaks between tests to allow advection of fresh fog over the runway.

Initial conditions were 1000-ft visibility in a 300-ft thick fog deck, temperature 31F, with a crosswind from 320° at 2–4 kt. At the test site, a 100-gm pilot balloon was tethered 250 ft above the runway at the position of the observer (Fig. 2) to ensure that ceilings of at least 200 ft were attained. White streamers were attached at 50-ft intervals below the balloon. Runway lights and aircraft navigation lights were used by the observer as horizontal visibility targets.

5. Results

The minute-by-minute visibility changes in the three tests are shown in Fig. 3. In all tests the visibility increased from around 1000 ft to well over 1/2 mile. The

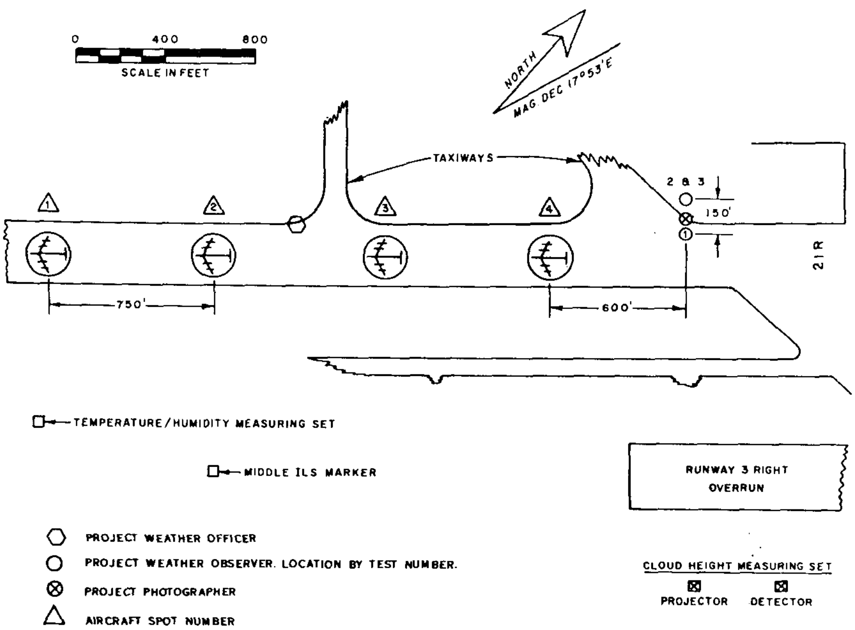

FIG. 2. Project Warm Fog test configuration.

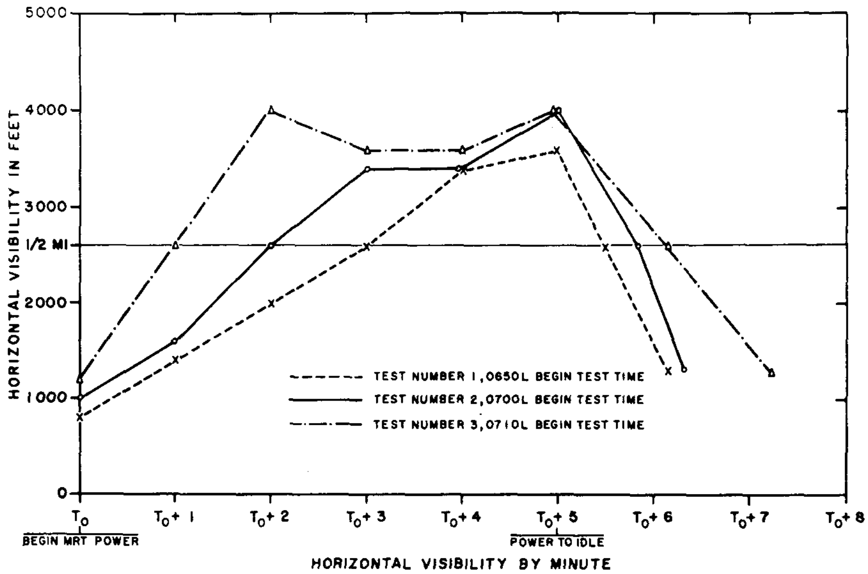

FIG. 3. Effect of jet engine exhaust.

1/2 mile clearing was achieved in ~3 min in Test 1, 2 min in Test 2, and 1 min in Test 3. Apparently not all the heat was dissipated between tests, despite the complete change of airmass during the 5-min interval. The main portion of the jet blast intersects the runway 50 ft behind the jet nozzle. Considerable heating of the runway surface takes place at this point and rearward. A somewhat quicker burnoff of the fog would reasonably be expected during successive tests.

Similarly, the clearing persisted slightly longer after engine shut-down in each successive test. In all cases, however, the duration of clearing was extremely short. Even in Test 3, the visibility fell below 1/2 mile in slightly over 1 min, and to the initial value of 1000 ft in 2 min. This was expected due to advection of new fog over the runway; entrainment of foggy air into the clearing may also have played a part.

Figs. 4 and 5 show the initial and final photographs taken during Test 2. At begin-test time (t_o), the test-site visibility was 1000 ft. Only the nearest of the four test aircraft is visibile. At end-test time (t_o+5 min), the visibility had reached 4000 ft, and all except the most distant aircraft can be seen. The clearing was estimated to be 4000 ft long and 1200 ft wide, with its center slightly behind the nearest aircraft. In all tests the hole created extended completely through the fog band, with blue sky visible above.

This test was a pilot study to determine whether or not jet engines could be used to create a clearing of usable size over a runway. This aim was accomplished. Temperature, wind, other meteorological equipment, and manpower were not available to carry out additional research. However, the project weather officer estimated a 15-kt wind was created at his location. All except

FIG. 4. Initial visibility (1000 ft) at begin-test time (t_0).

FIG. 5. Maximum visibility achieved (4000 ft) at engine shutdown (t_0+5 min).

the first aircraft experienced buffeting, and the last one reported moderate turbulence.

6. Conclusions

This pilot project clearly demonstrated that the heat and mixing generated by aircraft jet engines is sufficient to improve the visibility and ceiling in dense fogs to well above minimum conditions. However, the improved visibilities lasted only about a minute after engine shutdown due to advection of new fog over the runway. In an acutal operation the engines would have to be placed off the runway in such a position that they could be left running during aircraft landings and takeoffs. Such engines could be permanently mounted sufficiently far from the runway centerline for safety, or could be installed underground with the exhaust vented toward the runway.

The fuel cost for a 5 min run was ~$300. The cost would probably be less for an optimally designed system; also, a lower combustion rate would be required to maintain a clearing than to create it initially. In any case, however, several aircraft could be landed during the clearing produced. Diversion costs of a large military transport such as the C-141 average around $1000, without counting the loss due to unavailability of the passengers or cargo. Commercial aircraft costs are even higher. Thus, the jet engine system appears reasonably economical. The use of hygroscopic seeding agents could easily cost as much or more, with a far lower certainty of success. The Air Weather Service is investigating the desirability of following up this pilot project with a more complete field test.

The Paris Airport Authority and a French company, Bertin & Cie, are also investigating the jet engine technique for dissipating warm fog. They have carried out a pilot study in an open area on Orly airport. The installation consists of three engines. The middle engine is located underground as a prototype for an operational system. Results have been encouraging, and studies are being made that could eventually lead to an operational installation.

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