L. Nelson Contrail Studies — King Air
March–April 1989 - Project 9-760

1. General Information

This program was a study of contrail formation and composition. It was conducted in coordination with a Lear 35 Learjet (tail number N80BT), which flew with the Sabreliner on all research flights except R8 and R11. An experimental design document, written by Ophir Corp., is in the files. The program was flown in two segments: 20–24 March and 10–14 April 1989. Additional test flights were flown on 16 March and 20 April.

As an aid in predicting the levels of contrail formation, the charts shown in Figs. 1 and 2 were prepared. Figure 1 is a standard skew-T diagram (prepared for the flight levels of interest, and so only covering upper altitudes), onto which is superimposed a set of "Appleman" threshold curves showing the critical conditions for contrail formation. (However, the ratio of water vapor mixing ratio to heat released in the plume was taken to be 0.0295, in accord with the later studies of Pilie and Jiusto.) These lines show the threshold at 100% relative humidity, at ice saturation (dashed line), at 10°C dew point depression (solid line almost coincident with the ice saturation line), and at 0% relative humidity. This chart proved a good guide to contrail formation levels, which usually coincided approximately with the ice-saturation threshold. The other chart, Fig. 2, shows the water vapor mixing ratios for saturation relative to ice and to water as a function of time, and shows the critical thresholds for contrail formation.

The flight procedures featured two general patterns: verification of conditions for contrail formation, and measurement of particles from the contrails. The verification procedures featured climbs and descents with event marks that indicated onset of a contrail (MARK 1), onset of a continuous solid contrail (MARK 2), disappearance of a continuous solid contrail (END MARK 2), and disappearance of a contrail (END MARK 1). For these flight segments, the Sabreliner lead the formation and the Learjet maintained a good position for photography. During the first segment of the experiment (Flights R1–R4), marks only for the Sabreliner formation of a contrail were recorded; during the second half, marks for both aircraft were used. The original procedure described in the operations plan required a single event mark for MARK 1, a double event mark for MARK 2, a double event mark for END MARK 2, and a single event mark for END MARK 1. These proved awkward because of the latching of the event switches on the Sabreliner and the one-per-second resolution for event marks, so the following scheme was used (duplicating the previous scheme for the first part of the experiment, but used alone in the second part of the experiment):

DATE: ________________ TIME: ___________

SOURCE(S): _________________________________ DRDT=0.0295

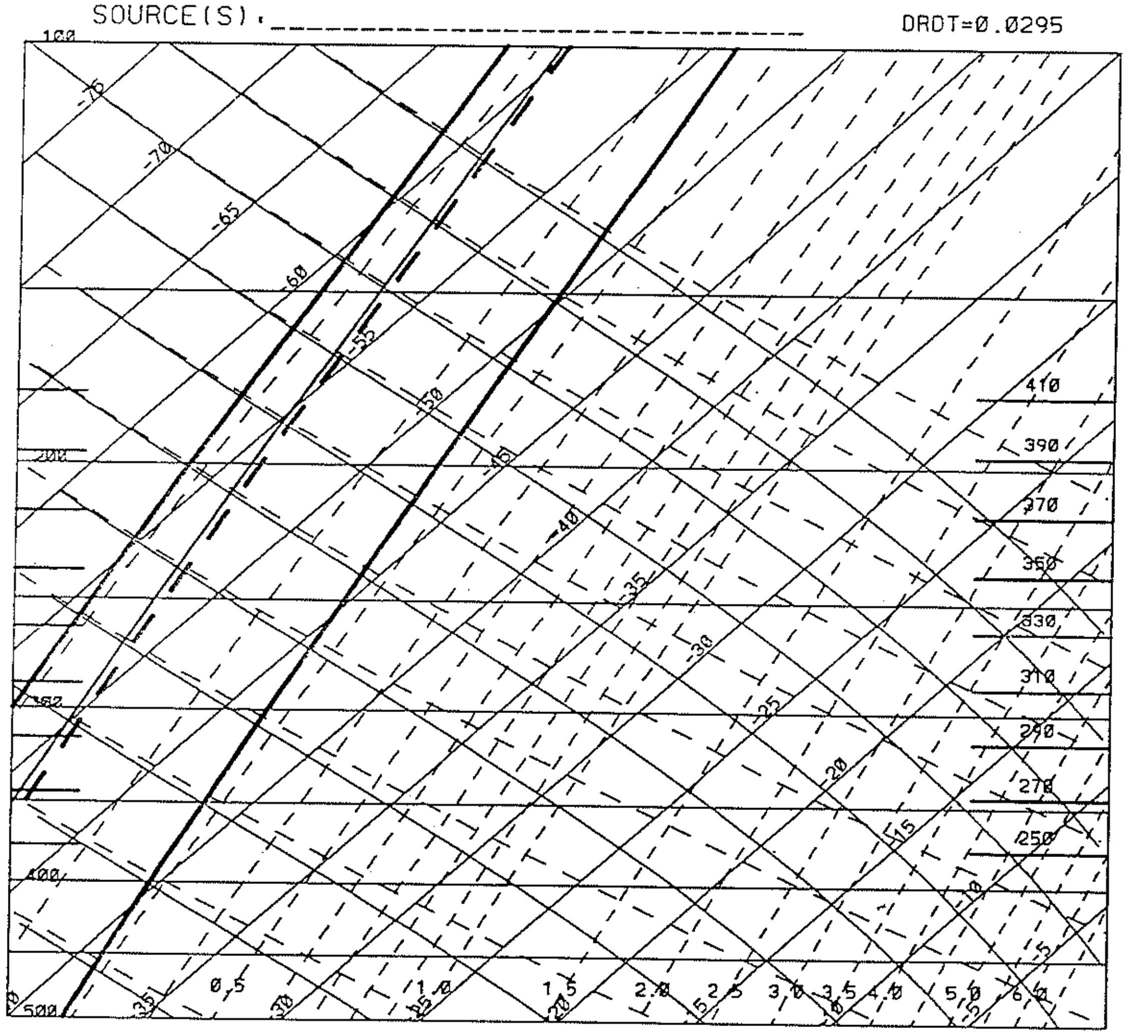

Figure 1: Skew T - log p diagram showing critical conditions for contrail formation (heaviest lines) according to the Appleman theory, but using the Pilie-Jiusto ratio (0.0295) for moisture to sensible heat. Four thresholds are shown: (right) water-saturated atmosphere; (dashed) ice-saturated atmosphere; (middle thin) $10^{o}C$ dew point depression; and (left) 0% relative humidity. Conditions to the right and below these thresholds should not lead to contrail formation.

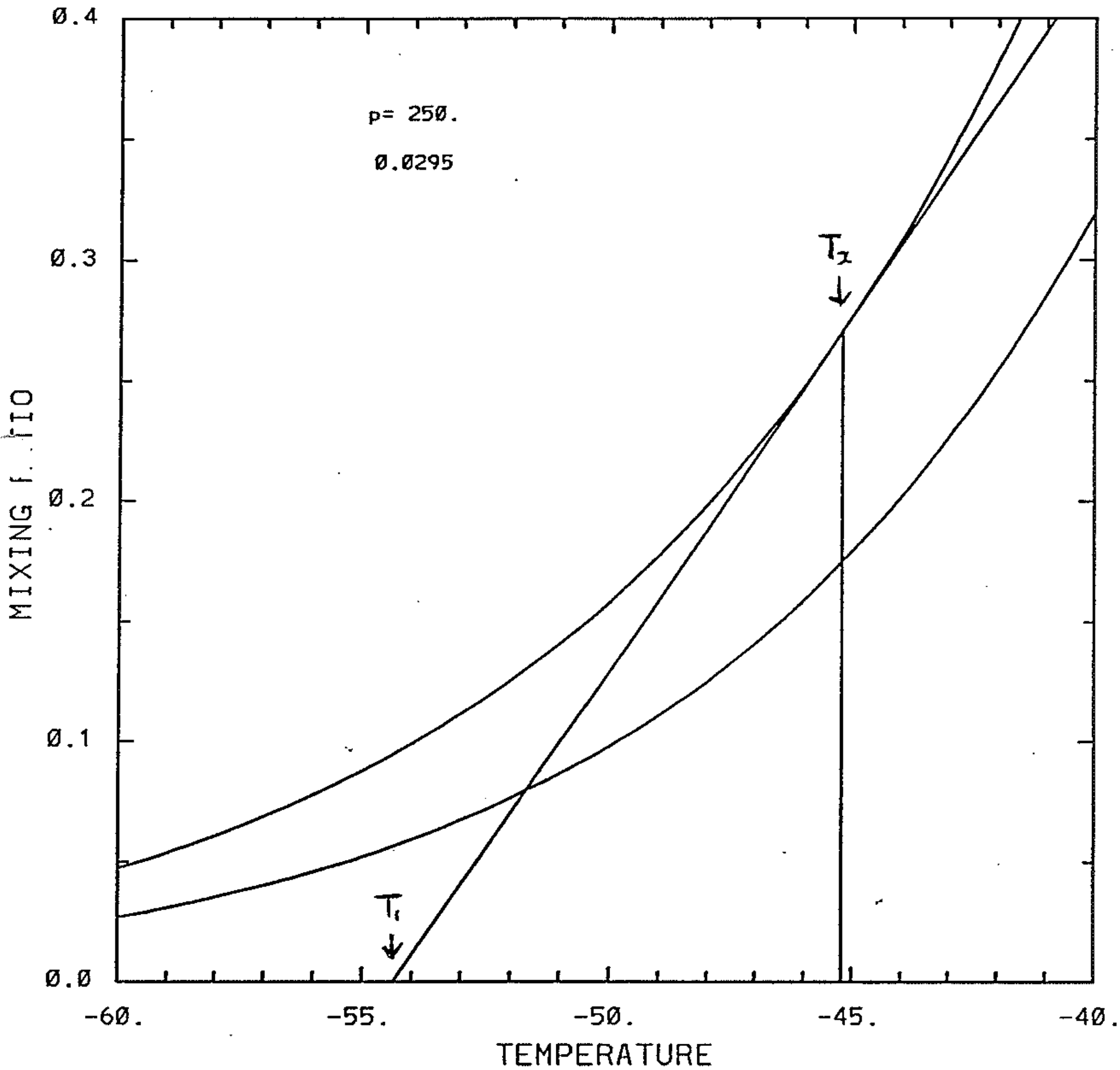

Figure 2: Ice-saturation (lower curve) and water-saturation (upper curve) mixing ratios as a function of temperature, for a total pressure of 250 mb. The threshold conditions of Fig. 1 were determined from T_1 and T_2 (left and right threshold curves of Fig. 1, respectively). The diagonal straight line has the slope 0.0295 specified by Jiusto and Pilie and is tangent to the water saturation curve.

EVENT 2: MARK 1 Sabreliner

EVENT 3: MARK 2 Sabreliner

EVENT 4: END MARK 2 Sabreliner

EVENT 5: END MARK 1 Sabreliner

EVENT 6: MARK 1 Learjet

EVENT 7: MARK 2 Learjet

EVENT 8: END MARK 2 or MARK 1 Learjet.

Some of the events were occasionally entered erroneously because of confusion over which aircraft was calling, etc.; the written record from the Learjet is generally more reliable, especially regarding observations of the Sabreliner by the Lear crew. Appendix A lists the event marks recorded on the Sabreliner.

The other flight pattern required the Learjet to be the leader, and the Sabreliner made passes through the contrail at varying distances behind the Lear. The flight cards (contained in the daily files) describe in detail how this and other flight patterns were flown. During these passes through the contrail, slide samples were collected for microscopic examination, and the hydrometeor spectrometers recorded particle sizes.

2. Flight Summary

Flights were conducted on the following days:

Table 1: Flight Summary†

DATE	FLT	B-O	T-O	LND	B-I	HRS	TAPES
16 MAR 1989	T0	1130	1136	1236	1240	1.2	V52861
21 MAR 1989	R1	1349	1357	1622	1625	2.6	V52862,3
22 MAR 1989	R2	1347	1354	1622	1624	2.6	V52864,5
23 MAR 1989	R3	1347	1352	1618	1621	2.6	V52866,7
24 MAR 1989	R4	1345	1355	1503	1505	1.3	V52868
10 APR 1989	R5	1652	1658	1923	1925	2.6	V52869,70
11 APR 1989	R6	1248	1253	1521	1522	2.6	V52871,2
12 APR 1989	R7	1246	1254	1520	1522	2.6	V52882,3
12 APR 1989	R8	1618	1623	1703	1707	0.8	V52884
13 APR 1989	R9	1248	1255	1522	1523	2.6	V52885, V56067
14 APR 1989	R10	1242	1248	1508	1510	2.5	V56068,9
20 APR 1989	R11	1504	1508	1602	1604	1.0	V52886

†B-O: block-out time (CUT); T-O: takeoff time; LND: landing time; B-I: block in time; HRS: operating hours (B-I–B-O). All times CUT; CUT=(Local Time + 7 h), March flights; (Local Time + 6 h), April flights.

3. Comments and instrumentation problems on each flight

a. Flight R1:

Left EGT gauge was bad soon after takeoff, but seemed to function properly after the initial climb. (It was repaired after this flight.) There were severe problems with visibility caused by sunlight on the gauges and on the pilot's bright sweater. The Lear time code generator was in error by 2 h 16 min. The microswitch on the ice sampling rod chattered and caused many false events. The cryogenic hygrometer was turned on somewhat late, and looked questionable. The CN counter looked suspicious after the passes through the contrail, which may have caused fluids to move around in the instrument. The output from the PMS probes looks very low (later thought to be caused by the very small sizes of the particles in the contrail). The Ophir radiometric thermometer was operated in the "in control" mode for all of this flight. There was some confusion over events and difficulty hearing from the station where events had to be entered, and so there are many errors in events for this flight. In particular, the first mark entered was at the time of the Lear MARK 1, not the Sabreliner MARK 1.

b. Flight R2:

Very good set of verification tests. Good sampling distances in plume at varying distances, but additional verifications terminated by developing cirrus clouds in the area. The Ophir thermometer was operated "out-of-control" for this flight.

c. Flight R3:

Ophir thermometer "in-control" mode. For this flight, the FSSP-300X was installed on the right wing, replacing the 260X, and the 260X was moved to the left wing, replacing the FSSP (and where only the first 15 channels of the 260X were recorded while all 32 channels of the 300X were recorded from the right wing in the first 32 channels of the 260X inputs). This change was made because no particles were being detected by the standard FSSP, and it was suspected that the sizes were too small. Note: It was later determined that the total strobe count from the standard FSSP was not being recorded properly during these flights (or during the preceding project in ERICA), and a constant beam fraction of 0.40 should be used for processing. Apparently, that is the default if no strobes are recorded, so the processing should be OK. This does not explain the problem. The fast-reset counts reached very high values; this apparently is because the fast-reset counts include particles that trigger the threshold of the annulus detector but do not trigger the signal detector. Note that the Learjet lost a contrail briefly at the top of the sounding, although the Sabreliner apparently continue to form a contrail (but the Lear crew was in a better position to see the Sabreliner contrail than vice versa). At the end of this flight, a filament of cloud was penetrated and a slide sample collected in it.

d. Flight R4:

This flight was terminated early because of a boost-pump failure on the Sabreliner (at about 1434). At 1428, the event marks were somewhat confusing and it will be necessary to check the tape or the written record from the Learjet. The Ophir radiometer was operated out-of-control, and the measurements do not look usable.

e. Flight R5:

The verification tests were limited by inability to get higher altitudes on this flight (which was the only one flown later in the day than our target time period preferred by the FAA). Initially, the CN counter looked suspicious, but later seemed OK. Note, Sabreliner time was about 10 s fast relative to WWV for this flight only. A new Lyman-alpha probe with large (1 cm) aperture was used for this flight and for the remainder of the experiment. Another change was that the ice collecting rod was modified from 0.5-inch to 0.25-inch wide slides to try to improve the collection efficiency for small hydrometeors. NOTE: During bench tests of the 300X probe between segments of this project, the probe was left with the velocity-reject circuitry suppressed. For this reason, the sample volume was rather large for the second part of the experiment and there may be overestimates of the concentration of small particles as a result. New impactor slides were exposed incorrectly (wrong side forward) on flights R5–R8, although impactor slides from the previous part of the experiment were OK. Also, this is a different radiometric thermometer with a four-stage cooler (?) and different calibration coefficients resulting from recent chamber tests.

f. Flight R6:

Good flight to examine for variations in humidity and its effect on contrail formation; see, e.g., 1502. Ophir thermometer locked on single value throughout flight.

g. Flight R7:

Good verification runs. Some power effect seen, esp. points 3.8, 3.9. Many of the sampling passes seemed high relative to the contrail. The Ophir radiometer was operated in the in-control mode until 1450, then switched out. Impactor slides were again exposed incorrectly (wrong side forward).

h. Flight R8:

Special flight (flown without Lear) to make passes through the bases and lower levels of cumulus clouds, to check that the PMS equipment is working properly for hydrometeor detection. Also, a good speed run at 1658 (but at relatively low altitude).

i. Flight R9:

Good set of impactor slides (correctly exposed). Ophir switched out-of-control at 1449; seemed to malfunction on this and preceding filghts R5–R8 by latching on certain values. This was apparently caused by the change to make the unit average many samples and output that average, and resulted from synchronization problems. A change was made before flight R10 to remove the averaging; this apparently returned the unit to having normal response to changes.

j. Flight R10:

Ophir thermometer was operated in-control until 1406; then switched out. This was the best flight for the new Ophir radiometer. Returned to control mode at 1430, as speed runs beginning, but the Ophir temperature seemed unreliable here. There was a good set of speed runs at high altitude to help determine accuracy of temperature measurement; see 1428–1452.

k. Flight R11:

Series of passes through wave clouds over Longs Peak and RMNP. Set of 15 impactor samples for verification of ability to distinguish water from ice. Good set, including good cloud water on impactor samples. Some good passes along wind through wave clouds also. Learjet not present.