1458
P9-760

*Atmospheric Technology Division — Research Aviation Facility*

MEMORANDUM

23 May 1989

MEMO TO: Celia Chen

FROM: Al Cooper *ac*

SUBJECT: Data Processing for Project 9-760

This memo describes the needs for GENPRO processing of the measurements from Loren Nelson's project.

Processing should be at the maximum rate available for all instruments. Wind measurements were at low rate (5 Hz, filtered to 1 Hz), but temperature, Lyman-alpha probe, CN counts, Ophir temperature, Ophir hygrometer, and fast ozone were sampled at 50 Hz and should be output at 20 Hz. The outputs from the PMS probes should also be output at the maximum rate available (10 Hz).

Only one change to calibration coefficients from those on the tapes is needed. The coefficients for the cryogenic hygrometer should be changed to (0,−1,0) prior to using the special processing described below.

Attachment 1 lists tapes for this project. Attachment 2 is a list of the instruments used and the rates at which they were sampled. Primary sensors should be: QCRC, TTF (or ATF), PSFDC, DPTC, ADIFR, BDIFR. Times on the flight tapes are UTC, and should be unchanged for output. The radome wind calculations should use biases of 0.0 and a "boom" length of 4.52 m.

Processing of the PMS probes should be in the form of histograms for 10 s intervals, output only when the average concentration exceeds 10 $\mathrm{cm}^{-3}$ in any of the probes and the altitude is above 30,000 ft, except in the case of flights R8 and R11 where all 10-s intervals with concentrations exceeding 10 $\mathrm{cm}^{-3}$ should be plotted.

Attachment 7 is a list of variables to be printed and plotted. Please note that the variables from the noseboom are absent, so the usual calculations and plots for these variables are not needed.

## 1. Ophir Radiometer

Processing for this instrument should be as for the Electra in ERICA, except that different coefficients should be used. Attachment 3 is a memo describing the processing needed for this instrument. Please note that the coefficients to be used change between flights R4 and R5, when the instrument was changed.

## 2. Ophir Hygrometer

This was an experimental instrument, and no consistent algorithm could be found to provide suitable processing. Therefore, I recommend we only output the raw measurements, in terms of voltages. Attachment 4 is a section from my skeleton processor which converts the digital outputs from the hygrometer to voltages. Attachment 3 also discusses this instrument, but the processing described there should not be used. for the Ophir hygrometer.

## 3. CN Counter

Processing for this instrument should be as for the Saberliner in ERICA.

## 4. Lyman-alpha hygrometer

The standard processing for this instrument did not work very well because we operated at very low humidity. I recommend the revised processing method described in Attachment 5. The instrument was operated with an unusually large gap (1 cm), and at low humidities where the oxygen correction is very important. The processing recommmended in Attachment 5 provides for updating of the Lyman-alpha hygrometer to the cryogenic hygrometer, and is based on fits to the measurements from the cryogenic hygrometer. It should not be used for any other project, because the best-fit coefficients do not make sense physically, but it appears to be a fairly good representation for this project.

## 5. Temperature Recovery Factors

Attachment 5 also describes the determination of recovery factors for the temperature probes. I recommend that we use recovery factors of 0.98 and 1.00 for the unheated and heated Rosemount sensors, respectively. These differ from the current values of 0.95 and 0.98. At Sabreliner airspeeds, the difference amounts to about 0.5° C, so the change is not negligible in comparison to our quoted temperature uncertainties.

## 6. PMS 300X

For all flights including and after R3, this probe was flown on the right wing. The pod carrying this probe is the one normally used for the 260X probe, and the software was setup for the 260X probe. As a result the measurements will appear in the first 32 channels of the 62 channels normally reserved for the 260 probe. Attachment 6 documents the channel sizes, sample volume, and response times for this probe.

## 7. PMS 260X

On flights R1 and R2, this probe was flown in the normal right wing canister. On flights R3–R7 and R9–R10, this probe was in the canister on the left wing. On flights R8 and R11 this probe was not flown. For flights R1 and R2 processing will be standard. For other flights where this probe was present, the measurements will appear in the 15 FSSP locations, and measurements from the higher 260X channels are lost. The standard processing for the 260X probe should be used, for the first 15 channels, but some revisions to the processing program will be needed because the measurements do not appears where they are expected. For flights R8 and R11, an FSSP was flown on the left wing, so processing for the measurements from the left canister should be standard for flights R1, R2, R8, and R11.

## 8. Cryogenic Hygrometer

Because of the nonlinear response of the thermistor, the normal quadratic calibration did not work for this sensor. A cubic fit appears to be suitable, and such a fit is described in Attachment 5. I believe that the best procedure will be to use calibration coefficients in the calibration table of (0,−1,0), and then apply the cubic calibration equation from Attachment 5 in the processing code. After the mirror temperature is obtained using the coefficients from Attachment 5, the calculations of humidity and corrected frost point can proceed as for the other sensors and as was used for ERICA.

## 9. Fast Ozone

This instument was operated as a test, and it will not be necessary to output processed values. I recommend that we simply output the voltages as obtained from the calibrations, and leave the processing to Greg Kok.

Attachment 8 is a listing of the skeleton processor I used for this project, and that code may be useful as a reference if there are questions about how measurements are to be handled. Attachment 9 provides some additional information on the operations in this project, and may be of use in understanding problems.

— End of Memo —

cc: Dick Friesen
Paul Spyers-Duran

Attachments:

1. List of tapes
2. Instrument and sample table
3. Memo regarding Ophir instruments
4. Code for processing the Ophir hygrometer
5. Memo describing ~~instrumentation~~ special data processing
6. PMS probes
7. Print/Plot list
8. Listing of DAP skeleton processor
9. General information regarding the project

Attachment 1

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

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Table 2: Tape List

| DATE | FLT | TAPE NO | START | END | COPY(file) |
|---|---|---|---|---|---|
| 16 MAR 1989 | T0 | V52861 | 183003 | 183311 | – |
| 21 MAR 1989 | R1 | V52862 | 134938 | 150807 | 52887(1) |
| | | V52863 | 151138 | 162143 | 52887(2) |
| 22 MAR 1989 | R2 | V52864 | 135156 | 150907 | 52887(3) |
| | | V52865 | 151158 | 160513 | 52887(4) |
| 23 MAR 1989 | R3 | V52866 | 135120 | 150301 | 52860(1) |
| | | V52867 | 150522 | 161109 | 52860(2) |
| 24 MAR 1989 | R4 | V52868 | 134933 | 150028 | 52860(3) |
| 10 APR 1989 | R5 | V52869 | 165624 | 181457 | 53906(1) |
| | | V52870 | 181726 | 191443 | 53906(2) |
| 11 APR 1989 | R6 | V52871 | 125043 | 140830 | 53906(3) |
| | | V52872 | 141057 | 151638 | 53906(4) |
| 12 APR 1989 | R7 | V52882 | 125113 | 140946 | 55987(1) |
| | | V52883 | 141233 | 151232 | 55987(2) |
| 12 APR 1989 | R8 | V52884 | 162304 | 170207 | 55987(3) |
| 13 APR 1989 | R9 | V52885 | 125200 | 141039 | 55987(4) |
| | | V56067 | 141330 | 151503 | 54508(1) |
| 14 APR 1989 | R10 | V56068 | 124650 | 135949 | 54508(2) |
| | | V56069 | 140236 | 145957 | 54508(3) |
| 20 APR 1989 | R11 | V52886 | 150747 | 155610 | 54508(4) |

Attachment 2
(3 pp)

# Setup for Airborne Exhaust Project (Nelson)
## Project # 9-760

### Analog Channels

| Variable | Name | Rate | Fil-ter | Add | Chan | OS | Output | Gain | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Static Pressure, Fuselage | PSF | 5 | 1 | 401 | 1 | O | 0-10V | 2 | |
| Dynamic Press, Fuselage | QCF | 5 | 1 | 1 | 2 | O | 0-10V | 2 | |
| Total Temp, Fuselage | TTF | 50 | 10 | 402 | 3 | X | 0+2.5V | 4 | |
| Lyman-Alpha Voltage | VLA | 50 | 10 | 2 | 4 | X | +-10V | 1 | |
| Radome Vert. Diff Press | ADIFR | 5 | 1 | 403 | 5 | X | +-10V | 1 | |
| Radome Horiz Diff Press | BDIFR | 5 | 1 | 3 | 6 | X | +-10V | 1 | |
| Radome Total Pressure | PTR | 5 | 1 | 404 | 7 | O | 0-10V | 2 | |
| Radome Dynamic Pressure | QCR | 5 | 1 | 4 | 8 | O | 0-10V | 2 | |
| Dew Point, bottom | DPB | 5 | 1 | 405 | 9 | O | 0-5V | 2 | EG&G |
| Dew Point, top | DPT | 5 | 1 | 5 | 10 | O | +-5V | 1 | GE |
| Boom Vert. Diff Press | ADIF | 5 | 1 | 406 | 11 | X | +-10V | 1 | |
| Boom Horiz Diff Press | BDIF | 5 | 1 | 6 | 12 | X | +-10V | 1 | |
| Static Pressure, Boom | PSB | 5 | 1 | 407 | 13 | O | 0-10V | 2 | |
| Boom Dynamic Pressure | QCB | 5 | 1 | 7 | 14 | O | 0-10V | 2 | |
| Total Temp Fuselage Heat | TTFH | 5 | 1 | 10 | 16 | O | 0-5V | 4 | |
| Cabin Pressure | PCAB | 5 | 1 | 420 | 31 | O | 0-10V | 2 | |
| Cryogenic Hygrometer Out | VCRH | 5 | 1 | 20 | 32 | X | +-10V | 1 | |

## Analog Channels (Continued)

| Variable | Name | Rate | Fil ter | Add | Chan | O S | Output | Gain | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Cryogenic Inlet Temp | CRHT | 5 | 1 | 421 | 33 | X | +-2.5V | 1 | |
| Cryogenic Inlet Pressure | CRHP | 5 | 1 | 21 | 34 | X | 0-10V | 1 | |
| Pressure, CN Counter | PCN | 5 | 1 | 423 | 37 | 0 | 0-5V | 2 | |
| Flow Rate, CN Counter | FCN | 5 | 1 | 23 | 38 | 0 | 0-5V | 2 | |
| Temperature, Cabin | TCBADS | 5 | 1 | | | | | | hskp crd |
| Pressure, Ophir hygrom. | PHYG | 5 | 1 | 24 | 40 | X | 0-5V | 2 | |
| Ozone, NCAR Fast | O3F | 50 | 10 | 422 | 35 | 0 | 0-5V | 2 | |
| Ozone, NCAR Fast, Flow | O3FF | 5 | 1 | 425 | 41 | 0 | 0-5V | 2 | |
| Ozone, NCAR Fast, Temp. | O3FT | 5 | 1 | 25 | 42 | 0 | 0-5V | 2 | |
| | XICN | 5 | 1 | 424 | 39 | X | 0-10V | 2 | use 0-3V |

## Digital Channels

| Variable | Name | Rate | | Add | | | Comments |
|---|---|---|---|---|---|---|---|
| Digital Static Pressure | PSFD | 5 | | 505 | | | |
| Digital Static Pressure2 | PSFD2 | 5 | | 1105 | | | |
| Pitch, INS | PITCH | 5 | | 502 | | | |
| Roll, INS | ROLL | 5 | | 1102 | | | |
| Coarse Roll, INS | CROLL | 5 | | 2102 | | | |
| Platform Heading, INS | PHDG | 5 | | 4102 | | | |
| Vertical Velocity, INS | VZI | 5 | | 2101 | | | |
| PMS-FSSP Strobe Count | STROB | 5 | | 515 | | | |
| CN Counts | CNCTS | 50 | | 2111 | | | |

Key: The O/X column marks the offset status for a parameter.

ontinued next page

Digital Channels

| Variable | Name | Rate | | Add | | | Comments |
|---|---|---|---|---|---|---|---|
| TOPH Detector Sample V | TAIRV | 50 | | 517 | | | |
| TOPH BB ref #1 | TREF1 | 50 | | 1117 | | | |
| TOPH BB ref #2 | TREF2 | 50 | | 520 | | | |
| TOPH Internal Temp. | TIREF | 50 | | 1120 | | | |
| HYG Clear Ch. Intensity | HYCI | 50 | | 521 | | | |
| HYG Vapor Ch. Intensity | HYVI | 50 | | 1121 | | | |
| HYG External Temp. | THYGE | 50 | | 522 | | | |
| HYG Internal Temp. | THYGI | 50 | | 1122 | | | |
| Ice sampler events | XMARK | 50 | | | | | special, P760 |

Other: FSSP, 260X, events (EV1)

Attachment 3
(11 pp)

*Atmospheric Technology Division — Research Aviation Facility*
MEMORANDUM

17 May 1989

MEMO TO: Loren Nelson file (9-760)

FROM: Al Cooper Al

SUBJECT: Processing for the Ophir thermometer and hygrometer

This memo describes the processing techniques developed for the Ophir radiometric thermometer and for the IR hygrometer for the flights of Project 9-760.

## Radiometric thermometer:

The processing techniques used for the radiometric thermometer were based on the fits developed for use in the ERICA project. On the assumption that the Rosemount temperature ATF was correct, corrections to the Ophir measurements were developed that produced agreement with ATF.

The procedures provided for correction of the calibration of the reference black-body temperature $T_2$, and also used corrections to account for bias in the measurements from the window, pedestal, and can temperatures. (For the first part of the experiment, flights R1–R4, the pedestal temperature was $T_1$ and the can temperature was $T_3$. For the second part of the experiment, flights R5–R11, the window temperature was $T_1$ and the can temperature was $T_3$.

The fits used were to the functions $P$ describing the intensity of radiation, rather than to temperature, because the measurement uncertainties are more nearly constant in $P$ than in temperature (and because linear fits could be used). The function $P$ is defined as

$$P(T) = \frac{c_1}{\lambda^5 (e^{\frac{c_2}{\lambda T}} - 1)} \tag{1}$$

where $c_1$ and $c_2$ are the coefficients specified in Bill Stahm's memo of 15 November ($c_1 =$ 3.7415E4 and $c_2 = 1.4388$E4 in Ophir's code). If it is assumed that $T_R$ (in this case, ATF) is correct in the absence of cloud water, then the correction needed is

$$P_E = P(T_R) - P(T_2) - \frac{V}{G(T_3)} \tag{2}$$

where $V$ is the radiometer output voltage (VAIR) and $G$ is the radiometer gain. For the first part of the project (flights R1–R4), this gain was taken to be a function of $T_3$; for the remaining flights, the gain was assumed constant.

The fit that was used was of the form:

$$P_E = a_0 + a_1(T_2 - T_0) + a_4(T_2 - T_0)^2 + a_2(P(T_1) - P(T_2)) + a_3(P(T_3) - P(T_2)) \\ + a_5 V + a_6 V(T_3 - T_0) + a_7 V(T_3 - T_0)^2 \qquad (3)$$

where $T_0$ =273.15 K. The coefficients $a_0$, $a_1$, and $a_4$ provide for recalibration of the reference black-body temperature $T_2$, while $a_2$ and $a_3$ compensate for contributions to the detected intensity of radiation caused by reflections from or emission from the window and can. The coefficients $a_5$–$a_7$ provide a calibration for the gain of the radiometric detector as a function of the pedestal temperature $T_3$. Because no temperature dependence was expected for flights R5–R11, $a_6 = a_7 = 0$ for those flights.

Because the nature of the instrument changed between flights R4 and R5, separate fits were made to data from the first flights (R1–R4) and to the second (R5–R11). One-minute average values of all measurements (Ophir radiometer and Rosemount temperature) were used for the fits, and each value included all samples (at 50 Hz) from that minute. The best-fit values $\{a_i\}$ were determined from flights (R2+R3) for week 1 and R10 for week 2, as follows:

| coefficient | Week 1 (R1–R4) | Week 2 (R5–R11) |
|---|---|---|
| $a_0$ | -0.26562E-5 | 0.81814E-6 |
| $a_1$ | 0.68010E-6 | 0.13598E-6 |
| $a_2$ | 0.76928 | 0.11441 |
| $a_3$ | -0.30724 | 0.34564E-1 |
| $a_4$ | 0.12908E-7 | 0.21999E-8 |
| $a_5$ | 0.47772E-4 | -0.80493E-6 |
| $a_6$ | 0.34395E-6 | 0.0 |
| $a_7$ | -0.31028E-7 | 0.0 |

These coefficients can be used to correct $P(T_2)$, and then (1) can be inverted to obtain $T$.

Figure 1 shows corresponding measurements from the Rosemount and Ophir thermometers before these corrections, and Fig. 2 shows the results of applying these corrections. The corrections produce measurements in agreement with the Rosemount sensor and reduce the scatter substantially.

For the second week of the experiment, the radiometric thermometer used differed in having greater cooling capacity, and a new calibration of the thermometer was performed before this part of the experiment. On flights R5–R9, there were problems with the unit appearing to lock on particular output values. These were the result of incorporating considerable averaging into the circuitry of the unit, as a result of which the synchronization between sampling circuits seems to have been lost. This problem was fixed before flight R10 by suppressing the averaging, and flight R10 did not have the problem of latching on various output values, but the outputs also were single samples rather than averages. However, Fig. 4 shows that the measurements from flight R10 looked very good after correction, both for in-control and out-of-control-mode measurements. These were the best measurements obtained during these tests.

The fits indicated that there was a clear dependence of the output values on the window temperature, as shown in Fig. 3 and coefficient $a_2$. About an 11% correction for window temperature, and 3% correction for can temperature, was needed. Application of the fit reduced the RMS difference between the Ophir and Rosemount temperatures to about 0.5°C. The best fit also resulted in a gain term of G=300,000 (vs. 242,000 from the Ophir calibration).

Figure 4 shows examples of the temperature measurements plotted as functions of time for a flight segment including several climbs and descents. It shows that the measurements from the Ophir thermometer fluctuate more than those from the Rosemount, but the two are in good general agreement. The Rosemount sensor has adequate response characteristics to see such fluctuations if present, so it appears that the fluctuations are the result of noise in the Ophir thermometer. Additional sampling and averaging could reduce this noise, but such averaging was suppressed during this flight to avoid the problems of signal latching.

The coefficients listed above were used to process all measurements from this experiment. The procedure was as follows:

1. The temperatures $T_1$, $T_2$, and $T_3$ were calculated from calibrations by Ophir. For the first week of the experiment,

   $$T_1 = 0.048156V_1 + 1.582$$

   $$T_2 = 0.048937V_2 + 2.883$$

   $$T_3 = 0.048400V_3 \ .$$

   For the second week,

   $$T_1 = 0.049227V_1 + 2.223$$

   $$T_2 = 0.048655V_2 + 2.691$$

   $$T_3 = 0.048618V_3 + 1.473$$

2. Calculate $P(T_2)$ and $G(T_3)$ as in code recommended by Ophir; cf. Bill Stahm's letter of 15 November. For the first week of the experiment, $G(T_3) = -19,000 + 52.944T_3 + 0.5222T_3^2$. For the second week, $G(T_3) = -242,000$.

3. Also calculate $P(T_1)$ and $P(T_3)$ using the same functional form as for $P(T_2)$ but substituting $T_1$ and $T_3$ (after conversion to kelvin).

4. Calculate $P_E$ from (3), using the appropriate coefficients.

5. Calculate $P = P(T_2) + (V/G(T_3) + P_E$. Note that, in the ERICA version of this memo, the sign of the last term in this equation was incorrect. This sign corresponds to the meaning of the coefficients from the fit as listed above.

6. Invert (1) to get T from P:

   $$T = \frac{c_2}{\lambda \ln(\frac{c_1}{\lambda^5 P+1})}$$

7. Correct to degrees Celsius by subtracting 273.15 K.

## Ophir Hygrometer

A similar fit procedures was attempted to adjust the measurements from the Ophir hygrometer to match those from the NCAR cryogenic hygrometer, but the results were generally less satisfactory. The procedure was to assume that the measured ratio $R$ between absorbing and non-absorbing wavelengths is given by

$$R = (a_0 + a_1 T_I)e^{-b\rho^c} \tag{4}$$

where $\rho$ is the water vapor density and $T_I$ is the internal temperature in the hygrometer (ATHGI). A measure of goodness of fit can be taken to be the chisquare obtained from the differences between the measured ratios R and the ratios predicted from (4) using the vapor density determined from the cryogenic hygrometer. The fit is linear in $a_0$ and $a_1$ but non-linear in $b$ and $c$. The actual fit was performed by collecting a data set for which there was no cirrus present and then finding the best-fit values of the above coefficients. (Because there are physical grounds for expecting that $c \leq 1$, this constraint was imposed. The best fits consistently required $c > 1$, so $c$ was fixed at 1.)

The following flight segments were included in the fit: R2 (1400–1430), R3 (1358–1408, 1443–1451, 1525–1608), R4 (1400–1418, 1445–1452), R5 (1700–1730), R7 (1315–1505), R9 (1300–1510). From these flight segments, there were 384 60-s-average values used in the fits. The best fit was obtained for $a_0 = 1.11177$, $a_1 = 0.00080$, $b = 0.107$, and $c = 1.0$; when the constraint on $c$ was removed, the best fit was obtained for $a_0 = 1.10001$, $a_1 = 0.00073$, $b = 0.0873$, and $c = 1.546$. Figure 5 shows corresponding measurements of water vapor density from the Ophir hygrometer and the cryogenic hygrometer with this processing, for the set of coefficients with $c = 1$. Although there is considerable scatter, the measurements show a strong correlation. Figure 6 shows corresponding measurements of vapor density from these two sensors for one flight segment. The above coefficients (with $c = 1$) were used to process the measurements for this experiment.

— End of Memo —

Attachments:
six figures

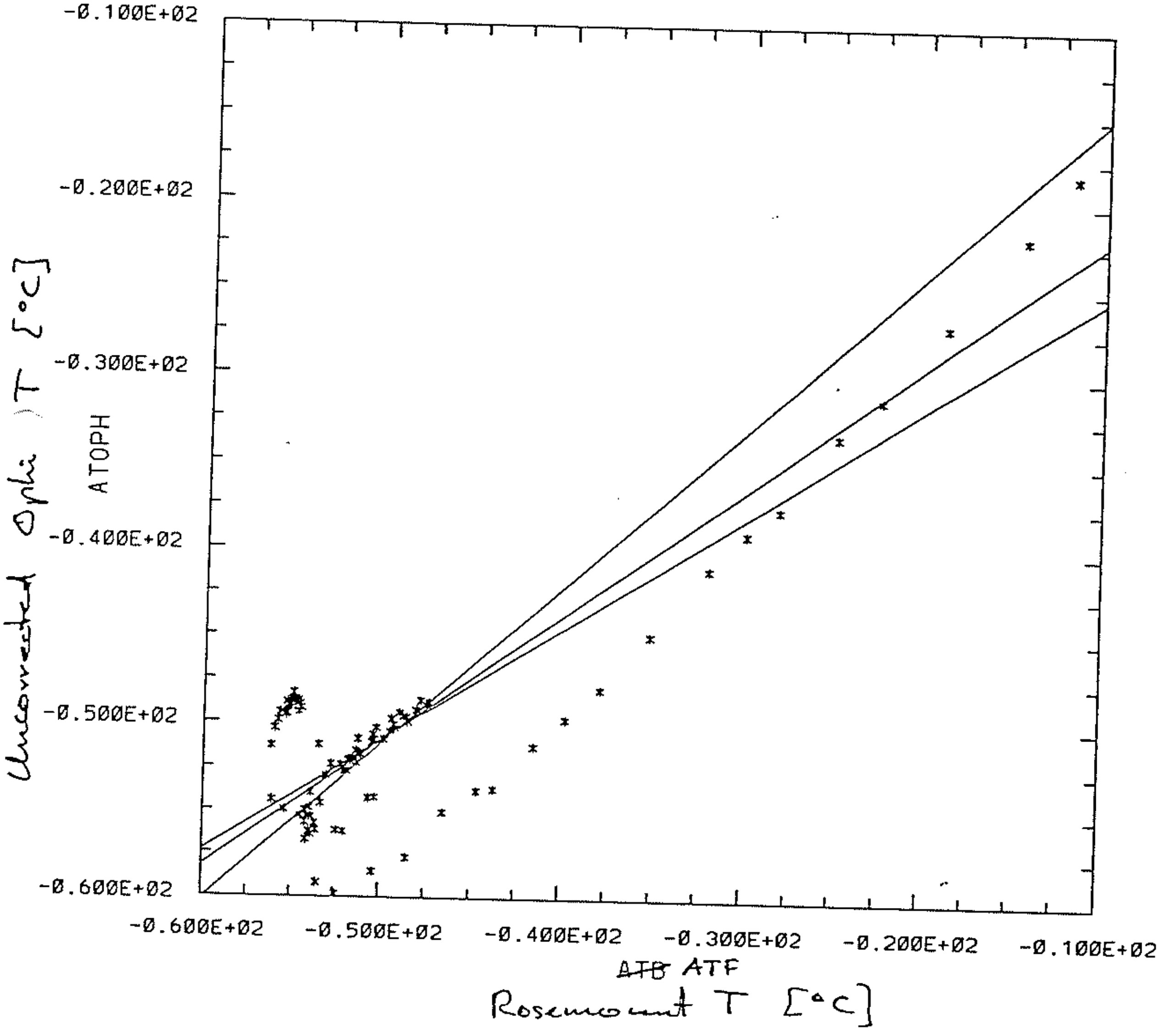

Fig. 1: Uncorrected Ophir thermometer measurements vs measurements from the Rosemount sensor ATF, for the period from 1255–1433 on flight R10 (14 april 1989).

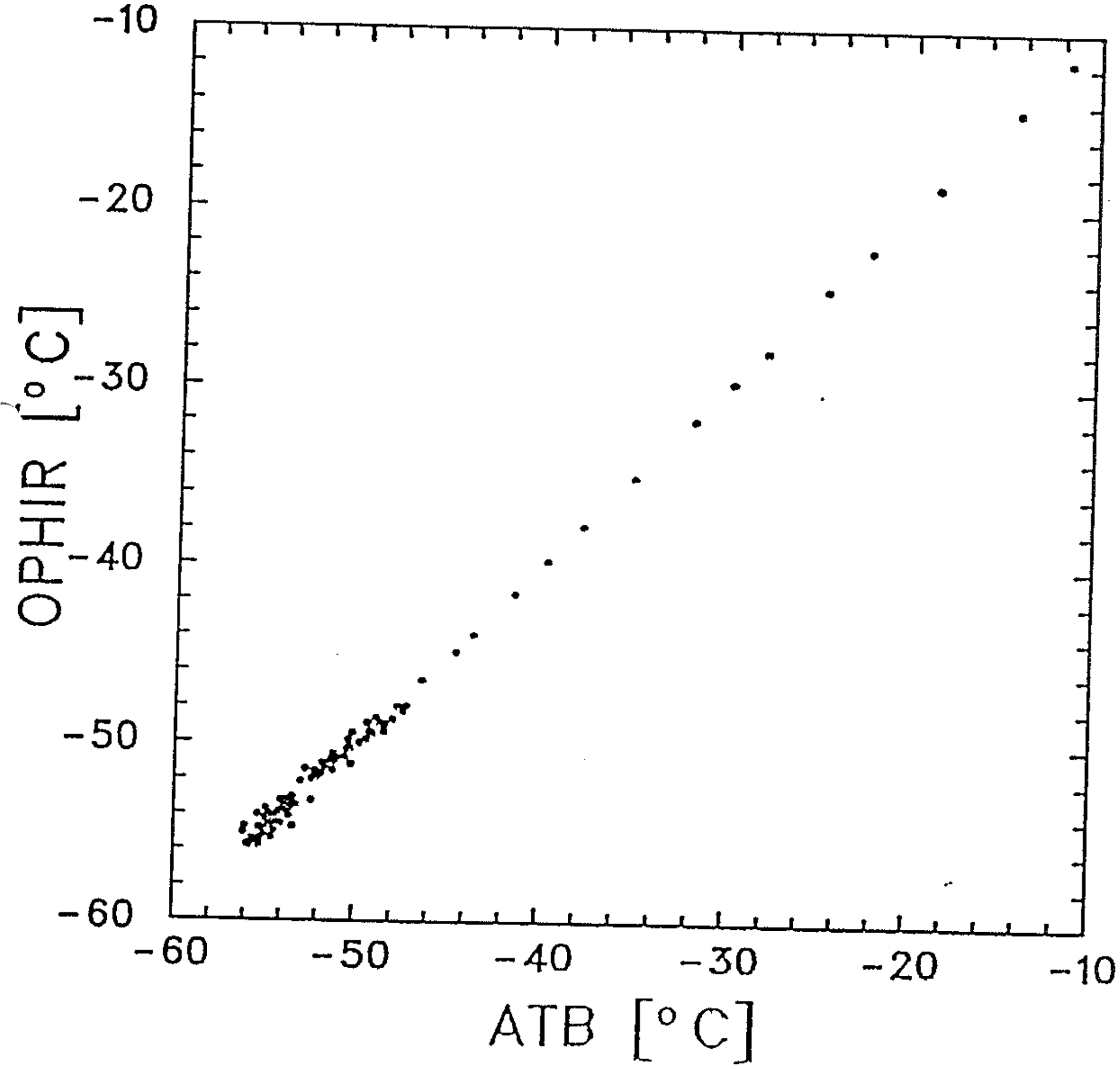

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Fig. 2: The same measurements as shown in Fig. 1, after applying the processing scheme described in this memo.

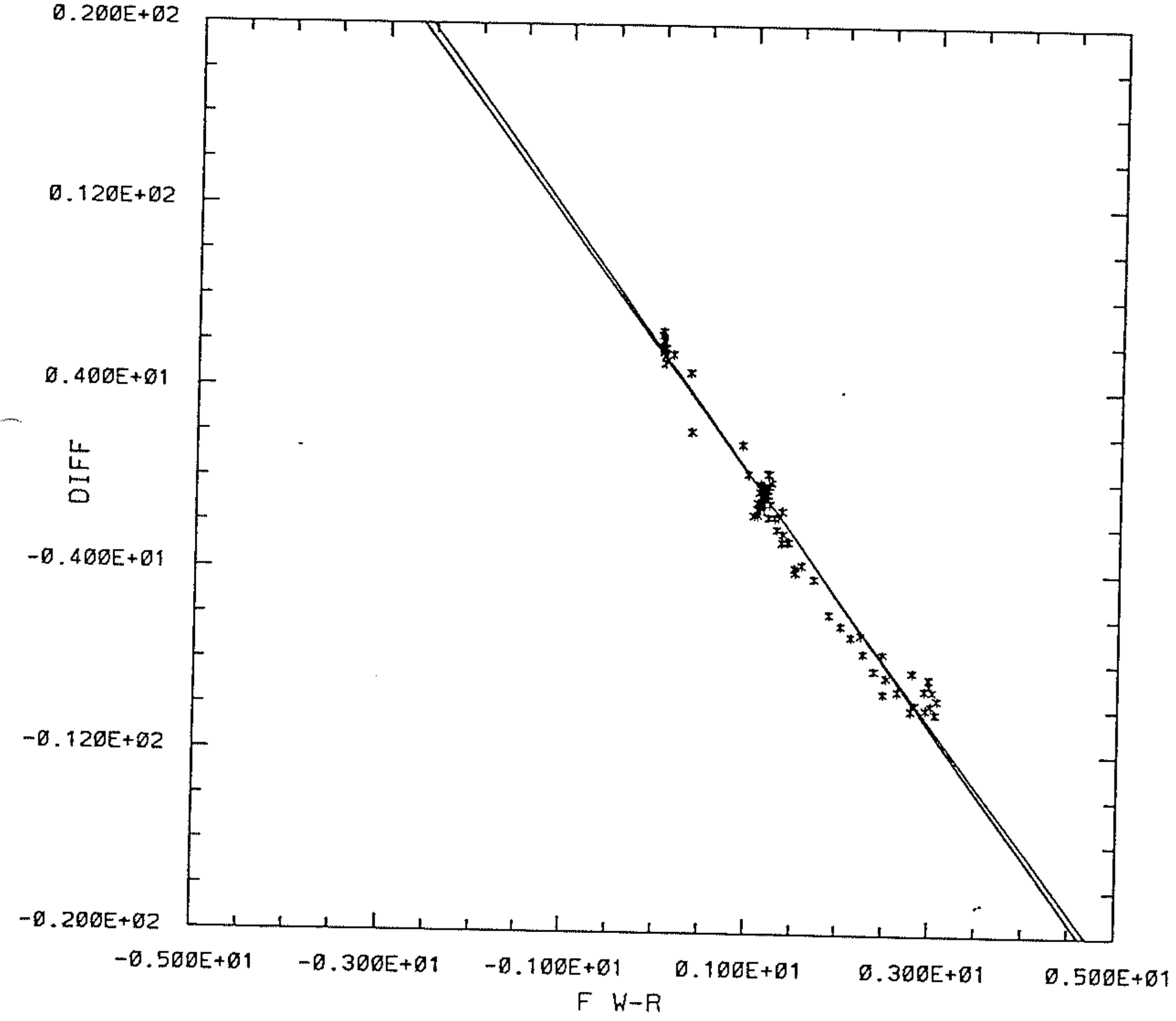

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Fig. 3: Difference $(T_{ophir} - T_{Rosemount})$ vs $F = \frac{P(T_1) - P(T_2)}{P(T_2)}$ for the uncorrected Ophir data of Fig. 1

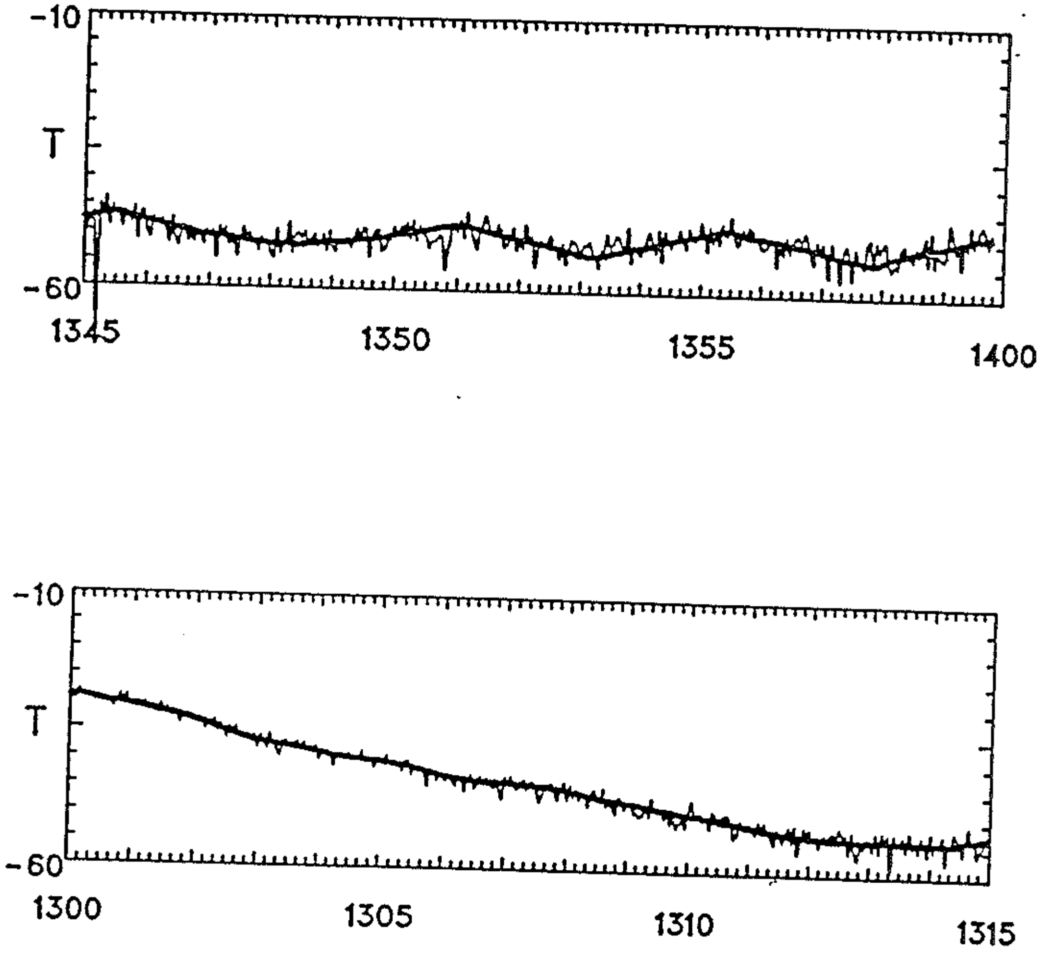

Fig. 4: Examples of measurements from the Rosemount sensor (thick smooth line) and the Ophir thermometer (thin line) from flight R10 (14 April 1989).

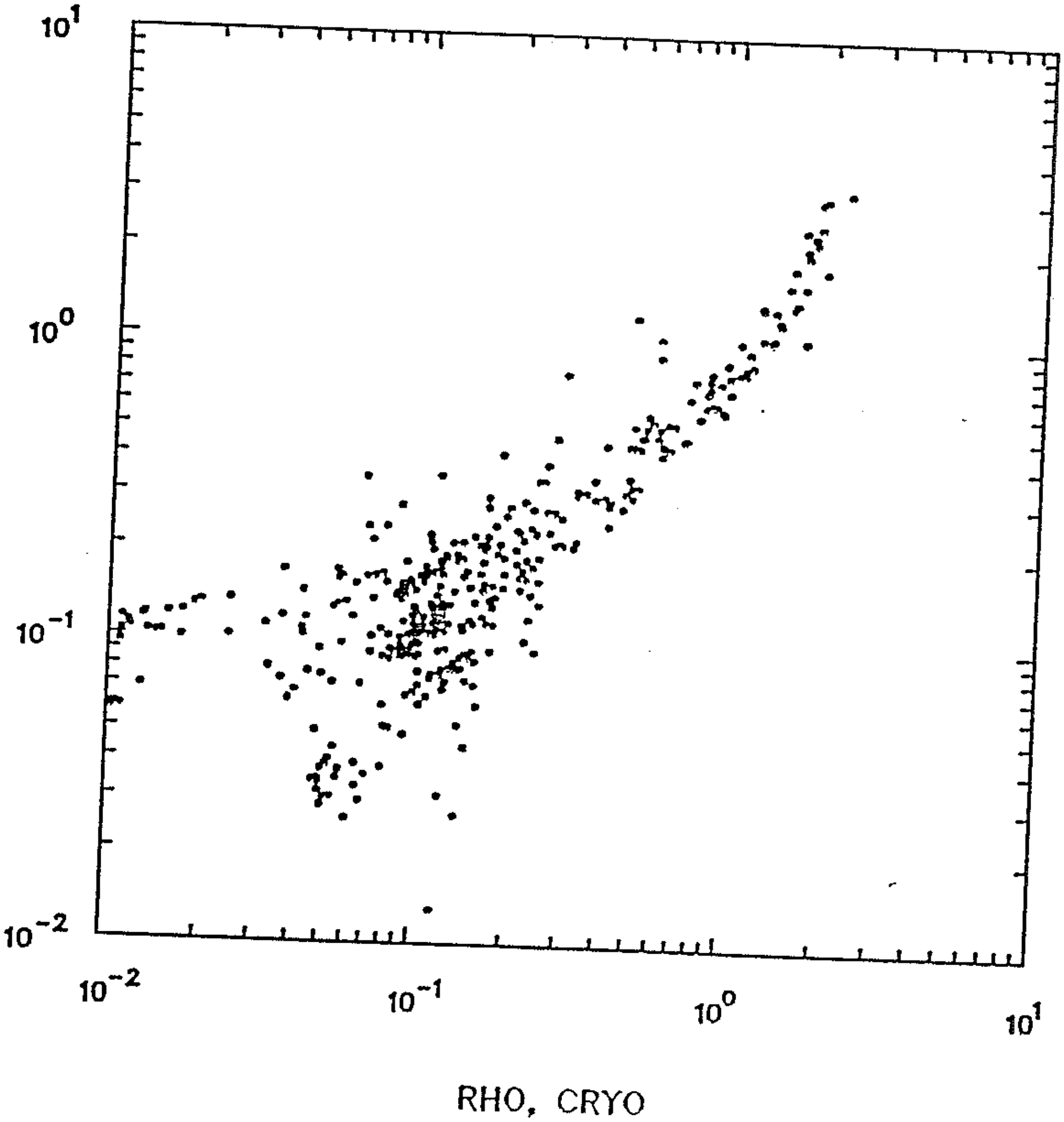

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Fig. 5: Comparison of data from the cryogenic and Ophir hygrometers, for all flight segments used to obtain the fit described in this memo.

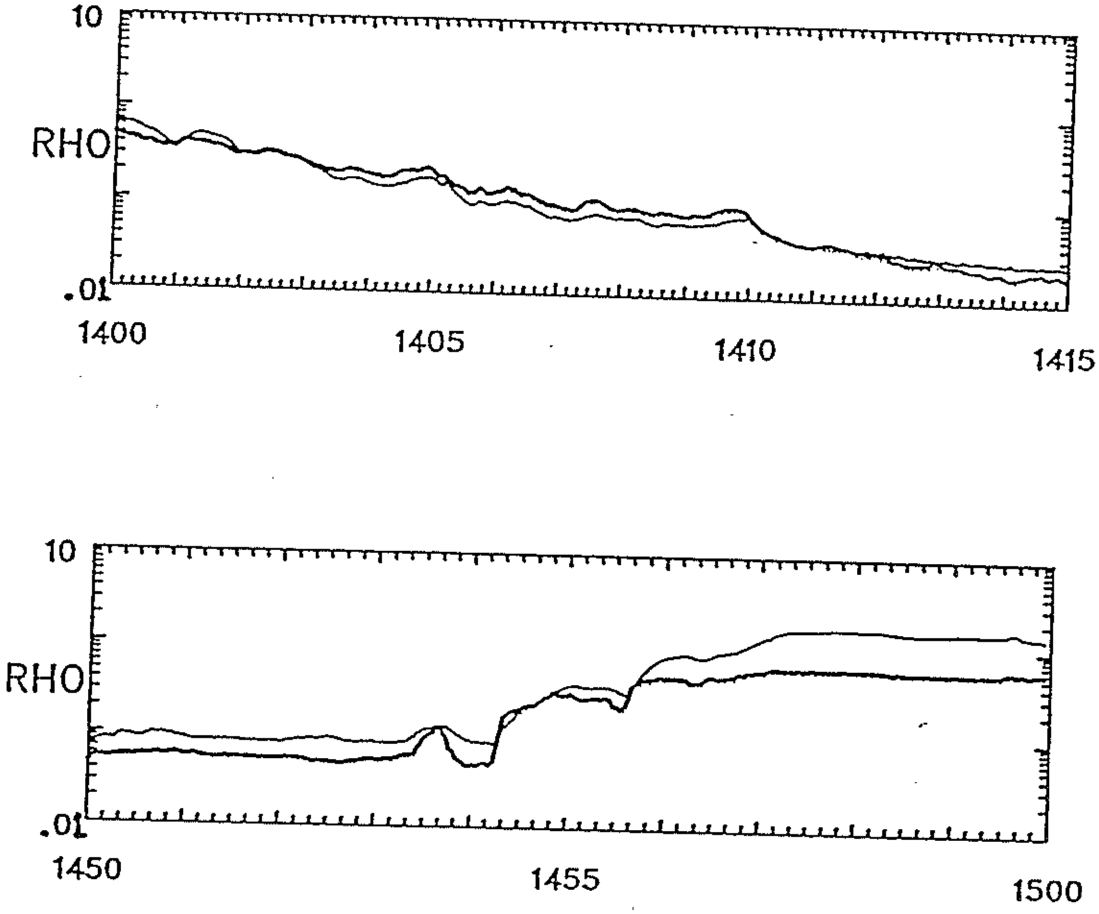


Fig. 6: Measurements of vapor density from the Ophir hygrometer (thin line) and the cryogenic hygrometer (thick line). Data from flights R2 (top) and R10 (bottom).

Attachment 4

SECTION FROM SKELETON PROCESSOR
USED TO PROCESS OPHIR HYGROMETER

```
      integer*2 jtairv,jtref1,jtref2,jtref3,jhyci,jhyvi,jthyge,jthygi
      integer*2 ifrac,isign,ifrac2

      DATA IFRAC/z'7fff'/,ISIGN/z'8000'/,IFRAC2/z'3fff'/

      CALL SERCH('HYCI  ',NAMES,NVAR,IHYCI ,0)
      CALL SERCH('HYVI  ',NAMES,NVAR,IHYVI ,0)
      CALL SERCH('THYGE ',NAMES,NVAR,ITHYGE,0)
      CALL SERCH('THYGI ',NAMES,NVAR,ITHYGI,0)

      CALL SERCH('PHYG  ',NAMES,NVAR,IPHYG ,0)

      JHYCI =VALUES(IHYCI )
      JHYVI =VALUES(IHYVI )
      JTHYGE=VALUES(ITHYGE)
      JTHYGI=VALUES(ITHYGI)
C
C....... NOW MANIPULATE BITS
      IF(JHYCI.LT.0) THEN
         HYCI=32768.+IAND(JHYCI,IFRAC)
      ELSE
         HYCI=JHYCI
      ENDIF
      IF(JHYVI.LT.0) THEN
         HYVI=32768.+IAND(JHYVI,IFRAC)
      ELSE
         HYVI=JHYVI
      ENDIF
      JTHYGE=IAND(JTHYGE,IFRAC2)
      JTHYGI=IAND(JTHYGI,IFRAC2)
      ATHGE=-0.01223*(16384.-JTHYGE)+113.4
      ATHGI=-0.01210*(16384.-JTHYGI)+100.0
      PHYG=VALUES(IPHYG)
      aphyg=(phyg+10.)*250./20.*68.95
c....... set-up changed from earlier tests:  sensitivity*4
      aphyg=aphyg/4.
c....... then output HYCI, HYVI, ATHGE, ATHGI, APHYG
```

Attachment 5
(6 pp)

*Atmospheric Technology Division — Research Aviation Facility*
MEMORANDUM

17 May 1989

MEMO TO: Loren Nelson file (P-760)

FROM: Al Cooper

SUBJECT: Data processing for project 9-760

Several special processing methods have been used with the data from project 9-760. Some of the procedures are described in a separate memo that deals with the Ophir instruments. In addition, the following have received special treatment:

## Cryogenic hygrometer

Most instruments on the aircraft are handled with calibration coefficients that allow for a quadratic relationship between the measured voltage and the parameter. For the cryogenic hygrometer, this has proven to be inadequate. For this reason, the calibration of the temperature sensor is handled separately in a special processing section of the skeleton processing program.

An attempt to fit the thermistor calibration values to the usual thermistor equation R=A exp(B/T) did not give a suitable fit to the measurements, and it was necessary to use a cubic expression relating temperature to voltage in order to get an acceptable RMS in the fit to the calibration data. The RMS of the fit did not improve significantly for higher-order fits, so the cubic form has been used:

$$T_{cryo} = -6.3188 + 18.739V + 2.0866V^2 + 0.11424V^3.$$

This expression gives an RMS of 0.125°C when compared to the calibration data for the cryogenic hygrometer over the range from $-20$ to $-80$°C. The calibration is plotted in Fig. 1.

## Lyman-alpha hygrometer

The Lyman-alpha sensor as operated for the first part of the experiment (R1–R4) had minimal sensitivity to humidity changes and appeared to produce large jumps and changes in operating characteristics. Therefore, the sensor was changed before flight R5 and the gap was increased from 0.5 cm to 1.0 cm. A calibration for this sensor was obtained by comparing the results to the output from the cryogenic hygrometer. It was assumed that

$$\rho = C\ln(V) + D(\frac{p}{T}) + F$$

where $C = -1/(bx)$, $b$ is the extinction coefficient for water vapor, $x$ is the path length (1 cm), $-D$ is the ratio of the extinction coefficients ($O_2$ to $H_2O$), and $F = \ln(V_0)/(bx)$. A fit to $\rho$ as determined by the cryogenic hygrometer (and ancillary measurements of temperature and pressure) can thus be used to determine values of $C$, $D$, and $F$. Because such an approach will take little account of measurements having very low humidity (because the uncertainty is assumed constant in the vapor density), while in this experiment low humidities are of primary interest, the fit was performed using weight factors that weight each measurement by $V^2$ (and so approximately represent constant errors in voltage measurement rather than in vapor density).

Because the Lyman-alpha voltage is recorded with an offset, this scheme should account for that offset. Therefore, $(10. - VLA)$ was used for V in the above fit and in subsequent processing. With this convention, the best-fit values for the coefficients were $C = -0.41438$, $D = 0.12669$, and $F = 0.52235$. For the first part of the experiment, the coefficients used were $C = -0.54972$, $D = .35086$, and $F = 1.0427$, although these did not provide a very consistent fit and the Lyman-alpha measurements will be of little use for R1–R4. Figure 2 shows the calibration data for flight R5, 1703–1815 and 1835–1915 (or excluding the contrail passes). There is a good correspondence between the measurements except at very low humidity, where there is an increase in scatter.

To account for drift caused by window contamination and other instrumental errors, an updating scheme was used in which $F$ was adjusted by the following equation each second:

$$f_{new} = 0.995 f_{old} + 0.005(\rho_{cryo} - \rho_{L\alpha}).$$

This provided a slow updating to the value from the cryogenic hygrometer and minimized drift while avoiding any significant effects on the high-frequency response of the Lyman-alpha instrument.

## Rosemount temperature sensors

Because most recovery factors have been determined at low altitude, and because the location of the Rosemount temperature sensors on the nose of the Sabreliner could affect the recovery factor applicable to those sensors, a set of speed runs at high altitude and low temperature was analyzed to determine the applicable recovery factors. Six speed runs were used, all from flight R10. When analyzed to determine the best-fit slope in the equation $T_s = T + bTAS^2$, the following results were obtained for the two Rosemount sensors ATF (unheated) and ATFH (heated):

| RUN | TIMES | $b_{ATF}$ | $b_{ATFH}$ |
|---|---|---|---|
| 1 | 143355–143525 | −.000029 | −.000016 |
| 2 | 143525–144010 | 0.000004 | 0.000005 |
| 3 | 144010–144145 | −.000053 | −.000039 |
| 4 | 144145–144630 | 0.000004 | 0.000001 |
| 5 | 144630–144755 | −.000043 | −.000021 |
| 6 | 144755–145210 | −.000016 | −.000016 |

There was an evident systematic trend in temperature during this flight segment, caused by a real gradient in the atmosphere, so some correction for this effect is needed. Averaging the values would only compensate partially, because the acceleration segments lasted about three times longer than the deceleration segments. If the atmospheric gradient contributes $\Delta$ to the deceleration segments, it contributes $3\Delta$ to the acceleration segments. The difference between acceleration and deceleration runs for ATF is +0.000039, so the real result is about $-0.000042+0.000010=-0.000032$. For ATFH, the corresponding correction is $-0.000020$. Because the processing to obtain the values plotted here used a recovery factor of 0.95 for the unheated sensor and 0.98 for the heated sensor, these results indicate that the former should be increased by $2C_p(0.000032) \approx 0.0323$, so that the recovery factor for the unheated Rosemount (ATF) should be $\alpha = 0.982 \pm 0.009$. Similarly, the recovery factor for the heated Rosemount (ATFH) should be increased to $\alpha = 1.00 \pm 0.01$. The resulting uncertainty contributed by an uncertainty in $\alpha$ of 0.01 is about 0.2°C at a true airspeed of 200 m/s, but without the above correction the error would be about 0.6°C in ATF.

## PMS spectrometers

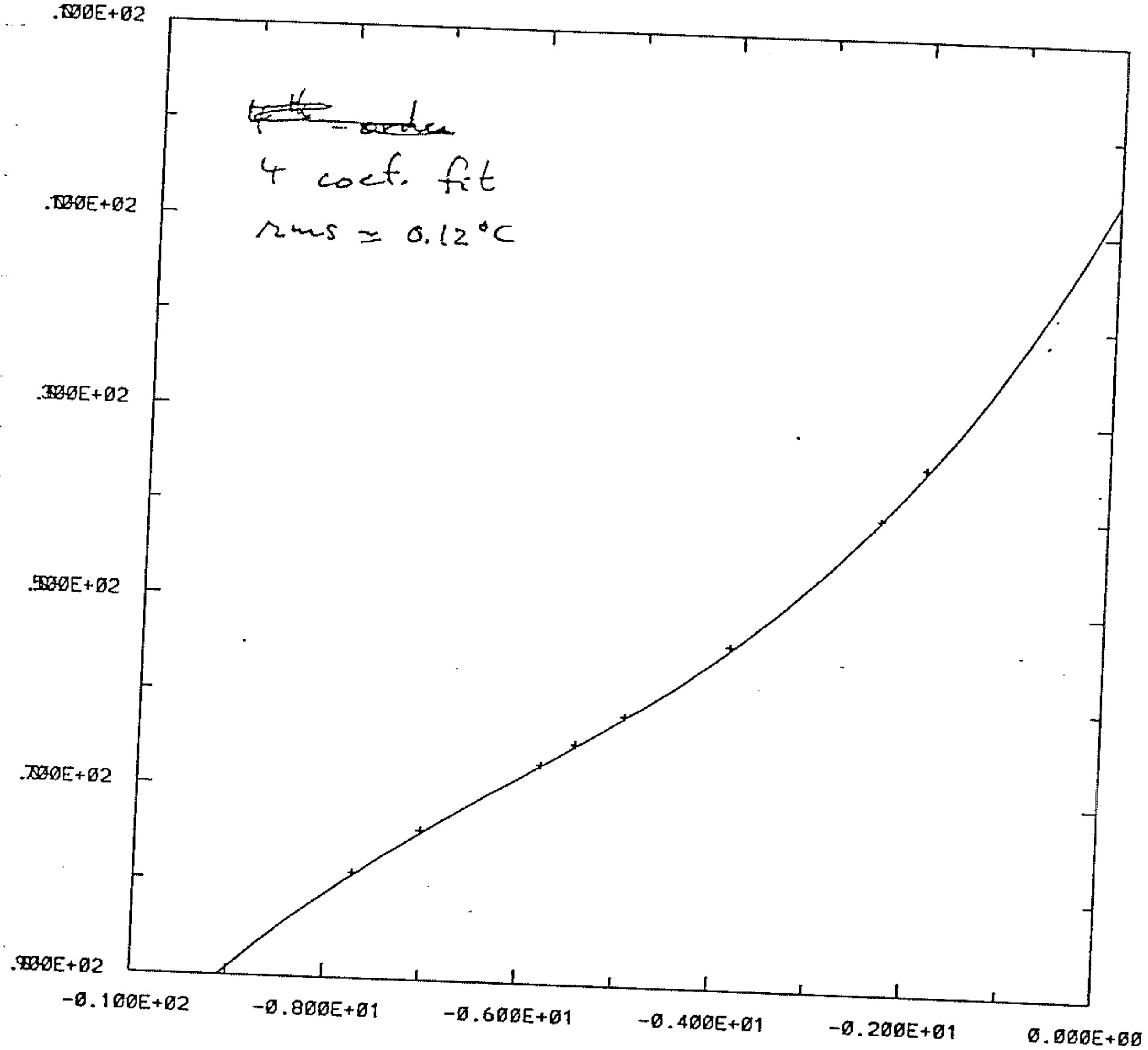
For flights R1 and R2, a PMS 260X spectrometer was flown in the right-wing pod and a conventional FSSP was flown on the left wing. It soon became evident that these probes were not able to detect the particles making the major contribution to the contrails, and before R3 the 260X spectrometer was moved to the left wing (where only the first 15 channels were recorded) while the new PMS 300X probe was installed in the right wing (where its 32 channels were recorded in the first 32 channels of the inputs usually used for the 62 260X channels). This latter configuration was used for the remainder of the experiment, except on flights R8 and R11, when the 260X probe was removed and the conventional FSSP was installed on the left wing for comparison to the PMS-300X probe.

The sample volumes, size limits, and other characteristics of these probes as used in this experiment are documented in ~~the attached~~ a separate memos.

— End of Memo —

Attachments:

two figures
~~memos describing PMS probe calibration~~



~~4th order~~
4 coef. fit
rms ≃ 0.12°C

Fig. 1: Calibration curve for cryogenic hygrometer

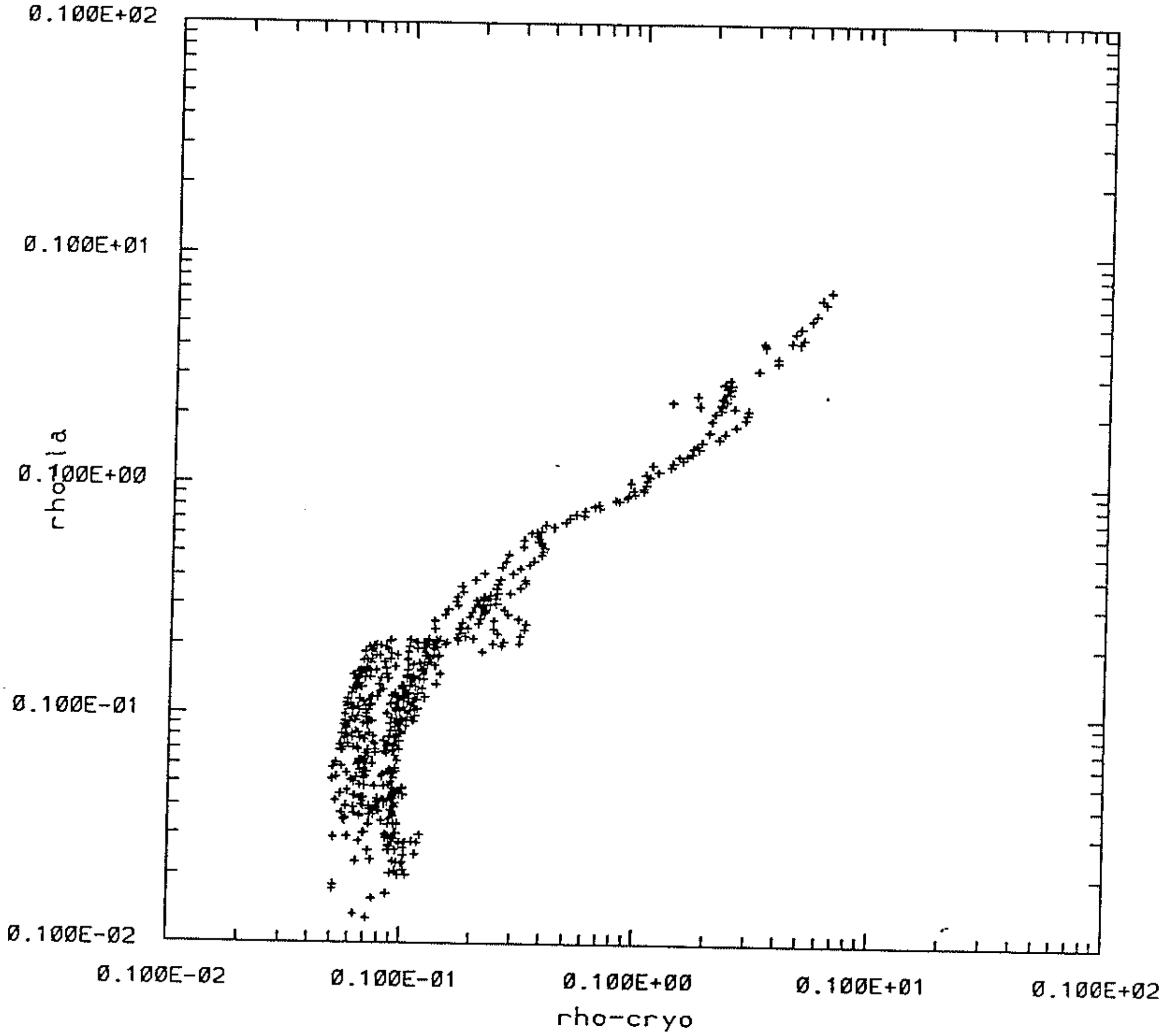


Fig. 2: Lyman-alpha vapor density vs vapor density from the cryogenic hygrometer, for the ~~complete~~ data set described in this memo.

Attachment 6

*Atmospheric Technology Division — Research Aviation Facility*

MEMORANDUM

23 May 1989

MEMO TO: Project 9–760 file

FROM: Al Cooper al

SUBJECT: PMS probe calibrations

The FSSP (Delany version) was calibrated with glass beads to obtain the size thresholds shown in Table 1. The bead sizes used were 19.5 $\mu$m, (Ranges 0 and 1) and 9.4 $\mu$m (range 2); these gave mean channel numbers of 6.4 (range 0), 10.8 (range 1), and 10.9 (range 2). The channel thresholds for water are indicated in Table 1.

For the FSSP-100, the beam diameter is 0.215 mm, the depth of field is 3.1 mm, and the slow and fast reset times are 5.4 and 1.8 $\mu$s, respectively. For the FSSP-300X, the sample area for flights R1–R4 is 0.08 mm$^2$; for flights R5–R11, the sample area is 1.3 mm$^2$. (This difference was caused by operating the instrument with the velocity reject circuit disabled, after calibrations were performed between flights R4 and R5.)

The processing for the 260X probe is standard, except that the locations where the variables will appear are not the usual locations on flights R3–R7 and R9–R10. The 260X was not present on flights R8 and R11, and was in the usual location on the right wing for flights R1 and R2.

**Table 1: Threshold sizes for FSSP channels [$\mu$m]**

| CHANNEL | RANGE 0 | RANGE 1 | RANGE 2 | 300X |
|---|---|---|---|---|
| 1 | 1.0 | 0.8 | 1.0 | 0.396 |
| 2 | 3.0 | 2.6 | 1.4 | 0.450 |
| 3 | 8.2 | 2.9 | 2.6 | 0.491 |
| 4 | 13.3 | 4.8 | 2.7 | 0.540 |
| 5 | 15.7 | 7.3 | 2.9 | 0.583 |
| 6 | 22.0 | 11.5 | 3.0 | 0.63 |
| 7 | 25.9 | 13.5 | 4.7 | 0.68 |
| 8 | 29.9 | 15.3 | 4.9 | 0.73 |
| 9 | 36.1 | 18.0 | 6.8 | 0.87 |
| 10 | 38.3 | 20.7 | 8.3 | 0.91 |
| 11 | 43.2 | 24.1 | 9.8 | 0.95 |
| 12 | 47.1 | 26.1 | 11.5 | 0.99 |
| 13 | 51.7 | 29.6 | 13.2 | 1.08 |
| 14 | 55.5 | 31.8 | 13.5 | 1.15 |
| 15 | 59.4 | 34.6 | 13.8 | 1.65 |
| 16 | 63.6 | 34.6 | 15.5 | 2.15 |
| 17 | | | | 2.65 |
| 18 | | | | 2.77 |
| 19 | | | | 3.63 |
| 20 | | | | 4.48 |
| 21 | | | | 5.34 |
| 22 | | | | 6.19 |
| 23 | | | | 7.05 |
| 24 | | | | 8.32 |
| 25 | | | | 9.88 |
| 26 | | | | 11.3 |
| 27 | | | | 11.9 |
| 28 | | | | 13.4 |
| 29 | | | | 13.8 |
| 30 | | | | 15.5 |
| 31 | | | | 19.5 |
| 32 | | | | 23.5 |

— End of Memo —

Attachment 7

# PLOT/PRINT LIST
## NCAR Sabreliner - Project #9-760
## Airborne Exhaust Studies
Loren Nelson

(* marks changes from ERICA or non-standard variables)

Raw INS Latitude vs Longitude (deg) - ALAT vs ALON
LORAN-C Derived Latitude vs Longitude (deg) - CLAT vs CLON

Corrected Static Pressure (digital) Fuselage (mb) - PSFDC
Corrected Static Pressure, Fuselage (mb) - PSFC
Corrected Static Pressure, Boom (mb) - PSBC
Ambient Temperature, Fuselage (°C) - ATF
Ambient Temperature: Heated, Fuselage (°C) - ATFH
Corrected Dew Point Temperature, Top Fuselage (°C) - DPTC
Corrected Dew Point Temperature, Bot Fuselage (°C) - DPBC
Corrected Cryogenic Dew Point Temperature (°C) - DPCRC

Pressure Altitude (m) - PALT
Pressure Damped Inertial Altitude (m) - HI3
Potential Temperature (°K) - THETA
Equivalent Potential Temperature (°K) - THETAE
Absolute Humidity, Top (g/m3) - RHODT
Absolute Humidity, Bot (g/m3) - RHODB
Absolute Humidity, Cryogenic (g/m3) - RHOCR
Relative Humidity (%) - RHUM
Mixing Ratio (g/kg) - MR
Specific Humidity (g/kg) - SPHUM

Total CN Particle Concentration (#/cm3) - CONCN
Corrected CN Particle Concentration (#/cm3) - CONCNC
FSSP Cloud Particle Concentration (n/cm3) - CONCF
FSSP Mean Particle Diameter (um) - DBARF
FSSP Estimated Dispersion (SIGMA/DBARF) - DISPF
*PMS 300X Particle Concentration (#/cm3) - CONC3
*PMS 300X Mean Particle Diameter (um) - DBAR3
260X Particle Concentration (#/cm$^3$)

Aircraft True Airspeed, Fuselage (m/s) - TASF
Aircraft True Airspeed, Radome (m/s) - TASR
Corrected Dynamic Pressure, Fuselage (mb) - QCFC
Corrected Dynamic Pressure, Radome (mb) - QCRC

Raw Dynamic Pressure, Fuselage (mb) - QCF
Raw Dynamic Pressure, Radome (mb) - QCR
Sideslip Angle, Radome Diff. Pressure (deg) - SSRD
Vertical Differential Pressure, Radome (mb) - ADIFR
Horizontal Differential Pressure, Radome (mb) - BDIFR

Raw Static Pressure, (digital) Fuselage (mb) - PSFD
Raw Static Pressure, Fuselage (mb) - PSF
Cabin Pressure (mb) - PCAB
Total Temperature, Fuselage (C) - TTF
Total Temperature: Heated, Fuselage (C) - TTFH
Frost Point Temperature, Fuselage Top (C) - DPT
Frost Point Temperature, Fuselage Bot (C) - DPB
Frost Point Temperature, Cryogenic (C) - DPCR

Raw Cryogenic Output (vdc) - VCRH
Raw Cryogenic mirror temperature (C) - TVCRH
Cryogenic Inlet Temperature (C) - CRHT
Cryogenic Inlet Pressure (mb) - CRHP
CN Counter: Isokinetic Flow Rate (l/min) - XICN
CN Counter: Corrected Isokinetic Flow Rate (l/min) - XICNC
CN Counter: Raw Inlet Pressure (mb) - PCN
CN Counter: Correct Inlet Pressure (mb) - PCNC
CN Counter: Raw Flow Rate (l/min) - FCN
CN Counter: Corrected Flow Rate (l/min) - FCNC
CN Counter: Raw CN counts (#/.02s) - CNTS
CN Counter: Inlet Temperature (C) - FCBADS

*Pressure, Ophir Hygrometer - PHYG
*Ozone Voltage - O3F
*Ozone Flow - O3FF
*Ozone Temperature - O3FT
*Event Marks - EV1
*Slide Marks - XMARK
*Ophir Hygrometer Clear Channel - HYCI
*Ophir Hygrometer Vapor Channel - HYVI
*Ophir Hygrometer External Temperature - THYGE
*Ophir Hygrometer Internal Temperature - THYGI
*Ophir Radiometer Voltage - TAIRV
*Ophir Radiometer Reference Temperature #1 - TREF1
*Ophir Radiometer Reference Temperature #2 - TREF2
*Ophir Radiometer Reference Temperature #3 - TREF3

Unaltered Tape Time (s) - TPTIME
LTN-51 ARINC Time Lag (s) - TMLAG
Fixed Zero Voltage (vdc) - FZV

## Quality Assurance Parameter List

DFATFFH = ATF - ATFH
DFPSDF = PSFDC - PSFC
*DFATFO = ATF - ATOPH
DFPHAKD = PITCH - AKRD
DFQCFR = QCFC - QCRC
DFDPTC = DPTC - DPCRC
Position Error for LORAN-C (n mi) - CCEP

Attachment 8 -
Skeleton processor
code

```
      SUBROUTINE DSKEL
c....... revised 30 April for flight R10
c....... revised 4 May to use fit to hygrometer for entire set of flts
c.......second part of project (April 1989) -- new version of
c..      radiometric thermometer
CU    Northrup-Ophir project, adds Ophir & Cryog. values
C Input buffer.
      INCLUDE '/users/dap/include/file.com'
C Output buffer.
      INCLUDE '/users/dap/include/fileo.com'
C User's buffer.
      INCLUDE '/users/dap/include/users.com'
      LOGICAL SEARCH
C***********************************************************************
      dimension ala(2),bla(2),alla(2),blla(2),clla(2)
      dimension dpc(2),rhot(2)
      integer xor
      integer*2 jtairv,jtref1,jtref2,jtref3,jhyci,jhyvi,jthyge,jthygi
      integer*2 ifrac,isign,ifrac2
      DOUBLE PRECISION C,AM,CFIT
      DIMENSION XFIT(7)
      DIMENSION CFIT(8)
      DIMENSION C(20)
      DATA NCOEF/6/
      data cfit/
     1  0.81814347D-06,
     2  0.13597565D-06,
     3  0.11440863D+00,              } R5-R11
     4  0.34564111D-01,
     5  0.21998663D-08,
     6 -0.80492862D-06,2*0./
c    1 -0.11842568D-04,
c    2  0.20791268D-06,
c    3  0.59901375D+00,
c    4 -0.15624474D+00,
c    5  0.61070724D-08,
c    6  0.25985814D-04,
c    7 -0.64791106D-06,
c    8 -0.11002608D-08/
C***********************************************************************
      DATA ALAMB/4.255/
      data rchop/0.98/,coph1/3.7415e4/,coph2/1.4388e4/
      DATA IFRAC/z'7fff'/,ISIGN/z'8000'/,IFRAC2/z'3fff'/
c     data ccal/9.3600/,bcal/16.006/,acal/0.7010/
      data ccal/-15.4687/,bcal/11.43052/,acal/0.4208915/
c     data afit/-0.41437882/,dfit/.12669169/,ffit/.52235/
      data afit/-1.7925842/,dfit/0.09794888/,ffit/4.743907/ } R5-R11
      data ifrst/0/
      save afit,dfit,ffit,ifrst,f
      data ala/1.0007,1.0003/,bla/3.46e-6,4.18e-6/
      data alla/6.1121,6.1115/,blla/17.502,22.542/
      data clla/240.97,273.48/
....... new coefficients from Vince 22 Mar 89
      data art/3.30110e-3/,brt/4.17961e-4/,crt/-6.14116e-6/
c     data r/30.959/,v0/1.265/,g/10.052/
```

```
      data rccrh/41.675/,v0ccrh/1.2690/,gccrh/8.239/
      DATA RAD / .01745329 /,  DEG / 57.29578 /
      DATA SEARCH / .TRUE. /
      save search,ala,bla,alla,clla
      save rchop,coph1,coph2
      save frac,frac2,isign,art,brt,crt,r,v0,g,rad,deg
C
C
C      * * * * * * * * * * * * * * *
C     *                             *
C    *  Executable code starts here  *
C     *                             *
C      * * * * * * * * * * * * * * *
C
      IF (SEARCH) THEN
C
C***********************************************************************
      CALL SERCH('TAIRV ',NAMES,NVAR,ITAIRV,0)
      CALL SERCH('TREF1 ',NAMES,NVAR,ITREF1,0)
      CALL SERCH('TREF2 ',NAMES,NVAR,ITREF2,0)
      CALL SERCH('TREF3 ',NAMES,NVAR,ITREF3,0)
      CALL SERCH('HYCI  ',NAMES,NVAR,IHYCI ,0)
      CALL SERCH('HYVI  ',NAMES,NVAR,IHYVI ,0)
      CALL SERCH('THYGE ',NAMES,NVAR,ITHYGE,0)
      CALL SERCH('THYGI ',NAMES,NVAR,ITHYGI,0)
      CALL SERCH('ATF   ',NAMES,NVAR,IATF  ,0)
      CALL SERCH('ATFH  ',NAMES,NVAR,IATFH ,0)
      CALL SERCH('VCRH  ',NAMES,NVAR,IVCRH ,0)
      CALL SERCH('PSFDC ',NAMES,NVAR,IPSFDC,0)
      CALL SERCH('CRHT  ',NAMES,NVAR,ICRHT ,0)
      CALL SERCH('CRHP  ',NAMES,NVAR,ICRHP ,0)
      CALL SERCH('DPTC  ',NAMES,NVAR,IDPTC ,0)
      CALL SERCH('DPBC  ',NAMES,NVAR,IDPBC ,0)
      CALL SERCH('TEO3  ',NAMES,NVAR,ITEO3 ,0)
      CALL SERCH('TET   ',NAMES,NVAR,ITET  ,0)
      CALL SERCH('TEP   ',NAMES,NVAR,ITEP  ,0)
      CALL SERCH('PHYG  ',NAMES,NVAR,IPHYG ,0)
      CALL SERCH('DPT   ',NAMES,NVAR,IDPT  ,0)
      CALL SERCH('DPB   ',NAMES,NVAR,IDPB  ,0)
      CALL SERCH('TASR  ',NAMES,NVAR,ITASR ,0)
      CALL SERCH('VLA   ',NAMES,NVAR,IVLA  ,0)
C
        SEARCH = .FALSE.
C
C   End of variable search.
C
      END IF
C
C....... GET OPHIR DIGITAL NUMBERS AND CONVERT BACK
      JTAIRV=VALUES(ITAIRV)
      JTREF1=VALUES(ITREF1)
      JTREF2=VALUES(ITREF2)
      JTREF3=VALUES(ITREF3)
      JHYCI =VALUES(IHYCI )
      JHYVI =VALUES(IHYVI )
      JTHYGE=VALUES(ITHYGE)
```

```
      JTHYGI=VALUES(ITHYGI)
C
C....... NOW MANIPULATE BITS
      IF(JHYCI.LT.0) THEN
          HYCI=32768.+IAND(JHYCI,IFRAC)
      ELSE
          HYCI=JHYCI
      ENDIF
      IF(JHYVI.LT.0) THEN
          HYVI=32768.+IAND(JHYVI,IFRAC)
      ELSE
          HYVI=JHYVI
      ENDIF
      JTHYGE=IAND(JTHYGE,IFRAC2)
      JTHYGI=IAND(JTHYGI,IFRAC2)
      ATHGE=-0.01223*(16384.-JTHYGE)+113.4
      ATHGI=-0.01210*(16384.-JTHYGI)+100.0
      if(abs(hyci).le.1.e-29) hyci=1.e-29
c     DENOM=-0.0015*THYGI+0.9838
c     DENOM=1.1111
c     if(abs(denom).le.1.e-29) denom=1.e-29
c     RRT=(HYVI/HYCI)/denom
c     IF(abs(RRT).le.1.e-29) RRT=1.e-29
c     if(RRT.gt.1.) RRT=1.
c     RHOPH=(-1.*ALOG(RRT)/0.1023)**1.3680
c....... cal of Apr 4 89
c....... best fit 1.1030, but 1.106 has slightly better low-q bhvr
c     denom=1.103
c....... use Ophir-derived coefficients but best-fit T-dependent a:
      denom=1.1180+athgi*0.00064
      rrt=(hyvi/hyci)/denom
      if(abs(rrt).le.1.e-29) rrt=1.e-29
      if(rrt.gt.1.) rrt=1.
      rhoph=(-1./0.1023*alog(rrt))**1.3680
c....... correct for pressure and temperature in the hygrometer
      PHYG=VALUES(IPHYG)
      aphyg=(phyg+10.)*250./20.*68.95
c....... set-up changed from earlier tests:  sensitivity*4
      aphyg=aphyg/4.
      if(aphyg.le.1.e-29) then
          write(6,'(" aphyg=",g13.5)') aphyg
          aphyg=1.e-29
         endif
      ATF=VALUES(IATF)
c....... revise temperature for new recovery factors
      CALL SERCH('ATF     ',NAMEO,NVARO,IATFO,0)
      CALL SERCH('ATFH    ',NAMEO,NVARO,IATFHO,0)
c     atf=values(iatf)
      atfh=values(iatfh)
      tas=values(itasr)
c....... processing uses r=0.95, but probe has r=0.982+/-0.009
c....... for ATFH, r=0.98 used, data look like 1.00+/-0.01
      atf=atf+0.0323*tasr**2/2010.
      atfh=atfh+0.02*tasr**2/2010.
      if(IATFO.gt.0) VALUEO(IATFO)=atf
      if(IATFHO.gt.0) VALUEO(IATFHO)=atfh
```

```
      ATX=ATF
c     write(6,'(" time,rhocr,atx,psxc=",3i4,3g13.5)') ihr,imin,isec,
c    $   rhocr,atx,psxc
c....... protection
      if(atx.lt.-100. .or. atx.gt.40.) return
      if(atx.lt.-100. .or. atx.gt.40.) atx=0.
      PSXC = VALUES(IPSFDC)
      RHOPH = RHOPH*(PSXC/APHYG)*((ATHGE + 273.15)/(ATX + 273.15))
      if(RHOPH.le.0.) RHOPH=1.e-20
      RHOPH2=RHOPH*100.
c....... get dew point from ophir hygrometer
      e=rhoph*1.e-3*461.51*(atx+273.15)/100.
c     write(6,'(" e,rhoph,atx=",5e13.5)') e,rhoph,atx
      dpophc=dewpt(e)
c     write(6,'(" dp from ophir=",e13.5)') dpophc
c....... tairv is radiometric voltage, tref1 is window T, tref2 is
c..      black-body T, tref3 is can or pedestal temperature (not
c..      sure which is passed through
      JTAIRV=XOR(JTAIRV,ISIGN)/16
      JTREF1=XOR(JTREF1,ISIGN)/16
      JTREF2=XOR(JTREF2,ISIGN)/16
      JTREF3=XOR(JTREF3,ISIGN)/16
c....... changed as per telecon with Stahm 11 April 89
c     TREF1=0.048156*JTREF1+1.582
c     TREF2=0.048937*JTREF2+2.883
c     TREF3=0.04840*JTREF3
c....... TREF1 is window temperature
      TREF1=0.049227*JTREF1+2.223053
c....... TREF2 is black-body temp
      TREF2=0.048655*JTREF2+2.6909
c....... assume TREF3 is can temp. (need to verify)
      TREF3=0.048618*JTREF3+1.473003
      VAIR=0.0048828*JTAIRV
c....... skip for VAIR large, and set flag
c     if(abs(vair).gt.9.9) then
c        tair=100.
c        goto 9100
c     endif
c....... correct (April 1989) for offset
      vair=vair-0.1
c....... black body temperature (K)
      atr=tref2+273.15
      pref=coph1/(alamb**5*(exp(coph2/(alamb*atr))-1.))
c....... window temp (K)
      atw=tref1+273.15
c....... can temperature
      atc=tref3+273.15
      pcan=coph1/(alamb**5*(exp(coph2/(alamb*atc))-1.))
      tccan=tref3
      pwin=coph1/(alamb**5*(exp(coph2/(alamb*atw))-1.))
c....... radiometer gain (Sept chamber test)
c     tcped=tref1
c     if(tcped.le.-20.) tcped=-20.
      grad=-65474.04+tcped*(351.7519+tcped*3.718527)
      grad=-19000.+52.944*tccan+0.52222*tccan**2
c....... new instrument April 1989, increased gain, no T dep:
```

```
      grad=-242000.
c     ptar=vair/grad+rchop*pref+(1.-rchop)*pped
      ptar=vair/grad+pref
      coop=coph1/(ptar*alamb**5)
      if(coop.le.-1.) coop=-0.9
      tair=coph2/(alamb*alog(coop+1.))-273.15
c     write(6,'(" tair,tref1,tref2,tref3,vair=",5e15.7)')
c    $               tair,tref2,tref2,tref3,vair
      XFIT(1)=TREF1
      XFIT(2)=TREF2
      XFIT(3)=TREF3
      XFIT(4)=VAIR
      XFIT(5)=PWIN
      XFIT(6)=PREF
      XFIT(7)=PCAN
c....... correction for fit
      PM=FUNCT(NCOEF,CFIT,XFIT)
     $   +PREF+VAIR/GRAD
      AA=COPH1/(ALAMB**5*PM)+1.
      if(aa.le.0.) then
         tair=101.
         goto 9100
      endif
      TAIR=COPH2/(ALAMB*ALOG(COPH1/(ALAMB**5*PM)+1.))-273.15
 9100 continue
      VALUEO(1)=TAIR
      VALUEO(2)=TREF1
      VALUEO(3)=TREF2
      VALUEO(4)=TREF3
      VALUEO(5)=HYCI
      VALUEO(6)=HYVI
      VALUEO(7)=ATHGE
      VALUEO(8)=ATHGI
      VALUEO(9)=PTAR
      VALUEO(10)=PREF
      VALUEO(11)=TREF
      VALUEO(12)=VAIR
      VALUEO(13)=RHOPH
C....... cryogenic hygrometer and ozone
      CRHF=VALUES(ICRHF)
      VCRH=VALUES(IVCRH)
c....... undo original cal coefficients (acal,bcal,ccal)
 9732 continue
      cc=ccal-vcrh
      rad=bcal**2-4.*acal*cc
      if(rad.lt.0.) then
         write(6,'(" neg radical, forced=0, rad=",g13.5)') rad
         rad=0.
      endif
      v=(sqrt(rad)-bcal)/(2.*acal)
c     write(6,'(" v,vcrh,cc,acal,bcal,ccal=",6g13.5)')
c    $               v,vcrh,cc,acal,bcal,ccal
c....... invert for cal coefs of (0,-1,0)
      vcrh=-1.*v
 ....... code from AJS 16 Sept 88
c     vdmb=vcrh
```

```
c     if(vcrh.lt.0.001) vdmb=0.001
cc    rt=(r*vdmb/g)/(v0-vdmb/g)
c....... code from Vince 22 Mar 89:
c     rt=rccrh*(v0ccrh*gccrh/vdmb-1.)
c     z=alog(rt)
c     t=art+brt*z+crt*z*z
c     dpcr=1./t-273.15
9731  continue
c     write(6,'(" dpcr,vcrh,rad=",3g13.5)') dpcr,vcrh,rad
c....... apply new cubic equation to voltage
      dpcr=-0.632e1+v*(0.187386e2+v*(0.2086581e1+v*0.11424365))
c     write(6,'(" vcrh,v,dpcr=",3e15.7)') vcrh,v,dpcr
c....... avoid bad values before operating
      if(dpcr.gt.40.) dpcr=40.
c     write(6,'(" dpcr,vcrh,rad=",3g13.5)') dpcr,vcrh,rad
c
c....... now get vapor pressure and dew point from frost point
      e=vapi(vcrh)
c....... correct for pressure and temperature in cryo
      CRHP = VALUES(ICRHP)
      if(crhp.le.50.) crhp=50.
      e=e*psxc/crhp
c     write(6,'(" e,psxc,crhp=",3g13.5)') e,psxc,crhp
      dpcrc=dewpt(e)
c     write(6,'(" corr cryo=",g13.5,", e,psxc,crhp=",3g13.5)')
c    $   dpcrc,e,psxc,crhp
c....... absolute humidity
      rhocr=e*100./(461.51*(atx+273.15))*1.e3
      RHOCR2=RHOCR*100.
c     DPCR=VCRH
c     IF(DPCR.LT.0.) DPCR=0.0091+DPCR*(1.134+DPCR*0.00104)
c     DPXC = DPCR
      CRHT = VALUES(ICRHT)
c....... correct other variables to use same code
      DPB=values(IDPB)
      DPT=values(IDPT)
      e=vapi(dpb)
      rhot(2)=e*100./(461.51*(atx+273.15))*1.e3
      DPBC=dewpt(e)
      if(dpb.gt.0.) dpbc=dpb
      e=vapi(dpt)
      rhot(1)=e*100./(461.51*(atx+273.15))*1.e3
      DPTC=dewpt(e)
      if(dpt.gt.0.) dptc=dpt
c     write(6,'(" corr b,tdp=",4g13.5)') dpbc,dptc,values(idpbc),
c    $   values(idptc)
c....... correct in output data
      CALL SERCH('DPBC  ',NAMEO,NVARO,IDPBCO,0)
      if(IDPBCO.gt.0) VALUEO(IDPBCO)=DPBC
      CALL SERCH('DPTC  ',NAMEO,NVARO,IDPTCO,0)
c     write(6,'(" dptc(n,o)=",2f7.2,i5)') dptc,values(idptc),idptco
      if(IDPTCO.gt.0) VALUEO(IDPTCO)=DPTC
      DPC(1) = DPTC
      DPC(2) = DPBC
 ...... now get saturation vapor density wrt ice
      e=vapi(atx)
```

Attachment 9 -
9 pp.

# 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):

```
      rhoi=e*100./(461.51*(atx+273.15))*1.e3
      e=vapor(atx)
      rhow=e*100./(461.51*(atx+273.15))*1.e3
      if(atx.gt.0.) rhoi=rhow
c     write(6,'(" rhoi,rhow=",2g13.5)') rhoi,rhow
C
C
C   Calculate absolute humidities from external hygrometers
C
      DO 42 ISET = 1,2
C
CP******RHOT(I)  ABSOLUTE HUMIDITY                (g/m3)              RHODT
C                 REQUIRES --- ATX, EDPC, DPC(I), PSXC
C VAPOR PRESSURE (EDPC IN MB) IS AN INTERMEADIATE VARAIBLE            EDPC
      K = 1
      IF(DPC(ISET).LT.0.) K=2
      FF = ALA(K) + BLA(K)*PSXC
      ex=b1la(K)*dpc(iset)
      denom=c1la(K)+dpc(iset)
      if(abs(denom).lt.1.e-29) write(6,'(" denom2=",g13.5)') denom
      if(abs(denom).lt.1.e-29) denom=1.e-29
      ex=ex/denom
      if(abs(ex).gt.30.) write(6,'(" ex2=",g13.5)') ex
      if(ex.gt.30.) ex=30.
      if(ex.lt.-30.) ex=-30.
      edpc=ff*a1la(K)*exp(ex)
c     EDPC = FF*A1LA(K)*EXP(B1LA(K)*DPC(ISET)/(C1LA(K) + DPC(ISET)))
      RHOT(ISET) = 216.68*EDPC/(ATX+273.16)
42    CONTINUE
C
CP******TEO3C    CORRECTED OZONE CONCENTRATION     (PPB)              TEO3C
c....... not on aircraft for this project
C
c     TETX= -13.559 + TET *(.005659 - TET *0.00000014907)
c     TEPX= 38.778 + TEP *(0.09339 + TEP *0.00000035275)
c     if(abs(tepx).lt.1.e-29) write(6,'(" tepx=",g13.5)') tepx
c     if(abs(tepx).lt.1.e-29) tepx=1.e-29
cc    write(6,'(" teo3,tepx,tetx=",3g13.5)') teo3,tepx,tetx
c     TEO3C = TEO3*(1013.16/TEPX)*((TETX+273.15)/273.15)
C
c
c........ revise lyman-alpha vapor density
      CALL SERCH('RHOLA ',NAMEO,NVARO,IRHOLA,0)
      if(ifrst.eq.0) then
         ifrst=1
         ffitx=ffit
      endif
      vla=values(ivla)
      if(vla.ge.10.) vla=9.999
      rhola=afit*alog(10.-vla)+dfit*psxc/(atx+273.15)+ffitx
c     ffitx=0.998*ffitx+0.002*(ffitx+rhocr-rhola)
      ffitx=ffitx+0.005*(rhocr-rhola)
c     write(6,'(" old,new rhola,vla,psxc,atc,f,afit,dfit",8e13.5)')
     $       valueo(irhola),rhola,vla,psxc,atx,ffitx,afit,dfit
      if(IRHOLA.gt.0) VALUEO(IRHOLA)=rhola
c     write(6,'(" vla,rhola,psxc,atx,f,rhocr,irhola=",6f8.4,i4)')
```

```
c     $               vla,rhola,psxc,atx,f,rhocr,irhola
C   Put new parameters into output arry
C
        VALUEO(14)  = ATX
        VALUEO(15)  = PSXC
        VALUEO(16)  = DPCR
        VALUEO(17)  = DPCRC
        VALUEO(18)  = RHOCR
        VALUEO(19)  = CRHT
        VALUEO(20)  = CRHP
        VALUEO(21)  = VCRH
        VALUEO(22)  = RHOT(1)
        VALUEO(23)  = RHOT(2)
c       VALUEO(24)  = TET
c       VALUEO(25)  = TEP
c       VALUEO(26)  = TEO3C
        VALUEO(24)=RHOPH2
        VALUEO(25)=RHOCR2
        valueo(26)=aphyg
        valueo(27)=dpophc
        valueo(28)=rhoi
        valueo(29)=rhow
C*******************************************************************
C
C       DPCR   : RAW CRYOGENIC FROST POINT
C       DPCRC  : CRYOGENIC DEW POINT CORRECTED TO AMBIENT
C       RHOCR  : CORRECTED CRYOGENIC ABSOLUTE HUMIDITY
        CRHT   : CRYOGENIC MANIFOLD TEMPERATURE
C       CRHP   : CRYOGENIC MANIFOLD PRESSURE
C       CRHF   : CRYOGENIC MANIFOLD FLOW
C       VCRH   : RAW CRYOGENIC OUTPUT IN VDC
C       TET    : OZONE CHAMBER TEMP
C       TEP    : OZONE CHAMBER PRESS
C       TEO3C  : CORRECTED OZONE CONCENTRATION
C       RHOGO  : OUTSIDE GE ABSOLUTE HUMIDITY
C       RHOBD  : STD EG&G ABSOLUTE HUMIDITY
C
C*******************************************************************
C
C
C   END OF COMPUTATIONS
C
C*******************************************************************
C
      RETURN
      END
C
      BLOCK DATA
C
C
C User's buffer.
      INCLUDE '/users/dap/include/users.com'
C
C     DATA SPECNM / 50*'        '/
C     DATA SPECUN / 50*'      ' /
C     DATA VALIN  / 50*'        ' /
```

```
C     DATA VCOEF  / 50*0.0      /
C
C**********************************************************************
CU  WARNING:  SPECNM names MUST be capitalized.
      DATA SPECNM(1)/'ATAIR '/,SPECUN(1)/' C  '/
      DATA SPECNM(2)/'ATREF1'/,SPECUN(2)/' C  '/
      DATA SPECNM(3)/'ATREF2'/,SPECUN(3)/' C  '/
      DATA SPECNM(4)/'ATIREF'/,SPECUN(4)/' C  '/
      DATA SPECNM(5)/'AHYCI '/,SPECUN(5)/'    '/
      DATA SPECNM(6)/'AHYVI '/,SPECUN(6)/'    '/
      DATA SPECNM(7)/'ATHGE '/,SPECUN(7)/' C  '/
      DATA SPECNM(8)/'ATHGI '/,SPECUN(8)/' C  '/
      DATA SPECNM(9)/'PTAR  '/,SPECUN(9)/'    '/
      DATA SPECNM(10)/'PREF  '/,SPECUN(10)/'    '/
      DATA SPECNM(11)/'TREF  '/,SPECUN(11)/'    '/
      DATA SPECNM(12)/'VAIR  '/,SPECUN(12)/'    '/
      DATA SPECNM(13)/'RHOPH '/,SPECUN(13)/'g/m3'/
      DATA SPECNM(14)  /'ATX   '/,   SPECUN(14)  /'C   '/
      DATA SPECNM(15)  /'PSXC  '/,   SPECUN(15)  /'mbar'/
      DATA SPECNM(16)  /'DPCR  '/,   SPECUN(16)  /'C   '/
      DATA SPECNM(17)  /'DPCRC '/,   SPECUN(17)  /'C   '/
      DATA SPECNM(18)  /'RHOCR '/,   SPECUN(18)  /'gm-3'/
      DATA SPECNM(19)  /'ACRHT '/,   SPECUN(19)  /'C   '/
      DATA SPECNM(20)  /'ACRHP '/,   SPECUN(20)  /'mbar'/
      DATA SPECNM(21)  /'VCRH  '/,   SPECUN(21)  /'degC'/
      DATA SPECNM(22)  /'RHOGO '/,   SPECUN(22)  /'gm-3'/
      DATA SPECNM(23)  /'RHOBD '/,   SPECUN(23)  /'gm-3'/
c     DATA SPECNM(24)  /'TETX  '/,   SPECUN(24)  /'C   '/
c     DATA SPECNM(25)  /'TEPX  '/,   SPECUN(25)  /'mb  '/
c     DATA SPECNM(26)  /'TEO3C '/,   SPECUN(26)  /'PPB '/
      DATA SPECNM(24)  /'RHOPH2'/,   SPECUN(24)  /'g m3'/
      DATA SPECNM(25)  /'RHOCR2'/,   SPECUN(25)  /'g m3'/
      DATA SPECNM(26)  /'APHYG '/,   SPECUN(26)  /' mb '/
      DATA SPECNM(27)  /'DPOPHC'/,   SPECUN(27)  /'deg '/
      DATA SPECNM(28)  /'RHOI  '/,   SPECUN(28)  /'g m3'/
      DATA SPECNM(29)  /'RHOW  '/,   SPECUN(29)  /'g m3'/
      DATA NSPCNM / 29 /
C
      DATA VALIN( 1) /'QECOEF'/,  VCOEF( 1) /       1.0         /
      DATA VALIN( 2) /'QNCOEF'/,  VCOEF( 2) /       1.0         /
C     DATA VALIN(  ) /'      '/,  VCOEF(  ) /                   /
CU  Set NVAL to the number of coefficients defined above.
C      The maximum number is 50.
      DATA NVAL /  2 /
      END
      function dewpt(e)
      common/subf/es
      external etodw
      tol=0.001
      es=e
      tdew=-20.
      call newtn(etodw,tdew,tol,tdw)
      dewpt=tdw
      return
      end
      function etodw(tdw)
```

```
      common/subf/es
      etodw=es-vapor(tdw)
      return
      end
      FUNCTION VAPI(TFP)
C INPUT IS IN DEGREES C, assumed to be frost point.
C ROUTINE CODES GOFF-GRATCH FORMULA
      if(TFP.lt.-200. .or. tfp.gt.200.) then
         vapi=1.e-20
         return
      endif
      T=273.16+TFP
C THIS IS ICE SATURATION VAPOR PRESSURE
      E=-9.09718*(273.16/T-1.)-3.56654*ALOG10(273.16/T)
     $  +0.876793*(1.-T/273.16)
      VAPI=6.1071*10.**E
      RETURN
      END
      FUNCTION FUNCT(N,C,X)
      DIMENSION C(1),X(7)
      DOUBLE PRECISION C,A
C....... XFIT(1) - ATREF1
C....... XFIT(2) - ATREF2
C....... XFIT(3) - ATREF3
C....... XFIT(4) - VAIRC
C....... XFIT(5) - PPED
C....... XFIT(6) - PREF
 ....... XFIT(7) - PCAN
C....... C(1) - P OFFSET
C..      C(2) - P LINEAR (T2-TZERO)
C        C(3) - P(T1)-P(T2)
C        C(4) - P(T3)-T(T2)
C        C(5) - QUADRATIC TERM IN P CALIBR (T2-TZERO)**2
C        C(6) - GAIN TERM, VOLTAGE
C        C(7) - LINEAR CORRECTION TO GAIN (T3-TZERO)
C        C(8) - QUADRATIC GAIN TERM (T3-TZERO)
      A=C(1)
      IF(N.GT.1) A=A+X(2)*C(2)
      IF(N.GT.2) A=A+(X(5)-X(6))*C(3)
      IF(N.GT.3) A=A+C(4)*(X(7)-X(6))
      IF(N.GT.4) A=A+C(5)*X(2)**2
      IF(N.GT.5) A=A+X(4)*C(6)
      IF(N.GT.6) A=A+C(7)*X(4)*X(3)
      IF(N.GT.7) A=A+C(8)*X(4)*X(3)**2
5     FUNCT=A
      RETURN
      END
```

differences,
code used for R1-R9: <
vs code used for R10-R11: >

```
0a1
>
2,5c3,6
< c....... first part of project (March 1989) -- version of
< c..      radiometric thermometer changed after that --
< c..      Uses fit to hygrometer based on entire set of flights
< c....... version for MAR 89 contrail study
---
> c....... revised 30 April for flight R10
> c....... revised 4 May to use fit to hygrometer for entire set of flts
> c.......second part of project (April 1989) -- new version of
> c..      radiometric thermometer
24,27c25
<       data afit/-3.1168183/,dfit/.041240729/,ffit/8.2287625/
<       data ifrst/0/
<       save afit,dfit,ffit,ifrst,f
<       DATA NCOEF/8/
---
>       DATA NCOEF/6/
29,36c27,32
<      1 -0.26562077D-05,
<      2  0.68009788D-06,
<      3  0.76928222D+00,
<      4 -0.30723631D+00,
<      5  0.12907714D-07,
<      6  0.47772050D-04,
<      7  0.34394904D-06,
<      8 -0.31028246D-07/
---
>      1  0.81814347D-06,
>      2  0.13597565D-06,
>      3  0.11440863D+00,
>      4  0.34564111D-01,
>      5  0.21998663D-08,
>      6 -0.80492862D-06,2*0./
50a47,50
> c     data afit/-0.41437882/,dfit/.12669169/,ffit/.52235/
>       data afit/-1.7925842/,dfit/0.09794888/,ffit/4.743907/
>       data ifrst/0/
>       save afit,dfit,ffit,ifrst,f
97c97
<       CALL SERCH('VLA   ',NAMES,NVAR,IVLA  ,0)
---
>       CALL SERCH('VLA   ',NAMES,NVAR,IVLA  ,0)
141,144d140
< c     rrt=(hyvi/hyci)/denom
< c     if(abs(rrt).le.1.e-29) rrt=1.e-29
< c     if(rrt.gt.1.) rrt=1.
< c     rhoph=(-1./0.0650*alog(rrt))**0.6647
187a184,186
> c....... tairv is radiometric voltage, tref1 is window T, tref2 is
> c..      black-body T, tref3 is can or pedestal temperature (not
> c..      sure which is passed through
192,194c191,200
        TREF1=0.048156*JTREF1+1.582
<       TREF2=0.048937*JTREF2+2.883
```

```
<             TREF3=0.04840*JTREF3
---
> c....... changed as per telecon with Stahm 11 April 89
> c     TREF1=0.048156*JTREF1+1.582
> c     TREF2=0.048937*JTREF2+2.883
> c     TREF3=0.04840*JTREF3
> c....... TREF1 is window temperature
>       TREF1=0.049227*JTREF1+2.223053
> c....... TREF2 is black-body temp
>       TREF2=0.048655*JTREF2+2.6909
> c....... assume TREF3 is can temp. (need to verify)
>       TREF3=0.048618*JTREF3+1.473003
197,200c203,208
<       if(abs(vair).gt.9.) then
<          tair=100.
<          goto 9100
<       endif
---
> c     if(abs(vair).gt.9.9) then
> c        tair=100.
> c        goto 9100
> c     endif
> c....... correct (April 1989) for offset
>       vair=vair-0.1
204,205c212,213
< c....... pedestal temp (K)
<       atp=tref1+273.15
---
> c....... window temp (K)
>       atw=tref1+273.15
210c218
<       pped=coph1/(alamb**5*(exp(coph2/(alamb*atp))-1.))
---
>       pwin=coph1/(alamb**5*(exp(coph2/(alamb*atw))-1.))
212,213c220,221
<       tcped=tref1
<       if(tcped.le.-20.) tcped=-20.
---
> c     tcped=tref1
> c     if(tcped.le.-20.) tcped=-20.
215c223,225
<       grad=-19000.+52.944*tccan+0.52222*tccan**2
---
> c     grad=-19000.+52.944*tccan+0.52222*tccan**2
> c....... new instrument April 1989, increased gain, no T dep:
>       grad=-242000.
217c227
<       ptar=vair/grad+rchop*pref+(1.-rchop)*pcan
---
>       ptar=vair/grad+pref
221,226c231,232
< c     TREF=TREF2+273.15
< c     PREF=1.1911E-12/(ALAMB**5*(EXP(1.4388/(ALAMB*TREF))-1.))
< c     PTAR=(VAIR+0.133)/(-11.54+0.05*TREF3)/0.971+PREF
  c     RRT=1.1911E-12/(PTAR*ALAMB**5)+1.
< c     IF(RRT.LT.1.E-30) RRT=1.E-30
```

```
< c      TAIR=1.4388/(ALAMB*ALOG(RRT))-273.15
---
> c      write(6,'(" tair,tref1,tref2,tref3,vair=",5e15.7)')
> c     $              tair,tref2,tref2,tref3,vair
231c237
<        XFIT(5)=PPED
---
>        XFIT(5)=PWIN
233a240
> c....... correction for fit
238c245
<           tair=100.
---
>           tair=101.
356c363
< c      EDPC = F*A1LA(K)*EXP(B1LA(K)*DPC(ISET)/(C1LA(K)  + DPC(ISET)))
---
> c      EDPC = FF*A1LA(K)*EXP(B1LA(K)*DPC(ISET)/(C1LA(K)  + DPC(ISET)))
378,379c385,386
<        if(vla.ge.0.) vla=-1.e-20
<        rhola=afit*alog(-1.*vla+10.)+dfit*psxc/(atx+273.15)+ffitx
---
>        if(vla.ge.10.) vla=9.999
>        rhola=afit*alog(10.-vla)+dfit*psxc/(atx+273.15)+ffitx
381a389,390
> c      write(6,'(" old,new rhola,vla,psxc,atc,f,afit,dfit",8e13.5)')
> c     $          valueo(irhola),rhola,vla,psxc,atx,ffitx,afit,dfit
382a392,393
> c      write(6,'(" vla,rhola,psxc,atx,f,rhocr,irhola=",6f8.4,i4)')
> c     $              vla,rhola,psxc,atx,f,rhocr,irhola
```

DATE: ________________ TIME: ________

SOURCE(S): ________________________

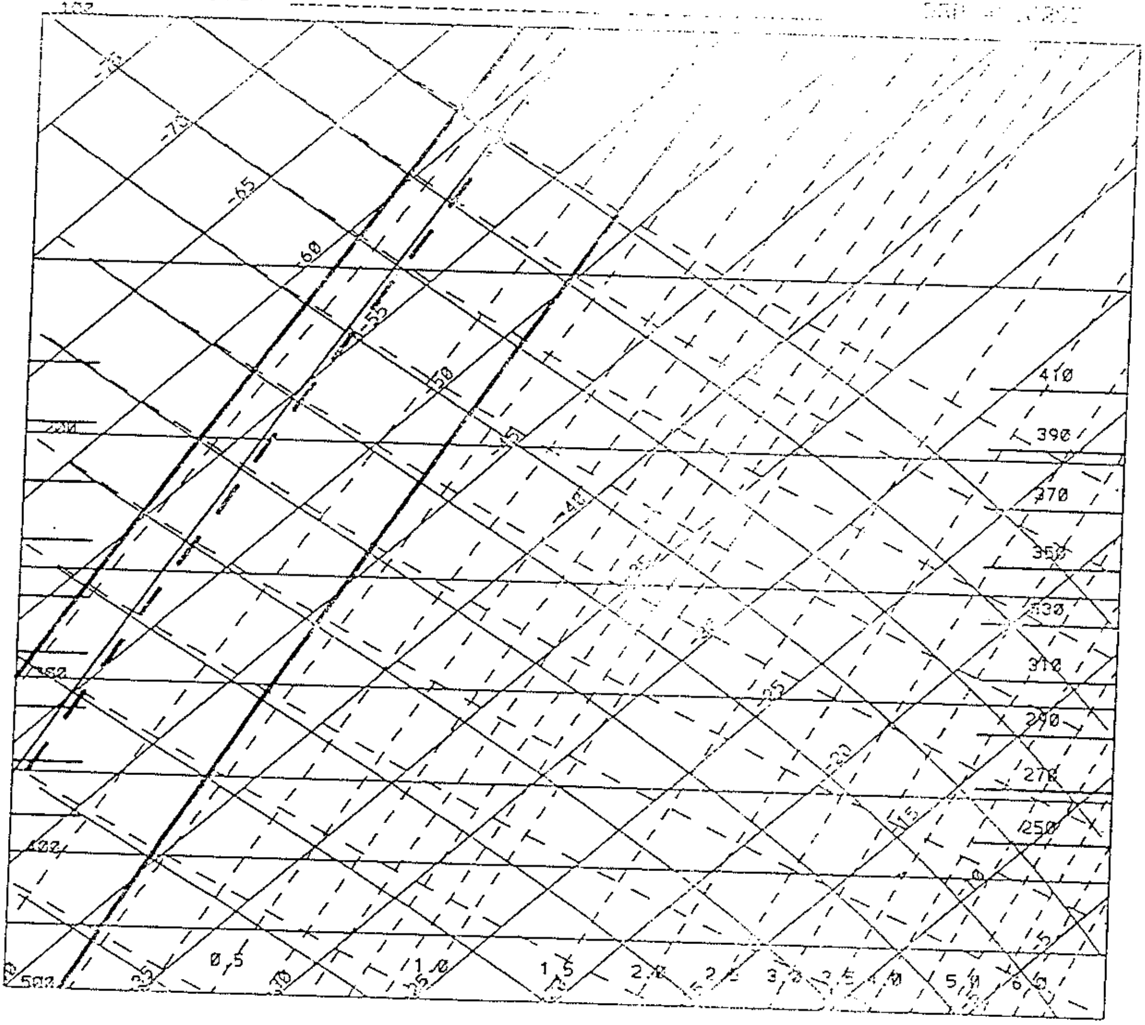


Figure 1: Skew T - log p diagram showing critical conditions for contrail formation (heaviest lines) according to the Appleman theory, but using the Pilie-Jiusto ratio (0.0295) for moisture to sensible heat. Four thresholds are shown: (right) water-saturated atmosphere; (dashed) ice-saturated atmosphere;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

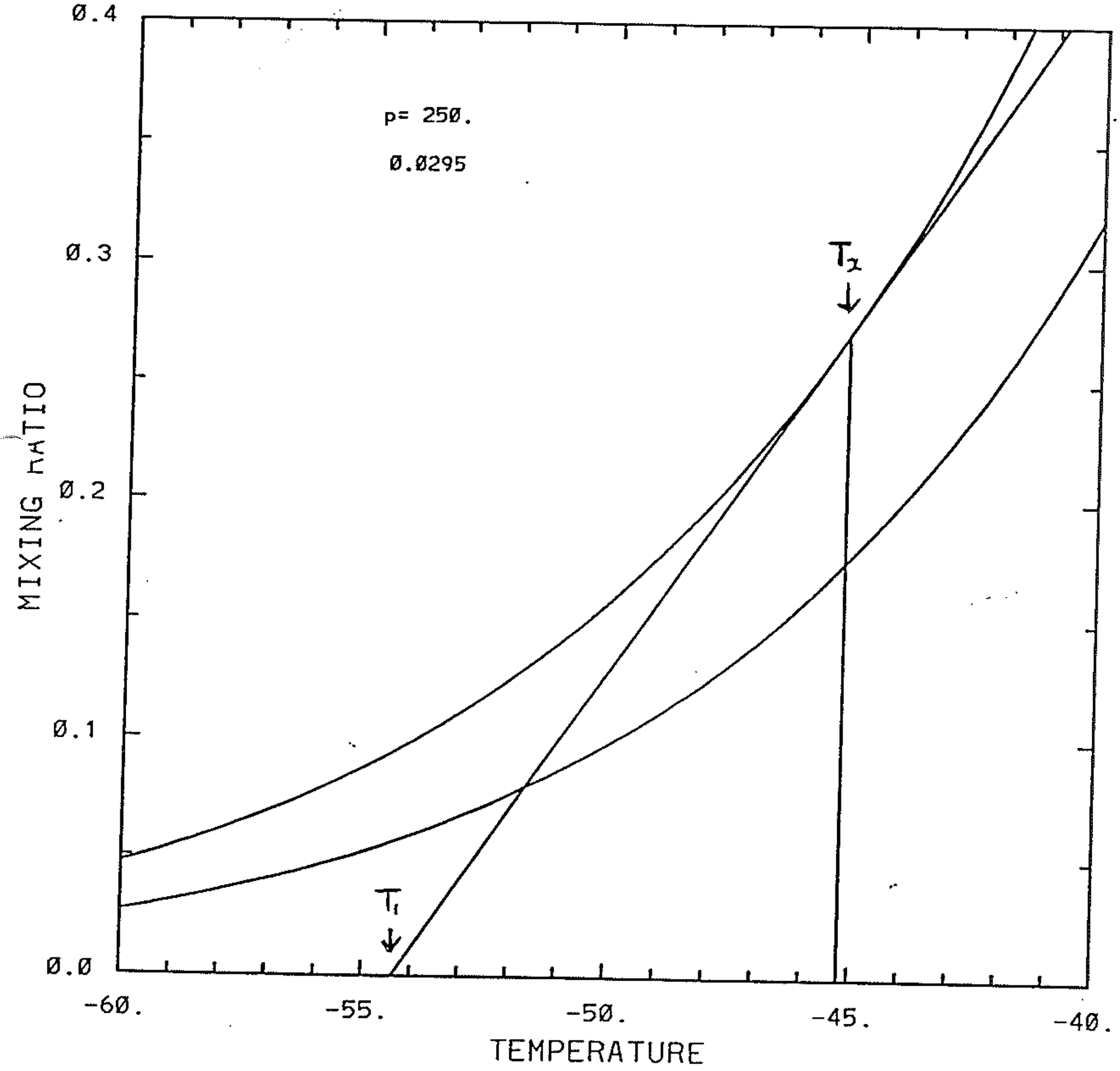


Figure 2: Ice-saturation (lower curve) and water-saturation (upper curve) mixing ratios as a function of temperature, for a total pressure of 250 mb. The threshold conditions of Fig. 1 were determined from $T_1$ and $T_2$ (left and right threshold curves of Fig. 1, respectively). The diagonal straight 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 C 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:

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**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,<br>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.

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## 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.

## 4. Data processing

### *a. RAF data files*

The flights were processed with RAF "DAP" programs on the Masscomp, and the DAP files (at 1 Hz rates) were processed using a skeleton processor ('contrails.f') to add the Ophir and cryogenic variables. A special version of d7inp was used that averaged all input variables so that the 1-Hz output values were averages of all samples from that interval (instead of the usual spot-samples). The output data files, after skeleton-processing, were named CONxy, where 'x' was a letter from A–K that corresponded to the flight numbers 1–11, and 'y' was the tape number for the flight (1 or 2). For example, CONC2 was the file produced by the second tape from flight R3. The skeleton program is saved as /users/science/al/dap/contrails/contrails.f, and is included in this report as Appendix D. The DAP files are saved as 'tar' format files, at 6250 cpi, on tape V55997. Tape copies of all the original tapes are also available. The tape list follows in Table 2.

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**Table 2: Tape List**

| DATE | FLT | TAPE NO | START | END | COPY(file) |
|---|---|---|---|---|---|
| 16 MAR 1989 | T0 | V52861 | 183003 | 183311 | – |
| 21 MAR 1989 | R1 | V52862 | 134938 | 150807 | 52887(1) |
| | | V52863 | 151138 | 162143 | 52887(2) |
| 22 MAR 1989 | R2 | V52864 | 135156 | 150907 | 52887(3) |
| | | V52865 | 151158 | 160513 | 52887(4) |
| 23 MAR 1989 | R3 | V52866 | 135120 | 150301 | 52860(1) |
| | | V52867 | 150522 | 161109 | 52860(2) |
| 24 MAR 1989 | R4 | V52868 | 134933 | 150028 | 52860(3) |
| 10 APR 1989 | R5 | V52869 | 165624 | 181457 | 53906(1) |
| | | V52870 | 181726 | 191443 | 53906(2) |
| 11 APR 1989 | R6 | V52871 | 125043 | 140830 | 53906(3) |
| | | V52872 | 141057 | 151638 | 53906(4) |
| 12 APR 1989 | R7 | V52882 | 125113 | 140946 | 55987(1) |
| | | V52883 | 141233 | 151232 | 55987(2) |
| 12 APR 1989 | R8 | V52884 | 162304 | 170207 | 55987(3) |
| 13 APR 1989 | R9 | V52885 | 125200 | 141039 | 55987(4) |
| | | V56067 | 141330 | 151503 | 54508(1) |
| 14 APR 1989 | R10 | V56068 | 124650 | 135949 | 54508(2) |
| | | V56069 | 140236 | 145957 | 54508(3) |
| 20 APR 1989 | R11 | V52886 | 150747 | 155610 | 54508(4) |

### *b. RAF listings*

A set of listings was made and retained at RAF. These listings include 6-s-average data for some standard parameters, and may be useful in special uses of these data. In addition, analog plots in strip-chart format are saved for some of the data from these flights.

### *c. GENPRO*

GENPRO processing will provide high-rate data, of particular interest for the contrail passes. A separate memo to Celia Chen of RAF describes the needs for this processing.

## 5. Other Information

### *a. Instrumentation*

1. The Ophir radiometric thermometer, new version used during ERICA on the Electra. This instrument was modified between parts of the project, and flights R5–R11 have the new unit. It was operated either "in" or "out" of control mode at various times in the project; the mode is easily recognized because control mode maintains the temperature of the black-body reference near the ambient temperature.

2. The pressurized Ophir IR humidity sensor and associated pumps, as flown during the test program last July.

3. The cryogenic hygrometer.

4. The TSI CN counter.

5. The fast-ozone (dye-chemiluminescence) instrument, flown as an experimental device.

6. An ice-collecting system consisting of a collecting rod, a supporting collar and airfoil mounted to a plate with a pressure interlock valve, and a styrofoam box to hold the samples and, in some cases, keep them frozen with dry ice. Nancy Knight photographed the samples. Event markers recorded the times of exposure, as listed in Appendix B. The collection efficiency can be estimated from the plots included in that Appendix. The collection efficiency probably became very low for droplet sizes smaller than about 5 $\mu$m (flights R1–R4) or 3 $\mu$m (flights R5–R11). The change occurred because the width of the sampler was reduced from 1 cm to 0.5 cm between flights R4 and R5. Events for this sampler were recorded as the digital variable XMARK.

7. Two dewpoint sensors, one General Eastern (DPT) and one EG&G (DPB).

8. A Lyman-alpha hygrometer, standard version, mounted on top of the fuselage. This unit was changed between R4 and R5 to increase the gap (to 1 cm) and to try to get more stable operation.

9. A PMS FSSP and a PMS 260X probe during R1–R4, and a PMS FSSP 300X and 260X during R5, R6, R7, R9, and R10. For R8 and R11, the standard FSSP and the FSSP-300X were flown.

In addition, standard instrumentation was operated as listed in Table 4. It included:

a. Standard airborne data acquisition system.

b. LTN-51 INS for accelerations, attitude angles, and position.

c. Static pressure measurements (fuselage ports OK). Boom is *not* needed for this project.

d. Dynamic pressure (radome and fuselage).

e. Air temperature: Rosemount (two sensors).

f. Standard radome gust sensing system.

See Table 4 for a complete list of the measurements.

### *b. Research Flight Reports*

Research flight reports are included as Appendix E. The contain some comments on the flight procedures, records of instrumentation problems, and information on flight times and tapes for each flight. They also document how well the inertial navigation unit performed on each flight.

### *c. Program listings*

Listings for the skeleton processor are included, as Appendix D.

### *d. Soundings*

Soundings were obtained before each flight, from Kavouras weather service. The soundings closest in time and space to the flights are contained in Appendix A.

End of Attachment 9; ~~attachments~~ Appendices to attachment 9 not included.