DOE/SC-ARM-TR-235

Chilled Mirror Hygrometer Aboard Aircraft (CMH-AIR) Instrument Handbook

L Goldberger

December 2019

DISCLAIMER

DOE/SC-ARM-TR-235

Chilled Mirror Hygrometer Aboard Aircraft (CMH-AIR) Instrument Handbook

L Goldberger, Pacific Northwest National Laboratory

December 2019

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AAF	ARM Aerial Facility
ACE-ENA	Aerosol and Cloud Experiments in the Eastern North Atlantic
ADC	analog-to-digital converter
AIMMS	aircraft-integrated meteorological measurement system
ARM	Atmospheric Radiation Measurement
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
CMH	chilled mirror hygrometer
DP	dew or frost point in deg C
DQ	data quality
e	vapor pressure in millibars
es	saturation vapor pressure in millibars
G-1	Gulfstream 159 aircraft
HI-SCALE	Holistic Interactions of Shallow Clouds, Aerosols, and Ecosystems
IOP	intensive operational period
LED	light-emitting diode
LLC	limited liability company
LPM	liters per minute
mA	milliampere
NIST	National Institute of Standards and Technology
OSS	Operation Status System
P	pressure in millibars
ppm	parts per million
QC	quality control
r	mixing ration by weight in parts per million
RH	relative humidity in percent
rho	absolute humidity in g/m^3
rhos	absolute humidity at saturation
RS-232	Recommended Standard 232 for serial communication data transmission
T	temperature in deg C
Tk	absolute temperature in deg K
V	volts
VDC	volts direct current

Contents

Figures

1.0 Instrument Title

Chilled mirror hygrometer aboard aircraft (CMH-AIR):

- Instrument name is GE-1011B from General Eastern
- Newest iteration from Buck Research Instruments LLC
- Routine data name is aafdewpoint currently in the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's Data Discovery tool.

2.0 Mentor Contact Information

Lexie Goldberger
Pacific Northwest National Laboratory
Richland, Washington 99352
ph: 509-375-3610
email: lexie.goldberger@pnnl.gov

3.0 Vendor/Developer Contact Information

Buck Research Instruments LLC
PO Box 19498, Boulder, Colorado 80308
main switchboard ph: 202-442-6055
ph: 1-800-HUMIDITY
email: www.hygrometers.com

4.0 Instrument Description

This instrument is a hygrometer designed for airborne platforms that uses the chilled-mirror principle of operation. The mirror is cooled to the dewpoint temperature thermoelectrically and maintained at that temperature. The condensation on the mirror is sensed optically via a signal output voltage corresponding to the temperature of the mirror. (https://www.hygrometers.com/products/1011c/)

5.0 Measurements Taken

The instrument measures atmospheric moisture.

6.0 Links to Definitions and Relevant Information

www.hygrometers.com

7.0 Data Object Description

The routine data set named aafdewpoint contains time and dewpoint temperature only.

8.0 Data Ordering

Data may be ordered via ARM.gov Data Discovery.

9.0 Data Plots

Data plots are provided by the ARM Data Quality Office at dq.arm.gov.

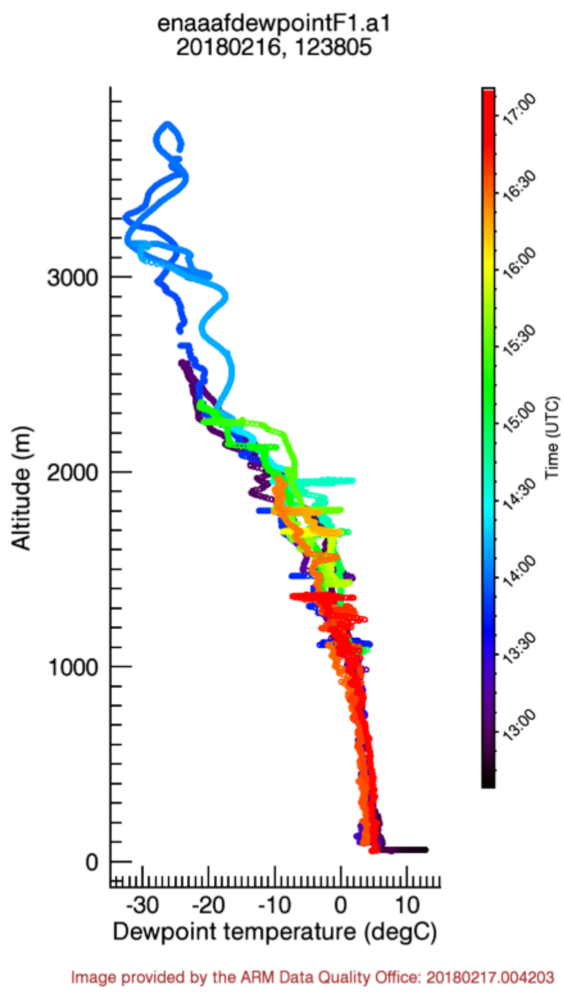

Figure 1. The altitude profile of dewpoint temperature taken from the data quality (DQ) plot browser on https://dq.arm.gove/dq-plotbrowser/.

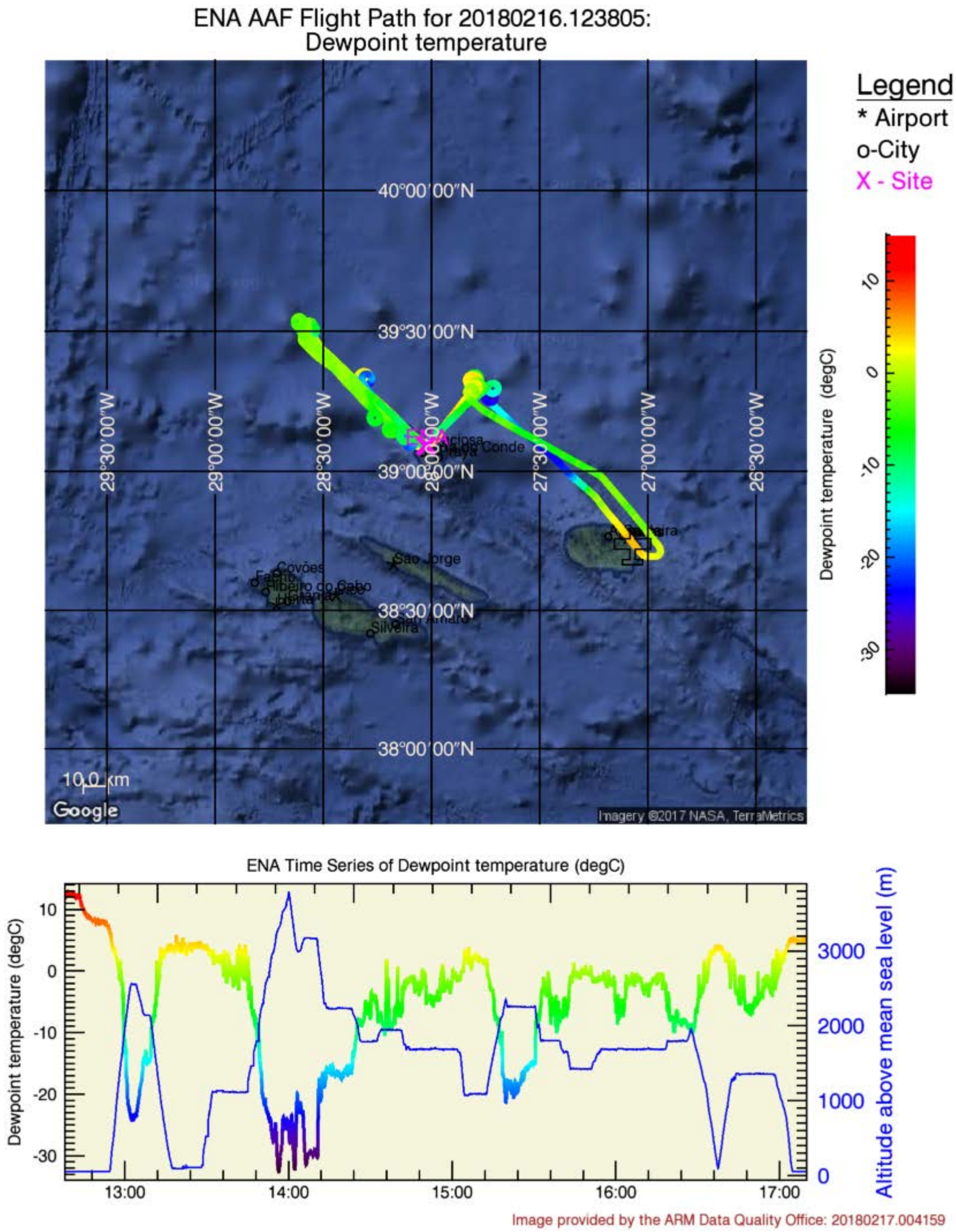

Figure 2. Map detailing dewpoint temperature from the DQ plot browser on https://dq.arm.gov/dq-plotbrowser/.

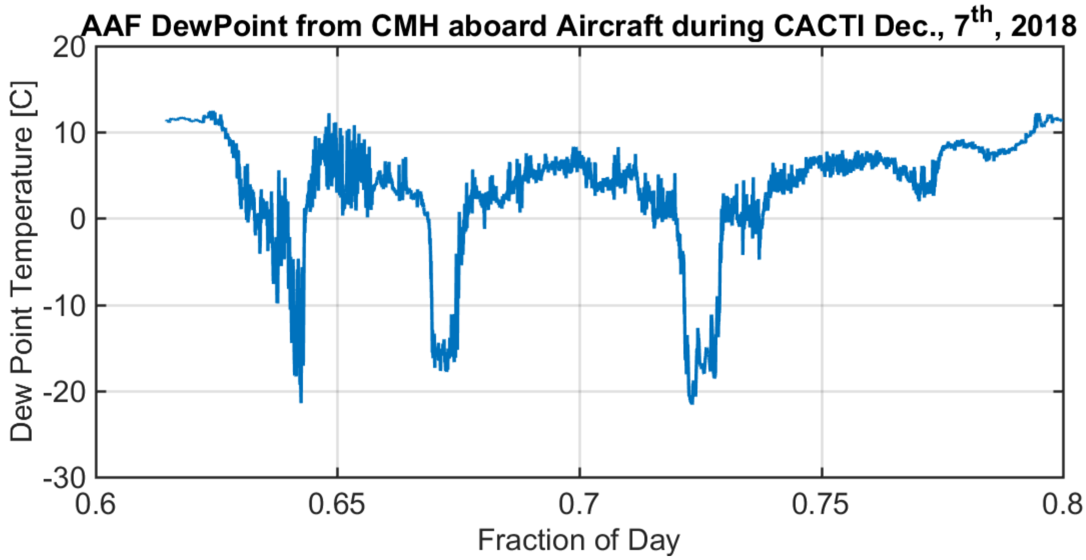

Figure 3. Time series plot made from the data available on https://adc.arm.gov/discovery/.

10.0 Data Quality

T moisture content of the air depends on relative and specific humidity, vapor mixing ratio, water vapor density, vapor pressure, and dewpoint. This data set is compared to and validated by auxiliary measurements of these variables taken by the aircraft-integrated meteorological measurement system (AIMMS) probe onboard the aircraft. Generally during level flight, the reported changes in dew/frost points should be accurate; however, responses under the following conditions should be analyzed closely: icing conditions, sudden transitions from low to high dewpoints, and aircraft descent into warm, moist air.

Data quality reports will be submitted to the ARM Data Quality Office as needed.

11.0 Instrument Mentor Monthly Summary

Data is quality controlled (QCd) by the mentor after an intensive operational period (IOP)-based field deployment before submission to the ARM Data Center. This instrument has been deployed regularly since 2016 on the following campaigns on board the G-1 aircraft without fault:

- Holistic Interactions of Shallow Clouds, Aerosols, and Ecosystems (HI-SCALE): https://www.arm.gov/research/campaigns/aaf2016hiscale
- Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA): https://www.arm.gov/research/campaigns/aaf2017ace-ena
- Cloud, Aerosol, and Complex Terrain Interactions (CACTI): https://www.arm.gov/research/campaigns/amf2018cacti

12.0 Calibration Database

This instrument is calibrated by the vendor. The latest calibration by the vendor was in August 2019. The result of this and previous calibrations are on file with AAF's Director of Engineering and are not currently in ARM's Operation Status System (OSS).

13.0 Technical Specification

The instrument is designed for operation and integration aboard an aircraft. The body and its electronics have aircraft engine noise certification and have been modified for weather.

13.1 Units

Units are in degrees Celsius.

13.2 Range

This instrument has a range of -75 to + 50 deg C, and a dewpoint depression of up to 85 deg C. Sample pressure range is 0 to 1100 mb, and the required flow rate is 0.23 to 3 liters per minute (LPM).

13.3 Accuracy

The calibration accuracy range is +/- 0.1 deg C.

13.4 Repeatability

Accuracy range is confirmed with four National Institute of Standards and Technology (NIST)-traceable standards at the following dewpoint temperatures: 11.78, 5.19, -11.74, and -27.87 deg C.

The response rate of the CMH is called the slew rate and is defined as the change in dewpoint temperature per unit of time and is typically 1 deg C/s. At lower dew points and greater difference between the mirror temperature and the housing's temperature, this rate can be reduced to minutes. At low temperatures, the reduced availability of water can result in slow crystal growth rate. To improve response time in cases like this, maximize flow over the mirror and ensure the sensor case temperature is kept as close to ambient temperature as possible.

13.5 Sensitivity

Resolution is 0.01 deg C on an RS-232 output. It is not necessary for the mirror's surface to be microscopically clean, and best performance will be a few hours after cleaning. Reduced flow rates are used to minimize the effects of contamination, for example, from sea spray in marine environments.

13.6 Uncertainty

Calibration uncertainty is +- 0.1 deg C on analog and RS-232 outputs.

13.7 Input Voltage

28 VDC

13.8 Input Values

Not applicable.

13.9 Output Values

0-10V and 4-20 mA scaleable analog outputs. Dewpoint conversion is 0.08 v/deg C, where 6v = 0 deg C.

14.0 Instrument System Functional Diagram

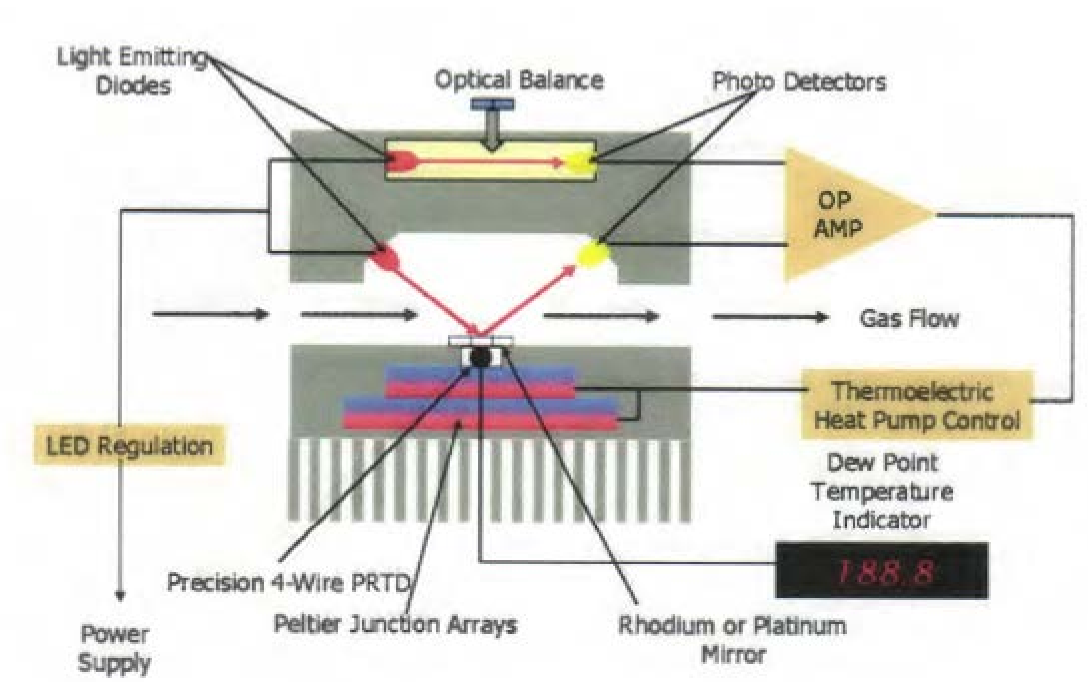

Figure 4. Original schematic provided by General Eastern: General Eastern's GE_Chilled_Mirror_Theory_Etc.pdf demonstrating how the measurement is achieved. The temperature measuring unit has been updated to an ultra-stable thermistor.

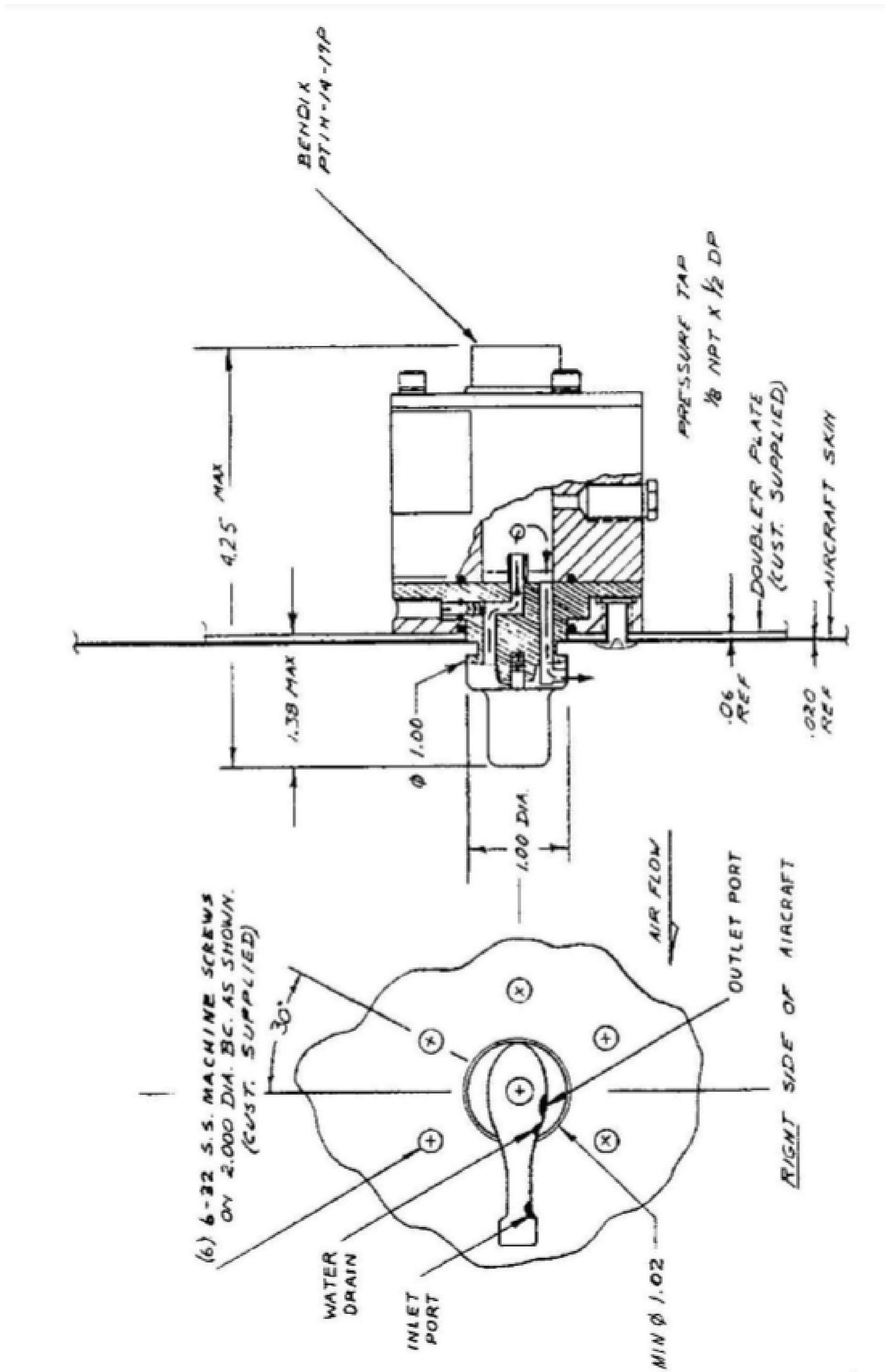

Figure 5. Schematic from 1011C-users-manual-2009-12.pdf demonstrating how the instrument should be mounted in the aircraft.

15.0 Instrument/Measurement Theory

Air is sampled via an inlet and flowed over the chilled mirror (either polished hexagonal rhodium, stainless steel, or platinum) that's temperature is controlled by a Peltier cooling module. A servo controller applies a current to the Peltier, causing the mirror to cool. An ultra-stable thermistor is imbedded in the mirror to measure temperature. The mirror is illuminated with a regulated LED and the reflected light is received by a photodiode. As water vapor condenses on the mirror as water or frost, the light measured by the photodiode is reduced due to scattering. The servo and the control system modulate the temperature of the mirror such that it maintains a constant rate of condensation and evaporation of water molecules and mass of water on the mirror is constant. The temperature of the mirror is, by definition, equal to the dew or frost point temperature. The temperature is measured with an analog-to-digital converter (ADC) that is calibrated each time the instrument is turned on and is not susceptible to drift like the analog electronics.

The vapor pressure formulations used in the development of this instrument are described in Buck et. al. 1981.

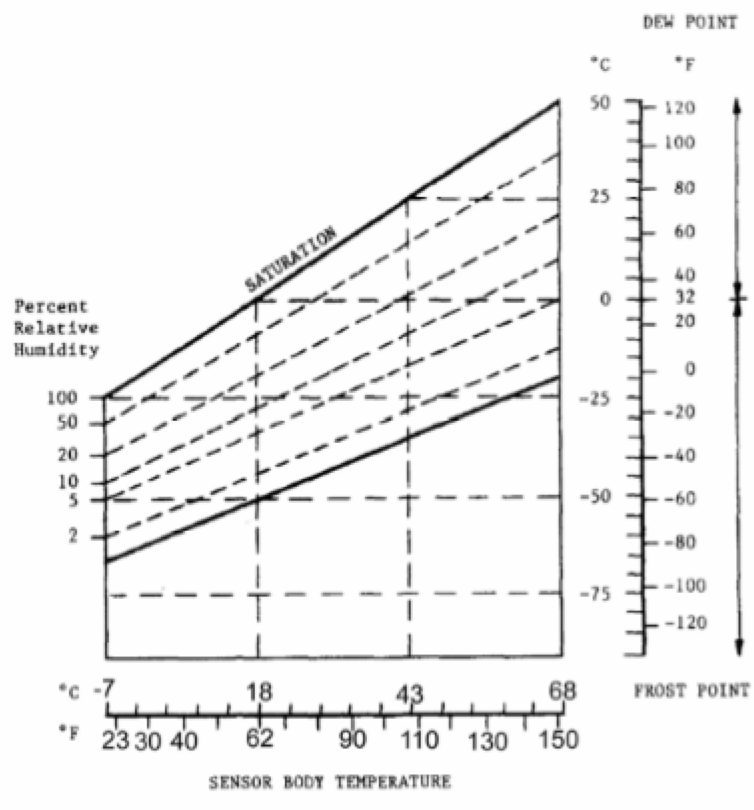

Figure 6. Depression capability for instrument. Dewpoint depression is the minimum dew point temperature to which a chilled mirror can operate in a given ambient temperature. Reducing the CMH's temperature allows lower dew points.

Saturation vapor pressure (es) = f1(T) = e/RH

Dew/frost point = f2(e) = f2[r X P/(622 e3 + r)] = f2(RH x f1(T) / 100) = f2(rho x Tk/216.7)

Vapor pressure = f1(DP) = r x P(622 x 10e3 + r) = RH x f1(T)/100 = rho x Tk/216.7

Mixing ratio = (18.02 / M.W. of gas) x 10^6 x e/(P-e)

Relative humidity = 100 x f1(DP)/f1(T)

Absolute humidity = 216.7 x f1(DP)/Tk

16.0 Setup and Operation of Instrument

Figure 7. Photos of the hygrometer.

16.1 Setup

The instrument has four separate parts: a sensing unit, a control/indicator unit, a power unit and associated cabling, and a maintenance unit. There are three modes of operation. In position “Dew Point”, operations are normal, allowing the system to maintain an equilibrium condensation layer on the mirror. When powering up in this position it will start a balance cycle. In “Max Cool” it applies full cooling current to the thermoelectric cooler. This is useful to determine if the system can operate normally at very low frost points and to convert any supercooled water deposits to frost. In position “Balance”, a balance cycle is started, heating the mirror to 40 deg C to evaporate all condensation from the mirror. For operations, the function switch should be in the “Dew Point” position.

The D/F Point LED lights up once the unit has stabilized on a dew or frost point. The rebalanced LED lights up while a balance is being performed. If the light does not shut off, it indicates mirror contamination and the mirror needs cleaning. The service mirror LED flashes when the mirror is too contaminated for operation and requires immediate cleaning.

For setup, the sensing unit comes with an inlet fitting that includes inlet, exhaust, and water drain ports and is designed for either the left or right side of the aircraft. The manufacturer has determined that shock mounts are not necessary for aircraft operations. There is an optional aspirating kit that provides airflow through the sensor when the aircraft is not in flight or in the lab, though a sampling pump can be used as well to provide airflow over the sensor.

For initial setup, the inlet should be placed where the sensor pressure is near static pressure. Leak-check the instrument by attaching a pump and flowmeter to the pressure tap on the sensor body and lowering the pressure inside the sensor as much as possible to check for leaks (the flow rate should not change).

16.2 Operation

For operations, the data can be collected either as analog or via serial with 9600 Baud. Turn the instrument on and set to “Dew Point”.

Operating Limits

- Operating temperature range
  - Sensing unit: -80 to +60 °C
  - Control/indicator unit: -40 to +60 °C
  - Power unit: -40 to +60 °C
- Airspeed (nominal): 450 knots
- Altitude (nominal): 45,000 feet
- Pressure limit: 1.5 atmospheres

17.0 Software

Connect the instrument to a computer running HyperTerminal via the RS-232 output. Once the balance has been completed, there will be a 1 in the third position of the line once dew or frost points are being output, otherwise this value is 0.

18.0 Calibration

Unit dewpoint temperature calibrated to four NIST-traceable standards and found to have an uncertainty of +/- 0.10 deg C. The NIST-traceable calibration equipment checked the humidity standard, temperature standard, voltage standard, and pressure standard. The humidity standards were a DewPrime 1 made by Edgetech and a CR-3 Cryogenic Hygrometer made by Buck Research Instruments. The temperature standard was a Platinum RTD by the manufacturer Logan. There were two 34401A voltage standards by Agilent and Hewlett Packard respectively. The pressure standard was a DPI-740 by Druck.

19.0 Maintenance

Perform periodic inspections of the system annually and before campaigns. Check for damage on cables, connectors, o rings, gaskets, front panel switches, system optics, and mounting hardware. Clean, lubricate, and replace any damaged parts found.

For cleaning the optics system:

1. Remove the four screws from the top of the sensor and set lid aside.
2. Unscrew the two screws holding optics block on using supplied ball driver and lift out optics block, exposing mirror.
3. Clean the mirror using supplied cotton swab moistened with an approved solvent, such as acetone followed by water. A few light swipes are sufficient; use only enough solvent to wet and clean the mirror. The maintenance kit consists of bottles for water and acetone, cotton swabs, and spare gaskets and o rings.
4. Reassemble the sensor by replacing optics block and lid.
5. Rebalance the CMH.

Return the instrument to the vendor for NIST calibrations.

20.0 Safety

Make sure no cabling is damaged and that all cabling is properly plugged in before turning the instrument on. Always visibly inspect the system components.

21.0 Citable References

Buck, AL. 1981. “New equations for computing vapor pressure and enhancement factor.” *Journal of Applied Meteorology* 20(12): 1527−1532, https://doi.org/10.1175/1520-0450(1981)020<1527:NEFCVP>2.0.CO;2

Buck Research Instruments LLC. 2009. 1011C Chilled Mirror Aircraft Hygrometer Brochure.

Buck Research Instruments LLC. 2009. Model 1011C Hygrometer Operating Manual.

General Eastern Instruments. 1987. Model 1011B Dew Point Hygrometer for Aircraft Preliminary Operating Manual. Revision A.

General Eastern Instruments. 2006. GE_Chilled_Mirror_Theory_Etc.pdf

www.arm.gov

U.S. DEPARTMENT OF ENERGY

Office of Science