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THE WC-130 METEOROLOGICAL SYSTEM AND ITS UTILIZATION IN OPERATI--ETC(U)

AUG 80 R S HENDERSON

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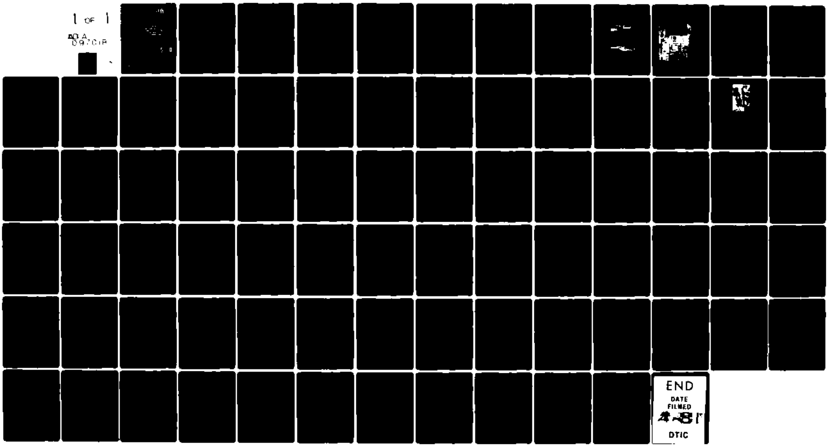

AWS/TR-80/002

THE WC-130 METEOROLOGICAL SYSTEM AND ITS UTILIZATION IN OPERATIONAL WEATHER RECONNAISSANCE

Rodney S. Henderson, Capt, USAF

August 1980

Approved For Public Release; Distribution Unlimited

AIR WEATHER SERVICE (MAC)
Scott AFB, Illinois 62225

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This report discusses the U.S. Air Force WC-130 weather reconnaissance system. It starts with a brief history of weather reconnaissance, then describes the Air Force WC-130 weather reconnaissance system including descriptions of the instrumentation used. The discussion of data dissemination and quality control is followed by discussion of the applications of weather reconnaissance in watching tropical cyclones and in weather modification.

PREFACE

The U.S. Air Force has conducted weather reconnaissance operations in many areas of the world for several decades. Despite the variety of missions flown by weather reconnaissance units and the worldwide scope of weather reconnaissance operations very little has been published regarding weather reconnaissance equipment, operations, and procedures in the general form most suitable for introducing these subjects to individuals who have not had previous exposure to them. The general lack of knowledge among meteorologists regarding Air Force weather reconnaissance has been a major source of concern within the operational weather reconnaissance units, especially when members of those units must work with "customers" who have only a limited understanding of the capabilities and limitations of the weather reconnaissance forces. Preparation of this report was undertaken as an attempt to introduce individuals newly-arrived in the weather reconnaissance units to some of the aspects of their new duties, to provide background material for the "customers" of weather reconnaissance operations, and, hopefully, to encourage interest in obtaining more detailed information on Air Force weather reconnaissance among potential "customers" and among Air Weather Service personnel who are considering applying for weather reconnaissance duty.

Development of this report began with a series of training publications developed at Keesler AFB under the auspices of Major Fred Foss, 920th Weather Reconnaissance Group and Captain Gibson Morris, Det 5, HQ Air Weather Service (AWS). Preparation of the initial and final draft did not occur until over a year later during January 1978. The report has also been developed in partial satisfaction of the requirements of a remote sensing meteorology course at Texas A&M University. Submission of the final draft to HQ AWS and the subsequent reviews by HQ AWS personnel took place during May and June 1978. Therefore, the information in this report is current as of that date.

The contributions of Major John Pavone, HQ AWS, Major James F. Shunk, Air Force Global Weather Central, (AFGWC) and Majors Bruce Ackert and Eugene Heald are gratefully acknowledged. Dedications are unusual in survey reports of this type; nevertheless, this report is respectfully dedicated to the crew of Swan 38, 54th Weather Reconnaissance Squadron, Andersen AFB, Guam.

Capt R. S. Henderson

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Chapter 1

INTRODUCTION

Hurricanes have played significant roles in the history and development of mankind. On one of his voyages, Christopher Columbus lost six ships from his fleet when they were sunk by a hurricane which struck their anchorage in Isabella Harbor. Columbus was on the only ship which survived the hurricane—the Nina. In 1889, German naval forces shelled some American property in Apia, Samoa. While warships of the United States, Great Britain, and Germany were confronting each other and preparing for battle, Samoa was hit by a hurricane. The American and German warships were sunk by the hurricane, the British ship Calliope managed to escape by steaming out of the storm's way, and an impending war was averted by the resultant lack of ships for doing battle! In 1900 more lives were lost in a single day than have been lost in some of mankind's many wars when 6000 people were killed by the storm that devastated Galveston Island in Texas (Cole, 1973).

In more recent time, Admiral William Halsey ran into a full-blown typhoon in the Pacific Ocean about 500 miles from the island of Luzon in the Philippines on 17 December 1944. Halsey lost about 800 men, 3 destroyers, and 146 aircraft in seas whipped by the 150 MPH winds of the typhoon (Cole, 1973). Halsey's forces tangled with yet another typhoon later on in the war with slightly less disastrous results. In 1969 Hurricane Camille killed 300 people and caused more than a billion dollars in damage along the Gulf Coast of the United States (Sheets, n.d.). The list of devastating tropical cyclones gets longer and longer with each passing year as their destructive effects impact on the lives of thousands of people in many lands. The destructive potential of these storms is awesome and the stories of their devastation have become legion, but relatively little is known about the U.S. Air Force's humanitarian role in helping to mitigate the destructive effects of these storms through a continuing hurricane and typhoon reconnaissance effort. Even less is known about the equipment and methods used by the men and women who routinely fly into some of the most vicious killers in nature's realm.

On 27 July 1943, Major Joe Duckworth flew a propeller-driven, single-engine North American AT-6 Texan trainer into the eye of a tropical cyclone. Major Duckworth flew into the eye of the cyclone twice that day, once with a navigator and again with a weather officer, in what are generally considered to be the first airborne attempts to obtain storm data for use in plotting the position of a tropical cyclone as it approached land (Doherty, 1977). Duckworth's pioneering efforts have developed over the years into the tropical cyclone reconnaissance mission of the U.S. Air Force's weather reconnaissance units.

Today, three Air Force weather reconnaissance squadrons fly Lockheed WC-130 aircraft on a wide variety of missions ranging from tropical cyclone reconnaissance to routine weather tracks off the coasts of the United States. Each squadron is supported by trained weather personnel in special Air Weather Service (AWS) detachments who fly aboard the aircraft as crew members in accomplishing weather reconnaissance operations in many different parts of the world. The knowledge, skill, and experience of these individuals are combined with the professional skills and abilities of the other crew members to form a highly competent team capable of conducting reconnaissance operations on a worldwide basis.

One of the primary reasons for preparing this report is to provide basic information on Air Force weather reconnaissance equipment, procedures, and typical operations for the use of individuals who are interested in such information but do not require the sort of detailed information provided in many of the weather reconnaissance regulations and technical publications. This "general overview" of WC-130 weather reconnaissance capabilities, equipment, and operations should be regarded as a simple introduction to the small but very active world of Air Force weather reconnaissance.

Chapter 2

THE WC-130 WEATHER RECONNAISSANCE SYSTEM

General Configuration of the Aircraft

In this decade, the workhorse of the Air Force weather reconnaissance fleet has been and continues to be the Lockheed WC-130 Hercules. Adapted for the weather reconnaissance role from transport and rescue versions of the C-130, the majority of the WC-130 aircraft in current use are of the WC-130E or WC-130H versions (the last remaining WC-130B is a specially-modified aircraft carrying an advanced weather reconnaissance system).

The WC-130 is an all-metal, four-engine, high-wing monoplane with retractable tricycle landing gear. The WC-130's Allison T-56 turboprop engines drive four-bladed Hamilton Standard full-feathering, reversible-pitch propellers at over 1000 revolutions per minute (RPM). The fuselage is divided into the cargo compartment and the flight station or flight deck by a bulkhead at the forward end of the cargo compartment. Normal access to the aircraft is obtained through a crew entrance door near the nose of the aircraft, a paratroop door on either side of the aircraft fuselage aft of the wing, or a cargo-loading ramp and door at the rear of the cargo compartment beneath the tail. Figure 1 illustrates the general configuation of the WC-130E and the WC-130H and the difference in their external appearances. Figure 2 shows the instrument layout at the Aerial Reconnaissance Weather Officer (ARWO) flight deck panel.

WC-130's carry a basic crew of six: pilot, co-pilot, flight engineer, navigator, aerial reconnaissance weather officer (ARWO), and dropsonde system operator. Flight deck positions are provided for five crew members (pilots, flight engineer, navigator, and ARWO), and a crew position for the dropsonde system operator is provided in the cargo compartment near the right paratroop door. An additional crew position is normally provided on WC-130E aircraft for a special equipment operator (SEO) when he is required for atmospheric sampling operations. H-model WC-130's were adapted from rescue-configured aircraft and retain the scanner's positions (and windows) in the cargo compartment aft of the bulkhead. Figure 3 is an internal arrangement drawing of a WC-130H and illustrates the locations of the crew positions and some of the equipment inside the aircraft.

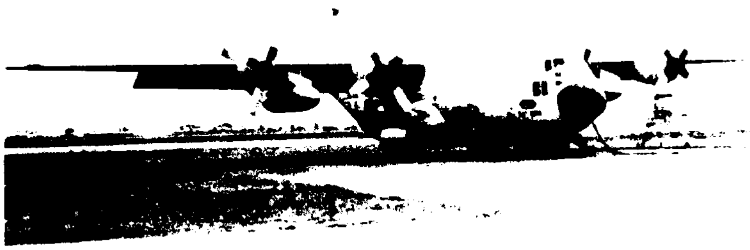
Meteorological systems aboard WC-130 aircraft are normally considered to be part of the Horizontal Meteorological System or part of the Vertical Meteorological System. Generally, the Horizontal Meteorological System consists of the instrumentation and support equipment utilized by the ARWO on the flight deck and the Vertical Meteorological System consists of the equipment and instruments used by the dropsonde system operator in preparing soundings obtained from dropsondes released by the aircraft. Additional equipment is installed as necessary for weather modification operations and special missions.

The Horizontal Meteorological System

Most of the present meteorological system on the WC-130E was installed under Project SEEK CLOUD after Hurricane Camille struck the Gulf Coast in August 1969. The meteorological system was intended to be an interim improvement in sensor capability but has now been in use for several years. The system later installed on WC-130H aircraft is basically a SEEK CLOUD system also. A prototype of a more advanced data acquisition system is the Airborne Weather Reconnaissance System (AWRS) presently installed on a WC-130B. The expense of the AWRS and lack of an inexpensive follow-on system make it likely that the present, aging SEEK CLOUD system will remain in use for some time with only minor modifications. There are some relatively minor differences in the Horizontal Meteorological System as installed on the WC-130E and the WC-130H. Table 1 lists system components and differences between versions of the aircraft.

a. AN/AMQ-28 Total Temperature System. The Rosemount AN/AMQ-28 Total Temperature System provides total air temperature information consisting of the free-air temperature and a small amount of friction-generated temperature. System components and their location in the aircraft are listed in Table 1. Figure 4 is a simplified block diagram of the AN/AMQ-28 Total Temperature System. System controls consist of an on/off switch and a deice switch.

The AN/AMQ-28 uses a resistance element mounted in an external probe in such a manner that frictional effects are minimized and are negligible at the WC-130's low operating airspeeds. The total temperature resistance signal from the probe forms one leg of a resistance bridge whose output is used to drive the indicator (USAF, 1974). The resistance value displayed on the motor-driven



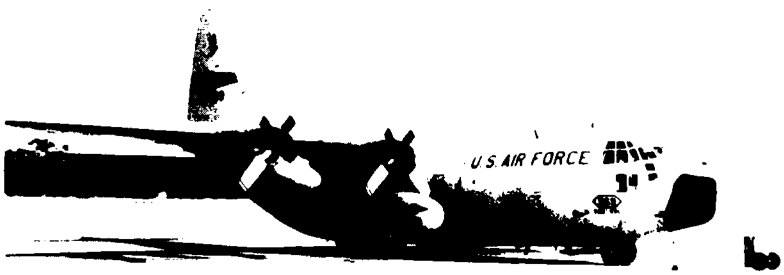
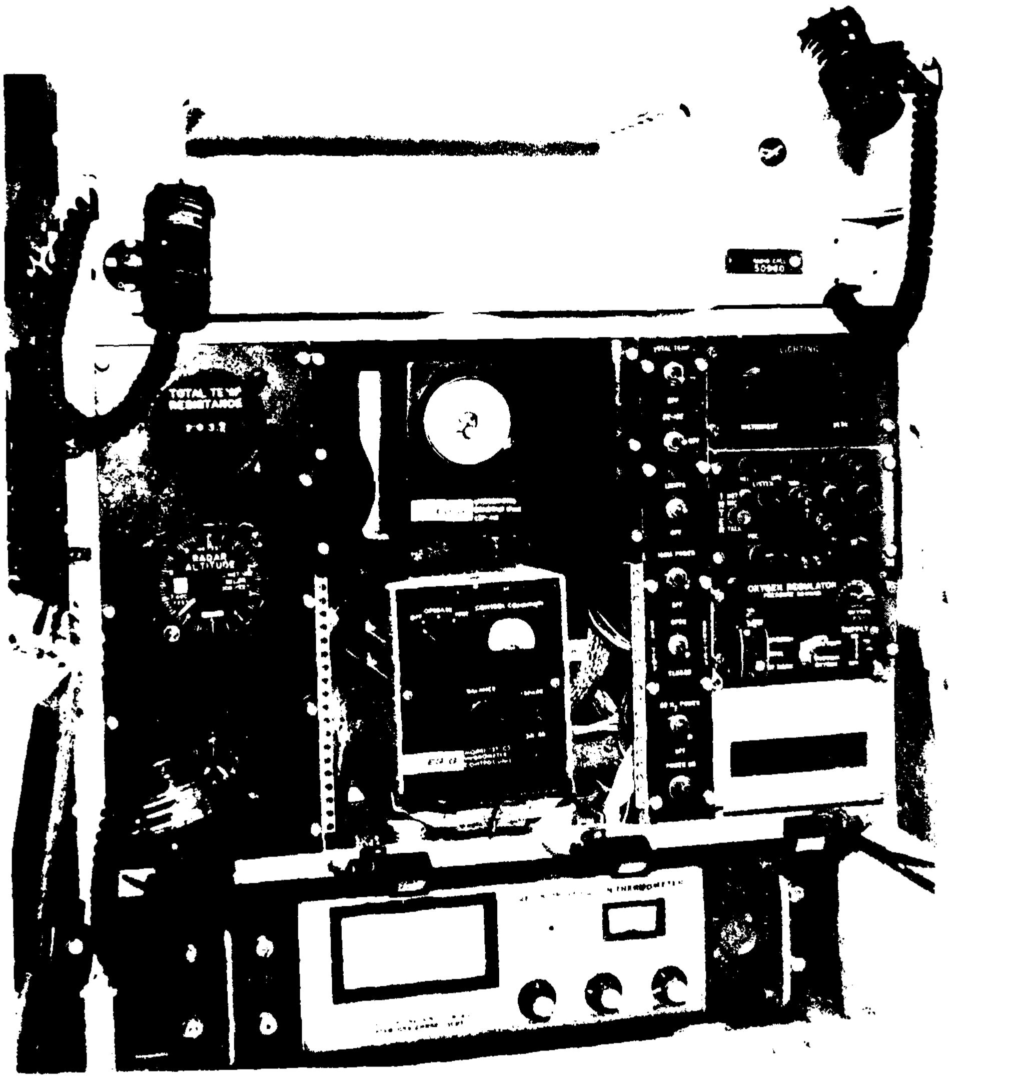


Figure 1. A WC-130E from the 54 WRS Parked on the Ramp at Clark AB, Republic of the Philippines (top photo) and a WC-130H from the 920 WRG at Keesler AFB, Mississippi (bottom photo). Note the U-1 Foil Assembly on the fuselage side ahead of the propeller warning stripes on the WC-130E.


TOTAL TEMP RESISTANCE
RADAR ALTITUDE
OXYGEN REGULATOR

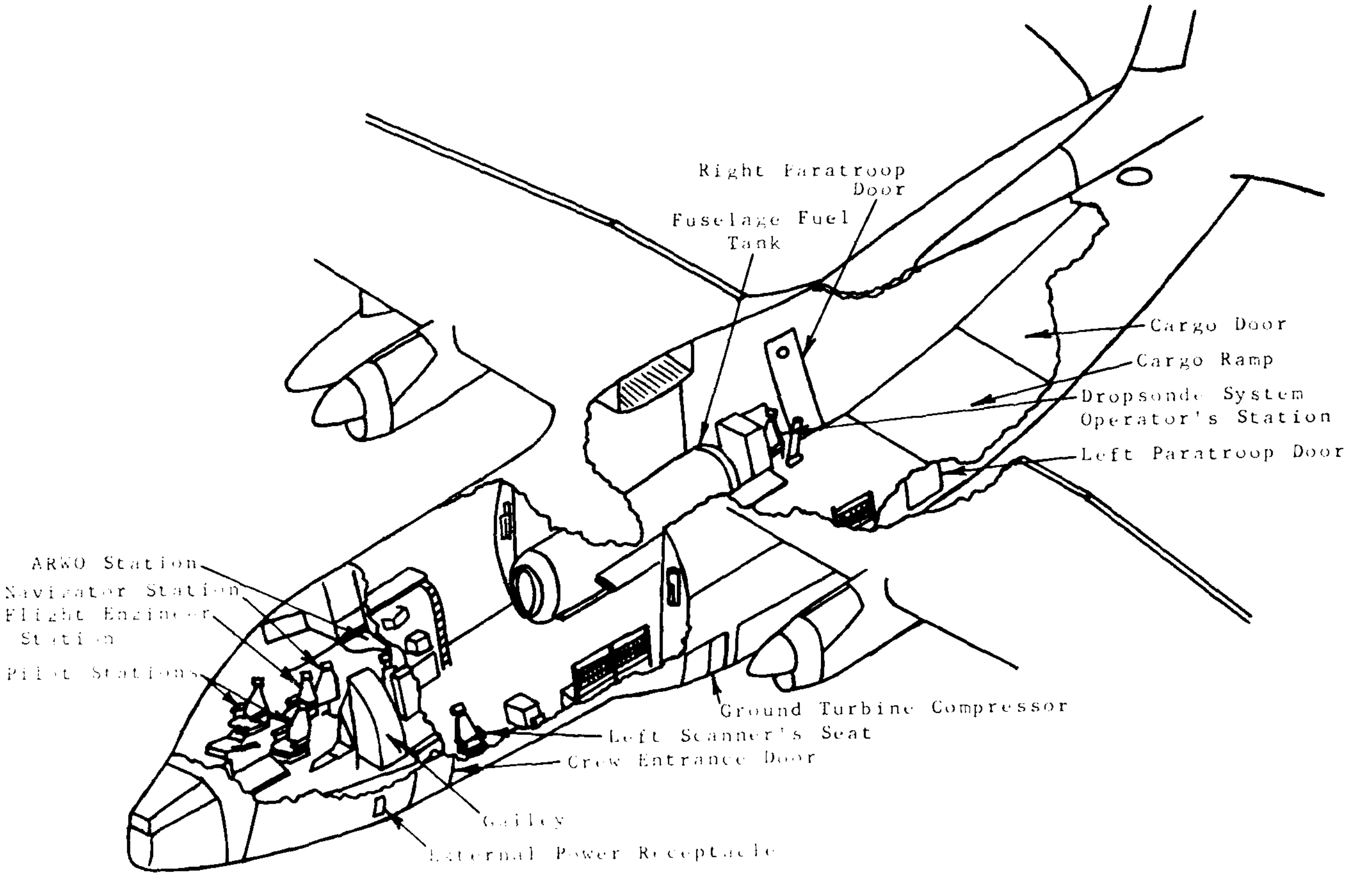


Figure 3. Internal Arrangement Drawing - WC-130H Fuselage.

TABLE 1. THE WC-130 HORIZONTAL METEOROLOGICAL SYSTEM.

PARAMETER SENSED	SUBSYSTEM	WC-130E	WC-130H	SUBSYSTEM COMPONENTS	LOCATION IN THE AIRCRAFT	POWER REQUIREMENTS
Atmospheric Pressure	1301A Pressure Transducer System (Copilot's pitot-static system)	Yes	Yes	Rosemount 1301A Pressure Transducer	WC-130E-shelf on rt fuselage near the ARE console in the cargo compartment WC-130H-shelf behind rt scanner's seat	115V, 400 Hz
				Newport Labs 2000-3 Digital Voltmeter	ARWO flight deck panel	115V, 60 Hz
	MA-1 Pressure Altimeter (Copilot's pitot-static system)	Yes	Yes	N/A	WC-130E-ARWO flight deck panel WC-130H-navigator panel	None
	AIMS Pressure Altimeter (Pilot's pitot-static system)	Yes	Yes	N/A	Pilot's instrument panel	Not avail. from references used
Atmospheric Temperature	Rosemount AN/AMQ-28 Total Temperature System (Requires TAS *from nav panel* for normal use)(Backup capability using C-3 OAT guage on nav panel)	Yes	Yes	ID-1121 Indicator	ARWO flight deck panel	115V, 400 Hz
				AM-3716 Amplifier J-2164 Interconnection Box	Electronics rack beneath the flight deck	
				ML-598 Temperature Sensor	External fuselage forward of the crew entrance door	
Atmospheric Dew Point	Cambridge Systems AN/AMQ-34 Aircraft Hygrometer System	Yes	Yes	137-C3 Control Unit	WC-130E-rack beside ARWO flight deck panel WC-130H-ARWO flight deck panel	115V, 400 Hz
				137-MR Readout Unit	ARWO flight deck panel	
				137-S10P Sensor Assembly	Rt fuselage side at fuselage station 300	
Absolute Altitude	AN/APN-42A Radar Altimeter	Yes	Yes	Receiver/Transmitter (R/T Unit)	Beneath the cargo floor aft of the main landing gear and above the antenna	115V, 400 Hz 28VDC

TABLE 1. WC-130 HORIZONTAL METEOROLOGICAL SYSTEM (Cont'd).

PARAMETER SENSED	SUBSYSTEM	WC-130E	WC-130H	SUBSYSTEM COMPONENTS	LOCATION IN THE AIRCRAFT	POWER REQUIREMENTS
				Antenna	Undersurface of the aircraft aft of the main landing gear and forward of the paratroop doors at fuselage station 610	
				Electronic Control Amplifier	Electrical equipment rack beneath flight deck	
				Height Indicator	ARWO flight deck panel	
	SCR-718 or AN/APN-133 Radio Altimeter	Yes	No	Receiver/Transmitter BC-788 (SCR-718) 529 (AN/APN-133)	Equipment rack beneath flight deck	115V, 400 Hz
				Indicator Unit I152E or D (SCR-718) I152E (AN/APN-133)	ARWO flight deck panel	
				Antennae 4 AT-505/AP (SCR-718) 2 AT-913 (AN/APN-133)	SCR-718: 2 antennae in a fiberglass panel under the aircraft behind the nose landing gear and 2 in a fiberglass panel between the main landing gear wells AN/APN-133: 1 antenna in each of the fiberglass panels	
	Pilot's Backup Altimeter (Backup system on WC-130H)	Yes	Yes	N/A	N/A	Not available from references used
Sea-Surface Temperature	Barnes Engineering Co. PRT-5 Precision Radiation Thermometer	Yes	Yes	Optical Unit	Forward undersurface of the aircraft inside the fuselage aft of the nose landing gear	115V, 400 Hz or NiCad batteries if the conversion has not been made
				Electronics Unit	ARWO flight deck panel	
				Solenoid-actuated Shutter	Undersurface of the aircraft beneath the optical unit	28VDC

TABLE 1. THE WC-130 HORIZONTAL METEOROLOGICAL SYSTEM (Cont'd).

PARAMETER SENSED	SUBSYSTEM	WC-130E	WC-130H	SUBSYSTEM COMPONENTS	LOCATION IN THE AIRCRAFT	POWER REQUIREMENTS
--	Ancillary Equipment:					
	17500A Strip Chart Recorders	Yes	No	N/A	ARWO flight deck panel	115V, 400 Hz
	6111A Power Suppliers	Yes	No	N/A	2 in pedestal at ARWO station and 2 in overhead equipment rack in cargo compartment	115V, 400 Hz
	CV-1393/AMQ-19 Synchro Assembly	Yes	No	N/A	Upper forward cargo compartment near 6111A power supplies	115V, 400 Hz $\pm$ 2.5VDC from 6111A's
	Hewlett-Packard HP-97 Programmable Calculator	Yes	Yes	N/A	ARWO station	--

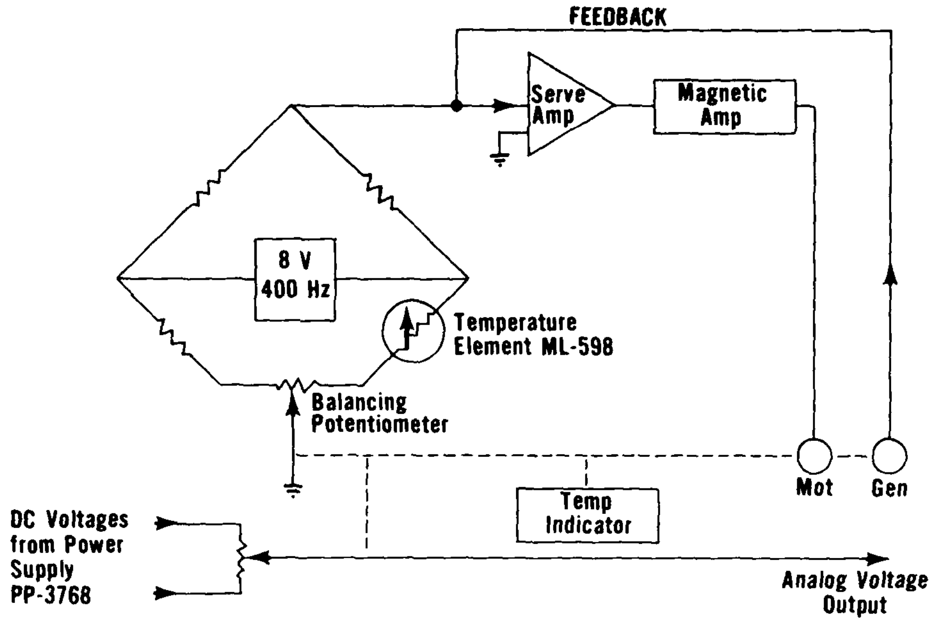


Figure 4. Simplified AN/AMQ-28 Block Diagram.

indicator is converted to a temperature by using a table of resistances versus true air speeds (TAS). A limited deice capability is provided to remove ice accumulations from the total temperature probe. The probe must be fully aspirated to provide reliable temperature indications. The AN/AMQ-23 is one of the simpler and more reliable meteorological systems aboard the aircraft.

b. AN/AMQ-34 Dew-Point Hygrometer. Flight-level dew point is obtained from the Cambridge Systems AN/AMQ-34 Aircraft Hygrometer System. The system provides a direct readout of atmospheric dew point in degrees Celsius on an indicator at the ARWO position. System components and their location in the aircraft are given in Table 1. Figure 5 is a simplified block diagram of the AN/AMQ-34 Dew-Point Hygrometer System (EG&G, n.d.). All operator controls for the system are mounted on the face of the control unit.

Functionally, the AN/AMQ-34 operates as two independent subsystems. One subsystem controls a mirror which has its temperature at the dew point and the other subsystem measures the mirror temperature. Both subsystems work together to measure and indicate the dew point of the air sample within the probe.

The dew-point control subsystem consists of a thermoelectric dew-point hygrometer and its control circuitry. In operation, an incoming air sample is directed into the dew-point hygrometer chamber which consists of a thermoelectric cooling module containing a mirror surface and an optical sensing subsystem. The cooling module utilizes the Peltier Effect and is sometimes referred to as a cooler. The optical sensing subsystem consists of a solid-state light source, two photoresistors, a control preamplifier, and a power output circuit. Light emanating from the solid-state source is reflected by the mirror to one photoresistor (called the direct photoresistor) while light controlled by the bias from the light source is detected by the other photoresistor (referred to as the bias photoresistor). The photoresistors feed signals to the control preamplifier and the power output circuit.

When power is first applied to the system, the mirror surface of the cooling module is normally dry and at the ambient temperature of its environment. The signals fed by the photoresistors to the control preamplifier and power output circuit cause current to flow to the cooling module which in turn reduces the mirror temperature until condensation occurs on the mirror surface. Condensation on the mirror surface scatters the light that had been reflected to the direct photoresistor while the light available to the bias photoresistor increases due to the same scattering. The resulting imbalance is detected by the control preamplifier which then reduces the amount of current to the

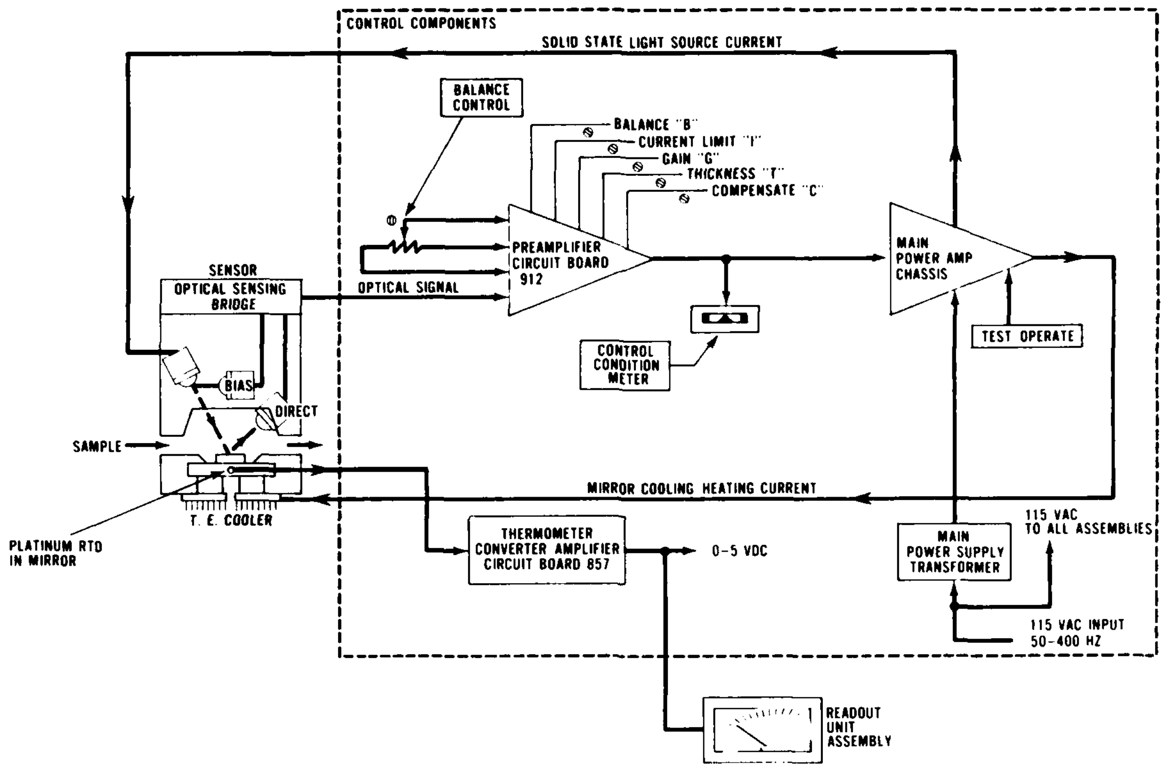


Figure 5. Simplified AN/AMQ-34 Block Diagram.

cooling module resulting in a subsequent increase in mirror temperature. This operation is continued until a constant dew layer thickness is maintained on the mirror surface in equilibrium with the partial pressure of the water vapor in the air sample. When the system is properly adjusted and aspirated, the temperature of the mirror corresponds to the dew point (or frost point) of the air sample.

The mirror temperature measuring subsystem consists of a bridge circuit and a platinum resistance thermometer embedded in the mirror surface. The resistance of the thermometer forms part of the bridge circuit so that any variation in mirror temperature has a corresponding influence on the voltage output of the bridge. The voltage output of the bridge is proportional to the dew point and is transmitted to the readout unit where it is displayed directly as dew point in degrees Celsius (EG&G, n.d.).

Two basic operator controls are provided: the Function Switch and the Balance Control. The Function Switch is a four-position switch with three positions marked OFF, OPERATE, and TEST and an unmarked position which provides maximum current to the cooling module. In the OFF position all power is removed from the system. In the OPERATE position the entire system is powered and the readout unit indicates mirror temperature (dew point of the air sample). In the TEST position the readout unit continues to indicate mirror temperature but the servo feedback loop is interrupted resulting in an increase in mirror temperature until the condensate is removed from the mirror surface. When the condensate has been removed, the Balance Control is adjusted to maximize the output of the control preamplifier.

The Balance Control is a potentiometer which, in effect, allows proper alignment of the optical dew-detection system when the Function Switch is in the TEST position. In the TEST mode, if the reading on the Control Condition Meter on the face of the control unit cannot be set to a centerline value (0.5 ma) by adjusting the Balance Control, then the indicated dew point in the OPERATE mode is unreliable (EG&G, n.d.). This inability to "balance" the hygrometer normally results when the mirror surface is contaminated or when the optical components are misaligned.

The Control Condition Meter indicates the "control condition" of the mirror surface and provides a means of checking system operation. Maximum current to the cooling module will result in a Control Condition Meter reading in the upper portion of the scale. Reduction in cooling current results in a lower reading. The final indication of the Control Condition Meter with the system in the OPERATE mode will be in the 0.1- to 0.3-ma range for a small amount of cooling (high relative humidity) and in the 0.5- to 0.85-ma range for large amounts of cooling (low relative humidity) (EG&G, n.d.). In the OPERATE mode the Control Condition Meter indicates between 0.1 to 0.85 ma for a reliable dew-point indication.

The AN/AMQ-34 is a fairly sophisticated system compared to the other SEEK CLOUD sensors on the aircraft. The system must be balanced and aspirated to obtain an accurate free-air dew point. The sampling rate of the AN/AMQ-34 is a compromise between a high rate which results in a rapid response and a low rate which reduces mirror thermal load and gives a low rate of contaminant buildup on the mirror surface (EG&G, n.d.). Because of the compromise flow rate, the air sample in the hygrometer chamber is not fully representative of the ambient conditions at the instantaneous aircraft position but represents conditions at some point close behind the aircraft on the aircraft flight path. For semihomogeneous atmospheres this situation does not present any serious operational problems. Rapid fluctuations in moisture content along the flight path, however, cause variations in the dew-point indication as the AN/AMQ-34 attempts to adjust to a stable condition. Saturation conditions (rain showers, etc.) may produce dew-point indications that are warmer than the ambient temperature while in "dry" atmospheres the system may be unable to determine a dew point (the Control Condition Meter indication will be greater than 0.85 ma). For all its relative complexity, however, the AN/AMQ-34 is generally regarded as one of the more reliable SEEK CLOUD systems when it is properly maintained.

c. <u>1301A Pressure Transducer System.</u> The 1301A Pressure Transducer System is currently the primary meteorological altimeter on Air Force WC-130 aircraft. The system is composed of a Rosemount 1301A Pressure Transducer and a Newport Labs 2000-3 Digital Voltmeter with associated wiring and plumbing to connect the voltmeter to the transducer and the transducer to the pressure source. Controls consist of a switch to provide power to the transducer (H-model only, the transducer is powered whenever the Main AC Bus is powered on E-model aircraft) and a switch which provides 60 Hz electrical power to systems such as the 2000-3 Digital Voltmeter which requires 60 Hz power for normal operation. The "Record Power" switch on the WC-130E supplies 60 Hz power to the 2000-3 and other equipment on that aircraft.

The 1301A Pressure Transducer contains a capacitive pressure-sensing capsule employing a "free edge" diaphragm and generating a variable capacitance value which is proportional to sensed pressure. The capacitance change with pressure is converted to a high-level DC voltage by signal conditioning circuitry within the transducer. The 2000-3 voltmeter displays this voltage in a direct readout of the pressure value in millibars and tenths.

The pressure source for the 1301A is the co-pilot's pitot-static system with the pressure transducer tapped into the static port tubing on the aircraft. The flush-mounted static ports on the WC-130 are located low of the fuselage ahead on the propeller warning stripe and are well within the boundary layer airflow around the fuselage. The 1301A requires periodic laboratory calibration and system drifts with time are not uncommon. Since the 1301A output is temperature dependent, resistive heaters are provided within the transducer to maintain close control of the temperature of the capacitive capsule and critical circuit components. Insufficient warm-up prior to launch or failure of the resistive heating elements may produce erroneous readings. For that reason, considerable care is exercised during the preflight phase of a mission to assure 1301A warm-up and to evaluate 1301A readings. The aging, logistically unsupportable 1301A will be replaced by the Garrett Airesearch Digital Pressure Encoder by the end of CY '78.

The drift observed in the readings from meteorological altimeters and the compatibility of pressure-height data derived from these altimeters and the absolute altimeters is the subject of a later section in Chapter 3. Many of the inaccuracies inherent in the systems, the operational environment, and the standard used for height data comparisons can be reduced by an effective historical calibration program as discussed later.

d. <u>AN/APN-42A Radar Altimeter.</u> Two basic quantities are required for height of standard pressure surface and D-value computations over the open ocean: The pressure heights of the sensor platform (or ambient pressure at the sensor platform altitude which can be converted to a standard day pressure height) and the absolute altitude of the sensor platform above the ocean surface. In operational weather reconnaissance, pressure heights are determined using standard pressure altimeters set at 29.92 inches of Mercury or by converting the readings from the 1301A to a pressure height value. Absolute altitudes are obtained from radar or radio altimeters. The primary meteorological absolute altimeter on WC-130 aircraft is the AN/APN-42A Radar Altimeter. The components of the AN/APN-42A and their location in the aircraft are given in Table 1.

The radar altimeter measures the distance between the aircraft and the terrain (or sea surface) below the aircraft by determining the time delay between transmitted pulses of radar energy and their reflected components which return to the aircraft. All controls necessary for the operation of the AN/APN-42A are located on the height indicator at the ARWO position. A switch on the upper right corner of the indicator turns the system on and off and has a center standby position in which the system components are powered but the receiver/transmitter (R/T) unit is not transmitting. A calibration knob on the lower left corner of the indicator is used for zeroing the altimeter system in flight.

The height indicator has a circular scale graduated from 0 to 1000 feet in increments of 10 feet. A counter in a window located to the left center of the indicator needle displays the thousands value of the altitude. Under some failure conditions and when the system is off or in standby, a "fail" flag is displayed in the altitude window. A window in the lower portion of the indicator displays a flag indicating the operating mode of the system: ON, OFF, or STANDBY.

The AN/APN-42A is subject to some minor operating limitations which normally do not interfere with its use on operational missions. The system requires a 2-minute warm-up period in standby prior to use and should not be operated below 200-feet altitude to preclude damaging the system. Height indications from the AN/APN-42A may be unreliable over large depths of snow and ice (USAF, 1974). It is possible to misread the altimeter if the counter in the thousands window has not completely rotated with a minor change in altitude, but this condition is not normally a problem since computation checks tend to easily show the thousand-foot error in height of standard pressure surface values.

AN/APN-42A failures tend to attract more attention than failures of other components of the Horizontal Meteorological System since heights of standard pressure surfaces are key elements in weather reconnaissance observations and these height values cannot be determined without an absolute altimeter. WC-130H aircraft currently lack a backup (or secondary) absolute altimeter capability (for meteorological purposes) above 1500 feet. WC-130E aircraft, however, have the SCR-718 or AN/APN-133 radio altimeter for backup absolute altitude indication if the AN/APN-42 fails. If the SCR-718 or AN/APN-133 fails or is unusable and the AN/APN-42A has failed then all capability for determining the heights of standard pressure surfaces is lost on the WC-130E.

e. AN/APN-133 or SCR-718 Radio Altimeter. WC-130E aircraft have a secondary absolute altimeter installed at the ARWO position on the flight deck. The secondary absolute altimeter is either an SCR-718 or an AN/APN-133 Radio Altimeter. The SCR-718 and AN/APN-133 are basically similar altimeter systems and determine the absolute height above terrain by the same time-delay method used in the AN/APN-42A. All controls necessary for the operation of these altimeters are located on the face of the indicator unit at the ARWO position. Table 1 lists system components and their location in the aircraft.

Height determination is made using a J-scan display on the face of a cathode ray tube (CRT) in the indicator unit. The display is in the form of a base circle with two lobes on the outside of the circle. One lobe is referred to as the reference lobe and remains relatively stationary throughout the operating profile. The other lobe is referred to as the reflected lobe and moves around the base circle to indicate absolute altitude (which is read off the "lower" edge of the lobe). Zeroing the altimeter is performed prior to flight by aligning the "lower" edge of the reference lobe (the reflected and reference lobes merge on the ground) with the zero mark on the circular scale on the face of the CRT. The scale divisions correspond to 0 to 5000 feet at 50-foot intervals in the "times one" mode and from 0 to 50,000 feet in the "times ten" mode. Movement of the reflected lobe around the base circle is continuous so that an indication of 3000 feet in the "times one" mode may actually represent some value corresponding to a multiple of 5000 feet plus 3000 feet (such as 8000, 13000, 18000, 23000, or 28000 feet). It can be readily seen that the possibility of misreading the instrument is always present, especially when under the pressure of operational reconnaissance missions. Separate controls are provided for zeroing the display in the two modes and mode selection is made using a toggle switch on the indicator unit.

The operating frequency of the SCR-718 places geographic limits on its use in order to avoid interfering with other radio facilities. The geographic limits are normally waived to a limited extent for weather reconnaissance operations but may hamper operations within a certain radius of Eglin AFB, Florida; Thule, Greenland; Clear Mews, Alaska; and within a certain distance from the land mass of Great Britain (USAF, 1974). This geographic limitation does not apply to the AN/APN-133 since it operates at a frequency that is different from that of the SCR-718.

The SCR-718 and AN/APN-133 are normally very reliable instruments but are not considered to be as accurate as the AN/APN-42A and are more difficult to read. At higher altitudes, the reflected lobe may disappear even at high-gain settings due to a "weak" receiver section. "Fuzzy" or indistinct reference or reflected lobes may render the altimeter unusable. These failures are rare, however, and have not significantly diminished the reliability of the altimeters over the course of many WC-130E operations. All WC-130E's and H's will be configured with the AN/APN-133 by the summer of 1979.

f. PRT-5 Precision Radiation Thermometer. To provide the capability of determining sea-surface temperature, a Barnes Engineering Company PRT-5 Precision Radiation Thermometer has been installed on the WC-130. Components of the PRT-5 are listed in Table 1 (Barnes Engineering Co., 1970). A simplified block diagram of the PRT-5 is given in Figure 6. The PRT-5 determines the temperature of an external target by continuously comparing the amount of energy emitted by the target in the 9.5- to 11.5-micron wavelength band with that emitted by an internal, temperature-controlled reference environment within the optical unit. The electronics unit processes this comparison into a voltage which is directly related to the energy difference between the target and the reference environment. This voltage is displayed in terms of equivalent black body temperature on a meter in the front of the electronics unit (Barnes Engineering Co., 1970). The optical unit in the aircraft is pointed down through a shuttered opening in the forward undersurface of the fuselage. A rain shield ahead of the opening protects the optical unit from debris and water thrown back by the nose landing gear.

Precision and stability are achieved in the PRT-5 by using a very sensitive, hyper-immersed thermistor bolometer as the radiation detector. The bolometer and the optical elements are mounted in the tightly controlled temperature-reference cavity within the optical unit.

Operation of the PRT-5 requires that the reference cavity reach and maintain its normal operating temperature of 45°C. The cavity temperature rises at a rate of approximately 10°C per minute after the PRT-5 is turned on. Approximately 3 minutes are required for warm-up from normal "room temperature" (it is worth noting that the temperature inside an aircraft parked on an open ramp is seldom "room temperature") (Barnes Engineering Co., 1970).

All controls for operating the PRT-5 are located on the face of the electronics unit with the exception of a switch which operates the solenoid-actuated shutter over the opening in the fuselage. The shutter-actuating switch is mounted on the switch panel at the ARWO position. The PRT-5 can be operated over three temperature ranges but normally only the medium range from -10°C to +40°C is calibrated for operational use. A function switch is used to select the operating mode of the PRT-5 (ON, OFF, BATTERY TEST, or FAST CHARGE) but amounts to little more than an on-off switch on units that have been converted to operate off aircraft power and that have had their NiCad batteries replaced by capacitors. A bandwidth switch selects the bandwidth of recorder output signals if a recording system is used.

Radiation emitted from the target (sea surface) arrives first at an optical chopper in the optical unit which alternately blocks the radiation and passes it to the detector in the temperature-controlled cavity so that the detector effectively "sees" itself and the target alternately. The detector produces an output signal proportional to the difference between the radiation received from the target and its own temperature-controlled environment. The output signal from the detector is applied to a preamplifier and than transmitted to the electronics unit. In the electronics unit, the signal is processed through a bandpass filter into a postamplifier. The output of the postamplifier is coupled to a demodulator which produces a DC voltage related in magnitude and polarity to the difference between the target and reference temperatures. The DC voltage is then applied across the output meter which is calibrated to indicate target temperature directly in degrees Celsius (Barnes Engineering Co., 1970).

The PRT-5 is a very reliable instrument when properly maintained and calibrated. In operational use, sea-surface temperatures from the PRT-5 are inaccurate when the surface is obscured by fog, thick haze, or cloud, or if the aircraft is operating above 1750 feet absolute altitude. A less common operational limitation occurs when the shutter will not open due to solenoid failure or inability of the solenoid to open the shutter at airspeeds greater than about 135 knots.

g. Secondary Pressure Altimeters. On all WC-130E and H airplanes, secondary pressure altitude data are obtained from the pilot's AIMS counterdrum-pointer aneroid pressure altimeter set at 29.92 in. Hg. On the specially modified WC-130B AWRS aircraft, a standard MA-1 aneroid pressure altimeter installed at the auxiliary ARWO position and set at 29.92 in. Hg is used as the secondary pressure altimeter for use in pressure height computations.

Aneroid pressure altimeters are subject to a number of errors including those resulting from hysteresis and friction, temperature, readability, static system leakage, nonlinearity, and the installation of the altimeters. As with the 1301A, much of the resultant error in computations using these altimeters can be reduced by an effective historical correction program. Hysteresis and friction errors in the AIMS altimeter are reduced by a built-in vibrator inside the instrument case (9WRW, 1975).

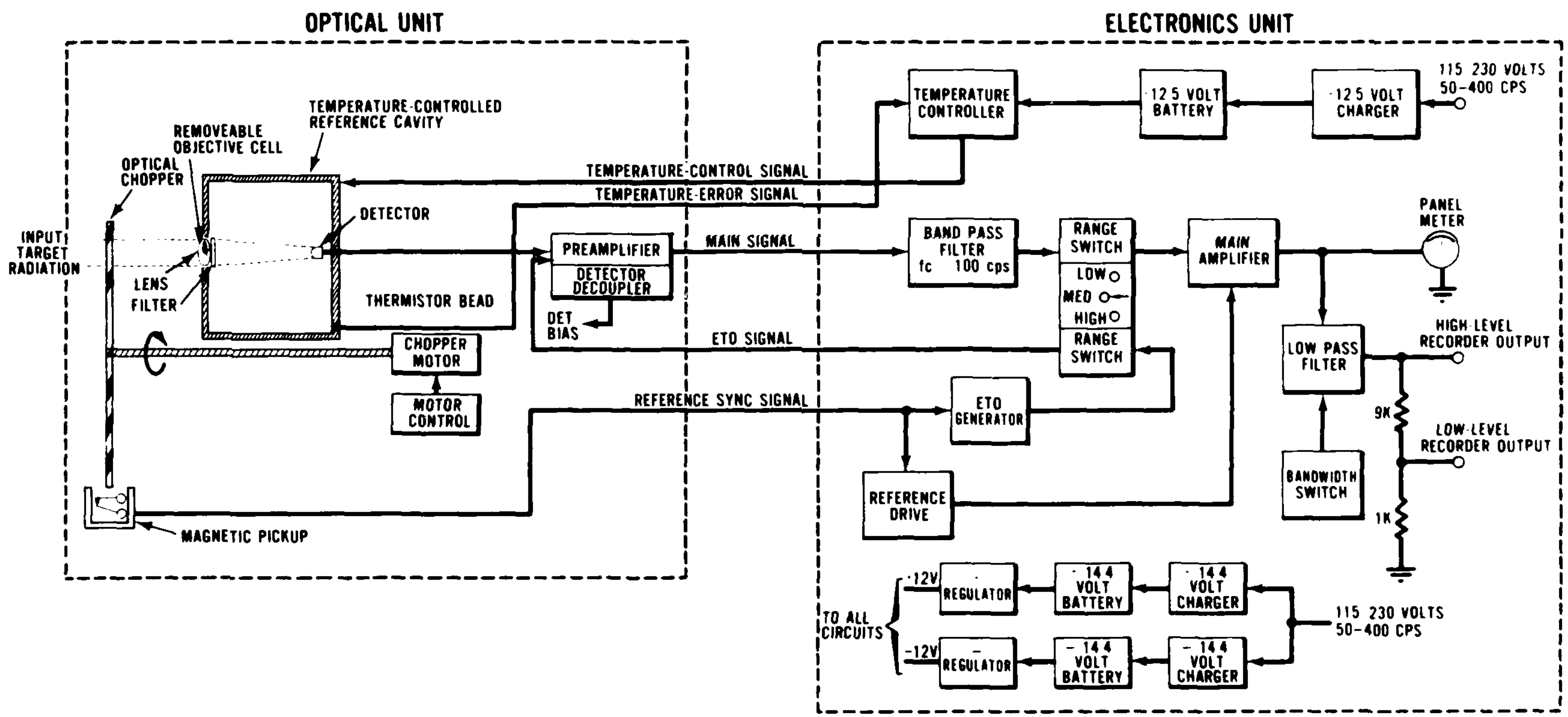


Figure 6. Simplified PRT-5 Block Diagram.

h. Hewlett-Packard HP-97 Programmable Calculator. A welcome addition to the Horizontal Meteorological System is the Hewlett-Packard HP-97 calculator which became available for use in weather reconnaissance units in 1977. The use of these calculators has greatly improved the speed and accuracy with which routine computations of meteorological parameters can be made using the raw data from the Horizontal Meteorological System sensors. The calculators are programmable and can be used for the calculations involved in both horizontal and vertical observations.

i. Ancillary Equipment and Circuit Protection. Three Hewlett-Packard 17500A Strip Chart Recorders were installed at the ARWO position during the SEEK CLOUD modification to record the output of the 1301A, the AN/APN-42A, the dew-point hygrometer, the Total Temperature System, and the PRT-5. The strip chart recorders are not used at present since a valid requirement for the data and the necessary customer support have not developed.

Four Hewlett-Packard 6111A Power Supplies are provided on WC-130E aircraft. Two 6111As are located in the overhead equipment rack in the cargo compartment and two in the pedestal beside the ARWO position on the flight deck. The flight deck 6111As are used to provide an offset voltage to the AN/APN-42A strip chart recorder input and to condition the 1301A strip chart recorder input. The two cargo compartment 6111As provide DC inputs to the CV-1393/AMQ-19 Synchro Assembly.

The CV-1393/AMQ-19 Synchro Assembly receives synchro output signals from the AN/APN-42A and converts them to an analog DC voltage related to radar (absolute) altitude. Output from the synchro assembly is offset as necessary by the appropriate flight deck 6111A power supply.

The equipment listed in this section thus far is related to the recording of various parameters on the 17500A Strip Chart Recorders and is of small consequence as long as the recorders remain unused. Current maintenance support allocated to the strip chart recording system due to the lack of an operational requirement makes it unlikely that many of the recorders are capable of operation. WC-130H aircraft do not have any of this recording equipment installed as part of the Horizontal Meteorological System.

A limited backup absolute altitude capability is currently provided on the WC-130H by using the pilot's radar altimeter at 1500 feet and below. The pilot's radar altimeter on the WC-130H is calibrated in the historical calibration program along with the other altimeters and has been used on operational missions when the AN/APN-42A failed and low-level data were required.

Additional equipment located at the flight deck ARWO position includes an interphone panel and cord, an oxygen regulator and hose, and a lighting system. A small shelf table is provided for preparing observation forms and to support checklists and reference tables.

Circuit protection for electrical equipment is provided by fuses within the equipment and/or by circuit breakers located on various circuit breaker panels in the aircraft (primarily on the flight deck). Loss of engine-driven generators or other electrical problems may require turning off some or all of the meteorological equipment in order to reduce electrical loads.

The Vertical Meteorological System

The Vertical Meteorological System is designed to collect pressure, temperature, and relative humidity (dew-point depression when coded in an observation) in a sounding between the aircraft and the surface. The Vertical Meteorological System consists of the AN/AMQ-29 Dropsonde Data Recording System, AN/AMT-13 Radio Dropsonde, MX-9133/AMQ-31 Radiosonde Dispenser (and control panel), HP-9100B Calculator (replaced by the HP-97 on 920 WRG aircraft), and the Unitron Frequency Converter. For convenience, all equipment except the AN/AMT-13 has been grouped under the AN/AMQ-29 system in most discussions and in Table 2 of this report. The AN/AMT-13 Radio Dropsonde is released from the aircraft and transmits sounding data back to the aircraft as it falls through the atmosphere. Dropsondes are normally released over open ocean areas due to their mass and fall rate.

The Vertical Meteorological System installed on the WC-130 was pieced together from usable components of the AN/AMQ-19 meteorological system from the WB-47 and the AN/AMQ-25A meteorological system from the WC-135B along with new Hewlett-Packard systems. The R-1196 sonde receiver from the AN/AMQ-19 was the departure point from which the current system was pieced together. The C-8804 Power Vertical Subsystem Control Panel came from the AN/AMQ-25A. The result of the piecing together of new and old components is the AN/AMQ-29 Dropsonde Data Recording System and the other components of the Vertical Meteorological System. Components of the Vertical Meteorological System and their functions are listed in Table 2.

The Unitron Frequency Converter is not exclusively part of the Vertical Meteorological System. Normal aircraft power on the WC-130 is 115V, 400-Hz AC, and 28V DC. The Unitron takes normal aircraft 400-Hz power and converts it to the 115V, 60-Hz power which is required for the normal operation of some of the meteorological systems on the aircraft.

TABLE 2. THE WC-130 VERTICAL METEOROLOGICAL SYSTEM.

SUBSYSTEM	SUBSYSTEM COMPONENTS	FUNCTION	POWER REQUIREMENTS
AN/AMT-13 Radio Dropsonde	N/A	A cylindrical radiosonde which, when dispensed from the aircraft, transmits temperature, relative humidity, pressure, and ref. signals.	18VDC from self-contained batteries
AN/AMQ-29 Dropsonde Data Recording System	MX-9133/AMQ-31 Radiosonde Dispenser	Used to arm the dropsonde and eject it from the aircraft. The dropsonde is locked in place in the chamber assembly, armed by a plunger (or manually), and ejected by spring force released electrically or by the gate valve lever on the base of the dispenser.	28VDC
	Unitron Frequency Converter	Provides 115V, 60 Hz power to equipment requiring 60 Hz power for normal operation.	115V, 400 Hz
	AT-896 Antenna	A quarter-wave stub antenna designed for operation at a nominal frequency of 403 MHz. Acts as a receiving surface for the dropsonde signal.	N/A
	R1196/AMQ-19 Radiosonde Receiver	Receives the signals transmitted by the dropsonde. Supplies the signals to the recording components and provides an audio signal for intercom monitoring at the dropsonde system operator's console.	115V, 400 Hz
	C-8804/AMQ-25A Power Vertical Subsystem Control Panel	Controls on this panel permit energizing the equipment, selecting the operating mode, and tuning the receiver when the manual mode is selected.	115V, 400 Hz 28 VDC
	Hewlett-Packard 5332A Preset Controller/Counter	Receives and counts electrical events and provides output signals to the electronic counter when preset values are reached.	115V, 400 Hz
	Hewlett-Packard 5216A Electronic Counter	Makes the time period average measurements and transmits them to the digital recorder (printer).	115V, 400 Hz
	Hewlett-Packard 562ARC10 Digital Recorder (Printer)	Provides a printed record of digital input information received from the electronic counter. The recorder also converts the digital input to an analog voltage and outputs this voltage to the strip chart recorder.	115V, 60 Hz
	Hewlett-Packard 7128A Strip Chart Recorder	Provides a strip chart record of four parameters: pressure, temperature, relative humidity, and low reference.	115V, 60 Hz

TABLE 2. THE WC-130 VERTICAL METEOROLOGICAL SYSTEM (Cont'd).

SUBSYSTEM	SUBSYSTEM COMPONENTS	FUNCTION	POWER REQUIREMENTS
	Hewlett-Packard 3310A Function Generator	Provides a calibration signal to the 7128A strip chart recorder.	115V, 400 Hz
	Hewlett-Packard 9100B Programmable Calculator (See Note)	A programmable desk-top calculator with a simple memory enabling storage of instructions and data for repetitive operations. Programs used to reduce data from the AN/AMT-13 are recorded on magnetic cards and read into the calculator using a built-in magnetic card reader. Use of the calculator eliminates many of the steps required in manual data reduction and speeds sounding preparation considerably.	115V, 60 Hz
	Manual Pressurization/Depressurization Control Panel	Provides a means of controlling the pressurization of the dispenser.	N/A
	Dropsonde Storage Bin	Provides storage for 15 dropsondes.	N/A

NOTE: The HP-9100B has been replaced by the HP-97 on 920 WRG aircraft and is expected to replace the 9100B on aircraft in the active duty squadrons as well.

The 7128A Strip Chart Recorder can be used to provide a record of pressure, temperature, relative humidity, and low reference signals received from the dropsonde. The recorder is not used at present but is retained with the system.

Most of the equipment in the Vertical Meteorological System is located at or near the dropsonde system operator's position in the cargo compartment near the right paratroop door. The Unitron Frequency Converter is located in the overhead equipment rack forward of the wing carry-through structure in the WC-130E and on a shelf behind the right scanner's seat on the WC-130H. The antenna for the receiver is located on the undersurface of the aircraft near the dispenser chute. Additional equipment at the dropsonde system operator's console includes an oxygen regulator and hose, an interphone panel and cord, and a work table next to the console. Figure 7 is a photograph of the equipment installation at the dropsonde system operator's console in a WC-130H.

The Atmospheric Sampling System (Atmospheric Research Equipment)

WC-130E aircraft are equipped for particulate and gaseous atmospheric sampling operations using systems designated as Atmospheric Research Equipment (ARE). ARE aboard the WC-130E consists of an ARE console, two U-1 Foil Systems, one I-2 Foil System, a whole air sampling system, a sphere case rack, and an air cooling assembly for the air sampling pressure system (AWS, 1973). ARE is operated by SEOs on sampling missions.

a. P-System (Gaseous Whole Air Sampling System). The P-system is a whole air sampling system designed to compress air samples obtained from the engine bleed air system through the transfuselage bleed air duct just forward of the wing carry-through structure in the cargo compartment. The compressed air samples are stored in spherical bottles under pressure. The P-system is composed of three major components: a pressure platform with four 115V, three-phase AC compressors, each supply two individually-selected 900-cubic inch spheres; a control panel located on the ARE console; and engine bleed air source plumbing, filters, valves, and other hardware. The compressors and storage spheres are mounted in a pressure platform secured to the cargo floor at the forward left side of the cargo compartment. Through the P-system and the air-cooling assembly, engine bleed air is cooled, corrected to sea-level atmospheric pressure, compressed, and stored in the eight storage spheres in the pressure platform (AWS, 1973).

b. Air Cooling Assembly. The air cooling assembly is located overhead and forward of the wing carry-through structure in the cargo compartment. Engine bleed air is cooled in the assembly before being compressed and stored in the storage spheres (AWS, 1973).

c. Sphere Case Rack. This rack is installed on an as-required basis and provides secure in-flight storage for an even number of sphere cases up to a total of 18 (USAF, 1974).

d. U-1 Foil System (Particulate Air Sampling System). The U-1 Foil System is a universal, "record-changer" type, particulate air sampling system. It is designed to filter slipstream air through a filter paper ring-grid assembly approximately 16 inches in diameter. These filters are changed automatically so that 12 possible sample papers can be provided. WC-130E aircraft are configured to accept two removable U-1 Foil Assemblies with one mounted on either side of the forward fuselage.

Each U-1 Foil Assembly consists of both an automatic and manual filter changer assembly, a duct assembly, a duct sealing mechanism, an inlet air-control mechanism, and 12 filters. A pressure-sealed cowling contains the foil systems and a control panel is mounted on the cargo compartment cover. The automatic filter changer inserts and removes one of the 12 filters from the duct as controlled from the ARE console. The manual filter changer holds one filter which must be manually inserted and removed from the duct. Pressure-sealed panels are provided to cover the fuselage openings when the U-1 foils are removed (AWS, 1973) (USAF, 1974).

e. I-2 Foil System. The I-2 Foil System is a manually-changed particulate air sampling system designed to filter slipstream air through a 4.5-inch diameter filter paper screen assembly. The filters are changed manually by the SEO and enable the SEO to monitor collected samples and select flight paths to maintain contact with samples of interest.

The I-2 Foil System is composed of a three-section foil assembly with gate valves and actuators, a heater with rheostat, a control panel on the ARE console, and removable screen assemblies. The air intake duct of the foil assembly extends forward and through the right side of the fuselage and boundary layer and is directed straight ahead into the relatively undisturbed slipstream outside the boundary layer. The exhaust duct extends aft and through the fuselage. The I-2 Foil System is located next to the ARE console on the forward right side of the cargo compartment (AWS, 1973) (USAF, 1974).

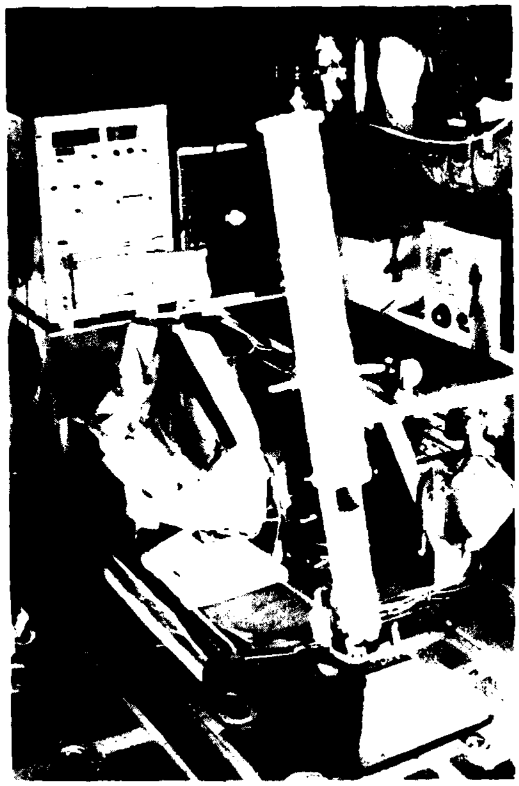


Figure 7. Dropsonde System Operator's Console on a 920 WRG WC-130H. Note the dropsonde dispenser in the open position in the foreground of the photograph. A dropsonde is positioned in the lower portion of the dispenser chamber.

f. Atmospheric Research Equipment (ARE) Console. The ARE console contains controls for the operation of the sampling systems, the rate-meter systems, an interphone panel with cord, an oxygen regulator with hose, a lighting system, an extendable writing table, and a seat for the SEO. All fuses and circuit breakers for ARE systems are mounted on the console. A filter frame on the console provides storage for 12 I-2 foil filters and storage is also provided for two monitoring probes. The console platform is bolted to the floor on the right side of the cargo compartment forward of the right main landing gear well.

The rate-meter system on the ARE console is a B-400A Dual Channel Count Rate Meter System designed to detect and display low intensity radiation levels. Data collected by the B-400A is recorded on a Rustrak recorder assembly on the ARE console. Monitoring probes are located in the U-1 and I-2 foil assemblies.

General Performance Characteristics of the WC-130

The performance of an aircraft is a function of many variables and may even vary among individual aircraft of the same type and model. Some of the variables which have to be considered in determining aircraft performance include: ambient temperature; aircraft weight; fuel type, quantity, and distribution; atmospheric density; length of available runways; aircraft trim; aircraft configuration (gear up, gear down, flaps, no flaps, etc.); atmospheric turbulence;

flight-level winds; and a host of other variables. The following performance figures for the C-130H are taken from Green (1969), and are generally applicable to the WC-130H (without considering the additional fuel capacity provided by the WC-130H fuselage fuel tank):

Maximum Cruising Speed	385 MPH (334K)
Normal Cruising Speed	340 MPH (295K)
Initial Climb Rate (at 155,000 lbs.)	1880 FPM
Range (maximum payload):	2430 miles
Range (maximum fuel and 20,259 lb. payload)	4780 miles

The problem with cut-and-dried figures like those given above is that they are misleading when viewed in the context of normal day-in-and-day-out weather reconnaissance operations. WC-130 operations are conducted over a wide range of altitudes from low levels (around 1500 feet and below) to around 30,000 feet (approximately 300 mb). Airspeeds at the standard levels flown on weather reconnaissance missions are selected to provide continuity between instrument calibrations from mission to mission on individual aircraft. The following lists a typical (but not exclusive) range of operating airspeeds (which is subject to change) at various altitudes:

Altitude (Feet)	True Airspeed (TAS) Range (Knots)
1,500 (absolute)	190-230
4,780 (850 mb)	220-240
9,880 (700 mb)	200-250
18,290 (500 mb)	260-290
23,570 (400 mb)	270-300
30,070 (300 mb)	270-310

Range and endurance are two of the factors which enter into most of the planning for weather reconnaissance missions. These two factors are heavily dependent on aircraft weight, fuel quantity, type, and flow rates, aircraft configuration, flight levels and winds at those levels, and, from an operational standpoint, the duty status of the crew. Normal weather reconnaissance missions typically last 11 to 13 hours and may cover in excess of 3500 miles. Maximum time-on-station in area-type reconnaissance operations usually depends on flying time to and from the area and the flight levels required in the area.

Conclusion

The WC-130 weather reconnaissance aircraft is a specially adapted version of its cargo-hauling and rescue cousins. The meteorological systems on the WC-130 were installed in WC-130B and WC-130E aircraft after Hurricane Camille devastated the Gulf Coast and represented a reasonable interim improvement in WC-130 capability while awaiting the development and deployment of an advanced system. The lack of a viable follow-on system and an increasing shortage of spare parts coupled with the age of instruments which date to early 1960's technology and much earlier (the SCR-718 was in use during World War II) is increasing the difficulty of providing data of the density and quality demanded on many missions. Current system performance peaked some time ago and it is uncertain how long that peak performance level can be maintained.

Chapter 3

UTILIZATION OF THE WC-130 WEATHER RECONNAISSANCE SYSTEM

The central concept in aircraft weather reconnaissance operations is to place a manned sensor platform in the atmosphere at the time, place, and altitude requested by a "customer," to collect data according to the customer's requirements, and to relay those data to the customer in a usable coded form as rapidly as possible. The requirement for the data is normally critically constrained by time considerations and it must be regarded as a highly perishable commodity on most missions. To provide Air Force resources for furnishing weather reconnaissance support to military and other government agencies, three main organizational structures have been established within the weather reconnaissance forces.

Weather Reconnaissance Organizational Structure

The history of weather reconnaissance forces is marked by rapid changes in organizational structure. Since 1973 at least five major organizational changes have occurred within the Air Force weather reconnaissance forces ranging from the deactivation of a squadron of WB-57s to establishment of an Air Force Reserve weather reconnaissance organization. Since organizational change is a way of life in weather reconnaissance, any effort to produce other than a temporary guide to weather reconnaissance organization is a difficult undertaking and is doomed to eventual failure, at least in part.

Current operational Air Force weather reconnaissance is performed by Military Airlift Command (MAC) and Air Force Reserve (AFRES) units. Active duty weather reconnaissance units are assigned to the Aerospace Rescue and Recovery Service (ARRS) and to the Air Weather Service (AWS). AFRES weather reconnaissance units are assigned to the Fourth Air Force (AFRES) and are MAC-gained during wartime. Figure 8 illustrates weather reconnaissance organization under MAC and AFRES.

a. ARRS Weather Reconnaissance Organization. ARRS exercises control of active duty weather reconnaissance forces through the 41st Rescue and Weather Reconnaissance Wing (41 RWRW) headquartered at McClellan AFB, California. The 41st has two primary missions: combat rescue and aerial weather reconnaissance. The 41st also provides a wide range of services ranging from logistic support to isolated sites to atmospheric sampling. The humanitarian goals of the 41st are reflected in the organization's motto, "Serving Mankind."

Three active duty squadrons provide the weather reconnaissance capability within the 41 RWRW: the 54th Weather Reconnaissance Squadron (54 WRS), Andersen AFB, Guam; the 53 WRS, Keesler AFB, Mississippi; and the 55 WRS, McClellan AFB, California.

The 54 WRS operates Lockheed WC-130E and WC-130H aircraft on its primary mission of tropical cyclone reconnaissance in the Western Pacific Ocean area. The "Typhoon Chasers" of the 54th also perform atmospheric sampling and specialized missions in supporting the manned space flight program, atmospheric research programs, and missile research activities.

The 53 WRS operates Lockheed WC-130E and WC-130H aircraft and one specially-modified WC-130B (the AWRS aircraft). The "Hurricane Hunters" provide tropical cyclone reconnaissance for the National Hurricane Center (NHC), Coral Gables, Florida, and fly atmospheric sampling missions, winter storms missions off the United States east coast, and a variety of special missions, in support of worldwide military operations.

The 55 WRS operates Boeing WC-135B aircraft, does not currently operate WC-130s, and is included to complete the organizational picture of the weather reconnaissance forces. The primary mission of the 55th is atmospheric sampling for government agencies. A limited weather reconnaissance capability exists in the 55th when augmenting weather personnel from 41 RWRW headquarters or from AWS headquarters are on board the WC-135s. The WC-135Bs are air-refuellable to permit greater ranges and longer on-station times than otherwise would be possible.

b. AFRES Weather Reconnaissance Organization. The AFRES weather reconnaissance organization differs from the ARRS organization due to the much heavier training activity associated with AFRES units and the need to maintain AFRES units to perform functions normally provided by host air base organizations or by higher headquarters. Weather reconnaissance in the AFRES is the responsibility of the 403d Rescue and Reconnaissance Wing (403 RWRW), Selfridge ANG Base, Michigan. The 403 RWRW, which reports to the Fourth Air Force (AFRES), is a parallel organization to the 41 RWRW in the ARRS.

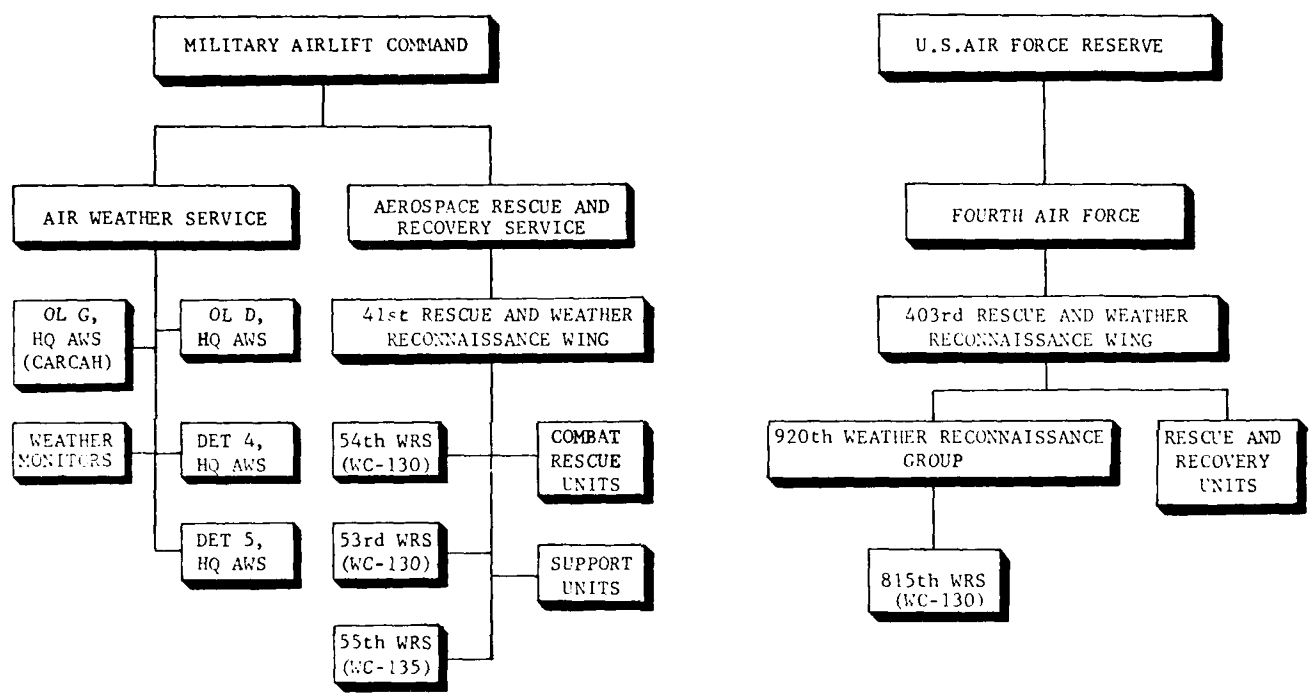


Figure 8. U.S. Air Force Weather Reconnaissance Organizational Structure.

The 403 RWRW is composed of one weather reconnaissance group and four rescue and recovery squadrons. The peacetime mission of the 403d is to provide command and staff supervision for assigned units in developing and maintaining an operational capability for providing worldwide rescue and recovery and weather reconnaissance operations. The wartime mission of the 403d is to mobilize and execute mission tasking under MAC.

The 920 WRG, Keesler AFB, Mississippi, provides command and staff support for a weather reconnaissance squadron, a consolidated aircraft maintenance squadron, a civil engineering flight, a tactical clinic, and a consolidated base personnel office. The 815 WRS, also at Keesler AFB, is the flying organization within the 920 WRG. The 815th operates WC-130H aircraft on tropical cyclone reconnaissance missions for the NHC, on tactical support missions during aircraft deployments, and on AFGWC support missions. The 815th also flies winter storms missions off the U.S. east coast and other special missions.

c. Air Weather Service (AWS) Weather Reconnaissance Organization. With the deactivation of the 9th Weather Reconnaissance Wing (AWS) and transfer of the active duty weather reconnaissance squadrons to ARRS in 1975, the AWS role in weather reconnaissance is to validate operational requirements, develop priorities for employment, and to task the missions. AWS supplies trained weather personnel, provides observations, monitorial services and quality control, and monitors meteorological systems status and development. In April 1977, weather personnel in the operational squadrons were placed in separate detachments under AWS headquarters to establish the current AWS weather reconnaissance structure.

Two detachments and one operating location are maintained by AWS to supply trained weather personnel to the flying squadrons, to the 41 RWRW, and, to a lesser extent, to the 815 WRS. Detachment 4 HQ AWS, Andersen AFB, Guam, provides weather officers and dropsonde system operators to the 54 WRS. Detachment 5 HQ AWS, Keesler AFB, Mississippi, provides weather officers and dropsonde system operators to the 53 WRS and to the 815 WRS (in a modest augmentation program). Operating Location D, HQ AWS, provides staff weather support to the 41 RWRW at McClellan AFB, California.

AWS also operates a network of weather monitors which receive observations from weather reconnaissance aircraft via phone patch, analyze the observations for quality control purposes, and transmit the observations over longline teletype circuits. Most weather monitor activities are performed by base weather stations at selected locations. Specialized weather monitoring and tasking for tropical cyclone reconnaissance missions are also provided by Operating Location G, HQ AWS, Coral Gables, Florida, which is colocated with the National Hurricane Center. The list of monitoring stations is subject to rapid change. Table 3 is a list of the weather monitors in current use. [Editor's Note: This table was current as of 1977-1978.]

Typical Operating Concepts and Procedures

At considerable risk of extreme oversimplification, the material in this section is designed to introduce some of the basic concepts and procedures that generally apply to weather reconnaissance operations. Much detail is omitted in the hope of presenting a rough outline of typical weather reconnaissance operations.

a. Crew Composition and Duties. A basic weather reconnaissance crew on the WC-130 consists of two pilots (an Aircraft Commander and a Copilot), a Navigator, an ARWO, a Flight Engineer, and a Dropsonde System Operator. Additional instructor or evaluator personnel may be provided as necessary and augmenting crew members are sometimes provided for extended operations.

The aircraft commander is a rated pilot, flies the aircraft, commands the crew, and is responsible for the safe execution of the mission. His judgement and experience are utilized in almost every facet of the reconnaissance operation. The copilot assists the aircraft commander in flying the aircraft and managing the activities of the crew. Because of the complexity of weather reconnaissance support to the NHC, many tropical cyclone observations are relayed by the copilot to free the ARWO for data collection, cyclone location, and mission-director duties.

The navigator on the aircrew is a rated officer and is responsible to the aircraft commander for the safe navigation of the aircraft. He also provides positions, times, and flight-level winds to the ARWO for use in observations and works very closely with the ARWO on tropical cyclone and specialized reconnaissance missions.

The flight engineer is a specially-trained noncommissioned officer (NCO) who operates many of the aircraft systems for the aircraft commander. His knowledge of aircraft systems, emergency procedures, and normal operating procedures is essential to safe WC-130 operation.

TABLE 3. AIR WEATHER SERVICE WEATHER MONITORS RESPONSIBLE FOR COLLECTING WEATHER RECONNAISSANCE DATA, THEIR LOCATIONS, AND USAF AERONAUTICAL STATIONS TYPICALLY USED IN CONTACTING EACH WEATHER MONITOR.

WEATHER MONITOR	MONITOR LOCATION	USAF AERONAUTICAL STATION
Miami Monitor	OL G, HQ AWS Coral Gables, Florida	MacDill Airways
Swan Monitor	Det 2, 1WW Andersen AFB, Guam	Andersen Airways
Lajes Monitor	Det 19, 7WW Lajes Field, Azores Is	Lajes Airways
Mather Monitor	Det 7, 24WS Mather AFB, California	McClellan Airways
Elmendorf Monitor	Det 1, 11WS Elmendorf AFB, Alaska	Elmendorf Airways
Letterman	Det 4, 1WW Hickam AFB, Hawaii	Hickam Airways
Yokota Monitor	Det 17, 30WS Yokota AB, Japan	Yokota Airways
Clark Monitor	Det 5, 1WW Clark AB, Philippines	Clark Airways
Rhein-Main Monitor	Det 25. 31WS Rhein-Main, Germany	Croughton Airways
Incirlik Monitor	Tuslog Det 2 Incirlik, Turkey	Incirlik Airways

Meteorological expertise on WC-130 aircrews is provided by the ARWO and the dropsonde system operator. ARWOs are selected from qualified Air Force weather officers and must complete special qualification and survival training before assuming duties as a fully qualified ARWO. Dropsonde system operators are selected from qualified Air Force NCO weather observers and must also complete special qualification and survival training which includes training as scanners and loadmasters in C-130 operations.

The ARWO prepares horizontal and special weather observations and transmits observations from the aircraft. The ARWO is responsible to the aircraft commander for coordinating and, in many cases, directing the aircrew effort in accomplishing the weather reconnaissance mission to the satisfaction of the mission customer. The ARWOs knowledge of customer requirements, weather reconnaissance procedures and techniques, and meteorological expertise is essential to the successful accomplishment of weather reconnaissance operations.

The dropsonde system operator operates the Vertical Meteorological System to produce atmospheric soundings at points selected by the ARWO or the mission customer. The dropsonde system operator also has special responsibilities involving the inspection of the aircraft and the loading of cargo and passengers. Some aspect of the dropsonde system operator's duties figures into every phase of the weather reconnaissance mission.

Successful weather reconnaissance operations require that every crew member function as a member of a team in accomplishing the mission. Constant crew coordination is required in executing back-to-back weather reconnaissance missions in a timely, efficient, and effective manner.

Each crew member has duties requiring his particular area of expertise in the ground phase of the weather reconnaissance operation. ARWOs provide staff weather officer, training, quality control, and altimetry services in addition to their flying duties. Dropsonde system operators provide training, quality control, administrative, and logistic support to the operational units. Operations centers are frequently manned by weather personnel in addition to or instead of other personnel.

b. Predeparture Activity. Activity during the predeparture phase of the reconnaissance operation varies considerably and depends on the nature of the mission, the priority and difficulty of the mission, the lead time available for assigning a crew, aircraft availability, and customer requirements. Activity associated with the predeparture phase of a tasked mission may occur over a period of several days or even weeks but is normally confined to the 24- to 48-hour period prior to launching the aircraft and often occurs over periods shorter than 24 hours. In nonwartime situations, the minimum time to "generate" an aircraft and crew is the time necessary for crew rest (normally 12 hours) and for preflighting, starting, and launching the aircraft (normally around 3 hours) (ARRS, 1976). The 15-hour period assumes that no TDY is involved, that the aircraft functions normally, and that the crew has been previously identified and placed in crew rest at the start of the 15-hour period. The rules and procedures involved for every case in setting up crews and aircraft for operational missions are too complex to be covered in detail in this report.

A typical sequence in the predeparture phase of a mission begins with mission tasking by an authorized customer. After the mission tasking receives any necessary coordination with other agencies involved in the operation and is approved by higher headquarters, it is transmitted to the operational squadrons for execution.

When the squadrons receive tasking for a mission, they identify a crew and notify the crew members to enter crew rest for the mission. Mission folders and trip kits containing forms and publications required on the mission are prepared and checked. If time permits, the route of flight is plotted and preliminary flight planning is accomplished before the crew reports for the mission. Maintenance organizations supporting the flying squadrons prepare an airplane and a backup airplane if one is available. As much preparation and coordination as possible are done prior to alerting the crew to report for the mission.

When the crew reports, they receive a mission briefing or set of briefings and complete any remaining coordination activities with the customer and other agencies involved in the mission. If the aircraft is ready for preflight inspection (or "preflight"), the crew loads baggage and mission kits and preflights the aircraft to assure that all necessary aircraft systems are operational. This process of checking and evaluating system performance continues throughout the predeparture time period and continues into the flight phase. Systems that are not operational and that are required for the mission are repaired as necessary by maintenance personnel. If repair time exceeds time available for predeparture activity, the crew moves to a backup aircraft if one is available or delays departure.

After completing their portion of the preflight, the pilots, navigator, and ARWO finish any remaining flight planning and coordination activity at an operations facility (normally base operations) and return to the aircraft after receiving a weather briefing and filing a flight plan. On return to the aircraft, each crew member mans a crew station, engines are started, the crew entrance door is secured, and the aircraft is taxied to an engine runup area. In the runup area, the engines and propellers are checked at various power settings and last minute systems checks are performed. Normally, flight plan clearance is available from the control tower at this point. If all is in order and the necessary clearances are obtained, the aircraft is taxied onto the runway and launched on the mission.

c. In-Flight Activity. During the climb out from the departure base, contact is established with controlling agencies and departure reports are made to command and control centers. Meteorological altimeters are calibrated during climb out if this phase of flight occurs over open ocean. Systems checks continue and a watch is maintained for other aircraft traffic. Initial contact is made with a High-Frequency (HF) Aeronautical Station for relaying weather observations and position reports later on in the mission.

After leveling off at cruise flight level (or the first of many such levels), normal activity is associated with two main functions: the safe operation of the aircraft in its operational profile, and the collection and dissemination of weather data. The safe operation of the aircraft on the mission involves many functions but chief among them are obtaining clearances and flight-plan changes, maintaining contact with flight-following and control agencies, navigation, command and control, systems monitoring and operation, customer coordination, and the most important of all, flying the aircraft.

Every part of the flight profile on an operational WC-130 mission involves clearances of some sort from a flight control agency. Obtaining clearances and changing flight plans to adapt the flight profile to mission requirements is accomplished by the pilots after coordinating as necessary with the navigator, ARWO, and flight engineer. Clearance constraints may make some desirable aspects of a mission impossible to attain (a flight level or operating area may not be available for use, etc.).

Effective communications are essential to the successful conclusion of the weather reconnaissance mission. Contact must be maintained between the aircraft and flight control agencies, command and control centers, HF Aeronautical Stations for relaying weather observations, position reports, and clearance requests, and with the customer or a customer-coordinating agency. A number of radios are maintained aboard the aircraft for communications purposes and some WC-130Es are equipped to accept secure communications devices for special operations.

Navigation over an airways network between VOR, TACAN, VORTAC, and beacon facilities is normally accomplished by the pilots with monitoring by the navigator. Outside the range of these short-range navigation facilities the navigator comes into his element. Using primarily OMEGA, Doppler, and celestial navigation techniques to obtain lines-of-position (LOPs), the navigator keeps track of the aircraft position relative to planned flight path, determines headings to maintain the aircraft on its planned flight path, and furnishes this information to the pilots for position reports and course control. The navigator also maintains a radar watch for hazardous weather and keeps track of fuel status using data furnished by the flight engineer.

Command and control of the mission is exercised by the aircraft commander and ground-based control centers and is normally accomplished by radio contact. On most missions, command and control functions are performed by wing or squadron operations centers with the aircraft commander having the final responsibility for the safe execution of the mission. Command and control functions normally performed by operations centers during the flight phase of the mission include assigning recovery bases if a new recovery base is required, modifying mission tasking, and coordinating various aspects of the mission with the customer, maintenance, and other agencies.

Systems monitoring and operation is performed by every crew member to a degree but is accomplished primarily by the flight engineer. The flight engineer keeps track of the operation of aircraft engines, the fuel and electrical systems, the hydraulic systems, propellers, etc., and maintains a record of discrepancies and operating conditions during the flight. The flight engineer adjusts the operation of various systems to maintain normal operations or as directed by the pilots. Much of the effectiveness of emergency procedures depends on the flight engineer's thorough knowledge of aircraft systems and how they operate.

Customer coordination is normally performed by the ARWO or the ARWO and aircraft commander. Operational constraints may require modifying flight profiles in such a way as to adversely affect customer-required data. Data coverage may be different from that expected by the customer if constraining situations develop. Changes in communications facilities or data transmission procedures may be required. In these cases and many others it is necessary to contact the customer and coordinate changes in procedures or requirements. Effective customer coordination is especially essential in tropical cyclone reconnaissance and on special operations.

Recovery of the aircraft involves securing more clearances, descent and calibration of meteorological altimeters, and approach and landing at the recovery base. After landing, the aircraft is taxied to parking, engines are shut down, systems are turned off, and the aircraft is secured.

d. Postflight Activity. Postflight activity involves all crew members and consists mainly of completing paperwork, moving baggage, coordinating support activities at the recovery base, closing out the flight plan, and contacting command and control facilities with arrival reports. In most cases, the ARWO contacts the mission customer to make sure that the customer has received all the data and that his requirements have been met.

Any necessary postflight maintenance is accomplished if the necessary personnel and facilities are available. Maintenance activities are normally performed or coordinated by the crew chief and assistant. The crew chief and assistant are furnished by the home base maintenance organization, fly aboard the aircraft on deployments, and are responsible for accomplishing or coordinating maintenance of the aircraft.

If necessary, the aircrew enters crew rest for the start of a new mission cycle. As much preplanning and coordination as possible for any new mission tasking is accomplished before the crew actually enters a new crew rest period.

e. Variations. All sorts of variations in procedures occur due to weather conditions, equipment failure, changes in customer requirements, personnel changes, and even individual preferences to a limited degree. Changes in operational concepts require changes in procedures. Changes in equipment or equipment status precipitate still more changes. Weather reconnaissance operations and concepts must be and are flexible enough to accommodate all customer requirements in a wide range of operational situations.

Horizontal Data Collection

Horizontal data collection refers to data collected using the Horizontal Meteorological System, data inputs from the navigator, and the visual and other elements used in the preparation of horizontal observations. A horizontal observation is a meteorological observation taken from a reconnaissance aircraft in which the observing platform (aircraft) is considered to be located at the center of a cylinder of air 30 NM in radius (9WRW, 1975). Measured parameters are reported for the aircraft flight level (or computed as in height of standard pressure surface data). Visual and radar data are reported within the 30-NM radius cylinder and for occurrence off or along the aircraft course of flight outside the cylinder. WC-130 horizontal observations are prepared and encoded by the ARWO.

Elements of the horizontal observation provided by the nagivator include time (which may also be determined by the ARWO), aircraft position, and most important meteorologically, flight-level wind. Flight-level wind data is normally obtained by using the Doppler radar system's ground-speed and drift-angle readouts along with the TAS value from another indicator and the aircraft heading from the compass system. Using ground speed, drift angle, heading, and TAS, it is possible to compute a flight-level wind speed and direction. If the Doppler system fails, fix-to-fix winds are provided if possible. Each position determination is referred to as a "fix" or "position fix." By knowing two successive positions, ground speed, TAS, and aircraft headings, it is possible to produce an average wind direction and speed between the two positions. This method is subject to considerable error in some circumstances and is used only after failure of the Doppler system.

Elements obtained or computed using the Horizontal Meteorological System include height of the standard-pressure surface, temperature, dew point, and sea-surface temperature. Height of standard pressure surface [or D-value or sea-level pressure (SLP)] computations are made using absolute and pressure altitudes along with corrections for geopotential (variation in gravity with latitude and absolute altitude) and for virtual temperature. Virtual temperature is computed for the aircraft flight level and a correction based on the virtual temperature is used to account for density variations due to water-vapor content in the layer between the aircraft and the standard pressure surface. The basic process consists of computing a D-value, correcting the D-value for geopotential and virtual temperature variations, and extrapolating the corrected D-value in computing the height of the standard pressure surface. The same basic process is used in computing sea-level pressure except that the geopotential correction is regarded as unnecessary within current accuracy constraints.

Height of standard pressure surface data are reported when the aircraft meteorological absolute and pressure altimeter systems are operational and calibrated, the aircraft is over open ocean, and the aircraft is at or within 1500-pressure feet of a standard pressure surface. Similarly, sea-level pressure data are calculated and reported if the aircraft is at or within 1500-absolute feet of the ocean surface. The 1500-foot limit is considered to be the limit of acceptable accuracy for computational purposes. If the aircraft is not at or within the 1500-foot limit, D-values are computed and reported. Failure of the dew-point hygrometer system does not preclude height of standard pressure surface computations even though the failure prevents computation of a virtual temperature. In this case and for the situation in which the air sample is too dry for dew-point determination, virtual temperature and ambient temperature are assumed to be the same.

Temperature and dew point are obtained from the AN/AMQ-28 and AN/AMQ-34 as discussed previously. Measured frost points are converted to dew points using a special table before the dew point is encoded. Backup temperature information is available from the navigator's Outside Air Temperature (OAT) gauge but this indicator is seldom used for observational purposes due to its relative inaccuracy. The aircraft does not have a backup system for determining dew point.

Sea-surface temperature is obtained from the PRT-5 and is reported when the aircraft is at or within 1750-feet absolute altitude of the sea surface. Sea-surface temperature is not reported if the PRT-5 is inoperative or if the sea surface is obscured by meteorological phenomena (9WRW, 1975).

Radar data are reported using the aircraft AN/APN-59 Airborne Radar which has an operating wave length of 3.2 cm. Two plan-position indicator displays are available on scopes at the navigator's position and on the pilot's instrument panel. An iso-echo capability is provided and usable ranges for meteorological purposes extend to about 100 or 150 NM. Radar data are encoded by the ARWO and reported when meteorological returns are present.

Subjective observer inputs to the horizontal observation include clouds, visibility at flight level, precipitation, turbulence, haze or fog, surface wind direction and speed, and aircraft icing. Subjective observer inputs can be divided into two categories: weather phenomena occurring inside the 30-NM observation cylinder and weather phenomena occuring outside the cylinder (weather off course) or along the flight path outside the cylinder (significant weather changes). Weather off-course data include visual phenomena such as cirrostratus or altostratus shields or banks, heavy cumulus lines, cumulonimbus or thunderstorms, waterspouts, dust storms or sandstorms, fog or ice fog, and the bearing from the aircraft with respect to true north where these phenomena are observed. Significant weather changes may include marked wind shifts, the beginning or ending of marked turbulence, marked temperature changes at constant altitude, changes in cloud forms, the beginning or ending of precipitation or a fog bank, and passage through cold fronts or warm fronts. The distance to the point of occurrence of the significant weather change is also reported (9WRW, 1975).

Clouds are reported in layers by type, amount of coverage in the layer, the altitude of bases and tops of the layer, and a flight-condition element in the coded observation which is designed to augment and amplify the reported layered cloud groups. Specific cloud types include cirrus, cirrostratus, cirrocumulus, altocumulus, altostratus, nimbostratus, stratocumulus, stratus or stratus fractus, cumulus or cumulus fractus, and cumulonimbus. Cloud amounts are reported in octas for each layer. The flight-condition element is the average cloud condition experienced by the aircraft in the 30-NM radius observation cylinder and is considered to be the total amount of cloud above the aircraft in a ratio to the total amount of sky visible above the aircraft and the total amount of cloud below the aircraft in a ratio to the total amount of surface visible below the aircraft. The summation principle does not apply in determining the flight-condition element of the observation (AWS, 1977b).

Visibility at flight level is somewhat difficult to determine due to the lack of established reference points for visibility estimates. For this reason, flight-level visibility in horizontal observations is reported in three coarse categories: visibility 1 NM or less; visibility 1 to 3 NM; and visibility greater than 3 NM. These three categories have been found to be adequate for most weather reconnaissance purposes (9WRW, 1975).

Precipitation is determined from its appearance (on the windshield, against a background such as a cowling or wing, or at a distance), duration, and intensity. Precipitation is reported in types ranging from drizzle to hail and intensities of light, moderate, or heavy (9WRW, 1975). Some difficulty may be encountered in interpreting weather reconnaissance reports of precipitation until the user recalls that the data are reported from a continuously moving platform rather than from a fixed land station or a relatively stationary ship.

Turbulence is estimated and reported in four main categories as light, moderate, severe, or extreme turbulence with subcategories of light chop and moderate chop. Turbulence is estimated using criteria developed for standard reporting based on aircraft reaction to the turbulence and the reactions of occupants and objects inside the aircraft (9WRW, 1975).

Haze and fog are reported when they occur in the 30-NM observation cylinder in the same code element in which precipitation is reported. Fog decks outside the observation cylinder may also be reported as weather off course (9WRW, 1975).

Surface winds are estimated from the appearance of the ocean's surface and are required reporting items when the aircraft is operating at the 700-mb level or lower and the surface is visible (9WRW, 1975). Surface winds may also be reported when the aircraft is operating at higher altitudes at the ARWOs discretion. Surface wind estimates of both direction and speed have proved to be quite accurate after some experience is gained by new ARWOs in interpreting the appearance of the ocean's surface.

Aircraft icing is reported by type, rate, altitude of occurrence, and point along the flight path at which the icing begins or ends. Icing rates are subjectively determined as light, moderate, or heavy with types ranging from rime ice in clouds and clear ice in precipitation to frost (icing in clear air). The altitudes of the top and base of the icing stratum or, if the icing occurred in level flight, the altitude of the aircraft are also reported (9WRW, 1975). WC-130s have an anti-ice capability only and are not designed to cope with rapid rates of ice accumulation for long periods of time.

Subjective observer inputs to horizontal observations may be amplified by plain-language remarks appended to the observations. Horizontal observations may be encoded in several different forms depending on the type and amount of data required by the individual customer. The reporting criteria mentioned in the preceding paragraphs apply to the format used most often in weather reconnaissance operations: the RECCO code.

The RECCO code uses 5-digit numerical groups to encode horizontal observation data. The symbolic form of the RECCO code is given in Table 4 along with a brief description of the information coded in each group. The first eight groups of the RECCO observation are mandatory groups and must be reported for every observation. Groups with indicators from 1 to 8 may be omitted if the data are not available or may be repeated as necessary to completely describe weather conditions. The group with an indicator of 9 is used to report visibility and sea-surface temperature data. Plain-language remarks are appended after the 9-group.

Complete instructions for encoding weather phenomena in the RECCO code are far too lengthy to be covered in their entirety here. Individuals interested in decoding RECCO observations from weather reconnaissance aircraft should consult AWS Regulation 105-2' or AWS Regulation 105-25 for complete coding procedures.

TABLE 4. SYMBOLIC FORM OF THE RECCO CODE.

Indicator	Time and Dew-Point Capability	Day of the Week, Octant of the Globe and Latitude	Longitude, Turbulence, and Flight Condition	Absolute Altitude, Type of Wind and Reliability of Wind	Flight-Level Wind Direction and Speed	Temperature, Dew Point, Present Weather
9XXX9	$GGggi_u$	$YQL_aL_aL_a$	$L_oL_oL_oBf'_c$	$hhhd_td_a$	ddfff	TTT_uT_uw

Rmks on Present Weather, Hgt of Std Pressure Surface	Cloud Group-Number of Layers and Amount in Each Layer	Cloud Type, Base and Top. Cloud Groups Are Repeated as Necessary	Surface Wind	Alternate Sfc Wind Format	Significant Weather Off Course and Significant Wx Changes
mjHHH	$ik_nN_1N_2N_3$	ChhHH	4ddff	$5DFSD_k$	$6W_sS_sW_cD_w$

Icing Groups		Radar Groups		Visibility Sea-Surface Temperature
$7I_rI_tS_bS_e$	$7h_ih_iH_iH_i$	$8d_rd_rS_rO_e$	$8w_ea_ec_ei_e$	$9V_iT_wT_wT_w$

Vertical Data Collection

Vertical atmospheric soundings are obtained below WC-130 aircraft by releasing special radiosondes which transmit temperature, relative humidity, pressure, and reference signal data by radio back to the aircraft as the radiosonde falls to the surface of the earth. Sondes released from the aircraft are referred to as "dropsondes" and the encoded sounding produced from the raw data is referred to as a "drop." The radiosonde used by WC-130 weather reconnaissance units is the AN/AMT-13 Radio Dropsonde.

a. AN/AMT-13 Radio Dropsonde. The AN/AMT-13 is an expendable, cylindrical radiosonde (dropsonde) which is 18 inches long, 3.5 inches in diameter, and weighs 4.7 pounds. The AN/AMT-13 transmits temperature, relative humidity, pressure, high reference signals, and low reference signals by radio as it falls through the atmosphere. Dropsondes are released from the aircraft using a dispenser located beside the dropsonde system operator's console near the right paratroop door. As the dropsonde leaves the aircraft, a small parachute is deployed which stablizes the instrument in its fall and extends the antenna for the radio transmitter. Radio signals from the dropsonde are received and interpreted using the other components of the Vertical Meteorological System.

The dropsonde consists of a solid-state pulse generator and modulator, a vacuum tube type radio-frequency (RF) oscillator and final amplifier, a parachute and antenna assembly, an aneroid pressure sensor, a motor-driven commutator assembly, a humidity and temperature-sensor assembly, and a rechargeable 16-volt battery pack with associated circuitry (Bendix Corporation, 1968). The humidity element is installed in the dropsonde during the baseline calibration process.

The radio signal produced by the AN/AMT-13 is a pulse time-modulated signal with a variable pulse-repetition frequency (PRF) ranging from 2400 Hz (open space frequency between segments ± 50 Hz) to 6050 Hz (high reference signal ± 100 Hz). The low reference signal has a PRF of 3100 ± 100 Hz. PRFs for temperature, relative humidity, and pressure signals are variable and fall between the values for high and low reference signals. A "segment" of signals is produced in the following sequence:

High reference
Temperature
Humidity
Pressure
Temperature
Humidity
Low reference
Temperature
Humidity
Pressure
Temperature
Humidity

Segments are separated by the open space-frequency of 2400 Hz (Bendix Corporation, 1968). The signals from the dropsonde are converted by the AN/AMQ-29 Dropsonde Data Recording System into "time periods" for each signal received from the dropsonde and are printed out for use by the dropsonde system operator. The dropsonde system operator converts the time period printout from the AN/AMQ-29 to the actual temperature, relative humidity, and pressure data in the atmospheric sounding (9WRW, 1975).

In general, the operation of the AN/AMT-13 is represented by the block diagram in Figure 9 (Bendix Corporation, 1968). Power from the battery pack is applied to the dropsonde just prior to its release from the aircraft. Applying power activates the dropsonde components and starts the commutator motor. As the commutator rotates, various resistors or resistive sensors are placed in the Resistance-Capacitance (RC) circuit of a relaxation oscillator. As these resistances are placed in the circuit, the time constant and frequency of the relaxation oscillator changes. Variation in the resistances of the sensor elements also produces a time-constant change as the ambient atmospheric conditions change during the fall of the instrument. Two stable resistances are used to set the time constants for the reference frequencies. The signals from the resistance elements (reference and sensor) are fed to relaxation and blocking oscillators to produce a pulse time-modulated output signal in a 402.5-MHz band (Bendix Corporation, 1968).

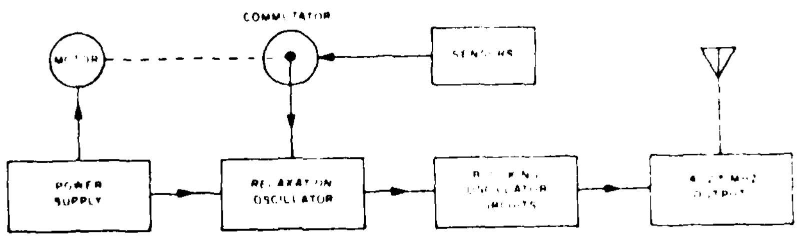


Figure 9. Simplified Block Diagram of the AN/AMT-13 Radio Dropsonde.

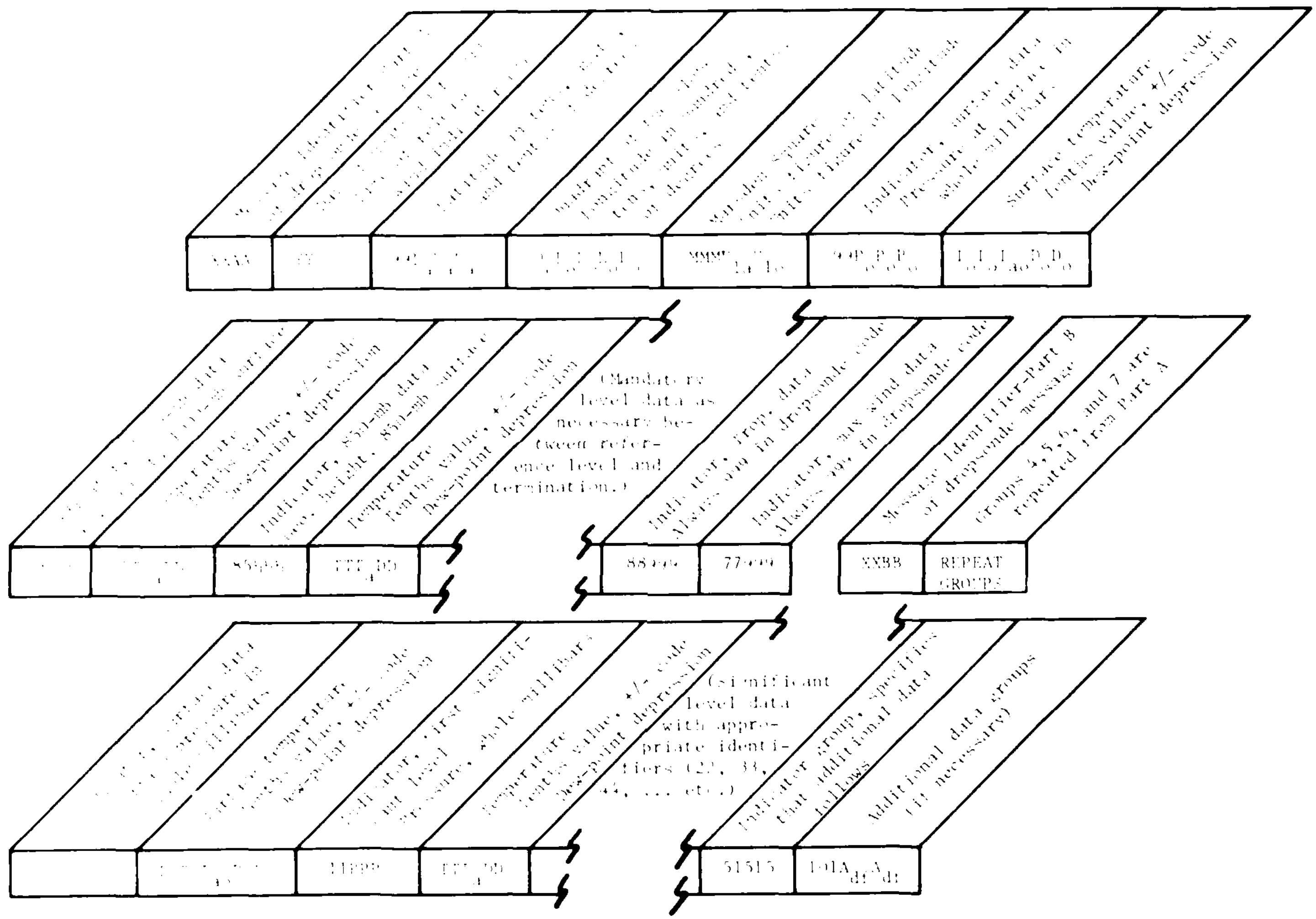


Figure 10. The Symbolic Form of Coded Dropsonde Soundings.

The commutator of the dropsonde completes one revolution every 6 seconds and produces 12 bits of information per revolution in the sequence previously discussed. Temperature and relative humidity information are obtained directly from resistance elements. Pressure data is obtained using an aneroid cell mechanically connected to a wire-wound resistor element. The cam-controlled sensor arm from the aneroid cell is raised and lowered to contact the resistor element twice during each commutator revolution so that pressure is sampled twice while temperature and relative humidity are sampled four times during each revolution (Bendix Corporation, 1968).

b. Atmospheric Soundings. Data produced by the AN/AMT-13 are reduced on board the aircraft by the dropsonde system operator. The time required to produce the sounding varies depending upon the experience and proficiency of the dropsonde system operator, the altitude from which the dropsonde was released (and hence, the amount of data to be reduced), and whether or not the calculator is used for data reduction. A sounding from 700 mb to the surface may take 30 minutes to compute and encode for transmission if the calculator is used. Soundings from 300 mb with many significant levels may take more than an hour to produce and encode even when the calculator is used.

Atmospheric data encoded in the completed sounding include temperature, dew-point depression, and pressure. The data are encoded in a World Meteorological Organization (WMO) TEMP SHIP code form as modified for use in dropsonde sounding. Figure 10 illustrates the general form of the code. More complete information on encoding dropsonde data is given in AWS Regulation 105-25 (AWS, 1975).

Chapter 4

THE DISSEMINATION OF WC-130 METEOROLOGICAL DATA, ITS ACCURACY, AND QUALITY CONTROL

Customers using meteorological data from WC-130 weather reconnaissance aircraft need to have some understanding of the way the data are handled before transmission over teletype networks and some idea of how accurate these data are in final form. Basic dissemination of the data takes advantage of existing high-frequency radio facilities and ground weather organizations. Quality control of WC-130 meteorological data occurs at many points in the data gathering and transmission process and again in the post mission environment.

Data Dissemination

Dissemination of completed horizontal and vertical observations from the aircraft is normally made over high-frequency radio through a USAF Aeronautical Station phone patch to a "weather monitor." The weather monitor copies the observation, checks it, and transmits it over teletype channels. Transmission of the data is made from the aircraft by using plain-language voice contact and is subject to the vagaries of high-frequency radio propagation conditions on the normal operating frequencies of the aeronautical stations. Table 3 of Chapter 3 of this report lists AWS Weather Monitors and the aeronautical stations normally used to contact them. Figure 11 is adapted from AWSR 105-25 (AWS, 1975), and illustrates the worldwide distribution of the aeronautical stations.

The USAF Aeronautical Stations provide the primary means of air/ground communications for weather reconnaissance data transmission to the weather monitors. Under normal propagation conditions, these stations have an operational range of less than 3000 miles for single-sideband high-frequency communications. Diurnal variations and other variations in atmospheric propagation conditions prevent designating any single station as the only contact point for specific reconnaissance tracks or specific operations. Normally, the station closest to the departure base

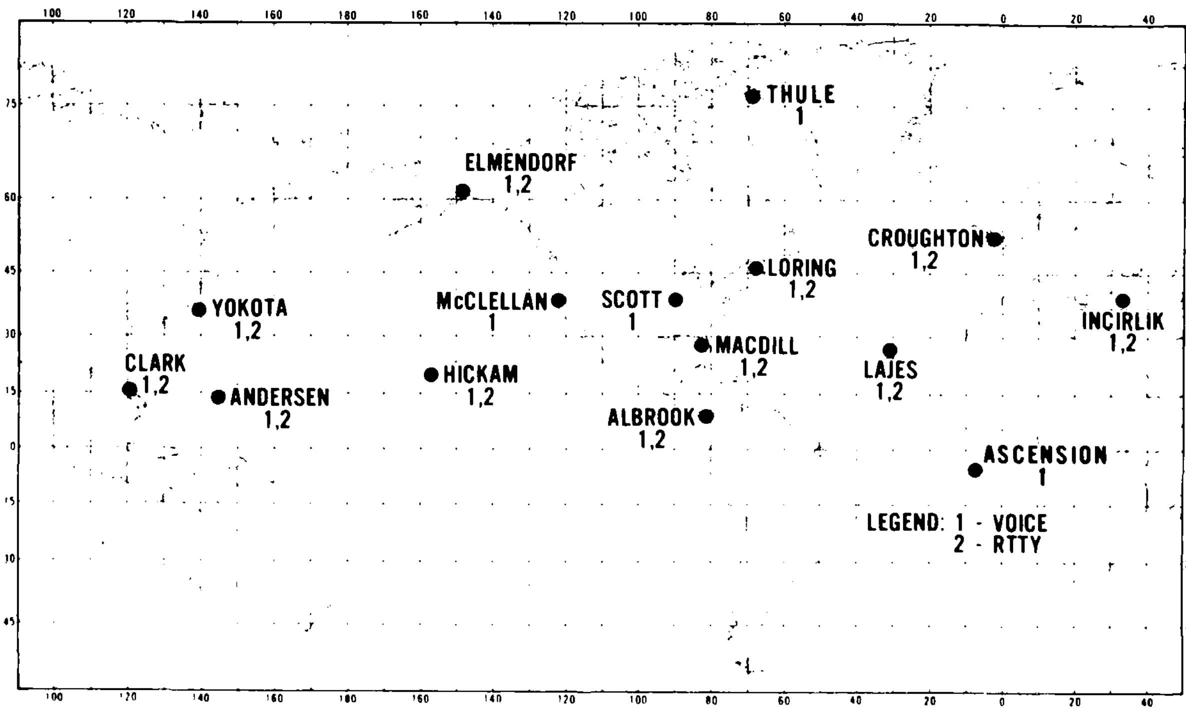


Figure 11. USAF Aeronautical Stations.

will be contacted along the first portion of the track and the station nearest the arrival base will be contacted along the last portion of the track. On long reconnaissance tracks contact may be made with several different aeronautical stations and data transmitted by phone patch to several weather monitors.

Radio frequencies available at each USAF Aeronautical Station are listed in the appropriate USAF/USN Flight Information Publication, Enroute Supplement, with the common user high-frequency radio frequencies falling within a 2.8- to 23-MHz range. Higher frequencies (from around 13 to 23 MHz) are used during the day and give ranges of from 300 or 500 miles to about 2000 miles. The ranges associated with higher frequencies become erratic at night and lower frequencies (3 to 9 MHz) are normally used and give ranges of 0 to 1000 miles (3 MHz) or 500 to 2000 miles (9 MHz) (AWS, 1975). Frequencies from around 8 to 11 MHz are often used during both day and night depending on the actual propagation conditions at the time.

USAF Aeronautical Stations provide many services to military aircraft ranging from relaying position reports and requests for clearances to handling emergency traffic for aircraft in distress. The communications traffic load is enormous at times and is particularly huge when propagation conditions are poor on some of the allotted common user frequencies. Weather reconnaissance observations form only a small part of the traffic handled by the aeronautical stations on any given day. "Discrete frequencies" are sometimes obtained from aeronautical stations for high-priority weather reconnaissance missions and permit transmission of weather data and other traffic without much of the delay due to message traffic from other aircraft. Discrete frequencies are usually necessary for the effective transmission of large volumes of data on tropical cyclone reconnaisance missions.

Direct phone patch between the weather reconnaissance aircraft and the weather monitor is the primary method for relaying weather observations and is generally an effective means of rapidly collecting reconnaissance reports and placing them into the dedicated weather communications system. If propagation conditions are poor or if the quality of the phone patch is poor then the air/ground radio operator at the aeronautical station is frequently asked to copy the observation and relay it by telephone to the weather monitor.

Weather monitors are usually located at a weather facility in close proximity to an aeronautical station or at a weather facility with efficient telephone links to an aeronautical station. In most cases, weather monitor functions form only a small part of the overall responsibility of the weather facility. Frequently, in addition to their many other duties, weather monitor duties are also performed by behind-the-counter forecasters. Most weather monitors operate on a 24-hour basis, but reduced manning situations have resulted in less than 24-hour operation at some locations.

The timeliness of the data from weather reconnaissance aircraft is critical to its effective use by the reconnaissance customer. Many factors affect the timeliness of the data but the principal delays are those occurring aboard the aircraft, the delays associated with contacting the aeronautical station, and the delays resulting from the handling of the data by the weather monitor and the dedicated weather communications system. The combined effect of excessive delays at these points is a seriously degraded weather reconnaissance product and may result in customer dissatisfaction with the results of the weather reconnaissance mission.

Delays aboard the aircraft are due to many different causes. Failure of the calculator may result in delays in preparing atmospheric soundings. Dropsonde failure may require make up releases and new computations by both the ARWO and the dropsonde system operator. Encoding RECCO observations may take several minutes under the pressure of other aircrew duties and also when weather conditions along the track and within the observation cylinder require the coding of many groups. Checking the observations also causes some minor delay in transmitting observations. Delays resulting from radio failure are rare although propagation conditions may delay observation transmission. WC-130s carry two high-frequency radios and normally [illegible] operational throughout the entire mission although in-flight failure of both radios has occurred [illegible] missions.

Contacting the aeronautical station and setting up the phone patch is probably the most frequent reason for delayed observation transmission. As mentioned earlier, the volume of message traffic handled by aeronautical stations can be very large and weather reconnaissance crews frequently are third or fourth in line waiting for phone patches while other message traffic is handled by the station. Problems with phone patch equipment at the aeronautical station have also caused delays. Delays occasionally occur when air/ground operators at the aeronautical station copy observations for relay and then become immersed in higher priority duties before relaying the [illegible].

Data handling by the weather monitor and the dedicated weather communications system can cause delays. Adverse atmospheric conditions can interfere with the HF radio transmission; the weather monitor has difficulty copying the observation in those cases. Further delay may be encountered in preparing the observation for longline dissemination, and even then the nature of the dedicated weather communications system may cause delays of several hours to days in providing teletype hardcopy to the reconnaissance customer. Garbling of the observations requires their retransmission which also results in some delay.

Current methods of data dissemination from weather reconnaissance aircraft are archaic from a technological viewpoint but are constrained by economic realities and the ability of weather reconnaissance customers to accept some transmission delays and even partial loss while utilizing weather reconnaissance data. The use of newer communications methods or the utilization of older but improved communications systems may become possible for weather reconnaissance forces as the requirement for high-density data in remote areas gets larger.

Problems in Determining the Accuracy of Weather Reconnaissance Data

Objective appraisals of the accuracy of meteorological data obtained using aircraft systems are exceptionally hard to make because of the nature of operational weather reconnaissance. Weather reconnaissance operations are routinely conducted into so-called "data-sparse areas" where most data consist of satellite photographs, transient ship reports, and possibly, one or more island weather stations. Comparison of measured and computed atmospheric data from WC-130s with conventional upper-air data obtained by radiosonde is difficult and usually inconclusive due to the impossibility of matching the aircraft flight profile with that of the radiosonde, the different methods used in computing height of standard pressure surface data, the use of different sensors and their different accuracies, and the economic constraints of performing enough comparisons to produce a statistically significant result.

Because of the large volume of upper-air data generated by radiosonde stations, such data have become the standard against which much of the data in weather reconnaissance observations are compared. Many attempts have been made to compare data from weather reconnaissance aircraft with radiosonde data in the operational squadrons and at other levels within the Air Force. Most of such efforts have proved inconclusive due either to a lack of enough high-quality data or to the more basic problems in attempting to compare the data from two such widely different sources.

Part of the problem in comparing weather reconnaissance data with radiosonde data arises from the inaccuracies associated with the standard of comparison, the radiosonde. In AWS TR 240, Atkinson (1971) presented some data relating to the accuracy of upper-air observations in his chapter on analysis in the tropics (Chapter 10). The root-mean-square (rms) errors of radiosonde sensors from various sources were given in TR 240 as:

Temperature	0.5 to 1.0°C
Pressure	2 mb (surface to 50-mb)
	1 mb (above the 50-mb level)
Humidity	5% (temperature above 0°C)
	10% to 20% (temperature under 0°C)

These values were considered representative of observations taken under optimum conditions and were not expected to be obtained routinely in an operational radiosonde network, especially not in the remote areas where reconnaissance operations are routinely conducted. Atkinson computed probable rms thickness errors and height errors resulting from an rms temperature error of 1.0°C and an rms pressure error of 2.0 mb. Data extracted from Atkinson's tables that apply to the normal weather reconnaissance operating altitudes are given in Table 5 (Atkinson, 1971). The methods used to compute these values are beyond the scope of this report but are amply explained in TR 240. Atkinson further considered the accuracy of humidity data and the accuracy of rawinsonde wind direction and speed.

AWS TR 240 (Atkinson, 1971) also indicates some accuracies for weather reconnaissance data and gives estimated rms accuracies for temperature, wind, and D-value observations as:

Temperature	1°C
Wind	3° and 5 kt for spot Doppler winds
D-value	25-30 m at 3 km increasing to 50-60 m at 12 km

TABLE 5. ERRORS IN RADIOSONDE HEIGHT MEASUREMENTS.
(Adapted from AWSTR 240, Chapter 10)

RMS THICKNESS ERRORS (meters)

LAYER (mb)	DUE TO TEMPERATURE ERROR	DUE TO PRESSURE ERROR
1000-700	10	1
700-500	10	2
500-300	15	4
300-200	12	4

RMS HEIGHT ERRORS (meters)

PRESSURE LEVEL (mb)	DUE TO TEMPERATURE ERROR	DUE TO PRESSURE ERROR	TOTAL RMS HEIGHT ERROR
1000	0	0	0
700	10	1	10
500	20	3	20
300	35	7	36

RMS ERRORS IN TRUE HEIGHT OF THE RADIOSONDE (meters)

PRESSURE (mb)	ERROR
700	26
500	37
300	59

Most of the SEEK CLOUD sensors were in limited use around the time of Atkinson's analysis but it is not clear whether his values apply to aircraft equipped with those systems. Atkinson indicated rms temperature and pressure accuracies for dropsondes to be 1.2°C and 6.0 mb, respectively, at the time his report was prepared. Relative-humidity accuracies were more uncertain but were indicated to be at least 10 percent at temperatures above 0°C and 15 percent for temperatures between 0°C and -20°C. At temperatures below -20°C Atkinson indicated that dropsonde relative-humidity values were virtually worthless. He indicated, however, that instrument improvements should make temperature and pressure more accurate for dropsondes but that relative humidity measurement would continue to be a problem. Again, it is not clear from TR 240 if the current dropsonde (the AN/AMT-13) was in use or if the accuracies referred to the older AN/AMT-6.

More recent estimates of the accuracy of radiosonde sensors indicate that the accuracy of pressure sensors is around 1.5 mb and temperature sensors around 0.2°C, a significant increase in the accuracies over those reported in TR 240. Estimates of height of standard pressure surface accuracy indicate that accuracies of around 3 to 8 meters are possible at lower levels (850 to 700 mb). It is important to note that the accuracies reported from various sources have been estimated using data from tightly-controlled test situations and are not representative of the accuracies that can be expected from operational radiosonde networks. Any comparison of weather reconnaissance data with radiosonde data from an operational network in an effort to determine the relative accuracy of weather reconnaissance data must, therefore, be regarded with a prudent measure of suspicion.

System Accuracy Determinations

As a result of concern over reported inconsistencies and apparent errors in aircraft weather reconnaissance data, a special group was established to study and report on the need for standardizing, calibrating, and recalibrating weather reconnaissance instrumentation. To evaluate the reconnaissance systems in use by each weather reconnaissance service, a set of comparison flights were conducted in which the data from the various aircraft could be compared against that from other aircraft and between the aircraft involved and radiosondes released at routine intervals and at special release times. Comparison data were collected on 28 May 1971 with actual flight test data recorded between 1202Z and 2125Z. Radiosonde data and station pressure corrected to sea level at each of the launch times were used as the basis for adjusting the aircraft data to a common time (all data) and common altitude (temperature and dew point only) for each set of observations. Radiosonde data were obtained at frequent intervals from Cape Kennedy and at 1400Z, 1700Z, and 2000Z from Miami, Tampa, and Key West (AWS, 1971).

Aircraft participating in the test included: an AWS WC-135B; three AWS WC-130Bs; a U.S. Navy WP-3A; a U.S. Navy WC-121N; and a Research Flight Facility (RFF) DC-6. The performance characteristics of the aircraft were different (widely so in the case of the WC-135B) and necessitated considerable coordination of airspace use near the comparison points. No attempt was made to adjust individual aircraft locations to a common point for each set of observations since it was assumed that each aircraft would be at some common intermediate location in the vicinity of the radiosonde observation for each set of observations. This assumption was based on an expected homogeneous atmosphere within the immediate vicinity of the radiosonde observation. The resulting data indicated that this assumption was reasonably valid for aircraft-to-aircraft comparisons but not quite as valid for comparing aircraft horizontal data to radiosonde data (AWS, 1971).

Aircraft flight-level data were collected in ascending and descending data collection patterns between 25 NM and 75 NM northeast of Patrick AFB, Florida; within 30 NM northwest of St Petersburg, Florida; within approximately 40 NM south of Ft Myers, Florida; within 20 NM north of Key West, Florida; and within 10 NM south of Biscayne Bay, Florida. Dropsonde data were collected within 50 NM northeast of Cape Kennedy, Florida; within 30 NM northwest of St Petersburg; and within 20 NM north of Key West. Horizontal data were obtained at altitudes ranging from 1110-pressure feet to 289 mb and included the standard 1500-foot, 850-mb, 700-mb, 500-mb, and 300-mb levels. The WP-3A and DC-6 did not collect data above 500 mb, the WC-121N did not collect data above 700 mb, and two of the WC-130Bs were running low on fuel toward the end of the mission and did not make as many observations as the other WC-130B and the WC-135B. The WC-135B, the DC-6, and the three WC-130Bs each collected three sets of vertical data while the WP-3A and WC-121N collected two sets (AWS, 1971).

Instrumentation aboard the aircraft, equipment calibration procedures, and computational procedures were the standard in use by each service at the time of the test. The instrumentation on the WC-130Bs was newer and the 1301A was not used as a primary meteorological pressure altimeter at the time of the test.

All aircraft data in the 28 May 1971 test were adjusted to a common intermediate time (approximately the mid-time between corresponding observations recorded by the first aircraft and the last aircraft) based upon parameter time gradients determined from the nearest radiosonde data. Temperature and dew-point data were also adjusted to a common altitude based on the lapse rates determined from the nearest corresponding radiosonde data. Interpolations were made between successive sets of radiosonde data to determine comparison data for each set of adjusted aircraft data.

The lower range values in the computed range of variations were determined by calculating the smallest difference between parameters recorded at a particular observation location. The upper range between the extreme values recorded by the various reconnaissance aircraft was determined by calculating the arithmetic difference between the highest and lowest values of each parameter recorded at a particular observation location. Variations of the rms differences between the data recorded by an individual aircraft and the average of all aircraft data recorded at corresponding observation locations were calculated for all aircraft and for each aircraft individually. Root-mean-square variations between the data recorded by each aircraft and the corresponding radiosonde data were similarly calculated. Tabulated results for flight-level (horizontal) data are presented in Table 6 and results for vertical data in Table 7 (AWS, 1971).

Given the nature of the test, particularly the impossibility of locating all the aircraft and the radiosonde in the exact same point in the atmosphere at the exact same time, the flight-level temperature data proved to be very consistent from aircraft to aircraft and more consistent than expected between aircraft and radiosonde data. Dew-point data indicated large variations at times from aircraft to aircraft and between aircraft and radiosonde data. Explanations offered for the variations in dew point include differential moisture content in the test areas (small patches of cumulus were present although the overall synoptic situation was relatively stable), observer lack of familiarity with the instrument (the dew-point hygrometers were newly installed on WC-130Bs), and instrument failure which caused one WC-130B to produce faulty data for several observations. Another WC-130B produced obviously faulty data (dew point higher than ambient temperature) for several observations before the dew-point hygrometer settled down to produce reasonably valid data (AWS, 1971).

TABLE 6. HORIZONTAL DATA COMPARISONS FROM THE 28 MAY 1971 TESTS.

PARAMETER:	FREE-AIR TEMPERATURE (°C)		DEW POINT (°C)		MAGNITUDE OF VECTOR WIND (kt) (all levels)		PRESSURE HEIGHT (Geopotential meters) 850 mb		PRESSURE HEIGHT (Geopotential meters) 700 mb	
Comparison:	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB
Range of Variations:	0.0-4.0	0.0-2.9	0.0-9.7	0-9.7	0-27	0-19	0-56	1-30	0-47	0-49
RMS Variations:										
All Aircraft	0.9	1.1	2.6	4.6	7.9	9.6	16.6	16.8	13.1	18.9
WC-135B 666	0.8	1.0	N/A	N/A	9.6	12.0	11.3	12.8	9.8	22
WP-3A 674	1.6	1.6	2.7	4.9	11.7	13.3	22.4	16.8	14.4	8.2
WC-121N 929	0.6	0.7	1.9	4.0	4.5	7.3	18.3	12.1	19.1	17.4
DC-6 539C	0.5	0.7	2.0	4.7	4.4	6.5	6.9	11.7	5.7	11.9
WC-130B 733	0.9	1.2	2.6	4.1	7.2	7.4	16.1	23.3	10.8	21.7
WC-130B 741	0.6	0.9	3.3	5.5	4.8	6.9	14.0	20.3	18.0	28.6
WC-130B 493	0.7	1.1	N/A	N/A	9.5	11.6	13.7	20.1	4.5	13.5

PARAMETER:	PRESSURE HEIGHT (Geopotential meters) 500 mb		PRESSURE HEIGHT (Geopotential meters) 300 mb		EXTRAPOLATED SLP (mb)		SEA-SURFACE TEMPERATURE (°C)
Comparison:	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC
Range of Variations:	0-49	1-32	2-34	0-24	0.0-5.5	0.1-4.1	0.1-5.1
RMS Variations:							
All Aircraft	12.1	14.3	10.4	11.2	1.5	1.8	1.7
WC-135B 666	14.4	17.9	13.2	15.3	1.7	2.4	N/A
WP-3A 674	21.0	21.8	M	M	1.0	1.2	1.7
WC-121N 929	M	M	M	M	2.8	2.7	1.5
DC-6 539C	6.3	7.0	M	M	1.0	1.4	0.6
WC-130B 733	9.8	13.9	14.0	13.7	0.6	0.9	1.8
WC-130B 741	5.6	7.1	7.3	7.7	0.9	1.5	2.2
WC-130B [illegible]	7.1	11.2	4.3	5.2	0.6	1.1	N/A

TABLE 7. *VERTICAL DATA COMPARISONS* FROM THE 28 MAY 1971 TESTS.

PARAMETER:	TEMPERATURE (°C)		DEW POINT (°C)		SLP (mb)		PRESSURE HEIGHT (HGT) 1000 mb		PRESSURE HEIGHT (HGT) 850 mb	
Comparison:	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB
Range of Variations:	0-10.3	0-7.4	0-18.5	0.1-17.7	0.3-14	0-13	1-118	1-97	1-69	3-83
RMS Variations:										
All Aircraft	1.3	2.9	3.2	7.3	3.8	4.8	25.1	19.0	20.9	24.0
WC-135B 666	2.2	2.2	4.2	7.6	6.3	7.7	31.1	14.4	33.4	14.5
WP-3A 674	1.2	2.6	4.5	8.5	3.4	4.5	21.8	31.8	31.7	32.0
WC-121N 929	1.5	2.0	2.3	9.0	0.6	2.1	6.0	14.1	7.3	16.9
DC-6 539C	1.2	3.2	3.9	5.6	5.4	7.4	44.6	22.8	12.5	25.8
WC-130B 733	0.6	2.8	1.7	7.2	1.7	1.6	11.8	17.7	13.3	24.8
WC-130B 741	0.5	2.8	2.1	6.7	2.3	2.5	23.5	19.4	19.0	30.0
WC-130B 493	1.5	3.6	2.8	7.3	2.4	2.2	11.2	16.4	15.4	19.4

PARAMETER:	PRESSURE HEIGHT (HGT) 700 mb		PRESSURE HEIGHT (HGT) 500 mb		PRESSURE HEIGHT (HGT) 400 mb	
Comparison:	AC/AC	AC/RAOB	AC/AC	AC/RAOB	AC/AC	AC/RAOB
Range of Variations:	5-44	5-46	3-28	5-20	6-23	2-15
RMS Variations:						
All Aircraft	17.7	30.1	19.1	27.8	8.6	47.3
WC-135B 666	22.8	30.2	10.4	11.5	10.0	37
WP-3A 674	35.0	34	N/A	N/A	M	M
WC-121N 929	8.2	20.3	N/A	N/A	M	M
DC-6 539C	6.0	26.0	N/A	N/A	M	M
WC-130B 733	13.0	32.9	12.7	30.9	13.0	60
WC-130B 741	17.0	34.4	12.7	15.3	5.0	42
WC-130B 493	10.8	28.8	14.1	21.8	0.0	47

All aircraft participating in the test demonstrated an inability to measure TAS any more accurately than ±5 knots and this inaccuracy had a direct influence on the ability to determine winds. The WC-135B inaccuracy was particularly marked (±8 knots) so that errors in TAS determination, Doppler radar drift angle and ground-speed determinations, and the uncertainty in determining aircraft heading could easily produce the variations observed in the resulting data (AWS, 1971).

Variations in pressure-height data were highest in the lower levels and smallest in the upper levels. The opposite situation was expected since the accuracy of absolute and pressure altimeters diminishes with altitude. Small-scale perturbations in the lower level air mass may have accounted for part of the results. Wider variations in extrapolated sea-level pressures were experienced than had been expected and some of the variations may have been due to gradients within the test areas (AWS, 1971).

The PRT-5s installed on the WC-130Bs were new equipment during the test period and some observer or instrument-induced error probably entered into the data. The variations in sea-surface temperature data were still greater than could be attributed to actual differences in sea-surface temperatures in the test areas.

Dropsonde data were also compared with radiosonde data and the results tended to show that dropsonde temperature variations above 850 mb were within the specifications of the instruments used (AN/AMT-13 by the Air Force, AN/AMT-6 by the Navy, and AN/AMT-3 by the RFF). Dropsonde data at 850 mb and below showed large variations and the last dropsonde temperature data from the WC-135B were obviously in error, indicating a malfunctioning temperature sensor. Without exception, temperatures at the lower levels (850 mb and below) were significantly lower than the corresponding radiosonde data. The most likely explanation is that the atmosphere above 850 mb was more homogeneous and that radiosonde temperature sensors were affected by the heating and radiation of the landmass shortly after launch while the dropsonde sensed different temperatures at the lower levels due to different heating and radiation effects on the low-level air mass over water (AWS, 1971).

Large variations were observed in dew-point data and were considered indicative of the same type of inhomogeneities observed in flight-level data. The variations in the dropsonde data, however, were greater than those observed for flight-level data.

The accuracy of dropsonde height of standard pressure surface and sea-level pressure is dependent on "platform data" from the horizontal systems, dropsonde temperatures, and dropsonde dew points, as well as the pressure data sensed by the instrument. Considering the variations in aircraft pressure heights, the calculated variations in dropsonde pressure heights from aircraft to aircraft were small. The erroneous temperature data from the last WC-135B dropsonde were evident in the variations in all dropsonde pressure height and sea-level pressure determinations. The large variations in WP-3A dropsonde data are reflected in the large variations of the dropsonde 700-mb, 850-mb, 1000-mb, and sea-level pressure calculations for that dropsonde. The DC-6 dropsondes were extremely old (calibrated in 1953 and 1954) and showed large variations in pressure heights at the 1000-mb level and in sea-level pressure (AWS, 1971).

The results of the 28 May 1971 tests illustrate the difficulty of making objective comparisons of aircraft reconnaissance data against radiosonde data. The sensors aboard the WC-130s were new at the time and some of the variations can be attributed to the normal problems associated with learning to use new measuring equipment in any operation. The tests put to rest some of the old questions (although they cannot be regarded as conclusive for the WC-130 fleet due to improved sensors and sensor use since 1971), provided some first-order approximations to the accuracy of weather reconnaissance data, and raised some new questions about the accuracy of weather reconnaissance sensors and procedures for their use.

The problem of testing WC-130 sensors has always been constrained by the economic cost of flying missions dedicated to systems tests alone and the difficulty of establishing an objective standard to compare the weather reconnaissance data against. Tests of most sensor systems have had to rely on data accumulated on operational missions where the test conditions were not always as rigorous as those normally expected in more scientific environments. Nevertheless, in 1973, tests of the WC-130 dew-point hygrometer were conducted and used data obtained by all three WC-130 squadrons. On takeoff and landing roll of each mission flown over a 3-month period (February, March, and April), the ARWO obtained a dew-point reading for comparison with the base weather station dew point at the same time. Five hundred fourteen aircraft and base weather station comparisons were received during the test period. The range of differences between aircraft and weather station dew points was from -5.0 to +7.8°C. The distribution of the differences is given in Table 8, a distribution that is better than normal although the rms difference of the 514 comparisons was 1.78°C.

TABLE 8. DISTRIBUTION OF THE DIFFERENCES BETWEEN DEW POINTS FROM BASE WEATHER STATIONS AND FROM THE AN/AMQ-34.

PERCENT OF THE COMPARISONS	AMOUNT OF DIFFERENCE
23%	0
36%	0.5°C or less
62%	1.0°C or less
70%	1.5°C or less
83%	2.0°C or less
86%	2.5°C or less

Dedicated WC-130 test runs were made in 1973 utilizing facilities of the Air Force Western Test Range (AFWTR) at Vandenberg AFB, California, in an effort to confirm the accuracy of the primary absolute altimeter, the AN/APN-42A. AN/APN-42A data were compared against absolute aircraft altitude data obtained from the AFWTR Askania ground camera stations. The results of the test were considered as supporting the accuracy of the system as claimed by the manufacturer (±20 feet ±0.025% altitude). Further tests on operational missions of the AN/APN-42A and three possible replacement absolute altimeters are being made aboard a 920 WRG aircraft utilizing a laser altimeter as the standard for comparison. The results of the tests thus far appear to confirm the previously determined accuracy of the AN/APN-42A.

Tests of the other SEEK CLOUD sensors have been made on operational missions to confirm the accuracy and repeatability of the systems. The results of these tests have been positive and indicate that properly maintained SEEK CLOUD sensors operated by qualified personnel produce data that is at least comparable in accuracy to that produced by other upper-air sensor platforms. The difficulty of making objective tests of the accuracy of SEEK CLOUD sensors in their normal operating environment is compounded by the lack of suitable standard of comparison to use in objectively evaluating the weather reconnaissance data. As indicated in the next section, comparisons with standard radiosonde data have often been less than satisfactory.

The Historical Calibration Program

The attention given to the accuracy of weather reconnaissance data has been largely focused in recent years on height of standard pressure surface data. As indicated in the 28 May 1971 tests, height of standard pressure surface computations vary widely from aircraft to aircraft and between aircraft and radiosonde data, particularly at lower altitudes. The difficulty in evaluating height of standard pressure surface computations is due in part to the use of two separate sensor systems to provide base data for the computations.

Height of standard pressure surface data are computed using the absolute altitude of the aircraft as determined by a radar or radio altimeter and pressure altitude obtained from a standard pressure altimeter or other pressure-sensing device such as the 1301A Pressure Transducer. The procedure used for computations involves computing a basic D-value (subtracting pressure altitude at 29.92 in. Hg, from absolute altitude), correcting the D-value for geopotential variation in absolute altitude with latitude due to nonsphericity of the earth, correcting the D-value for the assumed mean virtual temperature in the thickness layer represented by the difference between the aircraft altitude and the altitude of the standard pressure surface, and extrapolating the resultant corrected D-value to obtain the geopotential height of the standard pressure surface. Sea-level pressure computations are similar but do not require a geopotential correction.

Height of standard pressure surface computations are only made if the aircraft is within 1500-pressure feet of the standard pressure surface (within 1500-absolute feet for sea-level pressure computations), due to the assumptions inherent in employing the virtual temperature correction and the cumulative effects of system errors. The data are calculated by hand (or more recently, by calculator) for each observation, recorded on a worksheet, and encoded in standard observations.

Since the majority of operational meteorological upper-air data is obtained by radiosonde, weather reconnaissance units employ a historical calibration process in an attempt to make weather reconnaissance data compatible with the standard used by the rest of the meteorological community. The historical calibration process involves collecting aircraft data in close proximity to radiosonde stations or, in a more recent modification of the process, in close proximity to selected calibration points for which AFGWC publishes calibration data based on their analyses of height fields. Aircraft data are compared with radiosonde or AFGWC data and a correction is computed to account for any difference. When a statistically significant number of these corrections has been determined, they are averaged to produce an overall "historical correction" for the absolute and pressure altimeter pair. Published historical corrections are then used in computing height of standard pressure surface and sea-level pressure data for individual aircraft on operational missions.

At first inspection, it would appear that a comprehensive historical correction program would provide a bias correction which would eliminate most of the differences between routine upper-air data and weather reconnaissance data. Historical corrections do provide a general bias correction that is useful in most applications of the weather reconnaissance systems but the historical correction values are variable over short and long time periods. The variability of the historical corrections is considered to result from several causes depending upon who does the considering and is subject to controversy in the weather reconnaissance community. The most likely explanation is probably an amalgam resulting from the synthesis of some of the current explanations (none of which are pertinent to this discussion beyond noting the existence of the problem).

Some meteorologists tend to regard upper-air data obtained by radiosonde as sacrosanct and abandon a little of their objectivity in the shear joy of having quantity upper-air data available on a regular basis. While some improvement in radiosonde sensors has undoubtedly occurred since Atkinson's analysis, it is unlikely that such sensors have achieved the kind of accuracy that justifies their use as the final arbitor of weather reconnaissance data accuracy. Errors in radiosonde sensors undoubtedly produce some (and possibly most) of the variations observed in the historical corrections of WC-130 altimeter systems.

Height of standard pressure surface and sea-level pressure computations depend heavily on the accuracy of two measured parameters: absolute altitude and pressure altitude (or ambient pressure). Inaccuracies in the two measurements are compounded in the resulting computations where they are used. Precision Measurement Equipment Laboratory (PMEL) calibrations of the 1301A Pressure Transducer support the accuracy of properly maintained 1301A systems. Most evaluations of the AN/APN-42 support the accuracy of that system as installed on the aircraft. Aircraft system-produced variations in historical corrections obtained in the historical calibration process must then be due to operator error, errors due to the pitot-static system installation of the meteorological pressure altimeters, to the basic altimetry process used to compute height of standard pressure surface data, or to undetected sensor errors. As in past years, the focus of current efforts to explain the observed variations in historical correction values is on the accuracies of the sensor systems.

Pending a final solution to the problem, the historical calibration process appears to offer the best chance of making weather reconnaissance height of standard pressure surface and sea-level pressure data compatible with the much more abundant radiosonde data. Except for equipment failure in isolated cases, the variability of historical corrections remains unexplained, particularly the variations experienced on operations in areas off the United States coast that are not normal operational areas for weather reconnaissance aircraft.

Sources of Error in Weather Reconnaissance Data and Data Quality Control

In broad terms, errors in weather reconnaissance data result from two sources: human error and system error. System error is also regarded as including errors induced in the data by the use of data from outside sources (such as radiosonde data) used in the historical calibration program. Human error encompasses errors resulting from misreading instruments, miscalculations, and errors in utilizing or employing sensor systems. The primary focus of the quality control programs currently in effect is the reduction of both human and system errors wherever possible.

The WC-130 meteorological system is about as basic an operational system as can be effectively utilized on most Air Force weather reconnaissance missions. The design of the system, with its emphasis on operator manual reduction of primary data (using pencil and paper or a calculator), is well-suited to long missions with observations occurring at intervals of about 150 NM. The system is not well-suited for high-density data collection under adverse meteorological or operational conditions.

System errors include everything from failure of sensors which still indicate acceptable values to the more basic errors inherent in the sensor systems themselves. Mechanical pressure altimeters (aneroid types such as the AIMS or MA-1) are subject to many types of errors such as those resulting from friction, hysteresis, temperature, readability, zero-setting, and static system leakage. The 1301A is subject to hysteresis and temperature-induced errors (although they are small) and is sensitive to small fluctuations in flight level that are "integrated out" by the mechanical linkage of the aneroid altimeters. The 2000-3 Digital Voltmeter is also subject to a gradual failure in readout capability which may remain unnoticed in its early stages but is evident in the rapid fluctuations indicated in its later stages. The AN/AMQ-28 Total Temperature System measures temperature resulting from atmospheric friction as well as the ambient atmospheric temperature. For WC-130 airspeeds, the friction effect is negligible. The AN/AMQ-34 Dew-Point Hygrometer produces errors resulting from misaligned optical elements or contamination of the mirror surface and may indicate a dry atmosphere when the aircraft is flying through a cloud. The AN/APN-42 may exhibit fluctations of up to 50 to 100 feet before complete loss of reliable altitude indications. Errors in the final data can result from the use of instruments under these conditions although most of these failures are readily observed and data from systems exhibiting these failures are not transmitted from the aircraft.

Human errors are the most detectable errors in weather reconnaissance data. The WC-130 meteorological system requires a human operator to reduce the raw data to a form that can be coded and used by the meteorological community. The amount of recording and computing that is required on many reconnaissance missions can be large at times and requires highly trained and competent personnel. ARWOs and dropsonde system operators receive extensive in-unit training to prepare them for their duties and are evaluated and reevaluated as to their ability to perform those duties throughout the time they are assigned to weather reconnaissance duty. Most of the human errors in weather reconnaissance data result from inexperience, a situation that is produced by high personnel turnover rates among ARWOs and dropsonde system operators and by a lack of in-depth operational training before beginning training in the operational units. Errors attributable to the human element affect 5 to 7 percent of the observations in any given month and usually affect less than 1 percent of all the encoded groups in the observations for the month. High-density requirements on tropical cyclone and special reconnaissance missions usually produce higher rates.

Quality control programs have been designed to identify errors both during and after operational missions. The primary responsibility for detecting errors during the mission rests upon the mission ARWO with the dropsonde system operator having the responsibility for detection of errors in the reduction of dropsonde data. Every effort is made to check and evaluate reconnaissance data prior to transmission from the aircraft and still provide a timely product. The time available for checking observations, however, is a function of the required data density and the amount of time necessary to encode the observations as well as other operational considerations.

The weather monitor shares the responsibility for checking weather reconnaissance data during the mission. The effectiveness of the weather monitor's data checking is a direct function of the monitor's familiarity with the data format and his knowledge of the reconnaissance operation. The effectiveness of quality control by monitors that frequently handle weather reconnaissance data is normally very good.

The post-mission phase of quality controlling weather reconnaissance data focuses primarily on the detachment level program. Each unit maintains additional duty quality control officers and NCOs to conduct post-mission evaluations of weather reconnaissance data. Errors are identified, corrected on the mission forms, and brought to the attention of the ARWO or dropsonde system operator involved. The operational result of this phase of the quality control program is primarily educational for the personnel involved so that future errors of the same type may be avoided.

The Impact of Data Accuracy and Reliability on Weather Reconnaissance Customers

Air Force weather reconnaissance forces serve many different customers with widely varying data requirements. The overall impact of data accuracy is difficult to assess in an objective fashion because of the diversity of customer requirements and, quite often, the reluctance of operational users to perform objective evaluations of missions flown in support of the customer's requirements. Frequently, the reconnaissance customer merely identifies outstanding or poor mission performance and does not attempt to provide evaluations of all the missions flown or to objectively assess the impact of data accuracy and availability on the customer's operation. Over the past 2 or 3 years a small amount of effort has been generated in an attempt to objectively evaluate the contribution made by the weather reconnaissance forces to the operations of various customers. Some of these assessments have provided the basis for planned system improvements or proposals for totally new weather reconnaissance systems.

AFGWC uses weather reconnaissance data produced on AFGWC support missions as well as data that have been produced for other customers. In addition to flight-level winds, AFGWC utilizes height of standard pressure surface data in its forecast models. In an August 1976 evaluation of the accuracy requirements for absolute altitude measurements, AFGWC indicated that systematic or bias errors were not handled well by the AWS Primitive Equation (AWSPE) Model and that calibration of aircraft sensors was important for that reason. AFGWC also indicated that noise errors were quickly damped out

[illegible]

The "bread-and-butter" mission of the weather reconnaissance squadrons is tropical cyclone reconnaissance. The United States is historically the only nation in the world that flies routine weather reconnaissance missions to locate and measure the intensity of tropical cyclones. Air Force WC-130 squadrons provide the major portion of that humanitarian effort. The impact of the accuracy of weather reconnaissance data on tropical cyclone reconnaissance missions has received a moderate amount of attention in the past years.

In August 1975 the U.S. Department of Commerce (DOC) published an evaluation of the effectiveness of weather reconnaissance as compared with other elements of the hurricane warning system (especially satellite systems) (DOC, 1975). Forecasts of tropical cyclone development and movement depend heavily on accurate determinations of the intensity of the cyclone and the location of the cyclone center. The Ad Hoc Group concluded that the Dvorak technique did not define the strength of strong hurricanes with sufficient resolution and that there was some doubt that the technique could identify rapidly strengthening hurricanes. The report indicated that over 15 percent of the time the range in strength estimates of hurricanes made from satellite photographs was greater than plus or minus one current intensity number (C.I. number) which, for a strong hurricane, corresponds to around 30 mb of pressure, 30 knots of wind, and 5 to 10 feet in storm surge. Measurement of the strength of a hurricane by satellite alone was not considered accurate enough for warning purposes (DOC, 1975).

The report further concluded that the positions of hurricanes within 500 miles of landfall as determined by reconnaissance aircraft were 25 to 50 percent more accurate than those interpreted from the then-current satellite data. The seasonal average position error for aircraft was between 15 and 20 NM while the same figure for satellites was around 30 NM. The accuracy of satellite locations, however, increased significantly for a strong hurricane with a well-defined eye. Forecast models are very sensitive to initial motion which is a function of errors in the initial position. Forecasts based on motions determined by weather reconnaissance aircraft were expected to be superior to those based on satellite photographs and the report concluded that the net difference would result in a 20 percent decrease in the extent of coastal hurricane warnings with a potential annual savings in preparedness costs of about $16 million per year. The more accurate inputs from an AWRS-type system would further minimize the extent of coastal warning necessary to the point that the cost of instrumenting the weather reconnaissance fleet with a new system could conceivably be recovered in 1 to 3 years based on decreased preparedness costs alone (DOC, 1975).

The last conclusion established in the report was that numerical hurricane models anticipated for the late 1970s will require AWRS-type (i.e., high density) data for initialization. Current SEEK CLOUD systems are not capable of providing quality data in the quantities required for the newer numerical forecasting models. The report recommended maintaining an aircraft weather reconnaissance program, instrumenting weather reconnaissance aircraft with a system that has equivalent AWRS capability, and refining the Dvorak technique for use on stronger hurricanes and testing it on rapidly deepening storms (DOC, 1975). In a review of the Ad Hoc Committee report, The National Academy of Science supported the conclusions and recommendations of the final report.

In December 1976, AWS established for MAC a "Required Operational Capability (ROC) for Improved Weather Reconnaissance" document which delineated four areas in which the current weather reconnaissance system is considered deficient:

a. Data obtained from the sensors are not sufficiently accurate to meet current forecasting requirements stated in interagency agreements and have even greater shortfalls with respect to meeting the requirements for driving the numerical models developed for typhoon and hurricane forecasting.

b. The manual data processing technique cannot provide the volume, timeliness, and reliability of data needed for current requirements.

c. The present navigation capability does not provide the required accuracy for location of eye centers, maximum wind bands, and other significant features of tropical cyclones.

d. Meteorological equipment reliability is not adequate. The MAC/AWS Observation Evaluation reports from the 41 RWRW show that annually 42 percent of the observations from contemporary WC-130s are taken with one or more of the major meteorological components inoperative.

All the studies and reports [illegible] that [illegible] the current [illegible] weather reconnaissance system are adequate, even if [illegible], but [illegible] requirements in the very near future considerably exceed [illegible]. The "[illegible] measure" SEEK CLOUD system [illegible] observation [illegible] expected in the very near future. [illegible] sensor is also considered, the need for an improved [illegible].

The Accuracy of Meteorological Parameters Reported [illegible] Operational Weather Reconnaissance [illegible]

Despite the difficulty in [illegible] of the [illegible] data produced from weather reconnaissance aircraft, it is possible [illegible] the accuracy of most of the measured parameters reported [illegible]. [illegible] Weather Reconnaissance Wing [illegible] AWS [illegible] (Atkinson, 1971) as well as [illegible] May 1971 [illegible] Weather Reconnaissance [illegible] it becomes possible [illegible] be expected for properly maintained equipment [illegible] of the [illegible] pressure surface data with valid [illegible] corrections [illegible] for WC-130 SEEK CLOUD sensors as reported by the [illegible] June 1971 [illegible] service tests and continued operational experience with the system [illegible] accurate as claimed under most [illegible] conditions.

When the types of sensor system errors previously [illegible] are considered, the accuracies of the reported parameters given in Table [illegible] can be reasonably expected in typical operational [illegible]. However, system failure or improper maintenance may decrease the accuracy of the reported parameters.

Estimating the accuracy of height of standard pressure surface data is considerably more difficult since it is a function of so many variables. At the time of the [illegible] May 1971 tests the SEEK CLOUD sensors were newly installed and the 1301A Pressure Transducer system was [illegible] as the primary pressure altimeter. Using the [illegible] accuracies for the 1301A and the AN/APN-42A, it is possible to estimate the rms-height errors involved if it is assumed that the aircraft is flying exactly on the pressure surface, that no bias error is present in the final result, and that the geopotential correction is properly computed and applied. In this case, the total rms-height

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
Total Temperature [illegible]	[illegible]
1301A	[illegible]
AN/APN-42A	[illegible]

NOTE: [illegible]

TABLE [illegible]
PARAMETERS REPORTED FROM [illegible]

PARAMETER	[illegible]
Temperature	[illegible]
Dew Point	[illegible]
[illegible] Temperature	[illegible]
[illegible]	[illegible]
Absolute Altitude	[illegible]

TABLE [illegible] ERRORS DUE TO RMS ERRORS [illegible]

[illegible]	[illegible]	[illegible]	TOTAL RMS HEIGHT [illegible] (feet) (meters in parentheses)
[illegible]	[illegible]	[illegible]	26.3 (8.0)
[illegible]	[illegible]	[illegible]	28.8 (8.8)
[illegible]	[illegible]	[illegible]	34.3 (10.5)
[illegible]	[illegible]	[illegible]	38.8 (11.8)
[illegible]	[illegible]	[illegible]	[illegible].1 ([illegible])

error is the square root of the sum of the squares of the rms errors due to pressure altitude and absolute altitude measurements. If the manufacturer's accuracies given in Table 9 for the 1301A and the AN/APN-42A are used, then the rms-height errors due to sensor error at various levels are given in Table 11.

This brief exercise does little more than give a rough approximation to the accuracy of height of standard pressure surface determinations from the aircraft. The process of computing height of surface data involves extrapolating D-value data when the aircraft is not exactly on the standard pressure surface and also depends on the historical correction process which attempts to make the aircraft data compatible with standard upper-air data obtained by radiosonde. Current estimates of the accuracy of height of standard pressure surface data from weather reconnaissance aircraft indicate that accuracies of within 8 meters can be expected at and below 700 mb and that accuracies of within 10 meters can be expected above the 700-mb level. D-value computations can be expected to have like accuracies.

The accuracy of flight-level wind information is dependent on both the accuracy of the Doppler radar system and the skill of the navigator or ARWO in using it to compute the wind. The general accuracy of flight-level winds reported from reconnaissance aircraft is within 5 knots of speed and [illegible] degrees of direction. Aircraft position information is dependent on navigator skill and the availability of navigational aids. Position accuracy over the open ocean ranges from around 3 NM to as much as 2[illegible] NM in [illegible] instances. Occurrences of position errors as high as 60 NM have been observed in extreme cases with newly qualified navigators in areas with poor navigational aids. [illegible], the positions reported in weather reconnaissance operations are considered accurate to within 10 to 15 NM and are reported to the nearest tenth of a degree. New Omega navigation systems installed on WC-130s are expected to produce 2- to 4-NM position accuracies.

[illegible] observer inputs to weather reconnaissance observations are vulnerable to variations in accuracy due to the differing skill and abilities of the individual ARWOs. In general, the accuracy of [illegible] observer inputs is considered to be well within the limits imposed by the reporting criteria [illegible] in the RECCO code.

Dropsonde [illegible] generally be considered accurate to within 2 mb of pressure at sea level and [illegible] 1.[illegible] temperature. [illegible] humidity element has reduced the inaccuracy of dew-point data but [illegible] accuracy data were not available at this writing.

Conclusion

The [illegible] problem of determining absolute system accuracies remain with the weather [illegible] determining relative accuracies requires comparing aircraft data with a [illegible] standard and radiosonde data, the current standard, is susceptable to considerable error in [illegible]. Current techniques for attempting to force data compatibility through [illegible] correction process have not always had the degree of success desired due to the [illegible] in [illegible] upper air data and the difficulty in assuring that the air mass the aircraft is operating in has the same characteristics encountered by the radiosonde. More detailed [illegible] comparability, and the efficiency of the historical correction process are necessary if the [illegible] are to be answered objectively.

Chapter 5

TROPICAL CYCLONE RECONNAISSANCE AND RECONNAISSANCE FOR SPECIAL CUSTOMERS

Weather reconnaissance missions are flown for many different military and government agencies and are widely varied in the requirements for data and overall conduct of the mission or set of missions. Some missions require very little acquisition of meteorological data and are beyond the scope of this report. Similarly, some missions provide little data for highly specialized and sometimes classified support activities and are also not considered here. Typical routine weather reconnaissance operations are probably best illustrated by considering the tropical cyclone mission, missions flown in support of AFGWC, tactical support missions, and East Coast winter-storm missions.

Tropical Cyclone Reconnaissance

One of the Air Force's largest continuing humanitarian missions involves locating and tracking tropical cyclones in support of hurricane and typhoon warning centers. The Air Force provides the major portion of the reconnaissance effort in the Atlantic, Caribbean, Gulf of Mexico, and Eastern Pacific areas and all of the routine tropical cyclone reconnaissance effort in the Central and western Pacific areas. Historically, the United States is the only nation in the world to provide aircraft reconnaissance of tropical cyclones on a routine basis. Aircraft reconnaissance of tropical cyclones is an expensive undertaking and one best assumed by a relatively affluent nation. With the cutback in weather reconnaissance strength in the Western Pacific at least part of the aircraft reconnaissance effort is expected to be assumed by other nations but the economies of most of the smaller nations bordering the Caribbean and Gulf of Mexico areas would probably support only a token and largely inadequate reconnaissance effort. The United States is expected to continue to provide as large an aircraft reconnaissance effort as is required to provide effective and timely warning of the approach of destructive storms.

Air Force tropical cyclone reconnaissance missions are flown for the National Hurricane Center (NHC), Coral Gables, Florida in the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico areas. Missions are also flown for the Eastern and Central Pacific Hurricane Center (EPHC), Redwood City, California and the Central Pacific Hurricane Center (CPHC), Honolulu, Hawaii. Western Pacific tropical cyclone missions are flown for the Joint Typhoon Warning Center (JTWC) which is colocated with the Fleet Weather Central, Nimitz Hill, Guam and is jointly manned by Air Force and Navy weather personnel (AWS, 1977b). These agencies collect data from weather reconnaissance missions and many other sources in forecasting the intensity and movement of tropical cyclones.

a. Comments on Tropical Cyclone Classification and Structure. AWS TR 240 (Atkinson, 1971) points out that the term "tropical cyclone" is interpreted in various ways and that the classification of tropical cyclones into categories by intensity is subject to considerable variation around the world. The U.S. Department of Commerce (1977), defines a tropical cyclone as a "nonfrontal low pressure system of synoptic scale developing over tropical or subtropical waters and having definite organized circulation." The National Hurricane Operation Plan (NHOP) classifies tropical cyclones into three intensity categories:

"(1) TROPICAL DEPRESSION. A tropical cyclone in which the maximum sustained surface wind (1-minute mean) is 33 knots or less.

"(2) TROPICAL STORM. A warm-core tropical cyclone in which the maximum sustained surface wind (1-minute mean) ranges from 34 to 63 knots inclusive.

"(3) HURRICANE/TYPHOON. A warm-core tropical cyclone in which the maximum sustained surface wind (1-minute mean) is 64 knots or greater." (DOC, 1977).

These intensity categories are used by Air Force weather reconnaissance units and civilian and military warning agencies in both the Atlantic and Pacific and in the Caribbean Sea and Gulf of Mexico areas.

The term "warm-core" in the NHOP intensities indicates that the more destructive tropical cyclones are warm-core lows with maximum winds near the surface and decreasing system intensity with height. As the term implies, warm-core tropical cyclones have warmer temperatures at the center of the cyclone than in the outer portion. The primary energy source for tropical cyclones is the release of latent heat of condensation, mainly in the wall cloud and spiral rain-band structures. The maintenance of warm temperatures at the center of such systems depends on the addition of heat and moisture to the low-level air as it spirals inward so that the adiabatic cooling caused by decreasing pressures is compensated for and with the result that sea-level temperatures remain nearly isothermal. When warm-core tropical cyclones move over cooler surfaces, the [illegible] outflow [illegible] occurs, surface air is cooled by adiabatic expansion and [illegible], [illegible] cyclone eventually decays as the warm core is destroyed (Atkinson, 1971).

[illegible] flow layer extends from the surface to around [illegible] toward the cyclone center. The middle layer extends from [illegible] and has very little radial motion. The outflow [illegible] the top of the cyclone with maximum outflow in [illegible] outflow and middle layers [illegible] (Atkinson, 1971).

[illegible] "[illegible] bands," [illegible] the wall-cloud [illegible] in satellite [illegible] the wall-[illegible] wall. [illegible] satellite data. [illegible] individual cyclones [illegible]."

The material in this section is presented as a general introduction to the structure of tropical cyclones as it applies to the weather reconnaissance [illegible]. A more detailed introduction to tropical cyclone structure, climatology, and forecasting is provided in [illegible] from which [illegible] of the above material has been taken.

[illegible] Tropical Cyclone Reconnaissance Missions Form a Large Part of the Air Force Weather Reconnaissance Effort. This photograph was [illegible] WC-130 and shows the banding of cumulus and strato-[illegible] of Typhoon [illegible] at 0935Z on [illegible] 1974.

c. Methods of Locating the Tropical Cyclone Center (the Reconnaissance Fix). The primary objective of tropical cyclone reconnaissance is the location of the center of the tropical cyclone. Location of the cyclone center is normally made by flying the aircraft into the center of the cyclone using the AN/APN-59 radar, visual scanning of surface winds, Doppler flight-level winds, and data from the Horizontal Meteorological System. Flying to the center of the tropical cyclone is referred to as a "penetration" and locating the center by penetration as a "vortex fix." Under some conditions penetration is not possible and a "radar fix" of the tropical cyclone is attempted.

In determining the center of a cyclone several factors must be considered. The structure of tropical cyclones can vary considerably from cyclone to cyclone and from one time to the next in individual cyclones. "Centers" based on individual parameters such as pressure, temperature, the geometric wind center, and visual and radar centers may not coincide at exactly the same geographic location. The "tilt" of the cyclone may mean that the surface and upper-level centers are displaced horizontally by as much as tens of miles. The centers of tropical cyclones are referred to as "vortices" in many cases and the NHOP gives the priority of vortex location from highest to lowest as: pressure vortex, wind vortex, cloud vortex, and radar eye.

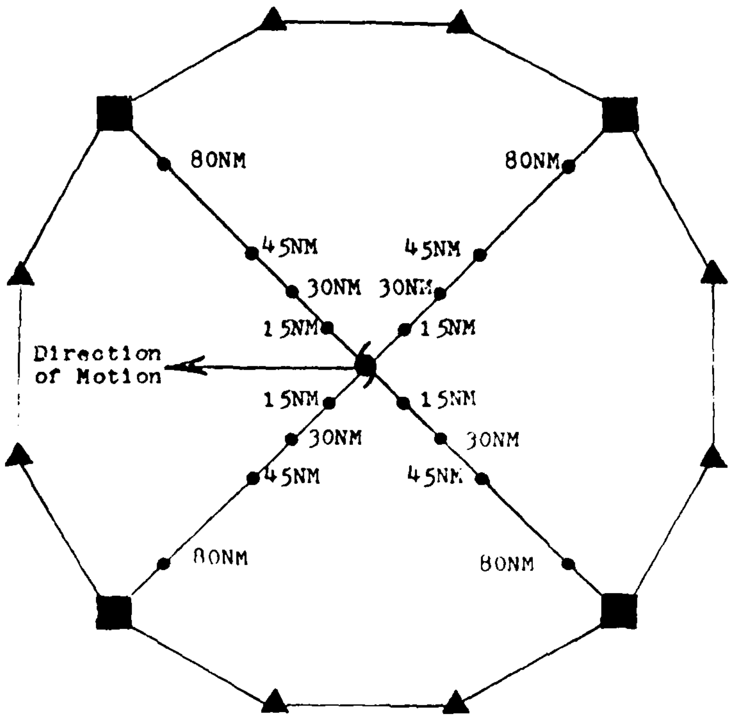
The low-level vortex of a tropical cyclone is normally located either visually (from the appearance of the ocean surface and surface winds) or by finding the minimum sea-level pressure (if the penetration is made at 1500 feet or below). Upper-level centers, if located, are reported relative to the low-level vortex. When the location of the low-level vortex cannot be made due to obscuration by cloud or at night or due to operational constraints, the 700-mb vortex is located and reported.

The relatively flat pressure and temperature gradients associated with the early development of a tropical cyclone or with many tropical disturbances that do not develop beyond that stage make locating a pressure or temperature center very difficult. In such cases, a geometric wind center may be determined and reported, or, if the wind field surrounding the center is not well-defined and the cloud field is, the cloud vortex may be used for reporting purposes. In all cases, the priority used in locating and reporting the vortex is that assigned by the NHOP.

Every source of information available to the ARWO and navigator is used in locating the tropical cyclone vortex. Constant comparison of flight level and surface wind direction with aircraft heading is made to assure that "the left wing stays into the wind" so that, within known and acceptable limits, direct flight to the cyclone center is possible. The radar presentation of rain bands is used to determine the approximate location of the cyclone center. The radar "eye" return from cyclones with well-developed wall-cloud structures makes the location of the general center of the cyclone obvious unless the return is masked by attenuation from heavy convective activity generally associated with such cyclones. At a constant-pressure altitude, the absolute altitude of the aircraft becomes lower, markedly so for intense cyclones, as the center is approached. Temperature increases with the maximum temperature gradient occurring at or near the wall-cloud structure. Surface and flight-level winds are continuously monitored (surface winds when visible), increase toward the cyclone center, and fall off sharply as the cyclone center is penetrated. All the information available is considered repeatedly throughout the location process. Observations are taken and recorded for transmission or for later use in reporting the reconnaissance fix. An in-flight analysis of plotted observations is normally maintained as an aid for locating the vortex and keeping track of cyclone progress and development during the mission.

d. Reconnaissance Flight Patterns. In addition to locating the tropical cyclone center and reporting its characteristics, observations are made on flight patterns in the cyclone to measure the intensity and distribution of flight level and surface winds, to measure height of standard pressure surface or sea-level pressure profiles, and to determine temperature and dew-point profiles in the cyclone. The flight patterns required under the NHOP require the largest amount of data gathering of all the current tropical cyclone flight patterns. The primary flight pattern required under the NHOP (i.e., the most often tasked pattern) is the "Alpha Pattern" illustrated in Figure 13 (AWS, 1977b). The execution of the Alpha Pattern depends on the quadrant first entered by the reconnaissance aircraft as indicated in Figure 14 (DOC, 1977). In the normal execution of the pattern, peripheral data are collected in each quadrant once, vortex profile data are collected along each radial leg twice, and four vortex fixes are made.

The altitudes normally flown on tropical cyclone reconnaissance missions are 1500 feet (a[illegible] altitude) and 10,000 feet (approximately 700 mb). Of the two altitudes, the actual altitude flown depends on mission tasking and safety of flight considerations. Altitudes flown in proceeding to and from the cyclone are selected to permit fuel conservation and to [illegible] the cyclone area (higher airspeeds are generally flown at higher altitudes). [illegible] operating altitude (1500 feet or 10,000 feet) is usually made [illegible] from the [illegible] location of the tropical cyclone center.



- ■ RECCO Section 1 Observations (Dropsonde observations required once during pattern execution - see Table 4).
- ▲ RECCO Section 3 Observations (Appended to the appropriate Section 1 observation). Vortex Peripheral Data.
- ● Vortex Profile Data for the Supplementary Vortex Data Message at the indicated radii from the cyclone center.

1. Abbreviated/Detailed Vortex Data is required for each levied and intermediate pattern fix as indicated in Table 4. Center data is also used in preparing the Supplementary Vortex Data Message.
2. Dropsonde releases are required at the end of each radial leg in each quadrant once during pattern execution (see Table 4).
3. Alpha Pattern radial headings should be maintained within ±20 degrees.

Figure 13. NHOP Alpha Pattern.

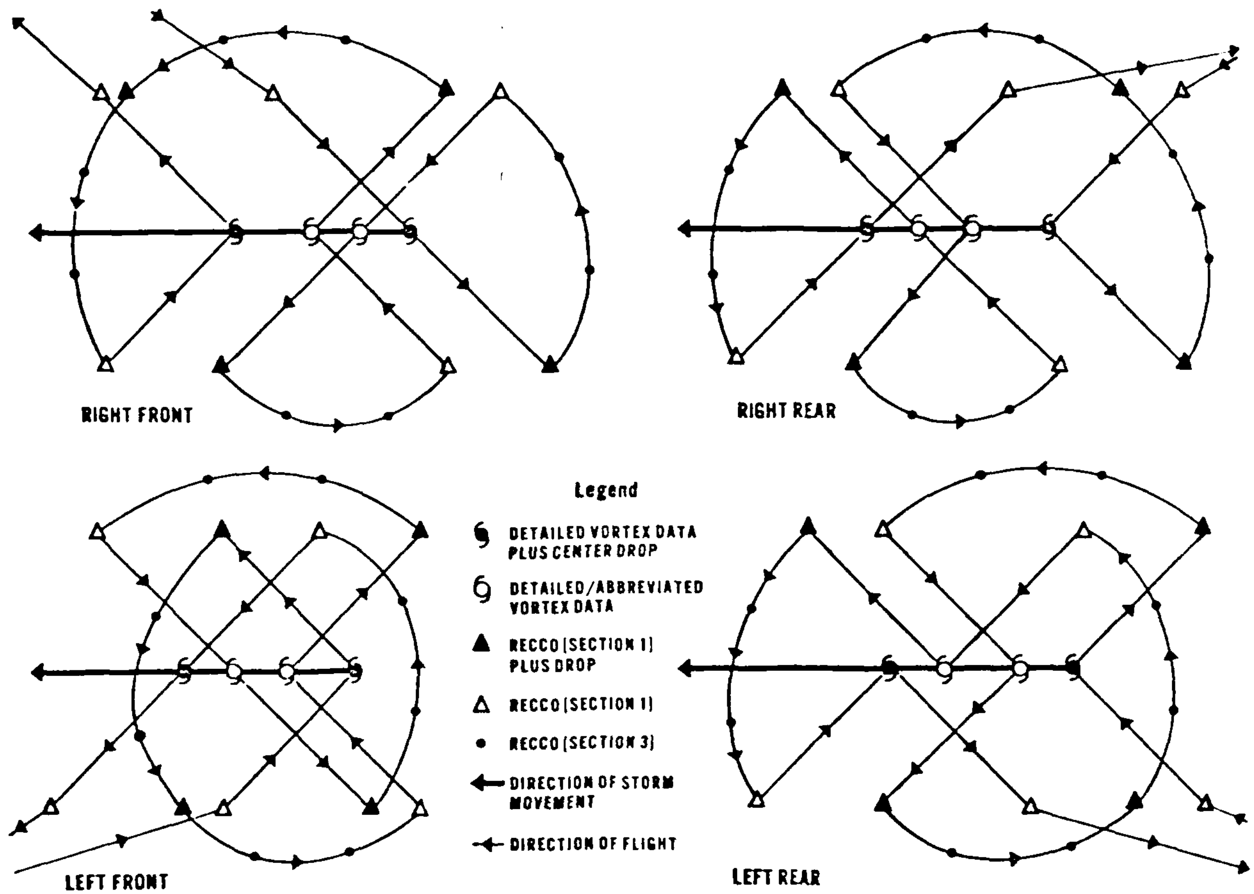


Figure 14. Pattern Execution.

Aircraft reconnaissance requirements are normally tasked by the Tropical Cyclone Plan of the Day (TCPOD) which specifies the times for vortex fixes, type of pattern, and altitudes for pattern execution as well as anticipated future requirements. Vortex fixes are normally levied at 6-hourly intervals but may be required at 3-hourly intervals if the cyclone is approaching land. Occasionally, vortex fixes are requested and provided at hourly intervals as the cyclone moves onshore.

d. Special Data Reporting. Weather reconnaissance data reporting on tropical cyclone missions involves modified RECCO observations and special observations used to report vortex fix data and vortex profile data collected on the radial legs of the flight patterns. RECCO observations reported for flight pattern observation points consist of the mandatory groups, surface wind group, and 9-group (RECCO Section 1). The first four groups (with a 95559 indicator as the first group), groups 6 through 8, the surface wind group, and the 9-group (RECCO Section 3) are reported for the intermediate observation points and are appended to RECCO Section 1 observations (DOC, 1977 and AWS, 1977b).

Vortex fix data are reported in Detailed Vortex Data Messages which are numbered in sequence with the other observations. Data reported in these observations include:

(1) Time of the vortex fix.

(2) Latitude and longitude of the fix.

(3) Minimum height of surface at standard level.

(4) Estimate of maximum observed surface wind and the bearing and range of that wind from the center.

(5) Maximum flight-level wind near the center and the bearing and range of that wind from the center.

(6) Minimum sea-level pressure.

(7) Maximum flight-level temperatures inside and outside the eye.

(8) Dew-point temperature and sea-surface temperature inside the eye.

(9) The "character" of the eye and its shape, orientation, and diameter.

(10) Confirmation of the fix time and coordinates, information on how the fix was made, and at what level the fix was made.

(11) Navigational and meteorological fix accuracy estimates.

(12) Amplifying remarks.

Detailed Vortex Data Messages are prepared and transmitted in an abbreviated form as soon as possible after penetration and are retransmitted later when all the required data are available (AWS, 1977b).

Supplementary Vortex Data Messages are used to report vortex profile data accumulated on the radial legs of the flight patterns. Supplementary Vortex Data Messages are numbered in sequence with other observations and include data on height of standard pressure surface (or sea-level pressure), temperature, and dew point at each of the required data points. Central sea-level pressure, height of the wall cloud, flight-level wind speed, and surface wind profiles are also reported when available. Dropsonde data (vertical observations) are numbered in sequence with the other observations on NHOP operational flight patterns. This procedure is somewhat unusual since vertical observations normally share the same number assigned to the corresponding horizontal observation on other types of missions. The data requirements of the JTWC flight patterns are less comprehensive than those required by the NHOP although the JTWC does require the Detailed Vortex Data message for vortex fixes.

e. Investigative Missions. Investigative missions are flown into suspected areas of tropical cyclone formation to determine whether or not a closed cyclonic circulation exists in the suspect area. Improved satellite data over the past few years have sharply reduced the requirement for investigative missions in the western Pacific and substantially reduced the number of investigative missions flown under the NHOP. These missions are still required to prove or disprove the existence of closed cyclonic circulations when rapid development is possible or as necessary to support the forecast center's operations.

Investigative missions are almost always flown during daylight and may well be timed to arrive in the suspect area at "first light" early in the morning or at "last light" in the evening. The procedure normally used on investigative missions is to take observations within the suspect area and locate winds supporting a cyclonic circulation if they exist. Investigative missions are usually flown in areas which experience flow from one predominant direction, in most cases, easterly flow. As the mission is flown, windshifts are watched for and, if found, are used to alter the mission track to locate other winds which support cyclonic flow. "Closing" the cyclonic circulation requires locating cyclonic winds which completely surround the cyclone center to prevent being misled by a trough embedded in the predominant flow regime or by other phenomena such as winds directly associated with the "enhanced convective activity" normally encountered in the suspect area.

In the high-pressure environment of tropical cyclone reconnaissance, investigative missions frequently are among the most challenging to the skills of the ARWO and the rest of the aircrew. Weak pressure gradients, large calm areas, and light winds coupled with heavy convective activity frequently make vortex fixes difficult to make on the weak tropical cyclones usually encountered on investigative missions.

f. <u>Weather Reconnaissance in Support of AFGWC (Volant Met).</u> AFGWC frequently requires upper-air data in quantity in areas where such data are not normally available (so-called "data sparse" areas). Weather reconnaissance missions are frequently flown during the winter months to provide 400-mb and 300-mb data in the Gulf of Mexico and off the Northwestern United States in support of AFGWC forecasting operations.

A number of special reconnaissance tracks have been developed and published for use on AFGWC support missions. Normal RECCO observation spacing and format are used for most of these missions with dropsonde data provided as required on the published tracks or the computer flight plans produced for the missions.

Most AFGWC support missions in the past 2 years have been flown from McChord AFB, Washington by both active duty and Reserve aircrews. Occasional missions in the Gulf of Mexico are also flown by crews from the squadrons at Keesler AFB. Routine training missions flown in the Gulf of Mexico area may also satisfy secondary AFGWC requirements when "hard-tasked" missions are not levied.

g. <u>Tactical Support Missions (Volant Cross).</u> Weather reconnaissance tactical support missions can normally be considered as falling into one of two basic categories: pathfinder or scout missions and area reconnaissance missions. The customer for tactical support missions is normally the weather support function at the highest level of command directly involved in the supported operation. For pathfinder or scout missions supporting tactical aircraft deployments, the mission customer is the weather support unit at major command level.

Pathfinder or scout weather reconnaissance missions are flown along the planned route for tactical aircraft deployments to investigate flight-level winds along the route and weather conditions in any refueling or special operating areas. Standard RECCO observations are normally taken on these missions and wind factor data are reported for track segments and for the entire track in remarks appended to the RECCO observations. The vast majority of peacetime tactical support missions are of the pathfinder or scout type.

Area reconnaissance missions are flown to support special operations within a specified area of tactical operations. The observation format used may be standard RECCO or specialized reporting codes.

In connection with tactical operations it is worth considering that WC-130 aircraft are unarmed modifications of slow turboprop transport or rescue aircraft. The survivability of such aircraft in a high-threat environment is limited unless adequate escort is provided or other protective measures are taken. Also, the number of operational squadrons and the number of weather reconnaissance aircraft have been reduced in this decade to the point that operational priorities have to be considered in allotting WC-130 resources against peacetime requirements. The demand for weather reconnaissance support during the tropical cyclone season and other peak operational periods is frequently so great that WC-130 aircraft and crews are not available for the lower priority missions.

The survivability of the WC-130 and the limited number in the inventory suggest that their commitment to high-risk missions in a combat environment be made only after careful consideration of the risks involved versus the necessity of obtaining weather reconnaissance data. The capability of performing combat weather reconnaissance and other missions in a limited-threat environment is maintained by all weather reconnaissance squadrons.

h. <u>East Coast Winter Storms Missions (Volant Coast).</u> Because of the threat of severe and crippling winter storms along the east coast of the United States, special arrangements have been made to provide weather observations for use in providing forecasts and timely warnings of their onset. The National East Coast Winter Storms Operations Plan has been developed and implemented since 1969 to coordinate the use of surface platform, aircraft, and satellite observations for forecast and warning use and, if practical, to meet the data requirements of research facilities. The plan is specifically developed to cover the time of year having a high incidence of winter storms along the East Coast, 1 November to 15 April, and generally considers only special arrangements between various agencies that are necessary in providing special weather observations (DOC, 1976).

The 53 WRS and 815 WRS from Keesler AFB fly special missions off the East Coast to provide data for forecasts and analyses produced by the National Meteorological Center (NMC) and for use of military forecast facilities. The requirements for winter storms missions, the tracks requested, control points and times, special observations or dropsonde release points, and other information are specified in a Reconnaissance Winter Storm Plan of the Day (WSPOD) produced by the Storm Coordination Center (SCC) in Washington D.C. Horizontal observations are taken in standard RECCO format at least every 30 minutes with midpoint data required between successive observations. Vertical observations are made as requested in the WSPOD (DOC, 1977).

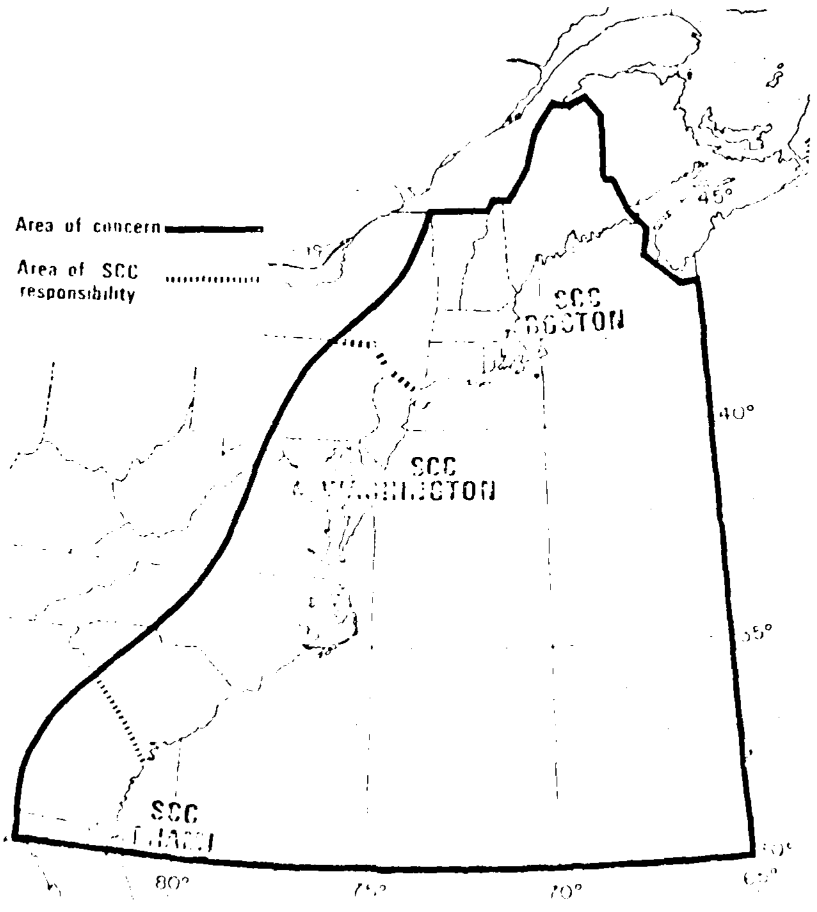
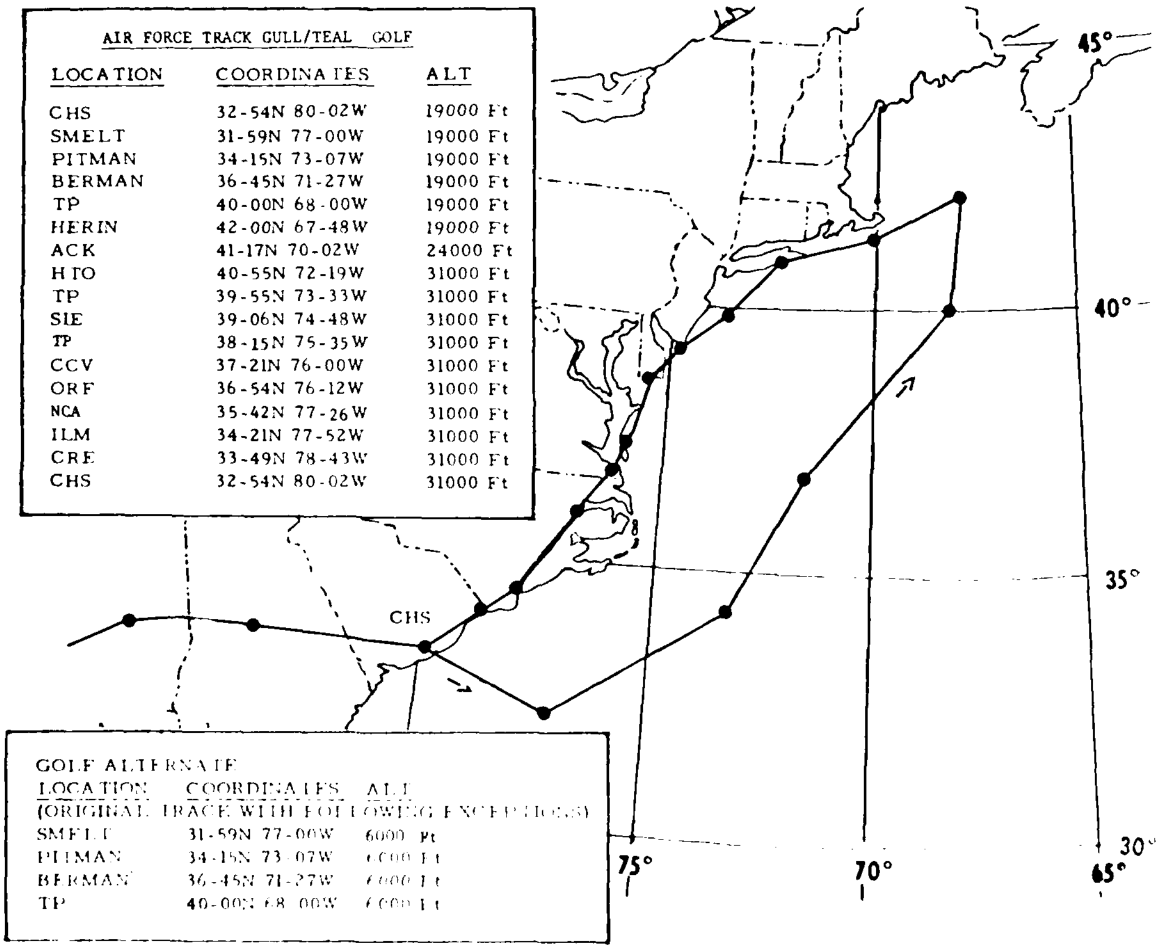


Figure 15. Area of Concern for East Coast Winter Storms Missions.

Several reconnaissance tracks have been designed to support the weather reconnaissance winter storms operation. All the reconnaissance tracks are designed to provide coverage in the near coast region of the "area of concern" delineated in Figure 15 (DOC, 1977). A typical reconnaissance track flown in support of winter storms forecasting is illustrated in Figure 16 (DOC, 1977). The reconnaissance tracks are normally flown from Keesler AFB and may require 11 to 13 hours flying time to complete. Because of the adverse weather conditions and the requirement for a relatively high density of data, particularly dropsonde data, winter storms missions are frequently among the more challenging missions flown during the winter season.

i. Specialized Reconnaissance Missions. Many different types of missions are flown by weather reconnaissance crews for agencies that require specialized data and that require data in support of special operations. Many missions have been flown in support of manned space flight and missile testing activities and to provide "ground truth data" for evaluating satellite systems. Atmospheric sampling and fog dispersal operations have been conducted by weather reconnaissance crews on missions in various parts of the world.

Many of the missions flown by weather reconnaissance crews are of a sensitive nature and involve special procedures, techniques, and observations. The range of activity is quite large and involves considerable variation within the basic concept of aerial weather reconnaissance. In the final analysis, the utilization of weather reconnaissance forces is limited by the operational capability of the airframe and crew and, more importantly, by the imagination and requirements of individual customers.



AIR FORCE TRACK GULL/TEAL GOLF

LOCATION	COORDINATES	ALT
CHS	32-54N 80-02W	19000 Ft
SMELT	31-59N 77-00W	19000 Ft
PITMAN	34-15N 73-07W	19000 Ft
BERMAN	36-45N 71-27W	19000 Ft
TP	40-00N 68-00W	19000 Ft
HERIN	42-00N 67-48W	19000 Ft
ACK	41-17N 70-02W	24000 Ft
HTO	40-55N 72-19W	31000 Ft
TP	39-55N 73-33W	31000 Ft
SIE	39-06N 74-48W	31000 Ft
TP	38-15N 75-35W	31000 Ft
CCV	37-21N 76-00W	31000 Ft
ORF	36-54N 76-12W	31000 Ft
NCA	35-42N 77-26W	31000 Ft
ILM	34-21N 77-52W	31000 Ft
CRE	33-49N 78-43W	31000 Ft
CHS	32-54N 80-02W	31000 Ft

GOLF ALTERNATE

LOCATION	COORDINATES	ALT
(ORIGINAL TRACK WITH FOLLOWING EXCEPTIONS)		
SMELT	31-59N 77-00W	6000 Ft
PITMAN	34-15N 73-07W	6000 Ft
BERMAN	36-45N 71-27W	6000 Ft
TP	40-00N 68-00W	6000 Ft

Figure 16. Typical Flight Pattern for East Coast Winter Storms Missions.

Chapter 6

WEATHER MODIFICATION

"Something else that appeared in Southeast Asia which no other combatant ever had in time of war was the capability to make it rain. The theory went that if the normal monsoon season could be extended the resultant mud on the main lines of communication from North Vietnam through Laos and Cambodia into South Vietnam--in the general vicinity of the Ho Chi Minh trail--would measurably reduce the flow of men and material to the enemy. According to the Pentagon Papers rainmaking was a course of action first proposed to President Johnson in February 1967 based on successful tests during 'Operation Pop Eye' in Laos the previous October. While the program came under fire from certain segments of Congress, top secret Defense Department testimony made public in May 1974 revealed that Air Force WC-130s and RF-4Cs dropping silver iodide during each southwest monsoon from 1967 to 1972 increased rainfall by approximately 30 percent in certain areas, according to some estimates, and slowed the flow of enemy supplies. The feeling was that, at a cost of $3.6 million annually, rainmaking was less costly than the traditional air interdiction methods. More important, it saved lives. It was more humane. Successes with the original rainmaking tests in Laos led one American ambassador to observe that the United States should 'make mud, not war!' (Reproduced without the footnotes from Fuller, 1974).

The capability to partially modify atmospheric phenomena has existed for several years in both military and civilian organizations in this country and elsewhere. Most of the weather modification capability is associated with enhancing convective activity to produce rain or with dissipating fog in order to produce increased visibility for aircraft or other operations. Air Force WC-130 weather reconnaissance squadrons maintain a weather modification capability for cold-fog dissipation, with limited involvement over the past few years.

Fog Dispersal

A great many techniques have been investigated for the operational dissipation of both "warm" fog and stratus and supercooled or "cold" fog in various regions of the world. Most of the airborne techniques for dissipating fog rely on "seeding" the fog deck with hygroscopic nuclei or other materials which increase condensation or the formation of ice crystals and produce clearing when the resulting larger droplets or ice crystals fall as precipitation.

In the case of supercooled fog, the use of dry ice or silver-iodide smoke to dissipate fog depends on the ability of these agents to initiate the Bergeron-Findeisen precipitation process. The process requires the coexistence of ice crystals and supercooled water droplets in the fog. Because the vapor pressure over ice is lower than the vapor pressure over water, the ice crystals created by the seeding agents grow at the expense of the water droplets and eventually fall as small ice crystals or snow flakes. As dry-ice particles fall they produce intense local cooling, resulting in the activation of large numbers of ice nuclei which can grow into ice crystals if the ambient air temperature is below freezing and sufficient moisture is available. Silver-iodide seeding produces ice crystals in a different manner. Silver-iodide pyrotechnics produce a vapor which subsequently condenses to form tiny crystals consisting of silver iodide, potassium iodide, and traces of other compounds. These tiny crystals serve as ice nuclei on which ice crystals can grow at ambient temperatures colder than about -5°C (AWS, 1969).

Tests of an airborne warm-fog seeding apparatus were conducted in 1971 using two modified Tactical Air Command C-130 aircraft (modified [illegible]) to dispense a hygroscopic solution from spray booms below and behind the cargo ramp in the aft fuselage. The hygroscopic seeding solution was developed by the Naval Weapons Center and consisted of four parts ammonium nitrate, three parts urea, and 6.76 parts water by weight. Seeding patterns were single straight lines flown [illegible] upwind of a transmissometer and at 400 feet above the ground (Chary, 1974).

At no time during the test period of seven seeding operations were any areas of clearing observed. It was determined that most of the seeded fog never drifted over the transmissometer due to wind fluctuations. The results of the tests indicated that targeting difficulties would make any attempt to develop an operational capability impractical if it was based on existing seeding systems and known hygroscopic materials (Chary, 1974).

The targeting problem in the airborne dispensing of seeding materials for fog dissipation results from the difficulty in determining how the light and variable winds involved in most fog situations will move the cleared area after seeding. Considerable effort must be expended to determine the wind field above the fog deck and select a series of seeding lanes upwind of the [illegible] target area. The seeding lines must be long enough and at sufficient [illegible]

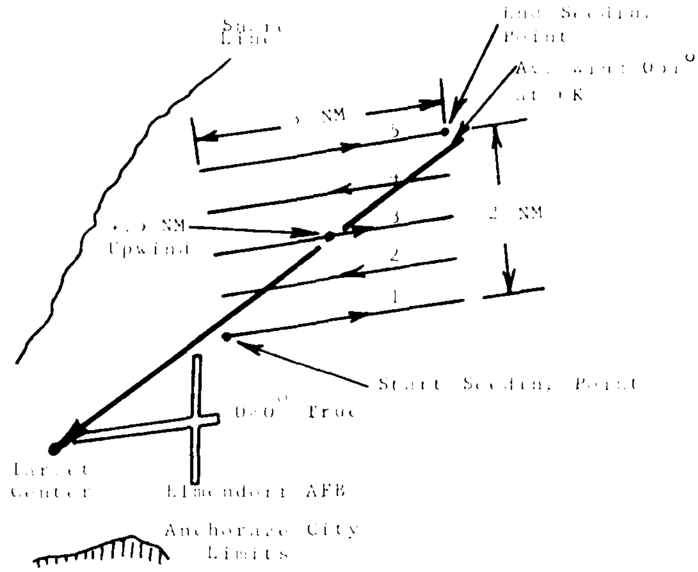


Figure 17. An Early Fog Seeding Pattern.

permit clearing as large an area as required. The orientation of and spacing between successive lanes must be adjusted for the average resultant wind to assure that a wide clear area is created and drifts over the target area instead of many clear lanes which miss the target or do not provide sufficient clearing in the target area. An example of an early airborne seeding pattern is given in Figure 17 as adapted from AWS TR 74-247 (Chary, 1974).

In contrast to the dissipation of warm fog, the airborne dissipation of supercooled fog or "cold" fog has achieved considerable operational success despite its expense and aircraft availability problems due to maintenance difficulties in cold operating environments. Airborne seeding with dry-ice pellets had been shown to be effective in creating holes in supercooled clouds as early as 1946. In the early 1960's the Air Force Cambridge Research Laboratories (AFCRL) experimented with a prototype dry-ice pellet dispenser. Contracted dry-ice seeding was used in the winter of 1965-66 at Fairchild AFB, Washington, and resulted in nine launches and five recoveries attributable to the seeding (Chary, 1974).

In August 1967, AWS was assigned the mission of cold-fog dissipation at Elmendorf AFB, Alaska. The undertaking became known as Project COLD COWL and, since it was the only reasonably proven agent suitable for operational use, dry ice was selected for seeding activities. A dry-ice crusher which was capable of producing dry-ice pellets up to 1 cm in diameter was installed on a WC-130 for the operation. Airborne seeding patterns consisted of five parallel lanes each about 2 miles long and 1/4 mile apart and were flown far enough upwind (around 30 to 45 minutes) to allow the clearing to be fully developed as it passed over the runway. Of the 37 missions flown, 25 successfully cleared the target area and permitted 185 aircraft takeoffs or landings (Chary, 1974).

Additional tests were run using various operational techniques and procedures and using other seeding materials. Dry ice and silver iodide (dispensed from modified ATO bottles attached to the sides of the aircraft ahead of the paratroop doors) were found to be the best seeding agents. Successful silver-iodide seeding, however, required a temperature of -5°C or colder (Chary, 1974).

In the winter of 1968-69 the seeding pattern was lengthened and widened but the basic operation remained the same. Operational airborne cold-fog dissipation activity was extended to Europe during this period under Project COLD CRYSTAL. The same operational procedures were used on a test basis in Europe that had proved successful in Alaska. Although COLD CRYSTAL was run on a test basis, several aircraft made ready use of the clearings produced. Operational seeding under both projects continued through the winter of 1970-71. For the 1971-72 winter, Projects COLD COWL and COLD CRYSTAL were combined into Project COLD CLEAR which was intended to be a continuing operational program designed to provide cold-fog dispersal to Air Force bases in Alaska and Europe. The Alaskan effort saw the greatest success that season with somewhat disappointing results in Europe due in part to above average temperatures and below average cold-fog occurrences (Chary, 1974).

TABLE 12. SUMMARY OF WC-130 AIRBORNE COLD-FOG SEEDING RESULTS.

AIRCRAFT MOVEMENTS PERMITTED BY COLD-FOG DISSIPATION EFFORTS

YEAR	PROJECT/LOCATION	LANDINGS	TAKEOFFS
FY68	COLD COWL/Elmendorf AFB	94	91
FY69	COLD COWL/Elmendorf AFB	180	155
FY70	COLD COWL/Elmendorf AFB	120	[illegible]
	COLD CRYSTAL/Germany	77	77
FY71	COLD COWL/Elmendorf AFB	171	217
	COLD CRYSTAL/Germany	80	155
FY72	COLD CLEAR/Alaska	127	[illegible]
	COLD CLEAR/Europe	15	[illegible]
FY73	COLD CLEAR/Alaska	77	45
	COLD SIGHT/Germany	[illegible]	[illegible]

In the winter of 1972-73 yet another name change had been made so that it [illegible] to refer to the Alaskan effort and Project COLD SIGHT to contingency weather modification [illegible] Europe. In Alaska the WC-130 aircraft was used as a backup to the new [illegible] dispenser network. Airborne fog seeding was used on six separate days with [illegible] of nearly continuous seeding. Much of the time the fog was too thin and patchy [illegible] clearing but the airborne system was credited with 45 launches, 77 recoveries, [illegible] diversions during airborne seeding operations. Six of the diversions were [illegible] earlier than their estimated time of arrival (ETA) and were unable to hold [illegible] et al., 1973). Since the propane dispenser network installed at Elmendorf was providing [illegible] excellent seeding support the airborne portion of the project was terminated in February [illegible]. In Europe, WC-130 support was deployed for Reforger IV operations but was not used for seeding since cold fog did not prove to be a significant problem during the exercise. Table 12 summarizes [illegible] the results of WC-130 operational cold-fog seeding during the primary operational years (Chary, 1974 and Chary, et al., 1973).

The success of the propane dispenser networks at some of the bases with a high rate of occurrence of cold fog has eliminated the necessity of maintaining deployed WC-130 fog dissipation aircraft at those bases. WC-130 cold-fog dissipation support is still available on a contingency basis for operations where propane systems are not installed and has been utilized for at least one major operation since 1973.

Equipment required aboard the aircraft for cold-fog dispersal consists of a Meteorology Research, Incorporated Dry Ice Crusher/Dispenser and several dry-ice chests to provide on-board dry-ice storage (AWS, 1969). The ice crusher/dispenser is attached to the cargo floor near the dropsonde system operator's console. With the dropsonde dispenser removed, the crushed dry ice is dispensed through the resulting opening in the underside of the fuselage or, alternatively, through an open paratroop door. The crusher/dispenser is operated as necessary by the dropsonde system operator with "ice chunking" assistance from other personnel.

Test programs and operational missions demonstrated that airborne seeding of supercooled fog could materially contribute to a more even and uninterrupted flow of aircraft traffic through Elmendorf AFB; that dry ice can effectively dissipate supercooled fog at temperatures [illegible] warm as -0.2°C at the surface, in decks deeper than 1000-feet thick, and in winds stronger than 10 knots; that silver-iodide aerosols are as effective as dry ice in fog at temperatures colder than [illegible]; and that compensating for winds which govern the movement of the clearings produced by the seeding is the single most important factor in effective cold-fog dissipation. Other results included the finding that clearings to above airfield minimums require about 60 minutes to achieve in daytime and about 45 minutes at night and that lanes spaced 3000 feet apart completely merge at Elmendorf while stronger winds and unstable lapse rates in Germany resulted in lane spreading [illegible]. Seeding rates of no more than 6 pounds per nautical mile into the fog were found adequate for the cold temperatures at Elmendorf (mostly below -10°C) while rates of no more than [illegible] pounds per nautical mile at temperatures equal to or below -2°C and 30 pounds per nautical mile for warmer temperatures were required in Germany (AWS, 1969).

Precipitation Augmentation

A great deal of misinformation exi[illegible] and elsewhere to exercise control over weather phenomena. [illegible] false impressions in a media-conscious world [illegible] increasingly aware of the atmospheric scales in which weather [illegible] of satellite photographs and radar displays on television [illegible] increasing awareness of the effect of severe weather phenomena [illegible] world in creating a climate in which considerable [illegible] atmospheric research projects and other efforts. [illegible] suggest the ability to produce drought and extensive flooding, [illegible] other severe weather, and to produce widespread and sweeping [illegible] weather modification and "weather warfare" have become [illegible] popular press with the vast majority of these writings [illegible] relationship to meteorological fact, theory, or practice.

Most civilian weather modification efforts have been [illegible] suppression activities which have produced varying degrees [illegible]. Most Air Force weather modification efforts have been directed toward [illegible] generally a secondary effort in precipitation augmentation. While [illegible] research efforts, the main Air Force emphasis has been on [illegible] relatively proven techniques.

It must be emphasized at the outset that the present capability in either the [illegible] military community is not by any means advanced to the point that [illegible] can produce rain from a cloudless sky. If synoptic conditions are such that the formation of "seedable" clouds is inhibited (as is normally the case in severe droughts), then nothing can be done by man to produce precipitation. Precipitation enhancement is only effective in instances where "proper" clouds are forming but are not efficiently precipitating (Sax and Cress, 1971).

For purposes of weather modification activities involving cloud seeding it is convenient to consider two basic types of operation: warm-cloud seeding and cold-cloud seeding. Convective clouds which fail to grow above the 0°C-isotherm level are classified as warm clouds. In temperate latitudes, such clouds seldom produce precipitation because they do not achieve sufficient depth to provide time for a broadening of the drop-size spectrum and the initiation of efficient coalescence. In theory, placing properly sized hygroscopic materials (such as urea or sodium chloride) into the updraft region of the cloud should hasten coalescence and permit precipitation. Although considered promising, this technique is not used for operational applications within the Air Force (Sax and Cress, 1971).

Cold clouds are considered to be convective clouds with tops above the 0°C-isotherm level. The approach to seeding cold clouds relies upon converting cloud water from the metastable supercooled liquid state into the stable ice phase. Ordinarily, significant conversion of supercooled water droplets to ice does not occur in the atmosphere at temperatures warmer than around -20°C. However, the addition of an efficient nucleating agent (such as silver iodide) into the cloud's updraft region causes ice-crystal formation at temperatures as warm as -4°C. Because the vapor pressure over ice is less than that over water at the same supercooling temperature, any ice crystals present in a mixed-phase cloud will grow faster than the coexisting water droplets. The resulting growth leads to a broadening of the particulate spectrum, initiation of the coalescence process, and colloidal instability with the onset of precipitation. This seeding to produce colloidal instability has been referred to as the "static" approach and only requires the introduction of sufficient ice-forming nuclei to initiate coalescence (Sax and Cress, 1971).

In regions where maritime tropical air provides sufficient moisture for the formation of broad, deep, supercooled convective clouds (cumulus congestus), a "dynamic" approach to seeding has been found to be very effective in augmenting precipitation. Proper application of the dynamic approach substantially influences the dynamic growth of the cloud as well as affecting the microphysical processes inside the cloud. About 80 calories of fusional heat are released to the environment for every gram of water frozen in the water-to-ice conversion process. Once a mixed phase, water-to-ice cloud is established, the direct deposition of water onto ice-crystal surfaces produces additional heating. A massive injection of ice nuclei may result in the total amount of fusional and depositional heat produced in the conversion process being large enough to greatly increase the buoyancy of the cloud mass and thus produce enhanced vertical and horizontal development with pronounced development occurring if a weak inversion (stable layer) is capping normal cloud growth. The resulting larger cloud mass will in theory have a longer lifetime and be more efficient at producing precipitation from available moisture so that the resulting rainfall will be significantly increased over that which would result from unseeded clouds. The dynamic approach has been utilized in most Air Force cloud seeding operations (Wax and Green, 1976).

GROMET II was a precipitation augmentation project developed and carried out at the request of the Republic of the Philippines. U.S. Air Force units were assigned the responsibility for cloud seeding operations with technical assistance from the Naval Weapons Center. Project operations were conducted from Clark AB, Republic of the Philippines, using two WC-130 seeding aircraft from the 54 WRS and silver-iodide pyrotechnics supplied by the Naval Weapons Center (Chary, 1974).

The seeding was done using silver-iodide flares dropped from special racks attached to the air deflector doors located aft of the paratroop doors on the WC-130s. Cumuli with a hard, cauliflower appearance were the prime targets for seeding with best seeding conditions being found in large cumulus towers ... which were developing new supercooled turrets on the upwind side of the cloud mass. In theory, seeding the upwind turrets as they developed enlarged and better organized the ... circulation which in turn led to an enhanced local rainfall (Chary, 1974).

Cloud seeding was conducted over the entire Philippine Archipelago from late April through ... 1969. Penetrations of convective clouds were made at altitudes from 17,000 feet to 19,000 feet and anywhere from ... to 2000 feet below the top of the target cloud. One silver-iodide flare was dropped every ... seconds while the aircraft was in the updraft. Penetration within about 500 feet of the top of the cloud turret was found to inhibit development of the cloud, possibly due to rapid entrainment of the drier air surrounding the turret. The actual effect of the seeding operations could not be determined although an estimated 30 billion cubic meters of water fell from seeded clouds and a marked improvement in agricultural production was observed (Chary, 1974).

Project COLD RAIN was the Air Force contribution to a large drought-relief program in south-central Texas which was organized and directed by the Bureau of Reclamation in 1971. The goals of Project COLD RAIN were to produce increased rainfall over that which would have occurred naturally over as wide a geographical area as possible, to investigate the response of clouds to seeding operations, and to refine and improve the precipitation augmentation techniques in use at that time. Seeding operations were conducted in June 1971 using three WC-130s from the 55 WRS operating from Kelly AFB, Texas (Wax and Green, 1971).

The operating area for Project COLD RAIN covered nearly 70,000 square miles with about 25 percent of the area being intensively seeded during the project. COLD RAIN operations were conducted from 6-30 June and involved 35 missions with more than 1000 penetrations into more than 200 individual cumulus towers. About 2700 flares were expended with each flare releasing 20 grams of silver iodide (Wax and Green, 1971).

The main difficulty in evaluating precipitation augmentation operations lies in determining how much of the resulting precipitation is actually due to the cloud seeding over and above the precipitation that would have occurred naturally. To partly alleviate this problem during Project COLD RAIN, extensive photographic coverage using 35mm cameras on the seeding aircraft and high altitude RB-57 photographic aircraft was used along with available surface radar observations and special recording procedures in developing and defining a set of "success" categories for the missions (Wax and Green, 1971).

The success categories were defined for evaluating COLD RAIN missions as follows:

a. Category A. Clouds responded explosively to seeding; seeded clouds exhibited anomalous growth when compared to unseeded clouds in the same general area; distinctively heavier or more widespread rain showers were observed to fall from the seeded clouds.

b. Category B. Clouds appeared to respond well to seeding but unseeded clouds in the same general area also grew and precipitated in a similar manner; a distinctive difference between seeded and unseeded clouds could not be readily discerned from aircraft visual observations.

c. Category C. Clouds showed poor response to seeding, either displaying negligible growth or even dissipating after seeding.

d. Category D. Growth and precipitation response of the seeded clouds relative to the unseeded clouds in the same general area could not be determined due to too small a sample or obstructed visibility from the aircraft.

Thirty-five cloud-seeding missions were flown with three missions on which flares were not fired. Silver-iodide pyrotechnics were used with 529 misfires in 3200 attempted firings. Of the misfires, ... percent were attributed to ignition relay problems and not to malfunctioning flares. Of the 35 missions, nine were category A, 10 were category B, six were category C (all occurring in the first week of operations), seven were category D, and three were unscored (flares were not expended) (Sax and Cress, 1971).

The relationship between cloud seeding and actual rainfall was impossible to determine during the COLD RAIN operation although there is little doubt that the seeding of suitable, supercooled convective clouds had a profound effect on subsequent cloud development in many cases. Analysis of the COLD RAIN operation was hampered due to the short duration of the project from a statistical rainfall analysis point of view and to the lack of a dense rain-gauge network or a calibrated S-band weather radar for the operation. However, of the 25 missions on which flares were expended and results determined, 19 (76%) gave evidence of enhanced cloud growth. Of the six missions where little or no cloud growth followed seeding, all took place in the first week of operations when convection in the target area was generally suppressed and only marginally suitable clouds were available for seeding (Sax and Cress, 1971).

Experience in Air Force cloud-seeding operations led the 9th Weather Reconnaissance Wing in 1974 to publish criteria which could be used on operational seeding missions. Despite the many variables involved, it was expected that the majority of clouds would respond favorably to seeding if the following criteria were met:

a. The cloud should be cumuliform with a top-to-base depth of at least 10,000 feet.

b. The cloud should have grown to at least the -4°C isotherm level, the point where silver iodide becomes an effective ice nucleus. The cloud should not have grown past the -20°C isotherm level, the point at which significant conversion of water to ice begins to occur by natural processes.

c. The cloud should possess a hard, cauliflower appearance indicating a "measurable" liquid water content ("measurable" implies the observation of water impinging on the windscreen of the aircraft after penetration) and be in a youthful stage of its life cycle.

d. The diameter of each cloud turret to be seeded should be at least one and a half miles.

e. The cloud turret should possess a well-defined updraft region, as determined by aircraft penetration.

These criteria would assure the maximum possible success in operational cloud seeding if such attempts were made. They were not intended to imply that clouds which did not meet all the above criteria would not respond to seeding (9WRW, 1974).

Project STORMFURY

The destructive potential of even relatively weak hurricanes or typhoons is so large that the losses from just one can be large enough to determine the success or failure of a small nation's economy and cause enormous human suffering. The average annual cost of hurricane damage to the United States runs around $450 million annually with over three times that amount of damage resulting from the effects of an intense hurricane such as Hurricane Betsy (1965) or Hurricane Camille (1969) (Sheets, n.d.). The cost of human suffering is beyond estimation. Project STORMFURY is a scientific effort to find techniques for reducing the intensity of severe tropical cyclones and alleviating much of the suffering and loss they produce.

Project STORMFURY had its formal beginnings as a joint Department of Commerce and Department of Defense (Navy) project designed to explore the structure and dynamics of tropical storms and to determine their potential for modification. From the formal inception of the project until 1971, AWS participated in a supportive role by supplying a limited number of aircraft for hurricane reconnaissance and intensity measurement. In September 1971, Air Force weather reconnaissance aircraft participated in the seeding of Hurricane Ginger (Chary, 1974 and Sheets, n.d.).

Four hurricanes were seeded under Project STORMFURY from 1961 through 1971: Hurricane Esther (1961), Hurricane Beulah (1963), Hurricane Debbie (1969), and Hurricane Ginger (1971). Varying degrees of success were observed but in every case except one indications of a reduction in wind speed were observed and there was no evidence of an increase in wind speed. Except for Ginger, each case involved seeding in or near the wall-cloud structure of the hurricane. The [illegible] seeding experiments were performed on a poorly-defined and diffuse tropical cyclone which made direct comparison with the results of the Hurricane Debbie experiments impossible. The two Debbie seeding experiments were the only ones conducted in a manner which resembles the [illegible] STORMFURY hypothesis (Sheets, n.d.).

The STORMFURY hypothesis has been developed to explain a process by which the intensity of a hurricane can be reduced for at least a short time period (6 to 18 hours). The hypothesis has undergone modifications as more data on the effects of hurricane seeding and more knowledge of the structure of hurricanes has been obtained. In general, the mid-1970's STORMFURY hypothesis was:

a. Clouds are seeded outward (away from the storm center) from the external edge of a mature hurricane eye wall.

b. The supercooled water in the seeded cloud freezes, latent heat of fusion is released, the buoyancy of the upper portion of the cloud increases, and increased ascent results in increased condensation rates and cloud growth.

c. The seeded cloud reaches the outflow level, providing a conduit for the major vertical mass transport at a larger radius.

d. The old eye-wall circulation weakens as the vertical mass transport is concentrated in the seeded clouds, and the subsidence in the eye decreases.

e. The maximum wind speeds are reduced due to the partial conservation of angular momentum and the decreased temperature gradients.

f. The pressure field adjusts to the wind and temperature fields.

g. Finally, the storm starts to return to its natural state, as determined by the synoptic-scale environment, some 6 to 18 hours after the final seeding.

Forming the basis for the STORMFURY hypothesis, hurricane modification research, including numerical simulation and field experiments in previous years, suggests that the maximum winds in hurricanes can be reduced by 10 to 20 percent when the proper clouds are seeded. Since the force of the wind varies with the square of the wind speed, reductions of 10 to 20 percent will result in a reduction of 19 to 36 percent in the maximum force of the winds with a comparable reduction in damage due to winds (Sheets, n.d.).

Recent efforts in Project STORMFURY have dealt with acquiring detailed data on hurricane structure and defining procedures and techniques for seeding operations when they are resumed (Sheets, n.d.). Most future STORMFURY seedings are expected to involve the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) research aircraft with high-density data acquisition capabilities and sophisticated instrumentation. Air Force participation in future STORMFURY operations is expected to involve the specially-modified AWS WC-130B due to the increased capability of its system as compared to those of other Air Force WC-130 aircraft.

Conclusion

As can be seen from the preceding discussions, we are far removed from the apocalyptic weather warfare capabilities postulated by science fiction writers and some of the less responsible segments of the communications media. At best, the current capability to modify weather phenomena is limited to relatively small areas and phenomena which exhibit a very small range of variation in their physical characteristics. Even the most ambitious weather modification effort as exemplified in Project STORMFURY involves several aircraft and at best can be expected to yield limited results over short time periods. Current airborne weather modification techniques have evolved over three decades of careful scientific research, investigation, and experimentation and have achieved limited but encouraging success in man's efforts to control some of the atmospheric phenomena which affect his daily existence. Currently, the only active on-going operational capability that AWS has in weather modification is the dissipation of cold fog.

Chapter [illegible]

FACTORS AFFECTING WEATHER RECONNAISSANCE EFFECTIVENESS AND IMPROVING [illegible] OF [illegible] RECONNAISSANCE [illegible]

Weather reconnaissance forces have been utilized in a wide variety of [illegible] since the end of World War II and have [illegible] in many different parts of the world using aircraft originally built to serve in other roles. Despite the [illegible] of weather reconnaissance missions flown over the years, very little [illegible] evaluating the effectiveness with which weather reconnaissance [illegible]. Improvements in weather reconnaissance [illegible] periods due to pressing priorities in the [illegible] determining the accuracy of meteorological [illegible] to provide an enhanced operational capability [illegible] WC-130B.

Factors Affecting Weather Reconnaissance Effectiveness

Unfortunately, a complete [illegible] analysis of the effectiveness of weather reconnaissance [illegible] considerably beyond the scope of this report. [illegible] examined operational [illegible] reconnaissance [illegible] reconnaissance [illegible] operations, and the effect of the availability [illegible] weather reconnaissance [illegible] on customer and other users' operations and forecast products. [illegible] such analyses provide [illegible] material for a report [illegible] this one. For that reason, only [illegible] of the factors influencing weather reconnaissance [illegible] will be qualitatively [illegible].

Aircraft availability [illegible] factor limiting weather reconnaissance effectiveness. The reduction in the number of weather reconnaissance [illegible] many missions have to be cancelled because the primary aircraft [illegible] aircraft are not available [illegible] aircraft. Some lower priority [illegible] "[illegible] season" or "typhoon season," because there simply aren't enough weather reconnaissance aircraft to meet the needs of all the customers who request weather reconnaissance data. Aircraft availability is a function of many variables [illegible] the number of aircraft in the fleet, and the location of the aircraft.

The WC-130 is a remarkably sturdy and reliable aircraft but requires [illegible] effort to meet the demanding requirements of weather reconnaissance operations. [illegible] inspections and routine maintenance may remove an individual airplane from operations for [illegible] days or even a month or more. Maintenance problems while deployed at forward operating locations may remove an aircraft from operations for lengthy periods if WC-130 maintenance [illegible] are not available at the operating location. Depot-level maintenance [illegible] away from flight operations for a month or several months at [illegible]. [illegible] discrepancies discovered in the aircrew's preflight inspection [illegible] or result in its cancellation. Aircraft maintenance [illegible] aircraft availability.

The small number of WC-130 aircraft and their concentration at one airfield in the continental United States and at one airfield on Guam also limits the availability [illegible] weather reconnaissance forces. [illegible] aircrews [illegible] Europe from Keesler AFB, [illegible] operations, for example, normally require [illegible] capability from a selected European airfield [illegible]. Tropical cyclone reconnaissance operations in the western Pacific require [illegible] aircraft during the typhoon [illegible] that aircraft and crews are flown from Keesler AFB to augment the [illegible] on Guam. Aircraft [illegible] and crew duty day restrictions make this a lengthy process [illegible] the initial and final [illegible] the season. As an economy measure, central control of weather reconnaissance aircraft is necessary but limits the effectiveness of a worldwide reconnaissance effort in responding to [illegible] requirements in areas far removed from the home [illegible]. The location of the [illegible] in [illegible] especially limits their effectiveness during the hurricane season since most tropical cyclone reconnaissance is conducted outside of the Gulf of Mexico in the Caribbean Sea and the western Atlantic Ocean areas. WC-130s have to be deployed to forward operating locations to ensure adequate reconnaissance coverage of tropical cyclones throughout their life cycles. Deployments are also necessary in the western Pacific due to the immense areas involved, but are generally [illegible] due to the more favorable central location of Guam within the normal operating area.

Probably the most significant factor in determining weather reconnaissance effectiveness is the ability of the sensor systems and current data reduction procedures to provide the type of high-density and high-quality data demanded by current and anticipated forecast techniques. The current sensor systems do not provide the reliability and accuracy necessary to meet mission requirements anticipated for the late 1970's and early 1980's and are hampered by the essentially manual data-reduction techniques now used, improved as they are by the use of the new hand-held calculators. Many of the SEEK CLOUD systems are no longer in production and are becoming more difficult to maintain in reliable operating condition. The ability of weather reconnaissance crews to provide quality data is becoming heavily dependent on operator skill in overcoming basic meteorological system limitations.

In a related area, the effectiveness of weather reconnaissance forces is also hampered, severely in some cases, by the current communications methods and procedures used to transmit data to the mission customer and to other users. Long-range voice-radio communications are subject to widely varying propagation conditions and the handling of data at two or more points by human operators inherently enhances the possibility of error, particularly if one of the operators is unfamiliar with the data and its coded format. More advanced long-range communications techniques have been in use for several years but, except for AWRS, have not been used aboard WC-130 aircraft due to the relative expense of such systems and the inability of some monitor facilities to handle radio teletype data. Weather data is very perishable and excessive delay in providing data to operational customers may seriously degrade its usefulness. Delays of several minutes to several hours have been encountered using the current communications procedure.

Solutions to the problems affecting weather reconnaissance effectiveness are available but generally are expensive to provide in an increasingly cost conscious environment. The expense of maintaining a weather reconnaissance capability is greater than most nations can bear. All sorts of costs are involved in weather reconnaissance operations and range from personnel temporary duty expenses and normal aircraft operating expenses to the costs of the supply system and of maintaining administrative and maintenance organizations. Much of the effectiveness of weather reconnaissance forces must be evaluated by considering the lack of available funding for improved sensors and data handling equipment and for developing automated systems to acquire data on a high density basis and provide it on a real-time basis to the mission customer. Economic constraints are perhaps the most significant limiting factor affecting weather reconnaissance operations.

Improving the Weather Reconnaissance Force

A number of concepts have been developed for improving the data acquisition and data communication capabilities of the WC-130 fleet over the past few years. As early as 1966, AWS was required to develop a "Minimal Program for Development of Sensors for Weather Reconnaissance Aircraft" which resulted in Project 5222, Sensors for Weather Reconnaissance Aircraft, established in October 1966. Project SEEK CLOUD was initiated to provide an interim improvement in sensor capability in the WC-130 aircraft as one result of Hurricane Camille's destructive rampage across the Gulf Coast in 1969. The "interim" SEEK CLOUD sensors have been in use for most of this decade. In 1971, development of an advanced system was directed and culminated in the present preproduction version of the AN/AMQ-32 AWRS installed on a single AWRS WC-130B.

The requirements for improved weather reconnaissance have been stated in the June 1974 Final Report of the USAF Scientific Advisory Board Geophysics Panel Task Group on Tropical Cyclone Forecasts (SAB Report) and in an August 1975 DOC/DOD Interdepartmental Ad Hoc Group Report on Aerial Weather Reconnaissance. The reports confirm a continuing need for weather reconnaissance and for modern instrumentation and data handling techniques in improving the effectiveness of weather reconnaissance. The National Academy of Science supported the conclusions and recommendations of the Ad Hoc Group Report in a review of its final version.

1. The AN/AMQ-32 Airborne Weather Reconnaissance System (AWRS). The preproduction version of the AN/AMQ-32 AWRS is presently installed on a WC-130B operated by the 53 WRS and based at Keesler AFB, Mississippi. The system was developed to provide a capability to obtain high-quality data in the density expected to be required by the numerical forecasting models envisaged for the mid and late 1980's. The AWRS is a complex and expensive system that is capable of providing high-quality data when properly utilized. The following paragraphs are intended to provide an introduction to the system and its utilization. It must be realized that a great deal of information has been omitted in the interests of brevity.

The AWRS consists of six interrelated subsystems: the Meteorological Data Converter Group (flight-level data sensing subsystem (FLSS)), the Meteorological Data Converter Group (vertical-profile sensing subsystem (VPSS)), Navigation Computer Set (navigation subsystem (NS)), the Meteorological Data Transmitter Group (communications subsystem), Data Analysis Central (automatic data processing subsystem (ADPS)), and the Control-Indicator Group (mission controller console/display subsystem (MCCDS)). A reasonably complete list of subsystem components is given in Table 13. A very simplified block diagram of the AWRS is given in Figure 16 (USAF, 1973).

Most of the system controls and indicating equipment are located at four points in the aircraft: on the flight deck navigator's panel; at the flight deck auxiliary ARWO position; on a large ARWO console in the forward cargo compartment; and at a dropsonde system operator's console in the cargo compartment near the right paratroop door. The flight deck navigator's panel contains the navigation control indicator which provides user access to the navigation computer and the ability to monitor, insert, update, and display navigation data from the navigation subsystem. The auxiliary ARWO position contains a few backup sensor indicators (such as the SCR-718 radio altimeter) and a "dedicated" display panel which provides an alphanumeric display of time, position, heading, and altitude information received from the ADPS. The cargo compartment ARWO console contains controls for activating AWRS subsystems, system components in an equipment rack, a keyboard for entering commands and data, a medium-speed printer for data output, a dedicated display, a "command" display on which selected alphanumeric data are displayed, a repeater radar scope, an O-15 camera for recording radar presentations, and auxiliary equipment. The dropsonde system operator's console contains controls for the vertical profile sensing subsystem, a keyboard for entering commands and data, the PRT-5 indicator and shutter controls, the radiosonde receiver, a high-frequency radio set control panel, other elements of the communication subsystem, and auxiliary equipment.

The AWRS is capable of providing high-quality data at frequent intervals along the aircraft flight path and has a navigation capability that is superior to that of the rest of the WC-130 fleet. An inertial navigation system and Omega navigation system are used to provide navigational accuracies on the order of 2 to 4 NM under good conditions. This navigational accuracy is combined with the ability to generate quality high-density meteorological data and, if the receiving site has a radio teletype capability, to transmit the data quickly and accurately to a mission customer. Against these qualities, the primary drawbacks to the AWRS include the expense of procuring and maintaining the system, the awkwardness of an input-output system using a medium speed printer (which may use upwards of three rolls of paper per mission), the location of the ARWO console in the cargo compartment with an inadequate view of the observation area, and the installation of the system aboard a limited-range WC-130B. Of these drawbacks, the cost of the system generally precludes its installation in its current form on the remainder of the WC-130 fleet.

b. The Improved Weather Reconnaissance System (IWRS). The need for improving the current weather reconnaissance system capability has been recognized for many years and the shortcomings of the current "interim" system become more evident each year. In December 1976 the Military Airlift Command produced a document which described the weather reconnaissance capability expected to be required in the near future, the shortcomings of the current system, and the capabilities required of any future system. The improved system described in the ROC is generally referred to as the Improved Weather Reconnaissance System (IWRS) within Air Force weather reconnaissance activities.

IWRS is still largely a concept with hardware development and deployment awaiting funding. Lack of IWRS funding in a viable system form may result in the adapting of new instrumentation to the current WC-130 system in an attempt to provide some of the capability of a complete IWRS. As an indication of some of the features of a modular, integrated IWRS the following list of characteristics of the desired system is extracted from the ROC:

(1) An improved navigation system.

(2) Improved wind determination.

(3) Improved flight-level sensors for more accurate measurement of meteorological parameters.

(4) The capability to determine vertical wind profiles below flight level.

(5) Automatic data processing and display.

(6) Improved telecommunications for transmission of weather data.

(7) Improved equipment maintainability and reliability.

(8) Growth capability.

TABLE 13. COMPONENTS OF THE AN/AMQ-32 AIRBORNE WEATHER RECONNAISSANCE SYSTEM (AWRS).

MAJOR SUBSYSTEM	COMPONENTS
Meteorological Data Converter Group OU-93/AMQ-32 (FLSS)	Static Pressure Sensor Differential Pressure Sensor Angle of Attack and Sideslip Sensors Hygrometer Control Unit Hygrometer Sampling Pump Hygrometer Filter Drain Hygrometer Flow Control Signal Conditioner Amplifier AN/APN-42A Radar Altimeter PRT-5 Precision Radiation Thermometer Linear Actuator and Sea-Surface Temperature Shutter Control Panel Probe Heater Controls
Meteorological Data Converter Group OU-94/AMQ-32 (VPSS)	AN/AMT-19 Radiosonde AT-896/A Antenna Radiosonde Receiver Radiosonde Decoder MX-9133/AMQ-31 Radiosonde Dispenser Radiosonde Dispenser Control Panels
Navigation Computer Set AN/AYK-12 (NS)	Navigation Control Indicator Receiver-Converter Group CN-1319/ASN-103(V) Inertial Measure Unit PP-6416/ASN-103 Control-Power Supply AN/AYK-6 General Purpose Computer (Navigation) N-1 Compass System AN/APN-147 Doppler Radar System Inertial Navigation Control Panel Antenna-Coupler
Meteorological Transmitter Group OT-72/AMQ-32	Liaison Communications Set Intercommunications Set AN/TGC-29(V) Teletypewriter Set TSQ-93(V) Distributor-Transmitter, Teletypewriter CV-786/TRC-75 Converter-Oscillator ARWO Communications Control Panel WO Communications Control Panel HFT Transfer Control Unit
Data Analysis Central AN/AYK-11 (ADPS)	Interconnecting Group Remote Analog-To-Digital Converter AN/AYK-6 General Purpose Computer TT-568/AGC-6 Teletypewriter Keyboard-Transmitter Medium Speed Printer Paper Storage Unit Magnetic Tape Control Panel Tape Annotation Switch Matrix Panel Status Panel
Control-Indicator Group OK-260/AMQ-32 (MCCDS)	Lighting Control Panel Power Control Panel Display Freeze Panel Display Control Panel Annunciator Panel Command Display Dedicated Display AN/APN-59B Radar Set O-15 Camera System

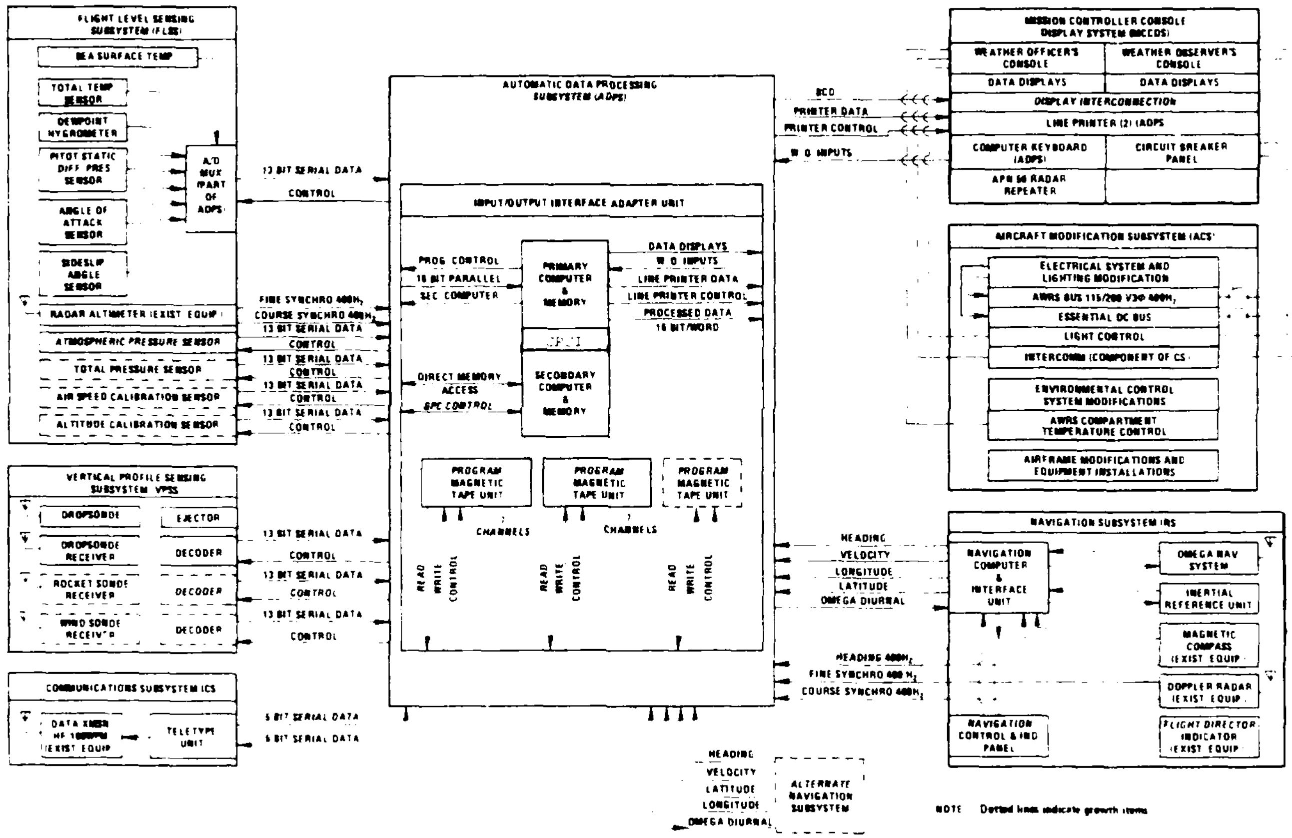


Figure 18. Simplified Block Diagram for the AN/AMQ-32 Airborne Weather Reconnaissance System.

The improvement in WC-130 weather reconnaissance effectiveness resulting from an IWRS capability would generally match that resulting from a fleet-wide deployment of an AWRS.

c. Other Improvements. The use of the Hewlett-Packard HP-97 calculator has greatly speeded data reduction aboard the WC-130. Special programs have been developed and have eliminated much of the paper-and-pencil effort previously involved in data reduction. As a result, more accurate and timely information can be produced on tropical cyclone and other missions.

Installation of Omega navigation systems on WC-130 aircraft should provide an improved navigational capability. This improved capability is especially desirable on tropical cyclone missions and in areas where coverage by other navigational aids is limited or nonexistant.

A wind-sounding capability is the subject of another ROC developed in May 1974 by the Military Airlift Command. The requirement for such a capability was identified as early as March 1952 and was included in the sensor requirements for the AWRS. The feasibility of operational techniques in producing wind soundings beneath aircraft has been demonstrated and developed by several agencies in recent years. The wind-sounding capability proposed in the May 1974 ROC also forms part of the desired capability of the IWRS.

Conclusion

A continuing effort has been made to improve the quality and effectiveness of the Air Force weather reconnaissance effort. New concepts for improved systems have been proposed and, in the case of the AWRS, developed to a point just short of installation on the entire WC-130 fleet. The current SEEK CLOUD sensor systems are rapidly aging, no longer in production, and have, in some cases, begun to demonstrate unsatisfactory relability in the operational environment. Implementation of an advanced system is badly needed at a time when the data requirements of weather reconnaissance customers are becoming more stringent.

REFERENCES AND BIBLIOGRAPHY

ARRS, 1976: Aerospace Rescue and Recovery Service Operations. ARRSR 55-1, Aerospace Rescue and Recovery Service, Scott AFB, Illinois, 1 November 1976.

Atkinson, Gary D., 1971: Forecaster's Guide to Tropical Meteorology. AWS TR 240, Air Weather Service, pp. 10-8 to 10-12 and Chapter 8, 1 April 1971.

AWS, 1969: A Summary of Field Activities Conducted Under USAF Test Directive COMBAT COLD, Final Report. Air Weather Service, Scott AFB Illinois, June 1969.

____, 1971: Draft Final Report of Comparative Meteorological Measurements from Weather Reconnaissance Aircraft. Ad Hoc Group on Comparison Tests of Meteorological Measurements from Weather Reconnaissance Aircraft, Air Weather Service, Airborne Systems Division, 28 May 1971.

____, 1973: WC-130 Payload Systems. AWSP 105-5, Chapter 3, Air Weather Service, 23 November 1973.

____, 1975: Weather Reconnaissance Observations. AWSR 105-25, Air Weather Service, 23 June 1975.

____, 1977a: ARWO Training Notes. Det 5, AWS, Keesler AFB, Mississippi, 19 April 1977.

____, 1977b: Tropical Cyclone Reconnaissance Guide, 1977. Det 5, AWS, Keesler AFB, Mississippi, 1 June 1977.

Barnes Engineering Co., 1970: Instruction Manual for Precision Radiation Thermometer Model PRT-5. T.O. 33A6-5-9-1, Stamford, Connecticut, 12 November 1970.

Bendix Corporation, 1968: Radio Dropsonde Technical Manual, Service Instructions. Environmental Science Division, June 1968.

Boehm, Albert, 1975: Estimated Improvement in Forecast Accuracy of the SANBAR Hurricane Model Using the Airborne Weather Reconnaissance System. USAFETAC TN 75-1, USAF Environmental Technical Applications Center, Scott AFB, Illinois, January 1975.

Chary, Henry A., 1974: A History of Air Weather Service Weather Modification, 1965-1973. AWS TR 74-247, Air Weather Service, June 1974.

____, et al., 1973: Sixth Annual Survey Report on the Air Weather Service Weather Modification Program (FY 1973). AWS TR 73-251, Air Weather Service, October 1973.

Church, James F. and Twitchell, Paul F.: Atmospheric Corrections for Airborne Radiation Thermometers. AFCRL ERP 399. Air Force Cambridge Research Laboratories, 26 April 1972.

Cole, Dave, 1973: Stalking Weather's Wicked Women. Airman, Vol XVII, No. 1, January 1973.

Department of Commerce, 1975: Report of the Ad Hoc Group on Aerial Weather Reconnaissance. Federal Coordinator for Meteorological Services, Subcommittee on Basic Meteorological Services, Rockville, Maryland, August 1975.

____, 1976: National East Coast Winter Storms Operations Plan. NOAA FCM 76-5, Washington, D.C., December 1976.

____, 1977: National Hurricane Operations Plan. NOAA FCM 77-2, Washington, D.C., May 1977.

Doherty, Dan, 1977: Circle of Terror. Airman, Vol XXI, No. 6, June 1977.

EG&G: Instruction Manual, Cambridge Systems Model 137-C3 Aircraft Hygrometer System. T.O. 12M3-4-2-1, Environmental Equipment Division (date unknown).

Fuller, John F., 1974: Weather and War. Military Airlift Command, Scott AFB, December 1974, p. 16.

Green, William, 1969: The Observer's Book of Aircraft. 1969 Edition, Frederick Warne and Co., Ltd., London, pp. 146-147.

Ruskin, Robert E. 1968: Measurement of Atmospheric Dewpoint from Aircraft. NRL Report 6725, Naval Research Laboratory, Washington, D.C., 12 June 1968.

Sax, Robert L. and Ted S. Cress 1971: Final Report-Project COLD RAIN. AWS TR 245, Air Weather Service, December 1971.

Sheets, Robert C.: Project STORMFURY Hurricanes - Can Their Destructive Force be Reduced? Reprint from the Mariner's Weather Log, (publisher and data unknown).

USAF, 1973: Preliminary Technical Manual, User's Manual, Weather Reconnaissance System AN AMQ-32. T.O. 12M1-2AMQ32-21, U.S. Air Force, 1 October 1973.

___, 1974: Partial Flight Manual, USAF Series WC-130B, WC-130E, and WC-130H Aircraft. T.O. 1C-130 (W)B-1, U.S. Air Force, 1 September 1974.

9WRW, 1974: Seeding Supercooled Cumulus Clouds. 9WRWP 105-7, 9th Weather Reconnaissance Wing, McClellan AFB, California, 15 October 1974.

___, 1975: Weather Reconnaissance Observations, Volume I. 9WRWR 105-1, 9th Weather Reconnaissance Wing, McClellan AFB, California, 1 January 1975.

Appendix A

SYSTEM SPECIFICATIONS FOR SELECTED METEOROLOGICAL SENSOR SYSTEMS

Barnes Engineering Company PRT-5 Precision Radiation Thermometer

1. Temperature measurement range (°C):

   -30 to +10 (LO)

   -10 to +40 (MED).....(Normally only this scale is calibrated for operational use)

   +20 to +80 (HI)

2. Accuracy (°C): 0.5

3. Response (Time constant):

Bandwidth	Time Constant
0.3	500 milliseconds
3.0	50 milliseconds
30	5 milliseconds

4. Reference temperature:

   45°C ±1/2°C

5. Ambient operating temperatures:

   -20°C to +40°C

6. Filter band:

   9.5 to 11.5 microns

7. Field of view:

   2 degrees (nominal)

AN/AMQ-34 Dew-Point Hygrometer

1. Dew-point range:

   -50°C to +50°C

   (The lowest dew point which can be measured is dictated by the ambient temperature at which the sensor is operating. In general, the system has the capability to measure dew points corresponding to 10 percent relative humidity at aircraft skin temperature. At an ambient temperature of +20°C the lowest measurable dew point is approximately -20°C.)

2. Accuracy:

   ± 0.5°C at ambient temperatures above or at 0°C

   ± 1.0°C at ambient temperatures below 0°C

3. Response:

   The sensor mirror typically cools or heats at a rate of 2°C/second at nominal depressions

4. Depression capability:

   36°C at 27°C ambient temperature; depression capability drops 1°C for each 3°C reduction from 27°C ambient temperature

5. Repeatability: ± 0.5°C

6. Ambient temperature limits:

Control Unit: $-20^{o}C$ to $+60^{o}C$
Sensor Unit: $-60^{o}C$ to $+70^{o}C$

1301A Pressure Transducer

1. Ambient temperature range:

   $-40^{o}F$ to $+130^{o}F$

2. Repeatability:

   0.2% full scale

3. Resolution:

   Infinite

4. Nonlinearity:

   [illegible].1% full scale maximum

5. Time constant:

   [illegible] milliseconds at 15 psia

AN AMT-13 Radio Dropsonde

1. Weight:

   4.7 pounds

2. Atmospheric measurement range:

   Pressure: 100 to 1060 mb
   Temperature: $+55^{o}C$ to $-85^{o}C$
   Relative Humidity: 5% to 100%

3. Radio transmitter:

   Relative Humidity Frequency: 402.5 ± 1.5 Mhz
   Type of Signal: Pulse time modulated
   Pulse Repetition Frequency: Variable 2400 Hz to 6050 Hz

4. Battery life:

   Approximately 20 minutes

5. Rate of fall (stabilized):

   4600 feet-per-minute (average)

The material in this appendix has been based on manufacturer's publications.

GLOSSARY

ADPS	automatic data processing subsystem
AFB	Air Force Base
AFCRL	Air Force Cambridge Research Laboratories
AFGWC	Air Force Global Weather Central
AFRES	Air Force Reserve
AFWTR	Air Force Western Test Range
AIMS	aneroid altimeter
ARE	atmospheric research equipment
ARRS	Aerospace Rescue and Recovery Service
ARWO	Aerial Reconnaissance Weather Officer
ATO	assisted take-off
AWRS	Airborne Weather Reconnaissance System
AWS	Air Weather Service
AWSPE	AWS Primitive Equation Model
CPHC	Central Pacific Hurricane Center
CRT	cathode ray tube
DOC	Department of Commerce
DOD	Department of Defense
EPHC	Eastern Pacific Hurricane Center
ETA	estimated time of arrival
FLSS	flight-level data sensing subsystem
FPM	feet per minute
HF	high frequency
Hg	Mercury
IWRS	Improved Weather Reconnaissance System
JTWC	Joint Typhoon Warning Center
LOPs	lines-of-position
ma	milliampere
MAC	Military Airlift Command
MCCDS	mission controller console/display subsystem
MPH	miles per hour
NASA	National Aeronautics and Space Administration
NCO	noncommissioned officer
NHC	National Hurricane Center
NHOP	National Hurricane Operations Plan
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NS	navigational subsystem
OAT	outside air temperature
PMEL	Precision Measurement Equipment Laboratory
PRF	pulse repetition frequency
PRT-5	precision radiation thermometer
RC	resistance capacitance
RECCO	weather reconnaissance code
RFF	Research Flight Facility
rms	root-mean-square
ROC	required operational capability
RPM	revolutions per minute
R/T	receiver/transmitter
RWRW	Rescue and Weather Reconnaissance Wing
SCC	Storm Coordination Center
SEO	Special Equipment Operator
SLP	sea-level pressure
STDE	standard deviation of error
TAS	true air speed
TCPOD	Tropical Cyclone Plan of the Day
US	United States
USAF	United States Air Force
USN	United States Navy
VPSS	vertical profile sensing subsystem
WMO	World Meteorological Organization
WRG	Weather Reconnaissance Group
WRS	Weather Reconnaissance Squadron
WRW	Weather Reconnaissance Wing
WSPOD	Reconnaissance Winter Storm Plan of the Day

DATE

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