# CHAPTER 2

# SYSTEMS AND EQUIPMENT

**2.1 Introduction**. This chapter describes the upper-air sounding systems and associated equipment used for fixed land-based, shipboard, and mobile rawinsonde observations taken by U.S. agencies. Upper-air systems are composed of a flight subsystem (inflated balloon, flight-train, radiosonde) and a ground-based subsystem (tracking, receiving, and signal- and data-processing equipment).

**2.2 Accuracy and Precision of the Measurements.** Table 2-1 presents accuracies and functional precisions of the measured variables: these ***shall*** be considered minimum standards. They are not to be interpreted as technical standards, but as quantities easily achievable with present (1997) technologies. Two important points about these specifications should be noted. The accuracy and precision of wind measurements depends upon the balloon-tracking system employed and the conditions under which the sounding is made. The geopotential height values are calculated and are a complicated function of the accuracy and precision of the individual pressure, temperature, and humidity variables. The values in the Table are based upon actual field tests (see Table 2-1 footnote #3).

**2.3 Flight Subsystem**. The flight subsystem is composed of a balloon, flight-train, and radiosonde. The free-flight meteorological sounding balloon is designed to lift the radiosonde to a desired height at a desired ascension rate. The flight-train connects the radiosonde to the balloon and *may* include a combination of parachute, train regulator, lights or radar reflector. The flight-train is designed to aid in radiosonde launching, flight, and descent. The radiosonde is composed of meteorological sensing instruments, telemetry encoders, and a radio-signal transmitter. The radiosonde is designed to make in-flight measurements and transmit them to the ground subsystem. The flight subsystem is designed to be expendable, although some radiosondes are recovered, reconditioned, and used again.

**2.3.1 Balloons.** Meteorological sounding balloons used for routine operational synoptic soundings are made of natural (latex) or synthetic (neoprene) rubber. The latex balloons tend to be more spherical when inflated and have a faster, more uniform ascension rate in the lower atmosphere. Comparatively, the neoprene balloons tend to be elongated vertically when inflated to the same lift and, because their tops tend to flatten when rising, have a slower, less uniform ascension rate. High wind launches are also more difficult with neoprene balloons. Severe weather and fast-rising balloons are also made, and are used for special conditions and purposes. Sounding balloons are made in a variety of sizes or weights. This variety allows for tailored performance in bursting height and ascent rates for combinations of gas type, lift, and payload weight. The inflation guidance and performance data of a specific balloon can be obtained from the balloon manufacturer. Typical lighter-than-air gasses used for upper-air soundings are hydrogen, helium, and natural gas. (See Chapter 3 and Appendix B for balloon preparation and inflation safety standards and guidelines.)

**2.3.1.1 Inflation Gases.** Hydrogen is used at most land stations because its price is only a fraction of the cost of helium. However, it is a highly combustible gas and can cause fires or explode. Hydrogen is either manufactured, compressed, and bottled by a gas distributor or produced locally at field sites by a hydrogen generator.

**Table 2-1 Accuracy and Precision of the Variables**

| Variable being Sampled | Range Capability of Measurement | Accuracy of Measurement[1] | Precision of Measurement[2] | Resolution of Measurement |
|---|---|---|---|---|
| Air Temperature | +50 to -90°C | 0.5°C | 0.40°C for 1050 - 20 hPa | 0.1°C |
| | | | 1.00°C for < 20 hPa | |
| Relative Humidity | 1 to 100% | 5% | 2.5% for 100 - 30% | 1% |
| | | | 3.5% for 29.9 - 1% | |
| Wind Speed | 0 to 225 knots | 3 knots<br>1.5 mps | 6 knots<br>3 mps | 1 knot<br>0.5 mps |
| Wind Direction | 360 degrees | 5 degrees | Varies with wind speed | 1 degree |
| Atmospheric Pressure | 1070 to 2 hPa | 2.0 hPa for P > 300 hPa | 1.5 hPa for 1050 - 100 hPa | 0.1 hPa for P > 50 hPa |
| | | 1.5 hPa for 300 # P < 50 hPa | 1.5 hPa for 99.9 - 50 hPa | 0.01 hPa for P # 50 hPa |
| | | 1.0 hPa for P # 50 hPa | 1.5 hPa for 49.9 - 2 hPa | |
| Geopotential Height[3] of the Pressure Levels | 1070-500 hPa | < 10 m | < 10 m | 1 m |
| | 500-300 hPa | < 15 m | < 15 m | |
| | 300-100 hPa | < 20 m | < 20 m | |
| | 100-10 hPa | < 30 m | < 30 m | |
| | 10-3 hPa | < 50 m | < 50 m | |

1- Sensor accuracy is defined as the closest whole or decimal value a given type of sensor is capable of measuring in the environment in which it is intended to operate and is expressed as the root mean square of differences between the sensor readings and the standard.

2- Sensor precision is defined as how closely randomly selected sensors of the same type may be expected to measure a quantity repeatedly. This type of precision is normally made by comparing in flight two or more sensors of a given type that are identical. When tested over the full range of measurement and environmental conditions, the precision of the sensor can be determined. The root mean square error of a large data sample may be considered its "precision", with respect to time.

3- Geopotential heights of the pressure surfaces as estimated from Ref. 3.

Helium is used for shipboard and mobile operations because it is an inert gas and does not pose as much of a safety hazard as hydrogen. It *may* also be used at fixed field sites owing to safety and supply considerations. Helium gas is normally compressed and bottled. Liquid helium is often used onboard ships owing to space constraints.

Natural gas is used in the Arctic because it is readily available and is more economical than hydrogen or helium in that remote region. It is a combustible gas and can cause fires or explode. While natural gas is usually cheaper than helium or hydrogen, its use is less desirable because it produces less lift per unit volume.

**2.3.1.2 Safety Standards.** Hydrogen and natural gas are extremely explosive. Extreme caution ***shall*** be taken when inflating sounding balloons with hydrogen or natural gas. The operator ***shall*** follow the hydrogen and natural gas safety regulations (refer to appendix B). Required safe practices ***shall*** be strictly adhered to when using hydrogen or natural gas. Proper caution ***shall*** be taken when handling bottles of compressed gas. Since the boiling-point of helium is -268°C (5.2°K), special care ***should*** be taken to prevent injury when handling it in its liquid form.

**2.3.2 Flight-Train.** The flight-train used for routine operational synoptic soundings typically consists of a parachute, a train-regulator, and a lighting unit attached at night, all connected and rigged with string of appropriate strength. The rigging between the radiosonde, balloon, and flight-train devices is illustrated in Figure 2-1 and discussed in Chapter 3.

**2.3.2.1 Parachutes.** Parachutes ***shall*** be used at all stations unless the parent agency issues specific instructions to the station to exclude them. Parachutes are optional in areas where risk of injury to people is essentially non-existent, (e.g., an island or at sea) and risk of property damage is negligible. The color of the parachute ***shall*** be orange or some other bright color that can be distinguished from the sky background.

**2.3.2.2 Train Regulators.** A train regulator (also termed dereeler or let-down) *may* be used when the release is made in high winds. Train regulators come in various designs. Train regulators *may* be provided by the radiosonde manufacturer as an add-on or incorporated into the radiosonde itself or *may* be acquired separately.

**2.3.2.3 Shock Unit.** A shock unit *may* be used in the flight train between train regulator and radiosonde if the vibration caused by the regulator tends to produce unstable signals.

**2.3.2.4 Lighting Units.** Tracking systems that require manual antenna positioning to track the radiosonde during the first few minutes of flight *may* use a lighting unit for nighttime releases to help in locking the tracking antenna on to the radiosonde's signal. The candlepower emitted from a lighting unit ***shall*** be sufficient that the position of the balloon flight-train can be distinguished from the background for at least five minutes after launch. Battery powered light bulbs or chemically activated light sticks are two commonly-used devices.

**2.3.3 Radiosondes.** The basic parts of the radiosonde are: the meteorological sensors, the data encoding electronics, and the telemetry transmitter. The traditional radiosonde measures atmospheric state properties of pressure (P), temperature (T), and relative humidity (U). This PTU or met (meteorological)

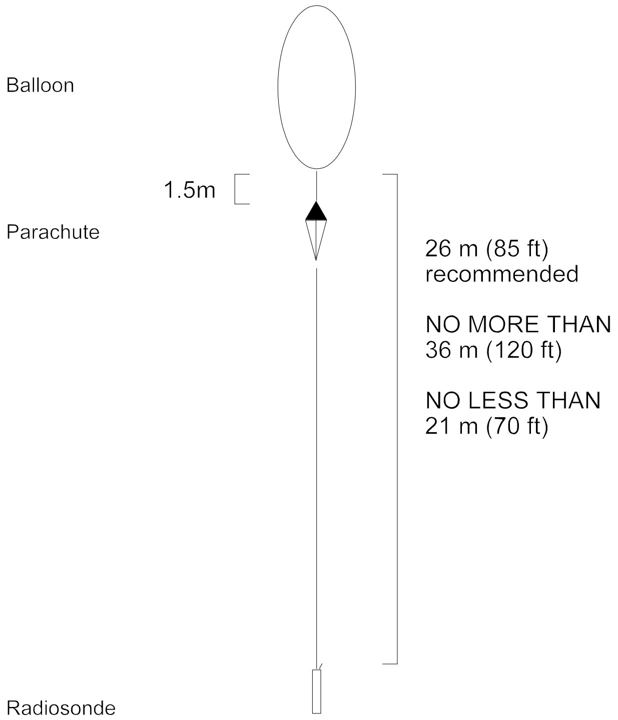

**Figure 2-1. Schematic of a sonde with balloon, parachute, and train.**

data is used to calculate derived variables such as geopotential height and dewpoint. With the wide-spread access to radio broadcasts of Navigational Aids (NAVAIDS) such as VLF and Loran-C systems, and Global Positioning System (GPS), a NAVAID translator or sensor has been incorporated into some radiosonde designs. These NAVAID sensors are used to determine upper-air winds represented by balloon movement. An alternative to using NAVAID sensors is to track the radiosonde with a precision radiotheodolite or a windfinding radar to determine the upper-air winds.

**2.3.3.1 Meteorological Sensors.** The meteorological sensors measure the bulk thermodynamic state properties of the atmosphere — specifically pressure, temperature, and relative humidity. Sensors are factory calibrated: the calibration ***shall*** be ground checked ("base lined") during preflight preparation (see Chapter 3). This process verifies that all radiosonde components are operating properly prior to release and that calibration values are appropriate. Descriptions of commonly employed sensors are given below.

The pressure sensor measures the ambient pressure over the whole range of flight conditions from launch to balloon burst. This sensor is usually an evacuated aneroid cell, a part of which flexes with variations in pressure. The flex is proportional to the absolute pressure. The flex is reported as a movement of a mechanical arm, as a capacitance, or as the amount of voltage required to balance a wheatstone bridge. The pressure cell is usually temperature-compensated to measure pressures at temperatures that range from +50°C to -90°C. A hypsometer can be also used to measure the ambient atmospheric pressure. The hypsometer bases its measurement on the known boiling-point of a fluid at a specific external pressure. By keeping the fluid at its boiling-point and measuring its temperature, the ambient air pressure can be calculated.

Some radiosondes do not use a pressure sensor. Instead, the pressure levels are computed from the hypsometric equation using height determined from radar together with the temperature and humidity measurements from the radiosonde (see Appendix D).

The temperature sensor measures the ambient temperature over the whole range of flight conditions from launch to balloon burst. This sensor is usually an electrical device whose resistance or capacitance varies proportionately with the change in temperature. The temperature sensor is exposed during flight to solar and infrared radiation which can introduce temperature measurement errors. Radiation, sensor lag, and other errors depend on the sensor coating, size, shape, mounting, and position in relation to the radiosonde and the balloon. Radiosonde manufacturers and various researchers have developed adjustment schemes to reduce biases in temperature measurements [e.g. Ref. 2].

All temperature sensors are affected to some extent by both solar short-wave and infrared long- wave radiation. The effect on the sensor is to cause it to report a temperature that differs from that of the ambient air. While the solar effect always causes warming, the long-wave effect may be either warming or cooling depending on the ambient air temperature and the temperature of bodies surrounding the temperature sensor. Because multiple long-wave sources exist (i.e., space, ground, clouds, atmosphere, radiosonde, balloon, etc.), determination of the net long-wave radiation effect is difficult. Radiation effects on temperature sensors also differ in the troposphere and stratosphere owing to the reversal of the thermal lapse rate. In general, radiation effects are larger in the stratosphere, where sensors read too warm in the daytime and usually too cold at night. The differences can be up to a few tenths C degrees in the troposphere and 1 C degree or more in the stratosphere.

The humidity sensor measures the ambient water vapor (humidity) over the whole range of flight conditions from launch to balloon burst. Physical sensors such as hair and goldbeaters skin, with poor measurement accuracy or precision, slow response times, or limited measurement range, are inadequate and ***shall not*** be used. Electrical sensors which have adequate accuracy, time response, and measurement range, such as the carbon element and the thin-film capacitance sensors, are recommended for use. Humidity sensors typically used on radiosondes measure relative humidity directly. The relative humidity is a function of the temperature, so any temperature errors will be reflected in the relative humidity measurements. The humidity sensor can also be affected by liquid and frozen precipitation encountered below and in precipitating clouds. Sensors have been typically placed in a duct within the radiosonde or otherwise protected to minimize this effect, but this placement can lead to inadequate ventilation.

Common limitations to sensors include sensor lag and hysteresis. Sensor lag mainly affects temperature and humidity sensors. A sensor's time constant is the time that the sensor takes to respond to some arbitrary quantitative change in the ambient environment. As the balloon rises, a sensor's value can lag significantly behind the actual values of the atmospheric environment. For temperature sensors, the lag is typically on the order of seconds. For the humidity sensor the lag may range from seconds to minutes. A carbon element sensor may require one minute or more to stabilize to the new conditions when passing through steep humidity gradients at temperatures lower than -40°C.

Hysteresis refers to the property of a sensor failing to reproduce the same values when cycling from an initial value to another value and then back again to the original value. For example, when a balloon enters and exits clouds, hysteresis of the carbon element sensor can cause a measurement error. Limiting the hysteresis effect in humidity sensors is important because of the highly variable nature of the vertical humidity profile in the atmosphere.

**2.3.3.2 NAVAID Windfinding.** Radiosondes that use NAVAID signals for windfinding contain electronics that receive the NAVAID signals from fixed transmitting stations on the ground (in the case of LORAN or VLF signals) or from moving satellites in space (in the case of GPS). The radiosonde then either retransmits the received signal to the ground subsystem or processes the received signals into Doppler-shift, velocity, or position information and then transmits. Balloon position and wind data are contained in or derived from this information. A description of the common NAVAID sensors flown on radiosondes follows:

**2.3.3.2.1 GPS.** Each one of the GPS satellites in the 24-satellite constellation transmits a very stable 1575.42 (L1) and 1227.60 (L2) MHZ frequency, precise time, and orbital almanac information. The L1 band is available for civilian use with a Selective Availability degradation of the positioning capability. The carrier is a spread-spectrum signal of about 2 MHZ bandwidth. Because of the large bandwidth, full signal translation is not desirable, so a number of alternatives have been used. They include velocity information extraction and retransmission, partial sampling of position information and retransmission, and full position processing onboard the radiosonde with digital position data transmitted to the ground system. GPS is a 24-hour, world-wide, all-weather navigational positioning system. GPS is capable of providing wind component accuracies of 0.5 m/s or better.

**2.3.3.2.2 Loran-C.** Each Loran-C station transmits a unique series of pulses on a 100 kHz carrier wave. The Loran-C sensor flown on Loran radiosondes receives the signals from all stations within reception range and retransmits them as a modulated signal on top of the radiosonde's carrier frequency. For this reason, it is commonly called a Loran translator. Loran-C coverage is not world-wide and the usefulness of regional chains is limited by transmitting power, skywave contamination, and geometry. Loran-C provides wind component accuracies of about 0.5 m/s.

**2.3.3.2.3 VLF Systems.** Currently radiosondes that use VLF translators for windfinding are in general use, and most use a hybrid of all available VLF system signals. VLF systems provide wind component accuracies of about 3 m/s.

**2.3.3.3 Data Encoding Electronics.** The data encoding electronics periodically sample the various sensors, encode the sensor signals, and modulate them on the radiosonde's carrier frequency. The sampling rate for each measurement ***shall*** be such that a representative profile of the atmosphere can be derived from the telemetered data. Present radiosonde sampling rates are in the 1- to 6- second range. The sensor data can be in digital or analog form and either amplitude modulated (AM) or frequency modulated (FM) on the radiosonde's carrier frequency. For the case of the digital radiosonde, the sensor's analog signal is digitized. For an analog AM radiosonde, the sensor's signal is Pulse Code Modulated on an AM carrier frequency. For a NAVAID radiosonde, the electronics also combine the NAVAID signal with the radiosonde's carrier frequency.

**2.3.3.4 Telemetry Transmitter.** A radiosonde can travel in excess of 200 km from its ground subsystem. The radiosonde ***shall*** transmit its carrier frequency at sufficient power, typically about 250 milliwatts, for the ground system to receive its signal at 250 km. The radiosonde ***shall*** transmit its carrier frequency within either of the two primary Meteorological Aids Service transmission bands. The carrier frequencies currently authorized are: 400.15 to 406.00 MHZ and 1668.4 to 1700 MHZ. Authorization for the 1680 MHZ band will decrease by 6.6 MHZ on January 1, 1999, to only allow use from 1675 to 1700 MHZ. Table 2-2 lists the applicable telemetry frequencies for the various types of radiosondes in use.

**2.4 <u>The Surface Subsystem</u>.** Several different systems located on the ground or aboard ship presently are used by U.S. agencies for rawinsonde observations. Specifics of engineering, design, configuration, and operation for these systems are addressed in agency manuals. The surface system typically fulfills the tracking, receiving, and signal- and data-processing functions.

**2.4.1 The Antenna.** The antenna for the ground subsystem detects the radiosonde's signal, provides signal amplification through its gain, and, if it is a directional antenna, allows for tracking the radiosonde. If the tracking is used for radio-direction-finding windfinding, the tracking control is a much more critical function of the antenna than signal strength. Otherwise, the critical function of the antenna is to pass a sufficiently strong signal to the receiver.

**2.4.1.1 RDF Windfinding Antennae.** A Radio Direction Finding (RDF) antenna is designed to track a radiosonde transmitting in the 1680 MHZ Meteorological Aids band. The antenna position information (i.e., azimuth and elevation) is combined with the height calculations from the radiosonde to determine the changes in position of the radiosonde during flight. These changes in position are taken as representative of the winds encountered during flight. A RDF antenna is also called a radiotheodolite. A parabolic dish antenna can resolve azimuth and elevation or azimuth angles to 0.05°. Newer phased-array RDF antennas resolve angles to about the same accuracy and have fewer moving parts. Both types of antennae suffer from multipath contamination when the elevation angle of the antenna to the radiosonde gets close to the horizon or any interposed obstruction. If it is expected that the flight will encounter elevation angles below those limited by multipath propagation, a radiosonde *may* be augmented with a transponder (i.e., a ranging adjunct) in order to measure its slant-range or distance to the radiosonde. Winds can then be determined using the azimuth, slant-range, and height of the radiosonde. With adequate antenna elevation angles, RDF systems provide wind component accuracies of about 1 m/s.

**2.4.1.2 Other Antennae.** Non-RDF windfinding antennae need only detect and amplify the radiosonde's telemetry signal. Current (1997) NAVAID processing units exist for Loran-C, VLF, and GPS systems.

**2.4.2 The Receiver and Sensor Processing Units.** The surface-based receiver filters, demodulates and outputs the various signals from the radiosonde. The receiver also tracks the telemetry signal to control the tuning circuits for optimum gain and frequency reception, and passes the meteorological signals to the signal processing units.

The signal processing units take these demodulated signals and convert them into values of pressure, temperature, and humidity. If appropriate, NAVAID signal processing units output times-of-arrival (TOAs) or pseudo-ranges from the various stations or satellites. The units may then process this

Table 2-2 Radiosonde Telemetry Frequencies

| Ground System | Tracking/ Positioning | Nominal Frequency (MHZ) | Maximum Range* (MHZ) |
|---|---|---|---|
| **RDF** | **Standard** | **1680±4** | **1668.4-1700** |
| **Ranging Adjunct** | **Transponder** | **1680±4**<br>**403 MHZ** | **1668.4-1700** |
| **NAVAID** | **Loran-C** | **403±1** | **400.15-406.00** |
| **NAVAID** | **VLF** | **403±1** | **400.15-406.00** |
| **NAVAID** | **GPS** | **403±1** | **400.15-406.00** |

***Refers to the maximum tuning range allocated for meteorological aids by the National Telecommunications and Information Administration Table of Frequency Allocations. Sondes must not be permitted to drift outside these ranges and cause interference with other frequencies.**

information into position and/or velocity information, or pass the information directly to the data processing unit that performs the actual windfinding computations.

The meteorological processing units are typically radiosonde-specific "blackboxes" that convert the demodulated radiosonde signal containing the sensor measurements into calibrated meteorological data expressed in the proper units. The output is typically a digitized signal to the data processing unit for storage, display, or further processing.

**2.5 <u>The Data Processing Subsystem</u>**. The data processing system ***shall*** have built-in capabilities for viewing, editing, and printing data. Systems ***shall*** have the capability to produce a hard copy of products that can be generated from the observation. Examples include: data versus time plots; quality control and system monitoring; time-tagged data files; coded messages for transmission (see Chapter 7 and Appendix E); and archiving file format (see Appendix F).

Graphical plotting of the meteorological variables serves to identify problems during the flight, providing the operator with an additional method for determining such things as sensor failures, unusual meteorological phenomena, and potential hardware problems. Data versus time plots are useful in identifying problems or phenomena that require observer editing, as are thermodynamic diagrams such as a Skew T-log P chart.

In addition, the data processing subsystem ***shall*** have the capability of performing signal processing, managing the meteorological information, and performing general file management and data-base tasks.

**2.5.1 Recording Data**. The release time of the radiosonde observation ***shall*** be determined and recorded and an elapsed time ***shall*** be assigned to in-flight data. The time of release may be determined externally by a release signal or internally by software detecting a decreasing trend in pressure.

The time-stamped in-flight data from the radiosonde ***shall*** be recorded electronically in a file consisting of the elapsed time in seconds, pressure in hPa, temperature in Celsius or Kelvin degrees, and relative humidity in percent of saturation with respect to water. The wind velocity data ***shall*** be recorded as vector wind components or as wind direction and speed.

**2.5.2 Signal Processing**. Before derived variables are calculated and subsequent processing is begun, the telemetered data ***should*** be analyzed to detect system noise and signal dropouts. The exact algorithm will depend upon the signal and noise properties of the radiosonde system used. The data telemetry will also depend upon the type and make of radiosonde: nominal procedure ***should*** maintain a high data-rate record of the telemetry for processing, thus allowing for maximum resolution in pressure (time). The intent of this requirement is to provide a time-tagged file of high quality basic variables for use in subsequent data manipulation. Similar signal processing ***shall*** be performed upon the balloon tracking data.

**2.5.3 Data File Formats**. A minimum of three files ***should*** be maintained during the processing described in this Chapter: a time-tagged file of the original, unedited values of pressure, temperature, and humidity; a time-tagged file of balloon position; and an edited, quality-controlled file of all variables and derived data.