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Barometric Pressure	Standard Atmosphere
Humidity	Temperature
Meteorological Data	Weather Information
Meteorological Instruments	Wind Velocity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Provides methods for obtaining meteorological data. Includes definition of "standard atmosphere" and an example of a typical metro report to a test director.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RI-702-102
*Test Operations Procedure 3-1-003 2 June 1981
AD No.

METEOROLOGICAL DATA FOR TESTING

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1. SCOPE. This TOP describes procedures for obtaining meteorological data. These data may then be used during or in support of many types of tests or during data reduction to normalize recorded weapon test data. This TOP is designed mainly to provide the test director with available meteorological information; specific data needed for a test are stipulated in the various applicable TOPs.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities. A building suitable for housing instrumentation and equipment and for filling balloons.

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2.2 Instrumentation.

ITEM	MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*
Navigation aid (NAVAID) or other suitable meteorological system	Humidity: ± 5% reading (1 SD) Temperature: ± 0.5° C reading
Rawinsonde	Pressure: ± 4 millibars reading
Theodolites	Direction and speed: ± 0.05° between 10 and 60° elev. reading
Radiosonde and recorder	
Balloon	
Fluid-filled probe and soil thermograph, if required	Soil temperature: ± 1° C
Thermometers and psychrometer	Temperature: -0.2° C to ± 0.4° C reading (3 SD) between 0 and 18° C
Hygrothermograph or micro-hygrograph	Humidity: ± 1% reading
Portable anemometers	Wind speed: ± 1.5 knots wind direction: ± 3° reading distance constant: 4.6 to 5.5 m
Barometers	± 0.01 inch Hg reading (3 SD)
Microbarograph	
Rain gages, if required	± 0.01 inch reading
Pyrheliometer, if required	Solar radiation: ± 5% full-scale reading

3. REQUIRED TEST CONDITIONS. All instrumentation should be calibrated and working properly. NOTE: The hygrothermograph and/or microhygrograph must be regularly checked to ensure their accuracy.

*Values may be assumed to represent ± 2 standard deviations unless otherwise stated; thus, the stated tolerances should not be exceeded in more than 1 measurement of 20.

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4. METEOROLOGICAL MEASUREMENTS.

4.1 Measurements of Winds Aloft. Winds aloft are measured by either optical or electronic instrumentation. The "double theodolite" optical method, using two specially designed metro theodolites, can be used only when atmospheric phenomena such as cloud cover do not interfere with visual observation. A single theodolite method using the rate of balloon rise to determine altitude can also be used. The electronic method, known as the rawinsonde system, is employed almost exclusively since it has the capability of taking atmospheric soundings to obtain upper air metro data during all weather conditions. The rawinsonde system is also able to obtain pressure, temperature, and humidity data throughout the vertical profile of the flight.

4.1.1 Double Theodolite Method. Set up two metro theodolites (graduated in tenths of degrees) at either end of a measured base line relative to the local grid system. Both theodolites track a free balloon. Record elevation and azimuth angles of both theodolites at selected time intervals. By triangulation, determine the space-time position of the balloon. These data are used to compute wind speed and direction at various altitudes.

4.1.2 Rawinsonde System Method. The rawinsonde system consists of an electronic theodolite (Rawin Set AN/GMD-1, Figure 1), a radiosonde recorder (Figure 2), and a radiosonde (Figure 3). The balloon-borne battery-powered radiosonde (the transmitter) is tracked by the directional antennae of the Rawin set. The azimuth and elevation angles of the antennae print on the control recorder at pre-selected time intervals, and with the altitude of the balloon (as computed from the pressure and temperature data), determine the position of the balloon. Changes in the balloon position in a space-time relationship then reveal wind direction and speed.

4.1.3 WL-2DF Lo-Cate NAVAID Meteorological Data-Acquisition and Processing System. This system is comprised of the cabinet-mounted and free-standing equipment shown in Figure 4, plus corner reflector antennae/preamplifier, omnidirectional antenna/preamplifier, coupler (local NAVAID antenna), remote start control, and a radiosonde (sondi). The system is a low-level and upper air sounding system that obtains and processes complete atmospheric profiles. Flight data are filed after each flight. Using the balloon-borne expendable radiosonde, the system remotely senses atmospheric pressure, temperature, and relative humidity, and transmits these data to the base station via UHF (403 MHz) telemetry link. Loran-C radio navigation aid (NAVAID) signals received at the radiosonde are re-transmitted to the base station, using this same link (Figure 5). Automatic tracking is accomplished by the base station Loran-C processor. NAVAID signals are digitized by NAVAID/Met Analyzer. As the radiosonde changes position, the time difference of the Loran signals to the radiosonde or angular position of the tracking antenna also change. Automatic wind speed and direction computation are calculated by the computer and printed on the teleprinter. As the flight progresses, wind speed and direction are processed and printed every minute of the flight. Range and azimuth are processed and printed every 5 minutes.

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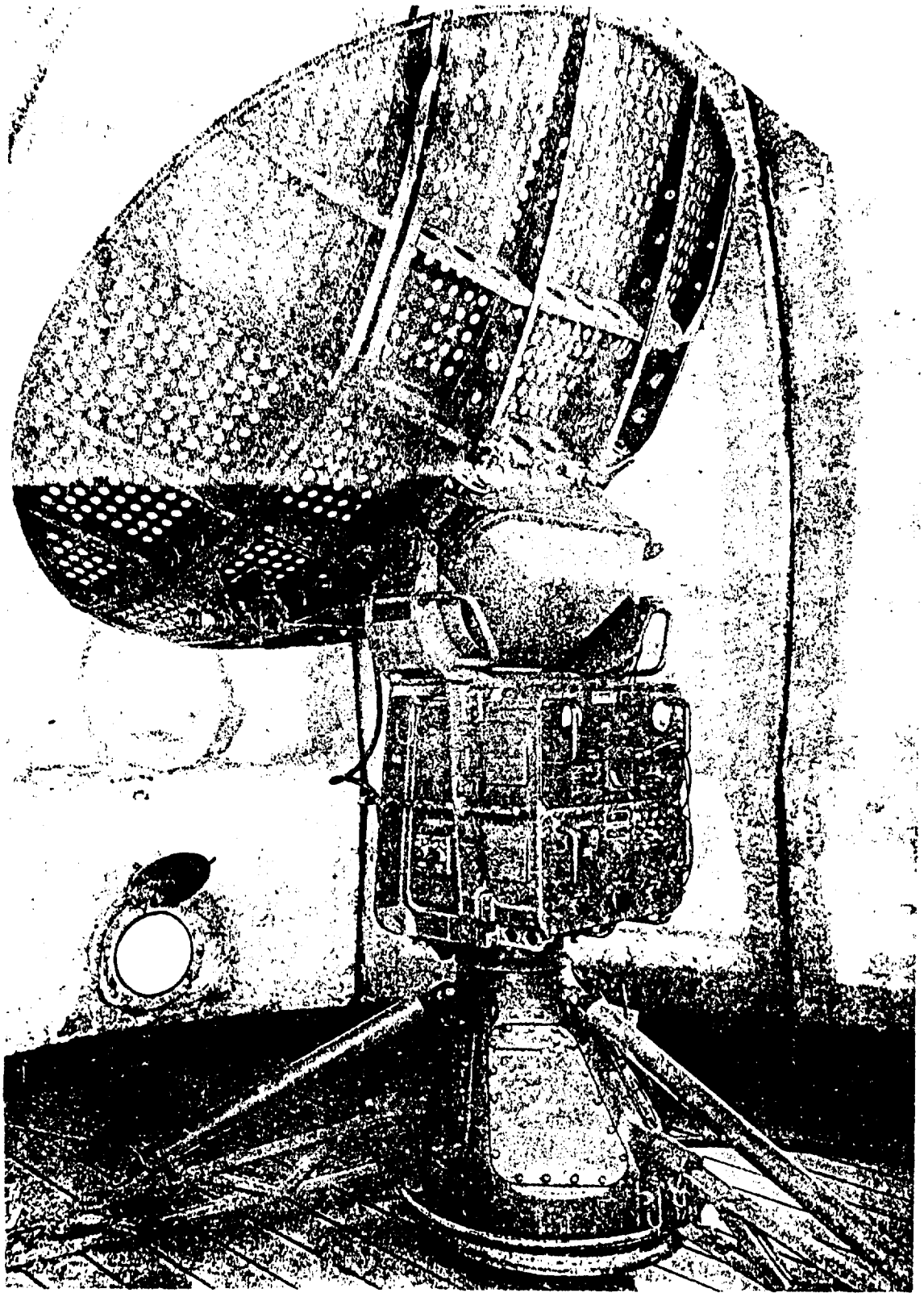


Figure 1. Rawin Set AN/GMD-1

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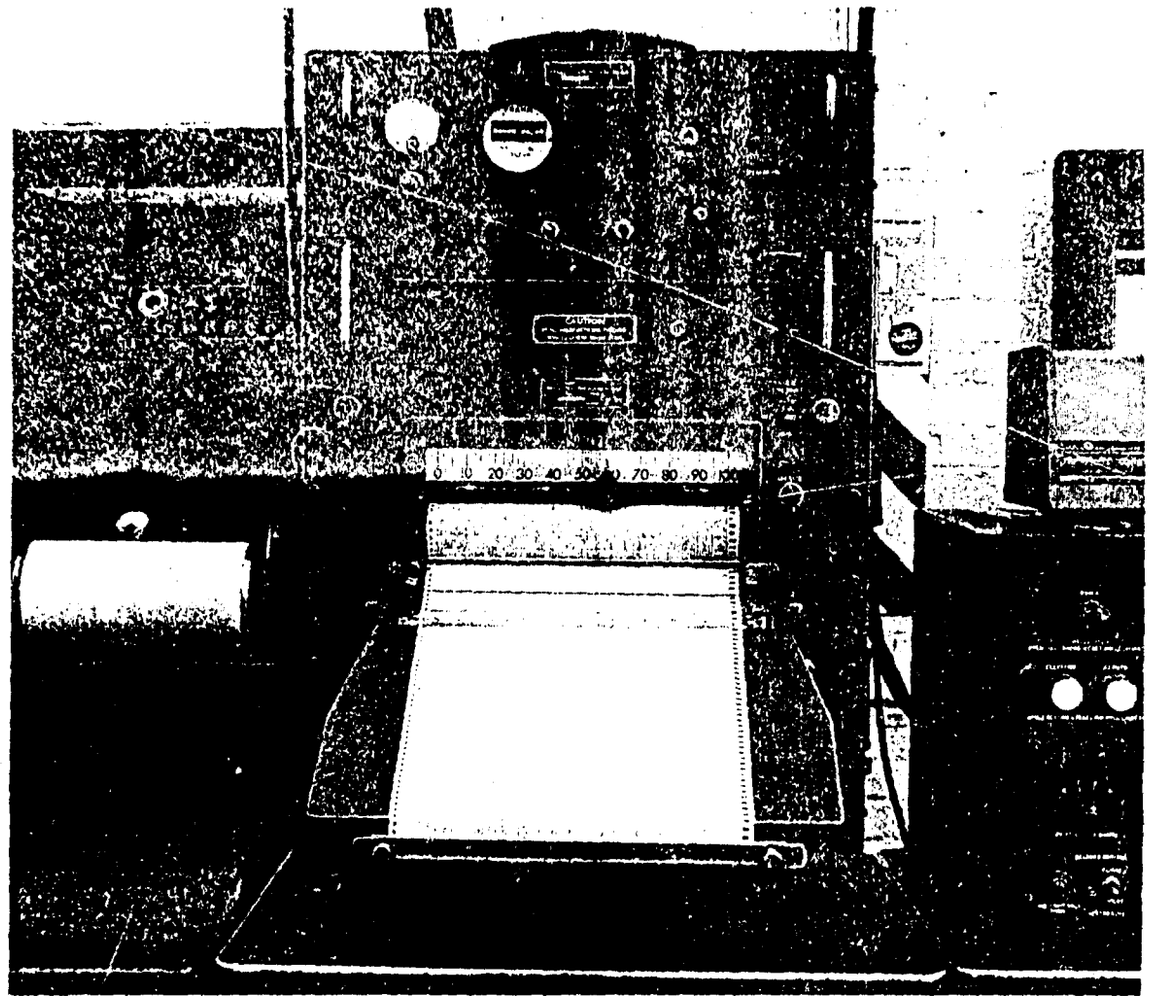
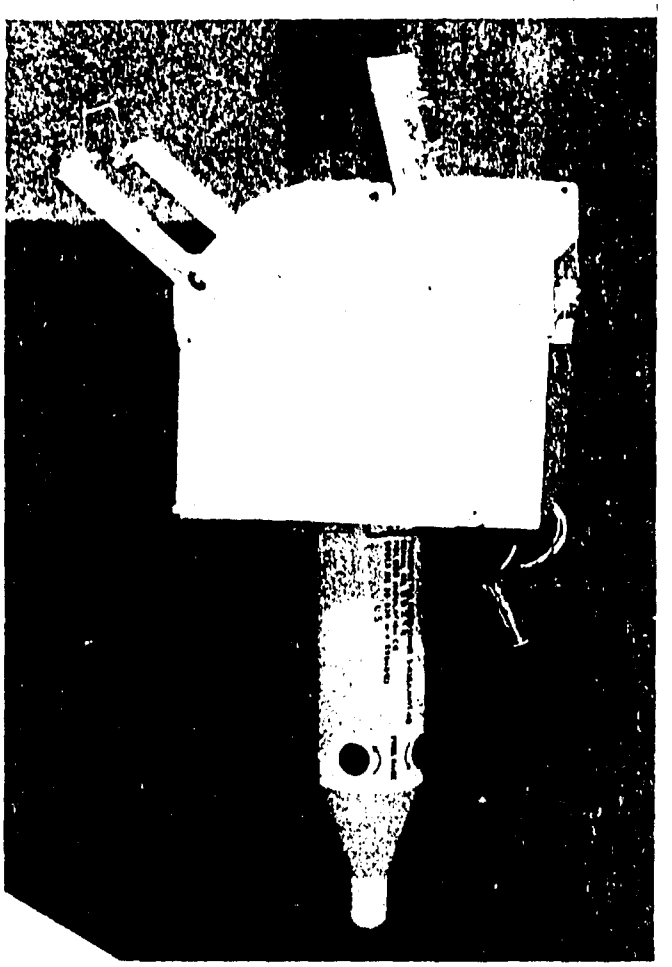


Figure 2. Radiosonde Recorder AN/TMQ-5

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The conical element below is the FM transmitter. Electrical contact with the sensing elements is through the small connector suspended by wires to the right of the transmitter. The straight section of "wire" supported by two arms at the upper left is the "thermistor" which measures temperature. Protruding at upper center is the element that senses humidity.

Figure 3. Radiosonde AN/AMT-4

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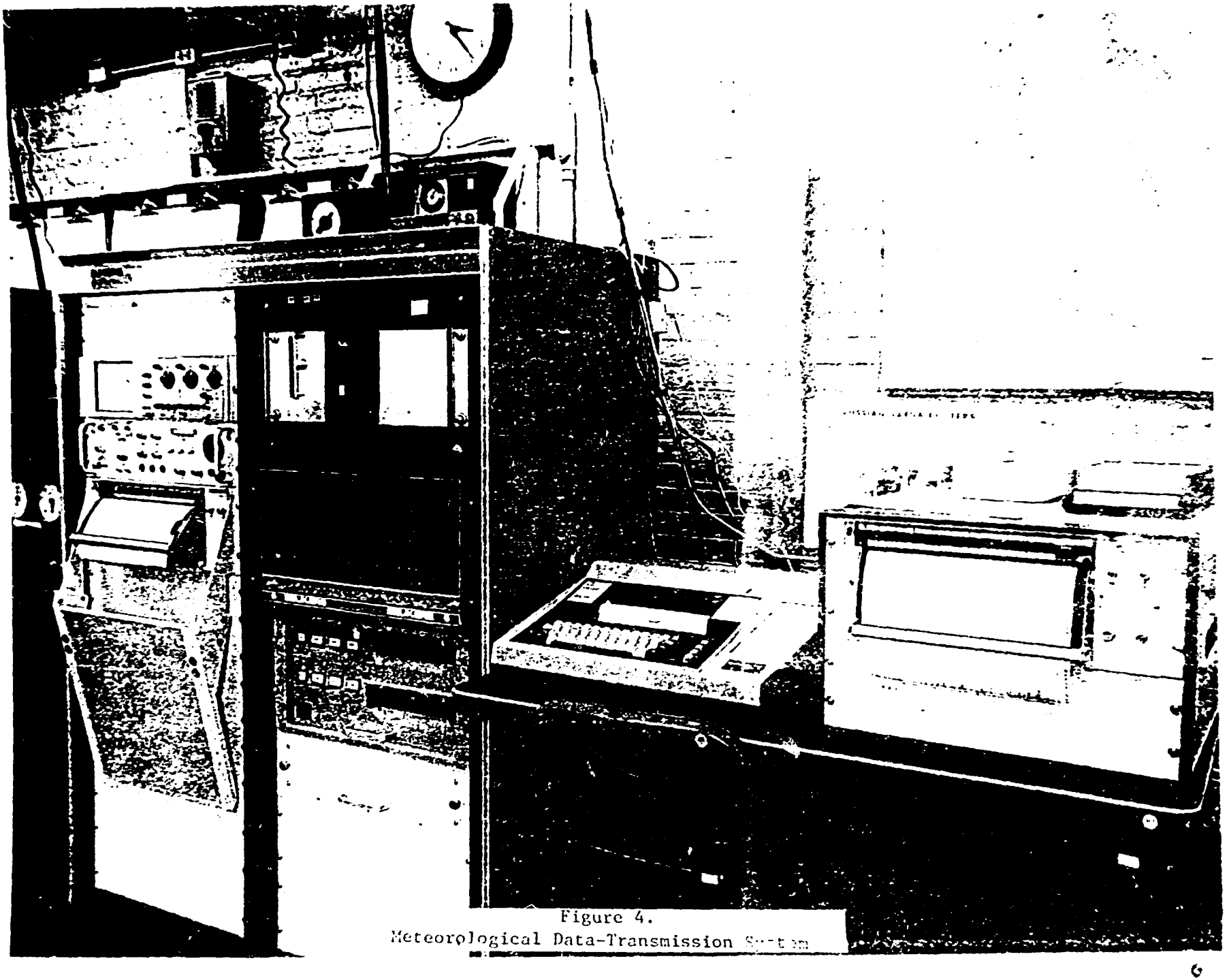


Figure 4.
Meteorological Data-Transmission System

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1. Tape Punch and Reader
2. Computer (Met. Analyzer)
3. Dual Disk Drive
4. Blank Panel
5. Utility Drawer
6. Teleprinter
7. Met. Data Recorder
8. Antenna Select Panel
9. Antenna Positioner Control
10. Monitor Oscilloscope
11. LO-CATE Loran C Processor

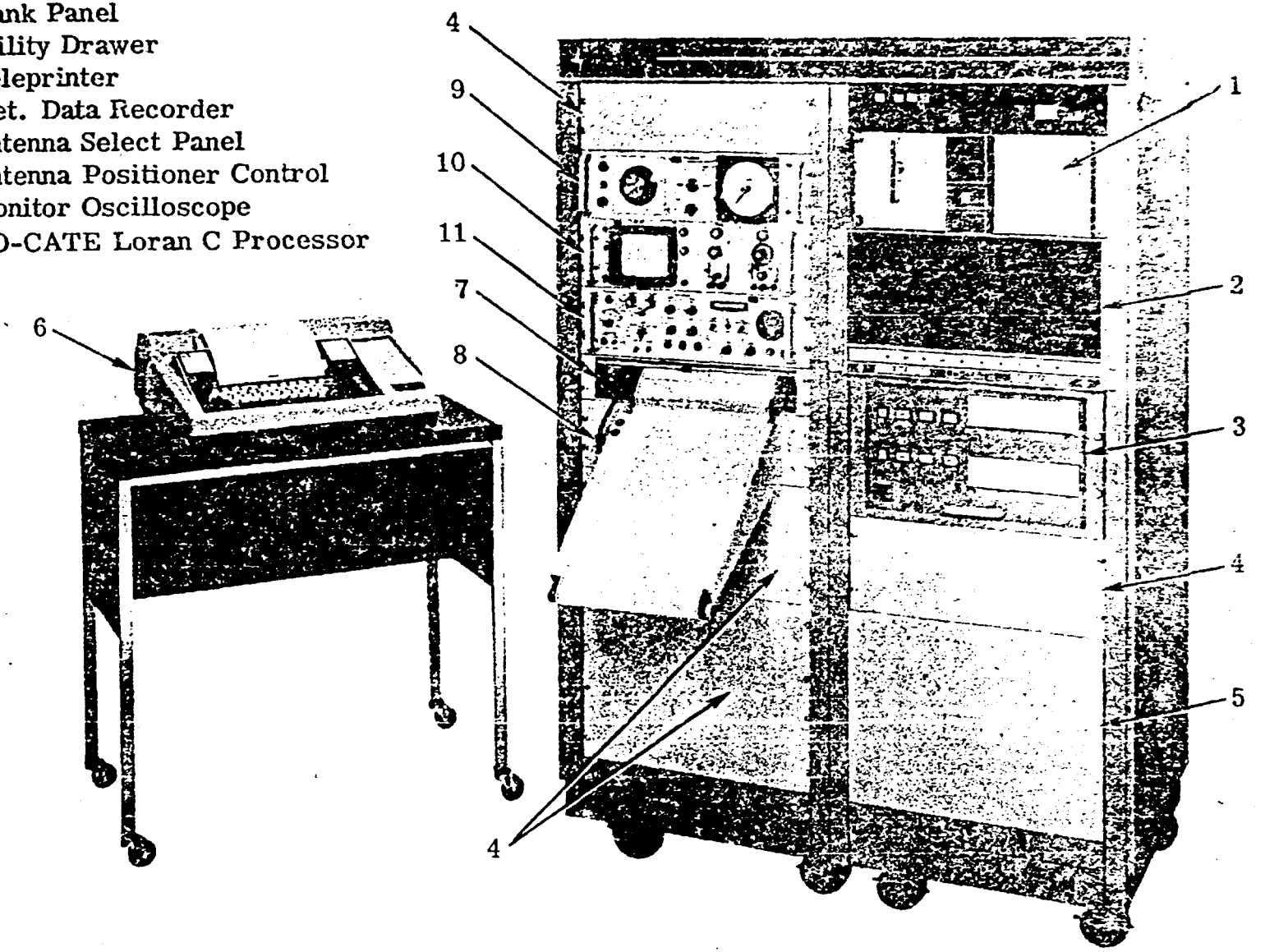


Figure 5. Model WL-2DF, NAVAID Integrated Meteorological System

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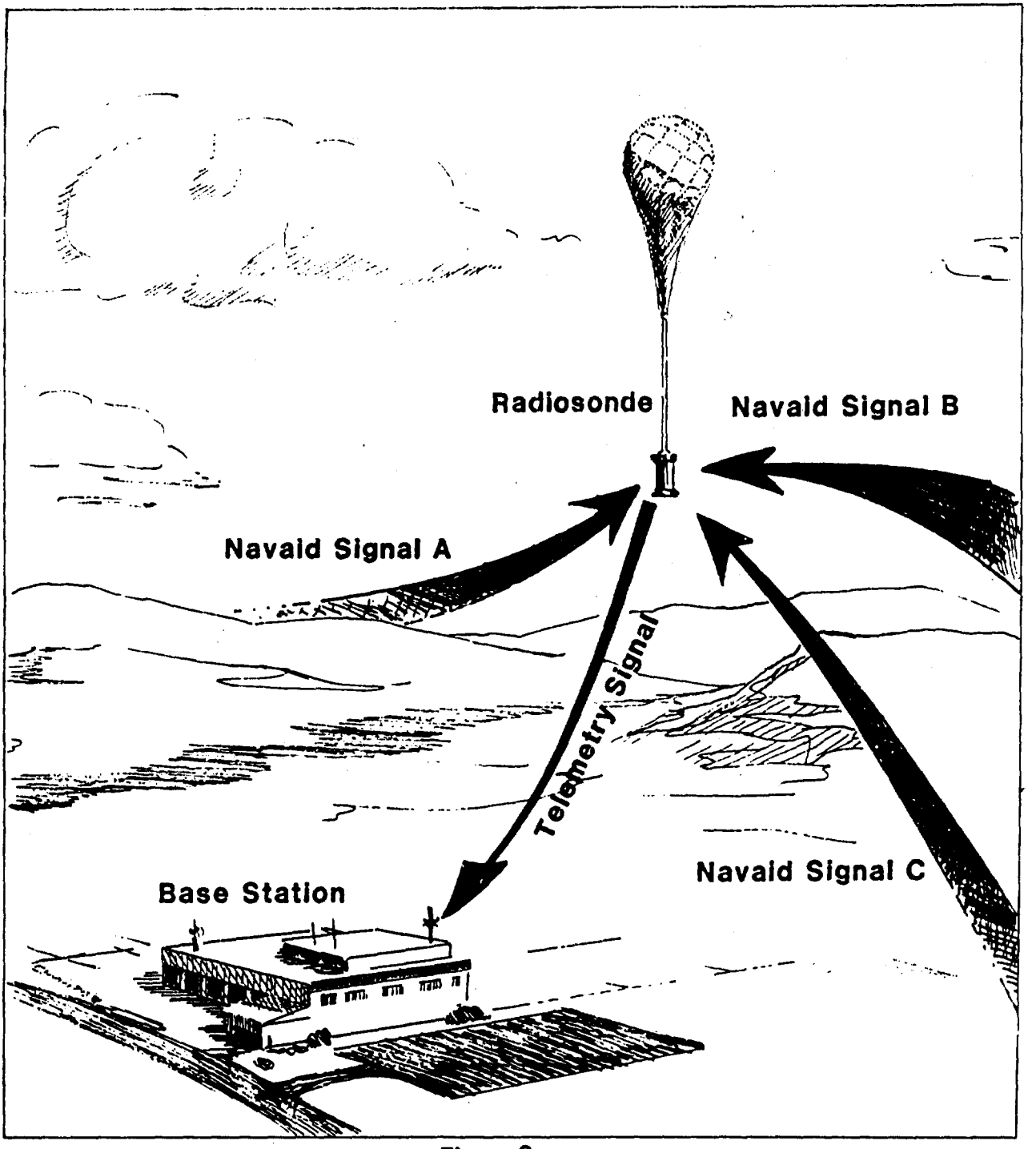


Figure 6

LO-CATE RETRANSMISSION CONCEPT

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4.2 Pressure, Temperature, and Humidity Aloft.

4.2.1 Rawin Set AN/GMD-1. As indicated in paragraph 4.1.2, the rawinsonde system is used to obtain pressure, temperature, and humidity data, as well as to determine winds aloft. Pressure is recorded as a series of transitions corresponding to the calibrated contact of the radiosonde's baroswitch. The balloon-borne radiosonde automatically transmits pressure, temperature, and humidity information by frequency-modulated radio signal to the Rawin set which amplifies the signal and passes it to the radiosonde recorder. For altitudes lower than 18,000 meters, the pressure-actuating element of the radiosonde transmitter is an aneroid cell (Figure 6). The pressure sensor with a commutator bar serves as a switching system for a sequence of temperature, humidity, and reference signals transmitted by the radiosonde.

The radiosonde recorder is an electronic metro instrument especially designed for use with the Rawin set. It converts the radiated audio frequency signal received from the Rawin set to a graphical form that is then evaluated in terms of the metro parameters of pressure, temperature, and humidity by use of an adiabatic chart WBAN-31 or the altitude-pressure-density chart ML-574/UM.

4.2.2 WL-2DF Lo-cate System. This system is equipped with analog chart recorders for both meteorological and NAVAID data. The "met" recorder displays the pressure, temperature, and humidity, and a reference level. Pressure is recorded as a series of transitions corresponding to the calibrated contact of the radiosonde's baroswitch. Temperature and humidity are recorded as analog traces that can be read as ordinates on the chart. The operator can thereby qualitatively monitor the temperature, pressure, and humidity as the flight progresses. Slide rule type evaluators are then used to convert chart recorder ordinates directly to standard units of measure (i.e., degrees Celsius, percent relative humidity, and millibars pressure).

4.3 Surface Ground Winds. Low-level winds are measured and can be graphically recorded from the surface to any practical height. Several different types of portable anemometers or wind-measuring sets are used, such as the AN/PMQ-3 and AN/MMQ-1.

4.4 Surface Temperature and Humidity. Ambient temperatures are measured by thermometers such as the ML/352/UM or by a psychrometer ML-224 that gives wet and dry bulb temperatures of air, from which the relative humidity can be recorded by portable recorders such as the hygrothermograph or microhygrograph. These instruments contain pens that trace the values of temperature and humidity on graph paper. The temperature of the soil may be required during testing of land mines, automobiles, trucks, and tanks. A fluid-filled probe is inserted into the soil and connected to a portable recorder (soil thermograph) to obtain the soil temperature.

4.5 Atmospheric Pressure. Pressure at the surface is measured by a mercurial barometer and recorded by a microbarograph. Portable aneroid barometers such as the ML-102 measure the pressure at test sites.

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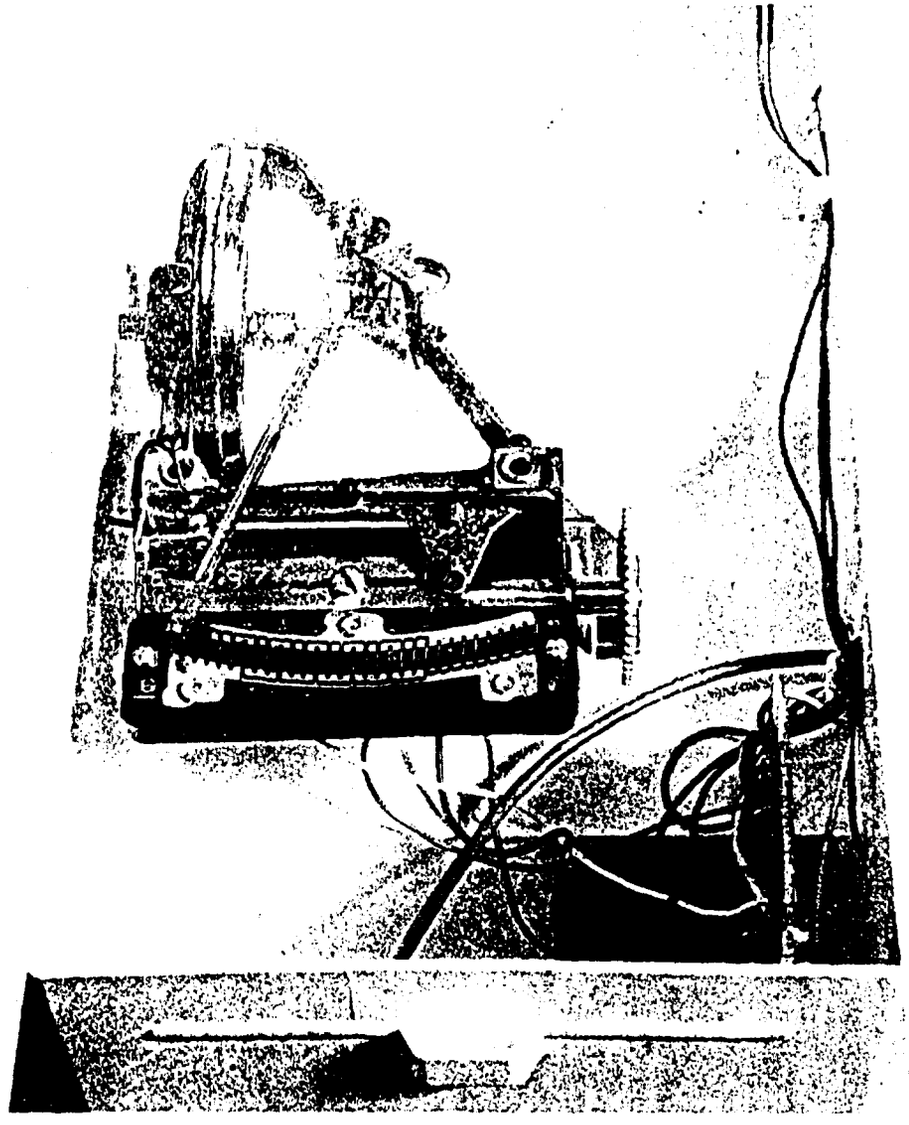


Figure 6. Radiosonde AN/AMT-4, Internal View of Aneroid Cell.

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4.6 Additional Meteorological Data. Additional information required for mine and automotive tests is the amount of precipitation measured by portable and permanent rain gages. The amount of solar radiation is also required during mine tests. For range firing with water impact, the height of the tide must be obtained.

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APPENDIX A

RELATIONSHIP OF METEOROLOGICAL DATA TO TESTING

Meteorological data obtained reveal the extent to which the meteorological conditions at the time of firing differ from the Standard Atmosphere (that of the International Civil Aviation Organization; see Appendix B) to which the firing table will be referenced, and thus permit the correction of firing data for nonstandard meteorological effects.

For example, in range firings for firing table ballistic data, the trajectories of the various rounds are significantly affected at different altitudes. A crosswind will cause deviation from the line of fire, while a range wind will increase or decrease projectile range. Increased air density will decrease range.

Meteorological data are essential in assembling firing tables which are computed on the basis of range firings at various weapon elevations and take into account the observed meteorological conditions. The ballistic coefficient is calculated to give the observed range under the specific firing conditions. Further calculations are then performed with this computed coefficient to obtain firing table range data, based on the ICAO standard atmosphere previously mentioned. The resulting artillery firing table can then be used in the field to lay the weapon, which includes correcting for the effects of nonstandard meteorological conditions. Corrections are included for range wind, crosswind, air temperature and density, as well as factors other than meteorological.

When the maximum ordinate (peak of trajectory) is above 300 meters, wind speed and direction (meteorological data aloft) from the surface to the maximum ordinate at 250- to 300-meter intervals of altitude are required. Temperature, virtual temperature, pressure, and density profiles are also generated at the same altitude intervals as the wind components, plus special data on any significant points that show a deviation of 1° C from a straight line (constant slope) temperature- altitude plot. Samples of metro data and a typical metro report to a test director are shown as Tables I-IV and Figure C-1 in Appendix C. These data are determined by Rawinsonde observation just before firing begins, at least every hour while firing is in progress, and within 20 minutes after firing ceases, except during relatively short programs that can be effectively covered by hourly observations.

In addition to the data aloft described above, meteorological data at the earth's surface are required for artillery firing. These data consist of observed sky conditions (e.g., percent cloudiness), weather phenomena such as rain, visibility, ambient temperature, atmospheric pressure, relative humidity, virtual temperature, absolute air density, and wind speed and direction (recorded at least every hour) during range firing program. When the maximum ordinate is below 300 meters, these data are taken at the firing site for each round.

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For range firing of rockets, metro data aloft and surface data are required, and the information is taken at the firing site for each round fired.

Firings to determine time of flight to a vertical target in order to establish form factors also require complete surface metro data at the test site for each round fired.

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APPENDIX B

DEFINITION OF THE STANDARD ATMOSPHERE USED BY BALLISTICIANS

The standard atmosphere is defined as follows:

a. Dry atmosphere
b. No wind
c. Surface temperature 15° C, with a 6.5° lapse rate per 1000 meters up to a height of 11,000 meters and a constant -56.5° C between 11,000 and 25,000 meters. The ICAO atmosphere now includes data up to 30,000 meters.
d. Surface pressure of 1013.25 millibars, decreasing with height in accordance with the equation of hydrostatic equilibrium:

$$dP = \rho g \, dZ$$

wherein P is the pressure in millibars; ρ is the density in grams per cubic meters; g is the acceleration of gravity; and Z is the geometric altitude in meters.

e. Surface density of 1225 grams per cubic meter, decreasing with height according to the density equation:

$$\rho = \frac{KP}{T_v}$$

wherein ρ is the surface density in grams per cubic meters; K is the constant, 348.38; P is the pressure in millibars; and T_v is the virtual temperature in degrees Kelvin. Variations of air pressure temperature, and density with altitude for the "standard atmosphere" are illustrated in Figure B-1.

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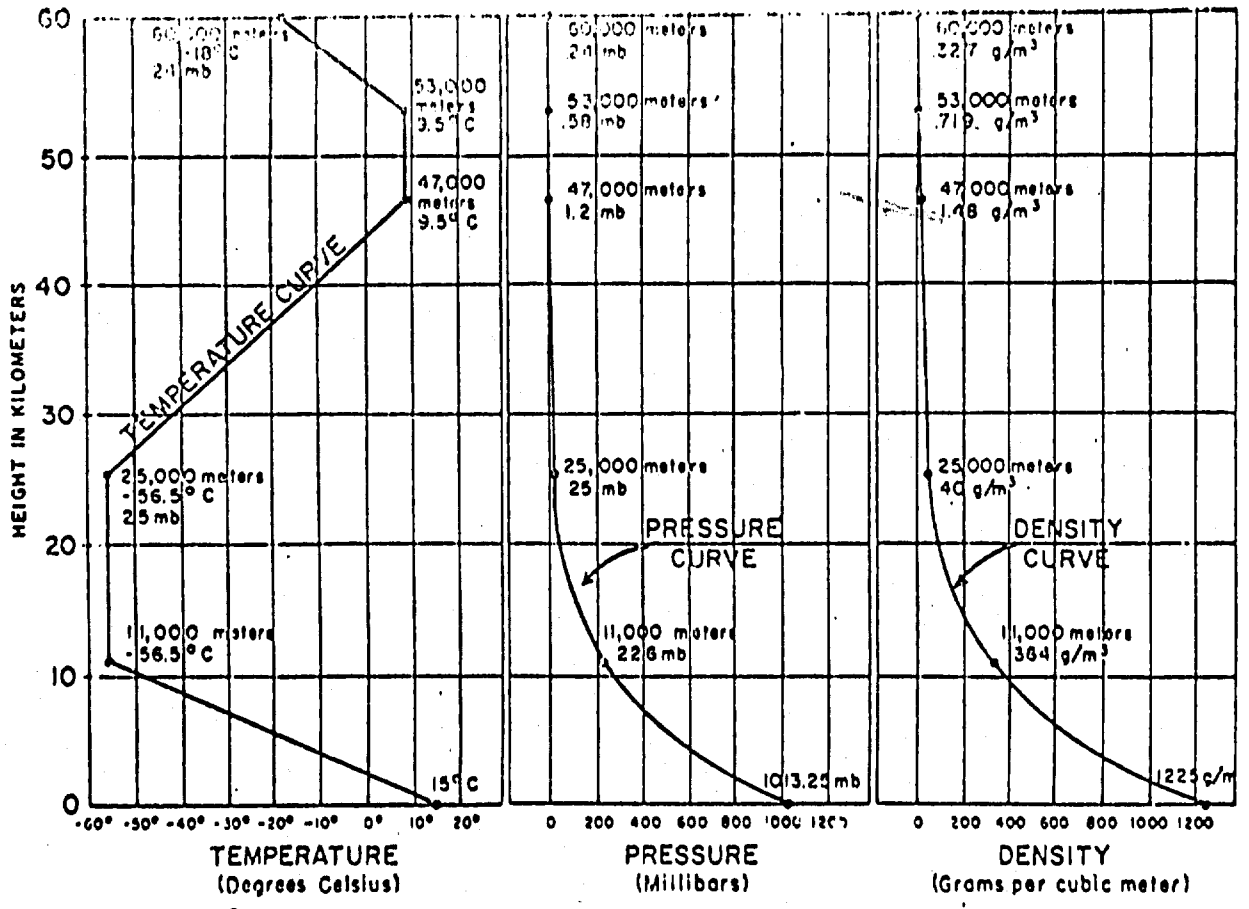


Figure 1. Temperature, Pressure, and Density at Various Altitudes Above Sea Level in the Standard Atmosphere.

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APPENDIX C

EXAMPLES OF METEOROLOGICAL DATA

Tables I through IV contain examples of Aberdeen Proving Ground meteorological data selected as representative for each season of the year.

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Table I: Examples of Metro Data Measurements During Winter

Time (min.)	Altitude (meters)	Temperature (°Celsius)	Density (kg/m^3)	Standard Density (kg/m^3)	Relative Density (%)	Range Wind[1] (knots)	Cross Wind[1] (knots)
0	0	-6.5	1.3464	1.2250	1.099	[2]+6.6	-11.3
0.2	50	-8.2	1.3470	1.2191	1.105	....	....
1	220	-9.9	1.3271	1.1994	1.106	+4.5	-16.1
2	510	-12.4	1.2904	1.1662	1.106	+5.2	+18.8
3	800	-14.2	1.2523	1.1337	1.105	+15.7	-22.9
3.3	900	-12.0	1.2244	1.1226	1.091	....	....
4	1140	-12.0	1.1884	1.0965	1.084	+20.4	-22.5
5	1440	-13.2	1.1456	1.0645	1.076	+15.7	-21.6
6	1760	-15.1	1.1068	1.0311	1.073	+10.5	-22.9
7	2040	-15.9	1.0696	1.0025	1.067	+7.2	-27.8
8	2320	-16.4	1.0324	0.9745	1.059	+6.8	-34.6
9	2600	-14.3	0.9863	0.9472	1.041	+6.4	-40.6
9.4	2710	-12.7	0.9656	0.9366	1.031	....	....
10	2900	-13.4	0.9440	0.9185	1.028	+9.7	-47.2
11	3210	-13.9	0.9069	0.8896	1.019	+12.4	-55.2
12	3520	-13.3	0.8686	0.8614	1.008	+9.7	-57.5
13	3830	-15.3	0.8416	0.8339	1.009	+9.7	-59.1
14	4115	-17.4	0.8172	0.8092	1.010	+14.2	-62.7
15	4410	-20.0	0.7925	0.7843	1.010	+13.6	-61.6
				Avg.	1.059		

[1]With reference to Aberdeen Proving Ground firing of weapons in an azimuthal direction of 35° west of south.

[2]A positive (+) range wind is a projectile tailwind. A positive (+) crosswind blows from left to right relative to the gunner looking downrange.

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Table II. Examples of Metro Data Measurements During Spring

Time (min.)	Altitude (meters)	Temperature (°Celsius)	Density (kg/m^3)	Standard Density (kg/m^3)	Relative Density (%)	Range Wind[1] (knots)	Cross Wind[1] (knots)
0	0	9.3	1.2506	1.2250	1.021	+7.6	-4.3
1	310	4.1	1.2261	1.1890	1.031	[2]+12.8	-15.0
2	070	0.6	1.1871	1.1482	1.034	+20.2	-15.0
3	990	-2.6	1.1544	1.1127	1.037	+27.0	-11.5
4	1300	-4.4	1.1177	1.0793	1.036	+27.8	-12.4
5	1650	-7.7	1.0843	1.0424	1.040	+28.2	-14.2
6	2000	-10.3	1.0474	1.0065	1.041	+30.5	-14.2
7	2260	-8.3	1.0061	0.9804	1.026	+31.1	-14.2
8	2470	-8.1	0.9771	0.9598	1.019	+30.5	-17.1
9	2680	-7.4	0.9476	0.9395	1.009	+32.1	-22.5
9.6	2830	-6.6	0.9278	0.9253	1.003	....	....
10	2930	-7.4	0.9122	0.9110	1.001	+33.4	-29.3
11	3340	-9.4	0.8782	0.8777	1.001	+28.7	-31.9
12	3700	-12.0	0.8443	0.8454	0.999	+23.1	-31.1
13	4030	-15.1	0.8180	0.8165	0.992	+24.7	-34.2
14	4380	-17.4	0.7886	0.7868	1.002	+24.1	-30.9
15	4674	-18.6	0.7635	0.7628	1.001	+21.8	-25.3
					Avg. 1.017		

[1]See footnote 1, Table I. [2]See footnote 2, Table I.

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Table III. Examples of Metro Data Measurements During Summer

Time (min.)	Altitude (meters)	Temperature (°Celsius)	Density (kg/m^3)	Standard Density (kg/m^3)	Relative Density (%)	Range Wind[1] (knots)	Cross Wind[1] (knots)
0	0	34.0	1.1417	1.2250	0.932	0.0	-5.2
1	310	28.8	1.1211	1.1890	0.943	-1.4	-5.4
2	690	25.5	1.0882	1.1459	0.950	-2.5	-7.2
3	1080	21.7	1.0536	1.1030	0.955	-0.6	-8.7
4	1360	19.2	1.0301	1.0728	0.960	[2]+4.1	-9.7
5	1580	17.5	1.0092	1.0497	0.961	+6.4	-11.1
6	1870	16.7	0.9814	1.0197	0.962	+3.3	-12.4
7	2140	15.9	0.9530	0.9924	0.960	-0.2	-15.0
8	2430	13.3	0.9301	0.9637	0.965	+0.8	-15.2
9	2650	11.6	0.9100	0.9423	0.966	+1.7	-13.6
10	2930	9.9	0.8866	0.9157	0.968	+0.6	-13.2
11	3200	7.5	0.8644	0.8906	0.971	-0.2	-12.0
12	3440	5.6	0.8457	0.8686	0.974	-0.8	-13.4
13	3750	3.6	0.8191	0.8410	0.974	-0.2	-16.3
14	4040	1.6	0.7960	0.8157	0.976	+1.0	-18.3
15	4365	-0.1	0.7713	0.7880	0.979	+1.2	-19.0
					Avg. 0.962		

[1] See footnote 1, Table I. [2] See footnote 2, Table I.

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Table IV. Examples of Metro Data Measurements During Fall

Time (min.)	Altitude (meters)	Temperature (°Celsius)	Density (kg/m^3)	Standard Density (kg/m^3)	Relative Density (%)	Range Wind[1] (knots)	Cross Wind[1] (knots)
0	0	14.4	1.2418	1.2250	1.014	[2]+1.2	[2]+3.1
1	260	12.5	1.2167	1.1947	1.018	+8.0	+1.9
2	440	10.4	1.1959	1.1775	1.016	-4.7	+1.6
3	620	9.0	1.1756	1.1538	1.019	+3.5	+1.9
4	820	7.6	1.1514	1.1315	1.018	+4.5	+2.3
4.9	1020	6.7	1.1278	1.1095	1.016	....	....
5	1080	7.1	1.1200	1.1030	1.015	+0.4	+2.1
5.3	1125	8.4	1.1099	1.0981	1.011	....	....
6	1280	9.5	1.0842	1.0814	1.003	-1.2	+1.6
7	1560	8.7	1.0542	1.0518	1.001	+3.3	+1.4
8	1780	7.9	1.0249	1.0289	0.996	+3.9	+1.2
9	2050	6.8	0.9979	1.0014	0.997	+3.9	+1.2
10	2300	5.4	0.9733	0.9765	0.997	+2.5	+1.2
11	2560	5.6	0.9417	0.9510	0.990	+1.2	+1.2
12	2830	5.3	0.9140	0.9252	0.988	+1.2	+1.0
13	3090	5.2	0.8844	0.9007	0.981	+2.5	+0.6
14	3370	3.6	0.8593	0.8750	0.982	+5.2	+0.4
15	3640	3.1	0.8332	0.8507	0.979	+6.4	+0.4
					Avg. 1.002		

[1]See footnote 1, Table I. [2]Footnote 2, Table I.

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TEST PROGRAM	155MMHOWITZER	RADIOSONDE NO.	13719
PROJECT ENGINEER	MR. COLLINS	ASCENSION NO.	6R
DATE	06 JUN 1983	MAX ORDINATE	
TIME OF RELEASE	1503	REQUIRED	3700 METERS
LINE OF FIRE	44 DEG 48 MIN FROM SOUTH	ACHIEVED	3700 METERS

SURFACE DATA

ATMOSPHERIC PRESSURE (MB)	TEMPERATURE (DEG C)	RELATIVE HUMIDITY (PER CENT)	WIND DIRECTION (DEGREES)	WIND SPEED (MPS)	WIND GUSTS (MPS)
1015.6	22.3	66.	135.0	8.5	11.2

TIME (MIN)	ALTITUDE (METERS)	ALTITUDE (FEET)	GEOPOTENTIAL ALTITUDE (METERS)	GEOPOTENTIAL ALTITUDE (FEET)	TEMP (DEG C)	VIRTUAL TEMP (DEG K)	PRESSURE (MBS)	DENSITY (KG/CU M)	WIND DIRECTION (DEGREES)	WIND SPEED (MPS)	RANGE WIND (MPS)	CROSS WIND (MPS)
0.0	0.	0.	0.	0.	22.3	297.5	1015.6	1.1894	135.0	8.5	-0.0	8.5
1.0	328.	1075.	327.	1073.	17.0	291.4	977.8	1.1692	145.1	11.0	-2.0	10.8
2.0	662.	2171.	660.	2167.	15.1	289.2	940.2	1.1328	174.1	11.5	-7.3	8.9
3.0	1024.	3359.	1022.	3352.	13.0	287.2	900.8	1.0928	202.0	11.6	-10.7	4.5
4.0	1401.	4596.	1398.	4586.	11.0	285.3	861.3	1.0515	226.5	12.4	-12.4	-0.4
5.0	1748.	5736.	1744.	5723.	8.9	283.4	826.2	1.0155	240.1	11.6	-11.2	-3.1
6.0	2091.	6859.	2086.	6844.	7.3	281.8	792.6	0.9800	249.4	9.4	-8.5	-3.9
7.0	2397.	7865.	2391.	7846.	7.7	282.0	764.0	0.9437	266.1	8.8	-6.6	-5.8
8.0	2725.	8944.	2720.	8923.	7.0	281.1	734.2	0.9099	291.4	11.6	-4.6	-10.7
9.0	3042.	9980.	3035.	9956.	6.2	280.2	706.6	0.8786	304.1	14.8	-2.7	-14.5
10.0	3349.	10988.	3341.	10961.	3.8	277.8	680.6	0.8535	305.3	14.9	-2.5	-14.7
11.0	3624.	11889.	3615.	11859.	1.7	275.6	658.0	0.8319	308.0	15.5	-1.8	-15.4
12.0	3940.	13156.	3929.	13122.	-1.5	273.2	629.6	0.8028	314.4	16.6	-0.1	-16.6
13.0	4316.	14164.	4304.	14125.	-2.3	271.3	608.2	0.7732	78.6	0.0	0.0	0.0

Figure C-1. Typical metro report to test director.

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