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SECTION 6

HUMIDITY

6.1 Introduction. The water vapor or moisture content of the atmosphere plays a significant role in the fabrication, test, operations, and flight of aerospace vehicles because it can cause both physical and chemical deterioration of materials as well as affect vehicle functions. Some effects atmospheric moisture may have on aerospace vehicles are:

1. Minute particulates can be corrosive when they settle from the air. The rate of corrosion increases with humidity.

2. Humidity can affect the performance of electronic equipment, i.e., changes the dielectic constants of capacitors, decreases the breakdown voltage between potentials, and causes deterioration of electronic components through metallic corrosion or electrode chemical reactions.

3. Organic growth, bacteria, and fungi thrive in warm, moist air, consequently degrading performance of aerospace systems and sensors.

4. The low temperature of the cryogenic fuels cools the moist air, often resulting in condensation and icing or frost which can be detrimental to vehicle operation.

This section will define some terminology associated with water vapor and discuss some of the effects of the vapor. Various tests are required to measure the effects of water vapor as early as possible in a program development cycle. Most of these tests are outlined in references 6.1 and 6.2; however, some test criteria for specific sites are described herein.

6.2 Definitions (Ref. 6.3)

Absolute Humidity: In a system of moist air, the ratio of the mass of water vapor present to the volume occupied by the mixture; that is, the density of the water vapor component.

Condensation: The physical process by which a vapor becomes a liquid or solid; the opposite of evaporation.

Critical Point: The thermodynamic state in which the liquid and gas phases of a substance co-exist in equilibrium at the highest possible temperature. (At higher temperatures the liquid phase will not exist.)

Dew-Point Temperature: The temperature to which a given parcel of air must be cooled at constant pressure and constant water-vapor content in order for saturation to occur.

Dry-Bulb Temperature; The temperature of the air. The temperature registered by the dry-bulb thermometer of a psychrometer (sometimes referred to as ambient temperature).

Evaporation: The phase transition in which the liquid or solid is transformed into the gaseous state; the opposite of condensation. In meteorology, evaporation is usually restricted to a liquid becoming a gas, while sublimation refers to phase changes between solids and gases.

Frost Point: The highest temperature at which sublimation directly from water vapor to ice crystals occurs. It is analogous to the dew point at 0° C, but below 0° C, the frost point becomes greater than the dew point since the saturation vapor pressure over ice is less than the saturated vapor pressure over water.

Humidity: A general measure of the water vapor content in air. (See absolute humidity, relative humidity, specific humidity, mixing ratio, and dew point.)

Hydrology: The branch of physical geography which deals with the waters of the Earth exclusive of the oceans. The moisture (vapor, liquid, and solid) in the atmosphere is one phase of the "hydrologic cycle."

Hygrometer: An instrument which measures the water vapor content of the atmosphere.

Hygrometery: The study which deals with the measurements of the humidity and other gases of the atmosphere.

Latent Heat of Condensation: The heat released per unit mass as water vapor condenses to form water droplets or ice crystals.

Latent Heat of Vaporization: The heat absorbed per unit mass as water or ice is vaporized into the gaseous state. The inverse of the latent heat of condensation can be estimated within 0.8 percent for temperature T within the range of meteorological interest by the equation:

$$L_v = (2{,}500 - 2.274\text{T °C})\ J/g \quad \text{(Ref. 6.4)} \qquad (6.1)$$

More precise values are available from a table in reference 6.5.

Mixing Ratio: In a system of moist air, the dimensionless ratio of the mass of water vapor to the mass of dry air.

Moisture: A term usually referring to the water vapor content of the atmosphere, or to the total water substance (gaseous, liquid, and solid) present in a given volume of air.

Moisture Inversion: An increase with altitude of the moisture content of the air; specificially, the layer through which this increase occurs, or the altitude at which the increase begins.

Relative Humidity: The dimensionless ratio of the actual water vapor pressure of the air to the saturation vapor pressure. Relative humidity above 100 percent occurs (particularly with respect to ice) which gives rise to dew and frost. This may be relevant to surfaces which are locally colder (by radiation or otherwise).

Saturation: The condition in which the partial pressure of any fluid constituent is equal to its maximum possible partial pressure under the existing environmental conditions, such that any increase in the amount of that constituent without a change in the surrounding conditions will create a thermo-dynamically unstable environment where, if a nucleation site exists, condensation will occur.

Specific Humidity: In a system of moist air, the dimensionless ratio of the mass of water vapor to the total mass of the system.

Sublimation: The transition of a substance from the solid phase directly to the vapor phase, or vice versa, without passing through an intermediate liquid phase.

Supersaturation: The condition existing in a given portion of the atmosphere (or other space) when the relative humidity is greater than 100 percent; that is, when it contains more water vapor than is needed to produce saturation with respect to a plane surface of pure water or pure ice.

Vapor: A substance existing in a gaseous state at a temperature lower than that of its critical point. It is formed by evaporation or sublimation and can become liquefied with compression.

Vapor Concentration: (previously called absolute humidity (Ref. 6.6)). The ratio of the mass of water vapor present to the volume occupied by the mixture, i.e., the density of the water content. This is usually expressed in grams of water vapor per cubic meter of air.

Vapor Pressure: The pressure exerted by the molecules of a given vapor. For a pure, confined vapor, vapor pressure is the pressure on the walls of its containing vessel; and for a vapor mixed with other vapors or gases, it is that vapor's contribution to the total pressure (i.e., its partial pressure).

Wet-Bulb Temperature: The temperature read from the wet-bulb thermometer. More formally: "The temperature an air parcel would have if cooled adiabatically to saturation at constant pressure by evaporation of water into it, all latent heat being supplied by the parcel." The thermometer reading can be used on a psychrometry chart to determine the corresponding value of relative humidity.

6.3 Vapor Concentration

6.3.1 Background Information. A significant amount of moisture exists in the atmosphere, the majority of which comes from the Earth's surface. The equatorial region of the Earth is the main source from which moisture is supplied to the atmosphere. Broad-scale evaporation takes place in this area due to the vast oceanic area and moist land regions in addition to the warm climatic conditions.

Since the molecular weight of water vapor is less than the molecular weight of dry air, moist air is less dense than dry (drier) air. This contributes to the lower atmospheric pressure which is common to warm, moist air masses. To a great extent, the dynamic variations of global circulation are due to the pressure difference between moist (warm) and dry (cold) air.

The various measures of water vapor are related, as shown by table 6.1 (ref. 6.7) as well as the following approximated equations:

1. Vapor pressure in terms of frost point

$$\log_{10}e = -2{,}485.0/T_F + 3.5665 \log_{10}T_F - 0.0032098T_F + 2.0702 \qquad (6.2)$$

2. Vapor pressure in terms of dew point

$$\log_{10}e = -2{,}949.1/T_D - 5.028 \log_{10}T_D + 23.832 \qquad (6.3)$$

3. Absolute humidity (g/m^3) (vapor concentration) in terms of vapor pressure and air temperature

$$\rho_v = 216.68\ e/T \qquad (6.4)$$

4. Mixing ratio (g/kg) in terms of vapor pressure and atmospheric pressure

$$r = 621.97\ e/(p-e)\ , \qquad (6.5)$$

where

e = vapor pressure (mb)
T = air temperature (K)

T_D = dew point temperature (K)
T_F = frost point temperature (K)
p = atmospheric pressure (mb)
ρ_v = absolute humidity (g/m^3)
r = mixing ratio (g/kg).

6.3.2 Testing. Testing is a necessary precaution in order to minimize failure due to atmospheric moisture. The effects of moisture are measured by humidity cycling, a procedure in which test items are placed in a closed chamber where temperature and relative humidity are closely regulated to simulate environmental conditions (ref. 6.2). Chamber test procedures and criteria for various systems and their associated electrical-mechanical components are usually identified in the various system requirements documents. This document recommends criteria based on actual environmental records, including extreme values, in component testing to promote realism about the actual environment.

NASA's External Tank Verification Plan (ref. 6.8) lists the following general statements under Test Controls and Test Methods: (1) the item is sealed or potted and subjected to a seal test, (2) the item is located in a controlled-humidity or air-conditioned environment during operation and is protected from humidity when non-operating, (3) the item is subjected to propellant compatibility testing which is considered to be a more severe environment, and (4) the item is fabricated from materials which preclude corrosion by humidity. This requires additional and different quality control standards than those discussed previously.

The space shuttle program, shuttle master verification plan document, states that the humidity and other environmental parameter tests will use the procedures outlined in "Military Standard 810" (ref. 6.2 is the latest version, i.e., MIL-STD 810D).

A temperature of 71 °C (160 °F) and 95-percent relative humidity represent a dew-point temperature of 69 °C (156 °F), which is much higher than any natural extreme in the world. Dew points above 32° (90° F) are extremely unlikely in nature (ref. 6.9), since the dew-point temperature is limited by the source of the water vapor, i.e., the surface temperature of the water body from which the water evaporates (ref. 6.10). The following paragraphs contain site-specific humidity criteria to be used in aerospace vehicle testing.

6.3.2.1 High Vapor Concentration at Surface.

a. Huntsville, New Orleans, and Kennedy Space Center:

(1) An extreme humidity cycle of 24 hours with a wind of less than 5 m/s (9.7 knots): Three hours of 37.2 °C (99 °F) air temperature at 50-percent relative humidity and a vapor concentration of 22.2 g/m^3 (9.7 gr/ft^3), 6 hours of decreasing air temperature to 24.4 °C (76 °F) with relative humidity increasing to 100 percent (saturation), 8 hours of decreasing air temperature to 21.1° C (70° F) with a release of 3.8 grams of water as liquid per cubic meter of air (1.7 grains of water per cubic foot of air) with relative humidity remaining at 100 percent, * and 7 hours of increasing air temperature to 37.2 °C (99 °F) and a decrease to 50-percent relative humidity (Fig 6.1).

*The release of water as a liquid on the test object may be delayed for several hours after the start of this part of the test because of thermal lag in a large test object. If the lag is too large, the test should be extended in time for each cycle to allow condensation.

TABLE 6-1. The Correspondence Between the Several Measures of Water Vapor Content (Ref. 6.7).

Dew Point (K)	Frost Point (K)	Vapor Pressure (mb)	Absolute† Humidity (g/m^3)	Mixing Ratio (g/kg)								
				1,000 mb	850 mb	700 mb	500 mb	400 mb	100 mb	50 mb	10 mb	1 mb
313		7.378+1	5.119+1	4.980+1	5.941+1	7.361+1	1.080+2	1.411+2	*	*	*	*
308		5.624+1	3.963+1	3.725+1	4.427+1	5.456+1	7.910+1	1.020+2	8.008+2	*	*	*
303		4.243+1	3.038+1	2.769+1	3.282+1	4.029+1	5.786+1	7.399+1	4.590+2	*	*	*
298		3.167+1	2.305+1	2.044+1	2.417+1	2.959+1	4.219+1	5.363+1	2.886+2	*	*	*
293		2.337+1	1.730+1	1.495+1	1.766+1	2.156+1	3.059+1	3.870+1	1.899+2	5.462+2	*	*
288		1.704+1	1.283+1	1.083+1	1.278+1	1.557+1	2.201+1	2.775+1	1.279+2	3.217+2	*	*
283		1.227+1	9.399	7.762	9.146	1.113+1	1.569+1	1.973+1	8.707+1	2.024+2	*	*
278		8.719	6.797	5.495	6.471	7.870	1.107+1	1.389+1	5.946+1	1.314+2	*	*
273	273.0	6.108	4.847	3.839	4.519	5.492	7.710	9.664	4.049+1	8.659+1	9.764+2	*
268	268.6	4.215	3.407	2.644	3.112	3.780	5.300	6.637	2.739+1	5.728+1	4.533+2	*
263	264.1	2.863	2.358	1.794	2.110	2.562	3.590	4.492	1.834+1	3.779+1	2.495+2	*
258	259.6	1.912	1.605	1.197	1.408	1.709	2.393	2.993	1.213+1	2.474+1	1.470+2	*
253	255.1	1.254	1.074	7.847–1	9.227–1	1.120	1.568	1.960	7.903	1.601+1	8.919+1	*
248	250.5	8.070–1	7.047–1	5.048–1	5.936–1	7.204–1	1.008	1.260	5.603	1.021+1	5.461+1	*
243	245.8	5.088–1	4.534–1	3.182–1	3.742–1	4.540–1	6.352–1	7.938–1	3.183	6.397	3.335+1	6.443+2
238	241.2	3.139–1	2.856–1	1.963–1	2.308–1	2.801–1	3.918–1	4.896–1	1.960	3.931	2.016+1	2.846+2
233	236.5	1.891–1	1.757–1	1.183–1	1.390–1	1.687–1	2.360–1	2.948–1	1.179	2.362	1.199+1	1.450+2
273.0	273	6.107	4.847	3.839	4.518	5.492	7.709	9.668	4.048+1	8.658+1	9.759+2	*
267.3	268	4.015	3.246	2.518	2.963	3.599	5.047	6.322	2.604+1	5.433+1	4.722+2	*
261.8	263	2.597	2.139	1.627	1.913	2.324	3.255	4.075	1.660+1	3.409+1	2.182+2	*
256.2	258	1.652	1.387	1.034	1.216	1.476	2.067	2.592	1.045+1	2.126+1	1.231+2	*
250.8	253	1.032	8.835–1	6.456–1	7.592–1	9.214–1	1.289	1.613	6.490	1.311+1	7.158+1	*
245.3	248	6.323–1	5.521–1	3.955–1	4.650–1	5.643–1	7.895–1	9.872–1	3.961	7.969	4.199+1	*
239.9	243	3.798–1	3.385–1	2.375–1	2.792–1	3.388–1	4.740–1	5.926–1	2.373	4.763	2.456+1	3.809+2
234.6	238	2.233–1	2.032–1	1.396–1	1.642–1	1.993–1	2.787–1	3.483–1	1.393	2.791	1.420+1	1.788+2
229.3	233	1.283–1	1.192–1	8.026–2	9.434–2	1.144–1	1.600–1	2.001–1	7.996–1	1.601	8.084	9.154+1
224.1	228	7.198–2	6.836–2	4.503–2	5.293–2	6.422–2	8.981–2	1.122–1	4.483–1	8.970–1	4.510	4.824+1
	223	3.935–2	3.821–2	2.463–2	2.895–2	3.512–2	4.910–2	6.135–2	2.450–1	4.901–1	2.457	2.548+1
	218	2.092–2	2.078–2	1.309–2	1.539–2	1.867–2	2.611–2	3.261–2	1.302–1	2.604–1	1.304	1.329+1
	213	1.080–2	1.098–2	6.761–3	7.947–3	9.640–3	1.347–2	1.684–2	6.723–2	1.344–1	6.725–1	6.791
	208	5.006–3	5.627–3	3.386–3	3.979–3	4.826–3	6.749–3	8.427–3	3.365–2	6.728–2	3.362–1	3.381
	203	2.615–3	2.784–3	1.639–3	1.926–3	2.336–3	3.265–3	4.076–3	1.628–2	3.254–2	1.627–1	1.631
	198	1.220–3	1.334–3	7.646–4	8.986–4	1.090–3	1.524–3	1.902–3	7.593–3	1.518–2	7.590–2	7.597–1
	193	5.472–4	6.138–4	3.423–4	4.023–4	4.882–4	6.828–4	8.530–4	3.406–3	6.810–3	3.404–2	3.405–1
	188	2.353–4	2.710–4	1.472–4	1.730–4	2.099–4	2.936–4	3.668–4	1.465–3	2.928–3	1.464–2	1.464–1
	183	9.672–5	1.144–4	6.051–5	7.111–5	8.629–5	1.207–4	1.508–4	6.020–4	1.204–3	6.016–3	6.016–2

† At saturation only.
* Atmospheric saturation is not possible at this ambient temperature and pressure

(2) An extreme relative humidity between 75 and 100 percent and air temperature between 22.8 °C (73 °F) and 27.8 °C (82 °F), which would result in corrosion and bacterial and fungal growths, can be expected for a period of 15 days. A humidity of 100 percent occurs one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air by condensation is replaced from outside sources to maintain at least 75-percent relative humidity at the higher temperature.

b. Vandenberg AFB:

(1) An extreme humidity cycle of 24 hours with a wind of less than 5 m/s (9.7 knots): Three hours of 23.9 °C (75 °F) air temperature at 75-percent relative humidity and a vapor concentration of 16.2 g/m^3 (7.1 gr/ft^3), 6 hours of decreasing air temperature to 18.9 °C (66 °F) with relative humidity increasing to 100 percent, 8 hours of decreasing air temperature to 12.8 °C (55 °F) with a release of 5.0 grams of water as liquid per cubic meter of air (2.2 grains of water per cubic foot of air) with relative humidity remaining at 100 percent, and 7 hours of increasing air temperature to 23.9 °C (75 °F) and a decrease to 75-percent relative humidity (Fig. 6.2).

(2) Bacterial and fungal growth should present no problem because of the lower temperatures in this area. For corrosion, an extreme relative humidity of between 75 and 100 percent and air temperature between 18.3 °C (65 °F) and 23.3 °C (74 °F) can be expected for a period of 15 days. The humidity should be 100 percent during one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air condensation is replaced from outside sources to maintain at least 75-percent relative humidity at the higher temperature.

c. White Sands Missile Range: This area is located at 1,216 m (4,000 ft) above sea level and is on the eastern side of higher mountains. The mean annual rainfall of 250 cm (10 in) is rapidly absorbed in the sandy soil. Fog rarely occurs; therefore, at this location, a high vapor concentration over periods longer than a few hours need not be considered.

6.3.2.2 Low Vapor Concentration at Surface

6.3.2.2.1 Introduction. Low water-vapor concentration can occur at very low or at high temperatures when the air is very dry. In both cases, the dew points are very low. However, in the case of low dew points and high temperatures, the relative humidity is low. When any storage area or compartment of a vehicle is heated to temperatures well above the ambient air temperature (such as the high temperatures of the storage area in an aircraft standing on the ground in the Sun), the relative humidity will be even lower than the relative humidity of the ambient air. These two types of low water-vapor concentrations have entirely different environmental effects. In the case of low air temperatures, ice or condensation may form on equipment, while in the high-temperature, low-humidity condition, organic materials may dry and split or otherwise deteriorate. When a storage area (or aircraft) is considerably warmer than the ambient air (even when the air is cold), the drying increases even more. Low relative humidities may also result in another problem—that of static electricity. Static electrical charges on equipment may ignite fuel, result in shocks to personnel when discharged, or interfere with performance of the microelectronic components of the system. Because of these dangers, the two types of low water-vapor concentrations (dry extreme) are given for testing criteria in the following paragraph.

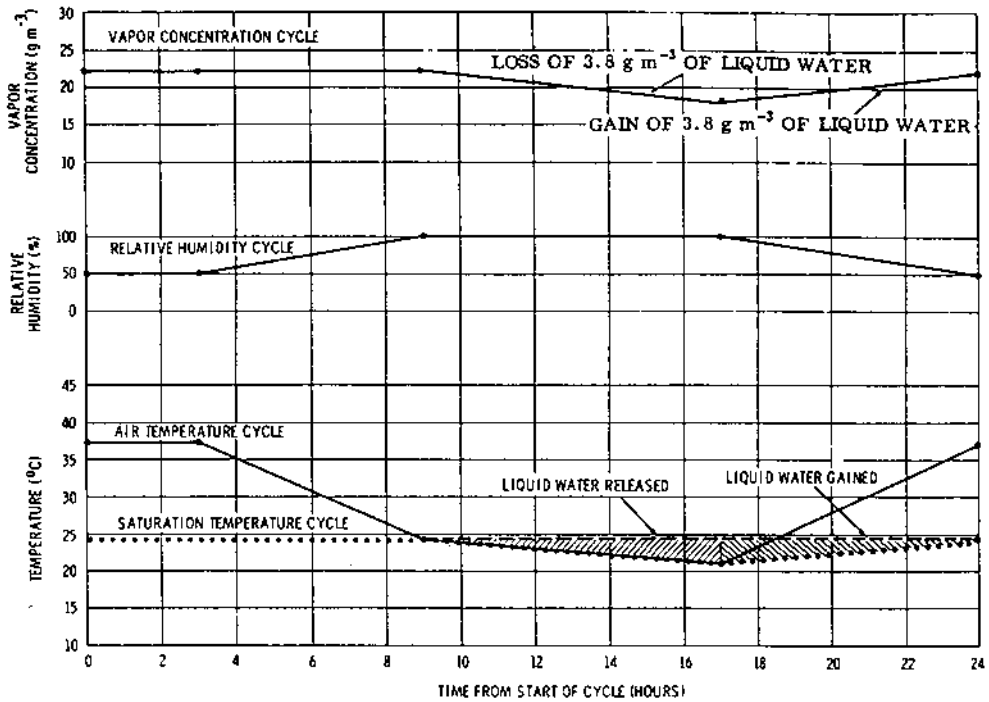

FIGURE 6.1 Extreme High Vapor Concentration Cycle for Huntsville, New Orleans, and Kennedy Space Center.

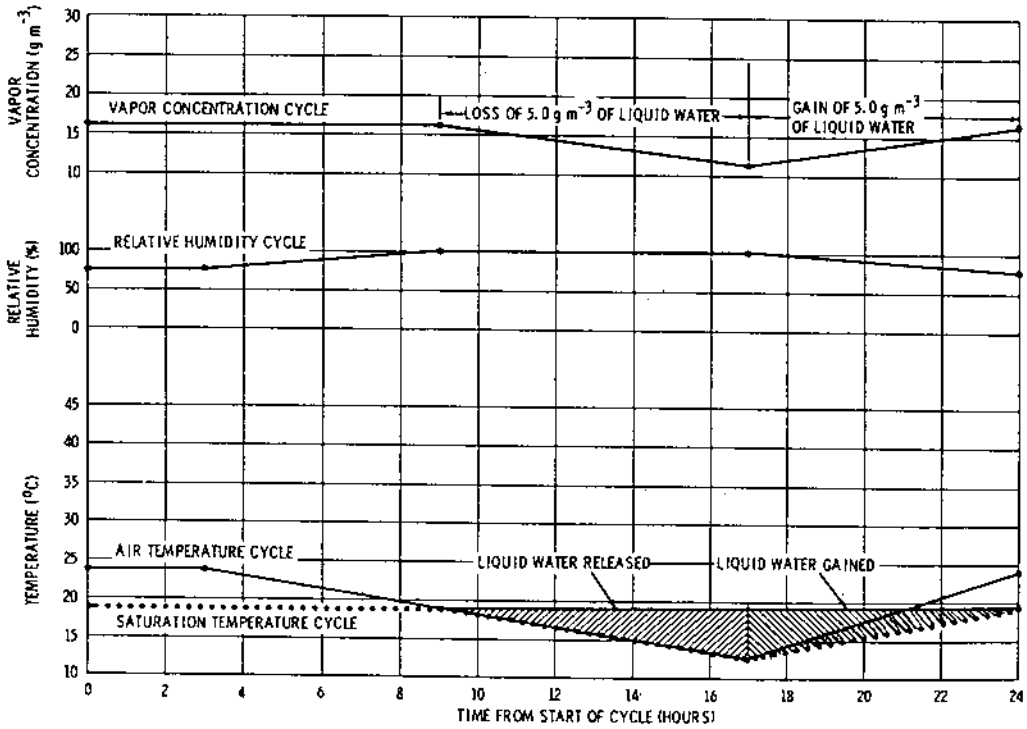

FIGURE 6.2 Extreme High Vapor Concentration for the Vandenberg AFB.

6.3.2.2.2 Surface Extremes of Low Vapor Concentration

a. Huntsville and White Sands Missile Range:

(1) An air temperature of –11.7 °C (+11 °F) and a vapor concentration of 2.1 g/m^3 (0.9 gr/ft^3), with a relative humidity between 98 and 100 percent for a duration of 24 hours.

(2) An air temperature of 28.9 °C (84 °F), a vapor concentration of 4.5 g/m^3 (2.0 gr/ft^3) (corresponding to a dew point of 1.1 °C (30 °F)), and a relative humidity of 15 percent occurring for 6 hours; a maximum relative humidity of 34 percent at an air temperature of 15.6 °C (60 °F) for the remaining 18 hours of the day for a 10-day period.

b. New Orleans and Kennedy Space Center:

(1) An air temperature of –2.2 °C (28 °F) and a vapor concentration of 4.2 g/m^3 (1.8 gr/ft^3), with a relative humidity between 98 and 100 percent for a duration of 24 hours.

(2) An air temperature of 22.2 °C (72 °F), a vapor concentration of 5.6 g/m^3 (2.4 gr/ft^3) (corresponding to a dew point of 2.2 °C (36 °F)), and a relative humidity of 29 percent occurring for 8 hours; a maximum relative humidity of 42 percent at an air temperature of 15.6 °C (60 °F) for the remaining 16 hours of the day for a 10-day period.

c. Vandenberg Air Force Base:

(1) An air temperature of –2.2 °C (28 °F) and a vapor concentration of 4.2 g/m^3 (1.8 gr/ft^3), with a relative humidity between 98 and 100 percent for a duration of 24 hours.

(2) An air temperature of 37.8 °C (100 °F), a vapor concentration of 4.8 g/m^3 (2.1 gr/ft^3) (corresponding to a dew point of 0.0 °C (32 °F)), and a relative humidity of 11 percent occurring for 4 hours; a maximum relative humidity of 26 percent at an air temperature of 21.1 °C (70 °F) for the remaining 20 hours of the day for a 10-day period.

6.3.3 Compartment Vapor Concentration at Surface. For testing to simulate conditions in the interior of an aircraft or space vehicle compartment, the following criteria should be used for all locations: a low water vapor concentration extreme of 10.1 g/m^3 (4.4 gr/ft^3), corresponding to a dew point of 11.1 °C (52 °F) at a temperature of 87.8 °C (190 °F) and a relative humidity of 2 percent occurring for 1 hour, a linear change over a 4-hour period to an air temperature of 37.8 °C (100 °F) and a relative humidity of 22 percent occurring for 15 hours, then a linear change over a 4-hour period to the initial conditions.

6.4 Vapor Concentration at Altitude. In general, the vapor concentration decreases with altitude in the troposphere, because of the decrease of temperature with altitude. Stratospheric and mesospheric levels of atmospheric moisture are small. Figure 6.3 presents an interim reference model for the mean and variability of middle atmospheric water vapor (ref. 6.11). It represents mean, Northern Hemisphere, mid-latitude, springtime, mixing ratios (ppmv) along with its variability (bars) and accuracies (brackets). The data presented in the following paragraphs are appropriate for design purposes.

6.4.1 High Vapor Concentration at Altitude. The following tables present the relationship between maximum vapor concentration and the associated temperature normally expected as a function of altitude.

a. Maximum Vapor Concentrations for Kennedy Space Center, Table 6.2.

b. Maximum Vapor Concentrations for White Sands Missile Range, Table 6.3.

c. Maximum Vapor Concentrations for Vandenberg AFB, Table 6.4.

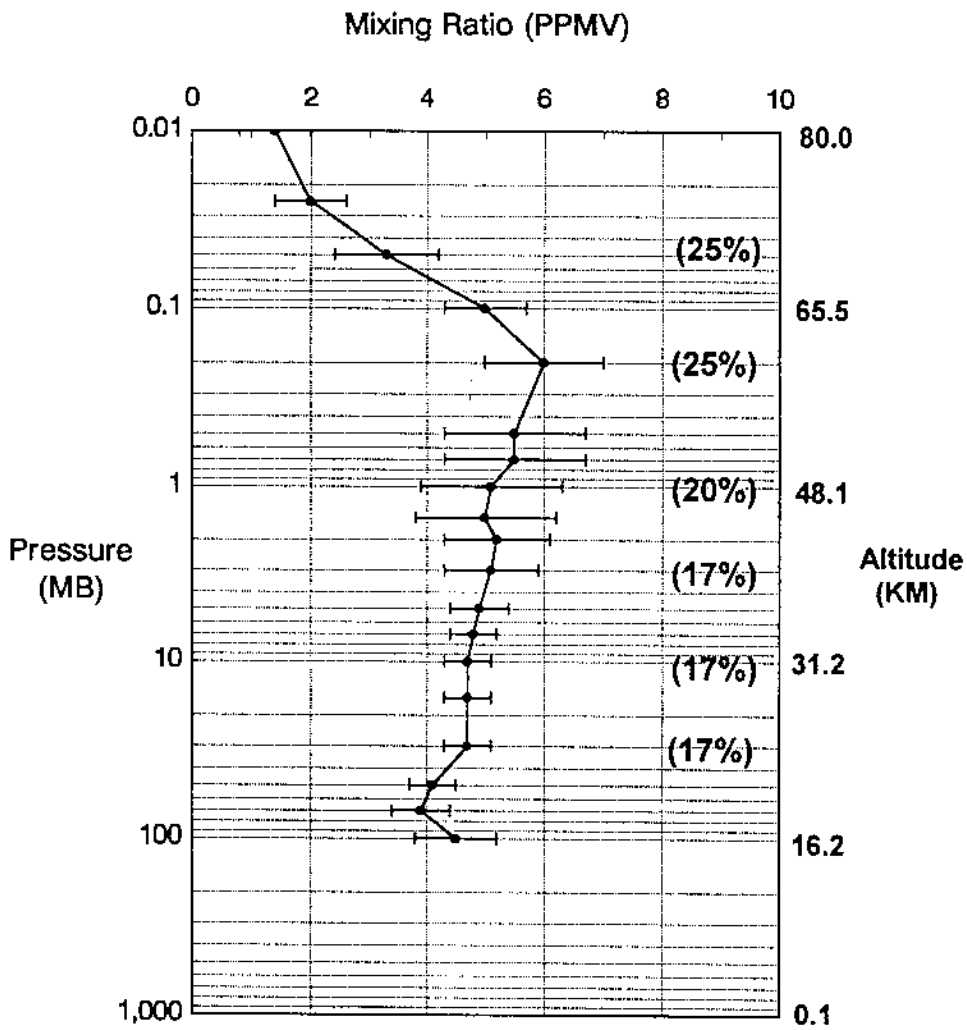

FIGURE 6.3. Reference Profile of Middle Atmosphere Mixing Ratio Mean, Variability, and Accuracy; Representative of Northern Hemisphere, Mid-Latitude, Springtime Conditions (Ref. 6.11).

6.4.2 Low Vapor Concentration at Altitude. The values presented as low extreme vapor concentrations in the following tables are based on data measured by standard radiosonde equipment.

a. Minimum Vapor Concentrations for Kennedy Space Center, Table 6.5.

b. Minimum Vapor Concentrations for White Sands Missile Range, Table 6.6.

c. Minimum Vapor Concentrations for Vandenberg AFB, Table 6.7.

TABLE 6.2 Maximum Vapor Concentration for Kennedy Space Center.

Geometric Altitude		Maximum Vapor Concentration		Temperature Associated With Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SFC (0.005 m.s.l.)	(16)	27.0	11.8	30.5	87
1	3,300	19.0	8.8	24.5	76
2	6,600	13.3	5.8	18.0	64
3	9,800	9.3	4.1	12.0	54
4	13,100	6.3	2.8	5.5	42
5	16,400	4.5	2.0	–0.5	31
6	19,700	2.9	1.3	–6.8	20
7	23,000	2.0	0.9	–13.0	9
8	26,200	1.2	0.5	–20.0	–4
9	29,500	0.6	0.3	–27.0	–17
10	32,800	0.3	0.1	–34.5	–30
16.2	53,100	0.025	0.01	–57.8	–72
20	65,600	0.08	0.03	–47.8	–54

TABLE 6.3 Maximum vapor concentration for White Sands Missile Range.

Geometric Altitude		Maximum Vapor Concentration		Temperature Associated With Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SFC (1.2 m.s.l.)	(3,989)	16.0	7.0	21.5	71
2	6,600	13.2	5.8	18.9	66
3	9,800	9.0	3.9	12.8	55
4	13,100	6.8	3.0	7.8	46
5	16,400	4.9	2.1	2.2	36
6	19,700	3.4	1.5	–2.2	28
7	23,000	2.2	1.0	–10.0	14
8	26,200	1.3	0.6	–16.1	3
9	29,500	0.6	0.3	–22.8	–9
10	32,800	0.2	0.1	–30.0	–22
16.5	54,100	0.08	0.03	–47.8	–54
20	65,600	0.05	0.02	–52.2	–62

TABLE 6.4 Maximum Vapor Concentration for Vandenberg AFB.

Geometric Altitude		Maximum Vapor Concentration		Temperature Associated With Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SFC (0.113 m.s.l.)	371	17.5	7.6	30.5	87
1	3,300	14.8	6.5	24.2	76
2	6,600	10.0	4.4	20.6	69
3	9,800	7.5	3.3	11.0	52
4	13,100	5.0	2.2	4.7	41
5	16,400	3.7	1.6	–1.4	30
6	19,700	2.3	1.0	–8.1	17
7	23,000	1.6	0.7	–12.5	10
8	26,200	0.8	0.3	–20.2	–4
9	29,500	0.4	0.2	–28.2	–19
10	32,800	0.2	0.1	–34.3	–30

TABLE 6.5 Minimum Vapor Concentration for Kennedy Space Center.

Geometric Altitude		Minimum Vapor Concentration		Temperature Associated With Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SFC (0.005 m.s.l.)	(16)	1.5	0.7	7.0	45
1	3,300	0.5	0.2	6.0	42.8
2	6,600	0.2	0.1	0.0	32.0
3	9,800	0.1	0.04	–11.0	12.2
4	13,100	0.1	0.04	–14.0	6.8

TABLE 6.6 Minimum Vapor Concentration for White Sands Missile Range.

Geometric Altitude		Minimum Vapor Concentration		Temperature Associated With Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SFC (1.2 m.s.l.)	(3,989)	1.2	0.5	–1.0	30
2	6,600	0.9	0.4	–5.0	23
3	9,800	0.6	0.3	–12.0	10
4	13,100	0.4	0.2	–20.0	–4
5	16,400	0.2	0.1	–26.0	–15
6	19,700	0.1	0.04	–36.0	–33
7	23,000	0.09	0.03	–42.0	–44
8	26,200	0.07	0.03	–49.0	–56
9	29,500	0.03	0.01	–55.0	–67
10	32,800	0.02	0.01	–60.0	–76

TABLE 6.7 Minimum Vapor Concentration for Vandenberg AFB.

Geometric Altitude		Minimum Vapor Concentration		Temperature Associated With Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SFC (0.113 m.s.l.)	371	1.6	0.7	4.5	40
1	3,300	0.7	0.3	–1.4	30
2	6,600	0.4	0.2	–7.5	19
3	9,800	0.3	0.1	–12.6	9
4	13,100	0.1	0.04	–19.4	–3
5	16,400	0.07	0.03	–27.3	–17
6	19,700	0.03	0.01	–35.1	–31
7	23,000	0.02	0.009	–39.5	–39

SECTION 6

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