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SECTION 3

THERMODYNAMIC PROPERTIES AND ATMOSPHERIC MODELS

3.1 Introduction. This section presents the surface and inflight thermodynamic parameters (temperature, pressure, and density) of the atmosphere in a statistical and a modeling mode. Mean and extreme values of these thermodynamic parameters can be used in application to many aerospace problems, such as: (1) research planning and engineering design of remote Earth sensing systems; (2) vehicle design and development; and (3) vehicle trajectory analysis, dealing with vehicle thrust, dynamic pressure, aerodynamic drag, aerodynamic heating, vibration, structural and guidance limitations, and reentry analysis. The first part of this section gives median and extreme values of these thermodynamic variables at sea level and surface level. The thermodynamic variables are then presented as a function of altitude in terms of median and extreme values. An approach is also presented for relating temperature, pressure, and density as independent variables, with a method to obtain simultaneous values of these variables at discrete altitude levels. A subsection on reentry is presented, giving atmospheric models for use in reentry heating, trajectory, etc., analyses. Sites presented in this section include Kennedy Space Center (KSC), Florida, Vandenberg Air Force Base (VAFB), California, Edwards AFB (EAFB), California, and White Sands Missile Range (WSMR), New Mexico. If other United States or world site surface extreme thermodynamic parameter values are needed, consult section 5. Many of the atmospheric models described in this section are available as a computer program or subroutine, from NASA/MSFC Earth Science and Applications Division.

3.2 U.S. Standard Atmosphere 1976 Sea Level Values. Standard sea level values of temperature, pressure, and density (Ref. 3.1), which are representative of annual conditions at 45° latitude in the U.S., are given below.

	Metric Units	U. S. Customary Units
Temperature	15.0 °C or 288.15 K	59 °F or 518.67 °R
Pressure	1.013250 x 10^5 Newton m^{-2} [Newton m^{-2} is equivalent to a Pascal (Pa) in SI units; a Pascal is equivalent to 100 millibars (mb)]	2,116.22 lb ft^{-2} or 14.696 lb in^{-2}
Density	1.2250 kg m^{-3}	0.076474 lb ft^{-3}

3.3 Surface Atmospheric Thermodynamic Parameters

3.3.1 Atmospheric Temperature

3.3.1.1 Definition. The normal thermodynamic definition of temperature, the derivative of energy with respect to entropy, applies to the atmospheric environment.

There is also a virtual temperature, T_V, of a sample of moist air is defined as the temperature at which dry air of the same total pressure would have the same density as the sample.

$$T_V = T\,(1+0.61\,w)\,, \qquad (3.1)$$

where w = mixing ratio of water vapor to dry air (g/kg).

By substituting T_V into the ideal gas law in place of T, the variations of temperature and humidity are accounted for (to within the limits of ideal gas approximation).

$$PV = (R/M)\, T_V \ , \tag{3.2}$$

where

P = pressure

V = volume

M = molecular weight, where $M_{\text{dry air}}$ = 28.966 and $M_{\text{water vapor}}$ = 18.016

R = universal gas constant = 8.31436×10^{7} erg · K^{-1} · g mol^{-1}

3.3.1.2 Surface Temperature. Median and extreme values of surface atmospheric temperature for various NASA sites of interest are presented in subsection 3.4.1. Temperature aloft statistics are also presented in section 3.4.1. Other U. S. and world surface temperature extremes are given in section 5. Extreme and 95th percentile values of surface temperature for selected areas are given in Table 4.2.

3.3.2 Atmospheric Pressure

3.3.2.1 Definition. Atmospheric pressure (also called barometric pressure) is the force exerted, as a consequence of gravitational attraction, by the mass of the column of air of unit cross section lying directly above the area in question. It is expressed as force per unit area (Newtons per square meter or Newtons per square centimeter or millibars).

3.3.2.2 Surface Pressure. The total variation of pressure from day to day is relatively small. Diurnal, semidiurnal, and terdiurnal tidal variations can all affect the normal surface atmospheric pressure pattern. Rapid and slightly greater variations of pressure occur as the result of the passage of frontal systems, while the passage of a hurricane can cause somewhat larger, but still not significant, changes for pressure environment design of space vehicles. The pressure drop in a tornado is significant and can exceed 20 percent of ambient during the few seconds of its passage. Surface pressure extremes for various locations and their extreme ranges are given in Table 3.1. The data at these locations were mostly taken from their respective surface weather observation summaries (see Ref. 3.2 for example). Section 5 gives extreme pressures across the United States and around the world.

3.3.2.3 Surface Pressure Change.

a. A gradual rise or fall in pressure of 3 mb (0.04 lb in^{-2}) and then a return to original pressure can be expected within a 24-h period.

b. A maximum pressure change (frontal passage change) of 6 mb (0.09 lb in^{-2}) (rise or fall) can be expected within a 1-h period at all localities.

TABLE 3.1 Surface Pressure Extremes (Values Apply To Station Altitude Above Mean Sea Level (m.s.l..)).

Location	Units	Pressure Maximum	Pressure Mean	Pressure Minimum†	Station Elevation ft	Station Elevation m
Huntsville, AL	$N\ m^{-2}$	102,080.0	99,540.0	97,210.0		
	mb	1,020.8	995.4	972.1	644	196
	$lb\ in^{-2}$	14.8	14.4	14.1		
Kennedy Space Center, FL		103,600.0	101,670.0 *	99,970.0	16	5
		1,036.0	1,016.7 *	999.7		
		15.0	14.7 *	14.5	9‡	2.7‡
Vandenberg AFB, CA		102,000.0	100,250 *	99,010.0	371	113
		1,020.0	1,002.5 *	990.1		
		14.8	14.5 *	14.4	368‡	112.2‡
Edwards AFB, CA		95,560.0	93,410.0 *	92,030.0	2,316	706
		955.6	934.1 *	920.3		
		13.9	13.5 *	13.3	2,302‡	701.7‡
New Orleans, LA		104,160.0	101,780.0	99,900.0		
		1,041.6	1,017.8	999.0	6	2
		15.1	14.8	14.5		
Stennis Space Center, MS		104,410.0	101,640.0	99,150.0		
		1,044.1	1,016.4	991.5	31	9
		15.1	14.7	14.4		
Johnson Space Center, TX		103,960.0	101,530.0	99,530.0		
		1,039.6	1,015.3	995.3	50	15
		15.1	14.7	14.4		
White Sands Missile Range, NM		89,010.0	87,130.0 *	85,200.0		
		890.1	871.3 *	852.0	4,239	1,292
		12.9	12.6 *	12.4		

* The mean values given here will differ from the median surface values as given in Tables 3.10, 3.11, 3.12, and Ref. 3.5.
† Hurricane-influenced low pressures are not given here.
‡ Runway elevations above m.s.l..

3.3.2.4 Pressure Decrease With Altitude:

a. Pressure decrease is approximately logarithmic with height. Materials transported in mountainous terrain or in cargo compartments of aircraft must be packaged to stand the pressure differential without damage. Near sea level (i.e., < 3 km) the pressure will vary about 1 mb for each 10-m change in altitude. Figure 3.1 shows the standard atmospheric pressure decrease up to 5-km altitude (Ref. 3.1).

b. More detailed data on pressure distribution with altitude are given in subsection 3.4.2.1.

3.3.3 Atmospheric Mass Density

3.3.3.1 Definition. Mass density (r) is the ratio of the mass of a substance to its volume. (It also is defined as the reciprocal of specific volume.) Density is usually expressed in grams per cubic centimeter or kilograms per cubic meter.

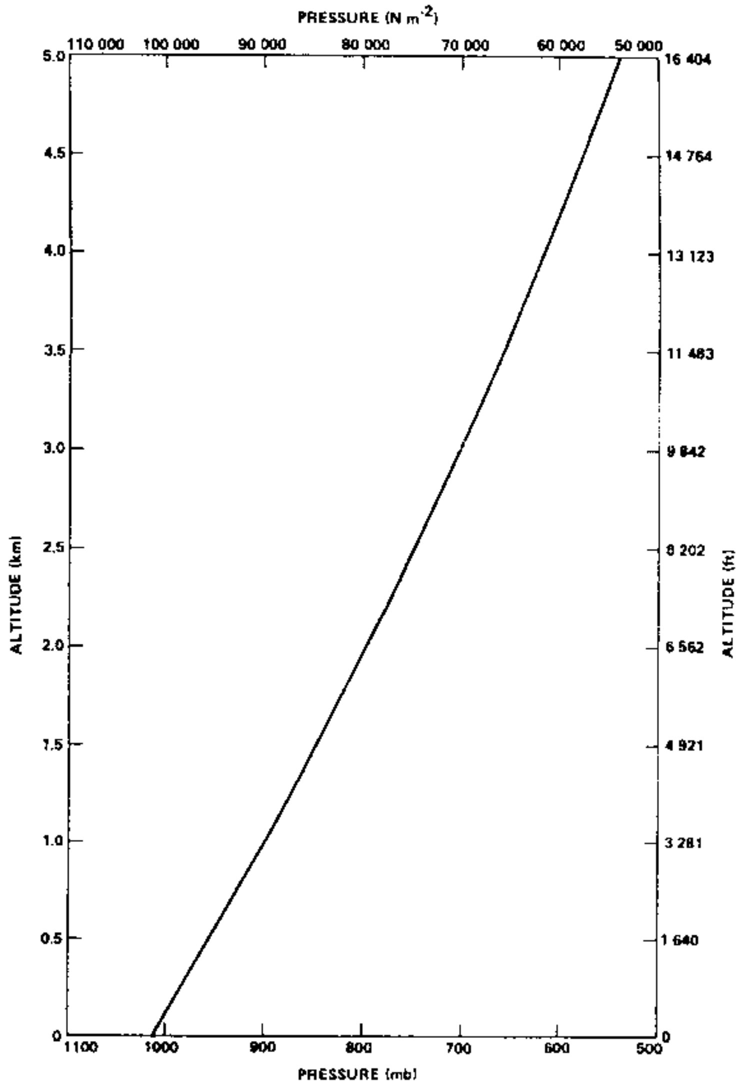

FIGURE 3.1 Pressure Change with Altitude for Packaging Materials (Ref. 3.1).

3.3.3.2 Surface Density. Generally the variation of atmospheric density at the Earth's surface between the measured station average and the area of interest (i.e., launch pad, runway, etc.) is small and should have no significant effect on preflight planning and operations. Table 3.2 gives annual median density values at the surface for the four main test ranges.

Atmospheric density, especially low density, is important to aircraft takeoff and landing operations and should therefore be considered when designing runway lengths or planning space shuttle orbiter ferry flights. Table 3.3 gives low density values that are equaled or exceeded approximately 5 percent of the time during the hottest part of the day in summer. Typical associated temperatures needed for engine power calculations are also listed. Since low density is found at high elevation and high temperatures, only the highest enroute airfield and the ferry flight terminals were considered. Since KSC and VAFB density extremes are given in section 3.4.3, only EAFB and Biggs AFB are listed here.

TABLE 3.2 Annual Median Surface Densities.

Area	Surface Altitude (m*)	Source of Data	Atmospheric Density	
			kg m^{-3}	lb ft^{-3}
Kennedy Space Center, FL	5	(Ref. 3.3)	1.1830	$7.385x10^{-2}$
Vandenberg AFB, CA	113	(Ref. 3.4)	1.2190	$7.610x10^{-2}$
White Sands Missile Range, NM	1,292	(Ref. 3.5 Item 5)	1.0580	$6.661x10^{-2}$
Edwards AFB, CA	706	(Ref. 3.13)	1.1210	$6.998x10^{-2}$

*Station elevation above m.s.l.

TABLE 3.3 Low Surface Density (5 Percentile Worst Day Of Year Reference) and Accompanying Temperatures for Orbiter Ferry Operations.

Location	Low Density		Temperature	
	kg m^{-3}	Percent Departure* from US 76	°C	°F
Edwards AFB California	1.0246	–10.5	39.4	103
Biggs AFB Texas	0.97555	–10.5	37.8	100

*Departure from U.S. Standard Atmosphere/1976 (3.1).

3.3.3.3 Surface Density Variability and Altitude Variations. Data on the variation of surface density and density aloft about its median annual values can be found in section 3.4. The Global Reference Atmosphere (Ref. 3.6) will also provide monthly mean density values versus altitude together with variability for any point on the globe.

3.4 Inflight Atmospheric Thermodynamic Parameters. Median and extreme values of atmospheric temperature, pressure, and density are presented in this subsection for various sites of interest to NASA. References 3.8 and 3.9 give worldwide extremes of the thermodynamic parameters aloft.

3.4.1 Atmospheric Temperature

3.4.1.1 Air Temperature at Altitude. Median and extreme air temperatures for the following list of test ranges were compiled from frequency distributions of radiosonde measured temperature data from 0- through 30-km altitude. Above 30-km altitude, mean and extreme temperatures for the different test ranges were obtained from meteorological rocketsonde observations:

a. KSC air temperature values with altitude are given in Table 3.4 (Ref. 3.3).

b. VAFB air temperature values with altitude are given in Table 3.5 (Ref. 3.4).

c. EAFB air temperature values with altitude are given in Table 3.6 (Ref. 3.5, item 6).

d. WSMR air temperature values with altitude are given in Table 3.7 (Ref. 3.5, item 5).

Reference 3.10 presents a classic description of the vertical temperature profile characteristics (and the variability of the tropopause level) by altitude, month, and latitude. A comprehensive listing of the extremes of surface temperature for different locations of interest to NASA can be obtained from section 4, Table 4.2 of this document.

3.4.1.2 Extreme Cold Temperature. Extreme cold temperatures for nonheated compartments during aircraft flight for KSC, VAFB, WSMR, and EAFB, are given in Table 3.8. Hot compartment temperatures are given in section 4, paragraph 4.6.4.

3.4.2 Atmospheric Pressure

3.4.2.1 Atmospheric Pressure at Altitude. Atmospheric pressure extremes which envelope all four locations (KSC, VAFB, WSMR, and EAFB) are given in Table 3.9. These values were taken from pressure frequency distributions of radiosonde observations from the four test ranges. Pressure means and extremes were computed above 25-km altitude using meteorological rocketsonde measurements.

Mean and extreme values of station pressure for many locations of interest are given in Table 3.1, whereas median pressure values up to 90 km altitude for the four key sites are given in Tables 3.10, 3.11, 3.12, and in reference 3.5. The U.S. standard atmosphere pressure decrease with altitude is illustrated in figure 3.1.

3.4.3 Atmospheric Density

3.4.3.1 Atmospheric Density at Altitude. The density of the atmosphere decreases rapidly with height, decreasing to one-half of the surface value at approximately 7-km altitude. Density is also variable at a fixed altitude, with the greatest relative variability occurring at approximately 70-km altitude in the high northern latitudes (60° N.). Other altitudes of maximum density variability occur around 16 km and 0 km. Altitudes of minimum variability occur around 8-, 24-, and 90-km altitude.

TABLE 3.4 KSC Air Temperatures At Various Altitudes

Geometric Altitude (km)	Minimum		Median*†		Maximum	
	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)
SFC (0.005 m.s.l.)	–7.2	19	23.5	74	37.2	99
1	–8.9	16	17.4	63	27.8	82
2	–10.0	14	12.2	54	21.1	70
3	–11.1	12	7.1	45	16.1	61
4	–13.9	7	1.8	35	11.1	52
5	–20.0	–4	–4.1	25	5.0	41
6	–26.1	–15	–10.5	13	–1.1	30
7	–33.9	–29	–17.4	1	–7.2	19
8	–41.1	–42	–24.8	–13	–13.9	7
9	–50.0	–58	–32.4	–26	–21.1	–6
10	–56.1	–69	–40.0	–40	–30.0	–22
16.2	–80.0	–112	–70.3	–95	–57.8	–72
20	–76.1	–105	–62.8	–81	–47.8	–54
25	–67.5	–90	–51.4	–61	–38.9	–38
30	–58.9	–74	–42.4	–44	–30.0	–22
35	–47.4	–53	–30.6	–23	–14.6	6
40	–36.7	–34	–17.8	0	1.9	35
45	–23.0	–9	–6.3	21	12.8	55
50	–18.2	–1	–2.5	27	22.0	72

55	–34.4	–30	–12.4	10	18.9	66
60	–28.5	–19	–26.1	–15	17.0	63

* For higher altitudes, see Ref. 3.3 and Table 3.10 of this report.
† Median values aloft are annual values taken from Ref. 3.3.

TABLE 3.5 VAFB Air Temperatures at Various Altitudes

Geometric Altitude (km)	Minimum		Median*†		Maximum	
	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)
SFC (0.1 m.s.l.)	–3.9	25	12.7	55	37.8	100
1	–3.6	26	13.3	56	33.4	92
2	–7.0	19	10.1	50	28.0	82
3	–15.2	5	5.1	41	17.6	64
4	–22.6	–9	–1.0	30	12.1	54
5	–29.7	–22	–7.5	18	3.3	38
6	–35.6	–32	–14.4	6	–2.7	27
7	–43.3	–46	–21.8	–7	–9.9	14
8	–47.4	–53	–29.5	–21	–15.9	3
9	–51.3	–60	–37.3	–35	–26.8	–16
10	–57.0	–71	–44.6	–48	–31.2	–24
16.3	–76.0	–105	–64.0	–83	–51.0	–60
20	–74.9	–103	–59.8	–76	–49.0	–56
25	–69.3	–93	–51.2	–60	–39.2	–39
30	–63.7	–83	–42.7	–45	–29.4	–21
35	–53.0	–63	–32.1	–26	–5.8	22
40	–42.2	–44	–19.3	–3	17.8	64
45	–30.5	–23	–5.8	21	27.6	82
50	–18.2	–1	–2.0	28	28.0	82
55	–21.8	–7	–6.8	20	31.6	89
60	–25.1	–13	–20.5	–5	35.7	96

* For higher altitudes, see Ref. 3.4 and Table 3.11.
† Median values aloft are annual values taken from Ref. 3.4.

TABLE 3.6 EAFB Air Temperatures at Various Altitudes

Geometric Altitude (km)	Minimum		Median*†		Maximum	
	(C)	(F)	(C)	(F)	(C)	(F)
SFC (0.7 m.s.l.)	–15.6	4	16.1	61	45.0	113
1	–6.0	21	16.2	61	35.3	96
2	–12.9	9	11.2	53	26.2	79
3	–16.9	2	5.1	42	19.0	66
4	–23.4	–10	–1.0	30	10.7	51
5	–29.7	–21	–7.5	17	5.2	41
6	–35.2	–31	–14.4	4	–2.9	27
7	–42.0	–44	–21.8	–9	–12.1	10
8	–48.9	–56	–29.5	–23	–17.4	1
9	–55.0	–67	–37.3	–37	–24.2	–12
10	–58.8	–74	–44.7	–50	–30.8	–23
17.8	–78.0	–108	–64.3	–82	–53.0	–63
20	–73.5	–100	–59.8	–76	–49.6	–57
25	–73.2	–100	–51.2	–62	–40.4	–41
30	–66.1	–87	–42.7	–49	–29.1	–20
35	–54.2	–66	–32.1	–26	–5.7	22
40	–42.2	–44	–19.3	–3	17.8	64
45	–30.5	–23	–5.8	21	27.6	82
50	–18.2	–1	–2.0	28	28.0	82
55	–21.8	–7	–6.8	20	31.6	89
60	–25.1	–13	–20.5	–5	35.7	96

* For higher altitudes, see Ref. 3.13 and Table 3.12.
† Median values aloft are annual values taken from Ref. 3.5, Item 6.

TABLE 3.7 WSMR Air Temperatures at Various Altitudes

Geometric Altitude (km)	Minimum		Median*		Maximum	
	(C)	(F)	(C)	(F)	(C)	(F)
SFC (1.3 m.s.l.)	–25.6	–14	14.6	58	44.4	112
2	–11.7	11	12.7	55	31.1	88
3	–18.9	–2	6.0	43	22.2	72
4	–23.9	–11	–0.8	31	12.8	55
5	–31.1	–24	–7.5	19	6.1	43
6	–36.1	–33	–14.2	6	0.0	32
7	–42.2	–44	–21.1	–6	–7.2	19
8	–48.9	–56	–28.3	–19	–13.9	7
9	–55.0	–67	–35.6	–32	–21.1	–6
10	–60.0	–76	–42.7	–45	–27.2	–17
16.5	–80.0	–112	–66.3	–87	–47.8	–54
20	–77.8	–108	–61.0	–78	–52.2	–62
25	–68.4	–91	–52.2	–62	–39.2	–39
30	–58.9	–74	–44.3	–48	–26.1	–15
35	–52.2	–62	–33.2	–28	–7.8	18
40	–41.8	–43	–19.7	–3	5.0	41
45	–30.5	–23	–7.9	18	19.6	67
50	–29.1	–20	–5.8	22	25.9	79
55	–28.7	–20	–11.7	11	30.2	86
60	–35.8	–32	–19.9	–4	28.0	82
65	–36.5	–34	–30.2	–22	31.3	88

* Median values aloft are annual values taken from Ref. 3.5, Item 5.

TABLE 3.8 Low Atmospheric Temperature Extremes Applicable for all Locations (KSC, VAFB, WSMR, And EAFB)

Maximum Flight Altitude (Geometric) of Aircraft Used for Transport		Compartment Cold Temperature Extreme	
(m)	(ft)	(°C)	(°F)
3,048	10,000	–25.0	–13
4,572	15,000	–35.0	–31
6,096	20,000	–45.0	–49
7,620	25,000	–50.0	–58
9,144	30,000	–57.0	–71
10,668	35,000	–65.0	–85
12,192	40,000	–70.0	–94
13,716	45,000	–75.0	–103

TABLE 3.9 Atmospheric Pressure-Height Extremes Applicable for all Locations (KSC, VAFB, WSMR, And EAFB).

Geometric Altitude (above m.s.l.)		Atmospheric Pressure			
		Maximum		Minimum	
(km)	(ft)	(mb)	(lb in^{-2})	(mb)	(lb in^{-2})
0	0	(Use values in Table 3.1 for surface pressure for each station)			
3	9,800	730	10.6	680	9.86
6	19,700	510	7.40	457	6.63
10	32,800	295	4.28	251	3.64
15	49,200	135	1.96	116	1.68
20	65,600	60	8.7×10^{-1}	51	7.4×10^{-1}
25	82,000	30	4.4×10^{-1}	22	3.2×10^{-1}
30	98,400	14.5	2.1×10^{-1}	10.4	1.5×10^{-1}
35	114,800	7.4	1.1×10^{-1}	4.9	7.1×10^{-2}
40	131,200	3.8	5.5×10^{-2}	2.4	3.5×10^{-2}
45	147,600	2.0	2.9×10^{-2}	1.2	1.7×10^{-2}
50	164,000	1.2	1.7×10^{-2}	6.1×10^{-1}	8.8×10^{-3}
55	180,400	6.0×10^{-1}	8.7×10^{-3}	3.1×10^{-1}	4.5×10^{-3}
60	196,800	3.2×10^{-1}	4.6×10^{-3}	1.6×10^{-1}	2.3×10^{-3}
65	213,300	1.7×10^{-1}	2.5×10^{-3}	8.3×10^{-2}	1.2×10^{-3}
70	229,700	8.5×10^{-2}	1.2×10^{-3}	4.1×10^{-2}	5.9×10^{-4}
75	246,100	3.1×10^{-2}	4.5×10^{-4}	2.1×10^{-2}	3.0×10^{-4}
80	262,500	1.4×10^{-2}	2.0×10^{-4}	8.9×10^{-3}	1.3×10^{-4}
85	278,900	5.9×10^{-3}	8.6×10^{-5}	3.7×10^{-3}	5.4×10^{-5}
90	295,300	2.6×10^{-3}	3.8×10^{-5}	1.4×10^{-3}	2.0×10^{-5}

TABLE 3.10 KSC (Patrick) Reference Atmosphere (PRA-63) (Ref. 3.3).

Geometric Altitude (MSL) Z (km)	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (Newtons cm^{-2})	Atmospheric Density D (kg m^{-3})
0	296.68	299.37	1.01701+1	1.18355+0
2	285.33	286.53	8.05212+0	9.79028–1
4	274.92	275.31	6.31517+0	7.99157–1
6	262.68	262.74	4.90089+0	6.49834–1
8	248.34	248.33	3.75320+0	5.26518–1
10	233.14	233.15	2.82776+0	4.22555–1
12	218.82	218.82	2.09093+0	3.33021–1
14	208.16	208.16	1.51990+0	2.54326–1
16	203.04	203.04	1.09118+0	1.87177–1
18	205.30	205.30	7.80974–1	1.32392–1
20	210.35	210.35	5.63157–1	9.31938–2
22	215.37	215.37	4.08992–1	6.61933–2
24	219.81	219.81	2.99188–1	4.74789–2
26	223.45	223.45	2.20382–1	3.43825–2
28	226.44	226.44	1.63274–1	2.51190–2
30	230.79	230.79	1.21463–1	1.83341–2
32	235.32	235.32	9.09051–2	1.34578–2
34	240.07	240.07	6.84299–2	9.93010–3
36	245.04	245.04	5.18072–2	7.36542–3
38	250.16	250.16	3.94480–2	5.49342–3
40	255.31	255.31	3.02092–2	4.12202–3
42	260.28	260.28	2.32624–2	3.11347–3
44	264.82	264.82	1.80045–2	2.36846–3
46	268.59	268.59	1.39948–2	1.81515–3
48	271.19	271.19	1.09106–2	1.40158–3
50	270.61	270.61	8.51802–3	1.09655–3
52	267.31	267.31	6.63932–3	8.65267–4
54	263.13	263.13	5.15531–3	6.82532–4
56	258.26	258.26	3.58521–3	5.37567–4
58	252.87	252.87	3.06511–3	4.22275–4
60	247.10	247.10	2.34420–3	3.30489–4
62	241.11	241.11	1.78185–3	2.57452–4
64	235.00	235.00	1.34542–3	1.99444–4
66	228.89	228.89	1.00864–3	1.53525–4
68	222.84	222.84	7.50591–4	1.17342–4
70	216.91	216.91	5.54143–4	8.89980–5
72	211.14	211.14	4.05760–4	6.69493–5
74	205.51	205.51	2.94587–4	4.99355–5
76	200.02	200.02	2.12002–4	3.69234–5
78	194.60	194.60	1.51198–4	2.70674–5
80	189.15	189.15	1.06843–4	1.96775–5
82	183.56	183.56	7.47938–5	1.41944–5
84	180.65	180.65	5.18782–5	1.00043–5
86	180.65	180.65	3.59147–5	6.92584–6
88	180.65	180.65	2.48690–5	4.79578–6
90	180.65	180.65	1.72244–5	3.32158–6

NOTE: Within table, the number format for 10^{-x} is shown as -x

TABLE 3.11 VAFB Reference Atmosphere (VRA-71) (Ref. 3.4).

Geometric Altitude (MSL) Z (km)	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (Newtons cm^{-2})	Atmospheric Density D (kg m^{-3})
0	285.88	287.15	1.01899+1	1.23618+0
2	283.30	283.59	8.02435+0	9.85756–1
4	272.17	272.35	6.27618+0	8.02762–1
6	258.71	258.79	4.85388+0	6.53426–1
8	243.68	243.70	3.69780+0	5.28600–1
10	228.50	228.50	2.77068+0	4.22426–1
12	217.79	217.79	2.03786+0	3.25934–1
14	212.89	212.89	1.48392+0	2.42845–1
16	209.46	209.46	1.07403+0	1.78628–1
18	210.39	210.39	7.76046–1	1.28512–1
20	213.39	213.39	5.63983–1	9.20191–2
22	217.34	217.34	4.10463–1	6.58104–2
24	220.68	220.68	3.00775–1	4.74989–2
26	223.11	223.11	2.22059–1	3.46574–2
28	226.09	226.09	1.64058–1	2.52891–2
30	230.43	230.43	1.22067–1	1.84539–2
32	234.66	234.66	9.12335–2	1.35440–2
34	238.84	238.84	6.85327–2	9.99594–3
36	243.35	243.35	5.17707–2	7.41121–3
38	248.38	248.38	3.93437–2	5.51828–3
40	253.89	253.89	3.00832–2	4.12777–3
42	259.62	259.62	2.31396–2	3.10498–3
44	265.00	265.00	1.78959–2	2.35255–3
46	269.19	269.19	1.39041–2	1.79938–3
48	270.97	270.97	1.08385–2	1.39342–3
50	271.16	271.16	8.45501–3	1.08625–3
52	270.79	270.79	6.60657–3	8.49939–4
54	268.26	268.26	5.14789–3	6.68511–4
56	264.09	264.09	3.99676–3	5.27219–4
58	258.74	258.74	3.08929–3	4.15944–4
60	252.61	252.61	2.37542–3	3.27585–4
62	246.07	246.07	1.81566–3	2.57051–4
64	239.38	239.38	1.37858–3	2.00620–4
66	232.78	232.78	1.03911–3	1.55505–4
68	226.40	226.40	7.77072–4	1.19570–4
70	220.28	220.28	5.76248–4	9.11308–5
72	214.39	214.39	4.23554–4	6.88241–5
74	208.58	208.58	3.08459–4	5.15182–5
76	202.61	202.61	2.22508–4	3.82588–5
78	196.11	196.11	1.58952–4	2.82366–5
80	188.60	188.60	1.12437–4	2.07684–5
82	180.65	180.65	7.86738–5	1.51716–5
84	180.65	180.65	5.44290–5	1.04962–5
86	180.65	180.65	3.76643–5	7.26323–6
88	180.65	180.65	2.60693–5	5.02723–6
90	180.65	180.65	1.80492–5	3.48063–6

NOTE: Within table, the number format for 10^{-x} is shown as –x

TABLE 3.12 EAFB Reference Atmosphere (ERA-75) (Ref. 3.13).

Geometric Altitude (MSL) Z (km)	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (Newtons cm^{-2})	Atmospheric Density D (kg m^{-3})
0.706	289.27	290.27	9.34079+0	1.12105+0
2	284.35	284.70	8.00722+0	9.79796–1
4	272.17	272.35	6.27618+0	8.02762–1
6	258.71	258.79	4.85388+0	6.53426–1
8	243.68	243.70	3.69780+0	5.28600–1
10	228.50	228.50	2.77068+0	4.22426–1
12	217.79	217.79	2.03786+0	3.25934–1
14	212.89	212.89	1.48392+0	2.42845–1
16	209.46	209.46	1.07403+0	1.78628–1
18	210.39	210.39	7.76046–1	1.28512–1
20	213.39	213.39	5.63983–1	9.20191–2
22	217.34	217.34	4.10463–1	6.58104–2
24	220.68	220.68	3.00775–1	4.74989–2
26	223.11	223.11	2.22059–1	3.46574–2
28	226.09	226.09	1.64058–1	2.52891–2
30	230.43	230.43	1.22067–1	1.84539–2
32	234.66	234.66	9.12335–2	1.35440–2
34	238.84	238.84	6.85327–2	9.99594–3
36	243.35	243.35	5.17785–2	7.41121–3
38	248.38	248.38	3.93437–2	5.51828–3
40	253.89	253.89	3.00832–2	4.12777–3
42	259.62	259.62	2.31396–2	3.10498–3
44	265.00	265.00	1.78959–2	2.35255–3
46	269.19	269.19	1.39041–2	1.79938–3
48	270.97	270.97	1.08385–2	1.39342–3
50	271.16	271.16	8.45501–3	1.08625–3
52	270.79	270.79	6.60657–3	8.49939–4
54	268.26	268.26	5.14789–3	6.68511–4
56	264.09	264.09	3.99676–3	5.27219–4
58	258.74	258.74	3.08929–3	4.15944–4
60	252.61	252.61	2.37542–3	3.27585–4
62	246.07	246.07	1.81565–3	2.57051–4
64	239.38	239.38	1.37858–3	2.00620–4
66	232.78	232.78	1.03911–3	1.55505–4
68	226.40	226.40	7.77072–4	1.19570–4
70	220.28	220.28	5.76248–4	9.11308–5
72	214.39	214.39	4.23554–4	6.88241–5
74	208.58	208.58	3.08459–4	5.15182–5
76	202.61	202.61	2.22508–4	3.82588–5
78	196.11	196.11	1.58952–4	2.82366–5
80	188.60	188.60	1.12437–4	2.07684–5
82	180.65	180.65	7.86738–5	1.51716–5
84	180.65	180.65	5.44290–5	1.04962–5
86	180.65	180.65	3.76643–5	7.26323–6
88	180.65	180.65	2.60693–5	5.02723–6
90	180.65	180.65	1.80492–5	3.48063–6

NOTE: Within table, the number format for 10^{-x} is shown as –x

Density varies with latitude in each hemisphere, with the mean annual density near the surface increasing toward the poles. In the region around 8 km altitude in the northern hemisphere, for example, the density variation with latitude and season is small. Above 8 km to approximately 28 km, the mean annual density decreases toward the north. Mean monthly densities between 30- and 90-km increase toward the north in July and toward the equator in January.

Considerable data are now available on the mean density and its variability below 30 km at the various test ranges from the data collected for preparation of the Range Commanders Council (RCC) Range Reference Atmospheres (Ref. 3.5). Additional information on the seasonal variability of density below 30 km is presented in reference 3.14. Above 30 km, the data are less plentiful and the accuracy of the temperature measurements (used to compute some densities) decreases with altitude.

Extreme minimum and maximum values of density for the KSC and VAFB are given in Table 3.13. These extreme density values approximate the $\pm 3s$ (corresponding to the normal distribution) density values. The relative deviations of density for KSC and VAFB as given in Table 3.13, are, respectively, defined as percentage departures from the Patrick Reference Atmosphere (ref 3.3) and the Vandenberg Reference Atmosphere (Ref. 3.4).

Median values of surface density for different locations of interest are given in Table 3.2 of this section, and mean values with altitude are given in Table 3.10 through 3.12 and in reference 3.5.

3.5 Simultaneous Values of KSC Temperature, Pressure, and Density at Discrete Altitude Levels

3.5.1 Introduction. This subsection presents simultaneous values for temperature, pressure, and density as guidelines for aerospace vehicle design considerations. The necessary assumptions and the lack of sufficient statistical data samples restrict the precision with which these data can currently be presented. The analysis is limited to KSC.

3.5.2 Method of Determining Simultaneous Value. An aerospace vehicle design problem that often arises in considering natural environmental data is stated by the following question: "How should the extremes (maxima and minima) of temperature, pressure, and density be combined (a) at discrete altitude levels? (b) versus altitude?" As an example, suppose one desires to know what temperature and pressure should be used simultaneously with a maximum density at a discrete altitude. From statistical principles set forth by Dr. C.E. Buell in reference 3.15, the solution results by allowing mean density plus three standard deviations to represent maximum density and using the coefficients of variations, correlations, and mean values as expressed in equation (3.1).

$$\text{Maximum } \rho = (\bar{\rho} + 3\sigma_\rho) = \bar{\rho}\left(1 + 3\frac{\sigma_\rho}{\bar{\rho}}\right) = \bar{\rho}\left\{1 + 3\left[\underbrace{\left(\frac{\sigma_P}{\bar{P}}\right) r(P\rho)}_{(A)} - \underbrace{\left(\frac{\sigma_T}{\bar{T}}\right) r(\rho T)}_{(B)}\right]\right\} . \qquad (3.3)$$

The associated values for pressure and temperature are the last two terms of equation (3.3), (A) and (B), multiplied by, $\bar{P}$ and $\bar{T}$, respectively, and then this result is added to $\bar{P}$ and $\bar{T}$, respectively. Appropriate values of correlation coefficients (r) and coefficients of variation (CV) are obtained from Table 3.14.

In general, the three extreme ρ, P, and T equations of interest are:

$$\text{extreme } \rho = (\rho \pm M\sigma_\rho) = \bar{\rho}\left[1 \pm M\left(\frac{\sigma_\rho}{\bar{\rho}}\right)\right] = \bar{\rho}\left\{1 \pm M\left[\left(\frac{\sigma_P}{\bar{P}}\right) r(P\rho) - \left(\frac{\sigma_T}{\bar{T}}\right) r(\rho T)\right]\right\}, \qquad (3.4)$$

Table 3.13 Density height maximum (≈ +3 sigma) and minimum (≈ −3 sigma) for KSC and VAFB.

Altitude*		Kennedy Space Center Density				Vandenberg AFB Density			
		Maximum		Minimum		Maximum		Minimum	
(km)	(ft)	(kg m^{-3})	% Deviation From PRA-63	(kg m^{-3})	% Deviation From PRA-63	(kg m^{-3})	% Deviation From VRA-71	(kg m^{-3})	% Deviation From VRA-71
0	0	1.326	12.0	1.141	−3.6	1.302	5.3	1.140	−7.8
2	6,600	1.047	6.1	9.497×10^{-1}	−3.0	1.046	6.1	9.518×10^{-1}	−3.5
4	13,100	8.287×10^{-1}	3.7	7.824×10^{-1}	−2.1	8.484×10^{-1}	5.7	7.766×10^{-1}	−3.3
6	19,700	6.706×10^{-1}	3.2	6.355×10^{-1}	−2.2	6.906×10^{-1}	5.7	6.299×10^{-1}	−3.6
8	26,200	5.428×10^{-1}	3.1	5.055×10^{-1}	−4.0	5.601×10^{-1}	6.0	4.971×10^{-1}	−6.0
10	32,800	4.352×10^{-1}	3.0	3.938×10^{-1}	−6.8	4.624×10^{-1}	9.5	3.835×10^{-1}	−9.2
15	49,200	2.345×10^{-1}	7.0	1.979×10^{-1}	−9.7	2.337×10^{-1}	12.0	1.851×10^{-1}	−11.3
20	65,600	1.002×10^{-1}	7.5	8.751×10^{-2}	−6.1	1.001×10^{-1}	8.8	8.420×10^{-2}	−8.5
25	82,000	4.274×10^{-2}	5.9	3.790×10^{-2}	−6.1	4.460×10^{-2}	10.0	3.634×10^{-2}	−10.4
30	98,400	1.976×10^{-2}	7.8	1.700×10^{-2}	−7.3	2.085×10^{-2}	13.0	1.634×10^{-2}	−11.5
35	114,800	9.427×10^{-3}	10.3	7.640×10^{-3}	−10.6	9.786×10^{-3}	13.8	7.505×10^{-3}	−12.8
40	131,200	4.637×10^{-3}	12.5	3.512×10^{-3}	−14.8	4.747×10^{-3}	15.0	3.424×10^{-3}	−17.0
50	164,000	1.275×10^{-3}	16.3	8.630×10^{-4}	−21.3	1.325×10^{-3}	22.0	8.473×10^{-4}	−22.0
60	196,800	3.946×10^{-4}	19.4	2.465×10^{-4}	−25.4	4.422×10^{-4}	35.0	2.359×10^{-4}	−28.0
70	229,700	1.100×10^{-4}	23.6	6.666×10^{-5}	−25.1	1.203×10^{-4}	32.0	6.197×10^{-5}	−32.0
80	262,500	2.342×10^{-5}	19.0	1.596×10^{-5}	−18.9	2.617×10^{-5}	26.0	1.433×10^{-5}	−31.0
90	295,300	3.684×10^{-6}	10.9	2.930×10^{-6}	−11.8	4.177×10^{-6}	20.0	2.785×10^{-6}	−20.0

* Geometric altitude above mean sea level.

TABLE 3.14 Coefficients of variation and discrete altitude level correlation coefficients between pressure-density r(Pp); pressure-temperature r(PT); and density-temperature 4 (pT)k KSC, Annual

Altiitude	Coefficients of Variation CV)			Correlation Coefficients r)		
	t7(P)/P rcent)	Q(P)/P (percent)	Q(T)IT (percent	r(Pp) (unitless)	r(PT) (unitless	r(PT) unitless)
0	1.8000	0.6000	1.5000	0.6250	0.3500	-0.9500
1	1.7000	0.5500	1.6000	0.3382	-0.0156	-0.9462
2	1.5000	0.8000	1.5900	0.1508	0.3609	-0.8675
3	1.1800	0.9800	1.5700	-0.0485	0.6606	-0.7818
4	0.9700	0.8500	1.4000	-0.1799	0.7318	-0.8021
5	0.8000	0.8700	1.3400	-0.2864	0.8203	-0.7830
6	0.7400	0.8400	1.2600	-0.2690	0.8246	-0.7666
7	0.8800	0.9800	1.4200	-0.1633	0.7913	-0.7324
8	0.9000	1.1300	1.4700	-0.0364	0.7910	-0.6402
9	1.1800	1.4700	1.6200	0.2678	0.7124	-0.4854
10	1.6300	1.7500	1.7200	0.4840	0.5588	-0.4553
11	1.8800	1.8000	1.7800	0.5328	0.4485	-0.5174
12	2.1500	1.8700	1.8500	0.5841	0.3320	-0.5717
13	2.3800	1.9000	1.8500	0.6470	0.1946	-0.6220
14	2.6200	1.9200	1.7700	0.7373	--0.0066	-0.6804
15	2.7800	1.8800	1.6700	0.8107	-0.2238	-0.7520
16	2.8800	1.8400	1.7100	0.8262	-0.3154	-0.7953
17	2.8800	1.8000	1.7000	0.8338	-0.3537	-0.8113
18	2.7500	1.7500	1.7000	0.8036	-0.2706	-0.7904
19	2.5000	1.7800	1.6700	0.7449	-0.0492	-0.7031
20	2.2700	1.8500	1.6500	0.6969	0.1625	--0.5944
21	2.0800	1.9500	1.6200	0.6786	0.3325	-0.4672
22	1.9800	2.1200	1.5700	0.7087	0.4565	-0.3041
23	1.9200	2.3200	1.4800	0.7721	0.5659	-0.0870
24	1.9500	2.4000	1.4300	0.8032	0.5831	-0.0157
25	2.0000	2.4300	1.4200	0.8116	0.5682	-0.0196
26	2.0800	2.5000	1.5000	0.8006	0.5565	-0.0523
27	2.1500	2.6000	1.5800	0.7948	0.5640	-0.0528
28	2.2300	2.6700	1.7500	0.7591	0.5584	-0.1161
29	2.3700	2.6300	1.8700	0.7249	0.4877	-0.2479
30	2.5200	2.6300	1.9200	0.7228	0.4211	-0.3224
31	2.7000	2.7000	2.0000	0.7257	0.3704	-0.3704
32	2.8800	2.7500	2.0800	0.7279	0.3142	-0.4222
33	3.0700	2.7300	2.1700	0.7260	0.2310	-0.5014
34	3.2700	2.6800	2.2300	0.7361	0.1223	-0.5817
35	3.4800	2.6000	2.3200	0.7454	0.0027	-0.6647
36	3.7000	2.5000	2.4300	0.7587	-0.1263	-0.7421
37	3.9200	2.3700	2.5500	0.7793	-0.2686	--0.8129
38	4.1200	2.4600	2.6300	0.7947	-0.3096	-0.8232
39	4.3300	2.6400	2.6900	0.8084	-0.3199	-0.8163
40	4.5500	2.7900	2.7680	0.8220	-0.3442	-0.8176
41	4.7500	2.8600	3.0200	0.7958	-0.3046	-0.8192
42	4.9300	2.9200	3.2600	0.7712	-0.2706	-0.8215
43	5.1300	3.0000	3.3400	0.7850	-0.3075	-0.8309
44	5.3200	3.1800	3.3500	0.8037	-0.3270	-0.8252
45	5.5000	3.2400	3.6000	0.7797	-0.2912	-0.8261
46	5.6700	3.3200	3.8300	0.7571	-0.2539	-0.8242
47	5.8300	3.4100	3.9800	0.7489	-0.2402	-0.8232
48	5.9800	3.4800	4.1900	0.7284	-0.2090	-0.8223
49	6.1300	3.5900	4.1400	0.7572	-0.2540	-0.8241
50	6.2700	3.6900	4.1900	0.7644	-0.2633	-0.8232
51	6.4200	3.8200	4.0800	0.7984	-0.3201	-0.8260
52	6.5500	3.9100	4.1800	0.7950	-0.3103	-0.8234
53	6.7000	4.0100	4.2700	0.7953	-0.3089	-0.8222
54	6.8000	4.0700	4.3100	0.7990	-0.3164	-0.8232
55	6.9200	4.1400	4.3700	0.8016	-0.3220	-0.8241
56	7.0300	4.2100	4.4200	0.8043	-0.3267	-0.8244
57	7.1500	4.2800	4.4700	0.8081	-0.3351	-0.8258
58	7.2700	4.3600	4.5100	0.8127	-0.3434	-0.8263
59	7.3700	4.4200	4.5400	0.8172	-0.3530	-0.8277
60	7.4700	4.4800	4.5900	0.8188	-0.3565	-0.8283

TABLE 3.14 Coefficients of Variation and Discrete Altitude Level Correlation Coefficients Between Pressure Density r ($P r$); Pressure-Temperature r (PT); and Density-Temperature r ($r T$), KSC, Annual (Continued)

Altitude	Coefficients of Variation (CV)			Correlation Coefficients (r)		
(km)	$\sigma(\rho)/\bar{\rho}$ (percent)	$\sigma(P)/\bar{P}$ (percent)	$\sigma(T)/\bar{T}$ (percent	$r(P\rho)$ (unitless)	$r(PT)$ (unitless)	$r(\rho T)$ (unitless)
61	7.5700	4.5400	4.6300	0.8217	-0.3629	-0.8293
62	7.6500	4.7000	4.8600	0.7926	-0.2805	-0.8076
63	7.7500	4.9000	5.0000	0.7778	-0.2256	-0.7878
64	7.8300	5.1500	5.1500	0.7602	-0.1558	-0.7602
65	7.9000	5.3800	5.3800	0.7342	-0.0781	-0.7342
66	7.9800	5.5700	5.4400	0.7324	-0.0505	-0.7170
67	8.0300	5.6600	5.4700	0.7326	-0.0408	-0.7099
68	8.0700	5.7700	5.4000	0.7437	-0.0429	-0.6998
69	8.1000	5.8200	5.5100	0.7331	-0.0215	-0.6957
70	8.1200	5.8700	5.4900	0.7369	-0.0208	-0.6911
71	8.1200	5.8900	5.4700	0.7392	-0.0205	--0.6885
72	8.0700	5.7900	5.3800	0.7459	-0.0426	-0.6973
73	8.1200	5.6500	5.2900	0.7615	-0.1008	-0.7216
74	8.0700	5.5000	5.1700	0.7733	-0.1432	-0.7383
75	7.9000	5.2900	5.4100	0.7313	-0.0901	-0.7452
76	7.6800	4.9900	5.6500	0.6779	-0.0383	-0.7606
77	7.3800	5.0100	6.1600	0.5628	0.1390	-0.7403
78	7.0500	5.0400	6.5200	0.4587	0.2771	-0.7267
79	6.6800	5.1100	6.8400	0.3508	0.4045	-0.7145
80	6.3200	5.2700	6.7800	0.3265	0.4730	-0.6784
81	5.9500	5.3600	6.7200	0.2975	0.5342	-0.6482
82	5.5800	5.5200	6.6600	0.2800	0.5942	-0.6057
83	5.2500	5.1300	6.6100	0.1891	0.6259	-0.6475
84	4.9200	4.7800	6.5600	0.0855	0.6645	-0.6877
85	4.6300	4.4700	6.5100	-0.0232	0.7032	-0.7272
86	4.4000	4.1900	6.4500	-0.1271	0.7363	-0.7647
87	4.2000	3.9600	6.4000	-0.2296	0.7694	-0.7983
88	4.0200	4.0500	6.3400	-0.2344	0.7874	-0.7838
89	3.8800	4.1400	6.2800	-0.2255	0.7986	-0.7665
90	3.7800	4.0400	5.9600	-0.1608	0.7798	-0.7432

$$\text{extreme } P = (\bar{P} \pm M\sigma_P) = \bar{P}\left[1 \pm M\left(\frac{\sigma_P}{\bar{P}}\right)\right] = \bar{P}\left\{1 \pm M\left[\left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(P\rho) + \left(\frac{\sigma_T}{\bar{T}}\right) r(PT)\right]\right\}, \tag{3.5}$$

$$\text{extreme } T = (\bar{T} \pm M\sigma_T) = \bar{T}\left[1 \pm M\left(\frac{\sigma_T}{\bar{T}}\right)\right] = \bar{T}\left\{1 \pm M\left[\left(\frac{\sigma_P}{\bar{P}}\right) r(PT) - \left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(\rho T)\right]\right\}, \tag{3.6}$$

where M denotes the multiplication factor to give the desired deviation. The values of M for the normal distribution and the associated percentile levels are as follows:

	M		Percentile
Mean	–3	standard deviations	0.135
Mean	–2	standard deviations	2.275
Mean	–1	standard deviations	15.866
Mean	±0	standard deviations = median	50.000
Mean	+1	standard deviations	84.134
Mean	+2	standard deviations	97.725
Mean	+3	standard deviations	99.865

The two associated atmospheric parameters that deal with a third extreme parameter are listed, in more detail, in the following chart.

	For Extreme Density	For Extreme Temperature	For Extreme Pressure
$P_{\text{assoc.}} =$	$\bar{P}\left[1 \pm \left\{M\left(\frac{\sigma_P}{\bar{P}}\right) r(P\rho)\right\}\right]$	$\bar{P}\left[1 \pm \left\{M\left(\frac{\sigma_P}{\bar{P}}\right) r(PT)\right\}\right]$	
$T_{\text{assoc.}} =$	$\bar{T}\left[1 \pm \left\{M\left(\frac{\sigma_T}{\bar{T}}\right) r(\rho T)\right\}\right]$		$\bar{T}\left[1 \pm \left\{M\left(\frac{\sigma_T}{\bar{T}}\right) r(PT)\right\}\right]$
$\rho_{\text{assoc.}} =$		$\bar{\rho}\left[1 \pm \left\{M\left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(\rho T)\right\}\right]$	$\bar{\rho}\left[1 \pm \left\{M\left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(P\rho)\right\}\right]$

Use + sign when extreme parameter is maximum
Use – sign when extreme parameter is minimum.

It must be emphasized that this procedure is to be used at discrete altitudes only. Whenever extreme profiles of pressure, temperature, and density are required for engineering application, the use of these correlated variables at discrete altitudes is not satisfactory. Subsection 3.6 deals directly with this problem, since profiles of only extreme values of pressure, temperature, or density from 0 to 90 km altitude is unrealistic in the real atmosphere.

3.6 Extreme Hot and Cold Atmospheric Profiles for KSC, VAFB, and EAFB. Given in this section are the two extreme density profiles that correspond to the summer (hot) and winter (cold) extreme atmospheres for KSC (Tables 3.15A and 3.15B); VAFB (Tables 3.16A and 3.16B); and EAFB (Tables 3.17A and 3.17B)(see refs. 3.12 and 3.13 for detailed information pertaining to the VAFB and EAFB extreme atmospheres, respectively). Associated values of extreme temperature and pressure versus altitude are also tabulated. These extreme atmospheric profiles should be used in ascent design analyses at all altitudes. For reentry studies they are to apply only from 30 km to the surface for vehicles to be used at KSC, VAFB, or EAFB. For those aerospace vehicles with ferrying capability, design calculations should use these extreme profiles in conjunction with the hot or cold day design ambient air temperatures over runways from paragraph 5.1.3.1 of section V. The extreme atmosphere producing the maximum vehicle design requirement should be utilized to determine the design.

The envelopes of density deviations given in Table 3.13 imply that a typical individual extreme density profile may be represented by a similarly shaped profile; that is, deviations of density are either all negative or all positive from sea level to 90-km altitude. However, examination of many individual density profiles shows that when large positive deviations of density occur at the surface, correspondingly large negative deviations will occur near 15-km altitude and above. Such a situation occurs during the winter season (cold atmosphere). The reverse is also true - density profiles with large negative deviations at lower levels will have correspondingly large positive deviations at higher levels. This situation occurs in the summer season (hot atmosphere) (figs. 3.2, 3.3, and 3.4).

The two extreme KSC density profiles of figure 3.2 are shown as percent deviations from the Patrick Reference Atmosphere, 1963 density profile (Ref. 3.3). The two profiles obey the hydrostatic equation and the ideal gas law. The extreme density profiles shown up to 30-km altitude were observed in the atmosphere. The results shown above 30-km altitude are somewhat speculative because of the limited data from this region of the atmosphere. Quasi-isopycnic levels (levels of minimum density variation) are noted at approximately 8 and 86 km. Another level of minimum density variability is seen at 24 km, and levels of maximum variability occur at 0-, 15-, and 68-km altitude. The associated extreme virtual temperature profiles for KSC are given in figure 3.5.

TABLE 3.15A KSC Summer (Hot) Atmosphere (KHA-71).

Geometric Altitude (MSL) km	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (N cm–2)	Atmospheric Density D (kg m–3)	Rel. Dev. (T*) Percent From PRA-63 RD (T*) %	Rel. Dev. (P) Percent From PRA-63 RD (P) %	Rel. Dev. (D) Percent From PRA-63 RD (D) %
0	307.40	309.90	1.01000+1	1.13537+0	3.5	–0.7	–4.1
2	294.70	296.37	8.06143+0	9.47571–1	3.4	0.1	–3.2
4	282.00	282.85	6.36690+0	7.84181–1	2.7	0.8	–1.9
6	269.32	269.32	4.97073+0	6.42972–1	2.5	1.4	–1.1
8	255.79	255.79	3.83152+0	5.21824–1	3.0	2.1	–0.9
10	242.26	242.26	2.91191+0	4.18724–1	3.9	3.0	–0.9
12	228.20	228.20	2.17801+0	3.32493–1	4.3	4.2	–0.2
14	213.60	213.60	1.59836+0	2.60682–1	2.6	5.2	2.5
16	199.00	199.00	1.14755+0	2.00889–1	–2.0	5.2	7.3
18	200.00	200.00	8.13695–1	1.41732–1	–2.6	4.2	7.1
20	208.33	208.33	5.82229–1	9.73585–2	–1.0	3.4	4.5
22	215.67	215.67	4.22016–1	6.81728–2	0.1	3.2	3.0
24	222.00	222.00	3.08751–1	4.84476–2	1.0	3.2	2.1
26	228.33	228.33	2.27940–1	3.47755–2	2.2	3.4	1.2
28	234.67	234.67	1.69726–1	2.51992–2	3.8	3.9	0.3
30	241.00	241.00	1.27321–1	1.84051–2	4.4	4.8	0.4
32	247.33	247.33	9.61987–2	1.35465–2	5.1	5.9	0.7
34	253.67	253.67	7.32790–2	1.00657–2	5.7	7.1	1.3
36	260.00	260.00	5.61455–2	7.52274–3	6.1	8.4	2.1
38	265.77	265.77	4.32945–2	5.67493–3	6.2	9.8	3.3
40	271.54	271.54	3.35705–2	4.30688–3	6.4	11.1	4.5
42	277.31	277.31	2.61721–2	3.28794–3	6.5	12.5	5.8
44	283.08	283.08	2.05077–2	2.52378–3	6.9	13.9	6.6
46	288.85	288.85	1.61481–2	1.94746–3	7.5	15.4	7.3
48	294.62	294.62	1.27777–2	1.51091–3	8.6	17.1	7.8
50	297.50	297.50	1.01482–2	1.18840–3	9.9	19.2	8.4
52	289.00	289.00	8.03999–3	9.69103–4	8.1	21.1	12.0
54	280.50	280.50	6.32437–3	7.85430–4	6.6	22.9	15.1
56	272.00	272.00	4.93788–3	6.32455–4	5.3	23.9	17.7
58	263.50	263.50	3.82537–3	5.05788–4	4.2	24.8	19.8
60	255.00	255.00	2.93909–3	4.01549–4	3.2	25.4	21.5
62	246.50	246.50	2.23836–3	3.16317–4	2.2	25.8	22.9
64	238.00	238.00	1.68846–3	2.47098–4	1.3	25.5	23.9
66	229.50	229.50	1.26059–3	1.91294–4	0.3	24.9	24.6
68	221.00	221.00	9.30524–4	1.46662–4	–0.8	24.0	25.0
70	212.50	212.50	6.78561–4	1.11268–4	–2.0	22.5	25.0
72	204.00	204.00	4.88448–4	8.34696–5	–3.4	20.5	24.7
74	195.50	195.50	3.47004–4	6.18641–5	–4.9	17.9	23.9
76	187.00	187.00	2.43192–4	4.52595–5	–6.5	14.6	22.6
78	178.50	178.50	1.67780–4	3.26383–5	–8.3	10.5	20.5
80	170.00	170.00	1.12901–4	2.31514–5	–10.1	5.7	17.6
82	170.00	170.00	7.55119–5	1.55048–5	–7.4	1.0	9.1
84	170.00	170.00	5.06592–5	1.03855–5	–5.9	–2.6	3.5
86	170.00	170.00	3.39222–5	6.97136–6	–5.9	–5.9	0.0
88	170.00	170.00	2.27356–5	4.67110–6	–5.9	–9.1	–3.4
90	170.00	170.00	1.51348–5	3.10707–6	–5.9	–12.2	–6.6

NOTE: Within table, the number format for 10^{-x} is shown as –x

TABLE 3.15B KSC Winter (Cold) Atmosphere (KCA-71).

Geometric Altitude (MSL) km	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (N cm^{-2})	Atmospheric Density D (kg m^{-3})	Rel. Dev. (T*) Percent From PRA-63 RD (T*) %	Rel. Dev. (P) Percent From PRA-63 RD (P) %	Rel. Dev. (D) Percent From PRA-63 RD (D) %
0	274.50	275.00	1.02700+1	1.30099+0	–8.1	1.0	9.9
2	264.70	265.00	7.97353+0	1.04820+0	–7.5	–1.0	7.1
4	254.90	255.00	6.13058+0	8.37528–1	–7.4	–2.8	4.8
6	245.24	245.24	4.66465+0	6.62784–1	–6.7	–4.8	2.0
8	235.87	235.87	3.51072+0	5.18423–1	–5.0	–6.5	–1.6
10	227.67	227.67	2.61414+0	4.00022–1	–2.4	–7.6	–5.3
12	220.59	220.59	1.92692+0	3.04362–1	0.8	–7.9	–8.6
14	214.29	214.29	1.40710+0	2.28093–1	3.0	–7.4	–10.1
16	209.49	209.49	1.01913+0	1.69535–1	3.1	–6.6	–9.5
18	208.28	208.28	7.34536–1	1.22832–1	1.4	–6.0	–7.2
20	209.00	209.00	5.29299–1	8.82292–2	–0.6	–6.0	–5.3
22	210.91	210.91	3.82184–1	6.31426–2	–2.1	–6.5	–4.6
24	213.63	213.63	2.77005–1	4.51690–2	–2.8	–7.4	–4.9
26	216.78	216.78	2.01682–1	3.23964–2	–3.0	–8.5	–5.8
28	220.08	220.08	1.47487–1	2.33454–2	–2.3	–9.7	–7.0
30	223.31	223.31	1.08321–1	1.69107–2	–3.2	–10.8	–7.9
32	226.44	226.44	7.99577–2	1.23019–2	–3.8	–12.0	–8.6
34	229.60	229.60	5.93149–2	8.98540–3	–4.3	–13.4	–9.5
36	233.84	233.84	4.41165–2	6.57245–3	–4.6	–14.9	–10.8
38	239.02	239.02	3.30396–2	4.81532–3	–4.5	–16.2	–12.3
40	244.20	244.20	2.49012–2	3.55236–3	–4.4	–17.6	–13.8
42	249.38	249.38	1.88809–2	2.63764–3	–4.2	–18.8	–15.3
44	254.55	254.55	1.43942–2	1.96985–3	–3.9	–20.1	–16.8
46	259.73	259.73	1.10347–2	1.47978–3	–3.3	–21.2	–18.5
48	264.91	264.91	8.50858–3	1.11871–3	–2.3	–22.1	–20.2
50	267.50	267.50	6.58344–3	8.57370–4	–1.2	–22.7	–21.8
52	267.50	267.50	5.09811–3	6.63959–4	0.1	–23.2	–23.3
54	264.64	264.64	3.94567–3	5.19359–4	0.6	–23.5	–23.9
56	261.79	261.79	3.04283–3	4.04911–4	1.4	–23.7	–24.7
58	258.93	258.93	2.33950–3	3.14785–4	2.4	–23.7	–25.4
60	256.07	256.07	1.79403–3	2.44083–4	3.6	–23.4	–26.1
62	253.21	253.21	1.37225–3	1.88792–4	5.0	–23.0	–26.7
64	250.36	250.36	1.04675–3	1.45631–4	6.5	–22.2	–27.0
66	247.50	247.50	7.95920–4	1.11993–4	8.1	–21.2	–27.1
68	244.64	244.64	6.02732–4	8.58059–5	9.8	–19.8	–26.9
70	241.79	241.79	4.54550–4	6.54950–5	11.5	–17.9	–26.4
72	238.93	238.93	3.41463–4	4.98157–5	13.2	–15.7	–25.5
74	236.07	236.07	2.56128–4	3.78041–5	14.9	–12.9	–24.2
76	233.21	233.21	1.92122–4	2.86884–5	16.6	–9.5	–22.4
78	230.36	230.36	1.43852–4	2.17018–5	18.4	–5.5	–20.2
80	227.50	227.50	1.05991–4	1.62312–5	20.3	–0.8	–17.5
82	221.00	221.00	7.81453–5	1.23199–5	20.4	4.5	–13.2
84	214.50	214.50	5.71060–5	9.27639–6	18.7	10.1	–7.3
86	208.00	208.00	4.13394–5	6.92224–6	15.1	15.1	–0.1
88	201.50	201.50	2.96044–5	5.11897–6	11.5	19.0	6.7
90	195.00	195.00	2.09474–5	3.74532–6	7.9	21.7	12.8

NOTE: Within table, the number format for 10^{-x} is shown as –x

TABLE 3.16A VAFB Summer (Hot) Atmosphere (VHA-73) (Ref. 3.12).

Geometric Altitude (MSL) km	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (N cm^{-2})	Atmospheric Density D (kg m^{-3})	Rel. Dev. (T*) Percent From VRA-71 RD (T*) %	Rel. Dev. (P) Percent From VRA-71 RD (P) %	Rel. Dev. (D) Percent From VRA-71 RD (D) %
0	310.40	312.70	1.01000+1	1.12520+0	8.9	–0.9	–9.0
2	296.80	298.59	8.07642+0	9.42286–1	5.3	0.7	–4.4
4	283.20	284.48	6.38872+0	7.82355–1	4.5	1.8	–2.5
6	269.60	270.37	4.99378+0	6.43448–1	4.5	2.9	–1.5
8	256.00	256.26	3.85219+0	5.23688–1	5.2	4.2	–0.9
10	240.53	240.53	2.92684+0	4.23899–1	5.3	5.6	0.4
12	223.20	223.20	2.17953+0	3.40178–1	2.5	7.0	4.4
14	205.87	205.87	1.58478+0	2.68177–1	–3.3	6.8	10.4
16	195.70	195.70	1.12412+0	2.00106–1	–6.6	4.7	12.0
18	200.74	200.74	7.95730–1	1.38101–1	–4.6	2.5	7.4
20	207.82	207.82	5.69371–1	9.54397–2	–2.6	1.0	3.7
22	214.89	214.89	4.12139–1	6.68144–2	–1.1	0.4	1.5
24	221.97	221.97	3.01463–1	4.73175–2	0.6	0.2	–0.4
26	229.05	229.05	2.22578–1	3.38482–2	2.7	0.3	–2.3
28	236.12	236.12	1.65959–1	2.44859–2	4.4	1.2	–3.2
30	243.20	243.20	1.24774–1	1.78725–2	5.5	2.2	–3.1
32	249.44	249.44	9.45606–2	1.32071–2	6.3	3.6	–2.5
34	255.67	255.67	7.21309–2	9.82767–3	7.1	5.3	–1.7
36	261.91	261.91	5.53982–2	7.36860–3	7.6	7.0	–0.6
38	268.14	268.14	4.28172–2	5.56344–3	8.0	8.8	0.8
40	274.38	274.38	3.32792–2	4.22565–3	8.1	10.6	2.4
42	280.61	280.61	2.60056–2	3.22793–3	8.1	12.4	4.0
44	286.85	286.85	2.04445–2	2.48289–3	8.2	14.3	5.6
46	293.08	293.08	1.61641–2	1.92235–3	8.9	16.2	6.7
48	296.20	296.20	1.28182–2	1.50758–3	9.3	18.3	8.2
50	296.20	296.20	1.01776–2	1.19701–3	9.2	20.4	10.2
52	296.20	296.20	8.08051–3	9.50404–4	9.4	22.3	11.8
54	287.91	287.91	6.39556–3	7.73812–4	7.3	24.2	15.8
56	279.63	279.63	5.02673–3	6.26232–4	5.9	25.8	18.8
58	271.34	271.34	3.92216–3	5.03576–4	4.9	27.0	21.1
60	263.06	263.06	3.03703–3	4.02224–4	4.1	27.9	22.8
62	254.77	254.77	2.33271–3	3.18976–4	3.5	28.5	24.1
64	246.49	246.49	1.77625–3	2.51029–4	3.0	28.8	25.1
66	238.20	238.20	1.34000–3	1.95943–4	2.3	28.9	26.0
68	229.91	229.91	1.00067–3	1.51604–4	1.6	28.8	26.8
70	221.63	221.63	7.39117–4	1.16191–4	0.6	28.3	27.5
72	213.34	213.34	5.39672–4	8.81491–5	–0.5	27.5	28.1
74	205.06	205.06	3.89199–4	6.61538–5	–1.7	26.3	28.4
76	196.77	196.77	2.77271–4	4.90758–5	–2.9	24.6	28.3
78	188.49	188.49	1.94712–4	3.59435–5	–3.9	22.3	27.2
80	180.20	180.20	1.34206–4	2.59447–5	–4.5	19.3	24.9
82	180.20	180.20	9.18913–5	1.77441–5	–0.3	16.7	17.0
84	180.20	180.20	6.29807–5	1.21765–5	–0.3	15.5	15.8
86	180.20	180.20	4.31919–5	8.33893–6	–0.3	14.2	14.5
88	180.20	180.20	2.96783–5	5.71060–6	–0.3	12.9	13.2
90	180.20	180.20	2.01511–5	3.90816–6	–0.3	11.7	11.9

NOTE: Within table, the number format for 10^{-x} is shown as –x

TABLE 3.16B VAFB Winter (Cold) Atmosphere (VCA-73) (Ref. 3.12)

Geometric Altitude (MSL) km	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (N cm^{-2})	Atmospheric Density D (kg m^{-3})	Rel. Dev. (T*) Percent From VRA-71 RD (T*) %	Rel. Dev. (P) Percent From VRA-71 RD (P) %	Rel. Dev. (D) Percent From VRA-71 RD (D) %
0	272.10	272.70	1.01800+1	1.30047+0	–5.0	–0.1	5.2
2	260.86	261.22	7.88092+0	1.05101+0	–7.9	–1.8	6.6
4	249.62	249.74	6.03127+0	8.41315–1	–8.3	–3.9	4.8
6	238.30	238.30	4.55804+0	6.66334–1	–7.9	–6.1	2.0
8	226.90	226.90	3.39765+0	5.21654–1	–6.9	–8.1	–1.3
10	220.87	220.87	2.49937+0	3.94219–1	–3.3	–9.8	–6.7
12	220.20	220.20	1.83347+0	2.90065–1	1.1	–10.0	–11.0
14	219.53	219.53	1.34374+0	2.13232–1	3.1	–9.5	–12.2
16	218.87	218.87	9.83871–1	1.56602–1	4.5	–8.4	–12.3
18	218.20	218.20	7.19692–1	1.14902–1	3.7	–7.3	–10.6
20	219.20	219.20	5.26594–1	8.36900–2	2.7	–6.6	–9.1
22	220.20	220.20	3.85822–1	6.10388–2	1.3	–6.0	–7.3
24	221.20	221.20	2.83123–1	4.45893–2	0.2	–5.9	–6.1
26	222.20	222.20	2.08033–1	3.26157–2	–0.4	–6.3	–5.9
28	223.20	223.20	1.53042–1	2.38865–2	–1.3	–6.7	–5.5
30	224.20	224.20	1.12781–1	1.75244–2	–2.7	–7.6	–5.0
32	225.20	225.20	8.32025–2	1.28706–2	–4.0	–8.8	–5.0
34	229.60	229.60	6.16129–2	9.34844–3	–3.9	–10.1	–6.5
36	234.00	234.00	4.58777–2	6.82981–3	–3.8	–11.4	–7.8
38	238.40	238.40	3.43580–2	5.02066–3	–4.0	–12.7	–9.0
40	242.80	242.80	2.58661–2	3.71133–3	–4.4	–14.0	–10.1
42	247.20	247.20	1.95663–2	2.75710–3	–4.8	–15.4	–11.2
44	251.60	251.60	1.48762–2	2.05959–3	–5.1	–16.9	–12.4
46	256.00	256.00	1.13715–2	1.54768–3	–4.9	–18.3	–14.0
48	258.20	258.20	8.71913–3	1.17640–3	–4.7	–19.6	–15.6
50	258.20	258.20	6.69192–3	9.02894–4	–4.8	–20.9	–16.9
52	258.20	258.20	5.13323–3	6.92657–4	–4.7	–22.3	–18.5
54	255.43	255.43	3.93843–3	5.37093–4	–4.8	–23.5	–19.7
56	252.65	252.65	3.00886–3	4.14851–4	–4.3	–24.7	–21.3
58	249.88	249.88	2.29069–3	3.19393–4	–3.4	–25.8	–23.2
60	247.10	247.10	1.73914–3	2.45237–4	–2.2	–26.7	–25.1
62	244.33	244.33	1.31731–3	1.87851–4	–0.7	–27.4	–26.9
64	241.55	241.55	9.95395–4	1.43540–4	0.9	–27.8	–28.5
66	238.78	238.78	7.50022–4	1.09377–4	2.6	–28.0	–29.8
68	236.01	236.01	5.62873–4	8.30355–5	4.2	–27.8	–30.7
70	233.23	233.23	4.20198–4	6.27451–5	5.9	–27.2	–31.2
72	230.46	230.46	3.11980–4	4.71759–5	7.5	–26.2	–31.4
74	227.68	227.68	2.30470–4	3.53189–5	9.2	–24.8	–31.1
76	224.91	224.91	1.70264–4	2.64292–5	11.0	–22.9	–30.6
78	222.14	222.14	1.26467–4	1.98240–5	13.3	–20.5	–29.9
80	219.36	219.36	9.43661–5	1.49002–5	16.3	–17.6	–29.1
82	216.59	216.59	6.84452–5	1.09730–5	19.9	–13.9	–28.2
84	215.20	215.20	4.93374–5	7.98684–6	19.1	–9.4	–23.9
86	215.20	215.20	3.59130–5	5.81396–6	19.1	–4.6	–20.0
88	215.20	215.20	2.61438–5	4.23253–6	19.1	0.3	–15.8
90	215.20	215.20	1.90330–5	3.08138–6	19.1	5.5	–11.5

NOTE: Within table, the number format for 10^{-x} is shown as –x

TABLE 3-17A. EAFB Summer (Hot) Atmosphere (EHA-75) (Ref. 3.13)

Geometric Altitude (MSL) km	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (N cm^{-2})	Atmospheric Density D (kg m^{-3})	Rel. Dev. (T*) Percent From ERA-75 RD (T*) %	Rel. Dev. (P) Percent From ERA-75 RD (P) %	Rel. Dev. (D) Percent From ERA-75 RD (D) %
0.7	316.45	318.05	9.29000+0	1.01756+0	9.6	–0.5	–9.2
2	300.67	301.46	8.04214+0	9.29341–1	5.9	0.4	–5.2
4	284.48	285.00	6.37015+0	7.78659–1	4.7	1.5	–3.0
6	268.92	269.16	4.97668+0	6.44131–1	4.0	2.5	–1.4
8	254.92	254.92	3.83393+0	5.23930–1	4.6	3.7	–0.9
10	241.23	241.23	2.91079+0	4.20355–1	5.6	5.1	–0.5
12	227.04	227.04	2.17387+0	3.33561–1	4.3	6.7	2.3
14	212.84	212.84	1.59320+0	2.60764–1	–0.0	7.4	7.4
16	198.65	198.65	1.14285+0	2.00419–1	–5.2	6.4	12.2
18	207.65	207.65	8.16392–1	1.36963–1	–1.3	5.2	6.6
20	214.23	214.23	5.91070–1	9.61192–2	0.4	4.8	4.5
22	218.38	218.38	4.30924–1	6.87411–2	0.5	5.0	4.5
24	222.53	222.53	3.16101–1	4.94846–2	0.8	5.1	4.2
26	226.69	226.69	2.33206–1	3.58394–2	1.6	5.0	3.4
28	230.84	230.84	1.72959–1	2.61005–2	2.1	5.4	3.2
30	235.00	235.00	1.29000–1	1.91239–2	2.0	5.7	3.6
32	239.15	239.15	9.66936–2	1.40849–2	1.9	6.0	4.0
34	246.76	246.76	7.29929–2	1.03052–2	3.3	6.5	3.1
36	254.36	254.36	5.55635–2	7.60930–3	4.5	7.3	2.7
38	261.97	261.97	4.26481–2	5.67157–3	5.5	8.4	2.8
40	269.58	269.58	3.29812–2	4.26250–3	6.2	9.6	3.2
42	277.18	277.18	2.56820–2	3.22755–3	6.8	11.0	4.0
44	284.79	284.79	2.01373–2	2.46297–3	7.5	12.5	4.7
46	292.40	292.40	1.58997–2	1.89494–3	8.6	14.3	5.2
48	296.20	296.20	1.26103–2	1.48314–3	9.3	16.4	6.4
50	296.20	296.20	1.00125–2	1.17761–3	9.2	18.4	8.4
52	296.20	296.20	7.94989–3	9.35009–4	9.4	20.3	10.0
54	287.91	287.91	6.29186–3	7.61269–4	7.3	22.2	13.9
56	279.63	279.63	4.94523–3	6.16080–4	5.9	23.7	16.9
58	271.34	271.34	3.85861–3	4.95412–4	4.9	24.9	19.1
60	263.06	263.06	2.98778–3	3.95703–4	4.1	25.8	20.8
62	254.77	254.77	2.29489–3	3.13804–4	3.5	26.4	22.1
64	246.49	246.49	1.74742–3	2.46960–4	3.0	26.8	23.1
66	238.20	238.20	1.31829–3	1.92767–4	2.3	26.8	24.0
68	229.91	229.91	9.84449–4	1.49145–4	1.6	26.7	24.7
70	221.63	221.63	7.27181–4	1.14307–4	0.6	26.2	25.4
72	213.34	213.34	5.30913–4	8.67226–5	–0.5	25.4	26.0
74	205.06	205.06	3.82895–4	6.50828–5	–1.7	24.2	26.3
76	196.77	196.77	2.72746–4	4.82824–5	–2.9	22.5	26.2
78	188.49	188.49	1.91569–4	3.53618–5	–3.9	20.3	25.2
80	180.20	180.20	1.32041–4	2.55060–5	–4.5	17.4	22.9
82	180.20	180.20	9.02891–5	1.74789–5	–0.3	14.8	15.1
84	180.20	180.20	6.19698–5	1.19743–5	–0.3	13.6	13.9
86	180.20	180.20	4.23431–5	8.20160–6	–0.3	12.4	12.6
88	180.20	180.20	2.90775–5	5.62477–6	–0.3	11.1	11.4
90	180.20	180.20	1.98078–5	3.84521–6	–0.3	9.8	10.1

NOTE: Within table, the number format for 10^{-x} is shown as –x

TABLE 3.17B EAFB Winter (Cold) Atmosphere (ECA-75) (Ref. 3.13).

Geometric Altitude (MSL) km	Kinetic Temperature T (K)	Virtual Temperature T* (K)	Atmospheric Pressure P (N cm^{-2})	Atmospheric Density D (kg m^{-3})	Rel. Dev. (T*) Percent From ERA-75 RD (T*) %	Rel. Dev. (P) Percent From ERA-75 RD (P) %	Rel. Dev. (D) Percent From ERA-75 RD (D) %
0.7	273.15	273.65	9.39000+0	1.19539+0	–5.7	0.5	6.6
2	264.71	265.06	7.96264+0	1.04652+0	–6.9	–0.6	6.8
4	251.67	251.79	6.11233+0	8.45689–1	–7.6	–2.6	5.4
6	239.65	239.65	4.62679+0	6.72573–1	–7.4	–4.7	2.9
8	228.65	228.65	3.45563+0	5.26494–1	–6.2	–6.6	–0.4
10	222.48	222.48	2.54834+0	3.99023–1	–2.6	–8.0	–5.5
12	221.15	221.15	1.87275+0	2.95006–1	1.5	–8.1	–9.5
14	219.82	219.82	1.37372+0	2.17708–1	3.3	–7.4	–10.4
16	218.48	218.48	1.00575+0	1.60365–1	4.3	–6.4	–10.2
18	217.15	217.15	7.34954–1	1.17907–1	3.2	–5.3	–8.3
20	217.48	217.48	5.36679–1	8.59659–2	1.9	–4.8	–6.6
22	217.82	217.82	3.92083–1	6.27082–2	0.2	–4.5	–4.7
24	218.15	218.15	2.86583–1	4.57648–2	–1.2	–4.7	–3.7
26	219.91	219.91	2.09783–1	3.32322–2	–1.4	–5.5	–4.1
28	221.68	221.68	1.53949–1	2.41935–2	–2.0	–6.2	–4.3
30	223.44	223.44	1.13252–1	1.76572–2	–3.0	–7.2	–4.3
32	225.20	225.20	8.35144–2	1.29190–2	–4.0	–8.5	–4.6
34	229.60	229.60	6.18410–2	9.38307–3	–3.9	–9.8	–6.1
36	234.00	234.00	4.60475–2	6.85513–3	–3.8	–11.1	–7.5
38	238.40	238.40	3.44851–2	5.03925–3	–4.0	–12.4	–8.7
40	242.80	242.80	2.59613–2	3.72509–3	–4.4	–13.7	–9.8
42	247.20	247.20	1.96382–2	2.76744–3	–4.8	–15.1	–10.9
44	251.60	251.60	1.49321–2	2.06726–3	–5.1	–16.6	–12.1
46	256.00	256.00	1.14139–2	1.55352–3	–4.9	–17.9	–13.7
48	258.20	258.20	8.75152–3	1.18076–3	–4.7	–19.3	–15.3
50	258.20	258.20	6.71674–3	9.06220–4	–4.8	–20.6	–16.6
52	258.20	258.20	5.15508–3	6.95519–4	–4.7	–22.0	–18.2
54	255.43	255.43	3.95301–3	5.39081–4	–4.8	–23.3	–19.4
56	252.65	252.65	3.01997–3	4.16381–4	–4.3	–24.5	–21.0
58	249.88	249.88	2.29916–3	3.20568–4	–3.4	–25.5	–22.9
60	247.10	247.10	1.74555–3	2.46135–4	–2.2	–26.4	–24.8
62	244.33	244.33	1.32215–3	1.88541–4	–0.7	–27.1	–26.6
64	241.55	241.55	9.99067–4	1.44072–4	0.9	–27.6	–28.2
66	238.78	238.78	7.52785–4	1.09777–4	2.6	–27.7	–29.5
68	236.01	236.01	5.64923–4	8.33397–5	4.2	–27.5	–30.4
70	233.23	233.23	4.21743–4	6.29730–5	5.9	–26.9	–31.0
72	230.46	230.46	3.13067–4	4.73404–5	7.5	–26.0	–31.1
74	227.68	227.68	2.31276–4	3.54486–5	9.2	–24.6	–30.9
76	224.91	224.91	1.70860–4	2.65102–5	11.0	–22.7	–30.3
78	222.14	222.14	1.26944–4	1.98898–5	13.3	–20.3	–29.6
80	219.36	219.36	9.46903–5	1.49574–5	16.3	–17.3	–28.9
82	216.59	216.59	6.87218–5	1.10025–5	19.9	–13.6	–27.9
84	215.20	215.20	4.95183–5	8.01647–6	19.1	–9.0	–23.6
86	215.20	215.20	3.60456–5	5.83524–6	19.1	–4.3	–19.7
88	215.20	215.20	2.62412–5	4.24784–6	19.1	0.7	–15.5
90	215.20	215.20	1.91021–5	3.09271–6	19.1	5.8	–11.2

NOTE: Within table, the number format for 10^{-x} is shown as –x

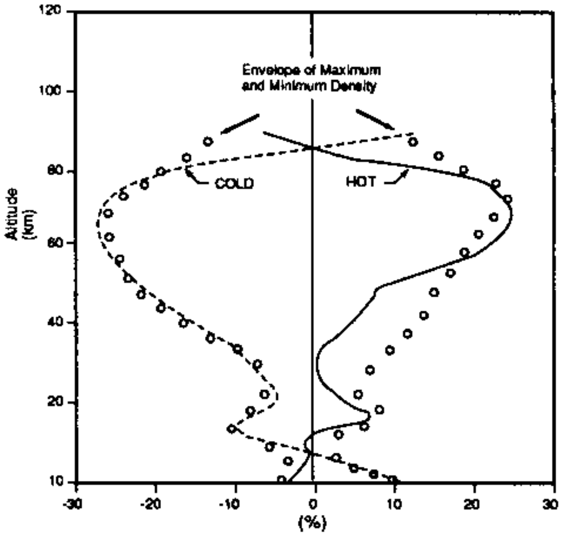

FIGURE 3.2 Relative Deviations (%) of Extreme KSC Density Profiles with Respect to PRA-63.

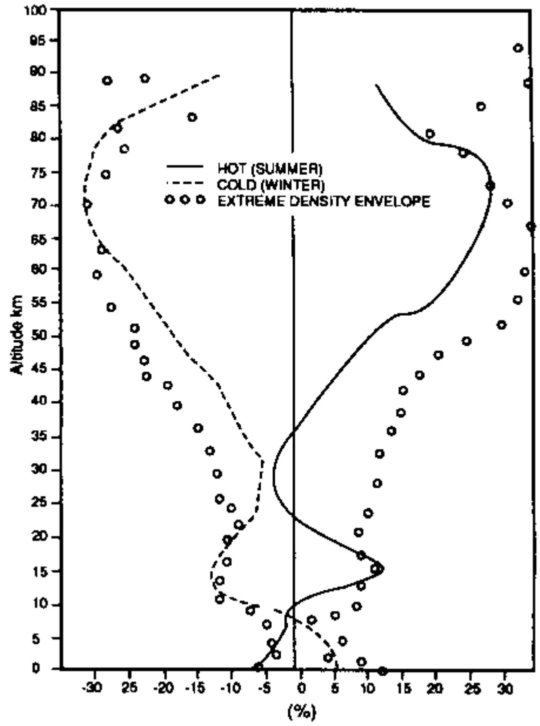

FIGURE 3.3 Relative Deviations (%) of Extreme VAFB Density Profiles with Respect to VRA-71.

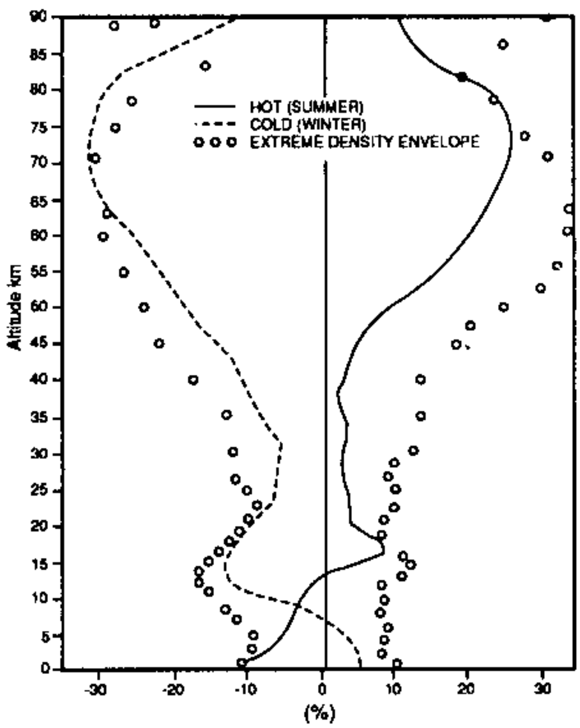

FIGURE 3.4 Relative Deviations (%) of Extreme EAFB Density Profiles With Respect to ERA-75.

The two VAFB extreme density profiles are shown in figure 3.3 as percent deviations from the Vandenberg Reference Atmosphere, 1971. Levels of minimum density variation are located at ~8, 30, and 90-km altitude. Levels of maximum variability occur at 0, 15 and 73 km. The hot and cold VAFB virtual temperature profiles are shown in figure 3.6.

The two EAFB extreme density profiles are shown in figure 3.4 as percent deviations from the Edwards Reference Atmosphere, 1975. The hot and cold EAFB virtual temperature profiles are shown in figure 3.7. These extreme density and temperature profiles again have structures similar to the KSC and VAFB models. Temperatures below approximately 10-km altitude are virtual temperatures. Virtual temperature includes moisture to avoid computation of specific gas constant for moist air (section 3.3.1.1).

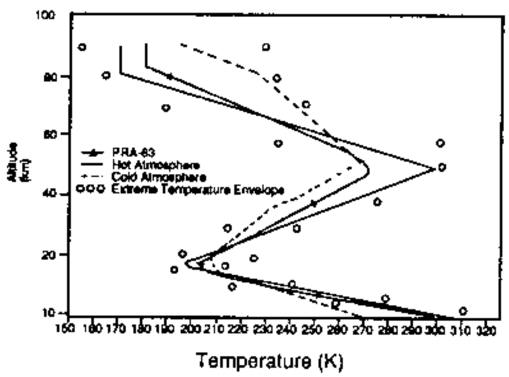

FIGURE 3.5 Virtual Temperature Profiles of The KSC Hot, Cold, and PRA-63.

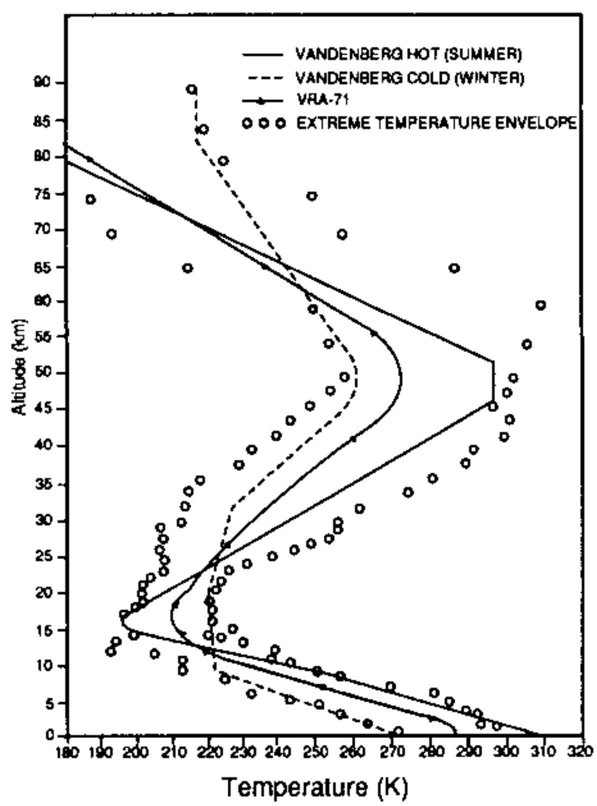

FIGURE 3.6 Virtual Temperature Profiles of the

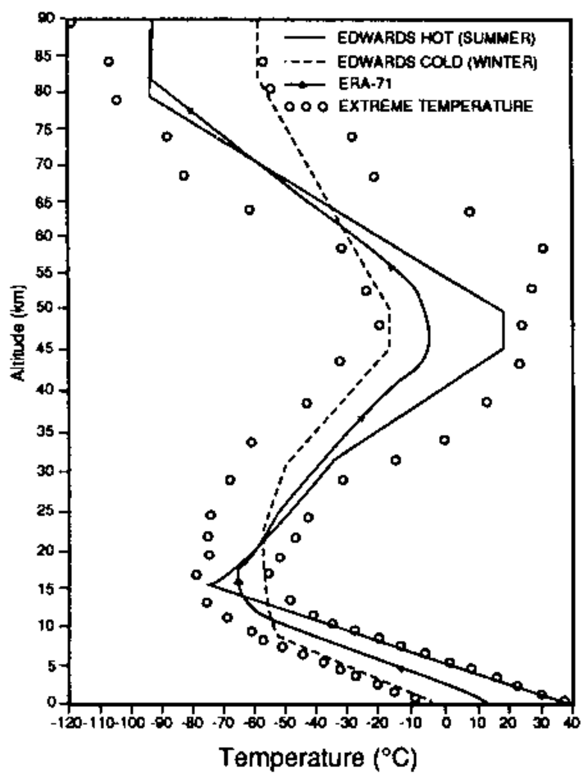

Figure 3.7 Virtual Temperature Profiles of the

VAFB Hot, Cold, and VRA-71. EAFB Hot, Cold, and ERA-75.

Tables 3.15A and B, 3.16A and B, and 3.17A and B give the numerical data used to prepare Figures 3.2 through 3.7.

3.7 Reference Atmospheres. In design and preflight analysis of aerospace vehicles, special average atmospheric models are used to represent the mean or median thermodynamic conditions with respect to altitude. For general worldwide design, the U.S. Standard Atmosphere, 1976 (US 76) (Ref. 3.1), is used, but site specific atmosphere models are needed at each launch area. A group of Range Reference Atmospheres (Ref. 3.5) have been prepared to represent the thermodynamic medians in the first 70-km altitude at various ranges and launch areas. References 3.16 and 3.17 (supplemental atmospheres) together with references 3.6 and 3.7, which describes the Global Reference Atmosphere Model (GRAM), are also useful in this regard.

The Patrick Reference Atmosphere (PRA-63) is a more extensive reference atmosphere presenting data to 700-km altitude for KSC. Because of the utility of this atmosphere, a simplified version is given as Table 3.10 from Reference 3.3. Criteria for orbital studies are given in reference 3.11.

Reference atmospheres are also available for VAFB (Ref. 3.4 and Table 3.11) and EAFB (Ref. 3.13 and Table 3.12). These provide an annual reference atmosphere model to 700 km and have been designated as computer subroutines VRA-71 and ERA-75, respectively.

In Tables 3.10, 3.11, and 3.12 the reference atmosphere values are given in standard computer printout, where the two-digit numbers that are at the end of the tabular value (number preceded by E) indicate the power of 10 by which the respective principal value must be multiplied. For example, a tabular value indicated as 2.9937265E 02 is 299.37265 or 0.15464054E-04 is 0.000015464054.

A detailed listing and description of many world-wide reference and standard atmospheric models is given in reference 3.18.

3.8 Reentry - Global Reference Atmosphere Model

3.8.1 Reentry Atmospheric Model. The atmospheric model recommended for all reentry analyses, except lower altitudes specified in subsection 3.6, is the NASA-MSFC Global Reference Atmosphere Model (GRAM)(Ref. 3.6). This model generates monthly profiles of atmospheric variables - wind, pressure, temperature, and density - along any vehicle trajectory from orbital altitudes to sea level on a worldwide basis. GRAM can also generate many different realistic, simulated atmospheric profiles. A Monte Carlo procedure utilizing correlative techniques with the daily variability of the atmospheric parameters has been used to accomplish the construction of individual, atmospheric profiles.

The GRAM model has been computerized and is available to give these variables and their structure as a function of the three spatial coordinates—latitude, longitude, and altitude—and of the time domain (monthly). The GRAM model is a composite of other atmospheric models melded together with new techniques to join models and simulate perturbations. The GRAM-99 computer program is available from the Environments Group, ED44, of the NASA Marshall Space Flight Center, MSFC, AL 35812.

3.8.2 Atmospheric Model for Simulation. A National Aero-Space Plane (NASP) Integrated Atmospheric Model (NIAM) (Ref. 3.7) has been developed at NASA/Ames-Dryden under guidance from NASA/MSFC, for NASP engineering design and flight simulation studies. The NIAM is based on an earlier version of GRAM, but has been expanded to incorporate other specific, realistic atmospheric thermodynamic and wind (turbulence) perturbations. NIAM is specific to NASP and was developed for real-time simulations; but is also appropriate for use in NASP off-line control, structure, and propulsion subsystem design activities, and in batch simulations. It simulates ascent, cruise, and descent of the X-30.

3.9 Atmospheric Orbital Model. General environmental criteria for NASA orbital studies are given in reference 3.11. The atmospheric model baselined to be used in all space station design studies (Ref. 3.19) is the NASA-Marshall Engineering Thermosphere Model (NASA-MET) (Ref. 3.20, 3-21, and 3.23). A good description of the upper atmospheric variations that have been programmed into the MSFC orbital atmospheric model can be obtained from References 3.22 and 3.11. The above mentioned GRAM-99 model also has the NASA-MET within its upper structure above 120-km altitude.

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(1) Cape Canaveral, Florida—Range Reference Atmosphere 0 to 70-km altitude, RCC Document 361-83, February 1983.

(2) Vandenberg Air Force Base, California—Range Reference Atmosphere 0 to 70-km altitude, RCC Document 362-83, April 1983.

(3) Dugway, Utah—Range Reference Atmosphere 0 to 30-km altitude, RCC Document 363-83, June 1983.

(4) Wallops Island, Virginia - Range Reference Atmosphere 0 to 70-km altitude, RCC Document 364-83, July 1983.

(5) White Sands Missile Range, New Mexico - Range Reference Atmosphere 0 to 70-km altitude, RCC Document 365-83, August 1983.

(6) Edwards AFB, California - Range Reference Atmosphere 0 to 70-km altitude, RCC Document 366-83, August 1983.

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