2

The atmosphere

Aviators flying in the upper reaches of the atmosphere need to know what they are up against. The stratosphere can be deadly. It has killed a lot of people; both those who were prepared and those who weren't. Even those who have climbed Mount Everest are aware of the "Death Zone" at 26,000 feet, the altitude at which supplemental oxygen is required. The stratosphere is more than twice as high as that; depending upon latitude and season. There is a higher altitude at 43,000 feet where you must have oxygen under pressure. At 63,000 feet, the atmospheric pressure is the same as the vapor pressure of water and bodily fluids. This is called the Armstrong Limit. This chapter describes the various layers of the atmosphere, and defines the relative depth of the stratosphere and the upper limit for would-be stratonauts.

To be a stratonaut is to fly in the stratosphere, which is simply a specific portion of the atmosphere. But for a human this presents a lot of problems which are ignored at one's peril. The upper regions of the atmosphere are not suited for human habitation. Neither are most of the lower regions. Most humans live below 10,000 feet but there are some who live in the high Andes and Himalayas. Few have climbed Mount Everest without oxygen. Some have died trying. There the "Death Zone" is considered to be 26,000 feet and this is not even in the stratosphere. We need to understand some atmospheric basics in order to appreciate what a would-be stratonaut is up against. But we don't need to get too scientific.

The atmosphere means different things to different people. To a meteorologist it is the climate and weather. To a biologist it is the interaction with various forms of life. To a chemist it is the composition of gases and their reactions. To a physicist it is the pressure and temperature. To the designer of a vehicle meant to fly in the stratosphere it presents a lot of problems. To the pilot and crew members of such a craft, it's a bit of all of the above.

The average person knows we live and breathe in the lowest levels of the atmosphere and we inhale air made up of about 78% nitrogen, 21% oxygen, about a percent or so of water vapor depending on the weather, and about a percent of argon and trace amounts of hydrogen and helium and a few others. We only breathe in 0.0314% carbon dioxide. The body doesn't like this very much. The average person probably doesn't realize that we exhale 78% nitrogen (all of what we inhale), 14 to 16% oxygen (most of what we inhale),

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4 to 5.3% carbon dioxide (much *more* than we inhale), and 1% of everything else. We all know that with increasing altitude the air pressure decreases and it becomes cooler. So let's look at the atmosphere one layer at a time.

2.1 TROPOSPHERE

We live in the lower part of the atmosphere called the troposphere. The term is derived from the Greek meaning that it's the area where all the mixing and turning goes on; i.e. the weather system. The troposphere is characterized by a reduction in temperature and pressure with increasing altitude. Under normal conditions this is about 3.6 degrees per 1,000 feet and is called a lapse rate. The rate itself decreases somewhat with altitude. It varies with moisture content but for our purposes this is near enough. The troposphere averages about 59°F on the surface and becomes colder and colder until you reach the tropopause, where this lapse rate ceases. In effect, it produces a temperature inversion layer. This layer varies with latitude, being lowest at the poles and up to twice as high at the equator.

By definition the troposphere is considered to be from the surface up to an altitude of about 12.4 miles, 20 kilometers, or about 65,620 feet. At the mid-latitudes, the upper limit is about 11 miles or about 58,000 feet. (Scientists use the metric system, but most aviators don't, so I'll always give the equivalent English units.) This is approximately twice as high as a commercial airliner flies. About 80% of the atmosphere by weight and 99% of the water vapor and aerosols are below this level. So one could define a "stratonaut" as one who has flown from about this altitude to the top of the stratosphere, which is generally defined as 31 miles (50 kilometers) or about 164,000 feet. Even this definition of the boundary between the troposphere and stratosphere is rather arbitrary. It is sufficient to think of the stratosphere as being roughly 100,000 feet deep from top to bottom.

There is a unique point within the upper levels of the troposphere that is called the "Armstrong Limit." Harry George Armstrong of the USAF's Department of Medicine was first to recognize the altitude at which a human absolutely cannot survive in an unpressurized environment. At this level, and above, exposed bodily liquids such as saliva, tears, and liquids within the lungs will boil. No amount of breathable oxygen will sustain life for more than several minutes. In fact, the pressure at this altitude is so low that water boils at normal body temperature. This altitude is about 62,000 to 63,500 feet. Notice that this physiological number is conveniently near the upper level of the troposphere (and lower level of the stratosphere) for definition purposes. So, one might define a "stratonaut" as someone who has flown to at least the Armstrong Limit.

The Concorde used to cruise in the 50,000 to 60,000 foot range, where the outside air temperature is about minus 50 to 70°F, but the passengers didn't have pressure suits. A rapid loss of cabin pressure would probably have been fatal for many, depending upon how rapidly the pilot was able to descend. All USAF pilots flying at this altitude have pressure suits.

2.2 STRATOSPHERE

The tops of thunder clouds are generally near the tropopause. Often they overshoot and punch through. The lower region of the stratosphere includes the ozone layer and there is a lot of interaction with various wavelengths of sunlight. The thin atmosphere absorbs higher energy ultraviolet B and C rays, creating the different forms of oxygen as well as various other chemical compounds. Some bacterial life survives here. The temperature begins to increase for some distance, but then decreases again. This transition point is called the stratopause.

The top of the stratosphere is considered to be in the neighborhood of 164,000 feet, making it about 100,000 feet deep. At the upper regions it is about 30°F, or just below the freezing point of water. It is layered in temperature throughout, depending upon the ultraviolet light and the amounts and types of oxygen. The lower levels are cooler than the upper levels.

2.3 MESOSPHERE

After the stratosphere there is the mesosphere. It begins at about 164,000 feet and goes to about 280,000 feet and is sandwiched between the stratosphere and the thermosphere. In the mesosphere the temperature declines with increasing height, reaching a minimum of minus 148°F. This point is called the mesopause, and as with the stratopause it varies with latitude and season.

The mesosphere is above the maximum altitude for aircraft and below the minimum altitude of orbital vehicles. This is the portion of the atmosphere where meteors melt or vaporize as a result of collisions with the gas particles. The upper regions also include an ionization layer. In this region the atmosphere is no longer mixed and becomes nonuniform. For example, there is a 3 mile deep layer of sodium atoms that contributes to the airglow phenomenon. This is the least understood part of the atmosphere, and is of current scientific interest.

2.4 THERMOSPHERE/EXOSPHERE

The thermosphere lies between the mesosphere and the exosphere above. It starts at an altitude of about 53 miles or about 280,000 feet and goes to about 310 miles. Heights in this part of the atmosphere are best measure in miles rather than feet. The International Space Station travels in a relatively stable orbit that varies between 200 and 270 miles high.

As its name implies, the thermosphere is characterized by temperature. This varies with solar activity over a roughly 11 year cycle. The highly diluted gas in this layer can reach over 4,500°F but a thermometer would not read this because there is hardly any heat transfer in a near total vacuum. Neither do the astronauts feel this high temperature on a spacewalk. The solar radiation also causes particles to become electrically charged. This is why radio waves can bounce off the atmosphere and be received far beyond the horizon. This area encompasses complicated interactions between the Earth's magnetic field and the solar wind in the polar regions. This is where auroras occur. There are also complicated wave actions going on that transport energy.

While pilots don't have to worry about this region, there is one arbitrary altitude of significance. In the 1950s, physicist and engineer Theodore von Kármán defined 100 kilometers (62 miles) as the boundary of outer space because at this altitude the air is so thin that in order for a vehicle to generate aerodynamic lift it would have to travel at an orbital velocity of over 17,000 miles per hour. Some purists prefer to use the term "edge of space"

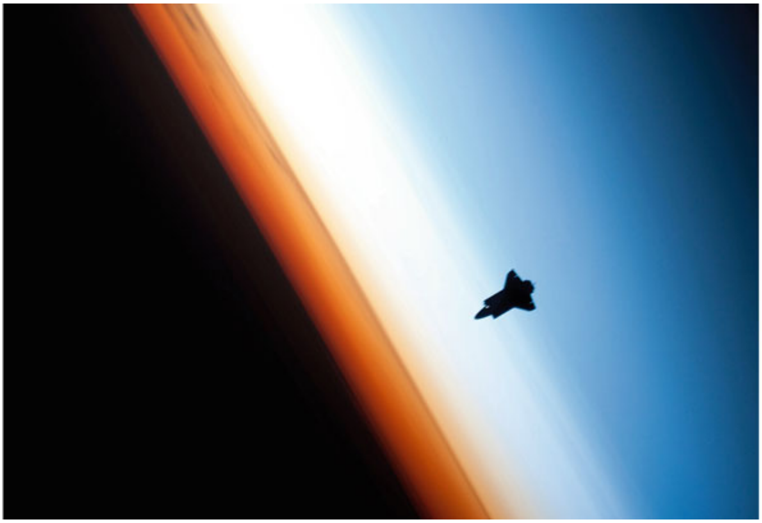

Fig. 2.1 In this orientation the nose of the Space Shuttle Endeavour (STS-130) points to the whitish stratosphere. Photo courtesy of NASA and Wikimedia Commons.

rather than "outer space." This height of 100 kilometers is recognized by the FAI but international law defines the lowest level of space as the altitude at which a body can achieve one full circular orbit without propulsion. Because of atmospheric drag, this turns out to be about 93 miles. With an elliptical orbit it could be as low as 80 miles. The first vehicle to cross the Kármán Line was the Nazi V-2 rocket.

Above the thermosphere is the exosphere, which is arbitrarily considered to extend to 10,000 kilometers or over 6,000 miles. What remains of the atmosphere are molecules and particles that are still gravitationally bound to the Earth but no longer act as gases. They consist primarily of hydrogen, some helium, carbon dioxide, and atomic oxygen. Now you're in interplanetary space.

That's just about all you need to know about the atmosphere in order to appreciate what it takes to fly in this environment. **Fig. 2.1** clearly illustrates some of the layers of the atmosphere. Endeavour was at an altitude of about 185 miles when this picture was taken on February 9, 2010, on its way to the International Space Station which orbits in the thermosphere. Below the 100,000 foot deep stratosphere is the orange layer of the troposphere in which all the weather occurs and most aircraft fly. Above the Shuttle, the bluish mesosphere yields to the black thermosphere and exosphere. Part of the black is the window frame on the International Space Station, from where this photo was taken.

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