

CHAPTER 6: WEATHER FOR SOARING

Weather patterns on Earth are complicated and chaotic. Weather is a result of the atmosphere's constant attempt to reach equilibrium. This equilibrium is continually upset by uneven solar heating of the Earth's surface caused by cloud cover, the uneven distribution of land and water, and the Earth's tilt and rotation, among other factors.

As glider pilots, we are dependent on the weather. As long as it isn't raining or too windy, or the clouds aren't too low, we can glide. But to soar, that is, to be able to stay aloft and climb, we must be able to find rising air, which we call "lift".

The four main types of lift are thermal, ridge, mountain wave, and convergence. Thermals are warm air masses that rise because they are less dense than the surrounding air. Ridge lift results when wind is forced up by a ridge. Mountain wave lift is created when winds aloft interact with low-level winds that have been displaced by a mountain. Convergence lift is formed any time two air masses collide, forcing the air to rise.

The weather can also create hazards for the glider pilot. Certain weather events can damage or destroy a glider, in the air or on the ground. Often, the very conditions that create good lift also can create hazards.

In this chapter, you will learn about the forces that create the weather so that you will be able to predict good soaring days, and to avoid dangerous conditions.

6.1 The Atmosphere

The atmosphere is a mixture of gases surrounding the Earth. Although the atmosphere has no specific upper limit, 99.9% of its mass lies below an altitude of 164,000 feet, or 27 nautical miles. Comparing this with the Earth's radius of 3,438 nautical miles, you can see that the atmosphere is extraordinarily thin; it is less than 1% of the Earth's radius. Most of what we think of as weather takes place in the lower 30,000 feet, or 5 nautical miles.

Composition of the Atmosphere

Approximately 99% of the atmosphere is composed of just two gases: nitrogen and oxygen. The other one percent is composed of various trace gases, including water vapor. The amount of water vapor in the air depends on the location and the source of the air. For example, water vapor accounts for as much as four percent of the air over tropical areas and oceans, but only one percent of the air over deserts and at high altitudes.

Although water vapor exists in the atmosphere in such small amounts compared to nitrogen and oxygen, it plays a crucial role in the production of weather. This

is because unlike the other gases, it exists in two other physical states, liquid (water) and solid (ice), within the atmosphere's range of temperature. This allows for the formation of clouds, precipitation, and fog, all of which are important to aviation weather. In addition, by absorbing the radiant energy from the Earth's surface, water vapor reduces surface cooling, causing surface temperatures to be warmer.

The State of the Atmosphere

The state of the atmosphere can generally be described by four characteristics: temperature, density, pressure, and humidity. These characteristics are always fluctuating and combined with the vertical and horizontal movement of the air, lead to variations in the weather.

Temperature

The temperature of a gas is a measure of the average kinetic energy of the molecules of that gas. Fast-moving molecules have high kinetic energy and therefore high temperatures. Slow-moving molecules have lower kinetic energy, with correspondingly lower temperatures.

Several things can change the temperature of a parcel of air. These include contact with ground or water that is at a different temperature, mixing with other air masses, warming through radiant energy, changes in pressure, and changes in moisture content.

If the ground is at a different temperature than the air, it can change the temperature of the air through direct contact. Cold air can be warmed as it moves over warm ground (or water), or it can be warmed as the ground under it is warmed by the radiant energy from the sun. At night, the ground radiates energy, causing it to cool, which cools the air above it.

Of course, when two air masses mix, the temperature of both will change. Mixing can occur as two large air masses collide horizontally, or as warm air rises through cooler air.

Water vapor in the air is especially good at absorbing radiant energy, either from the sun or from warmer objects, and in doing so, will cause the air temperature to rise. (This is why clear, dry nights are colder than cloudy or humid nights.)

If the pressure of a parcel of air is changed, either through a change in altitude or because the atmospheric pressure changes, the temperature of the air will change. The rapid decrease in pressure with increasing altitude results in a dramatic decrease in temperature.

Finally, if water vapor is added or removed from the air, the air temperature will also change.

Pressure

The pressure at any point in the atmosphere is determined by the weight of the air above it. The weight of the air depends on the depth of the air mass and the density of the air. At sea level, a column of air that is one-inch by one-inch and extends to the edge of the atmosphere weighs about 14.7 pounds. The pressure is therefore 14.7 lb./in.². The depth of the air mass can be affected by the dynamics of the atmosphere. Swirling flow causes the air to diverge and decrease in depth. Converging flow causes the atmosphere to “pile up” and increase in depth.

Pressure is often measured by using a mercurial barometer. Imagine a long test tube open at one end and a deep vat of mercury. You submerge the tube in the vat so that it fills up with mercury, and then pull the tube out of the vat, closed end up. The vacuum at the top of the tube will make the mercury stay at the top of the tube until the tube has been lifted about 30 inches out of the vat. At this point, no matter how high you lift the tube, the column of mercury will remain at about 30 inches long. Why is this?

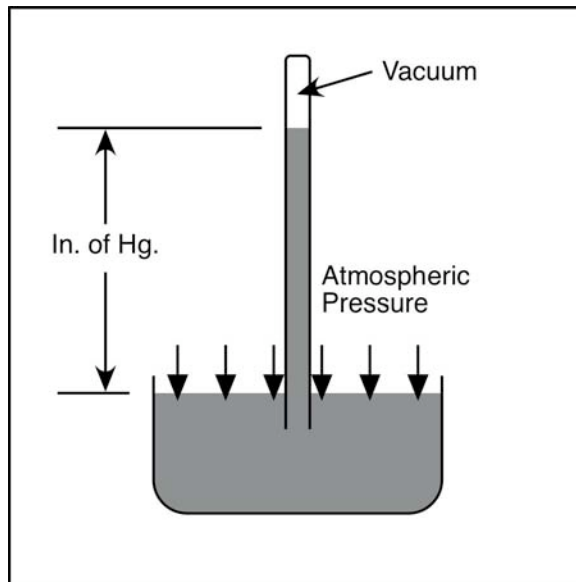


Figure 6.1 – Mercurial barometer. The weight of the atmosphere balances the weight of the column of mercury.

The vacuum at the top of the test tube is the same as the vacuum of space. The force pushing the mercury up the tube is the pressure caused by the weight of the atmosphere. For a given area, the weight of the atmosphere from sea level to the edge of the atmosphere is the same as the weight of a column of mercury that is about 30 inches tall and has the same cross-sectional area. As atmospheric pressure increases, the mercury will be driven higher; as it decreases, the mercury will fall. Measuring the height of the column gives you the pressure of the atmosphere in inches of mercury (in. Hg.). Pressure can also be measured in millibars (mb). 1,000 millibars is equal to 29.53 in. Hg.

Pressure (Millibars)	Pressure (In. Hg.)	Approx. Altitude (Feet)
300	8.86	30,100
400	11.81	23,600
500	14.77	18,300
600	17.72	13,800
700	20.68	9,900
800	23.62	6,400
900	26.58	3,200
1000	29.53	360
1013	29.92	Sea Level

Figure 6.2 – Conversion between millibars, inches of mercury, and altitude.

Density

The density of a gas is the total mass of the molecules in a specific volume, expressed in units of mass per volume. Lower density air has fewer molecules in a specified volume when compared to air at a higher density.

Dry air behaves almost like an “ideal” gas, meaning it obeys the gas law given by

$$P/DT = R,$$

where P is pressure, D is density, T is temperature, and R is a constant. The law states that the ratio of pressure to the product of density and temperature must remain constant. Therefore, for a given pressure, if the temperature increases, the density decreases, and vice versa.

Air pressure and temperature are easily measured, and density can then be calculated from them using the gas law.

Humidity

The atmosphere contains moisture in the form of water vapor. Humidity is a measure of how much water vapor is in the air, expressed as a percentage of the maximum amount of water vapor that the air can hold. The amount of water vapor that the air can hold is a function of temperature and pressure. If the pressure is held constant, every 20°F increase in temperature doubles the amount of moisture the air can hold.

The humidity of a parcel of air can change through the processes of evaporation and condensation (water changing from a liquid to a gas, and from a gas to a liquid), and through sublimation and deposition (water changing from a solid to

a gas, and a gas to a solid). The humidity can also change when two air masses of different humidity are mixed together.

6.2 Dew Point

Warm air can hold more water vapor than cool air. As air cools, its capacity to hold water vapor decreases. At some temperature the air will become completely saturated with water vapor, and any further cooling will cause liquid water to form. This temperature is called the dew point. If you have ever seen condensation form on the outside of a cold drinking glass, you have observed this process. As discussed earlier, there are many different mechanisms that can cool air, causing it to reach the dew point.

Dew and Frost

Dew is liquid condensation that forms on solid objects when their temperature is below the dew point. Frost occurs when the temperature of the object is below both the dew point and the freezing point. Dew and frost are likely to occur on cold, calm, clear nights.

While dew can increase the drag of a glider, frost poses a definite flight safety hazard. Frost disrupts the flow of air over the wing and can drastically reduce the ability of the airfoil to produce lift. It also increases drag. These two effects can make it impossible for a frost-covered tow plane or glider to take off. Both the glider and the tow plane should be cleared of frost before flight.

6.3 Atmospheric Stability

Atmospheric stability refers to the tendency of a parcel of air that is displaced vertically to either keep rising or to return to its original altitude. When a parcel of air is warmer than the air around it, and thus less dense, it will rise due to buoyancy. As the air rises, it expands because of decreasing pressure, and cools in the process. If the vertical temperature distribution in the atmosphere is such that the rising parcel of air will always be warmer than the air around it, it will keep rising, and the atmosphere is said to be unstable. If the rising parcel of air becomes cooler than the air around it, it will start to sink, and the atmosphere is said to be stable.

The rate at which air cools as it rises (the lapse rate) depends on whether or not it is saturated with water vapor. Therefore, the stability of a given atmosphere depends not only on the temperature distribution, but also on the moisture content of the air.

Dry Adiabatic Lapse Rate

The process of decreasing the temperature of a gas by decreasing the pressure without transferring heat is called adiabatic cooling. Likewise, the process of increasing the temperature of a gas by increasing the pressure without transferring heat is called adiabatic heating. In the altitudes of interest to a soaring pilot