1. The Air

A serious pilot cannot know too much about air. Without air there would be no flight, only ballistics. Air pressure, density, and viscosity are the ultimate sources of nearly all forces acting on an airplane. Air is needed for the combustion that provides thrust from the engines. We need to concern ourselves with the air we breathe as we operate at higher altitudes. And of course the air, with its accompanying weather, is the medium in which we operate.

In this chapter we will investigate some of the basic properties of air, such as pressure, density, and temperature. And we will study the meaning and cockpit measurement of certain vital pieces of air data, such as airspeed and altitude.

The Makeup of the Air

We live in an age when people do not easily accept the reality of something that they can neither see nor smell, buy nor sell. This observation opens a wide range of subjects, but at the moment I am interested simply in the air around us. Though we can neither see it nor hold it in our hands, the air is as real and substantive as any so-called solid object. The air is made up of atoms and molecules that have mass and weight. A moving parcel of air has momentum and kinetic energy—you can readily feel the energy transfer from a bombarding stream of air molecules when you stick your hand out the window of a moving car.

The air is made up of 78 percent nitrogen, 21 percent oxygen, .9 percent argon, and .1 percent carbon dioxide, neon, krypton, ozone, and other inert gases. These proportions are roughly constant in samples taken horizontally over a variety of locations and vertically at different altitudes up to about 50 miles. (Satellite drag data shows that there are measurable quantities of air even at altitudes of 1000 miles.) The air also carries along a mixture of dust, ash, salt, pollen, spores, bacteria, pollutants, and water vapor. Even in the humid tropics, water vapor content is generally below about 4 percent by volume.
It is critical to realize that air has mass and weight. You cannot weigh free air in a balance, because the balance itself is immersed in air. In the same

2. The Normally Aspirated Engine

Internal combustion engines are a lot like people. They inhale air for its oxygen, they eat "complex carbohydrates" (actually, hydrocarbons like C_8H_{17}, for instance), they excrete H_2O and CO_2, and in the process they generate a lot of heat and noise and a little bit of useful work.

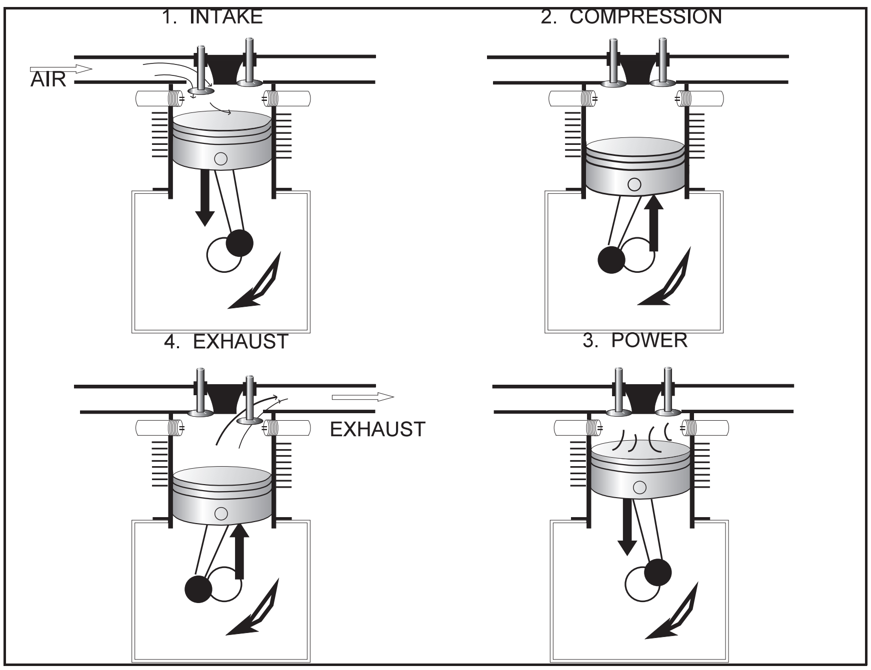

Figure 1. The four-stroke cycle engine.

The basics of the Otto cycle spark ignition engine are shown in Figure 1. During the intake phase, the rotation of the crankshaft pulls the piston down in the cylinder. With the intake valve open, a fuel/air mixture flows into the cylinder, due to the difference in pressure between the intake manifold and the interior of the cylinder. Picture it this way: If the intake valve were stuck shut, the downward motion of the piston in the cylinder would create a partial vacuum in the cylinder, so with the valve open, the mixture will be drawn into the cylinder.

3. *Turbocharging*

We learned in the last chapter that the amount of horsepower generated by a given engine largely depends on the amount of fuel and air it burns. If we assume the fuel/air ratio, the mixture, is fixed, then we can say that power depends on the amount of air the engine inhales. But the expression "amount of air" needs to be clarified. A normally aspirated 550 cubic inch four-stroke-cycle engine running at full throttle inhales a *volume* of a little less than 550 cubic inches of *ambient air* with each two revolutions. (The higher the volumetric efficiency, the closer the volume will be to 550 cubic inches.) But power is not a function of the *volume* of air, it is a function of the *mass* of the air, i.e., its *weight*, or th*e number of molecules* entering the combustion chamber. A 550 cubic inch engine inhales a volume of about 550 cubic inches of ambient air (per two revolutions) when it goes to full throttle at sea level on a standard day, and it inhales about 550 cubic inches of ambient air in Denver on a hot day, but the number of molecules of air and the resulting power are very different in these two cases. With the reduced ambient air density at Denver, there are fewer air molecules to pair with fuel molecules to support combustion. The result is less power from the same *volume* of air. (Remember, volume is not a measure of quantity, it is a measure of space.) And there is no point in giving the engine more fuel, because without more air, the fuel will not burn.

The purpose of a turbocharger is to stuff more molecules of air into the combustion chamber. More air means more fuel can be burned, and this means more brake horsepower (BHP). This is particularly important in aircraft, which operate over a wide range of altitudes. If you want 250 BHP at 18,000 feet, essentially your choice is this: either install a very large normally aspirated engine that can produce about 500 BHP at sea level, or a smaller turbocharged engine that gives you 250 BHP at sea level and 250 BHP at 18,000 feet. The second alternative is more popular, because it is cheaper, lighter, and generally more efficient. (This does not say that a turbocharged 250 is cheaper, lighter, and more efficient than a normally aspirated 250. That is not and probably never will be true.)

4. Mixture

We begin with some facts. Later we will get into theory and operational issues. Continental prints an interesting graph in its IO-550 Operator's Manual. The graph is redrawn here in Figure 1. As you look at this graph, imagine that we do an experiment while flying a Continental IO-550 in a Beech Bonanza or Baron. We set the MP at 24 inches and the RPM at 2300, and then we gradually lean the mixture from full rich to the point of lean misfire. The fuel flow, shown on the horizontal axis, falls from about 97 pounds per hour (pph) to about 62 pph. Our airplane is very well instrumented, and as we lean we watch the readout on four engine instruments: EGT, CHT, BHP, and BSFC. EGT is exhaust gas temperature. CHT is cylinder head temperature. BHP is brake horsepower. And BSFC is brake specific fuel consumption—the number of pounds of fuel being burned per hour divided by the present brake horsepower. The curves in Figure 1 show the four engine readings as we sweep through the various fuel flow values from rich to lean looking right to left. If you did this same experiment at other power settings or with other engines, you would see the same basic pattern, so we will take a closer look.

First, we define the fuel/air ratio. This is the number of pounds of fuel going into the engine per minute divided by the number of pounds of air per minute. As you read into this subject, you are just as likely to see reference to the air/fuel ratio, which is nothing but the inverse of the fuel/air ratio. Gasoline engines run over a wide range of fuel/air ratios—from about .055 to about .125. (That would mean air/fuel ratios of anywhere from 18/1 to 8/1.) The amount of air entering a naturally aspirated engine is governed largely by pressure altitude, outside air temperature, throttle position, and RPM. In our experiment, the amount of air entering the engine is roughly constant, since MP and RPM are fixed. And with throttle and prop controls fixed, the amount of fuel in our experiment, and therefore the fuel/air ratio, is determined by the mixture control. Notice that even though our "power setting" (MP and RPM) is fixed, the amount of power actually generated strongly depends on the fuel/air ratio of the charge. We will look at these curves one by one.

5. Turbine Engines

When you graduate to turbine-powered airplanes, it is time to take a specialized course for a week or so to study the airplane's systems, performance, procedures, and so on. A large part of such a course will deal with the powerplant. You will cover the engine layout, systems, and limitations as well as normal and emergency procedures. This chapter cannot possibly substitute for the detailed training you will need. My object here is to give you a brief introduction to the general features of gas turbine engines, so you will know a few basics and at least become an intelligent beginner or right-seat observer. What we will do is take a look at the Pratt & Whitney Canada PT6A turboprop, which is the most prevalent engine of this type.

The Layout of the PT6A

The photo on the previous page shows a cutaway view of one of the smaller versions of the PT6A. Figure 1 shows a highly simplified line drawing of the PT6A. Air enters near the rear of the engine and is directed to a three-stage axial compressor. An axial compressor is like a house fan; it moves air parallel to its axis of rotation. It is called "three-stage" simply because there are three of these compressors in a row. (Larger versions of the PT6A have four axial compressor stages.) Air leaving the third axial compressor is routed to a centrifugal compressor which pushes the air outward and then forward toward the combustion chamber. The centrifugal compressor and three (or four) axial compressors are mounted on a common shaft that extends forward to the compressor turbine and aft to drive the accessories. The engine employs a compressor for the same reason a piston engine has a turbocharger and a compression stroke, that is, to enable the engine to generate more power with greater efficiency.

The combustion chamber is a perforated annular ring-shaped steel shell surrounding the central axis of the engine. Air from the compressor section enters the combustion chamber through the perforations, and it is then mixed with fuel, which is sprayed into the chamber at a rate dictated by the fuel control unit. There are two ignitor plugs in the combustion chamber. These are used for starting and to insure continued combustion during operations in heavy precipitation.

6. *The Propeller*

The job of the propeller is to translate the brake horsepower (BHP) at the end of the crankshaft into thrust. Imagine that we set an airplane on a frictionless surface, tie a rope to the tail, and hook a scale to the rope. We then start the engine and measure the pull of the airplane in pounds as read from the scale. This pull is one of the basic forces in aerodynamics—it is thrust. The force is due to the fact that the propeller accelerates a mass of air aft. Newton's third law says that for every force there is an equal and opposite force, or for every action there is an equal and opposite reaction. The counterpart to the rearward acceleration of a mass of air is an equal forward force called thrust. We are just seeing F = ma once more, but this time the force, F, is called thrust.

In some applications, like performance analysis, it is better to think of power than thrust. Consider the magnitude TV, thrust times velocity, where V is true airspeed in feet per second. Since T is measured in pounds, TV must be foot-pounds per second. So 60TV would be foot-pounds per minute. Recall that one horsepower is the ability to do 33,000 foot-pounds of work per minute, so 60TV/33000, which equals TV/550, is the horsepower equivalent of the amount of thrust being generated. This is called the *thrust horsepower* (THP). If we measure velocity in knots TAS, then THP = TV/326. So, for example, 500 pounds of thrust at 160 KTAS comes from 245 thrust horsepower (500*160/326 = 245).

Propeller Efficiency

If the propeller were 100 percent efficient, then all the BHP generated by the engine would be converted to THP. But because of propeller skin friction drag, interference between blades, kinetic energy lost to the trailing propeller slipstream, and other factors, propeller efficiency is less than 100 percent. Propeller efficiency, abbreviated with the Greek letter η (eta, pronounced "eighta") is given by

$$\eta = \frac{THP}{BHP}$$

7. Drag

Imagine the following wind tunnel experiment. We take a 5300 pound twin engine airplane, something like an E55 Baron, and attach it as shown in Figure 1. The plane is secured at its center of gravity (cg) by a brace that runs down through a pivot on the floor to a pendulum-type weight below the floor. If we went into the wind tunnel and pushed on the nose, the airplane would move back (or to the right in the picture) and the pendulum weight would swing up and left. Assume that we have some means of controlling the angle of the airplane relative to the brace in order to control angle of attack. A cable runs forward from the brace/cg connection, over a pulley, and down to a tray that holds weights. What we are going to do is turn on the wind, set the angle of attack to get 5300 pounds of lift, and then put enough weight in the tray to keep the brace vertical. The amount of weight needed will tell us the drag of the airplane at the current wind

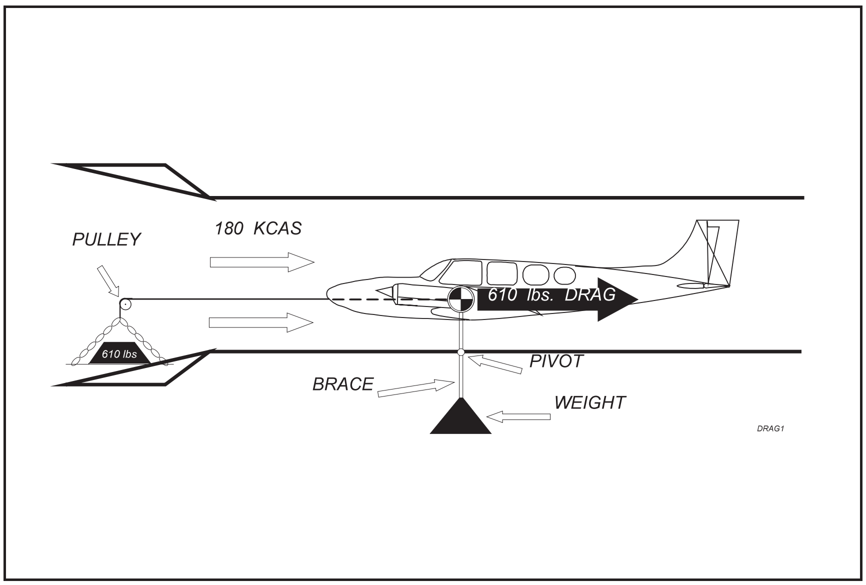

Figure 2. Measuring drag.

velocity and angle of attack. (Real wind tunnels are set up differently. We could, for example, measure drag by the rotation of the pendulum, but I think this presentation makes the issue more intuitive.)

8. Performance, Part I: Takeoff and Climb

We devoted a lot of effort in the early chapters toward improving our understanding of air, engines, props, and airframe drag. To a serious pilot, these subjects ought to be interesting in their own right, but one of the most important ancillary benefits of studying these subjects more deeply is an improved understanding of airplane performance. We will look at conventional performance issues in the next two chapters, and come back to the subject again later when we cover the aerodynamics of single-engine operations in multiengine airplanes.

In the present chapter, I want to cover general issues pertaining to takeoff and climb performance, either in a single or a twin with both engines operating. Special attention is given to factors affecting performance, including especially high density altitudes.

Normal Takeoff

Before we get into the subject of takeoff performance, I want to mention a few points regarding takeoff technique, meaning the "stick and rudder" basics of handling the takeoff. I will not insult your intelligence with a protracted discussion of the basics, just a few points related to some patterns I have detected watching hundreds of pilots doing takeoffs in high performance airplanes.

First, I have noticed that most pilots let the airplane stay on the ground too long during the takeoff run. The result is that the airplane accelerates to much too high a speed before leaving the ground, and the little tires and wheels end up spinning furiously at liftoff. The undercarriage was not built to run along the ground at speeds so far above the recommended takeoff and landing speeds; this is especially true if there is any tendency to wheelbarrow, that is, to roll with a lot of weight on the nose gear. Why would competent pilots stay on the ground way past the recommended liftoff speed? Here is my theory.

9. Performance, Part II: Cruise and Landing

We continue our discussion of performance issues in this chapter. Our focus is on cruising for maximum range plus some general points regarding landings. Specific issues related to multiengine flying, emergencies, or instrument flying are taken up in detail in other chapters. Here we concentrate on general issues of performance.

Cruising for Maximum MPG

Did you ever wonder how you could get maximum miles per gallon from your airplane? I can think of several inflight situations that could make this an important question. Maybe you have a trip planned that has a fairly long leg. If you fly the trip at your usual power setting, you will arrive with unacceptably low fuel reserves. (An hour is my personal minimum.) Stopping for fuel will add an hour to your trip. Could you use a different power setting, fly a little slower, and make the trip non-stop with good reserves? Maybe you gain time by giving up a few minutes in cruise, while saving an hour fuel stop. Another reason you might find yourself sweating out your range is that the weather got unexpectedly bad, and you are diverting toward the only decent alternate, which is some miles away. Or maybe it is just a matter of economics. At $2 per gallon, you might care more about speed than mpg, but what if it were $4 or $8?

Actually, you can learn a lot about getting maximum mpg in your airplane by doing a simple inflight experiment. The next time you have nothing to do enroute try this: Set your RPM on the low side of what you normally use, and set your MP at the highest allowable value for your present RPM. Now lean to the leanest approved fuel flow. Maybe this will be peak EGT, or 20° C lean of peak, or whatever. Give the airspeed five minutes to stabilize, and record your MP, fuel flow, and indicated airspeed. (If you do not have good fuel flow data, just record MP and indicated airspeed.) Now reduce MP by one inch, lean as before, and record MP, fuel flow, and indicated airspeed again after things stabilize. Continue the experiment until your power is so low you can no longer hold altitude. At home you can draw a graph and/or do a little arithmetic and learn something about maximum range for your airplane.

10. Instrument Flying by the Numbers

Until I know "the numbers" for a new airplane, I always feel more like a spectator than a pilot. Getting to know an airplane involves remembering a lot of different numbers—max weights, fuel capacities, torque or MP limits, and so on. When I refer to "the numbers" I do not mean all of these figures, though they are all important. The numbers I need to know before I feel at home in an airplane are the power/attitude/configuration combinations to be used for the basic phases of flight.

Pilots who fly by the numbers are believers in the old saying, "Power plus attitude equals performance." I like this better when it is amended to say, "Power plus attitude plus configuration equals performance." (P + A + C = Pf) The idea is that if you set the power at a given level, like 25" MP and 2500 RPM, and you put the airplane's nose at a fixed pitch attitude, like 5° above the horizon, and you configure the airplane with, say, the gear and flaps up, you will get a certain, predictable performance outcome, meaning a definite airspeed and vertical speed. We will refer to the Power, Attitude, and Configuration setups as PACs.

The P + A + C = Pf equation seems to be an incontrovertible truism. After all, the airplane is a physical thing operating in a physical environment. It has power available and power required curves that determine airspeed/vertical speed tradeoffs along with an aoa and pitch attitude for each power and airspeed combination. So since "the numbers" are always at work, isn't everyone a "by-the-numbers" pilot?

No. The key thing that separates by-the-numbers pilots from others is that when the numbers pilot wants to get the airplane to do something, he or she has a *preconceived idea* of how to set up the airplane to accomplish the task. If you asked a numbers pilot how he or she levels off at the MDA on a non-precision approach, you would get an answer that goes something like this: "I add 5 inches MP. The nose comes up on its own without trimming to 2° above the horizon. The speed stays at 120 KIAS, and the VSI goes to zero." That is what I mean by a "preconceived idea." In contrast, if you asked the same question to someone who does not fly by the numbers, you would likely hear some blustering non-answer that goes like

11. Limitations: Airspeed and G-Load Factor

When an airplane is designed and certificated, the FAA and the manufacturer agree on a set of operating limitations. There are: (i) weight and center of gravity limitations, (ii) power plant limitations for MP, RPM, CHT, etc. (iii) minimum takeoff fuel, (iv) maximum slip duration, (v) airspeed and g-load factor limitations, and so on. These limitations are printed in the Limitations section of the airplane flight manual, and at least some of them are also placed on placards in the aircraft. Under FAR 91.9, the pilot is required to abide by the airplane's limitations.

In this chapter we are concerned with the airspeed and g-load limitations. What exactly lies behind your handbook's warning to "not exceed 195 KCAS except in smooth air and then only with caution"? And why does the maneuvering speed drop as the plane gets lighter? The purpose of this chapter is to increase your understanding of why these and other limits look the way they do. It is my feeling that your respect for these limits is proportional to your understanding of the reasons behind the limits. And since I think these limits should most definitely be respected, I want to do what I can to improve your understanding of their rationale. The discussion can become fairly abstract and theoretical, and I will ask you to bear with me through it—this is important material, and I don't think pilots understand it as well as they should. If an inherent curiosity about airplanes isn't enough, then let this be your motivation: There is nothing abstract about an airplane coming apart in the air.

And when an airplane does come apart, chances are good that the pilot allowed it to get outside its maneuver-gust envelope. This envelope, shown in Figure 7 at the end of this chapter, is a handy summary chart showing the airspeed and g-load limits placed on the airplane. Deriving and explaining the envelope will be one of our main themes here. When you understand it better, you will have more respect for your airplane's limits, and that will make you a safer pilot. You will also finish this chapter with a generally better understanding of aerodynamics. And you

12. Strength, Stability, and Control

My motivation in writing this chapter is very similar to that for the previous chapter on airspeed and g-load factor limitations—I want you to take your weight and balance limitations more seriously, and the best way to do that is to improve your understanding of the reasons for the existence of these limits.

When an airplane is certificated, it must pass a long list of tests. Many of these tests have to do with strength, stability, and control. As a rule, the airplane's weight and/or center of gravity influence the results of each test; that is, the airplane can pass a test at one weight or cg position, but will fail at another. The FAA requires that the airplane pass each test at any point in its approved weight and balance envelope. "Each requirement of this subpart must be met at each appropriate combination of weight and center of gravity within the range of loading conditions for which certification is requested." (FAR 23.21(a)) And the FARs often mention that a test be passed with the "center of gravity in the most unfavorable position." (FAR 23.49(a)(6))

You can be sure the manufacturer wants to market an airplane with a wide weight and balance envelope, so the builder has an incentive to expand the envelope as much as possible, while still passing the certification tests. Some airplane builders are more conservative than others, but they all feel the pressure to keep the envelope wide. The end result is that when you exceed the weight and balance limits, your airplane is probably incapable of passing one or more of its certification requirements. Maybe it won't be able to climb in a balked landing. Maybe it will have an unrecoverable spin. Who knows? Whatever the case might be, you do not want to be the guinea pig who finds out.

In this chapter we will look first at the reasons for weight limits and then consider the rationale for cg limits.

14. Multiengine Aerodynamics

The aerodynamic theory behind multiengine operations has advanced considerably in the past few years, thanks largely to the work of Lester Berven, Melville Byington, Jr., and William P. Kelly, Jr. This chapter owes a lot to the work of these three, and I would recommend that every multiengine pilot get copies of and study the works cited by these three at the end of this chapter. If you are flying twins on one engine either the "old way," banked five degrees toward the good engine, or the "old, old way," wings level and ball in the center, your really need to study up, because what you are doing is not only inefficient and old-fashioned, it is dangerous.

There is not much difference between the aerodynamics of a conventional twin versus a single, as long as both engines are running. But when one engine is developing a lot of power and the other is shut down, or worse yet, windmilling, the differences between the conventional twin and the single are huge. We are going to focus here on three areas that are about equally responsible for fatal accidents during the takeoff phase in twin engine airplanes: (i) inadequate climb performance; (ii) loss of directional control; (3) stall/spin. An important sub-theme running through all three of these issues is zero sideslip.

Engine-out Climb Performance

Suppose your plane requires 146 thrust horsepower (THP) to fly straight and level at 100 KCAS. We could say then that your "thrust horsepower required" (THPr) at 100 KCAS is 146. The amount of thrust horsepower required with the airplane in a given configuration is primarily dependent upon airspeed. At low airspeeds you need a lot of power to overcome induced drag, and at high airspeeds you need THPr to overcome parasite drag. This produces a U-shaped THPr curve, as shown in Figure 1. If you were flying straight and level at 100 KCAS and you pushed the throttles up enough to add 100 THP to the 146 you already have, what would the airplane do? The added energy has to show up somewhere, but where?

15. Multiengine Operations

This is the second of two chapters on multiengine flying. The present chapter covers practical, operational issues. Having covered the theory in the last chapter, I am now interested more in *how* you do something than in the pure theory detailing *why*. This chapter primarily is a collection of plain English suggestions, rather than a lot of aerodynamic analysis. We will start at the beginning, with planning, and then cover the basic phases of flight in logical order.

Takeoff Planning

You must plan your takeoff long before you start the engines and head for the departure end of the runway. In fact, the best time to do the takeoff planning is prior to your flight *into* the airport you now plan to leave. Many times you can easily get into an airport only to find that it is a real challenge to get back out safely. This is most likely to be the case in a normally aspirated airplane at high altitude, but it is a problem worth watching for in any short field operation. If there is any doubt at all, check your takeoff requirements before you land.

We should answer several performance questions in our takeoff planning. We will consider them in turn.

Normal takeoff distance. Figure 1 shows a generic takeoff distance planning page. Let's say we are planning to take off at an OAT of 30° C at a pressure altitude (PA) of 5000 feet. We begin at point A, where the OAT is 30° C, and read up to the 5000 foot pressure altitude line at point B. If we are at maximum gross weight and there is no wind, we can read all the way to the right from point B to point C and find that our takeoff ground roll will be about 2250 feet. Looking back again to the left section of the figure, we see that both high temperature and high pressure altitude have the effect of raising point B and increasing the takeoff distance. There are several reasons for this: (i) Both high pressure altitude and high temperature act to reduce air density. In a normally aspirated airplane, the low air density will reduce maximum power output from what it would be at sea level, retarding the airplane's acceleration during takeoff and

16. Engine Failure in Single-engine Airplanes

We have just devoted two chapters to the analysis of multiengine operations, with special emphasis on engine failures. One of the basic lessons is that you must have a plan in mind prior to takeoff. You need to be thinking, "What will I do if the engine fails here? And what if it fails there?" This is no less true with regard to single-engine airplanes, though the subject gets much less attention. In this chapter I will focus on the techniques for handling an engine failure in a single-engine airplane. My special interest is the issue of a turn back to the airport following a failure.

Engine Failure on Takeoff

Every year needless tragedies occur as pilots try the impossible: a turn back to the airport from too low after an engine failure on takeoff. This prompts the most commonly heard advice on the subject, namely, don't try to turn back, land straight ahead. But is this *always* the best course? There must be an altitude high enough that you can make it back safely. How high is it? There must be an optimum path to follow, but what is it? A 180 degree turn? A 30/210 teardrop? A 90/270, or what? There must be an optimum glide speed. Is it the speed for best glide range in your POH? There should be an optimum bank angle to use in the turn. Is it 30 degrees, 60 degrees, or something else? And what about the effects of wind, density altitude, and aircraft weight? I will address these subjects in the following paragraphs. Some of the answers will depend upon the particular aircraft being flown, but surprisingly, some answers are the same for all aircraft. One major result is that a unique optimum bank angle, 45 degrees, works for all aircraft.

Memory items. Before we get to these subjects, I should point out that the pilot must immediately lower the nose to maintain a safe angle of attack, and that he or she should then without hesitation perform the memory items from the engine failure checklist in the POH. These items vary from airplane to airplane, but usually involve such actions as switching tanks, trying fuel pumps, checking ignition and power levers, and pulling the prop control back. (You pull the prop handle back because the sink rate is about

17. Pressurization

Having a turbocharger or a turbine powerplant really tempts you to higher altitudes. According to the Cessna T210 POH, for instance, you can expect to do 161 KTAS on 98 pph at 5000 feet and 183 KTAS on 98 pph at 20,000 feet. And aside from speed or economy, there are a lot of advantages to operating at high altitudes. You are more likely to be over the weather. There is less traffic. Radio reception is better. The air is usually smoother. And once in a while, there will be a tremendous tailwind.

Your plane may love to go high, but your body does not. It needs oxygen. At sea level ISA, where the pressure of the air is about 14.7 psi and the oxygen content is about 21 percent, the "partial pressure" of the oxygen is 3.087 psi (= 14.7 times .21). There are essentially two strategies for getting oxygen while operating at high altitudes. One is to increase the concentration of the oxygen in the air you breathe while letting the air pressure drop with the rise in altitude. This is what an oxygen mask does. If you breathed 100 percent oxygen at about 38,000 feet, the oxygen partial pressure would be about the same as at sea level. (Unless stated otherwise, the altitudes given in this chapter are pressure altitudes.) But this approach has never been very popular with pilots, passengers, and pets. The masks are uncomfortable, and oxygen is a hassle to acquire. The other approach is to raise the pressure of the air in the cabin above that of the outside air. The technique is simple enough in principle—you more or less seal up the cabin and use the turbocharger or compressor bleed air from a turbine engine to raise the cabin pressure by pumping ambient air into the cabin.

In this chapter we review the basic ingredients of the pressurization system and consider both the normal and emergency procedures related to the system.

Typical Pressurization Layout

Figure 1 shows the layout of a generic pressurization system. A line tees in between the turbocharger compressor and the intake manifold and bleeds compressed air past a dump valve, through a restrictor called a "sonic

19. Storm Avoidance Hardware

I will not insult your intelligence by lecturing on the hazards of thunderstorms. Any serious pilot is well aware of the reality of the threat. In this chapter I will cover the characteristics and proper use of several different pieces of storm avoidance hardware. Of course, the best hardware is your eyes. If the sky ahead looks ugly, stay out of it, regardless of what your electronics say. And the best software is your judgment. If your gut feeling is that carrying on is not the best idea, then it isn't. The weather will almost certainly be better tomorrow, if not in two hours. None of the hardware discussed below is meant to guide you through an active area of thunderstorms. It is meant to help you stay out of it.

Radar

"Radar" stands for RAdio Detection And Ranging. Just as a sound wave bounces off an object and returns as an echo to a listener, or a light wave reflects from an object and returns as a visual image to an observer, so too a microwave can bounce off an object and return to a receiver.

Modern X-band airborne weather radars transmit a short duration, fairly high power cone-shaped pulse with a frequency of 9375 MHz. The pulse travels at the speed of light. After the pulse is sent, the transmitter shuts down, and a receiver comes up to wait for an echo. Some objects reflect the pulse, bouncing a part of the original signal back to the airborne antenna, which has momentarily ceased transmitting and is now listening for the return. The signal is then sent to the receiver, which notes three things: (i) the round-trip time for the pulse, (ii) the strength of the returning signal, and (iii) the direction the antenna was pointed when the pulse was sent and the echo was heard. The round trip time for the pulse is easily converted into distance, since the speed of the signal is known. It takes 12.36 microseconds for each two-mile round trip, or for each one mile to the target. The strength of the signal tells about the size and the reflectivity of the target being struck by the pulse. And the direction the antenna was pointing identifies the azimuth of the target, i.e., its relative bearing in relation to the nose of the aircraft.

20. Icing

If water always froze as its temperature fell below 0^{o} C, we would not have much problem with aircraft icing. But that is not the way nature works. Water can exist *in liquid form* down to temperatures as low as -40^{o} C. Liquid water at temperatures below 0^{o} C is called "supercooled," and it generally does not turn into ice until it is disturbed in some way. Sometimes you will see this when you remove an almost-frozen liquid from your freezer; just the act of shaking it up will cause it to freeze solid. Aircraft can collect ice when they fly into an area of supercooled liquid water when the temperature of the aircraft skin is below 0^{o} C.

What Does Ice Do to the Airplane?

There is nothing good about collecting ice on an airplane. Ice will: (i) reduce lift at a given angle of attack; (ii) reduce the maximum lift coefficient and, therefore, increase the stall speed; (iii) increase drag; (iv) reduce propeller efficiency; (v) reduce visibility; and (vi) increase weight. Let us briefly look further into each of these effects.

Wing and tail airfoils are carefully designed, and their shape is critical. Ice and, to a lesser extent, frost alter the shape of the wing. On some airfoils as little as one-half inch of ice can lower the lift coefficient by 50 percent. This means that to maintain lift, more speed (and power) and/or a higher angle of attack are needed. But this is happening at a time when the drag from the ice may make it impossible to hold altitude and even maintain the present speed. And you don't want to increase the angle of attack in icing, because that will expose more of the airframe to the ice. Your only alternative may be to hold on to speed by lowering the nose and descending. More on this later.

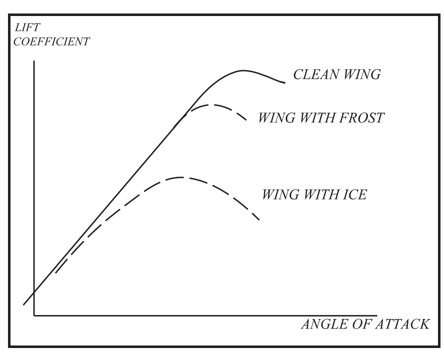

Figure 3. Effects of ice and frost on wing lift.