The Advanced Pilot's Flight Manual

9th Edition

Based on the original text by
William K. Kershner
Edited by William C. Kershner

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After doing his first spin at the age of 16 in an Aeronca TAC, **William K. Kershner** flew and taught aerobatics for 60 years. Bill put his degree in technical journalism and aerodynamics, along with his ability to make complex ideas seem simple, to work in writing *The Student Pilot's Flight Manual, The Instrument Flight Manual, The Advanced Pilot's Flight Manual, The Flight Instructor's Manual* and *The Basic Aerobatic Manual.* He also wrote *Logging Flight Time,* a collection of aviation anecdotes and experiences collected over a lifetime in aviation. The Kershner Flight Manual Series has influenced hundreds of thousands of pilots, with over 1.3 million copies printed in at least 3 languages.

Bill received the General Aviation Flight Instructor of the Year and the Ninety-Nines Award of Merit, among many other honors. To date he is the only person to have been inducted into both the International Aerobatic Club Hall of Fame and the Flight Instructor's Hall of Fame. He was among the first to be inducted into the Tennessee Aviation Hall of Fame.

Kershner operated an aerobatic school for many years at the Sewanee-Franklin County airport in Tennessee using a Cessna 152 Aerobat. His airplane, N7557L, is on display at the National Air and Space Museum's Udvar-Hazy Center at Dulles International Airport. Bill Kershner died January 8th, 2007.

Editor **William C. Kershner** received his early flight training from his father, William K. Kershner. He holds Commercial, Flight Instructor and Airline Transport Pilot certificates and has flown 22 types of airplanes, ranging in size from Cessna 150s to Boeing 777s, in his 15,000+ flight hours. He retired from commercial aviation as a 737 check airman and lives near Sewanee, Tennessee, with his wife and younger son.

Contents

To Mac and Sarah Lisenbee

Introduction

W.K. Kershner's Notes for *The Advanced Pilot's Flight Manual*

It has long been the writer's opinion that the average pilot could learn the basics of airplane performance very easily if the involved mathematics were bypassed. One of the purposes of *The Advanced Pilot's Flight Manual* is to bridge the gap between theory and practical application. If pilots know the principles of performance they can readily understand the effects of altitude, temperature, and other variables of airplane operation.

GAMA (General Aviation Manufacturer's Association) and the FAA together have established a *Pilot's Operating Handbook*, which will include information now scattered among several different sources. It has a standardized format so that the pilot can quickly find information (for instance, emergency procedures), whether flying a Piper, Cessna, or other makes. The older planes will still have several sources for finding operating information. *Pilot's Operating Handbook* will be used as a general term to cover all sources of information available to the pilot.

Thumb rules are used throughout as a means of presenting a clearer picture of the recommended speeds for various performance requirements such as maximum range, maximum endurance, or maximum angle of climb. Such rules of thumb are not intended in any way to replace the figures as given by the POH or comparable information sources, if available. However, the knowledge of even the approximate speed ranges for various maximum performance requirements will enable pilots to obtain better performance than if they had no idea at all of the required airspeeds. Naturally, this practice must be tempered with judgment. If a pilot flies a rich mixture and high power settings until only a couple of gallons of fuel are left, setting up either the rule of thumb or the manufacturer's recommended airspeed for maximum range still won't allow making an airport 75 miles farther on. The same applies to maximum endurance. Waiting to the last minutes of fuel

to set up the maximum endurance speed will have no perceptible effect on increasing endurance.

Many of the rules of thumb are based on the use of calibrated stall airspeeds, which are in turn based on the max certificated weight of the airplane (unless otherwise noted). Airplane weight variation effects on recommended airspeeds are to be ignored unless specifically mentioned.

The material in this book includes what the writer believes is of the most interest to the pilot who wants to go into more detail about airplane performance. For instance, the chapters on checking out in advanced models and types are intended to cover the questions most often asked by pilots checking out in those airplanes.

It is hoped that the material whets the reader's desire for more information. If so, then the mission of this book will have been accomplished. The books listed in the Bibliography are recommended for further study.

Introduction to the Ninth Edition

There have been two big changes to U.S. general aviation in the last few years: the implementation of the Airman Certification Standards (ACS), and the overhaul of 14 CFR Part 23 (now titled *Airworthiness Standards: Normal Category Airplanes*).

The ACS is the new, more thorough guide for practical tests. It lays out the specific requirements and the general format of the checkride. See Chapter 21, "The Practical Test" for more on this.

The revamped Part 23 changes how light planes (19 or fewer passengers and not heavier than 19,000 pounds) are categorized and certified and was largely done to encourage innovation and to help revitalize general aviation. To this end the aircraft certification philosophy has changed from a prescriptive one to a performance-based process.

A very general analogy to this can be characterized as follows—

Prescriptive certification of garage roofs: "The roof will be constructed of 2" × 8" rafters, no more than 16"

apart, supporting roof decking no less than 5/8" thick, this structure able to support 10 inches of wet snow weighing 25 pounds/square foot and to withstand lateral wind gusts of 60 fps."

Performance-based certification of garage roofs: "The garage roof will be constructed so as to be strong enough for the safety of any occupants or property."

The new Part 23 may appear to be written in a surprisingly vague manner, but there are industry standards and methods of compliance that will have to be addressed to prove that the new airplane meets the new requirements.

The new part also changes how airplanes are classified. The utility and aerobatic categories are gone and Normal category airplanes are put in *Levels* based on their passenger seats and low- or high-speed based on performance. For example, a newly certified 4-place airplane with a 150 KCAS V_{NO} would be *Level 2* (2 – 6 passengers) and *Low speed* ($V_{NO} \leq 250$ KCAS). Any maneuvers more extreme than what's found on the Commercial practical test will require a "Normal category airplane certified for aerobatics" label.

At the time of this writing no airplanes have been certificated under the new part, and since all Part 23 airplanes flying now were certified under the old Part, I've kept the detailed excerpts and references to those regulations.

On a more general note, you'll find that the commercial certificate opens up a lot of possibilities: from flying local charters to earning that CFI and instructing; from flying a high-performance airplane for a corporation or fractional to acquiring that ATP certificate and flying for the airlines. Performing a wider variety of flying gives opportunities to see and experience things few others can. As inspiring as it is to fly over the mountains of Alaska en route to Tokyo, it can be just as fulfilling (and entertaining) to watch someone make their first parachute jump.

A pilot's everyday flying is filled with habits that seem as normal as walking, but abnormal situations may require actions that seem unnatural in comparison. Spin recovery (Chapter 21), pitching down to extend the glide when you are below best glide speed (Chapter 8), or chopping power on the good engine of a twin in order to maintain control (Chapter 15) are examples of what might be called counter-intuitive flying. These are situations that require both solid use of the POH procedures and an in-depth knowledge of how the airplane flies.

As is said many times in this book, the Pilot's Operating Handbook/Airplane Flight Manual (AFM) has precedence on procedures for a particular airplane. Of course, the charts in the book are not to be used for navigation or flight planning.

William C. Kershner
Sewanee, Tennessee

Photo by Dan Akins / Shreveport, Louisiana (KSHV) / February 1990 / Boeing 727-223

Part One **Airplane Performance and Stability for Pilots** 1

1

Airplane Performance and Stability for Pilots

A Review of Mathematics for Pilots

A pilot doesn't have to know calculus to fly an airplane well, and there have been a lot of outstanding pilots who could add, subtract, multiply, and divide—and that's about it. *But* since you are going to be an "advanced pilot," this book goes a little more deeply into the whys and hows of airplane performance, including a little math review.

Trigonometry

Trigonometry can turn into a complex subject if you let it, but the trigonometry discussed here is the simple kind you've been using all along in your flying and maybe never thinking of it as such.

Take a crosswind takeoff or landing: you've been using Tennessee windage in calculating how much correction will be needed for a wind of a certain strength at a certain angle from the runway centerline. You correct for the crosswind component and know that the headwind component will help (and a tailwind component will hurt).

You have been successfully using a practical approach to solving trigonometric functions. (If an instructor had mentioned this factor earlier, some of us might have considered quitting flying.)

What it boils down to is this—whenever you fly you're unconsciously (or maybe consciously) dealing with problems that involve working with the two sides and hypotenuse of a right triangle. Flight factors involved include (1) takeoffs and landings in a crosswind, (2) max angle climbs, (3) making good that ground track on a VFR *or* IFR cross-country, (4) working a max range curve (if you are an engineer, too), and (5) calculating max distance glides. The following chapters will cover all these areas of performance in more detail.

Looking at a takeoff in a crosswind, you're dealing with the sines and cosines of a *right triangle*, a triangle with a 90° angle in it (Figure 1-1).

Sine

The sine (normally written as "sin," which perks it up a little) for an angle (α here) is the ratio of the nonadjacent side A to the hypotenuse (side C) (Figure 1-1). The Greek letters α (alpha) and β (beta) are used for the angles here because, well, it gives the book more class, and the Greek letters *are* used in aerodynamics equations. More Greek letters will be along shortly. The sides of a triangle are normally denoted by our alphabet (A, B, C).
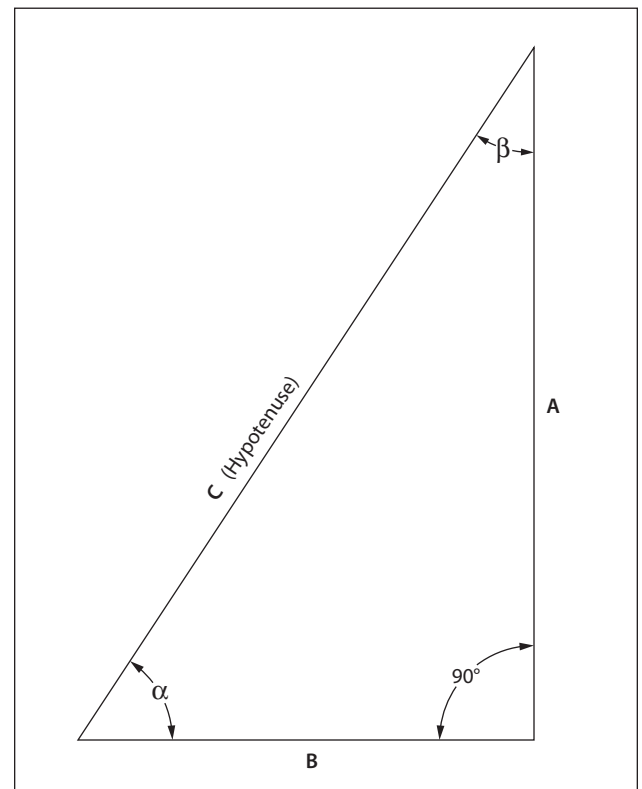
Figure 1-1. Right triangle components.

Look at a 30°-60°-90° triangle (Figure 1-2). The internal angles always add up to 180°; thus the other two angles of the right triangle (which has a 90° angle) always add up to 90° (10° and 80°, 45° and 45°, etc.). Another interesting point about right triangles is that the sum of the squares of the two sides is equal to the square of the hypotenuse, or $A^2 + B^2 = C^2$ (Figure 1-3). (This is what the Scarecrow recited after the Wizard of Oz gave him a diploma—and a brain.)

Cosine

For a 30° angle (β in Figure 1-2), the relationship of sides A and C (the hypotenuse), side A is *always* 0.866 of the length of side C (the cosine of 30° is 0.866; A/C = 0.866). Engineers add a zero before the decimal point for a value less than 1 so that it is clear that there isn't a missing number.

Looking at the angle α in Figure 1-2, note that the relationship of length of the adjacent side B at the 60° angle to the hypotenuse (side C) is the *cosine* of *that* angle, *always* 0.50 (B/C = 0.50).

Looking from the same angle of 60° (α), it is a fact that the *sine* (the nonadjacent side A divided by the hypotenuse, or A/C), is 0.866; that is, the length or value of side A is 0.866 the length of the hypotenuse. The sine of the 60° angle is the same as the cosine of a 30° angle—and why not? That's the same side (A). For side B, 0.500 is the cosine of the 60° angle and the sine of the 30° angle. (Got that?)

(Figure 1-2)—cosine α = B/C = 0.500
            sine β = B/C = 0.500

Take a practical situation: You are taking off in a jet fighter from a runway with a 40-K wind at a 30° angle to the centerline. What are the crosswind and headwind components? You're working with a right triangle with 30° and 60° acute angles (Figure 1-4). Solving for the crosswind component for the wind at a 30° angle you find that the ratio of A to C is 0.50 to 1, or one-half. The component of wind working across the runway is 0.50 of the total wind speed of 40 K, or a 20-K crosswind component, which means the same side force as if the wind were at 20 K at a 90° angle to the runway.

To make takeoff calculations in the *Pilot's Operating Handbook* (POH), you need to know the headwind component (B/C), or the cosine of the 30° angle, which is *always* 0.866. So, 0.866 × 40 K is 34.64 K. (Just call it 35 K.) If, however, the wind was 60° to the runway at 40 K, the situation would be reversed and the *crosswind* component would be 0.866 × 40 = 34.64 (35) K (and the *headwind* component would be 0.50 × 40 = 20 K), as
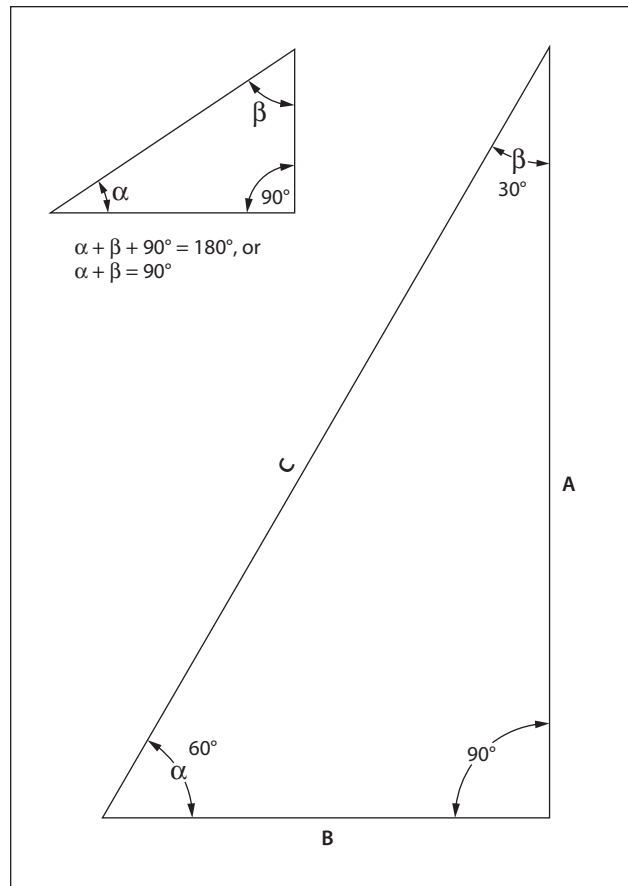

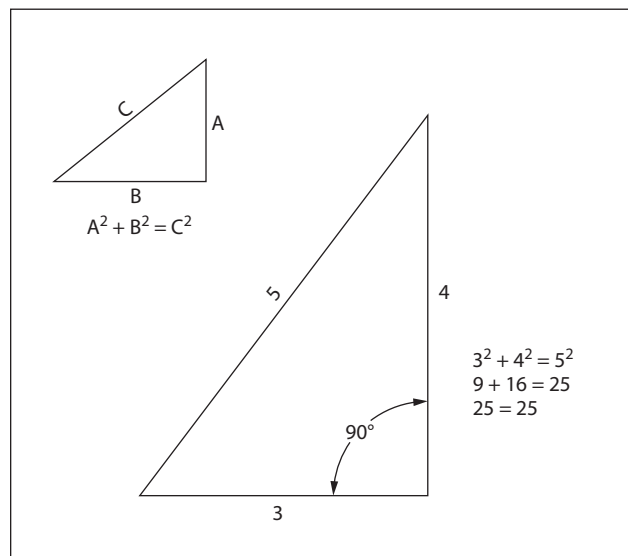**Figure 1-2.** A right triangle with 30° and 60° acute (less than 90°) angles.

Figure 1-3. Classic example of the relationship of the hypotenuse of a right triangle. (Another is a triangle with 7 and 24 sides and a 25 hypotenuse: $7^2 + 24^2 = 49 + 576 = 625$; $25^2 = 625$).
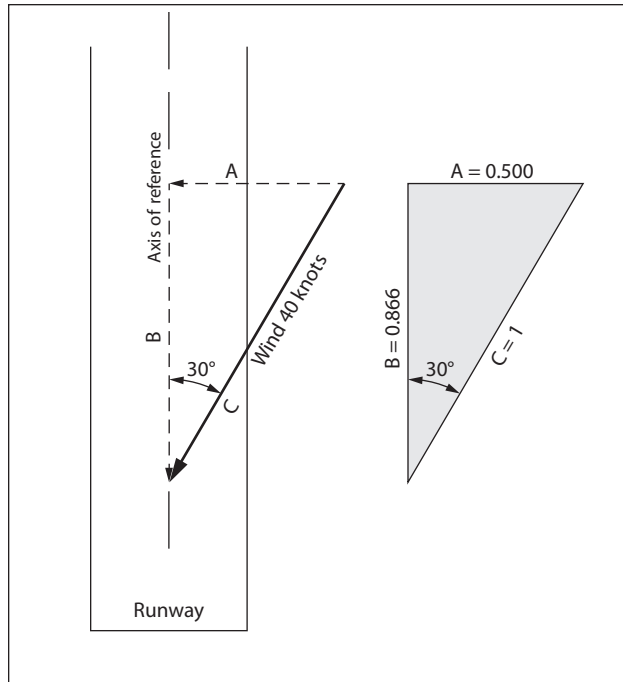
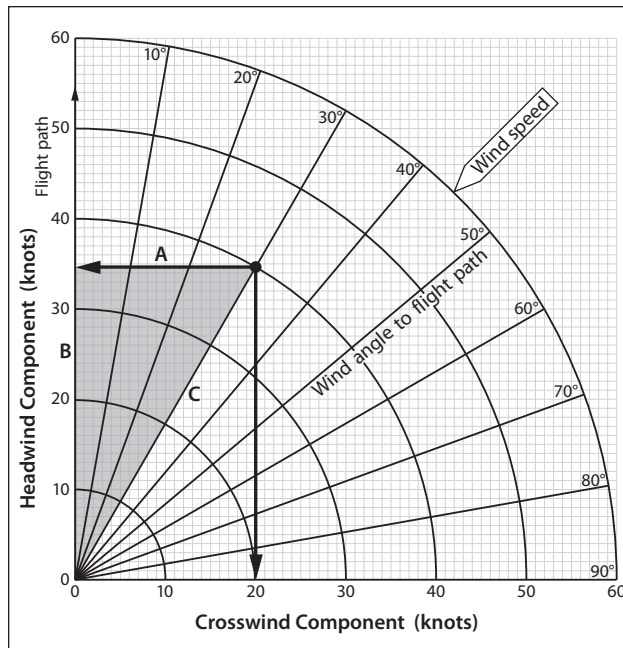**Figure 1-4.** Finding the headwind and crosswind components.

Figure 1-5. The wind component chart is a prepared set of right triangles, with sines and cosines precalculated and drawn. Horace Endsdorfer, private pilot, assumes that Figure 1-5 can only be used for crosswinds from the right, since that's the way it's drawn, but Horace has other problems as well (see Chapter 7—Endurance).

can be seen by checking the graph (Figure 1-5). What we've started here is a wind component chart like that found in a POH; here the engineers work out the sines and cosines for various angles the wind may make with the runway and all you have to do is read the values off the graph. Note that the triangle in Figure 1-4 and the shaded area of Figure 1-5 are the same. The wind speed in the graph is always the hypotenuse (side C) of the triangle.

Tangents

The tangent is the relationship between the *far side* (the nonadjacent side) and the *near side* (the side adjacent to the angle in question). Look back at Figure 1-2. The relationship A/B is the tangent of the angle α (60° shown there), and looking ahead at Figure 1-8 you can see that the tangent of 60° is 1.732. In a 60° angle, side A is 1.732 times as long as side B. The tangent is useful in such factors as finding the angle of climb, where the relationship of feet upward versus feet forward is essential.

To digress a little, Figure 1-6 shows the procedure probably first used in measuring the height of an object too high to be scaled easily. Although the example is better as a problem in geometry, it shows that for a given angle (the sun's rays forming the shadow), the sides of a right triangle have the same ratio.

If you were assigned the job of finding the height of the flagpole on a sunny day you could set up a vertical pole 4 feet tall and measure the shadow (3 feet here). You would then quickly measure the flagpole shadow to establish the ratio of the two poles (Figure 1-6). Your numbers would not likely work out as evenly as these, however, and there would be a problem on a cloudy day or at night.

If you had a device set on the ground for measuring the angle α (53° here) and knew the distance of that device from the flagpole (B), you would come up with tan α = A/30; A = 30 tan α; α = 53°, tan α = 1.33, A = 30 × 1.33 = 40 feet.

Okay, to review:

The sine of an angle is the ratio between, or relative value of, the "far" (nonadjacent) side of the right triangle and its hypotenuse and, like the cosine and tangent, is always the same for any given angle.

The cosine is the ratio between, or relative value of, the "near" (adjacent) side of the right triangle and its hypotenuse.

The tangent is the ratio of the "far" side to the "near" side of an angle of the right triangle.

The tangent shows the relationship in a climb between vertical and horizontal distances covered.
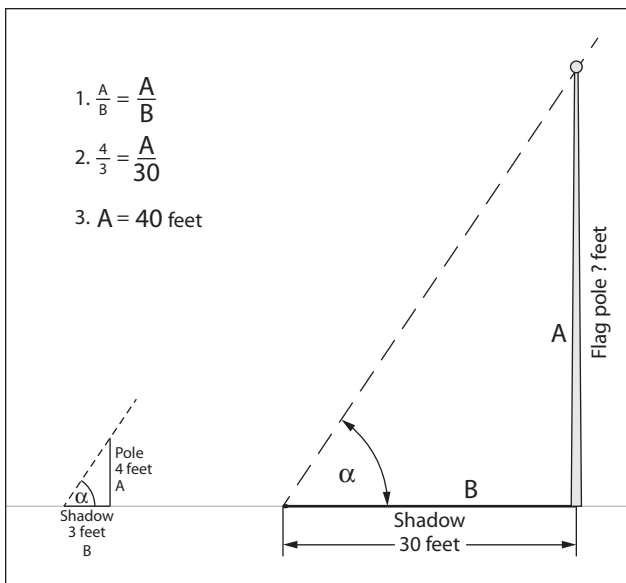
1. $\dfrac{A}{B} = \dfrac{A}{B}$

2. $\dfrac{4}{3} = \dfrac{A}{30}$

3. $A = 40$ feet

Flag pole ? feet

A

α   B

Shadow
30 feet

Pole
4 feet
A

α

Shadow
3 feet
B

Figure 1-6. Using the relationship between similar triangles to find the height of a flagpole by measuring sides A and B of the small triangle and side B of the large triangle to find side A (the height of the flagpole). It is assumed that the flagpole is greased so that it cannot be climbed and measured with a tape. (There's the old story of two physics students who were each given a very expensive barometer and told to find the height of a certain tall building. One dropped the barometer off the top and measured its fall with a stopwatch. The other went to the janitor and said, "If you tell me exactly how high this building is, I'll give you this fine barometer." Scientific research methods vary, it seems.)
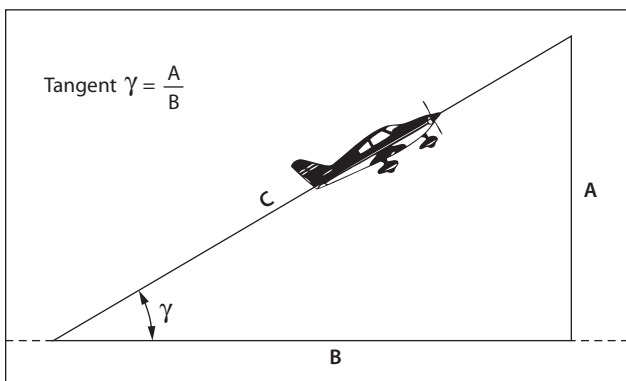

Tangent $\gamma = \dfrac{A}{B}$

C

A

γ

B

Figure 1-7. Max angle of climb (γ) is a tangent function and depends on the highest ratio of A (vertical height) to B (horizontal distance). Gamma (γ) is normally used to depict climb or descent angles.

The sine (0.500) of a 30° angle is the same as the cosine of a 60° angle. The sine of 55° equals the cosine of 35°, sine 20° equals cosine 70°, etc. (The "etc." is to cover the fact that the first time you encounter it this can be as confusing as an FAA directive.)

Figure 1-8 is a table of sine, cosine, and tangent functions for angles from 0° to 90° in 5° increments, plus three other selected angles that will be discussed later. Using a trig table (or the right kind of calculator app) you could, for instance, find the sine of an angle of 6°36' (6 degrees 36 minutes) or 6.6°, which turns out to be 0.1149372. (That's *all* you need—to be fumbling around with a trig table or calculator while you're flying.) But again, what it says is that the ratio of the value of the *far side* of the triangle to its hypotenuse is 0.115 (rounded off in Figure 1-8); it's about 11.5% as long as the hypotenuse.

At first glance in Figure 1-8, views A and B, our flagpole angle of 53° gives us problems. It's tough to interpolate accurately between 50° and 55° (Figure 1-8A) and the tangent of 53° is off of the chart. But we can use the reciprocal of tangent 37° (90°-53° = 37°); Tan 37° = 0.75: 1/0.75 = 1.33 = Tan 53°.

> *sine* (sin): the opposite side/the hypotenuse
>   (sin 30° = 0.5)
> *cosine* (cos): the adjacent side/the hypotenuse
>   (cos 45° = 0.707)
>   memory aid: the angle and the side are
>   "co-located"
> *tangent* (tan): the far side/adjacent side
>   (tan 45° = 1)

So that 20-knot wind 45° off of the runway has a 14-knot headwind component (nice), but a 14-knot crosswind component (20 × 0.707), too.

Max Angle Climb

A good example of finding the max angle of climb of an airplane at a particular density-altitude is shown in Figure 1-9, which is a variation of Figure 6-7. (You might take a look ahead at Figure 6-7 now.)

As noted in Chapter 6, the max angle climb speed is found by running a line from the origin of the graph (zero climb and zero knots) tangent to or touching (and passing) the curve.

The angle of climb (γ, or gamma) is the tangent, or the ratio of A to B (A/B); tan γ = rate of climb/velocity—or is it?

The rate of climb is 1,200 feet per minute (fpm) and the velocity is 75 K, so tan γ = 1,200/75 = 16, which would give a climb angle (after referring to your trig table or using a calculator) of 86.4°, *Now that's a climbing airplane!* (Figure 1-10).

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Chapters are dedicated to:
• Airplane performance and stability for pilots
• Checking out in advanced models and types
• Emergencies and unusual situations
• Advanced navigation
• High-altitude operations
• Preparing for the commercial knowledge and practical tests

With over six decades of experience as pilot-in-command in more than 100 types and models of airplanes, Bill Kershner was an FAA/General Aviation Flight Instructor of the Year, named Elder Statesman of Aviation, and inducted into the Flight Instructor Hall of Fame. His son, William C. Kershner, was soloed by his father, and holds Flight Instructor and Airline Transport Pilot certificates. He has flown 22 types of airplanes in his over 15,000+ hours of flight time, ranging from Cessna 150s to Boeing 777s.

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