Figure 8.1 The La Chapelle floor plan represents real framing to carpenters who read, visualize, and build from a set of plans.
Variation on framing for La Chapelle Plan Set Plan
OBJECTIVES
Define and explain the various sheets that make up a set of architectural plans.
Identify the sheets in a set of working drawings and explain the information available from each working drawing.
Define the most common scales used on architectural plans. Explain why scales are important and what information they make possible on a single plan sheet.
Give examples of electronic plan scaling aids and software available to estimators and builders. Explain how these tools help estimators work faster and more accurately.
Explain why section views and details are important plan sheets. How do carpenters and other trade workers use these views?
Explain how Building Information Modeling software helps build energy-efficient homes.

ARCHITECTURAL PLANS AND PLAN SHEETS
Contract-related documents include the final building contract, detailed specification sheet(s), and working drawings for construction. This set of paperwork becomes part of the legal foundation for the project. Each document is vital to the building process. The various plan sheets listed below make up the working drawings organized. The title sheet typically has a front elevation view of the home. The title sheet normally includes all pertinent information about the primary parties involved with the project. The title sheet will list the architect (designer), owner, builder, and major subcontractors, and it may include a green home certification program’s seal and the green verifier’s information. Other sheets in the plan set will use a title block. The title block organizes some of the same information from the title page for quick reference on each page. Page numbers will be part of a title block to help keep drawings organized.

Plan Visualization
Visualizing the finished home or addition by reviewing a set of working drawings is a learned skill developed by builders, carpenters, and other craftspeople. It takes practice to develop the spatial skills necessary to visualize a three-dimensional building represented on a two-dimensional sheet of paper. Experienced carpenters can take a virtual tour in their minds of the finished building as they read and interpret information in a set of architectural plans. As this chapter covers each plan sheet, draw a mental picture to visualize the information and begin developing spatial skills. Figure 8.1 illustrates how the 2-D drawing becomes a real 3-D structure.

Orthographic Projection
Drafters, engineers, architects, and builders use a system known as orthographic projection to create drawings of three-dimensional buildings on two-dimensional paper. Ortho means “straight line” and this projection provides a graphical representation on a two-dimensional plane. The projection represents objects drawn with a common relationship; that is, they are in scale with each other. Common perspectives and drawing techniques are shown in Figure 8.3.

A common drawing perspective providing a three-dimensional view (3D) is the isometric view. Isometric views place all horizontal lines at 30° angles relative to the horizon with vertical lines perpendicular to the horizon. With this method, all lines are to scale and remain in proportion. An example is shown in Figure 8.3.

The sophistication and detail in a set of construction plans may vary based on building design, owner’s need, and the architect. In any case, enough detail is required to help minimize mistakes and facilitate coordination within the various trades, subcontractors, and materials suppliers. In drawing construction plans, architects, drafters, or builders will illustrate many details in only one place to eliminate confusion and redundant information. For instance, specifying the same stud spacing on every wall section is not required for most plans.

Title Sheets
The title sheet (Figure 8.2) is the cover for a set of architectural plans. On new construction, the title sheet typically has a front elevation view of the home. The title sheet normally includes all pertinent information about the primary parties involved with the project. The title sheet will list the architect (designer), owner, builder, and major subcontractors, and it may include a green home certification program’s seal and the green verifier’s information. Other sheets in the plan set will use a title block. The title block organizes some of the same information from the title page for quick reference on each page. Page numbers will be part of a title block to help keep drawings organized.
 AVAILABLE RE-PURPOSED MATERIALS. PROTECT EXISTING PUBLIC
 SOON AS POSSIBLE AFTER CONSTRUCTION IS COMPLETE. LAWN
 4) ALL LAWN AREAS SHALL RECEIVE FINAL GRADING AND SEEDING AS
 SIDEWALK DURING CONSTRUCTION.

EP A CERTIFIED ENGINEER, POSSIBLE SITE RETENTION POND
INSTALLED AS PER CIVIL ENGINEER’S INSTRUCTIONS TO
A) THE GENERAL CONTRACTOR SHALL INSTALL AND MAINTAIN A
SITE PLAN NOTES:
ELEV . = 100.00
BENCHMARK
UNTIL CONCRETE IS PLACED
OPTIONAL SURFACES
10’ WIDE DRIVEWAY

Check the title sheet for contact information and other details.

Figure 8.2 Check the title sheet for contact information and other details.

ORTHOGONAL PROJECTION

Figure 8.3 A full set of building plans will use many drawing types to relate information using 2D and 3D techniques.
Dimensioning Aids for Working with Architectural Plans

Reading a set of construction plans requires practice, experience, and spatial skills. To quickly read rough dimensions or for estimating; a wide range of computer controlled, electronic, and manual dimensioning aids are available. Even though these tools usually provide enough accuracy for estimating and general drawings, always refer to the architectural plans for exact dimensions and details. Various scaling tools are available to increase accuracy and speed when estimating; see Figure 8.4.

Architect’s Scale

There are several versions of the architect’s scale; the most commonly used is triangular with 11 different scales, one being a full-size ruler. Common plan scales are shown in Figure 8.5. The end of each scale has a fraction that designates the particular scale. In residential construction, 1/4" = 1’ is the most common scale used on working drawings, as shown in Figure 8.6. However, some plan sheets, depending on paper size, building size, and objects represented, may use 1/8" = 1’ or other scales. Be sure to check each sheet for the appropriate scale before taking measurements.

How to Apply the Architect’s Scale Learning to use the architect’s scale is important to reading and interpreting working drawings. Follow the steps shown below and refer to Figure 8.7 to practice with an architect’s scale and develop accuracy and confidence in reading working drawings. The figure in this example is part of plan sheet A-5 the detached garage from the La Chapelle Plan. But the technique can be used throughout any scaled set of plans using an architectural ruler.

1. Find the appropriate fraction mark at the end of the scale that corresponds to the scale of plan sheet A-5. In this example shown in Figure 8.7, 1/4" = 1’ is used.
2. Using the 1/4" scale, set the architectural ruler on the zero mark and one corner of the garage front.
3. Read across the scale to the other end of the garage and note 22’.
4. On a 1/4" = 1’ scale, 5½” is equal to twenty-two 1/4” segments; i.e., 22’ as shown on plan sheet A-5. Take a basic ruler and you will see the garage’s actual measurement on the plan sheet is 5½”.
5. The area to the right of the zero mark on the architect’s scale is for measuring inches. For example, you can measure 9” on the scale right of the zero mark by counting nine hash marks.

Civil Engineer’s Scale

On a building lot or larger land area, surveyors use measuring equipment that divides parts of a foot into a decimal number carried to thousandths of a foot for accuracy; for example, 255.469’ may be the length of a property line. Because of the larger scales, decimal formatting, and accuracy, surveyors use this standard to create the property lines on most plot plans. A civil engineer’s

Figure 8.4 Manual and electronic aids help estimate plans quickly estimator work quickly and accurately.
Sources: (a, b, c) Alvin & Company, Inc.; (d) Scalex Corporation
scale can be used to read these large-scale drawings easily. The civil engineer’s scale divides into six scales; each scale further multiplies by a factor of 10 for increasingly larger scale drawings. See the engineer’s scale chart and example for reading a civil engineer's scale in Figure 8.8.

Electronic Scaling Tools

Electronic tools are available for scaling plans when estimating. Two popular types, the ScaleMaster II and the Scalex PlanWheel (shown in Figure 8.4), can perform linear, area, and volume measurements for easy and accurate estimating. Some electronic measuring aids are wireless and interface with spreadsheets and estimating software. Some versions have a small calculator built in to help with adding and subtracting measurements. All dimensioning aids help with calculations required for estimating. In addition, electronic aids increase accuracy to a higher level and can decrease overall estimating time.

WORKING DRAWINGS

Depending on building complexity, roof design, and other variables, a set of working drawings for a residential home may be 5 to 10 sheets. For basic designs, a simple floor plan, a few specifications, and possibly a roof plan is all many carpenters need once the building corners are determined with a site plan. The point is that working drawings may be very simple or very complex depending on the project and the experience level of the builder and crew members. Using the International Residential Code, experienced carpenters can easily adjust to a particular set of working drawings. The complexity of the drawing is a factor in determining the plan sheet size; standard sizes are shown in Figure 8.9.

The working drawings provided to contractors for bidding serve many purposes in the overall construction process. Below are some applications of working drawings other than physical construction.

1. **Estimating and Take-offs.** The builder and subcontractors use working drawings to calculate all of their materials, labor, and other expenses.

2. **Permitting.** In residential construction, the requirement for plans in the permitting process varies by jurisdiction. Some architects create a set of plans specifically for permitting; they may have a slightly different look than actual working drawings.

3. **Permanent Record.** A set of working drawings constitutes a permanent record of construction and design, along with all details and specifications. Provide a set to the homeowner for future repairs, additions, or remodeling projects.

4. **Legal Record.** The working drawings become part of the legal record for the building. If legal issues arise during or after construction, courts may use working drawings as a basis for determining important facts.
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Figure 8.6  Scaled drawings help to illustrate an entire building on a single plan sheet.

Figure 8.7  Using the scales on an architectural ruler, a carpenter, builder, or designer can draw large-scale areas on plan sheets.
PRESENTATION AND ELEVATION VIEWING STYLE

Presentation View

Plan books, internet sites, architects, or builders may provide a presentation view (Figure 8.10). This is essentially a tool for selling the plans or home and provides little related to actual construction detail. Presentation views, in pencil or color, typically show fully developed landscaping, distinctive features, and even people to present the finished home in a favorable light. Unless the owner specifically requests the added perspective provided by a presentation drawing, it is not included in most construction plans.

Whole House Elevation Views

Elevation views provide a visual and scaled view of the home’s exterior or interior. Most plan sets include views with each side shown and detailed. Elevations include references to many specifications for framing and exterior finishes. Roof slopes, ceiling heights, finished floor heights, and roofing and siding materials are usually identified on elevation sheets, as shown in Figure 8.11 and detailed as follows:

- Roof slope: Roof slopes may not be the same for all covered sections of the home. For example, dormers, shed roofs, and garages may have different slopes.
- Ceiling heights: Ceiling heights are provided on most elevation sheets and may be included on specifications or detail sheets.
- Exterior finishes: Exterior finishes are usually illustrated and noted on elevations. In some cases, the street side of a home will be brick and the other three sides are covered with siding or other materials to meet restrictions of the neighborhood or community.
- Topography: The actual lot grade (topography) helps estimators calculate foundation materials and grading work. Elevations also illustrate the home’s finished look in relation to grade.

Interior Elevations

Interior finish work such as cabinets, trim work, and built-in bookcases may have a plan sheet (see Figure 8.12) with interior elevations so carpenters know where to set these items. Interior elevations dimension universal design features like lowered counters or fixtures so carpenters can install the features according to requirements. Universal design heights and details for doors, cabinets, and other features are discussed in other areas of the text.

LAYOUT AND FRAMING PLAN VIEWS

For plan views, a cutting plane is a horizontal line “cutting” the object for a better view. For example, with typical floor plans, the horizontal cutting plane is typically at a height that cuts through doors and windows on exterior walls so they are in the final view. Removing the area above the cutting plane creates a bird’s-eye view looking down into the structure like the example in Figure 8.13.

P R O F E S S I O N A L  T I P

The oldest known plan or drawing dates back to around 2100 BC and is credited to the Chaldean Prince of Lagash, a city-state in ancient Mesopotamia. In his time, the prince was known as an engineer and a builder.

Plot or Site Plan

A site plan (Figure 8.14) contains information verified by a surveyor, engineer, and others. It illustrates important features such as utility easements, topography, property lines, setbacks, and elevations. Site plans usually include the building footprint, driveways, auxiliary buildings, and other constructed features on site as references. A plot plan, very similar to a site plan, is specifically for recording a piece of land and shows much of the information on the site plan without a house on the lot. Some of the important aspects include the following:

- Easements: Any property easements must be specifically located and identified. It is advisable to check with code officials and utility companies for restrictions and setbacks related to property easements.
- Setbacks: All property setbacks shown on site plans should be verified with local zoning officials before construction begins. A quick phone call can help eliminate serious code problems related to building within a setback area.
- Benchmark: The benchmark sets the elevation of many construction features, including finished floor levels and foundation heights.

Site plans contain very important information about elevation. Each site plan has an elevation called the benchmark. The benchmark represents a starting elevation that may be an actual elevation above sea level or, for ease of use, an arbitrary number like 100.00’. In either case, all points of elevation throughout the site plan reference against the benchmark elevation. Carpenters and masons will use these elevations as starting points to calculate foundations and finished floor heights. Masonry workers will use these elevations to build and check all foundation walls, piers, and other structural components of the foundation system.

Site or plot plans have become more significant in today’s environment of green building. The orientation of the building is important to operating efficiency. Windows and doors can be oriented and sized to maximize any solar advantages based on the home’s location. The site plan can be used to manipulate the scaled building footprint into the best orientation for solar efficiency based on location, building size, and limitations of the building lot. These plan sheets also show protected areas like tree drip zones and natural areas, as well as areas designated for materials storage and heavy equipment.
Foundation Plan

The information on a foundation plan provides critical dimensions for structural support features. The height of the cutting plane should be set to “cut through” any windows, doors, or other openings in basement walls so the builder can define locations,
type, and other specifics. Take a look at the information below and noted in Figure 8.15 of important specifications provided by foundation plans.

*Foundation wall type and width:* The foundation width as determined by code or design may not be the same for all areas of the building.

*Window openings:* Window type, size, and location may not be the same at all locations.

*Dimension lines:* Carefully note dimension lines and their reference points. They may represent the outside edge, the centerline, or the inside edge of the object referenced.

*Footings and piers:* Dashed lines represent the footing width for foundation walls, piers, and columns. The footing width beyond the foundation wall, column, or pier on either side is the footing projection (see Figure 8.15).

*Concrete:* Some concrete specifications may be listed on foundation plans, but refer to specifications sheets for all pertinent details.

*Local frost lines:* The depth of footings below grade must be defined by local code jurisdictions based on local soil and weather conditions. In the International Residential Code, Table R301.2(1), footnote b states, “The jurisdiction shall fill in the frost line depth . . . with the minimum depth of footing below finished grade.” (2015 IRC, p. 29)

### MATH TIP

The footing projection is the width of the footing beyond the foundation wall, pier, or column. IRC R403.1.1 Minimum Size states, “Footing projections, P, shall be not less than 2 inches and shall not exceed the thickness of the footing.” (2015 IRC, p. 80) For the example in Figure 8.15, what is the total footing width based on the footing projection and basement wall specifications?

**Answer:** Foundation wall is 108” concrete with an exterior footing projection of 34” and an interior footing projection of 34” – 16” total footing width.

### Floor Plan

Floor plans like the example in Figure 8.16 are usually the most information-packed of all plan sheets. Like the foundation plan, the floor plan cutting plane should be at a height that includes all window and door openings. This sheet defines the size and layout of all rooms and may include electrical, HVAC, and plumbing information. If the home design is more complex, however, electrical, HVAC, and plumbing may be on separate sheets to simplify the view and help eliminate mistakes and oversights during estimating and construction.

The floor plan provides the information needed to estimate many materials like studs, drywall, doors, windows, and floor framing. Many plan sets include framing sheets for floors, walls, and ceilings as shown in the following sections. Although not required, framing sheets help estimators work more accurately and help carpenters reduce material waste.

*Room size and layout:* As with any dimension, be sure of the reference point so the actual work will match the floor plan. In rooms with appliances, bathroom fixtures, or other equipment, the point of reference for dimensions is critical to design. For example, the kitchen cabinets are often preordered based on floor plan dimensions. A mistake in reference point here during rough framing means the cabinets may not fit in the finished wall space. See Figure 8.17 and the examples of minimum spacing requirements from the International Residential Code Figure R307.1, Minimum Fixture Clearances. Always confirm that dimensions meet any local changes to the model code.

*Piers and columns:* The surface contact area of support for framing materials over bearing supports (piers and columns) is regulated by IRC section R502.6.1. It requires floor joists ends over bearing support to lap a minimum of 3” and requires the boards to be nailed with three 10d face nails.

*Plumbing fixtures:* IRC Section R307, Toilet, Bath and Shower Spaces, specifies minimum spacing requirements for these fixtures. Reading the floor plans correctly while laying out the walls is critical to assure code-compliant spacing in all areas.

*Electrical and HVAC:* Floor plans are used by trades workers to position outlets, switches, home integration systems, HVAC supply and return registers, and many other components of the home design.

*Exterior features:* Floor plans dimensionalize the placement of decks, porches, garages, and other attached, exterior features. Depending on design, exterior features like decks may have details specified and illustrated on other plan sheets.

### MATH TIP

A floor plan measures from edge to edge on the exterior. One exterior kitchen wall shows an outside dimension of 12’-8”. According to the specifications, all exterior walls are framed with 2 × 6 studs, 1/2” gypsum board on the interior, and 1/2” OSB sheathing on the exterior. Wall-to-wall, what is the maximum width of the cabinet assembly?

Given dimension is 12’-8”. Subtract the 2 × 6 wall thickness from both sides (5/8” + 5/8” = 1”). Subtract the gypsum board and OSB from both sides (1/2” + 1/2” = 1” x 2 sides = 2”). Final answer: 12’-8” – 11” – 2” = 11’-7” maximum cabinet assembly width.
Figure 8.11 Elevation drawings may identify important framing and finish design requirements, such as roof slope.

Framing Plans for Ceilings and Roofs

**Ceiling or roof framing plans** provide details for all structural components and the layout spacing and arrangement of the system. For example, in Figure 8.18, spacing and framing details for all ceiling joists are noted on the ceiling framing plan (sheet A-6). In addition, the size and type of all materials is defined in the framing plan.

A ceiling or roof framing plan (Figure 8.18) will show details of framing for green features such as I-joists, raised-heel trusses, engineered lumber, or recycled steel. These green and sustainable design options must be detailed for carpenters to follow the design specifics. Estimators also need this information for bidding. Some of the green features on framing plans may be included on the specifications sheets.

Without a framing plan, carpenters will design a ceiling or roof system based on the IRC code requirements to provide a code-minimum system that meets all standards for safety. However, using the green features noted above will improve on the minimum design requirements of the International Residential Code and may reduce materials consumption.

Detail and Section Views

The **detail and section views** provide very specific information about a particular construction or design feature. These views provide enlarged drawings to show specific details. To assure compliance with design and efficiency standards for the home, carpenters need detail sheets to define materials, techniques, and special applications.

Detail and section views are often combined several to a sheet. When a particular area of a plan sheet has a corresponding alphabetical or numerical indicator, refer to the detail sheets. This indicator directs the carpenter to a particular enlarged view on the detail sheet. For example, note the window flashing details from plan sheet D-1 in Figure 8.19.

One of the most common detail views is a wall section. See Figure 8.20 for the wall detail from plan sheet D-1. Common practice is to include one typical wall section and any details unique to the home’s design or special features. A wall section may include green features and framing requirements above code minimums as shown in Figure 8.20. Study detail sheets carefully before construction begins to assure compliance with structural, materials, and energy-efficiency requirements.
Schedules and Specifications

With a set of architectural drawings, the most common schedule or specification sheet is for windows and doors. Throughout a plan set, windows, doors, and other components have a numerical or alphabetical designator corresponding to an entry on the schedule sheet. Information on the schedule sheet will provide specifications, model numbers, material type, size, rough openings, manufacturer, and may include a notation of the product’s efficiency. See the window schedule from plan sheet C-1 in Figure 8.21. Chapter 43, Windows, Skylights, and Tubular Day-Lighting Devices, covers the efficiency standards noted on the C-1 plan sheet.

**Professional Tip**

CAD (Computer-Aided Design) or CADD (Computer-Aided Design and Drafting) are very similar. Both are available as freestanding programs or as part of a total BIM package.

**CAD Programs for Design and Energy Efficiency**

CAD (Computer-Aided Design) software has been available for building design and estimating for years. Options range from simple to very sophisticated software and hardware packages for residential and commercial construction. The most advanced programs provide materials lists and 3D real-world walkthroughs and at the same time calculate the impact of materials and construction techniques on building operating efficiency. Standalone estimating and accounting programs are available as part of fully integrated modeling software called Building Information Modeling (BIM). BIM is sophisticated software that models many aspects of a building, including air quality, energy consumption, and operational efficiency.

**3D Design and Estimating Software**

Today’s estimating and 3D modeling software programs (residential and commercial) range from entry-level programs to highly sophisticated custom programs. A basic example of what
Figure 8.12 Elevations for interior work help carpenters meet layout and installation requirements.

Figure 8.13 Floor plans are horizontal section views and become part of a set of working drawings.
Figure 8.14 A site plan contains important information for positioning the home on the building lot. When builders have the option, solar orientation of the home can significantly improve a home’s energy efficiency.
Figure 8.15 Foundation plans detail all footings, piers, foundation walls, and basement walls.

these programs can do is shown in Figure 8.22. Most can produce a complete set of working drawings for any residential design. Some engineers, architects, and builders in residential construction use AutoCAD®. However, AutoCAD requires training and is primarily a commercial design product. Programs tailored for residential construction are easy to use and provide many levels of detail. Some 3D design programs can integrate with accounting programs for detailed cost reports and estimating functions.

Modern builders and subcontractors take advantage of technological advances in communications and software that integrate design, accounting, and scheduling software. These modern tools save time, reduce errors, and help builders become more efficient and profitable. Learning to work with these programs is a prerequisite to management positions in the construction industry.

**Building Information Modeling (BIM)**

An example of BIM software is the REM/Rate™ software used by Energy Star HERS raters. This software package provides energy modeling based on criteria input by the rater, such as blower door and duct blaster testing, insulation *quantity* and *quality* of installation, energy-efficient lighting, appliances, and heating and cooling equipment. Using BIM software, a rater can provide a detailed analysis to the builder or homeowner of the operating costs and operating efficiencies of the building.

One of the many functions of BIM software is to compare products for efficiency and cost. For example, windows of different efficiency levels can be compared to calculate the annual energy cost differences. BIM programs make calculations based on building orientation and latitude to determine solar heat gain for windows and doors. The software will calculate these numbers as part of operating efficiency and energy costs on an annual basis. Green remodelers and builders use the reports generated by BIM software programs to help customers see the advantages of green and efficient components and materials.
Figure 8.16  Floor plans contain abundant information for carpenters and other workers. Sometimes HVAC, plumbing, and electrical crafts have their own floor plan sheets to help increase detail and readability.

Figure 8.17  Reading floor plans to lay out walls is critical to assure code compliance in areas like bathrooms. Many jurisdictions will adapt (change) the model code to meet local requirements and concerns.
Figure 8.18 A framing plan helps eliminate errors in design and makes carpentry more efficient and cost effective.

Figure 8.19 Plan detail sheets help assure the building envelope construction meets design standards.
Figure 8.20 Wall sections provide information about all materials needed to construct the system in a way that meets design and efficiency requirements.
Figure 8.21 The schedule sheet provides details on specific components to assure compliance with certification programs like the ICC 700 National Green Building Standard, Energy Star, or LEED for Homes.

Figure 8.22 CADD-type programs can generate a wide range of detailed drawings and perspectives.
1. Describe how BIM software is important to building and verifying energy-efficient home construction.

2. What is the purpose of the benchmark on site plans? What important elements of construction reference the benchmark as a starting point?

3. How many scales does a triangular architectural ruler have? What is the most common scale used for residential plan sets? What are the advantages of a scaled drawing?

4. What accessory materials are available for scaling and estimating? What advantages do these accessories offer estimators and builders?

5. Describe and explain at least three advantages available when using design, estimating, and drawing software.

6. Which plan sheet usually has the most building information? What types of information are available from this plan sheet?

7. What plan sheets provide information about required types of windows and doors and their correct placement?

8. When locating the building on the site, which working drawing would verify information on setbacks, easements, orientation, and other factors?

9. What is the purpose of section and detail views?

10. Where in the plan set would you find information about the parties involved in the construction process?
THE COMMON RAFTER

The common rafter is the primary roof rafter used for gable roofs, combination gables in T or L shape designs, the saltbox roof, and gambrel roofs. There is even a common rafter in the center of a hip roof in many cases. Measuring, marking, and cutting common rafters for each of these roof styles follows exactly the same procedure. Therefore, learning and understanding the common rafter is the most important step toward building many types of roof systems.

Laying out and cutting dimensional lumber rafters is a systematic process. Carefully follow the descriptions in this chapter to understand plumb cuts, level cuts, bird’s mouths, line lengths, and other features of common rafters.

Calculating the Line Length

Common rafter line length can be determined using a conventional framing square, or a Speed Square and associated rafter tables. Accomplished carpenters have their personal preferences for particular tools and layout methods; however, knowing how to use different framing tools and methods makes a more versatile carpenter.

The line length calculation method (Figure 36.1) uses the Pythagorean Theorem and a right triangle to determine a rafter’s line length, which is the hypotenuse (C) of a right triangle. Using the unit run and unit rise will give you the theoretical line length of one unit length; if you know the total run of the rafter, you can calculate the line length. The total run and total rise will give you the total unit length, which is the theoretical length of the rafter. Remember the rafter is based on single units combined to complete the total rafter. See the illustrations and math examples in Figure 36.1.

Framing Square Step-Off Method

Stepping off a rafter is the oldest method still used to create rafters of all types. The process uses only a framing square or Speed Square and the information provided on plans. With the traditional framing square, use square gauges to improve accuracy and assure each step-off is the same as the last one. See the example of how to use square gauges and a framing square for increased accuracy in Figure 36.2.

Framing Square Tables

The blade portion of a professional framing square displays rafter tables for common, hip, and valley rafters. The same information can also be seen in Table 36.1. The tables give the unit length of a rafter based on the design roof slope. Most framing squares show common unit lengths for slopes from 1/12 up to 7/12. Table 36.1 shows the unit length information found on the side of a traditional framing square. Rafter tables are also readily available on the internet. The following examples show that one simple method for calculating the length of a rafter works for common, hip, and valley rafters.

Working with the information in Table 36.1, calculate the total length for a common rafter and a valley rafter using typical roof slopes such as 2/12, 4/12, or 6/12. The following example shows the simple steps using the 4/12 roof slope. Work with other slopes as practice and confirm your answers with Table 36.1.

1. Using Table 36.1, note the common rafter unit length for a 4/12 sloped roof is 12.65”.
2. Again using Table 36.1, note the valley rafter unit length for a 4/12 sloped roof is 17.44”. Remember, a professional framing square has all the solutions found in Table 36.1 and more right on the blade! (See the section of the framing square blade shown in Figure 36.1.)
3. Calculate the total rafter length for the common rafter. Assume the roof span is 28 feet, so total run (half the total span) is 14 feet. 14 units of run \( \times 12.65” \) per unit = 177.1”.
   Convert 177 to feet and inches: \( 177/12 = 14.75’ \) or 14’-9”.
   Now convert the decimal: \( .1 \times 16 = 1.6 \). Round to 2/16, which reduces to 1/8.
   Final common rafter length is 14’-9 1/8”.
4. Repeat the process in step 3 with the valley rafter. The total run is 14’ as shown in step 3.
5. Calculate valley rafter length:
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Figure 36.1 Calculation method for determining total rafter length.

C² = unit rise² × unit run²
C² = 8² + 12²
C² = (64 + 144)
C² = 208
C = √208
C (line length) = 14.42" as the unit length of the common rafter.

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The theoretical line length does not account for half the thickness of the ridge board which is subtracted from the theoretical line length:
Actual LL = 16.78' (theoretical LL) – ¾"
16 feet plus .78 \times 12 = 9.36
Keep the 9" with the 16' and convert the .36 .36 \times 16 = 5.76, rounded to 6\text{/16}, reduced to ¾"
Now we have the final total of 16'-9\text{\textfrac{3}{16}}" as the theoretical rafter length.
Subtract ¾, which is half the actual thickness of a 2\text{\x} ridge board, from 16'-9\text{\textfrac{3}{16}}" for the final and actual length to cut the common rafter:
16'-9\text{\textfrac{3}{16}}" – ¾" = 16'-8\text{\textfrac{5}{16}}"

Keep in mind the framing square tables are simple representations of the right triangle. Using the Pythagorean Theorem you can easily calculate any unit run for any rise. See the examples in Figure 36.3. You can also find the answer on the framing square. One example is for a common rafter with a 12' unit run; the other is for hip and valley rafters that have a 16.97' unit run.

14 units of run × 17.44" unit length = 244.16".
Convert 244 to feet and inches: 244/12 = 20.33' or 20'-4".
Now convert the decimal .16 to sixteenths of an inch: .16 \times 16 = 2.56. Round to 3/16.
Therefore, final valley rafter length is 20'-4 3/16".
Figure 36.2 The step-off method is more accurate with square gauges.

**TABLE 36.1** Rafter Table for Unit Length of Common, Hip, and Valley Rafter

<table>
<thead>
<tr>
<th>Roof Slope</th>
<th>Common Rafter Unit Length</th>
<th>Hip and Valley Rafter Unit Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.17</td>
<td>17.09</td>
</tr>
<tr>
<td>2</td>
<td>12.37</td>
<td>17.23</td>
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<td>3</td>
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<td>6</td>
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<td>16.28</td>
<td>20.22</td>
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<td>11</td>
<td>16.97</td>
<td>20.78</td>
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</tbody>
</table>
The seat cut creates a level surface so the rafter will sit securely on the wall plate and tight against the outside edge of the wall top plate. The seat cut, commonly known as a bird’s mouth, consists of a plumb line and a level line. Remember all plumb lines and level lines are marked the same way; the only thing that changes is the location of the mark. When using a framing square or a Speed Square, just repeat the process at each location.

The plumb line of the seat cut is the lower mark of the rafter line length. Use a square and mark a plumb line in this location. The level line of the seat cut does not have an exact procedure or standard. Many carpenters have their own methods; regardless of the method used, the important points to remember are these: the seat cut level line should never be wider than the wall plate and you should never remove more than one-third of the rafter depth. The level line length will decrease as the slope of the roof increases. See Figure 36.5.

Seat Cut Adjustment for Siding

Sometimes the seat cut is adjusted to allow exterior siding underneath the rafter. This technique helps protect the upper edge of the siding material and is more common with wood siding materials. In this case, the plumb line is moved down the thickness of the siding material and the level line is simply extended. See Figure 36.6.

Rafter Length Adjustments to Account for Ridge Boards

The line lengths calculated in the preceding examples are the theoretical line lengths; in other words, the actual mathematical calculated length from the outer plane of the wall to the center point of the ridge. To account for the thickness of the ridge board you must remove half the thickness of the actual ridge board from the rafter theoretical length. See Figure 36.4.

Electrical Tips

Calculators designed for construction are available to save time and increase accuracy. Framers may use them to double-check their calculations and estimators use them for speed and accuracy.

All rafters must be properly fastened on both ends to meet code minimums. However, areas subjected to high winds or the possibility of seismic activity often go beyond code in their fastening requirements. Some jurisdictions require structural strapping continuously from the rafters or trusses in the roof all the way down to the foundation. Check with local code officials for requirements at the building site. A wide range of ties and straps are available.

Protecting the windows and doors from solar heat gain with extended soffits and other methods can reduce the run time for cooling equipment, increasing building operating efficiency and reducing monthly utility costs for the life of the building.
Overhang and Projection of Rafter Tails

**Overhang** is the extended length of the rafter beyond the exterior edge of the wall system. Plans may provide the overhang length; however, in many cases the **projection** of the rafter tail is given. The projection is a horizontal measurement of the distance the rafter travels beyond the outer wall edge (plane). With either number, carpenters can complete the rafter design and mark the final plumb cut.

Figure 36.7 illustrates both the projection and overhang for a rafter tail. When plans provide the projection only, divide the projection by 12” to get the unit runs of a common rafter. This new number is the total run of the rafter tail because the tail is essentially a short rafter. Now measure along the top edge of the rafter from the seat cut plumb line to mark this line length for the rafter tail plumb line.

**Professional Tip**

Cutting plumb lines and level lines on rafter tails after the rafters are in place is tricky and can be dangerous. With carefully designed and cut rafters, these cuts are easily made before the rafters are installed, eliminating the hazards and difficulty of cutting from a ladder.
Figure 36.5 A seat cut is a plumb line and a level line combination.

Do not cut more than 1/3 of the rafter depth making a bird’s mouth.

Figure 36.6 The seat cut can be adjusted to allow siding under the rafter.

Figure 36.7 The rafter tail is essentially a short rafter with the line length calculated exactly like a common rafter.

The level line should never be wider than the wall plate or remove more than one-third of the rafter.
Section Eleven
Roof Components, Framing, and Assembly

Rake End Components

The area of a gable roof that extends beyond the plane of the end wall is called the rake end. A rafter known as a rake rafter is used to frame this area. Other common names for a rake rafter include a fly rafter or a barge rafter. Several methods are used, but each provides the same structural support for the rake end. Keep in mind the depth of the rake has a direct bearing on shading windows and protecting the end wall from rain, wind, and stormwater. Green, highly efficient design accounts for this principle and may require a design well beyond the very short rakes (0 to 6°) of some homes.

Rake Supports and Lookouts

Lookouts are short sections of framing lumber the same dimensional size as the rafter material. They provide the structural support for the rake rafter; finish fascia, and soffit material. Lookouts are installed and secured before the roof sheathing is applied. Later, when sheathing is applied, it adds support to the rake end by stopping any deflection in the rake. See the installation methods in Figure 36.10.

Cutting the Rafter Tail Level Line

A level line is commonly used on the rafter tail to provide a level nailing surface for soffit material. Like marking the level line for a bird’s mouth, no exact process is common in all areas. Whatever process is used, make sure the level line does not cut away too much of the plumb cut that is used to attach the fascia board. Use a framing square set to the roof slope to make this final cut on the rafter tail. See Figure 36.9.

Rafters Tail Variations

The end cuts on a common rafter will vary depending on the design requirements. Many variations are common in residential construction. When the roof’s edge design calls for a closed soffit, only a plumb cut is needed on the rafter’s tail. A closed soffit essentially “seals” the soffit area and rafter tails with a basic box technique. Hence, some carpenters call a closed soffit a boxed soffit.

When the roof edge design calls for an open soffit, a plumb cut and a level line cut are required. The open soffit design finishes the end of the rafter tail with fascia board and leaves the underside exposed. The roof system is “sealed” from the outside with a frieze board or similar method. Figure 36.8 illustrates the two basic methods. Details and fully illustrated construction techniques for both designs are found in Chapter 39, Cornice Construction.

When building a closed soffit, some carpenters will allow the rafters to run wild, meaning the rafter ends are not yet uniform in length. The final plumb cut, which sets the final length of all rafters, is not marked until all the rafters are secured in their final position. Carpenters then mark the plumb line on a rafter tail on both ends of the roof system and use a chalk line to snap a straight line down all rafter edges. Finally, a sliding T-bevel or level is used to plumb the chalk mark along the rafter sides and each is cut individually. See the Step by Step Procedure: Making a Plumb Cut on Common Rafter Tails for cutting a plumb and level line on rafter tails after they are installed.

Rake Overhangs

Figure 36.9 When setting the level line, be sure enough of the plumb line remains to fasten the fascia boards.
Figure 36.10 The rake end of a gable roof is supported with various methods depending on design and preference.
with the formula shown in the following example, which uses a roof with a slope of $\frac{8}{12}$.

1. Convert the on-center spacing to units of run. With 16" o.c. spacing you have $\frac{16}{12} = 1.33$ units of run. With 24" o.c. spacing you have $\frac{24}{12} = 2$ units of run.

2. Multiply the unit rise (slope) by the unit runs calculated in step 1. With studs spaced 16" o.c. you have $8 \times 1.33 = 10.64"$. Now convert the fraction: $.64 \times 16 = 10.24/16$. Reduce to 10/16, then $\frac{5}{8}$ for a common difference of $10 \frac{5}{8}"$. With studs spaced 24" o.c. you have $8 \times 2 = 16"$ common difference.

The gable stud directly under the ridge board must be square on both ends, then plumbed and toenailed to the top plate and underneath the ridge board with two 10d nails at each end. After the center stud is plumb and secure, mark the wall plate with the desired o.c. spacing, and then cut each stud to the appropriate length using the common difference method shown in Figure 36.11.

**Notching Gable End Studs**

A framing square or Speed Square can set the angle to mark the top end of gable studs for notching. Keep in mind the gable stud overall length is the common difference length illustrated in Figure 36.11. Make this mark so the top edge of the gable stud will be flush with (or slightly less than) the top of the rafter. The other mark for the gable stud determines the notch location that will support the rafter.

**Gable Stud Cut-and-Fit Method**

Depending on carpenter preference, gable studs can be easily set on the wall plate on-center marks and plumbed with a level, and then marked against the rafter directly. Mark the stud at the underside of the rafter and at the top of the rafter. Then cut the notch the same depth as the rafter stock thickness. This method is simple and does not require a framing square; however, each stud must be marked individually to ensure accuracy. See Figure 36.12.

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**GREEN Tip**

Using 24" on-center spacing is preferred where acceptable to reduce materials. When making gable end studs use the shortest available material to again reduce waste and improve framing efficiency.

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**GABLE END STUDS**

The gable end rafter is the rafter directly above the end wall of the house. **Gable end studs** provide the support for the gable end rafter. They are square on the end that sits on the wall top plate, then notched and angled on the upper end that directly supports the rafter above. The notched and angled end of gable studs are all the same, but the length changes at each on-center point by a common difference. Calculate the common difference for any roof slope
CHAPTER 36 Common, Hip, and Valley Rafters

**PROFESSIONAL TIP**

The notched section of a gable end stud should be no deeper than the thickness of the rafter.

**HIP RAFTERS**

*Hip rafters* travel from the ridge board to the wall top plate just like a common rafter but at a 45° angle. Since hip rafters are at an angle they have slightly different cuts on each end, and importantly, hip rafters are longer than common rafters because they travel at an angle to get to the wall plate. The hip rafter essentially creates a connection between two roof types, the gable and the hip. This effect, or change in roof plane, eliminates the gable end and makes the roof design very good at resisting high winds. Figure 36.13 illustrates basic hip roof framing components.

A professional framing square has hip and hip jack rafter tables that provide the unit lengths for hip rafters. Again, because hips form an intersection of two roof planes and run at 45° angles to the ridge board, they are longer than common rafters. The slope of a hip roof section is the same as the slope of the common rafters in the gable section. The rafter that connects between the hip rafter and the end wall plate of the building is the hip jack rafter. Hip jacks increase structural support and create on-center nailing surfaces for roof sheathing.

**Hip Rafter Unit Length**

For estimating purposes, the rough length of a hip rafter can be measured using a framing square once you know the total run and total length of the roof’s common rafters. See the example in Figure 36.14 and follow these simple steps using a common rafter that is 12’ long and a total run of 9’.

1. Use the 12” mark on the blade as the total length of the common rafter.
2. Use the 9” mark on the tongue as the total run for the common rafter.
3. Measure across the outside edges between the 12” and 9” marks, which in this case is about 15”.

This technique shows how powerful the right triangle and a framing square can be with simple framing or estimating tasks. For the rough length, good for estimating and ordering materials, the framing square measurement of 15” represents 15’, so the estimator or carpenter knows 16’ stock will be required. Remember this important aspect: this method is for rough estimating and does not account for overhangs. The length of the overhang must be added to the estimated length before ordering.

The Pythagorean Theorem will calculate the length of hip rafters using the same technique as common rafters. Since we already know all 45° hip rafters have the same slope (unit rise) as common rafters, we can calculate the unit length. The unit run of a common rafter is 12” because it travels straight to the wall top plate from the ridge board. The unit run of a hip rafter is 16.97” because it travels at a 45° angle between the ridge board and the wall top plates.

A hip rafter forms a 45° angle with the corner of the building and the ridge board. A common rafter forms a 90° angle with the ridge board. In both cases the right triangle can be used to calculate framing lengths and number of pieces required for estimating.
Follow the basic equations in Figure 36.15 to calculate a hip rafter length. Notice how the equation comes up with the same result found on framing squares. A good framing square or calculator is always valuable to carpenters.

**Math Tip**

Calculate the total line length for a hip rafter with a total run of 14 feet and a slope of $\sqrt{\frac{5}{12}}$. See Figure 36.16 and the following steps using a framing square and basic construction math.

Calculating dimensions of hip and other rafters is a basic process. Use these steps to calculate a hip rafter theoretical line length:

1. Looking at a framing square table, find the line for hip rafters, move down to the $\frac{5}{12}$ mark and find 17.69. This means 17.69” per foot of run for the hip rafter.
Length.

A hip rafter layout consists of the same plumb and level lines used for common rafters. Because the hip connects at a 45° angle, a few extra steps are required to lay out the unique cuts at each end. On the ridge board end, the hip requires a cheek cut, sometimes called a side cut. The lower end forms the corner of the eaves and has a cut layout unique to hips that allows for attaching fascia boards.

Figure 36.17 illustrates the various cuts required with hip rafters. These include the plumb and level lines with additional plumb lines needed to create the beveled ends and shorten the hip at the ridgeline. At the ridge, a hip rafter may use a single cheek cut or a double cheek cut.

Hip Rafter Line Length

The line length for a hip rafter is calculated with the same formula (Pythagorean Theorem) used to calculate common rafter length. Remember, hip and common rafters have the same slope. However, because the hip runs at a 45° angle to the ridge board it is longer than the common rafter which runs perpendicular (90° angle) to the ridge board. Therefore, the unit run of the hip rafter is 16.97” instead of 12”. Remember the unit lengths for hip rafters and common rafters is based on the roof slope and given on framing square tables.

The rafter tables and calculations provide the theoretical line length as shown in Figure 36.18. In the end, any necessary rafter rail length (check the plan design) is added to the theoretical line length. Using the basic steps that follow and Figure 36.18, calculate the theoretical line length of a hip rafter, answering this question: What is the theoretical line length for a standard 45° hip rafter on a roof with a common rafter total run of 12’ and a slope triangle of 4/12?

1. Use the framing square table under the 8” column. The second line gives the unit length per foot of run for a hip rafter, which in this case is 18.76”.
2. Multiply the total run (same as the common rafter) by the unit length from the rafter table on the framing square: $12 \times 18.76 = 225.12$”.
3. Convert to feet and inches.
   a. Divide by 12 to convert to feet: $225.12/12 = 18.76’$.
   b. Set the 18’ aside for now and multiply the .76 by 12 to convert to inches: $.76 \times 12 = 9.12$.
   c. Set the 9” aside and convert the remaining decimal to a fractional inch (sixteenths): $\frac{.12 \times 16}{16} = 1.92$ or 2/16, which reduces to 1/8.
   d. Now combine: 18’-9 1/8” is the final hip rafter theoretical line length.

Shortening the Hip Rafter at the Ridge Board

As with common rafters, the theoretical length of a hip rafter is shortened at the ridgeline to account for the ridge board thickness. However, the shortening distance is based on a 45° measurement.
Cheek Cut Layout Procedures

Once the hip rafter is marked to shorten the length as Figure 36.19 shows, a single or double cheek cut must be marked so the rafter will fit against the ridge board at the required 45° angle. The easiest method uses the framing square to make the required angle for a single cheek cut. See the example in Figure 36.20. A detailed method for measuring and marking both single and double cheek cuts is shown in the Step-by-Step Procedures section of the chapter.

Marking the Bird’s Mouth and Dropping the Hip

The bird’s mouth layout for a hip rafter is the same process used for common rafters with a couple of exceptions. The hip rafter bird’s mouth level line is always a little longer than a common rafter level line because the hip rafter sits at an angle across the corner of the building and requires the same full bearing for structural strength as common rafters. After the theoretical line length of the hip rafter has been marked on the lower end, use the framing square to mark the plumb line and level lines required for the bird’s mouth. See Figure 36.21 for the basic process of creating a bird’s mouth based on the simple steps that follow. Always start from the theoretical line length, which should be calculated and marked on the rafter at this point.

1. Align the framing square along the edge of the rafter at the mark for the roof rise on the tongue (8 ") and the hip rafter unit run (16.97") on the blade.
2. Shift the framing square to align the plumb line with the theoretical line length mark. Confirm the 16.97" on the blade is still aligned along the edge of the rafter and mark the plumb line on the side of the rafter by tracing along the tongue of the framing square as shown in Figure 36.21.
3. Measure down the plumb line made in step two the same distance as the common rafters. Now set the level line to complete the basic bird’s mouth or seat cut.

A hip rafter will also require dropping the hip. Dropping the hip is required because the top corners of a hip rafter will sit slightly higher than the plane of the roof and might interfere with sheathing.

**Professional Tip**

Instead of dropping the hip rafter, another method called backing the hip can be used. This process requires cutting a bevel line along the length of the hip rafter. Because this method takes more time and is tricky to cut, most carpenters drop the hip as shown in Figure 36.21.
Figure 36.19 Hip rafters are shortened the same amount with a single or double cheek cut.

Dropping the hip starts from the bird’s mouth and covers several additional steps as follows and shown in Figure 36.21. See the Step by Step Procedure section of the chapter for detailed descriptions of the entire hip rafter process. With a little practice, these rafters will become as easy as common rafters to lay out and cut.

1. Measure along the original plumb line back toward the ridge board half the thickness of the hip rafter, 3/4” in most cases.
2. Use the framing square and make another plumb line mark at this location.
3. Measure down this plumb line and make a level line mark. Remember, this depth is the same with hip and common rafters as shown.
4. Set the framing square and mark the new level line. Carry this line all the way over to the original plumb line made earlier creating the bird’s mouth.
5. Cut the rafter along this new level line and the original plumb line to complete the bird’s mouth and dropping the hip combination.

Figure 36.20 The framing square can be used to mark the proper angle of the cheek cut based on the roof slope and the framing square tables.
Hip Rafter Tail Section

Determining the length of a hip rafter tail section is similar to the process used for a common rafter with the exception that the unit run is now 16.97" (rounded to 17") instead of 12" for common rafters. Because some plan details provide only the rafter projection and, in many cases, only the common rafter projection, the projection of the hip rafter must be calculated to create the proper overhang length. Figure 36.22 shows how to calculate the hip rafter projection based on common rafter projection. See the Step by Step Procedures for each step to create the tail section of a hip rafter.

**PROFESSIONAL TIP**

Working with the common rafter projections from a plan set, a framing square can be used to determine the length of hip rafter overhangs. See the illustration in Figure 36.23.

**Hip Roof Assembly Basics**

The hip roof assembly follows a series of steps just like with common rafters. The exact method depends on crewmember availability, carpenter preference, and attachment design. Before assembly begins, the ridge board theoretical length is adjusted based on the method of hip rafter attachment. See Figure 36.24 for a basic method to determine the theoretical ridge board length to begin the process. The Step by Step Procedure, Assembling the Hip Roof, shows the details for assembling the system.

**VALLEY RAFTERS**

Valley rafters form the intersection or valley between roof sections moving in different directions. From the basic L or T roof shape shown in Figure 36.25 to more complex designs, most roofs will form valleys. The main roof section and the secondary roof sections may have gable ends, hip ends, or a combination as illustrated.
When the spans of the roofs are unequal, a **supporting valley rafter** runs from the wall plate up to the ridge board. On the other side, a **shortened valley rafter** runs from the wall plate to the supporting valley rafter. The rest of the roof system is a series of various jack rafters discussed in Chapter 37. See the illustrations in Figure 36.27.

The plan detail calls for a common rafter projection of 24”; complete this simple math procedure to calculate the hip rafter projection.

**Step 1)** Divide the projection by 12” to find the units of run. Remember the unit run is the same for common and hip rafters. \(24” \div 12” = 2\) unit runs.

**Step 2)** Since the hip unit length is 17” inches instead of 12” as with common rafters, multiply the unit runs by 17”. Calculate \(17” \times 2\) (unit runs) = 34”. This is the projection of the hip rafter.

See the Step by Step Procedures for layout of the hip rafter tail.

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**Figure 36.22** Calculating a hip rafter projection.

**Figure 36.23** Understanding the framing square and the right triangle are important skills for carpenters who build roof systems.

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The span of the roof determines the type of valley rafter required. For roofs with equal spans, valley rafters start on the wall plates and intersect at the main ridge board. When the end of the main roof is a hip, these valley rafters also run parallel to the hip rafters and are the same length as shown in Figure 36.26.

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When the spans of the roofs are unequal, a **supporting valley rafter** runs from the wall plate up to the ridge board. On the other side, a **shortened valley rafter** runs from the wall plate to the supporting valley rafter. The rest of the roof system is a series of various jack rafters discussed in Chapter 37. See the illustrations in Figure 36.27.

The plan detail calls for a common rafter projection of 24”; complete this simple math procedure to calculate the hip rafter projection.

**Step 1)** Divide the projection by 12” to find the units of run. Remember the unit run is the same for common and hip rafters. \(24” \div 12” = 2\) unit runs.

**Step 2)** Since the hip unit length is 17” inches instead of 12” as with common rafters, multiply the unit runs by 17”. Calculate \(17” \times 2\) (unit runs) = 34”. This is the projection of the hip rafter.

See the Step by Step Procedures for layout of the hip rafter tail.

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**Figure 36.22** Calculating a hip rafter projection.

**Figure 36.23** Understanding the framing square and the right triangle are important skills for carpenters who build roof systems.
Valley Rafter Layout Procedures

With equal span roofs, valley rafters have the same unit run (16.97) as hip rafters; therefore they are marked and measured in the same way. The total run is also the same: for standard 45° hip and valley rafters the total run is always one-half the total span of the roof. Note the spans for an equal span roof in Figure 36.27. Only the seat cut and the tail section is different for valley rafters on equal span roofs. With supporting valley rafters, calculating the theoretical line length is also the same process (unit length× run).

Calculating a Valley Rafter Theoretical Length

Remember that the span is the base of the right triangle, called the total run. With intersecting roofs of equal spans, the total rise
2. Multiply the total run (same as hip rafters on equal span roofs) by the unit length found in step one (18.76 \( \times \) 18.76 = 225.12"

3. Divide by 12 to convert to feet: 225.12 \( \div \) 12 = 18.76', which converts to 18'\(\frac{1}{8}\) as the valley rafter total theoretical length.

Understanding the simple relationship of the rafters to the right triangle is essential to efficient, safe, and faster roof framing. As this section shows, the lengths of hip and valley rafters are the same on equal span roofs. Only the seat cut and tail, discussed in the following sections, are different.

**Math Tip**

When calculating total length for equal span and supporting valley rafters, the framing square table provides the unit length per foot of run. Use the procedure illustrated in Figure 36.28.

### Valley Rafter Seat Cuts

The seat cut for valley rafters (Figure 36.29) is a unique cut with a double cheek cut on the bottom so the rafter will sit against the inside corner of the intersection wall plates. The seat cut is also longer because the rafter sits on the wall plates at a 45° angle, lengthening the effective support area (just like hip rafters). Remember, with all rafter types, the bird’s mouth must have full support from the wall plates below. See the Step by Step Procedure for making a valley rafter tail reverse cheek cut.

### Valley Rafter Tail Section

The length of a valley rafter tail is calculated by the same procedure used for hip rafters. See the description of the Hip Rafter Tail Section and Figures 36.22 and 36.23 as examples. The outward end of a valley rafter has a reverse cheek cut to allow the corner of the
1. At the theoretical line length, draw a plumb line.
2. Measure half the thickness of the supporting valley rafter (3/4" usually) perpendicular to the first plumb line. In other words, measure down the rafter 3/4".
3. Make a second plumb line mark at the mark made in step two.
4. Cut the shortened valley rafter along the second plumb line as the actual length.

Figure 36.28 Valley rafter length is calculated in the same way as hip rafter length.

finished fascia to remain in line with the rest of the fascia and soffit assembly, as shown in Figure 36.30. See the Step by Step Procedure at the end of the chapter for making this type of tail cut.

**Shortened Valley Rafter**

When building an intersecting roof where the major and minor spans are not equal, a supporting and a shortened valley rafter are required. The length of a shortened valley rafter is calculated based on the run of the minor span. Use the framing square table for hip and valley rafters to get the unit length and make the calculations as in previous sections of this chapter.

The shortened valley rafter intersects the supporting valley rafter at a 90° angle as shown in Figure 36.31. This is a square cut designed to mate flush with the side of the supporting rafter. After the theoretical line length is calculated, shorten the valley rafter with the following easy steps:

1. At the theoretical line length, draw a plumb line.
2. Measure half the thickness of the supporting valley rafter (3/4" usually) perpendicular to the first plumb line. In other words, measure down the rafter 3/4".
3. Make a second plumb line mark at the mark made in step two.
4. Cut the shortened valley rafter along the second plumb line as the actual length.

Figure 36.29 Seat cuts for valley rafters are designed to fit against the corner of intersecting wall plates.

Figure 36.30 The tail end of a valley rafter has a reverse cheek cut so the overhang fascia meets properly and square at the inside corner of the building.
1. Calculate these common rafter theoretical line lengths (LL) for roof slopes of \( \frac{5}{12} \), \( \frac{9}{12} \), and \( \frac{16}{12} \). Each building has a total span of 42 feet. Notice the LL is actually the hypotenuse of a right triangle; in other words, \( C \) of the right triangle formula \( C^2 = A^2 + B^2 \).

   a. \( \frac{5}{12} \): LL\(^2\) = unit rise\(^2\) + unit run\(^2\)
      \[ LL^2 = 25 + 144 \]
      LL\(^2\) = \( \sqrt{169} \)
      LL = 13”
      13” \( \times \) 21 unit runs = 273”
      Reduce to feet and inches: 273/12 = 22.75 or 22’-8”.

   b. \( \frac{9}{12} \): LL\(^2\) = unit rise\(^2\) + unit run\(^2\)
      \[ LL^2 = 81 + 144 \]
      LL\(^2\) = \( \sqrt{225} \) = 15”
      15” \( \times \) 21 unit runs = 315”
      Reduce to feet and inches: 315/12 = 26.25 or 26’-3”.

   c. \( \frac{16}{12} \): LL\(^2\) = unit rise\(^2\) + unit run\(^2\)
      \[ LL^2 = 256 + 144 \]
      LL\(^2\) = \( \sqrt{400} \) = 20”
      20” \( \times \) 21 unit runs = 420”
      Reduce to feet and inches: 420/12 = 35’.
      For example c, what product could you use to create this rafter?

2. Calculate the hip rafter theoretical line length (LL) for a roof slope of \( \frac{7}{12} \). The total span of the building end is 24 feet.
(continued)
Remember, the unit run for a hip rafter is 16.97\text{\textdegree}; when calculating, some carpenters may round this up to 17\text{\textdegree}.

\begin{align*}
de & = \sqrt{\text{unit rise}^2 + \text{unit run}^2} \\
\text{LL}^2 & = 49 + 288 \\
\text{LL}^2 & = \sqrt{337} = 18.35\text{\textdegree} \\
18.35\text{\textdegree} \times 21 \text{ unit runs} & = 385.35\text{\textdegree}
\end{align*}

Reduce to feet and inches: 385.35\text{\textdegree}/12 = 32.11 or 32\text{\textdegree}/8.

**Math Tip**
For practical purposes, the unit run (16.97\text{\textdegree}) of a hip or valley rafter can be rounded up to 17\text{\textdegree} for calculating.

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**Common Rafter Layout Using a Framing Square**

Follow this procedure for common rafter layout using a framing square. Notice in step 4b how the framing square can be used to lay out each unit of run (12) to develop the theoretical line length without calculations. However, the calculated and measured LL shown in the following steps is typically more common and eliminates most marking errors.

The roof system has a slope of 6/12 and a total span of 24\text{\textdegree}. Remember to check the rafter stock for any crowning and make sure the crowned edge is the upper edge as you begin marking the rafter. As always, the theoretical line length must be calculated first. Use the formula in step 1.

1. **Calculate the theoretical line length:** slope unit length \times unit runs. Half the total span is 12\text{\textdegree}, so you have 12 units of run. Look at the rafter table under the 6\text{\textdegree} mark to find the unit length for a 6/12 slope is 13.42\text{\textdegree}.

   \begin{align*}
   \text{Multiply} \ 13.42\text{\textdegree} \times \text{unit runs} & : 13.42 \times 12 = 161.04\text{\textdegree} \\
   \text{Convert the fraction} : .04 \times 16 & = .64, \text{and round to} \ 1/16 \text{ for a total of} \ 161\frac{1}{16}' \text{ or } 161\frac{1}{16}'/12' = 13'-5\frac{1}{16}' \text{ total theoretical line length.}
   \end{align*}

2. **Using the 6\text{\textdegree} mark on the framing square tongue and the 12\text{\textdegree} mark on the blade,** align the marks along the top edge of the rafter stock. Do this close to the end of the rafter to reduce waste.

3. **When the square is in place, mark the plumb line along the tongue of the framing square.** This will become the outward end of the rafter.

4. **Starting from the plumb line mark,** measure along the rafter stock the total theoretical line length calculated in step 1, 13'-5\frac{1}{16}'\text{, and make a mark.** This is the ridge board end of the rafter.

5. **Take half the ridge board stock thickness (typically 3/4\text{\textdegree}) and measure perpendicular (90\text{\textdegree}) to the plumb line made in step 4 and make a new plumb line mark.** This new plumb line will be the actual cut line that takes into account the ridge thickness.

6. **Align the framing square with the theoretical line length marked in step 3.** This becomes the bird’s mouth plumb line.

7. **Simply slide the framing square down the bird's mouth plumb line, maintaining alignment, and then mark the level line.** Make the line no longer than the width of the wall plate, which is usually 3\frac{1}{2}\text{ for 2\times 4 wall stock or 5\frac{1}{2}\text{ for 2\times 6 wall stock.**}

Complete the tail section as illustrated in the Step by Step Procedure: Calculating and Marking the Common Rafter Tail Section.
2-3

Mark rafter at 6° on tongue

12° on blade

4A

Mark rafter

Measure 13'-5 1/16"

4B

Mark rafter

Square

6° on tongue

12° on blade

5

Actual cut line

3/4"

Measure perpendicular

6

Draw plumb line at mark from step 3

7

Draw plumb line at mark from step 3

Wall width

Level line
Using a Speed Square (Rafter Square) to Lay Out a Common Rafter

A rafter square or Speed Square is the triangular square used by many carpenters because it is easy to carry in a tool pouch. The technique for using these smaller squares follows the same principles as using a full-size framing square. The steps that follow illustrate how to lay out a common rafter using a small rafter square. The example roof system has a slope of $\frac{6}{12}$ and a total span of 24’. Because the total run of a rafter is always half the total span, our example has a total run of 12’, as in the preceding example using the traditional large framing square.

Take the given roof slope of $\frac{6}{12}$ and go to the respective rafter table provided with the rafter square. These tables calculate the total rafter length based on the total run of the common, hip, or valley rafter. A typical chart will read, the total length for a 12’ total run is given as 13’-5”. You may notice the table value is slightly different from the calculated distance from the framing square method. This variance will be minimal and should not affect roof design in a meaningful way.

Always check the rafter stock for any crown and make this the top edge before proceeding.

1. Place the pivot point of the rafter square on the top edge (crown edge) and pivot the rafter square until the 6” mark on the common line intersects with the edge of the rafter stock.

2. Mark along the ruler edge of the rafter square to make the plumb line mark.

3. To intersect with the plumb line marked in step 2, mark a centerline along the ridge stock (1/2” total width). This is the plumb line cut mark.

4. From the first plumb line marked in step 2, measure down the top edge of the rafter stock the length found in the rafter table from step 2. This is the line length of the rafter, 13’-5” in our example.

5. At the 13’-5” mark, set the rafter square on the pivot point and the 6” common rafter slope line and make another plumb line mark. This plumb line represents the end of the rafter at the outer edge of the wall plane.

6. Line up the dashed line on the rafter square with the plumb mark. Make a mark along the edge opposite the ruler for the seat cut level line. Make sure this mark does not extend up more than one-third the thickness of the rafter stock.

With the above steps complete, the tail section can be calculated and marked. Use the same procedure shown next in the “Calculating and Marking the Common Rafter Tail Section”. The only difference is the tool used to mark the rafter.
Calculating and Marking the Common Rafter Tail Section

The tail section is marked according to the projection provided in the plan set detail. Follow this procedure for a given projection of 24" on a 6/12 roof slope.

1. Calculate the overhang length based on the given projection.
   a. Divide the 24" projection by the 12" unit run:
      \( \frac{24"}{12"} = 2 \) unit runs
   b. Refer to the framing square for a 6/12 slope and note a unit run is 13.42".
   c. Multiply 13.42" \( \times 2 \) units for an overhang length of 26.84".
   d. Convert the decimal of the 26.84" calculated in step c: .84 \( \times 16 = 13.44 \), rounded to the closest whole number gives 26 13/16" overhang length

2. Starting at the bird’s mouth plumb cut line, measure down the rafter top edge 26 13/16" and make a mark.

3. Set the framing square on the 6" tongue and 12" blade, just like any other plumb cut for a 6/12 roof slope, and mark a plumb line at the mark created in step 2. This is the rafter tail end plumb cut.

4. Use a level or the framing square, and make a level line cut intersecting with the rafter tail plumb line. This line should be long enough to allow full attachment of the soffit material.
Making a Plumb Cut on Common Rafter Tails

Some carpenters will allow each rafter tail to run wild and make the final overhang plumb cut after all rafters are installed. If any rafters are not exactly the same length or the building has very long walls, this technique helps assure the finished eave construction is very straight and true.

First the carpenter must calculate the overhang length using the same method as the last example. Once the length of the rafter tail is known carpenters mark and cut all rafters with the following steps.

1. Mark the rafter on each end of the wall with the calculated length. Then pull a chalk line and snap the line to all other rafters. This transfers the calculated overhang length to all rafter tails.
2. Take a framing square or level and working from the line snapped in step 1, mark the plumb line on each rafter.
3. Use all necessary PPE and safety precautions when cutting the rafter tails, typically from a ladder at this stage of construction.

Measuring and Marking Single Cheek Cuts for a Hip Rafter

1. Start by marking the second plumb line (actual cut line) described in the text under Shortening the Hip Rafter at the Ridge Board (Figure 36.19).
2. Use a square and make a square mark across the top edge of the rafter at the actual cut plumb line.
3. Make another mark down the center of the hip rafter from the edge to below the mark made in step 2.
4. From the cut line marked in step 1, measure perpendicularly (square to the line) half the thickness of the hip rafter stock, usually 3/4”, and make a mark.
5. Draw a third plumb line that intersects the mark from step 4.
6. Draw a line that runs diagonally from the top edge at the third plumb line back through the centerline. This line is the angle of the cheek cut.
7. Lay the rafter on the wide edge, set a circular saw to 45°, and make the cheek cut.
Measuring and Marking Double Cheek Cuts for a Hip Rafter

A double cheek cut is a continuation of the process for a single cheek cut. This may be required by plans depending on where the closest common rafter intersects the ridge board.

1. From the third plumb line marked in the preceding single cheek cut procedure (steps 4 and 5), make a mark square across the top edge of the rafter.

2. Draw a diagonal from the end of the line made in step 1 through the centerline of the rafter.

3. Use the framing square and draw another plumb line on the other side of the rafter where the diagonal meets the edge of the rafter as a guide for the saw when making the cheek cut.

4. Set the saw base at 45° to make single and double cheek cuts and follow the lines.

(continued)
Calculating and Marking the Tail of a Hip Rafter

1. Determine the common rafter projection; in this example the projection is 30”.

2. Divide the 30” by 12 to find the projection units of run. Remember the units of run for hips at 45° and common rafters is the same: $30”/12” = 2.5$ units of run.

3. Start at the plumb line marking the end of the hip rafter where the bird’s mouth is formed. Set the framing square tongue in line with the bird’s mouth plumb line and the blade 17” mark intersecting the edge of the rafter. Make a mark; this is one unit of run for a hip rafter.

4. Repeat step 3 for all full unit runs calculated. For the final 1/2 unit run, see step 5.

5. Now repeat the procedure for half a unit run because our example has $2\frac{1}{2}$ unit runs for the 30” projection. Half of 17” is $8\frac{1}{2}$”, so set the blade of the framing square on the $8\frac{1}{2}$” line and make the final mark.

6. Plumb this line as the end of the hip rafter tail.
Assembling the Hip Roof

After the ridge board theoretical length is adjusted to its actual length and all components are precut, the roof assembly can begin. The process involves the same steps from raising a common rafter roof system, keeping the ridge board equally supported as the components are added. The hip ends will be different than a straight gable roof, of course, so follow these steps:

1. After the ridge board length is adjusted, set the board against the wall plates and transfer the rafter on-center marks to the ridge.
2. Use sheathing material to create a working platform. Never try to build a roof system while walking on ceiling joists; this is very dangerous and may lead to serious injuries.
3. Depending on the size of the crew, set the ridge board at the total rise height either by using temporary braces or by attaching common rafters to the ridge and nailing the whole assembly in place.
4. Nail the common rafters that butt the ends of the ridge board. Most hip roofs have one common rafter in the center.
5. Set and nail all hip rafters into place. Hip rafters may be on both ends or on one end of the building, depending on the roof design.
6. Nail the remaining common rafters and hip jack rafters to complete the process.
Once the valley rafter theoretical line length has been calculated, the layout procedure can begin. Follow these steps to mark and cut the ridge board end of a supporting valley rafter. Equal-span valley rafters use the same cheek cut procedures shown in the Step by Step Procedures for hip rafters. Refer to the procedures for single and double cheek cuts on hip rafters and apply the technique to equal-span valley rafters.

1. Start from the plumb line representing the theoretical line length of the rafter.
2. Draw a centerline down the top edge of the rafter stock.
3. Measure at 90° to the plumb line half the thickness of the ridge board and make a mark. For a single thickness ridge board this is $3/4".$
4. Draw a second plumb line at the mark made in step 3.
5. Use a small square and draw a square line across the top edge of the rafter at the intersection with the second plumb line.
6. Measure $90°$ to the second plumb line, half the valley rafter stock, and draw a third plumb line.
7. Draw a square line across the rafter edge at the third plumb line.
8. Draw a fourth plumb line on the other side of the rafter stock at the line drawn in step 7. This step creates cut lines on both sides of the rafter stock as a guide.
9. From the top edge of the third and fourth plumb lines, use a straightedge and draw a diagonal back that intersects the square line drawn in step 5. This forms a small triangle that represents the cut line for the cheek cuts.
A supporting valley rafter must have one edge backed (beveled) from the main ridge board down to the intersection of the shortened valley rafter. Otherwise, this edge will be above the roof plane when sheathing is applied.

A centerline is easy to draw on the edge of rafter stock or any other lumber using a try square as shown in the accompanying illustration. Some squares have indentations in the end of the square to set the pencil and “slide” down the lumber being marked.

**Valley Rafter Tail Reverse Cheek Cut**

The final cut for a valley rafter tail is essentially a reverse cheek cut. The technique used for marking this cut is the same as other cheek cuts. Follow these steps:

1. To calculate the tail length for a valley rafter, follow the same procedure used for hip rafter tail lengths.
2. At the mark representing the length of the rafter tail, make a plumb line mark.
3. Make a centerline mark down the rafter tail in this area.
4. Measure 90° from the first plumb line half the thickness of the valley rafter (3/4") and place a mark.
5. Make a second plumb line mark at the location measured in step 4.
6. Take a small square and mark square lines across the top of the rafter edge at each plumb line.
7. Take a straightedge and mark from the second plumb line back through the centerline at the first plumb line, forming a small pyramid.
8. Cut along the marks made in step 7 to complete the reverse cheek cut.
(continued)

1. Tail length as calculated

2. Plumb line

3. Center line

4. 3/4" Reverse cheek cut

5. Plumb line

6. Square line

7. View from top

8. View from top

Reverse cheek cut

Diagonal lines

Plumb line

Square line

Center line

Reverse cheek cut

Tail length as calculated

View from top
**KEY TERMS**

- rafter tables
- theoretical line lengths
- bird's mouth
- overhang
- projection
- closed soffit
- open soffit
- run wild
- gable end studs
- hip rafters
- side cut
- single cheek cut
- double cheek cut
- dropping the hip
- backing the hip
- supporting valley rafter
- shortened valley rafter

**REVIEW QUESTIONS**

1. Explain the difference between the theoretical line length and the cut line length.
2. What are the rafter tables on a framing square used for during framing?
3. How do the framing square rafter tables relate to the Pythagorean Theorem and a right triangle?
4. Working with an \( \frac{1}{12} \) roof slope, what is the theoretical length for a common rafter on a roof system with a 24' total span?
5. Explain the difference between the overhang and the projection of a common rafter. Draw and dimension an overhang of 12" and a projection of 12"; then compare the results visually.
6. What is the typical angle at which hip rafters and supporting valley rafters attach to the main ridge board on an intersecting roof system?
7. What does shortening a rafter mean? How much is a supporting valley rafter shortened on the end that meets the ridge board?
8. For conventional intersecting roofs that create 45° angles, what relationship do the hip and valley rafters have with each other?
9. How many hip rafters are found on the main roof system when hips are designed for both ends of the roof?
10. Is there a difference between a single cheek cut and a side cut? What is it?
11. How would you define an equal span intersecting roof?
12. For a total run of 13', what is the length of a common rafter with a \( \frac{8}{12} \) slope roof? With a \( \frac{11}{12} \) slope roof using a 13' total run, what would be the length of a hip rafter?
13. Using a framing square, determine the total length for a rafter with a slope triangle of \( \frac{1}{12} \) and a total run of 12'. How about \( \frac{8}{12} \) slope and a total run of 9'?
14. What is the overhang length for a rafter tail with a projection of 20" and a roof slope of \( \frac{1}{12} \)?
15. What is the maximum depth of cut for a bird's mouth? Why is this important?
16. How can the overhang length affect overall operating efficiency of a home?