TIMBER FRAMING

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Framing a Round Barn

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On the front cover, mid-raising of a timber-framed round barn on an island in upstate New York. Story page 8. Photo by Jim Kearns. On the back cover, hydraulic joint-busting apparatus bending a bridled scarf joint at Cressing Temple, Essex, at 2008 UK Carpenters Fellowship meeting. Photo by Ben Brungraber.

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TIMBER FRAMING, Journal of the Timber Framers Guild, appears in March, June, September and December. The journal is written by its readers and pays for interesting articles by experienced and novice writers alike.

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Notes & Comment

Frame 2008

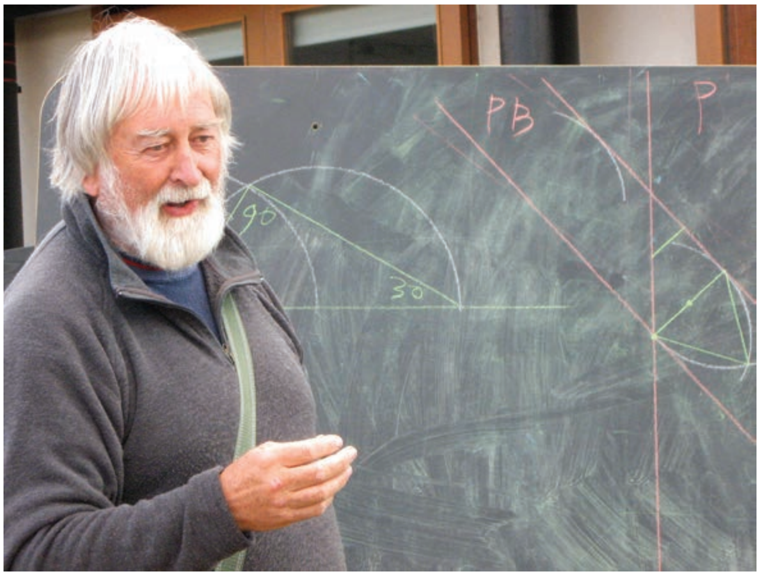
THIS year's annual gathering of the United Kingdom's Carpenters Fellowship, Frame 2008, returned to Cressing Temple, an open-air museum in Essex that features two magnificent barns built by the Knights Templar in the 13th century. Nine Guild members from North America joined hundreds of framers, many with families, from the UK and six other European countries for a weekend of camping, collegial education and fun. Campers and caravans created a village in the fields adjacent to the museum. Cooking and campfires gave people the option to fix their own meals or buy the catered ones served by a vendor on site. The highlights of the weekend were gorgeous weather by day and a full moon at night.

The CF gathering is, by the very nature of most timber framing work in Europe, mainly about traditional methods and materials. This practice was taken a step further and a few centuries earlier than usual by a five-day workshop preceding the general gathering, to build a gardener's shelter for Cressing's walled Tudor garden. Using techniques and tools appropriate to the 13th century, 30 timber framers hewed the timbers, split the chestnut laths and oak roof shakes and raised the structure designed on the geometric principles of the larger barns built at the site in the 1200s. (Visit www.cressingtemple.org.uk for a photo tour of the site.)

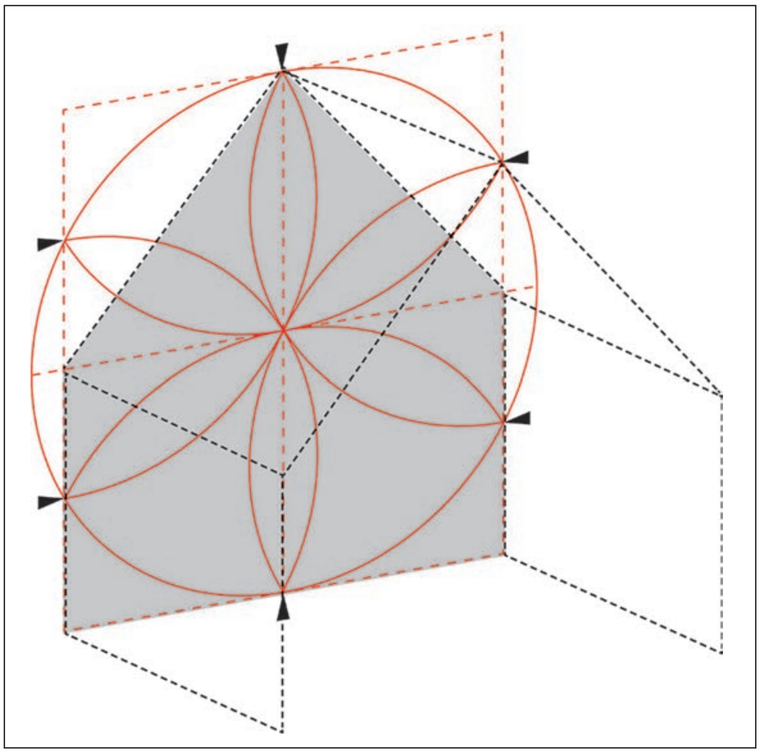
The motto for the workshops was "No math and no power." There were no electric or petrol-fueled tools in evidence, no graduated measuring tools such as rulers or tapes, no spirit levels, pencils or paper.

Laurie Smith and Joel Hendry were principal designers of the frame, assisted by Rick Lewis, Steve Westover and William Clement Smith as instructors during the workshop. Laurie is an accomplished artist and scholar and wrote about geometrical design in medieval Welsh frames in TF 70 (December 2003). The daisy wheel geometry underlying the frame design develops entirely from arcs of circles (it can be found sometimes as inscribed symbols on early American frames), and the physical dimensions of the building and its elements are geometrical fractions or multiples of a unit length kept in the form of a wooden rod.

Laurie and fellow scholar the late Adrian Gibson have proposed that many features of the Barley Barn, from the post-location plan to brace layout and peg location, were geometrically designed. The Barley Barn was built from 480 oak trees between 1205 and 1235, some 50 years before the slightly smaller Wheat Barn it faces across the farmyard green. The new gardener's shelter reflects the style and spirit of the time. The frame was raised in the corner of the walled garden and dedicated by means of a carving on one tie beam to Adrian Gibson and the late Cecil Hewett (well known in the US as author of *English Historic Carpentry*, and whose drawings inspired certain American timber frame revivalists).



Above, Laurie Smith describing the compass-obtained layout for the brace end and the peg hole. Above right, the layout executed on a passing brace. Below, daisy wheel layout yields proportions of garden shelter. Below right, the shelter frame completed in the garden.



Laurie Smith

Photos Will Beemer

You can always learn something new in timber framing. As I sat at the shaving horse making pegs, the order came in for some square and some octagonal pegs. Why different shapes? I asked. The square ones, I learned, were for the half-laps and joints that aren't drawbored, the octagons for the drawbored joints, as the shape naturally feeds better into the offset.

Presentations and other activities at Frame '08 included some shenanigans familiar from Guild events, including axe throwing and joint busting. Peter Walker and Jon Shanks of Bath University brought a devastating apparatus to put bending point loads on a few dozen scarf joints of varying complexity and strength (see several examples overleaf). Testing results will be forthcoming in the Fellowship's handsome quarterly journal, *The Mortice and Tenon* (subscriptions via membership at carpentersfellowship.co.uk). The Saturday-night auction raised over £5000 for developing the National Vocational Qualification for timber framing, one of the major goals for the Fellowship. The presentations in the barns covered square rule, scribing, rigging, engineering, business and history, complemented by outdoor demonstrations on hewing, sawing, archery and blacksmithing. I did a demonstration showing the differences between edge-reference and snap-line square rule layout, and noticed confusion in some of the Fellowship members about the term "mill rule." In the US we use the phrase, invented by Rudy Christian, to describe layout on timbers milled square and to an exact dimension on all four sides, where no discrepancies in size or section within the timber are considered. I learned that in the UK they call this "face framing." Some in the audience thought that mill rule might mean edge-reference square rule, and that square rule refers to snap-line reference only. Part of this confusion might be related to Old World reliance on the chalk line for all layout. I think international order has now been restored.

—Will Beemer

Joint Busting at Frame 2008

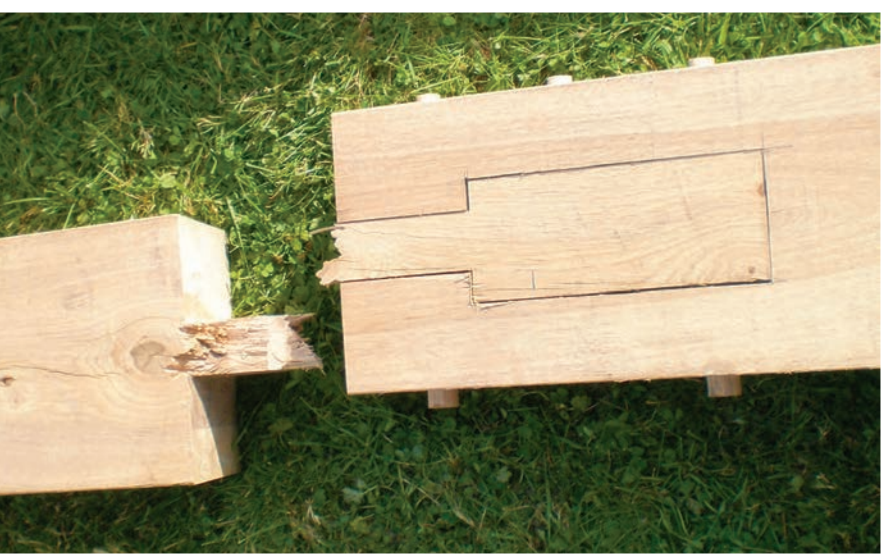
Hydraulic ram device, designed at the University of Bath, UK, testing and destroying edge-halved, splayed and pegged oak scarf joint.

Photos Ben Brungraber

Post scarf with tapered mortise and tenon and double-axis pegging, normally used for in situ repair. In bending it failed at mortise walls.

Very rare machine-cut, undersquinted, radiused, edge-halved, outside-wedge-keyed, wooden-bolted and pegged oak scarf joint before testing.

Bridled, face-halved and pegged scarf tested to destruction. Short grain at large knot made contest unfair, left joinery untested.



Gooseneck pegged scarf, failure in tension parallel to grain.

Gooseneck pegged scarf, failure in shear parallel to grain.

Brace Cutting for the Novice

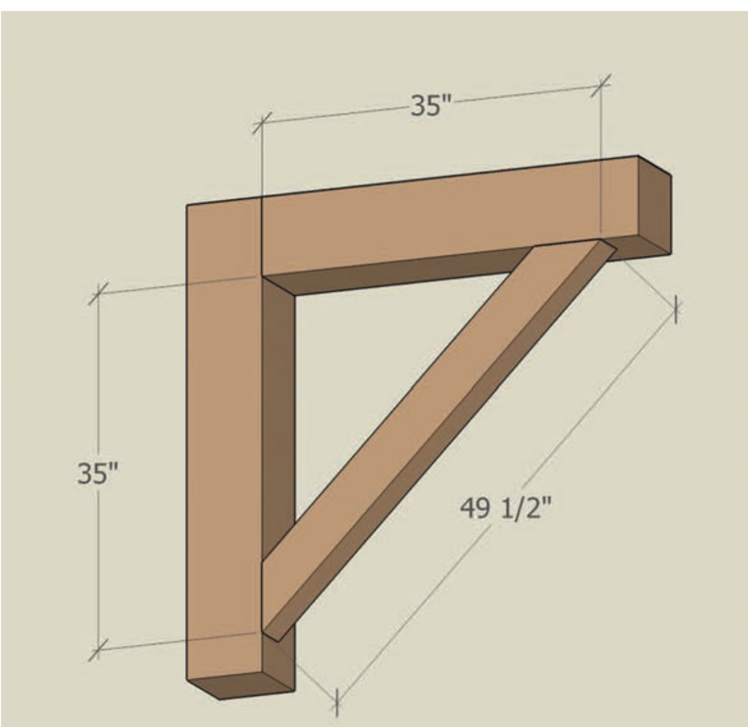
TO many novice framers, making braces seems like a formidable task, Jack Sobon observed in 1993 in *Build a Classic Timber-Framed House*. As a novice framer, I can attest that Mr. Sobon is right: my first braces involved a lot of head scratching. But after developing some simple procedures, and a bit of practice, I now understand braces and can cut them quickly and accurately.

Most timber framing books and classes teach historical methods of cutting joinery primarily using augers, chisels and hand saws. I have a great deal of respect for those craftsmen who can cut frames accurately and quickly using these methods, but I immediately realized that I am not one of them. My approach is to use power tools when they make sense—for quick removal of material—and hand tools when they make more sense for trimming and accuracy.

Realizing that a brace is one of the few components of a timber frame that can be brought easily to stationary woodworking tools, I first thought of cutting braces on a band saw, but the 45-degree cuts would have been awkward at best. My next idea, cutting with a sliding miter saw, worked out well. This tool excels at cutting angles, and most such miter saws can easily handle 3x5 and 4x5 lumber timber, typical sections for ordinary braces.

Brace Geometry. At first glance, 45-degree brace geometry looks pretty straightforward. (Braces at other angles are not so straightforward, since they have different conditions at each end, but they can be worked out on the same geometric principles. The most common brace angle in timber framing remains 45 degrees.)

The length of a brace is the hypotenuse of a right triangle. By the Pythagorean Theorem ($A^2 + B^2 = C^2$), the brace length (the C side, or the hypotenuse) is equal to the square root of $A^2 + B^2$, where A and B are the sides of the triangle or the leg lengths of the brace. For example, if the two sides of a triangle are each 35 in., the hypotenuse is 49½ in. (Fig. 1). Some common leg and brace lengths are listed in the table.



Drawings Ben Weiss

Fig. 1. Unhoused brace geometry.

Leg Length	Brace Length
30”	42 7/16”
35”	49 1/2”
36”	50 29/32”
42”	59 13/32”

For novices, two things complicate brace geometry. First off, when timber framers refer to “brace length,” they do not include the tenons, but braces obviously do include tenons at each end, and they must be accounted for. Second, most braces are housed. In other words, their shoulders are recessed some amount, usually ⅜ in. or ½ in. into the receiving timbers.

For a housed brace, the brace length is the distance from tip to tip (Fig. 2). When assembled in the frame, the brace noses will occupy the housings in the receiving timbers, and their extremities therefore become the points between which the triangle hypotenuse is measured. All this will start to make sense once you’ve done a few layouts and cuts.

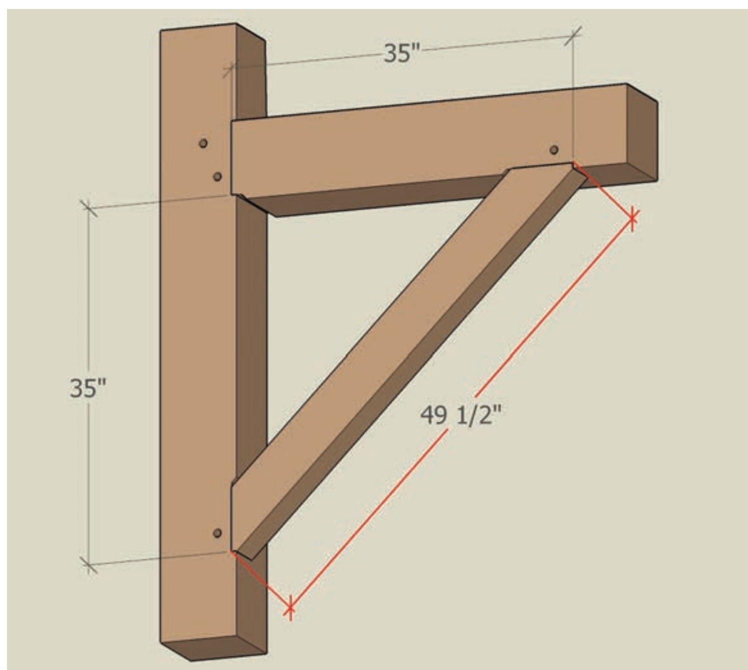


Fig. 2. Housed brace geometry.

Brace Layout. The first step in laying out a brace is to identify the reference edge. With the “best” face up, check both edges for square using a framing square. Draw a triangle on the best face pointing to the preferred edge, which will be the more visible of the two edges when the brace is seen. All layout and cutting will occur from the best face and the reference edge. If the brace stock is noticeably twisted or the reference edge is badly out of square with the face, true the face and square the edge before proceeding. And keep in mind that the reference face will be set flush with the outside of the timber frame, so the face *opposite* the best face will actually be the one seen inside the building.

Next, measure the brace stock to rough length. The rough length must be longer than the brace length to account for the tenons. Adding 6 in. to the brace length will give plenty of rough length for 3x5 or 4x5 braces with ordinary tenons. The brace width doesn't affect matters.

Start the layout on the right end of the brace. Draw a line perpendicular to the reference edge and 3 in. from the end (Fig. 3-1). This line, along with its counterpart on the left end of the brace, will define the brace length. Next, set a combination square or a gauge to ⅜ in. depth and intersect the first line by drawing a line parallel to the reference edge (Fig. 3-2).

Using the combination square or a Speed Square, draw two opposed 45-degree lines, both intersecting the same point defined by lines 1 and 2 (Figs. 3-3 and 3-4). The last mark, the tenon end cut line, is another 45-degree line (Fig. 3-5) parallel to line 4 and 2⅞ in. toward the end of the brace. This measurement assumes brace mortises 3 in. deep, adequate for normal compression braces. If, however, the brace mortises are to be standardized at 4 in. deep, like the mortises for the rest of the joinery, then add an inch to this measurement.

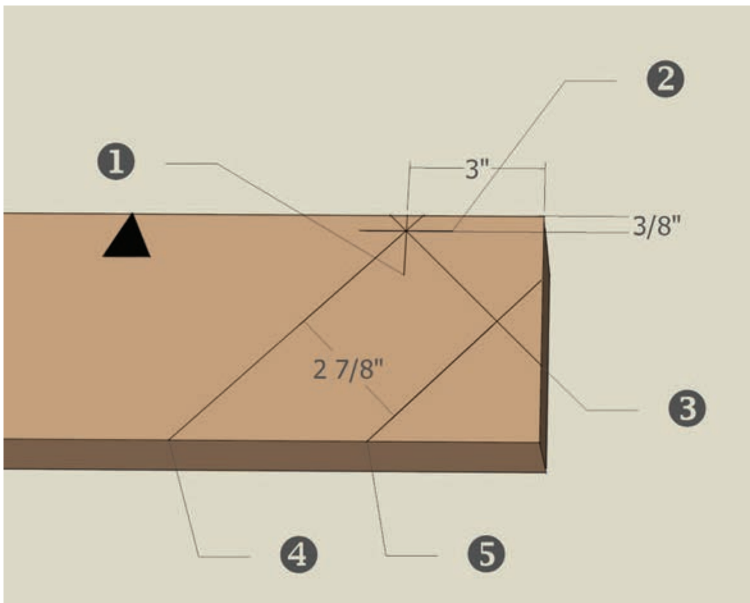


Fig. 3. Brace tenon layout lines.

Do the layout on the other end of the brace by repeating the same steps, but in mirror image. Remember that the position of line 1 determines the brace length, so be especially vigilant when marking this line. Timber frames usually have many braces, so using a length stick marked carefully with cut lines will be more reliable than measuring each time.

Miter Saw Cuts. Once you've finished the brace layout, you're ready to make the miter saw cuts. But before using the saw, make sure that it's set up properly. Check that the blade is perpendicular to the base at a 0-degree bevel setting and square to the fence at a 0-degree miter setting.

Start by cutting the lines on one end of the brace. Be sure to position the brace's reference edge firmly against the saw's fence. For all cuts, the blade should remain just on the waste side of your marks. First, rotate the miter saw table to 45 degrees and cut the tenon nose line (Fig. 4-1). Next, rotate the saw table to the opposite 45-degree setting and cut the tenon end (Fig. 4-2).

The third cut defines the brace shoulder (Fig. 4-3). This cut must not go through the brace, instead stopping at the tenon cheek. Use the depth stop on your miter saw to restrict the depth of cut, which will be equal to the brace thickness less the tenon thickness. In this case, using 4-in. brace stock and 1½-in. tenons, the depth of cut is 2½ in., which will match the offset of the brace

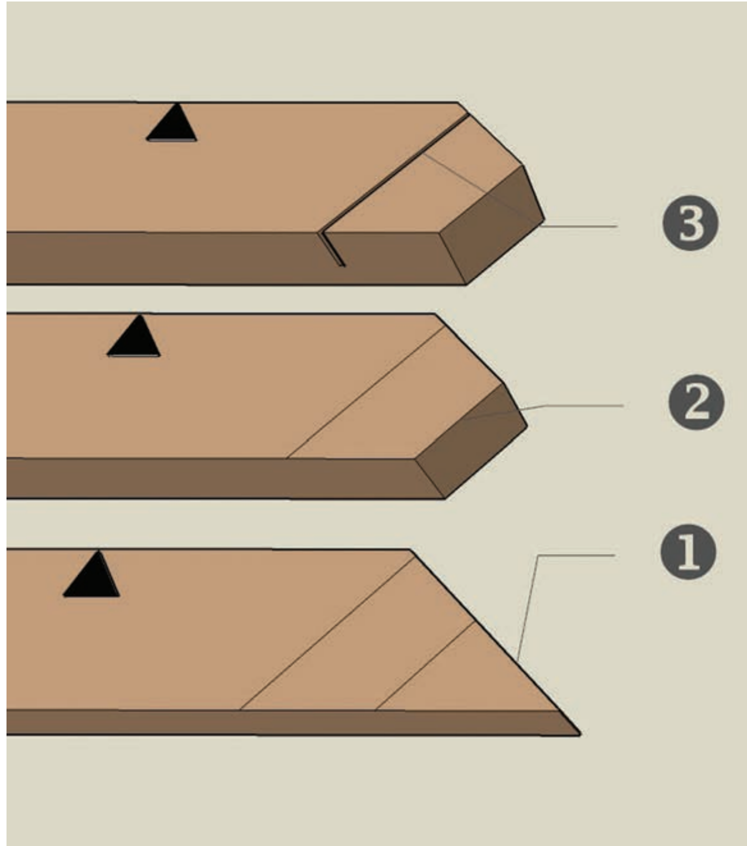


Fig. 4. Successive cuts for brace end.

mortise from the outside of the frame. If there's any irregularity at all in the thickness of your brace stock, it's a good idea to back off the depth by ⅛ in. or more. The remaining material can be removed later with a hand saw.

Repeat the same cuts on the other end of the brace, in mirror image. Remember to keep the reference edge of the brace against the fence for the new cuts (don't rotate the brace). Once you get comfortable with the procedure, you can save time and resetting of the miter saw angle by doing all parallel cuts at one setting, sliding the brace along the saw table as necessary—but be careful about the shoulder cut! It's all too easy to forget to set the depth stop. If your layout and cutting have been accurate, you should be able to set the hook of a measuring tape on the tip of one nose and get the proper brace length measurement by stretching the tape to the other tip (Fig. 5).

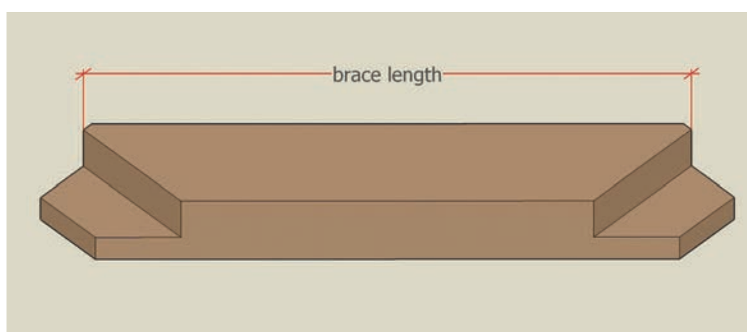


Fig. 5. Housed brace length measurement.

Tenon Cheek Layout. Now that the ends of the brace have been cut, the final round of layout can be done. In this case, using 4x5 stock with 1½-in. tenons, the tenon cheek will be located 2½ in. down from the best face. I use a Borneman layout tool to draw these necessary lines (this handy jig can be purchased on the Guild

Web site), although a combination square or a marking gauge can also be used. Note that our layout technique means that tenons will vary in thickness if there is any variation in the thickness of the brace stock. Tenons can end up thicker (or thinner) than their mortises and may need trimming before assembly.

Starting with one end of the brace, draw or scratch three lines parallel to the best face, defining the tenon (Fig. 6-1, 2, 3), and repeat this procedure at the other end of the brace.

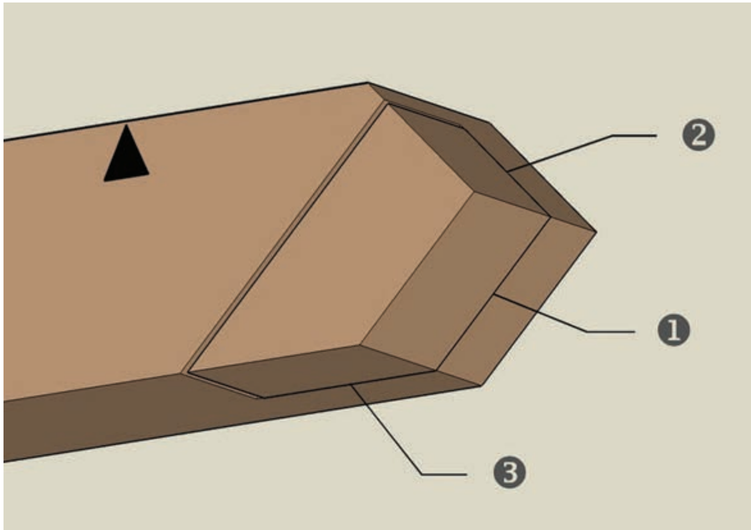


Fig. 6. Tenon cheek layout lines.

Finishing the Tenon. Now that the tenon cheek has been marked, you can rip cut it. Since this cut cannot be made on the miter saw, I decided to cut it with a portable circular saw. (Given a radial arm saw, the more powerful and adaptable original of sliding miter saws, you could do this cut like the others at a fixed machine. With care, you could also make this rip cut exactly on a table saw, though holding a heavy brace at 45 degrees to the table would need a jig.) Assuming you prefer to use a portable saw, take the brace to a workbench and clamp it in a vise. The brace should be mounted at a 45-degree angle, so that the leading end of the tenon is parallel to the floor (Fig. 7).

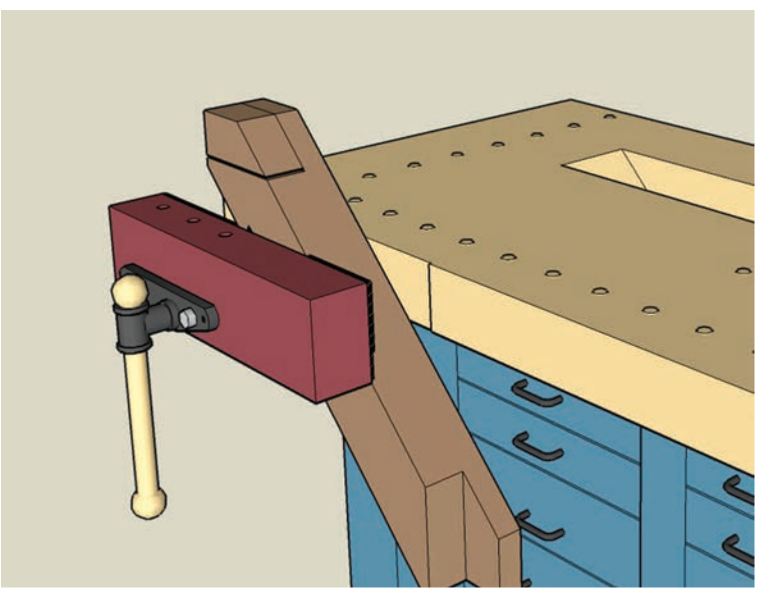


Fig. 7. Workpiece mounted in bench vise.

If you don't have a bench vise or another sturdy mount for the workpiece, this procedure is not safe and another approach should be adopted. It's always possible to chisel away the stock on the waste side of the cheek line, though you have to pay attention to the direction of the grain as you approach the line.

The maximum depth of cut for a 7¼-in. circular saw, the size you are likely to have, is around 2½ in., so it will not cut completely to the tenon shoulder, but it saves time over hand sawing the entire cut. Set the circular saw to its maximum depth and cut on the waste side of the tenon line, keeping the saw base flat on the top of the tenon (Fig. 8). Since this is a freehand cut, concentrate on keeping the saw blade a bit away from the line. Once the blade has emerged on the far side of the tenon cut, you can use the line there as a guide.

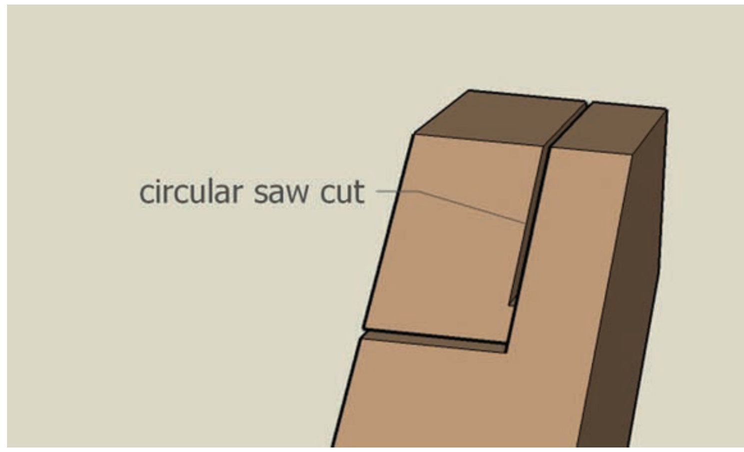


Fig. 8. Freehand rip cut with circular saw.

If the shoulder cut on the miter saw (the cut using the depth stop) was less than the full depth of the shoulder, you'll also need a bit of hand sawing in that direction too, to free up the waste block. Complete the tenon ripcut with a hand saw or, if the grain at the tenon is straight, strike off the waste with sharp blows of a mallet on the face and end of the tenon cheek block.

You can now trim the tenon cheek down to the line using a rabbet plane to trim at least the area next the shoulder, finishing the rest of the cheek with it or another plane. A homemade tenon tester can be used to check the work (Fig. 9).

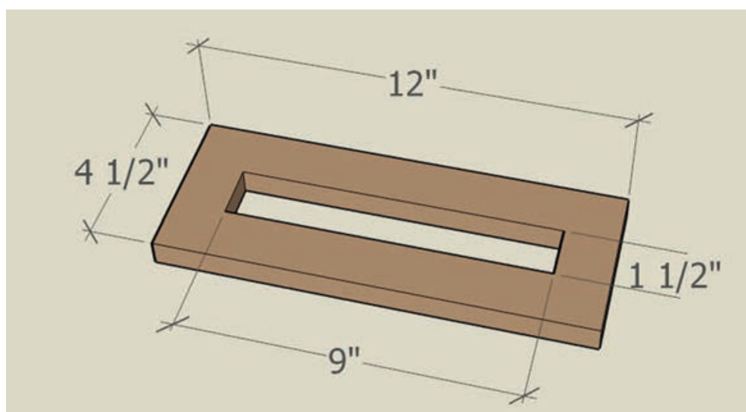


Fig. 9. Tenon tester made of ¾-in. MDF.

If a tenon is too thick, plane some material from the surface of the brace opposite the best face, again bearing in mind that this opposite face will be visible inside the frame. The final touch is to chamfer the ends of the tenon with a block plane. Then rotate the brace in the vise so that you can repeat the same procedure on the other end. Once you've completed both ends, you should have an accurately cut brace that was produced quickly. —Ben Weiss

Ben Weiss (ben@frame1.org) is cutting his first frame and posts his experiences in logging, milling and timber framing at www.frame1.org.

Timber Framing a Round Barn

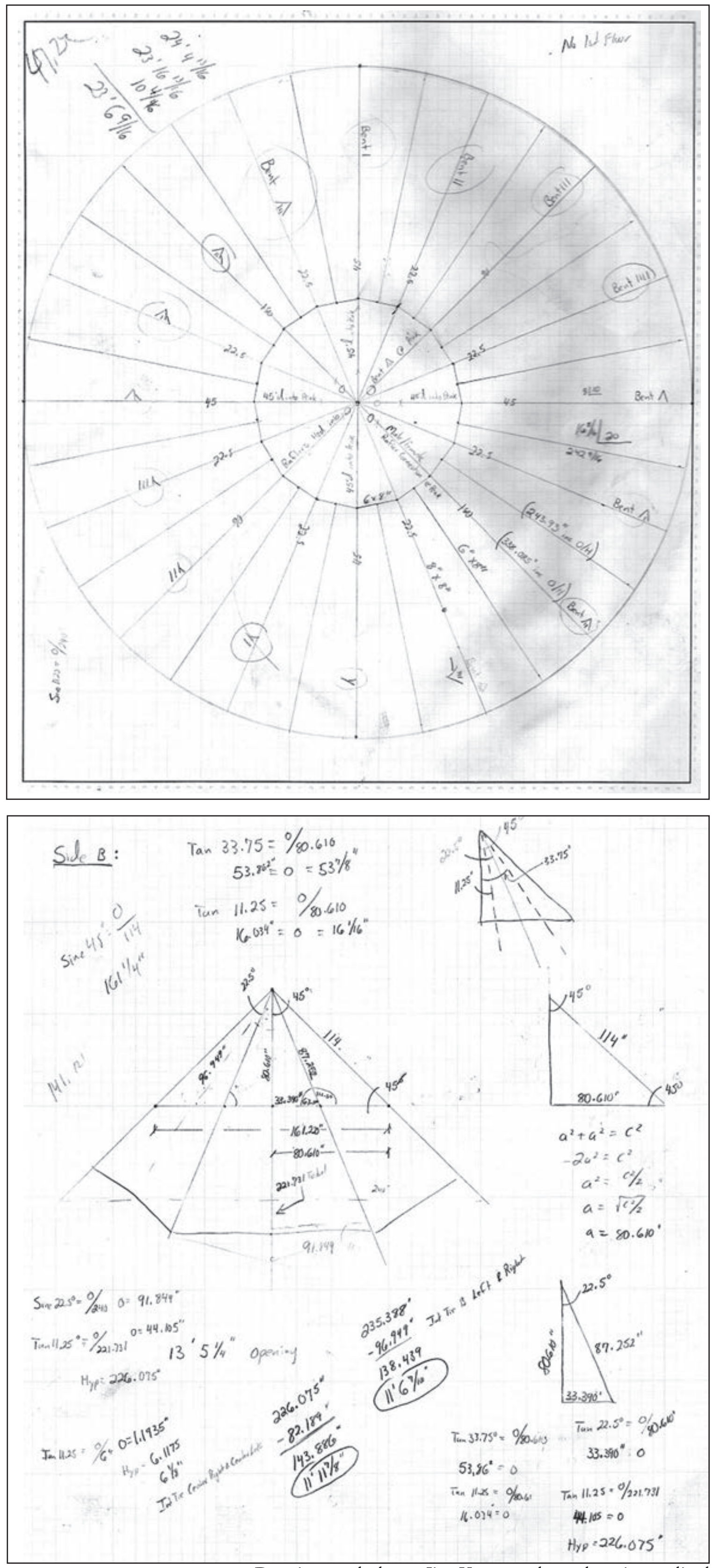
IN the summer of 2005 I received a call from a man two towns west of here in upstate New York, wanting to know if I would consider building him a round barn. The caller, George Story, had my name from a local sawyer whom we both use. He said he'd made sketches of the barn and that it had to be made of locust, timber framed. I told him I'd be glad to meet and look over the sketches. I was a little noncommittal on the phone because I had never even considered the possibility of timber framing a round structure. Years earlier I had attended a Guild compound joinery course and, while working at Vermont Timber Frames (Cambridge, New York) with Paul Martin, I had become fairly competent at the layout and cutting of compound joinery. But timber framing a round structure seemed to be something completely different.

George Story and I met at his home on Thompson Island, his 46-acre island in the Hudson River south of Fort Edward. George had seen round barns in his youth while visiting Amish country and had always wanted to build one. He had two sketches, one a profile of the barn, 40 ft. in diameter, 16 ft. high at the eaves and 32 ft. high at the center. The other sketch showed the footprint of sixteen outer posts and five inner posts forming an irregular pentagon in the center of the barn. One side of the pentagon would line up with the barn door. The other four sides of the pentagon would be the inner walls of horse stalls. The open side of the pentagon that faced the door was longer than the other four sides, allowing the five pentagon points to line up along the same lines as the sixteen outer posts. Outside of the pentagon would be a second-floor deck for hay storage. Even after reviewing the sketches, I was not certain how to timber frame the structure. I told George that I would have to do some research.

The first research step I took was to a bookstore. I leafed through the few books with round barn information and purchased *Round Barns of New York,* by Richard Triumpho, which chronicles the history of such barns (literally round or with six or more sides) in my state. I learned that the leading reason to expend the extra labor and materials to build a round structure was to increase productivity. Once hay was loaded into the center haymow, it did not need to be handled again, as the animal stalls faced the center. Agriculture was *the* big business of the late 1800s, and any potential productivity gains were as important as eliminating steps of any manufacturing process now.

The next step of my research was to visit the famous round barn at Hancock Shaker Village, just over the New York border in western Massachusetts. This is where I actually decided that I could do the job. Though its surrounding exterior wall is masonry, the Hancock barn is framed inside with a series of fairly regular radial bents proceeding around a circle. This approach seems pretty obvious now, but before seeing the Shaker barn I could not imagine how to go about timber framing a round building. Now all I had to do was to determine exactly how the eight bents would be configured to obtain the five-sided open area in the center of the barn. I called George and told him I could do his project.

Frame Detail Sketches. My first task in building anything is to draw it. I don't use design software; for me, drawing tools are pencil, graph paper, straight edge and calculator. Making these sketches was just a lot of fun (Fig. 1). The eight bents are arranged on a circle, and at the inner end of each are posts that all together form a five-sided interior. Each rafter is supported by one outer and one inner post and all meet at the peak. For a uniform appearance, the upper rafter braces all end 6 ft. from the peak despite their respective posts' different distances from the peak. Two flat trusses with steel tension rods span broad openings at the entrance and at the inner irregular pentagon. Fig. 2 shows the frame as we eventually built it, Fig. 3 how we got tools and materials to the site.



Drawings and photos Jim Kearns unless otherwise credited

Fig. 1. Author's typical hand-drawn sketches with integral calculations. At top, rafter centerline plan. Above, rafter elevations.

Fig. 2. Locust and hemlock 40-ft.-dia. round barn frame complete. Nailers are sawn to template arc for vertical board siding. Posts are backed but parallel sided, requiring girts and plates to meet at non-orthogonal joints and braces to meet at compound joints.

Nate Pallace for the Glens Falls *Post-Star*

Fig. 3. Towed barge hauls author, truck and tools to island work site in Hudson River.

Fig. 4. At author's framing yard in Belcher, N.Y., building locust truss to bridge barn door opening. Steel tension rods not yet installed.

Layout and Joinery. The main timbers of the barn are locust, the rafters hemlock. George Story uses a lot of locust on his island because of its reputation for permanence. Supposedly locust lasts two years longer than stone and is just as easy to work. (At least one of these statements is an exaggeration.) Locust has some peculiarities. It sometimes has voids within the wood and it tends to bow a bit when sawn. I would say that 30 to 40 percent of the locust timbers needed to be laid out from snapped chalk lines. Another challenge was to provide the five posts at the points of the pentagon. I was able to get only one at the needed 26-ft. length; the other four had to be scarfed.

I began layout with the two flat trusses, one to span the barn doorway, the other to span the entrance to the central pentagonal area (Fig. 4). This was a good place to start, because the first sections of the frame to be raised would be the bents supporting these two trusses. To determine exactly how the joinery between the upper and lower chords of the trusses and the posts would look, I drew the intersecting posts and chords to scale on a 3x4-ft. whiteboard, adding representations of the floor joists and the pentagon side headers. The whiteboard became the key to laying out most of the joinery in the lower half of the frame.

There are a lot of different angles in a "round" barn. While there are only a few non-orthogonal angles in a normal frame—the brace angles, the roof pitch and the peak angle—in this frame there were at least a dozen other layout angles that I had to apply continually, as well as some that I used only once or twice. I laid out in square rule, using centerlines for reference when necessary, and otherwise using the outside and top surfaces of the timbers.

The actual cutting of the joinery went far better than expected. I had purchased two additional chains for our Makita mortising machine in anticipation of rapid dulling in the locust. All in all, however, the green locust cut pretty well, similarly to white oak—a little harder, but tighter grained. Everyone much preferred working the locust to the hemlock for the rafters. One problem that we did have was cutting the 78.75-degree backing cuts on the outer posts. (Note that we did not cut five-sided posts to obtain orthogonal connections to the wall girts and braces.) Rip cuts in any species are tough on saws and ripping locust was especially so. We actually burned up one 10¼-in. Milwaukee saw.

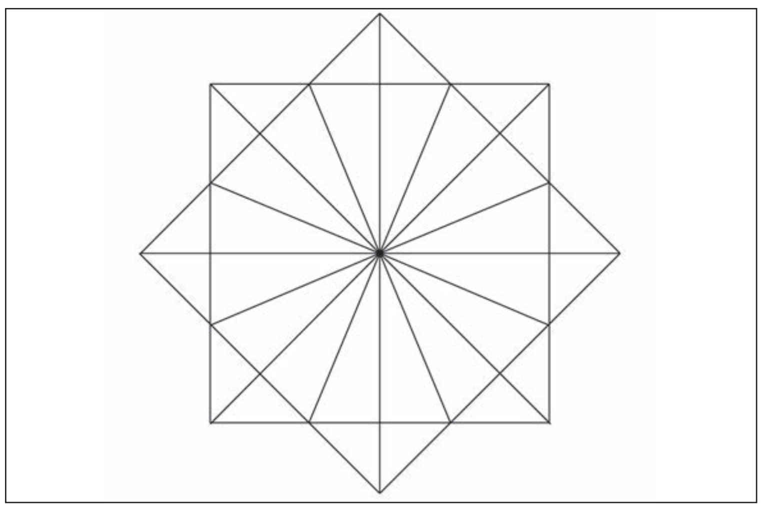
We did not cut joinery on the upper rafters before taking them to the island. The eight upper rafters (the short scarfed portions of the full-length rafters) meet at the peak, each with a compound-angle peak-cut, and all have compound-angle joints with the short purlins that head off the intermediate rafters. It was the purlin joints that I just could not get comfortable with. I decided to lay out all the upper rafters but not to cut them until we were on site. That approach would allow me to verify measurements and angles on the frame itself.

Fig. 5. Frame cutting ran right through the winter. Snow-covered piles made a chore of revisiting any work for reference.

The frame had over 300 pieces. To look at the growing piles of completed timbers all winter should have been very satisfying, but it was instead fairly unnerving (Fig. 5). There could be any number of costly mistakes in those piles, maybe even some show-stopping GCEs (Gross Conceptual Errors). I had no one but myself to check my layout or my trigonometry. Before each piece was cut, I rechecked its layout. This procedure eliminated some mistakes but wasn't as reassuring as a review by a second pair of eyes. Most of the joinery in this frame was cut by Todd Koch of Belcher Hollow Forge in Hebron, New York, who also supplied the ironwork. Todd and I, my son and two other joiners worked on the frame through the winter of 2007–08. We finished up in April. The frame could not be transported to the island until the water level in the Hudson River dropped sufficiently to allow safe barge transport (Fig. 3). As I recall, that was around the second week of May.

Raising the Frame. While we were waiting to transport the frame, another crew was building the deck for the barn. The barn is supported on 12-in. Sonotube-formed columns 5 ft. deep under each of the outer posts and the five inner pentagon posts. The concrete columns support locust sleepers bedded in shale fill and covered with a deck of 2-in. hemlock boards.

First step was to lay out the deck for the radial bents. We started with the main pair of stakes that the deck-building crew used to set up their Sonotube forms. Between them we snapped our first line. This line represented Bent VIII. We marked the end points at 0 and 40 ft., and the center point at 20 ft. From the center point we created a line perpendicular to the first line using 3-4-5 triangles and snapped that line representing Bent III. We then connected the four outer points into a square. The midpoint of each of the square sides became the snapline points for Bents I and V. Again, we connected all the outer points. The midpoints of these new outer lines became the snap points for Bents II, IIII, VI, and VII (Fig. 6). Laying out the deck pockets for each post was now merely a matter of locating each post along its bent line (Fig. 7).



Ken Rower

Fig. 6. Geometric layout to establish bent lines.

Fig. 7. Actual lines snapped on hemlock deck. Note post mortises.

Fig. 8. Lull forklift and first assembly, truss over pentagon opening.

Right about here we got our first curve ball. The outer door frames facing the paddock areas and the inner door frames to the open center area were to be timber framed, but these finish details had not been hammered out until after the frame had been cut. I should have pushed to have them settled before final sketch approval and before cutting. They weren't a big problem to do at the site, but they did delay the schedule. Live and learn.

The raising was unusual for three reasons. First, there was no way to get a decent-sized crane onto the island. The largest piece of equipment we could obtain was a 4WD Lull forklift with a 32-ft. boom. Compared with a real crane, the thing that we missed most in this apparatus was the ability to rotate its turret (Fig. 8).

Second, the ties and joists of this barn are 13 ft. above the deck, quite a bit higher than a standard residential frame's. Third, and most important, the frame structure does not lend itself to large preassemblies. The raising went along at a fairly slow, steady pace.

We started with the two bridge trusses and the posts that support them (Fig. 9). Then we moved counterclockwise, putting up the pentagon headers and the bent "halves" that attach to them (Fig. 10). Once all the outer and inner lower posts were up, we started on the four levels of the outer circumferential girts. In each of the 16 sides we put up the lower girt, the middle girt with its brace, the intermediate joist header with intermediate joist attached, and finally the upper plates (Fig. 11).

Fig. 9. Second raising assembly added truss over doorway and joists to make up main entrance bay.

Fig. 10. Half-bents installed around structure, ready for wall girts, braces, plates and rest of joists. Ties run post to post, joists header to post.

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Fig. 11. Barn takes shape with addition of perimeter elements. Central opening, entrance bay, joists and ties plainly visible from above.

Fig. 12. Lower rafters with braces in place, spanning inner and outer posts. Scarf joints await upper rafters.

The lower lengths of the scarfed rafters (lower rafters) were next. These went pretty quickly. Each joins the top of an outer post and an inner post, both rising from the level of the joists and ties. Each inner post joins the top of a pentagon header or point post. There is also a brace between each lower rafter and inner post (Fig. 12).

The upper rafters followed. These were the pieces with a lot of uncertainty. I had cut the first six. The first pair met in a mortise and tenon joint at the peak; the second pair were housed into the first. Next came one of the rafters that hit the peak at the 45-degree deck angle created by the first four rafters. Last, I cut one of the rafters that go between the last two at a 22.5-degree deck angle (Fig. 13).

We put up the first two sets of upper rafters; these defined the peak. We dropped a plumb bob from the peak to see if it landed over the center point of the snapped lines on the deck. Well, not quite, but with a bit of frame racking we got it exactly centered. Now we put the next two individual rafters in. These confirmed the accuracy of the layout and joinery of the compound angles used to form the peak. They also proved that I had incorrectly laid out the side angles of the purlins (GCE). Now came the painful part. We took the six upper rafters back down. The rest of the upper rafters now had to be cut and the purlin joints re-laid out. When all this joinery was completed, we re-raised the six rafters that had come down and raised the remaining ten. The last timbers to go up were the intermediate rafters with their drop-in purlins attached. The main part of the frame was now complete (Fig. 2).

I haven't mentioned backing cuts on the full-length rafters, because there were none. The rafters could have been backed to make a 16-sided roof, with the intermediate rafters lying in the plane of each roof panel, but this roof was to be conical (Fig. 14). The tapered roof boards would run vertically, with arched nailers between the full-length rafters (and bridging the slightly lower intermediate rafters) to support them. The nailers again would require a bit of trigonometry. Earlier, for the wall stage of the barn, we had made simple curved nailers to receive the vertical siding and make the barn appear round. I had made a faired template using nine calculated points along the 20-ft.-radius arc. Since one template could be used for 64 or so nailers, it was worthwhile to

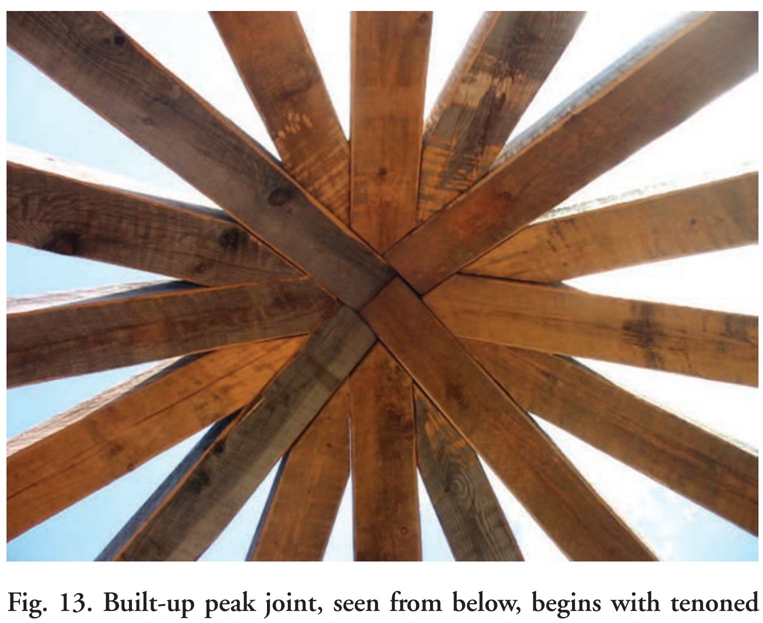

Fig. 13. Built-up peak joint, seen from below, begins with tenoned rafter pair, then adds housed pair, then 45-degree-nosed pairs, and last 22.5-degree-nosed pairs.

spend the time making it. But the procedure for the walls could not be used on the roof nailers because each time we moved up the roof we changed the radius of the arc, making any fixed template a waste of time. Luckily, I had just read a tip in *Scantlings* by Clark Bremer about laying out arcs using a chain. I was thus able to lay out an arc for each ring of nailers, connecting pencil points made through the chain links. The method worked great and was a huge time-saver.

Anything that I would have done differently? Oh yes, several things in addition to getting the timber frame finish details settled before cutting. I should have taken more pictures of the entire process. It always seemed to interrupt the flow of work to stop and take pictures, but this was a great project, possibly the best project I'll ever be involved with, so more pictures would have been good. I also would have taken better notes during layout. Unpiling timbers so that I could look at joints because I could not remember exactly how I laid them out was a giant pain and a big time-consumer. Finally, I would have avoided using purlins in the roof system. Instead I would have extended the truncated intermediate rafters right up to the peak so that the roof had 32 panels instead of 16. This would have made the roof arch nailers much easier to manufacture, since they would be shorter and not need to bridge the intermediate rafters, which now lie a little below the inside surface of the cone (Fig. 15).

In the end, I found eight layout mistakes. Five were minor and easily corrected. One required turning a timber over and cutting a new brace pocket. The last two required me to replace a post and an intermediate floor joist. —Jim Kearns

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Fig. 14. Finished barn with conical slate roof settles into rural idyll.

Fig. 15. View of underside of finished conical roof. Braced rafters are scarfed at inner posts.

WHEN ROOFS COLLIDE

IV. The Power of the Tangent

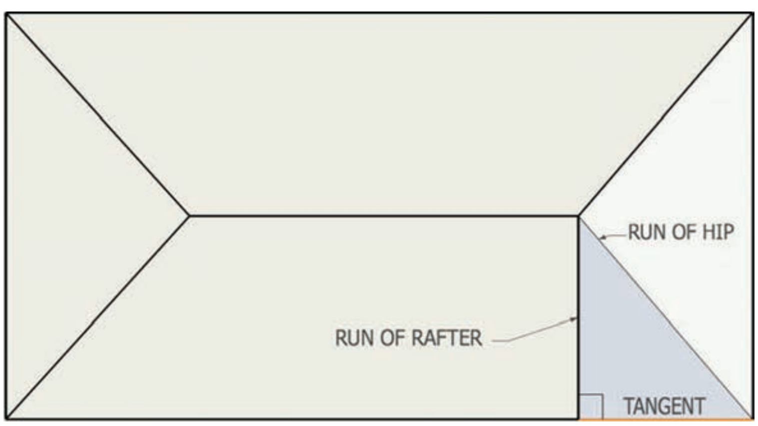
This article is fourth in a series on compound roof geometry and layout. Earlier articles, in TF 70, 71 and 73, appeared under the general heading "Timber Framing for Beginners."

IN previous articles in this series, we have looked at various ways to determine timber lengths and cutting angles at the joints in hip and valley roof systems. The framing square, developed drawing, the "kernel," the "multipliers" and the Hawkindale angles are all tools that can be used to find the required information. But visualization is the most important skill that the roof framer can develop; when one is able to see in the mind's eye the various roof planes coming together, these tools become more useful. Here we'd like to introduce another concept to help visualization: the *tangent*.

Plumb and level cuts on the sides of rafters are relatively easy to determine, but in compound roofs these rafters join other pieces that require a second angle laid on the top or bottom surface (or edge) that results in a bevel cut; hence the terms *edge bevel, compound joinery* and *compound roof*. The edge bevels are not easy to visualize—until you learn how to use the tangent.

In our context, the tangent is a line drawn in plan view square to the run of any rafter, and which we will use as one side of a right triangle. This line is extended out to intersect a line representing the edge of the member the rafter frames into. The triangle is completed by a line representing the rafter run.

Together with the rafter length (at right angles to the tangent, like the run), this triangle will define a tangent plane and ultimately the angles of the edge bevels (Fig. 1).



All drawings Will Beemer

Fig. 1. In hip roof plan view, tangent line is struck square to rafter run and extended to meet hip run, forming tangent plane.

Why call our line a tangent? The term appears in H. H. Siegele's manual *The Steel Square* and a few other carpentry texts, but without derivation. In fact, it is tangent to the square end cut of a rafter. Also, if we view the run of a rafter as the radius of a circle, the line square to the run at the perimeter is tangent to the circle, a more familiar context. The tangent lies in a right triangle opposite the angle we seek. Using the tangent as a hinge and substituting rafter length for rafter run and hip length for hip run, we pivot the plan triangle up into the main roof plane, to develop a new tangent plane triangle that contains the angles we seek (Fig. 2).

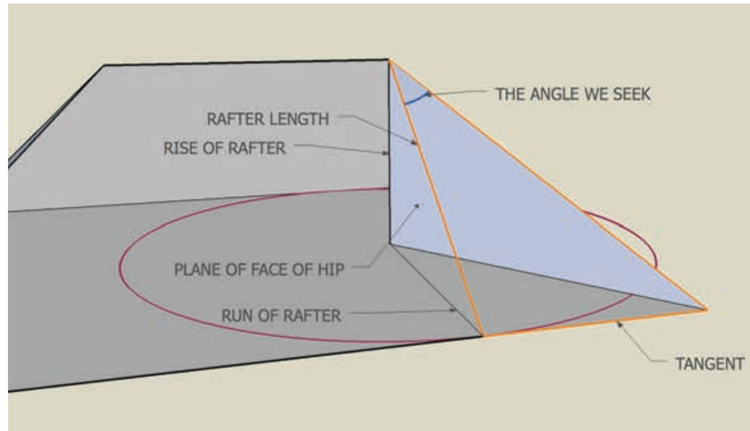


Fig. 2. Tangent triangle rotated up into main roof plane to become tangent plane containing desired edge bevel.

You'll want to draw the exercises, starting in plan view. I show them here in 3-D perspective for clarity and, for simplicity, I use lines and planes without showing timber thicknesses. Since we're looking just for angles, the results will be the same. The tangent and the tangent plane always appear in shades of orange and pink.

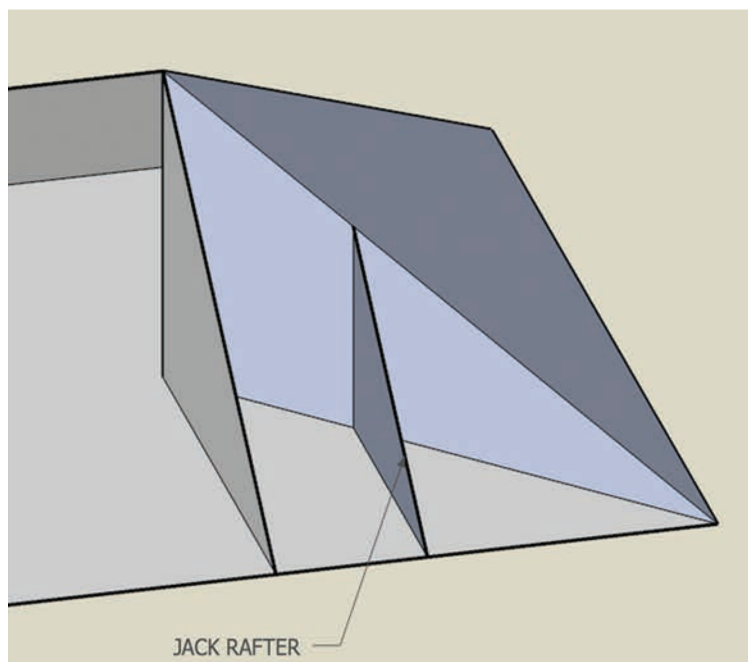


Fig. 3. Rendering of regular hip roof with jack rafter.

In Fig. 3 we have the representation of a 9:12 regular hip roof (main and adjacent roof pitches equal and forming a 90-degree corner in plan) with jack rafter, similar to the material example we used in the first article of the series. The angle we are looking for is the bevel to be laid out on the top of the jack, which together with the plumb cut for a 9:12 pitch will give us the cut on the jack where it meets the hip. Using our previous tools, this angle would be Hawkindale P2 or the angle defined by "side cut of jacks" in the table on a rafter square (Figs. 4 and 8).

In Fig. 5, strike a line *CD* (the tangent) square to the jack run from the foot of the jack. In this case it coincides with the eaves. Run it out to meet the plane of the side of the hip. That point coincides (again, in *this* case) with the point where the foot of the hip meets the eaves. If we connect the end point *E* of the run and the end *D* of the tangent, we get a plan view triangle *CED*. To find the rafter length we can lay out the rise (9 units) at right angles to the run (12 units) in plan view. To construct the tangent plane, set a compass to the rafter length and swing an arc *AB* back to an extension of the rafter run. Connect points to create the tangent plane, shaded orange in Fig. 5.

To see this better, imagine that the tangent line is a hinge, and lift point *X* up until it is plumb over point *Y* (Fig. 6).

This plumb line is the rise of the jack rafter, and the tangent plane in this case is the same as the roof surface triangle we developed in the kernel in earlier exercises.

For regular-pitch, regular-plan roofs like our example, the tangent will always equal the run because the plan view angle between the hips or valleys and the jacks is 45 degrees. Thus, to obtain the bevel for the jack for all regular roofs, imagine the blade of the square (the 2-in. arm) lying in the main roof plane and set against the back of the hip or valley. The bevel is found by holding the run on the tongue (the 1½-in. arm) and the length on the blade (Fig. 7).

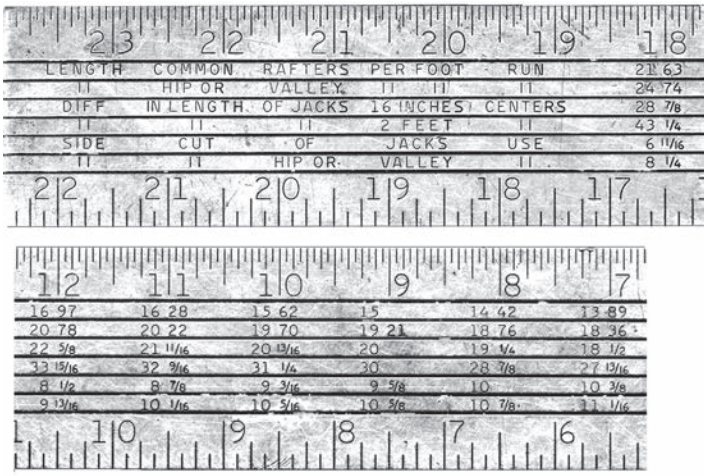


Fig. 4. Part of tables engraved on blade of rafter-square giving edge bevel ("side cut of jacks"). In the 9-pitch column, 9⅝ is shown as the number to hold, as in Fig. 8.

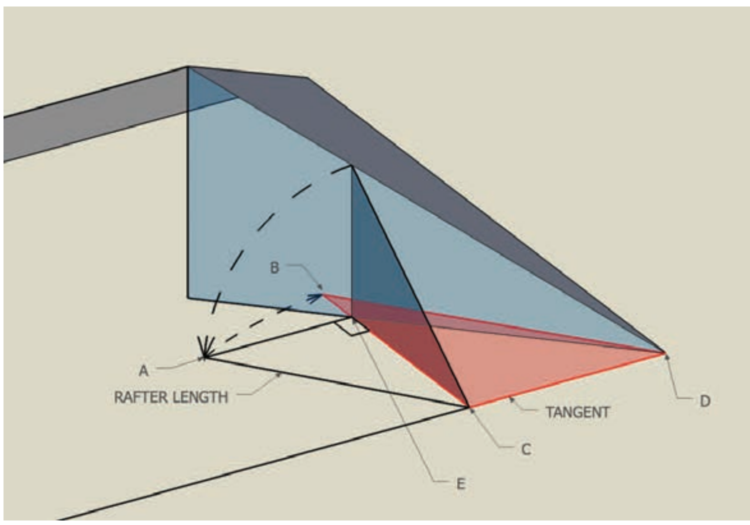


Fig. 5. Producing the tangent plane starting in plan view requires laying out jack rafter triangle and translating resulting rafter length to meet an extension of rafter run.

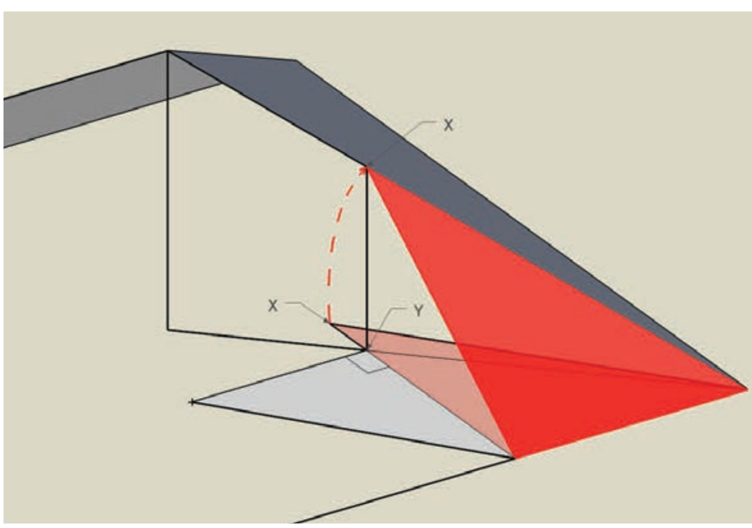


Fig. 6. Raising tangent plane into plane of roof.

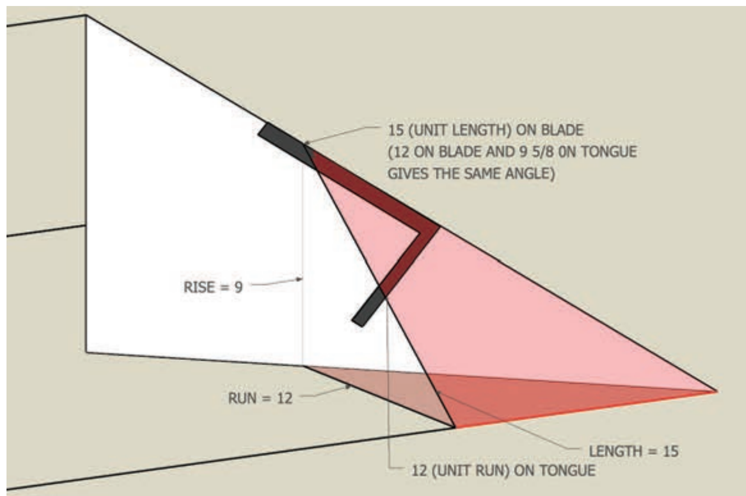


Fig. 7. Finding bevel angle for jack on framing square.

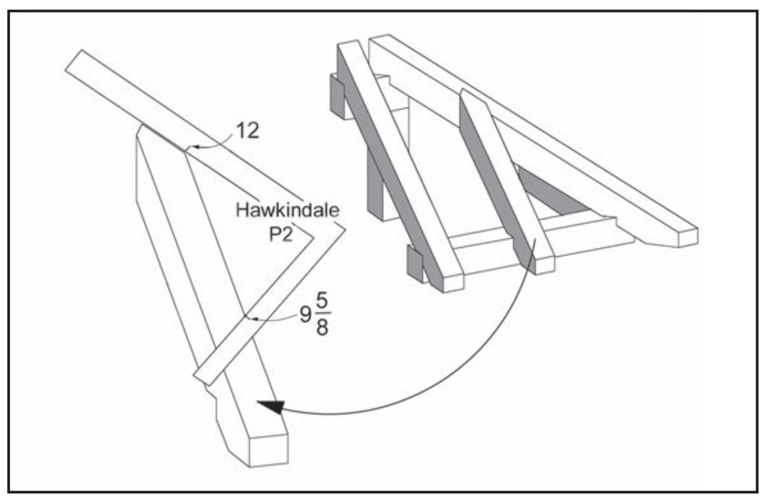


Fig. 8. Laying out edge bevel, also called "Hawkindale P2," with tongue set to 9⅝ and bevel drawn along edge of blade set to 12.

As we see in Fig. 7, this angle is formed by holding 12 (unit run) on one arm and 15 (unit length) on the other; mark the 15 side. On the framing square table "side cut of jacks," we will find the number 9⅝ under the 9-pitch column. This number, held on the tongue with 12 on the blade, will yield the same proportion (Fig. 8).

The numbers are just reduced to a common denominator of 12 to make them manageable on the square; otherwise at some pitches the numbers could be greater than the arm length of the square. In teaching the use of the square to students, the question always comes up: "How do I know to mark along the 12 side?" As we saw graphically in Fig. 6, the length of the rafter is longer than the run and the tangent is constant, so the angle at the peak of the tangent plane triangle must be more acute than the plan angle of 45 degrees. Holding the run on one arm of the square while marking the length along the other produces the more acute angle.

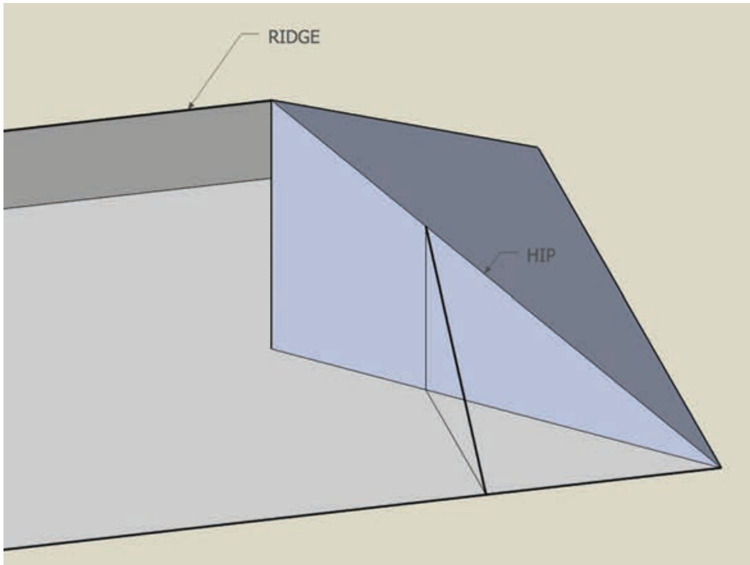


Fig. 9. Rendering of adjacent roof showing hip plane.

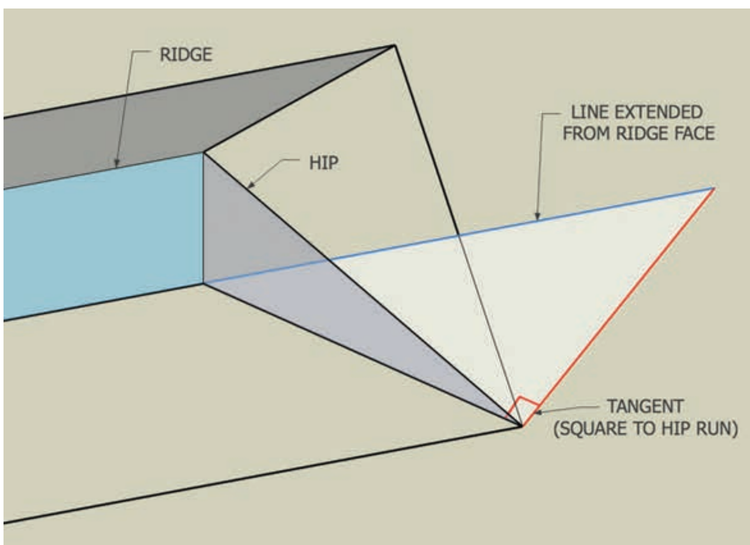


Fig. 10. Striking tangent square to the hip run to meet a second line representing plane of ridge face.

All of the above principles hold true for hips and valleys as well as jacks, and the power of the tangent will become more evident as we move through the next example and on to irregular roofs, which may have differing main and adjacent pitches, non-orthogonal plan angles or both.

LOOK at the hip run in Fig. 9, and suppose the hip is bearing against a ridge at the peak. Following our drawing script, (and with the reader drawing in plan), strike a line square to the hip run from the foot of the hip (Fig. 10).

Run this out to meet a line (blue in the 3-D rendering) representing the plane of the face of the ridge. Next, draw a hip elevation triangle with the common rafter rise perpendicular to the hip run and the line ends connected to find the length. (I assume here

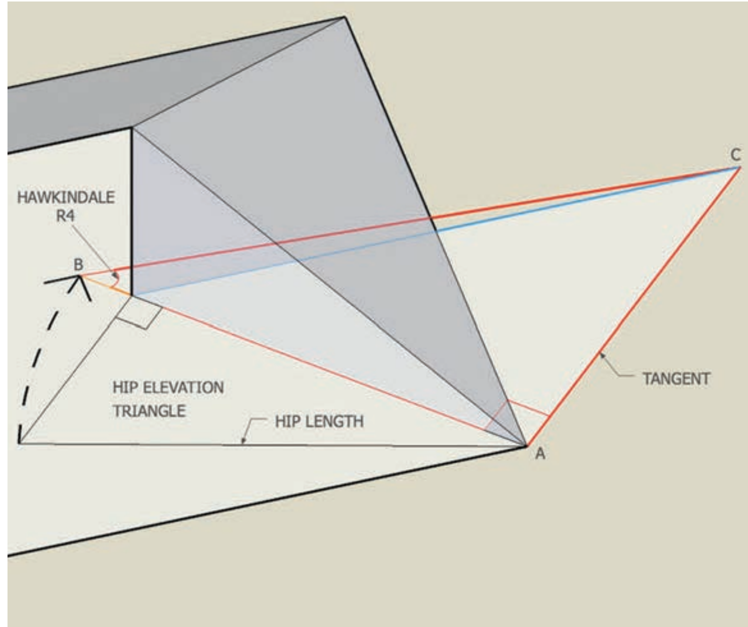


Fig. 11. Swinging hip length over to meet an extension of hip run and joining new point to end of tangent.

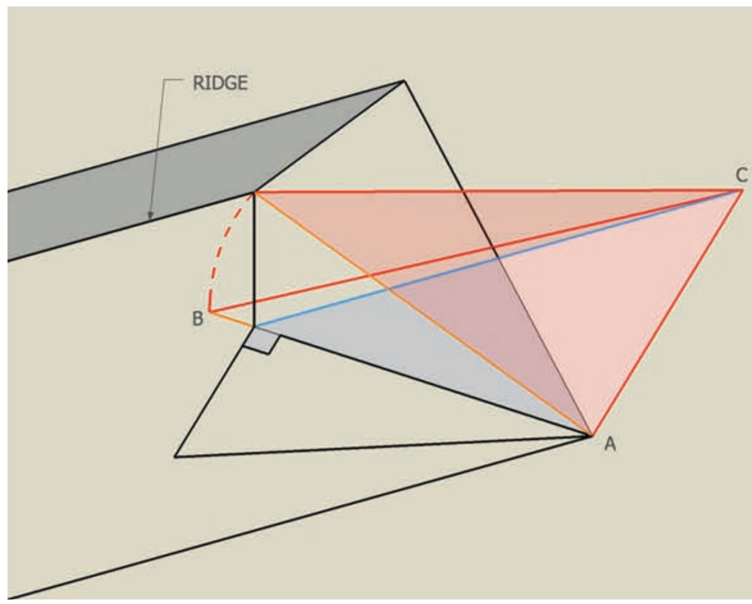


Fig. 12. Raising tangent plane for hip to meet peak.

that the reader knows how to find the rise for a given run for any rafter, as well as the principles of folding down an elevation triangle onto the plan view. If not, read the previous articles in this series and have them handy.)

Next, arc the hip length over to an extension of the hip run *B*, and connect this point to the end of the tangent line at *C* (Fig. 11).

We now have developed the tangent plane for the hip, and the angle given by *ABC* is the one we seek. It's Hawkindale R4, or "side cut of a hip or valley" on the rafter square.

If we lift point *B* up to the peak, as in Fig. 12, we see the tangent plane in place. Note that this plane and angle are on the *unbacked* surface of the hip. This is useful because usually the hip joinery will be cut, or at least laid out, before the backing cut is made. This attribute can also be seen in Fig. 13, where we've depicted a framing square with the tongue representing the tangent and the blade the surface (unbacked) of the hip timber.

We must have the square lying on that unbacked surface in order to strike a line perpendicular to the hip run (the backed surface of the adjacent roof is blue and runs under the orange tangent

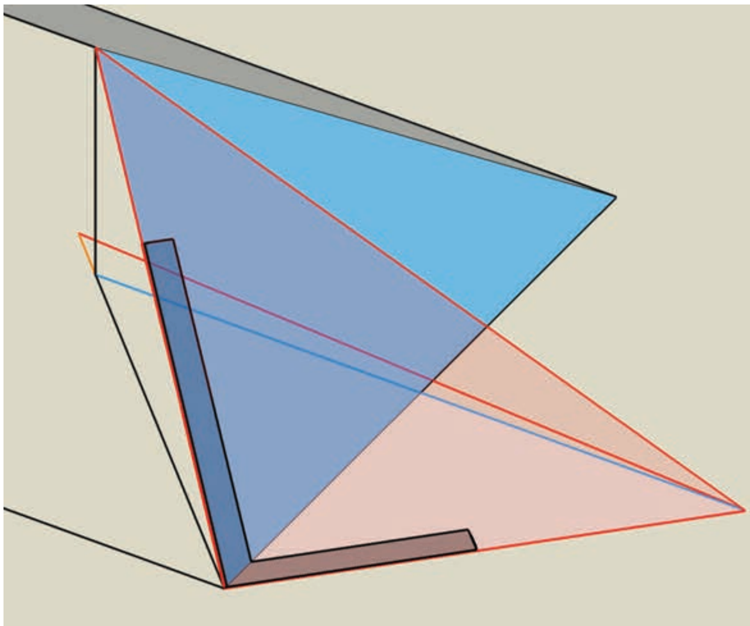


Fig. 13. Rendering of framing square with tongue representing tangent and blade representing unbacked surface of hip.

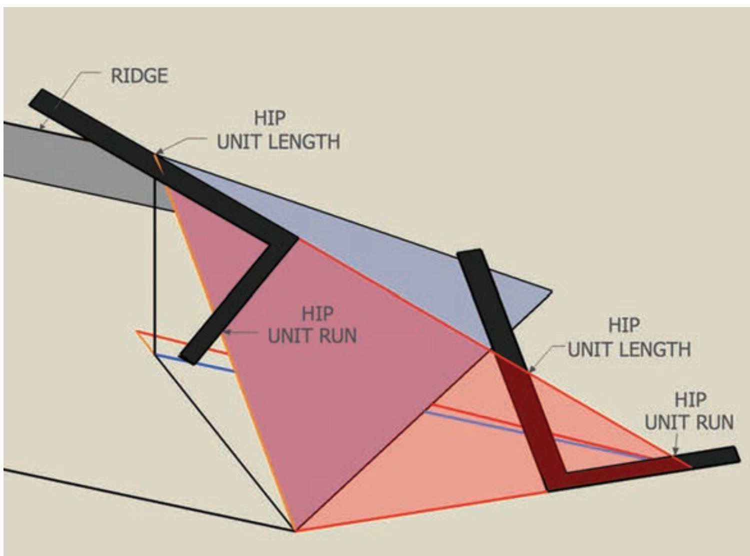


Fig. 14. Bevel angle for regular hip given by holding run of hip on tongue and length of hip on blade.

plane). We are assuming that all timbers are rectangular in section and have plumb sides, so the unbacked surface will be as shown. Again, the bevel angle for this regular hip can be drawn by holding the run of the hip on the tongue and the length of the hip on the blade and marking along the latter (Fig. 14).

For a 9:12 common pitch, by trigonometry the unit run for the hip is 16.9706 and the length 19.2094; the latter gives the edge bevel. The "Side Cut of Hip" table on the square shows 10⅝; holding this on one arm, 12 on the other and marking along the latter give the same angle because the proportion is the same.

Let's look back at the kernel we created for the hip roof in the second article of this series. It's a valuable visualization exercise to cut one of these kernels out of posterboard and fold it up to see how the surfaces intersect (Fig. 15).

Since it's not actually a plane of the roof, the tangent triangle for the unbacked surface for the hip is missing from the kernel, but it's easy to construct. Let's now develop this fifth triangle for the hip.

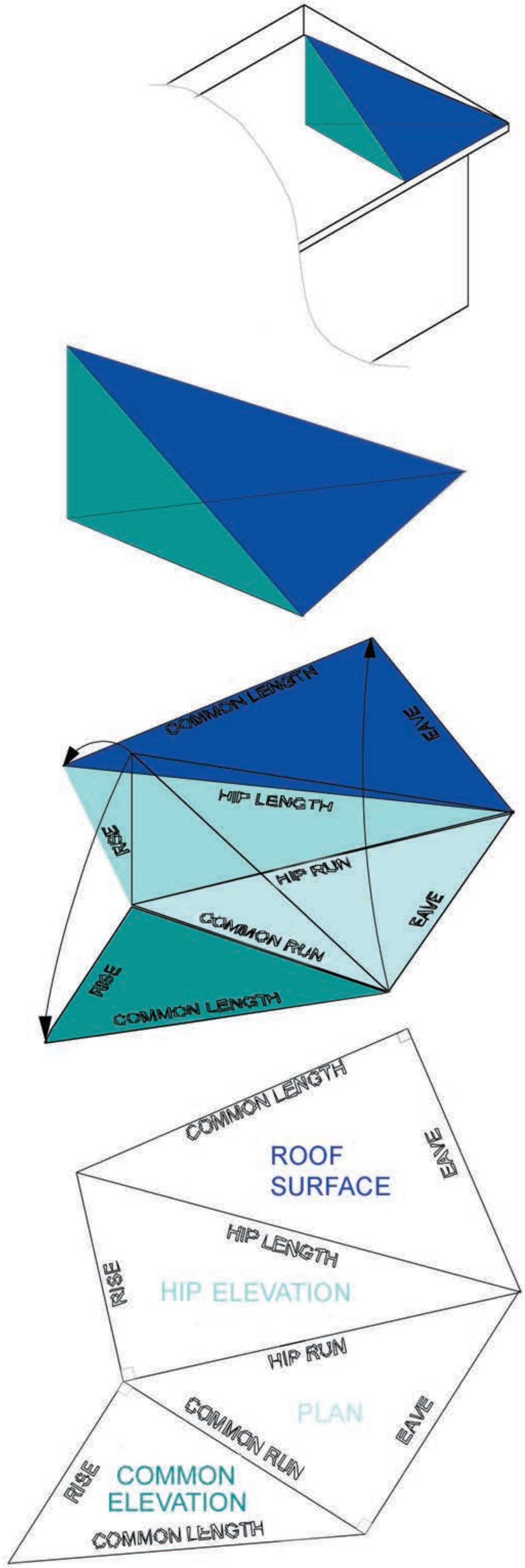


Fig. 15. Roof kernel for a hip roof, all surfaces ultimately unfolded onto a single flat sheet.

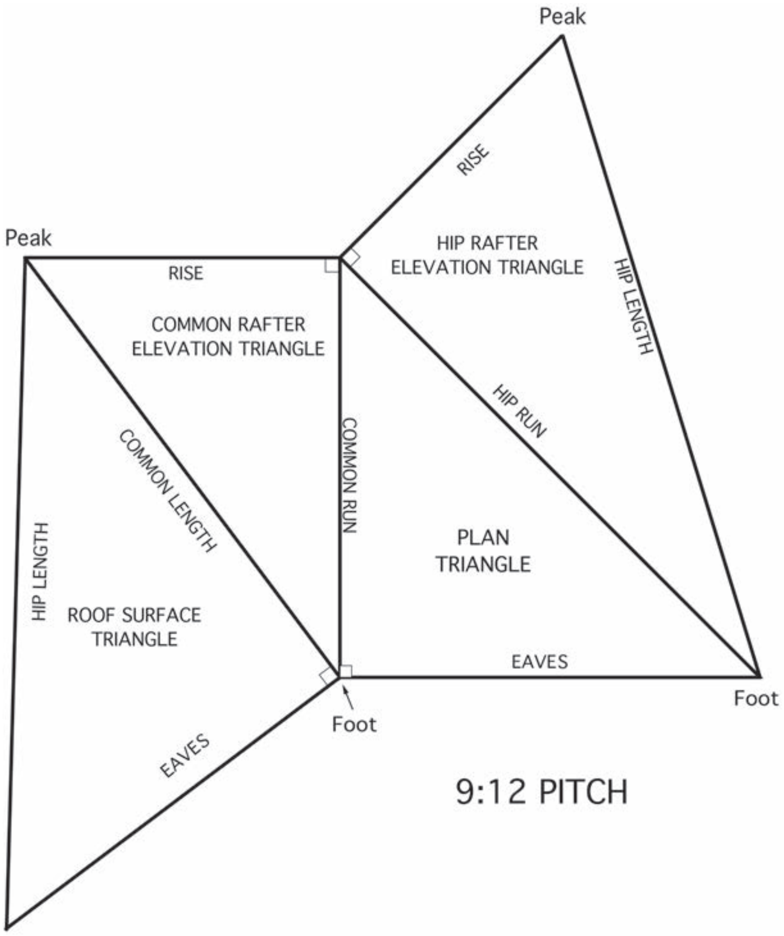


Fig. 16. Roof kernel alternate presentation.

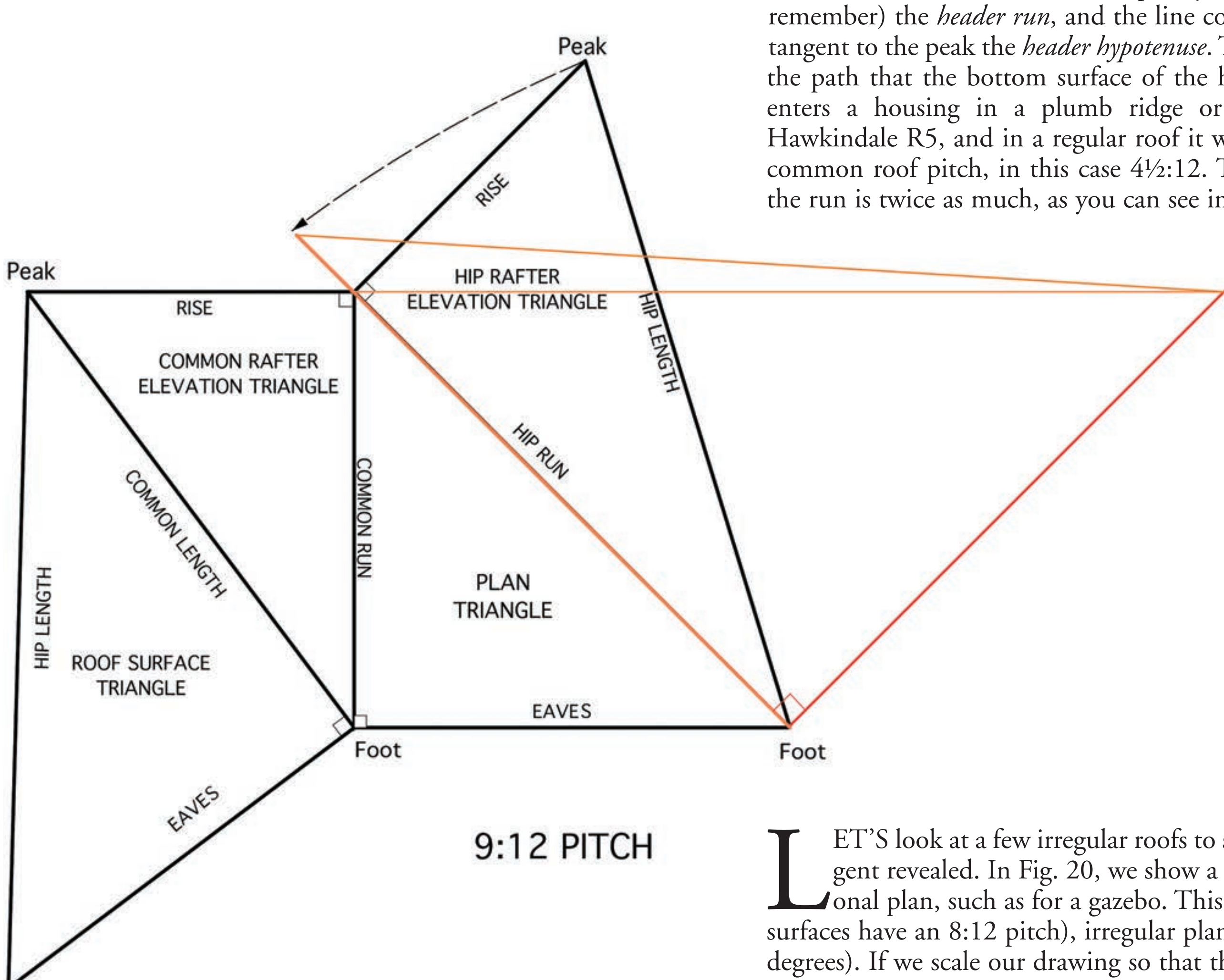


Fig. 17. Drawing tangent triangle superimposed on kernel.

Draw the four triangles for the hip by using the script in TF 71, page 9, except place the roof surface triangle on the opposite side, next to the common elevation triangle, with which it shares the common length line (Fig. 16).

Next, draw the tangent triangle by superimposing it over the kernel. As before, draw a line at right angles to the hip run from the foot of the hip. Extend a line out from the ridge (here a projection of the common rise line) until it intersects the tangent. Now we have the tangent length. (Remember, in a regular hip it's equal to the run.) We can now arc the hip length back down to an extension of the hip run, and connect the dots, as shown (Fig. 17).

Then we can swing this whole triangle out, pivoting on the hip foot, until the hip length lines coincide (Fig. 18).

It's a bit easier, though, just to arc the tangent length out until it's square to the hip length. Connect the end of the tangent line to the peak of the hip length and there you have it. Cut the perimeter of the model out and fold it up on the hinge lines (those shared by two triangles) to see various planes in action. Notice that the line you extended out from the ridge in Fig. 17 was exactly twice as long as the common rafter run—again, because of the 45-degree deck angle of a regular-plan roof.

In Fig. 19, we see the triangle *ABC*, standing in the plane of the plumb face of the ridge. This triangle is bounded by the common rise *AB*, the line *AC* that's twice the common run, and the line *BC* connecting the end of the tangent to the peak. Since this plane represents the plumb face of the ridge, it can also represent the face of a plumb header such as the one we saw in our valley model in the last article in this series (TF 73, page 4). Most of these constructions and resulting angles will be the same for a valley as a hip. To have some common terminology, then, let's call the line that's twice the common run (that relationship only applies in a regular roof, remember) the *header run*, and the line connecting the end of the tangent to the peak the *header hypotenuse*. The latter line represents the path that the bottom surface of the hip or valley traces as it enters a housing in a plumb ridge or header. This angle is Hawkindale R5, and in a regular roof it will always be half of the common roof pitch, in this case 4½:12. The rise is the same but the run is twice as much, as you can see in the drawing.

LET'S look at a few irregular roofs to see the power of the tangent revealed. In Fig. 20, we show a hip rafter over an octagonal plan, such as for a gazebo. This roof is regular pitch (all surfaces have an 8:12 pitch), irregular plan (the deck angle is 67.5 degrees). If we scale our drawing so that the common rafter run is 12 units (treating jacks as commons of varying lengths), the rise for both the commons and the hip will be 8.

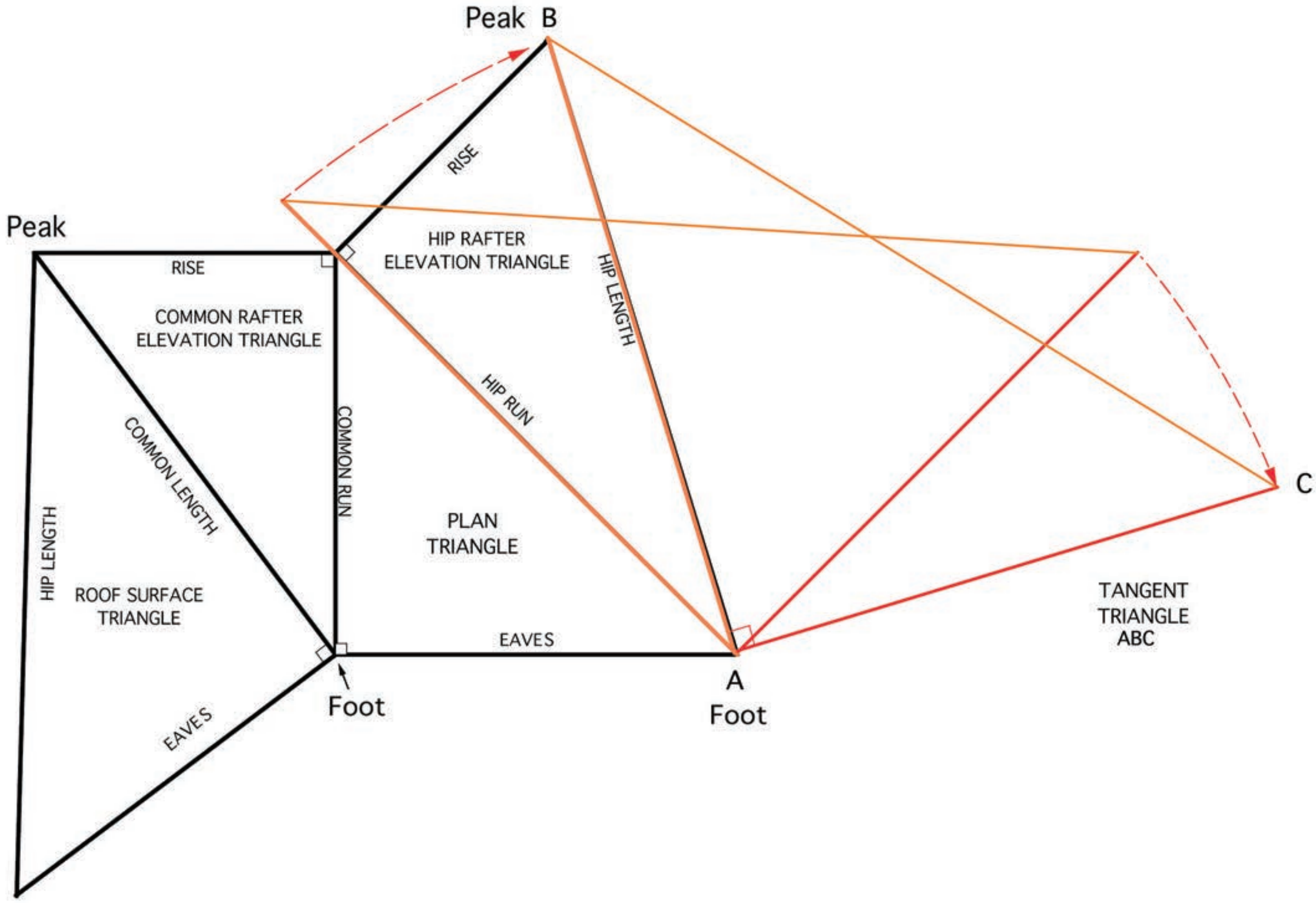


Fig. 18. Swinging out tangent triangle to coincide with hip length.

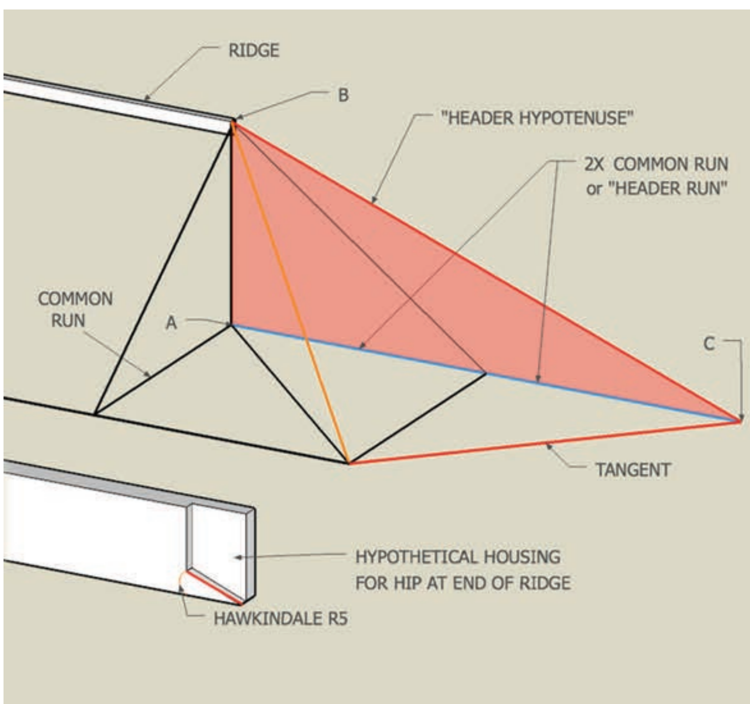


Fig. 19. Header hypotenuse, obtained by doubling common run and holding rise constant, gives seat angle for hip or valley entering ridge or plumb header.

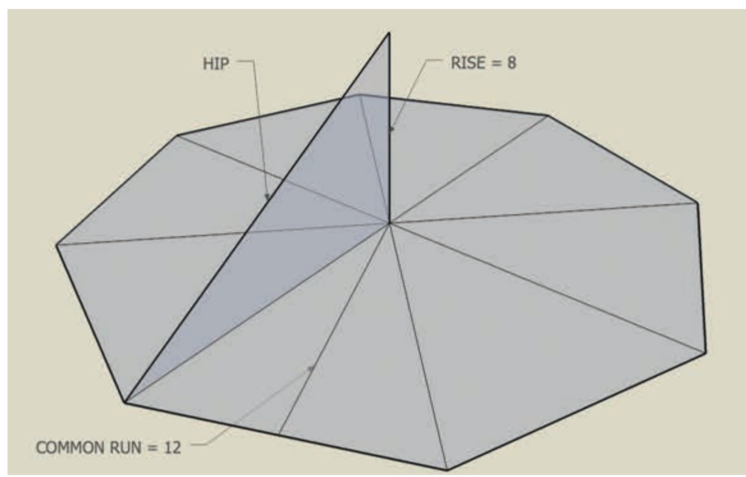


Fig. 20. Rendering of hip rafter in polygonal structure.

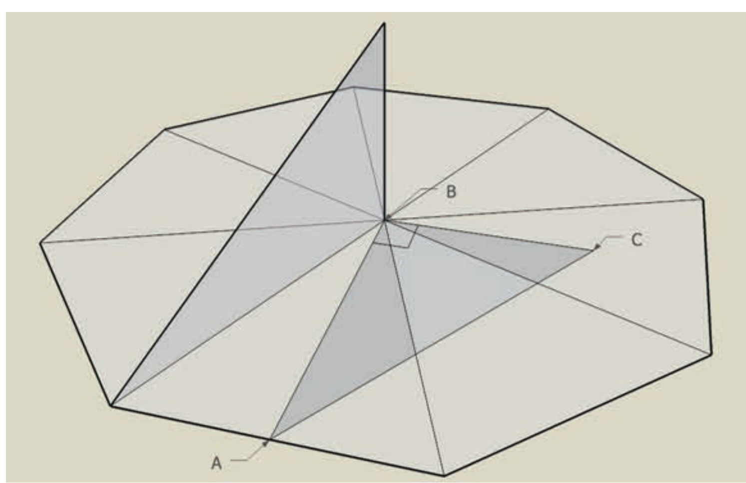


Fig. 21. Common elevation folded down onto plan.

Draw a folded-down version of common elevation as in Fig. 21. The plumb cut on the side of the commons will be *ACB* (or holding 8 rise and 12 run on the square). To find the edge bevel where the jack meets the hip, we can't use the framing-square tables anymore because they're only for regular roofs.

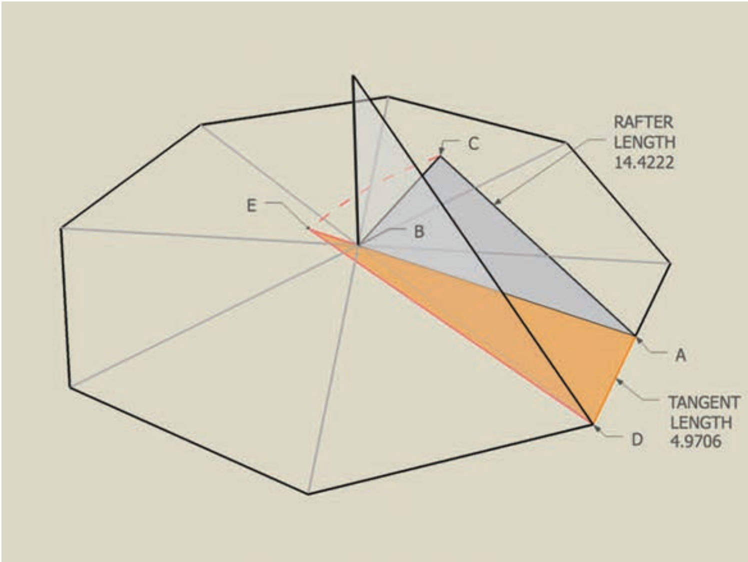


Fig. 22. Producing the tangent triangle for an irregular plan.

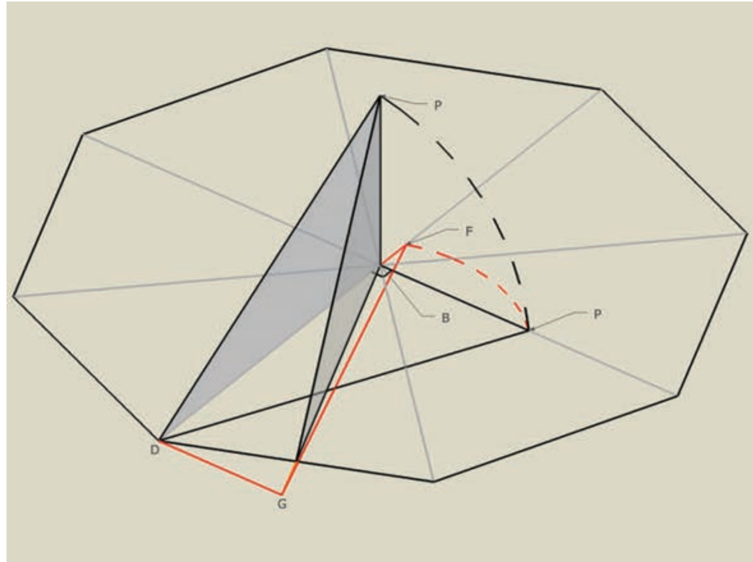


Fig. 23. Obtaining the bevel for hip lying on common rafter.

Instead, draw a tangent line at the foot *A*, square to the common run and out to *D* where it intersects the plane of the hip face (Fig. 22). Then arc over the common length to an extension of the common run at *E* and connect the points. Angle *AED* is the bevel (Hawkindale P2). You get the same result if you hold the tangent length of 4.9706 (can't use the run anymore—it's not a regular roof) on the tongue and the rafter length (14.4222) on the blade, the latter's edge giving the bevel. I used math to get those numbers, but the advantage of doing a scaled plan diagram is that you can just take the lengths with dividers and transfer them to the framing square, or use a bevel gauge right on the paper and avoid numbers. As long as your drawing is accurate and in proportion to the real roof, the angles will agree. For those who want to verify their angles using the Hawkindale spreadsheet, see the resources list at the end.

In laying out a hip, suppose we want to know the bevel angle on the top of the hip where it bears against a common rafter at *F* in Fig. 23 and the angles of the birdsmouth on the underside of the hip where it wraps over the corner of the plates at *D*.

Strike a tangent line *DG* perpendicular to the hip run and to intersect a line extended from the common run representing the plumb plane of the common. The hip length is found by drawing the rise *BP* perpendicular to the run *BD* and connecting the ends. Arc the hip length *PD* down and then over to an extension of the hip run and connect that point *F* to the end of the tangent *G* to form our tangent triangle. The angle at the peak of this triangle is the bevel to use where the hip lies against the common rafter (Fig. 23).

We have a bit of a problem for the birdsmouth layout on the underside of the hip at the bottom: if we extend the tangent out from the foot, it only gets farther away from the planes representing the plumb faces of the plates. Simple solution: run the tangent from the other end of the hip run (Fig. 24).

Extend the tangent out to intersect the plane of the face of the plate at *H* as shown. Extend the rafter run out at the opposite end as shown, so that its total length from the origin equals the rafter length (*DP* in Fig. 23). Connect to the end of the tangent to get the bevel for the birdsmouth as laid out from each edge (or the centerline) of the underside of the hip.

Lengths can get too big to transfer directly to the framing square for layout, depending on the scale of your original drawing. You may need to reduce them down proportionately to get the angle on the square.

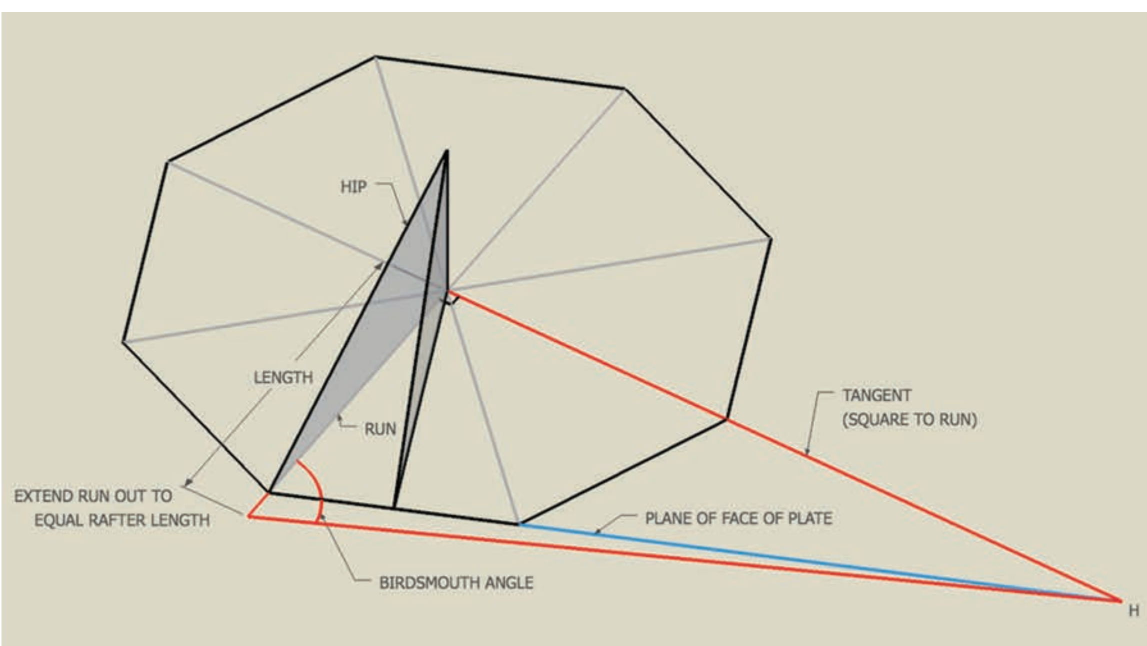


Fig. 24. Running tangent from opposite end of run to obtain bevel angle for birdsmouth.

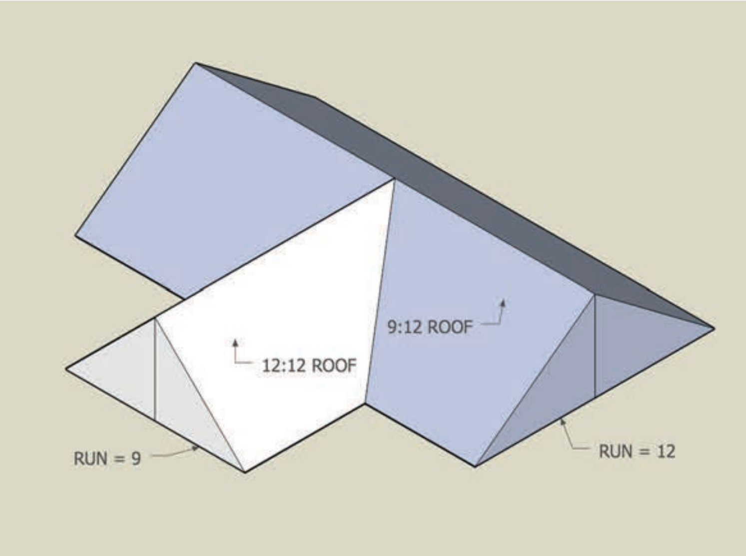


Fig. 25. Regular-plan, irregular-pitch compound roof.

IN Fig. 25 we have a regular-plan (90-degree intersection of the roofs) but irregular-pitch valley roof, 9:12 on the main roof and 12:12 on the adjacent roof. In this case, the valley does not run at 45 degrees, but we really don't need to know that angle since the ridges meet at the peak and the rise (9) is common to both roofs.

Suppose we want the valley to go right up into the corner and be cut to meet both ridges. To find the edge bevels for the valley where it meets this internal corner, draw the tangent at right angles to the valley run, but run it out in both directions this time because we want two bevels, one for each ridge (Fig. 26).

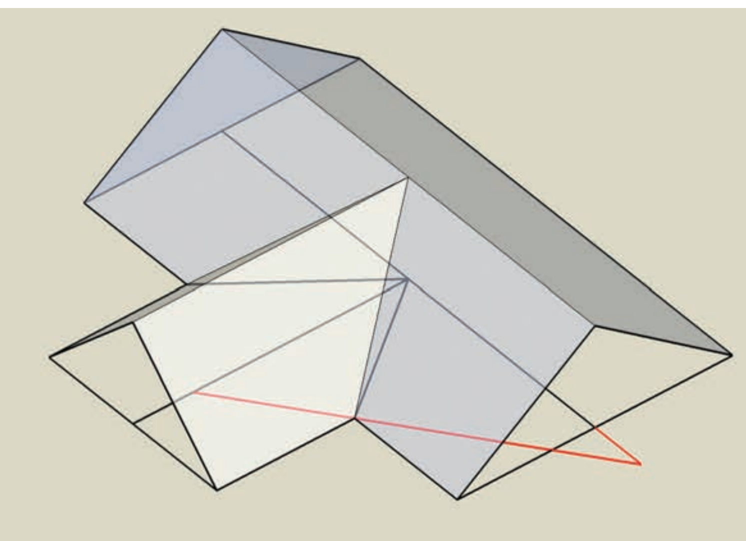


Fig. 26. Tangent line perpendicular to valley run in both directions.

For the adjacent ridge, run the tangent out to the left as shown until it intersects the vertical plane of that ridge. Find the valley rafter length with the usual method, drawing the rise perpendicular to the run and connecting the ends of the lines. Arc this length over to an extension of the valley run (Fig. 27), connect to the end of the tangent and you have the bevel angle where the valley meets the adjacent ridge (Fig. 28).

For the main ridge: same thing, opposite side. Run the tangent out on the right to where it intersects a line extended out from the main ridge, representing a plumb face of the ridge, and connect that point to the valley length to get the bevel (Fig. 28).

If we again imagine the tangent as a hinge and lift the triangle's opposite angle up to the peak, we can represent the unbacked surface of the valley; the triangle's sides other than the tangent lie in the planes of the ridge faces (Fig. 29).

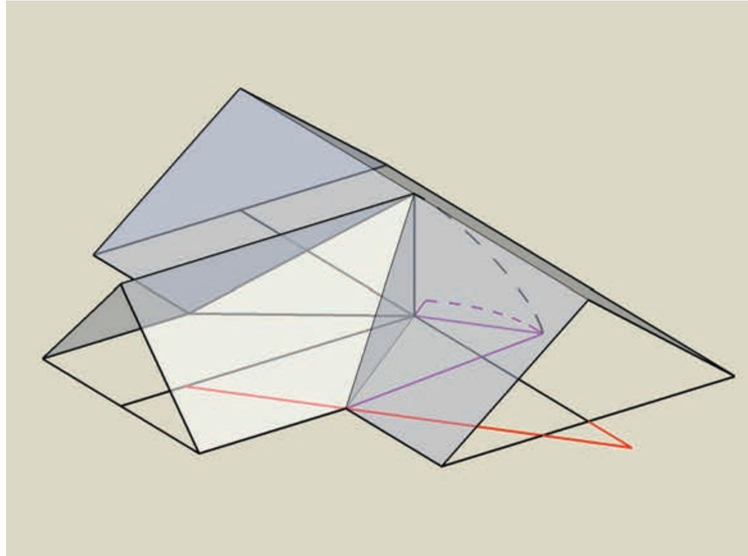


Fig. 27. Operations to find valley length leg of tangent triangle.

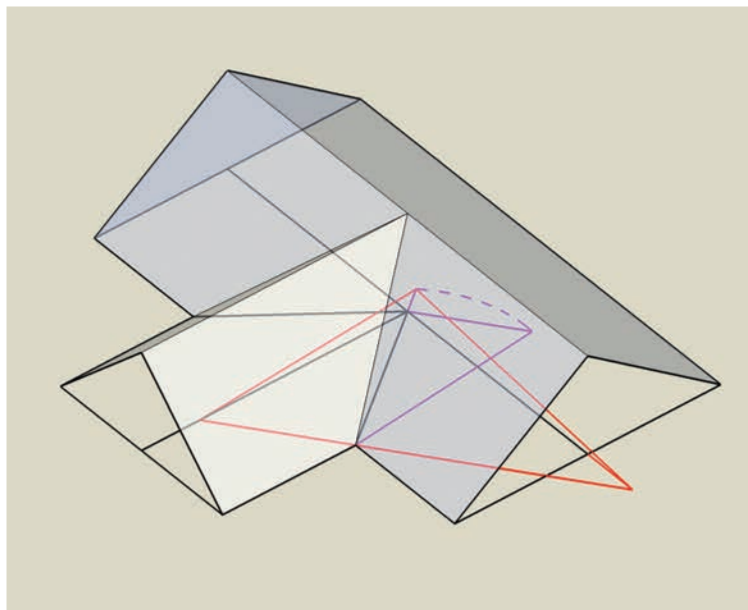


Fig. 28. Operations to obtain bevel for valley to main and adjacent ridge joints.

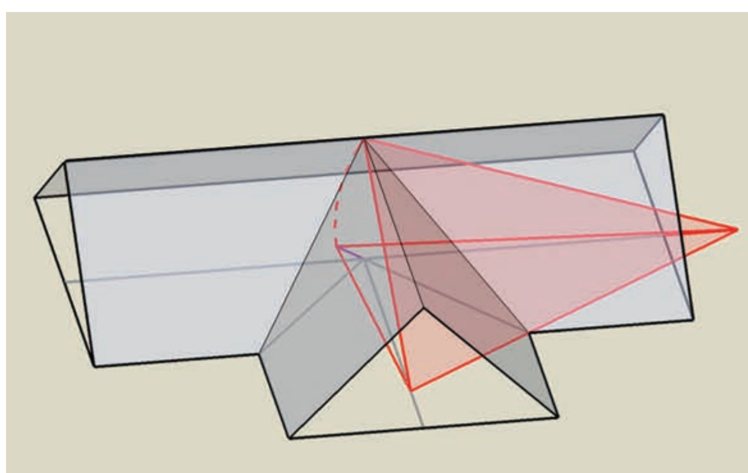


Fig. 29. Representing unbacked surface of the valley. Sides of tangent triangle lie in planes of respective ridge faces.

How about an irregular-plan, irregular-pitch roof? While this combination might give others the fits, we're ready to see that finding the edge bevel is no harder than for a regular roof. Let's say we have a hip where a 9:12 main roof meets a 12:12 adjacent roof, and the corner is 75 degrees (Fig. 30).

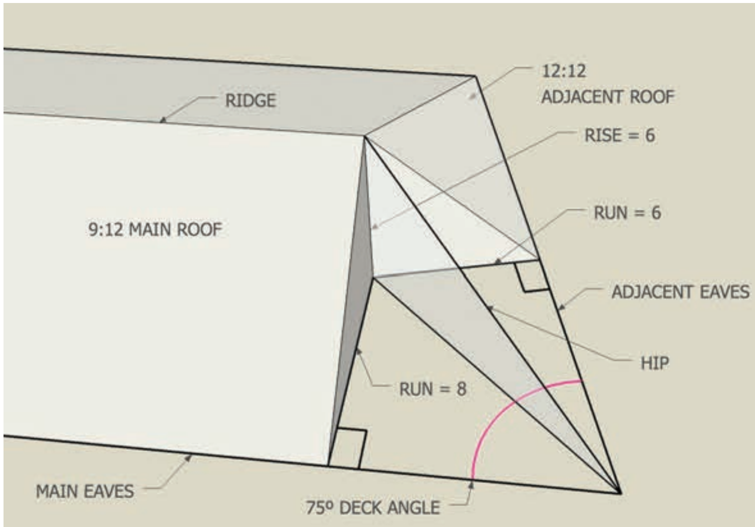


Fig. 30. Irregular plan, irregular pitch roof.

If we set the main run at 8 units, the adjacent run is 6 as is the rise where the hip, common rafters and ridge meet. We'll make the ridge parallel to the 9:12 eaves, and have the common and jack rafters run at 90 degrees to their respective eaves for both roofs. Note in the plan view in Fig. 31 that the irregular plan means that the ridge runs at a different angle from the adjacent rafter, and now we have a choice whether to have the face of the hip rest against the plumb ridge or against the adjacent common rafter.

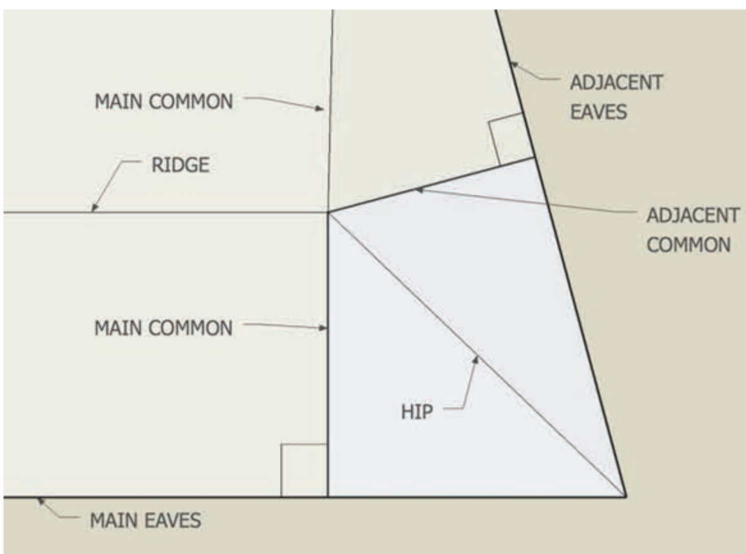


Fig. 31. Plan view showing common rafters running at right angles to eaves.

Let's choose the latter. Following the script, draw a tangent line square to the hip, running in both directions from the foot until it meets an extension of the 9:12 common rafter run on the left side and the 12:12 rafter run on the other (Fig. 32).

Get the hip length by drawing the rise square to the run, connecting points *A* and *B*, and then arc that length over to an extension of the hip run at *C*. Connect *C* to the ends of the tangent line to get the respective bevel angles (Fig. 33).

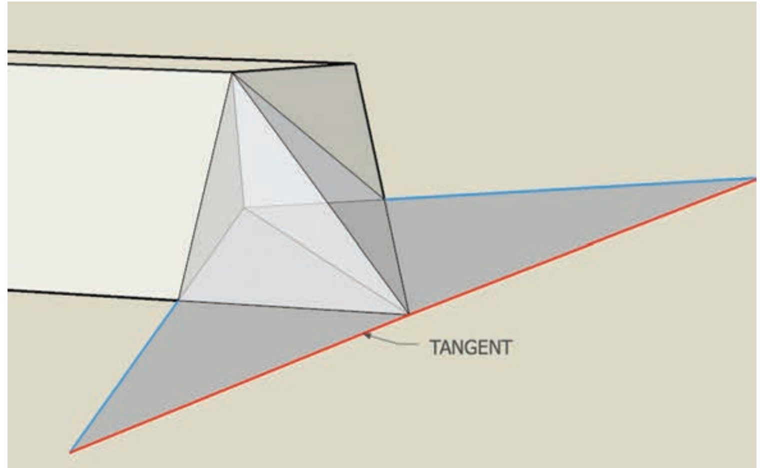


Fig. 32. Tangent drawn out perpendicular to hip run until it meets planes of common rafter faces.

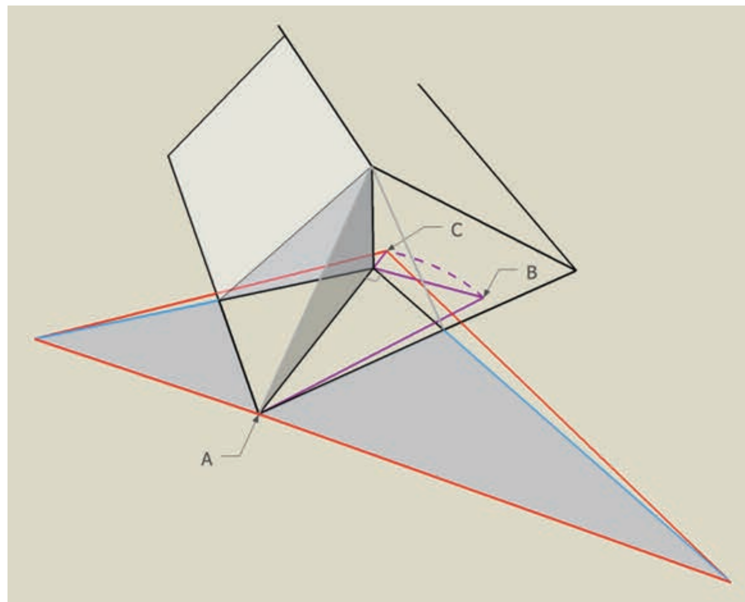


Fig. 33. Hip length arced over to hip run extension and connected to ends of tangent to form tangent triangle.

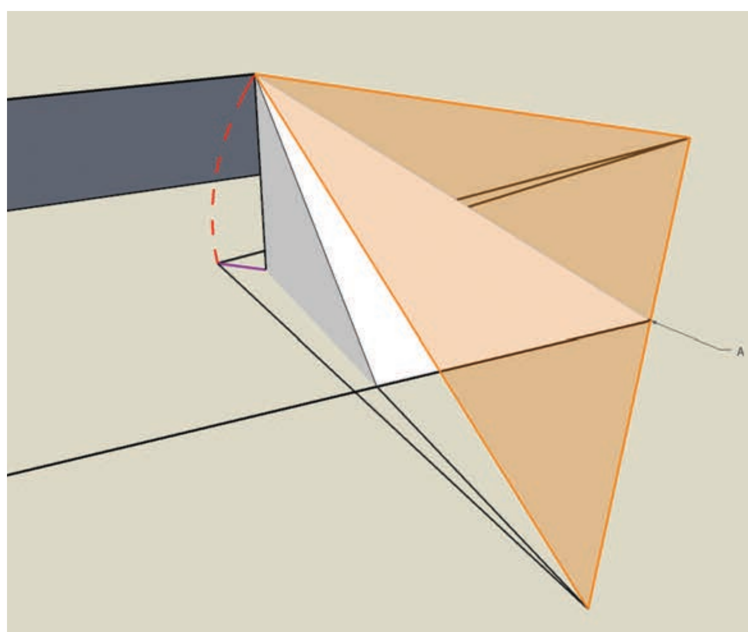


Fig. 34. Tangent plane tilted into place by lifting peak.

Again, we can pivot the tangent triangle on the tangent hinge to see it in place as the unbacked surface of the hip (Fig. 34).

To find the birdsmouth angles at the bottom of the hip where it crosses the plates, draw a tangent at the inner end of the hip run and extend the hip run out at the foot so its total length, from the inner end where the tangent is struck to the end of the extension, equals the hip length (Fig. 35).

Connect this point back to where the tangent intersects the main and adjacent eaves to get the respective edge bevels. These angles would also be the plumb bevels, if needed, for the eaves overhang to accept the two intersecting fascias (Fig. 36).

In the 3-D drawing, the pivot for lifting this triangle is at the foot and slides inward to allow the triangle to rise and lie in the plane of the hip. In 2-D, the tangent triangle is actually developed from the peak in plan and then, using the tangent as the hinge as in previous exercises, hinged down, so the opposite vertex drops to the foot of the hip. Lifting the tangent triangle as shown in Fig. 36 allows the tangent plane to fold down along the tangent hinge. The tangent lifts up to the peak and the opposite vertex slides in to meet the foot of the hip. The sides of the triangle other than the tangent represent the plumb faces of the plates. *A′* and *B′* are the angles of the birdsmouths laid out from the centerline or edge of the bottom of the hip.

Note that with irregular roofs it's usually desirable to offset the hip at the corner so that the exposed plumb sides of the hip below the backing are the same depth. This not only looks better but also makes trimming out the eaves easier.

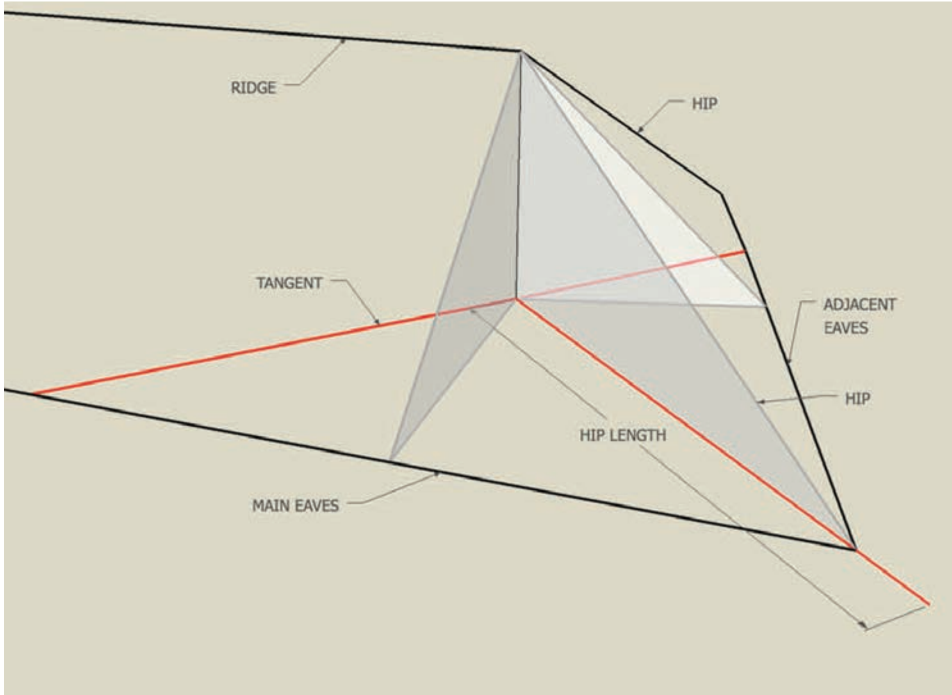


Fig. 35. Creating tangent for finding angles at foot of hip.

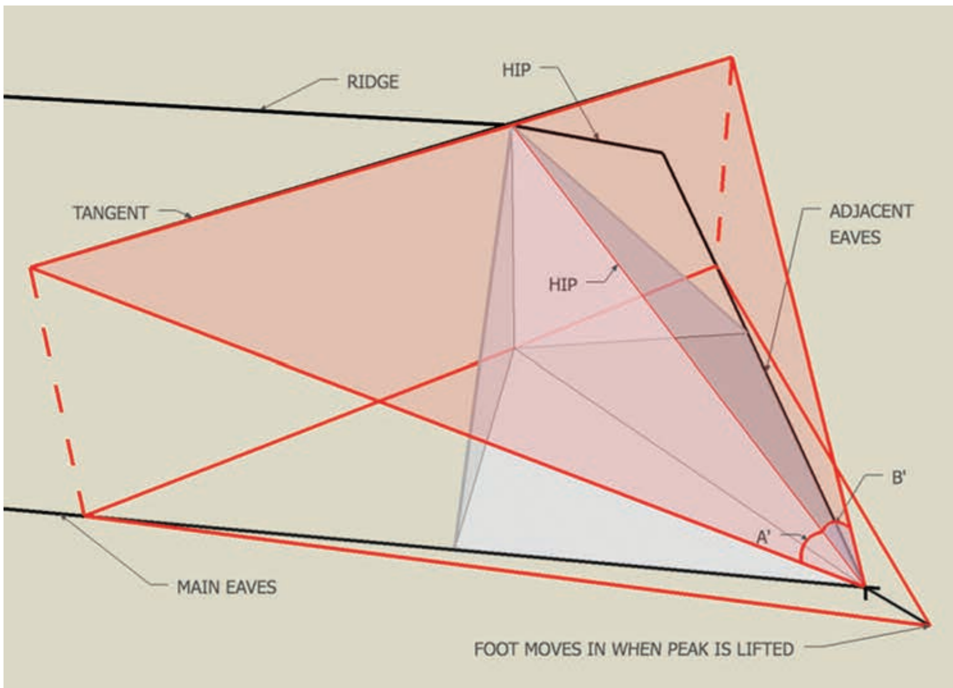


Fig. 36. Tangent triangle for foot bevels lifted into place.

THESE examples are fairly straightforward and can give you a place to start exploring the tangent concept. To summarize, we said that the edge bevel for compound joinery can be obtained by holding the rafter run on the tongue of the square and the rafter length on the blade, or a scaled-down version using the same proportion, and then marking the rafter length on the top edge of the workpiece. This procedure works for all regular-plan, regular-pitch roofs because the run is the same length as the tangent. But in any hip or valley roof, be it regular, irregular plan or irregular pitch, the edge bevel can be obtained by holding the tangent length on the tongue of the square and the rafter length on the blade, marking the bevel along the latter. Next time, we'll look at more uses of the tangent to determine the offset of the hip at the corner, how to find the backing angles on irregular roofs, and explore more mysterious things that happen . . . *When Roofs Collide!*

—Will Beemer

Curtis Milton contributed substantial research and advice to this article and has conducted a series of Guild workshops titled "Thinking Tangentially."

Resources

The Steel Square, H. H. Siegele, Sterling Publishing, 1991, ISBN 978-0806-9838-4.
"Roof Framing Revisited," Scott McBride, *Fine Homebuilding*, August 1985 (28: 31-37).

Curtis Milton's continuing Guild workshops offer insights into this method of compound roof analysis.

Additional resources on roof framing and using the rafter square are cited in our previous articles in TF, in December 2003 (70:14-25), March 2004 (71:4-11) and September 2004 (73: 4-15). The Hawkindale angle spreadsheet and guide are found on the Guild Web site at http://www.tfguild.org/tools/tool2.html.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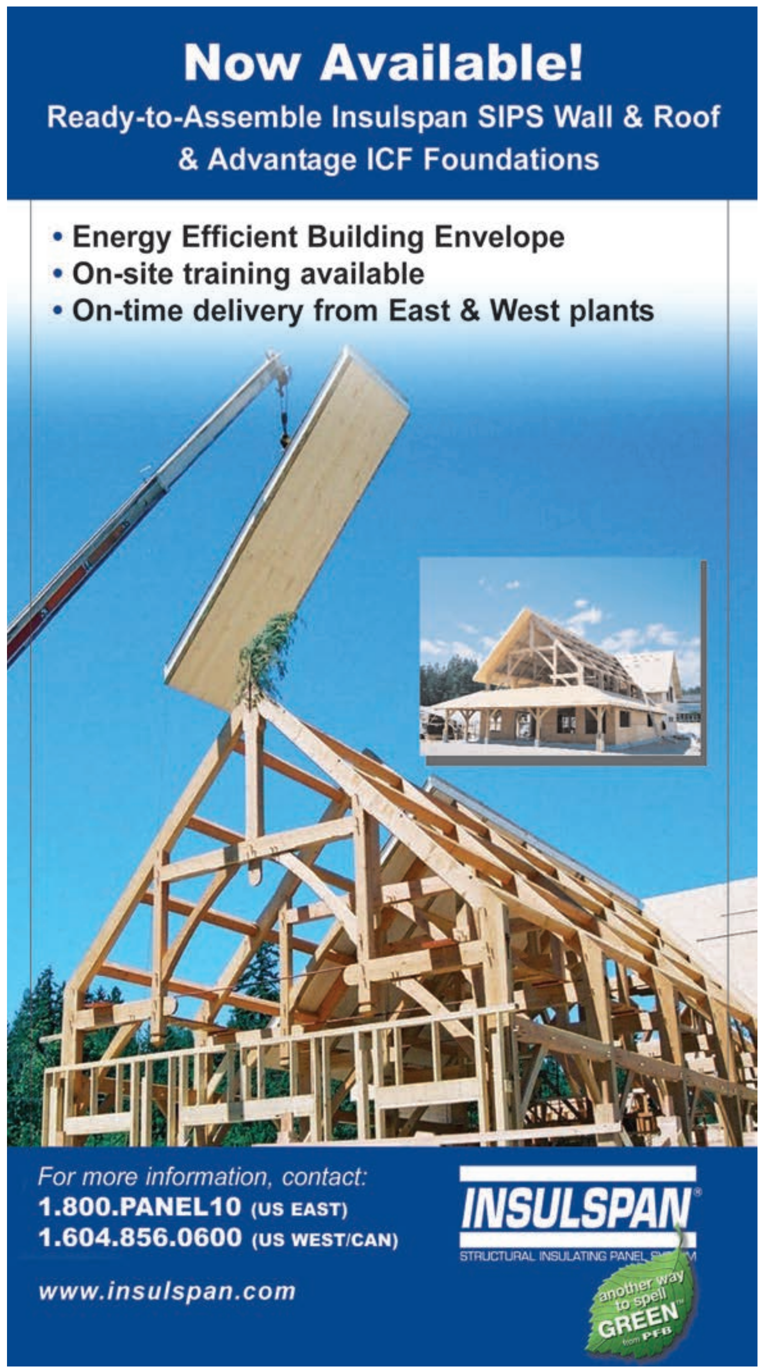
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