TIMBER FRAMING

Robert Smith and the Raised Bottom Chord Truss

CONTENTS

On the cover, interior view of St. George's Methodist Episcopal Church, Fourth Street, Philadelphia, 1763-69, showing the roof system and the audience room following a fire on August 12, 1865. Careful examination of the photo reveals the presence of the large Y-shaped iron yoke typically used by Robert Smith at the junction of the kingpost with the collar beam and hammer beams. Photo courtesy of St. George's Methodist Episcopal Church. An article on the work of 18th-century architect and timber framer Robert Smith begins on page 16.

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

1985

Notes & Comment

Memento Mori

Mark Witter of Bellingham, Washington, died suddenly of a heart attack at his place of work last June 16, and Dave Gaker of Liberty Township, Ohio, died July 7 at home after a long fight with cancer. Both men were 50 and well known in the Guild. Obituaries appeared in the August issue (Number 108) of the Guild newsletter Scantlings.

MARK WITTER'S farewell filled up an old wooden hall in downtown Bellingham with a broad variety of folks, fewer than half of whom were from the Guild community—testimony to Mark's wider interests in jazz, baseball and in his eclectic neighborhood. Ross Grier, uncharacteristically restrained, acted as master of ceremonies, if that is the proper term. Various luminaries from these diverse worlds addressed a standing-room-only crowd in serious (mostly) but never (almost) somber tones. This was all especially tough going, given the suddenness of Mark's departure, but we stuck it out. I wish I had had the tissue concession. The Guild was well represented on both sides of the podium, for all that. These events will no doubt become more frequent opportunities to take our own small comfort by catching up with old friends and their new adventures, which is exactly what we did in Bellingham, marching downstairs to a fabulous potluck spread and a long evening of new friends, terrific music, singing, dancing and the telling of tales. (Susan Witter and family had to do it all again in the East a few days later in the more formal confines of a large Catholic church in Utica, N.Y., Mark's hometown, an event that was moving in its own right, according to Susan, and that seguéd nicely to a looser gathering at the Polish Community Club, where Jonathan Orpin read the tender ode written for Mark by a musical colleague, and where Mark's father-in-law told an enchanted audience just how Mark had entered his family and his heart.) In Bellingham, we were able to drive some of our own blues away by singing, well, the blues.

DAVE GAKER'S own transition was long anticipated but no less difficult. Dave expressed some jealousy of Mark's method, an opinion emphatically not shared by those around him. Guild members wore out the Cincinnati airport and the interstate highway system getting to Hamilton in time for the smaller family service up on the hilltop at the farm, saying the words and spreading some of the ashes. It was church in the morning after a congenial night with old friends at the clubhouse, giving the family some space. I come from the "priesthood of all believers" school, and therefore I'm an enthusiastic supporter of the modern practice of offering the pulpit to those moved to speak. The service was astonishing—every seat taken, balcony full, great guitar music.

Hours of testimony, some awkward, some awesome, all in gratitude for this life. A hundred people gathered at the farm after the service for more stories, more music and more food, until dark. As in Bellingham, Guild members were the first to arrive and the last to leave, often not knowing what to do beyond sitting at the kitchen table, ready to listen or to run another errand. In Ohio, a band of members led by Michael Goldberg stuck around for yet another day to finish up a small job that had been hanging over Dave's head. So at least that small bit of tangible support was accomplished.

Our real test as friends and companions begins after the flowers are all distributed, those bleak Social Security forms completed, the black clothes packed away. Terry Clark, so overwrought that he couldn't bring himself to attend the services, says this is all too much, and so he is looking for younger friends. I disagree. This misery on the back end is the tuition for the great stuff on the front end: the equation is perfectly balanced. It's a deal I try to take every day. —Joel McCarty

TOPICS

Timber Frames and Fire

Picture this—you and your family are sleeping in the middle of the night in your stick-framed house. An electrical short in the attic causes a spark. That spark then ignites a splinter of one of the 2x6 prefabricated trusses comprising your roof support system. That's all that's needed to start a fire. The race is on. Ignition time: 00:00:01.

The fire climbs up the truss pulling oxygen from the gable end vents. The fire is now in the growth stage and doubles in size approximately every 30 seconds. Fire gases and heat are trapped under the roof assembly, and attic temperatures reach 500 degrees Fahrenheit. Eventually the attic is pressurized enough to force smoke down into the living compartments, and the smoke alarms begin sounding. Time from ignition: 00:01:56.

The temperatures in the attic keep climbing while carbon monoxide and other byproducts of incomplete combustion are trapped under the roof. The CO and miscellaneous fire gases reach their ignition temperature. Flashover (the simultaneous ignition of all combustible materials in the room) then occurs. Attic temperature: 1146 degrees. Time: 00:03:02.

The 2x6s in the truss system begin to char and the gusset plates used to hold them together lose purchase. As temperatures in the attic reach 1600 degrees, the weight of the air conditioner and roof assembly overcomes the trusses and the result is total roof failure and structural collapse. Time: 00:04:17. Time from warning to collapse: 2 minutes, 21 seconds. Did you get your family out in time?

The scenario above is not meant to frighten anyone into believing that they live in a firetrap, nor is it an exaggerated, melodramatic description of structure fire behavior. It is simply the reality of fire progression in modern houses that are built by the pound.

Timber-framed construction (or heavy timber as we call it in the fire service) is significantly more resistant to fire damage than common stick framing and considerably more fire resistant than construction using unprotected steel support members. Solid wood is very stable at high temperatures and creates its own insulation upon contact with fire. As a result, heavy timber construction is given a two-hour fire rating by the National Fire Protection Association (NFPA). The only construction method given a higher rating is so-called fire-resistive construction (structural members made of noncombustible materials).

Whereas a 50-ft. steel I-beam will elongate as much as 4 in. at 1000 degrees, forcing a collapse, a timber-framed bent will roughly retain its original dimensions. The beauty of timber frame joinery under fire load is that, as the outside of a beam chars, it turns mostly to carbon. Carbon is a great insulator, so the load-bearing portions of the joinery and members remain intact for much longer than in lightweight truss construction. Wood also conducts heat very poorly. Since most timber framers enthusiastically use traditional wood joinery techniques, there are no metal connectors to transfer heat to the inner load-bearing portions of the joint.

Modern stud framing techniques have no "fat" as traditional timber framing does. The gusset plates' staples typically only penetrate ⅜ of an inch. These connectors, which are adequate for their design load, will fail very quickly in a fire, causing failure of the entire truss. Engineered wooden I-beams such as TrussJoists will delaminate and collapse while the fire is still in the growth stages and temperatures are still relatively low. None of this is true for a building of heavy timber construction.

Heavy timber construction has many more benefits in the event of a fire, as well. The vaulted ceilings commonly used on the interiors provide much more warning if smoke detectors are placed at the highest point. Also, there are typically no void spaces like the ones hidden inside light-frame construction, where fire can travel undetected and unchecked.

These are issues that are absolutely vital to consider before building a house for your family or client. Modern fire codes are based on a time when furnishings produced a little more than one percent of the BTUs of today's polyurethane foam-based furniture, and none of the deadly fire gases such as hydrogen cyanide and phosgene. Firefighting techniques are quickly evolving to adapt to quick flashover times and even quicker collapses. I know that as a firefighter I always breathe a sigh of relief when arriving on the scene of a fire to find out that the building is of heavy timber construction. There is a much better chance of finding living occupants, and the officer in charge is considerably less hesitant to send in firefighters to search for victims.

If timber-framed houses are so overbuilt as to pose the threat that "the product might last too long," as Tedd Benson wrote tongue-in-cheek in *The Timber-Frame Home*, after fire involvement they are admirably so and might actually stand long enough for you and your family to escape that late-night fire.

—Ryan Gilbert

Ryan Gilbert has been a firefighter for four years and works for the City of Bellingham (Washington) Fire Department.

TIMBER FRAMING FOR BEGINNERS

IX. When Roofs Collide 3

I N THE first two articles of this series, we demonstrated how to lay out the joinery for a hip roof model using developed drawing techniques, some simple math, the framing square and the Hawkindale angles. In the first article (TF 70), we developed the common rafter and hip rafter by drawing views of the complete timbers at full scale, and we introduced and explained the Hawkindale angles, providing a spreadsheet. In the second article (TF 71), we abbreviated the process by introducing the use of multipliers to calculate lengths and joinery locations (working points), and then developing views of just the joinery using the kernel. Thus we drew the jack rafter-to-hip connection by drawing the elevation and roof surface views, which then could be transferred to the pieces to be cut.

In this article we tackle a compound joinery problem very common in timber framing: the valley dormer.

We saw earlier that using math to locate joinery saved us a lot of time and space by getting rid of the need to draw the whole timber. By the same token, we should only draw what we need to; a lot of information about joinery dimensions can be deduced by drawing the joint on the stick, avoiding paper altogether, and also by remembering a few rules of thumb. In reality, that's how a lot of this joinery is laid out: we'll go to the paper and develop the kernel for a joint we just can't see on the stick and, if still confused, go back to drawing the whole roof at scale as in the first article. We hope that this article will help you see how that deductive process works.

The Valley Model. In Fig. 1 we see a model of the valley dormer, which consists of principal rafters (supported on posts for modeling purposes) with a header running between them. Note that the header has plumb sides. It's also possible to frame the dormer with a header set flush, with its sides perpendicular to the roof plane. In such a configuration, the header would be called a principal purlin (Fig. 2). Plumb valleys intersecting plumb headers yield joints with plumb side cuts, and it's easier to comprehend a system where all side cuts are vertical. Also, plumb headers are, or can be, deeper than principal purlin alternatives, and thus more capable of handling long spans between principal rafters. On the other hand, while valley-to-purlin joints generate compound side cuts in the case of a principal purlin, mortises are at right angles to purlin faces instead of the oblique entrance of valley-to-header, and purlin stock can be smaller and rectangular, simplifying purlin-to-principal rafter connections. However, the valley must become *longer* on the bottom to reach underneath the principal purlin, and this can make assembly more difficult than dropping in a plumb header. In sum, plumb headers are generally preferred.

Dormer valley rafters rise from the principal rafters at the foot to the header at the peak. It's good practice to avoid placing a lot of joinery at the same location; thus the valley will often land well up on the principal rafter rather than down near the plate. The valley rafter has an "ear" riding over the principal rafter at the foot to carry the dormer roof sheathing and hide the intersection from below. For illustrative purposes we have included both a jack rafter
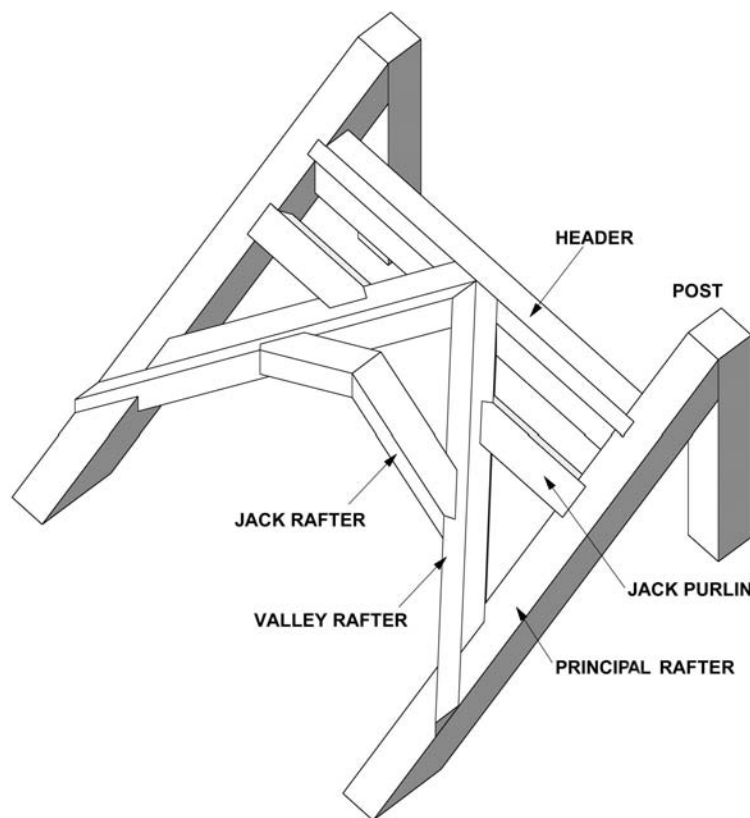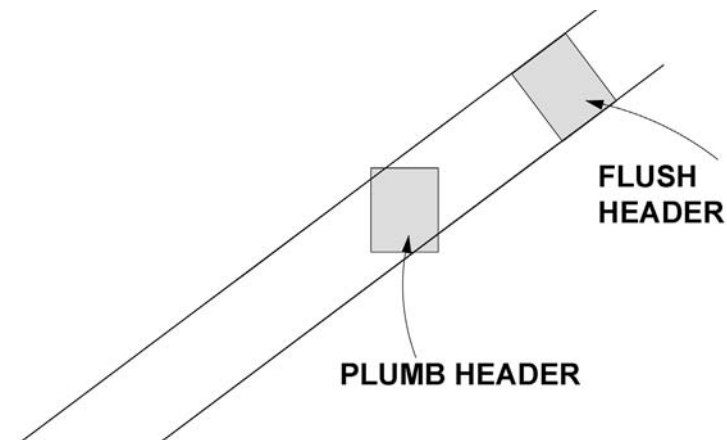

Fig. 1. Isometric view of valley model.

Fig. 2. Plumb vs. flush header sections on side of principal rafter.

and a jack purlin in this model, though typically only one or the other would be seen in practice. The jack rafter is framed with the same angles we used from our hip model in the last article; the jack purlin presents some new angles and interesting problems.

Fig. 3 shows a plan view of the model with dimensions. These dimensions, along with the roof pitch (9 in 12), give us all of the information we need to lay out the roof joinery. The sizes of the pieces for our model are given in the accompanying table.

DIMENSIONS OF PIECES: WIDTH X DEPTH

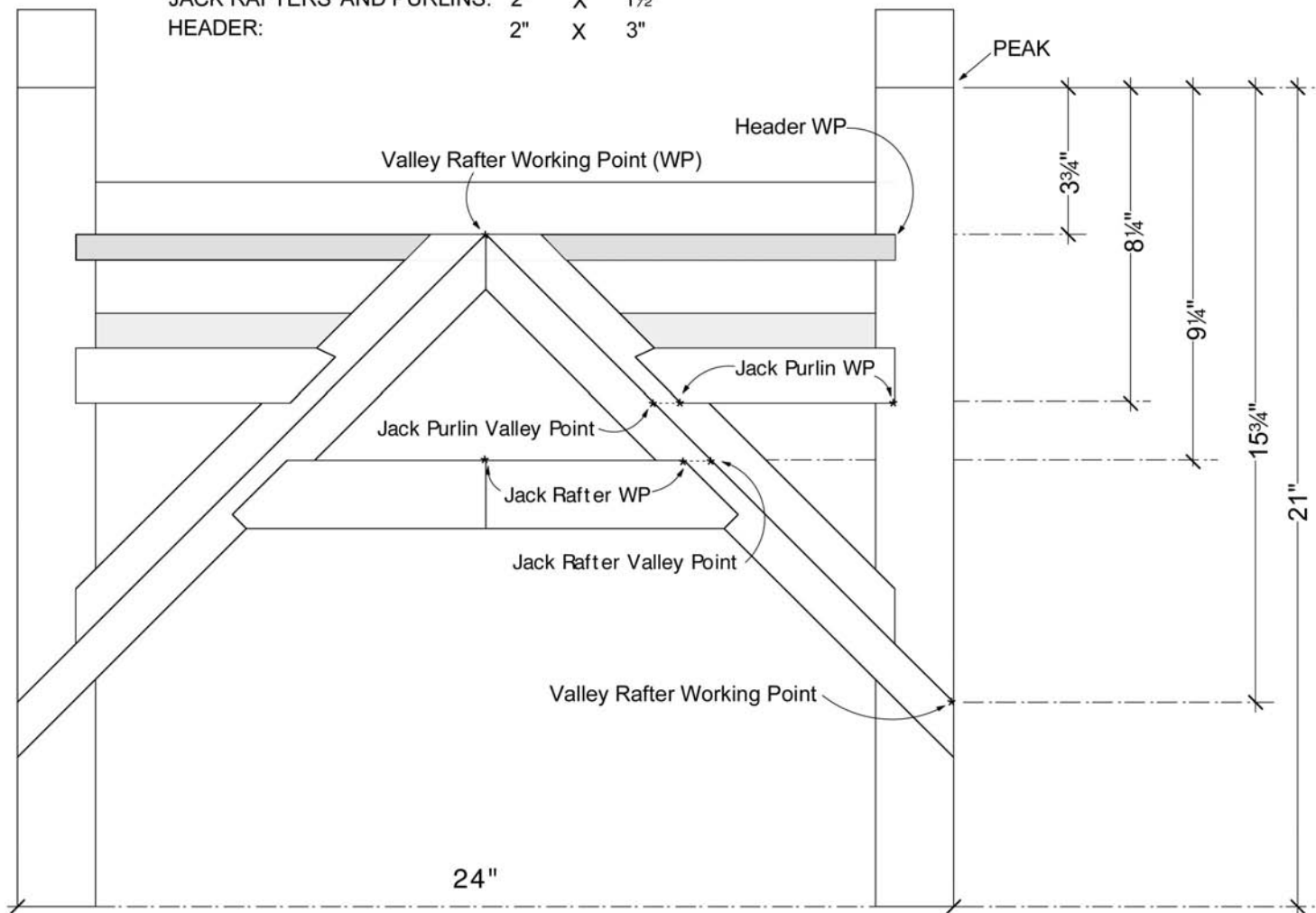|	WIDTH		DEPTH
VALLEY RAFTER:	2"	X	2"
PRINCIPAL RAFTERS:	2"	X	2½"
POSTS:	2"	X	2"
JACK RAFTERS AND PURLINS:	2"	X	1½"
HEADER:	2"	X	3"

Fig. 3. Plan view of model with working points.

Working points, as explained in the last article, are the points on the timber from which we lay out the joinery. Our first job is to transfer the working points (or WPs) indicated in the plan view up into the roof plane, using the multipliers. Let's review the multiplier ratios we found in the 9:12-pitch hip model, which are also applicable in the valley:

The ratio of common length to common run is 15:12
  or 1.25
The ratio of valley run to common run is 16.9706:12
  or 1.4142
The ratio of valley length to valley run is 19.2094:16.9706
  or 1.1319
The ratio of valley length to common run is 19.2094:12
  or 1.6008

To build our model, we need to calculate lengths and points for the following pieces:

Post
Principal rafter
Valley rafter (from valley rafter WP to valley rafter WP)
Header
Valley rafter WP on the header
Jack rafter (from jack rafter WP to jack rafter WP)
Jack purlin (from jack purlin WP to jack purlin WP)
Header WP on principal rafter
Jack purlin WP on principal rafter
Valley rafter WP on principal rafter
Jack purlin valley point (working point for the jack purlin on the valley)
Jack rafter valley point (working point for the jack rafter on the valley)

Once we locate each of these points and lengths on the timbers, we can apply angles from our framing square (or Hawkindales) and deduced (or drawn-on-paper) dimensions to lay out the joinery. Let's take each one of the above in turn; to better visualize the construction, you may construct the model as we go.

Post length. As seen from the elevation in Fig. 4 overleaf, and given the proportional relationship of rise to run as 9 to 12, the post heights can be found by figuring a new multiplier of .75 (9 divided by 12). Thus the post heights will be the run (21 in.) of the model principal rafters (which meet the tops of the posts) times .75, which equals 15¾ in.

Principal rafter length. Using our multiplier for common length to common run (1.25), a run of 21 in. times 1.25 gives the principal rafter length of 26¼ in.

Valley rafter length. Here we plug in the very useful multiplier of valley length to common run (1.6008). The common run over which the valley travels (at 45 degrees in plan) is 15¾ in. (the plan distance from the valley foot to the peak of the principal rafter) minus 3¾ in. (the run from the peak of the principal rafter to the peak of the valley), or 12 in. even. Remember, we stay in plan as long as we can, and we are using the common rafter runs for all of our calculations. The multipliers already account for the transition from common rafter run to lengths in the roof surface. The valley rafter length, from WP to WP, is thus 12 in. times 1.6008, or 19.2096 in.; notice in your rafter table on the framing square that this is the same number given for the Length of Hip or Valley per Foot of Run under the number 9 for a 9:12 pitch.

Header length. Since the header is set in the roof with plumb and level faces, its length doesn't change from the plan view up to the roof surface. All of our housings in the model will be ½ in. deep. Since the width of our model is 24 in., and the principal rafters are 2 in. wide, 1½ in. remain from the end of the header to the outside of the model at each principal. Thus the header length is 24 in. less 3 in., or 21 in.

Valley rafter working point (VRWP) on the header. This is easy, since the valley lands directly on the center of the header, or 10½ in. from either end.
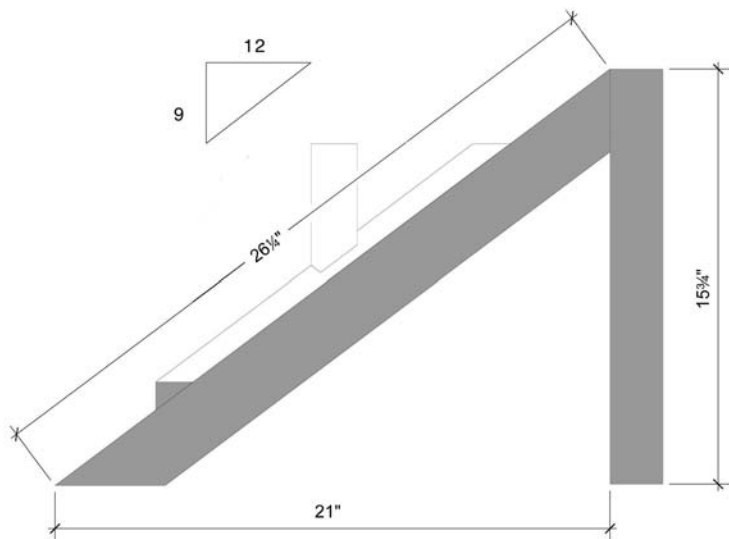

Fig. 4. Side elevation of model.

Jack rafter length. We need first to calculate the jack rafter run in plan from WP to WP, then apply the multiplier of common length to common run (1.25). Note that this distance is figured on the short side of the jack rafter. The run from a point under the peak of the jack to the jack rafter valley point is one leg of a right triangle (Fig. 5). The other leg of identical length is derived by subtracting the run to the valley rafter working point from the peak of the model (3¾ in.) from the run to the jack rafter working point from the peak (9¼ in.); the result is 5½ in. Staying in plan, we then subtract the distance from the jack rafter valley point to the jack rafter working point (Fig. 6). We can use our multiplier of common run to valley run here since it's 45 degrees in plan: ½ in. times 1.4142 equals .7071 in. Subtracting this from the run of 5½ in. results in a total run of the jack rafter of 4.7929 in. Multiply this times 1.25 to get the length of the jack rafter, which is 5.9911 in. (We'll call it 6 in.) Note that the back of the housing must be a set distance from the centerline, not the face, of the valley, especially in square rule layout.

Jack purlin length. This is a bit easier, since the purlin length in plan is the same as in the roof surface. Start by looking at the right triangle formed by the run from the jack purlin valley point (JPVP) to the outside of the edge of the model, which is the same dimension as the run of the principal rafter from the short side of
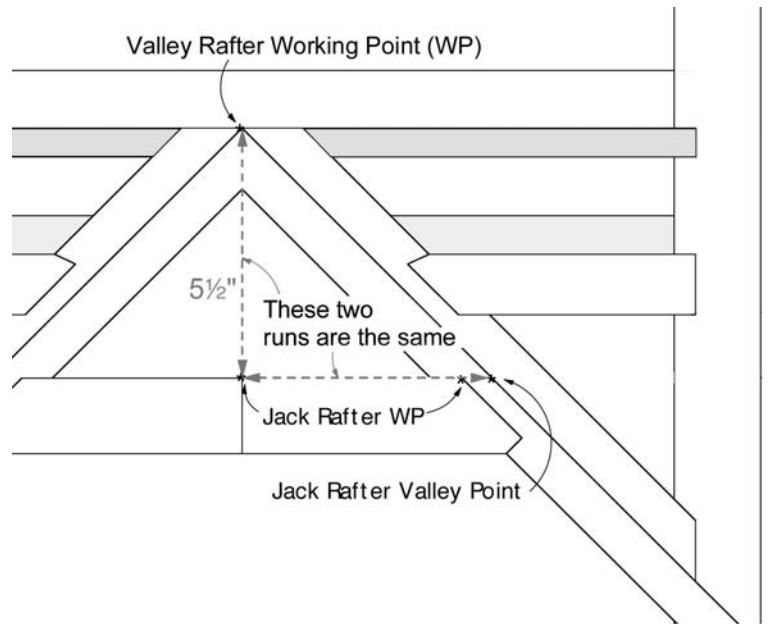

Fig. 5. Finding the jack rafter length.

the jack purlin to the valley rafter working point at the foot of the valley (Fig. 7 facing page). This is 15¾ in. less 8¼ in., or 7½ in. To get the jack purlin length, we then subtract the distance from the back of the purlin housing to the outside of the principal rafter, which is 1½ in., and also the plan distance from the jack purlin valley point to the jack purlin working point in the valley housing, which we figured already above as .7071 in. Thus the jack purlin length is 7.5 in. − 1.5 in. − .7071 in., or 5.2929 in.
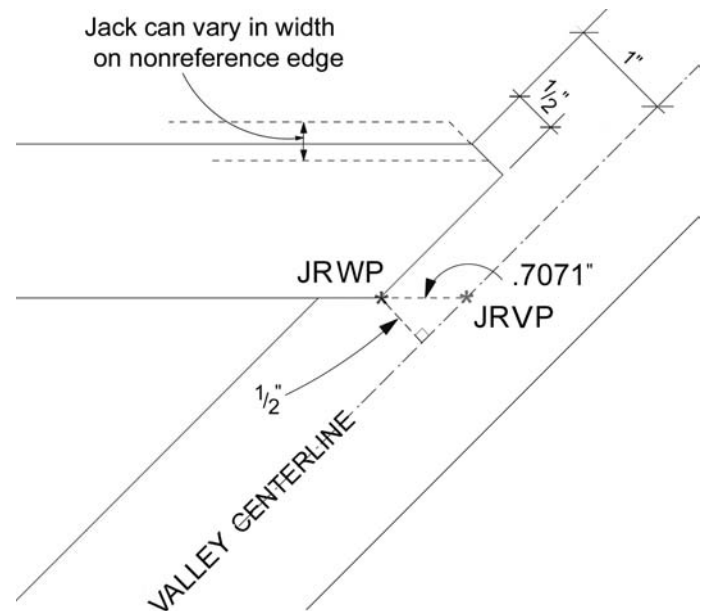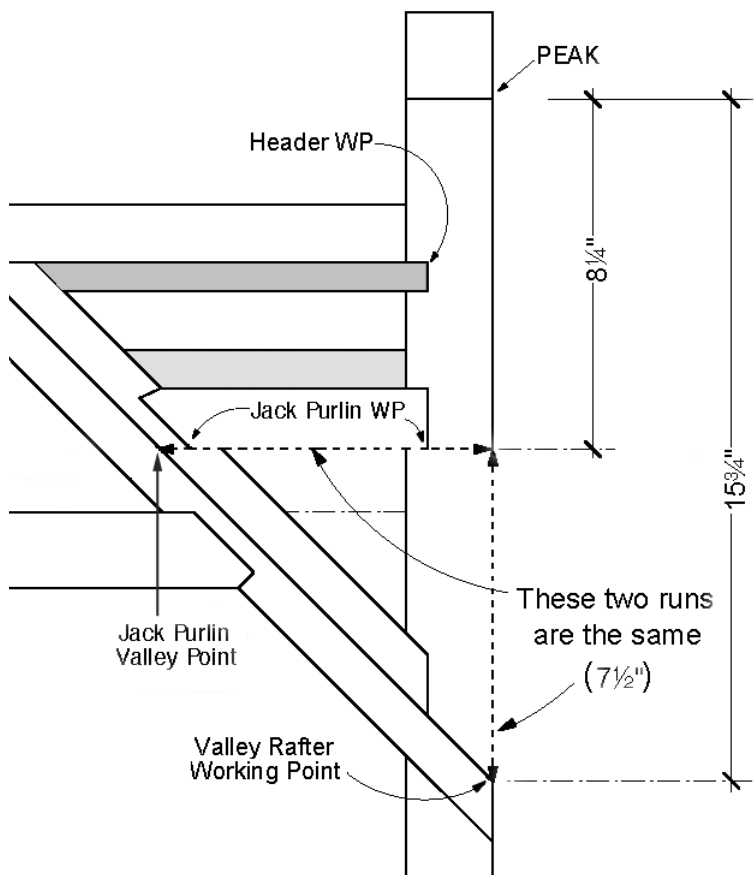

Fig. 6. Obtaining the JRVP to JRWP distance.

Fig. 7. Obtaining the jack purlin length.

THIS completes finding the lengths of all of our pieces for the model. Now we need to find the rest of the working points to locate the joinery. Refer back as necessary to the plan view of the model in Fig. 3 on page 5.

The header working point on the principal rafter is found by taking the run from the peak of the model to the header in plan (3¾ in.), and multiplying it by 1.25 (common length to common run). In the plane of the roof, the header WP is thus located $4^{11}/_{16}$ in. down from the peak of the principal rafter.

The jack purlin working point on the principal rafter is found by taking the run from the peak of the model to the purlin in plan (8¼ in.), and multiplying it times 1.25 (common length to common run). The jack purlin WP is thus located 10.3125 in. down from the peak of the principal rafter.

The valley rafter (foot) working point on the principal rafter is found by taking the run from the peak of the model to the valley rafter foot in plan (15¾ in.), and multiplying it by 1.25 (common length to common run). The valley rafter WP is thus located 19.6875 in. down from the peak of the principal rafter.

The working points for locating the joinery for the jack rafter and jack purlin on the valley lie on the valley's centerline. Angles are then projected out from these points to the edge of the valley to draw the housing. This procedure allows the valley to vary in width without affecting the location of the joinery. If we figured the housing location by measuring along the edge of the valley, it would change as the width changed.

The jack purlin valley point in the valley is found by first taking the run from the peak of the principal rafter to the short side of the purlin (8¼ in.) and subtracting the run from the peak to the header (3¾ in.). This result (4½ in.) is then multiplied by the ratio of valley length to common run (1.6008) to yield 7.2036 in., the dis-

tance from the peak of the valley to the jack purlin valley point, as measured down the centerline of the valley.

Because all of our working points will drop by the same amount after we put the backing angle on the valley, it makes no difference to their relationship if we lay out these points on the unbacked surface. However, it is generally easier to lay out all joinery before cutting the backing on valleys. (On hips it doesn't matter because the centerline remains unchanged on the top surface with the sides falling away.) It's difficult to get a bevel gauge or tape measure down into the valley after the backing is cut and then project angles out to the arris, although rigid rulers and protractor gauges can work. As we learned in the previous article in TF 71, Hawkindale R4 (or its complement) will get the angle for a jack rafter or purlin from the centerline to the arris on an unbacked surface; this angle becomes Hawkindale P2 (or its complement) on a backed surface. In many shops, it is standard practice to lay out on unbacked hip and valley surfaces, using R4 instead of P2 as the top surface layout angle. If you could look straight down on the frame with x-ray vision, the equivalency would become crystal clear as the layout lines in all three systems—laid level on the deck, laid on the valley backing and laid on the unbacked valley top edge—are perfectly superimposed over one another.
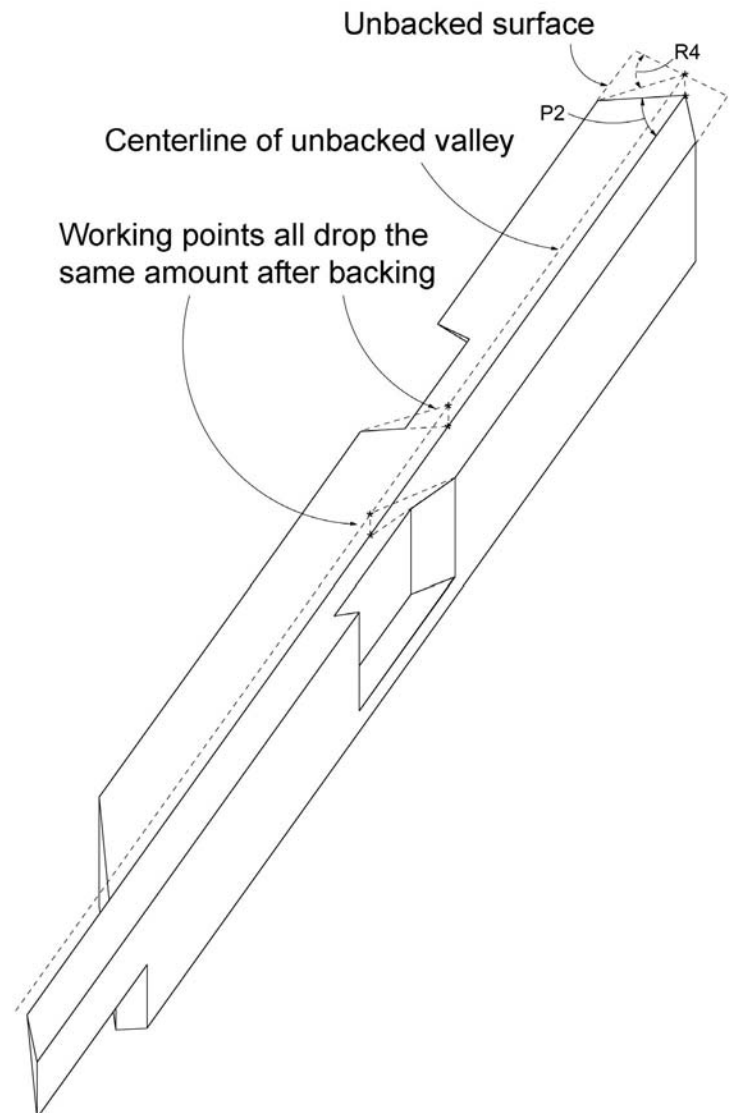

Fig. 8. Working points on valley centerline all drop the same amount, making it possible to lay out the points equally on a backed or unbacked (original) surface. Bevel angles change, however.

The jack rafter valley point in the valley is found by first taking the run from the peak of the principal rafter to the short side of the jack rafter (9¼ in.) and subtracting the run from the peak to header (3¾ in.). This result (5½ in.) is then multiplied by the ratio of valley length to common run (1.6008) to yield 8.8004 in., the distance from the peak of the valley down to the jack rafter valley point, as measured down the centerline of the valley.

L AYING OUT THE JOINERY AND CUTTING THE MODEL. Cut the posts to length (15¾ in.) and then the principal rafters (26¼ in. from long point to long point). Use the framing square set at 9 on the tongue and 12 on the blade to get the plumb cut at the peak and level cut at the foot of the rafters. Copy all angles onto a pitch board so you can retrieve them as needed with a bevel gauge; the level cut is 36.8699 degrees (Hawkindale SS). The plumb cut is 90−SS.

Cut the header to length and then rip the bevel on top to match the roof pitch. This bevel extends ½ in. into the header, the same as the depth of the housing to accept the valley. Use the pattern that appears on the end of the header to lay out its housing on the principal rafters. The bottom of the header can have a bevel ripped to be flush with the bottom of the principal rafters (Fig. 9).
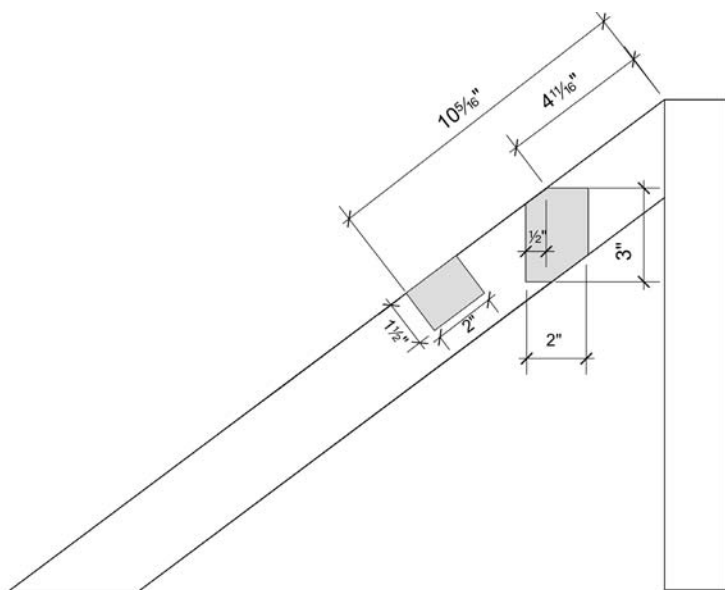
Next cut the housing for the jack purlin on the principal rafter. Measuring down from the peak 10.3125 in. to the low point of the housing, lay out a 2-in. wide by 1½-in. housing extending ½ in. into the principal. (All housings are ½ in. deep.) Note that the jack purlin and the jack rafter lie flat in this model, wider than deep.

Now lay out and cut the valley housing on the header. Both valleys meet in a housing that can be seen in the exploded views in Figs. 10 and 11. Here we can use a rule of thumb, that when a piece with plumb sides meets another piece with plumb sides, the resulting intersection will be plumb. (All of our pieces in the model have plumb sides except for the jack purlin.) From the center point of the header at the back of the valley housing (where the ripped bevel meets the level top of the header), measure half the 45-degree width of the valley. In Fig. 10 we see that this is 1.4142 in. This distance is the same in plan as it is in the roof surface and gives the width of the housing at the back; project a line at the Hawkindale angle 90+P2 down along the beveled roof surface to the front face of the header. The valley is at full depth where it enters this housing, so by marking a plumb line on the side of the valley we can measure the depth of the plumb line on the header. Set your framing square at 9 in 17 and draw this line on a sample piece of valley stock using the tongue (9-in. side) of the square. Measure this and transfer it to the header. Now we need to rely on the Hawkindale angles to project the angle back to the center of the header for the bottom of the housing on the face of the header. This angle is R5 (20.5560 degrees). The bottom of the housing also rises at this same angle from the face into the back of the header (Fig. 10). Draw a 20.5560 angle on a piece of paper and measure a run of ½ in. for the depth of the header and you will see that the rise is ³⁄₁₆ in. Draw a dotted line to indicate this rise in the housing on the header to guide you when cutting this housing. The angle of the housing base as measured with a protractor or bevel gauge set on the header face—that is, the angle of a guide block used to pare the housing surface, or the angle setting of a circular saw set to plunge cut—is 90+A5.

As you can see, we are taking information that appears during the layout of various pieces to find corresponding joinery dimensions on the mating pieces. Cut your more difficult joinery first, so you don't waste time in addition to material, cutting the simpler joints only to err on the difficult ones. Thus you should cut the compound joints on the pieces before cutting the simple ends. In the case of jacks, where you have only end cuts, you may still have length to move down the timber if the compound end is miscut.
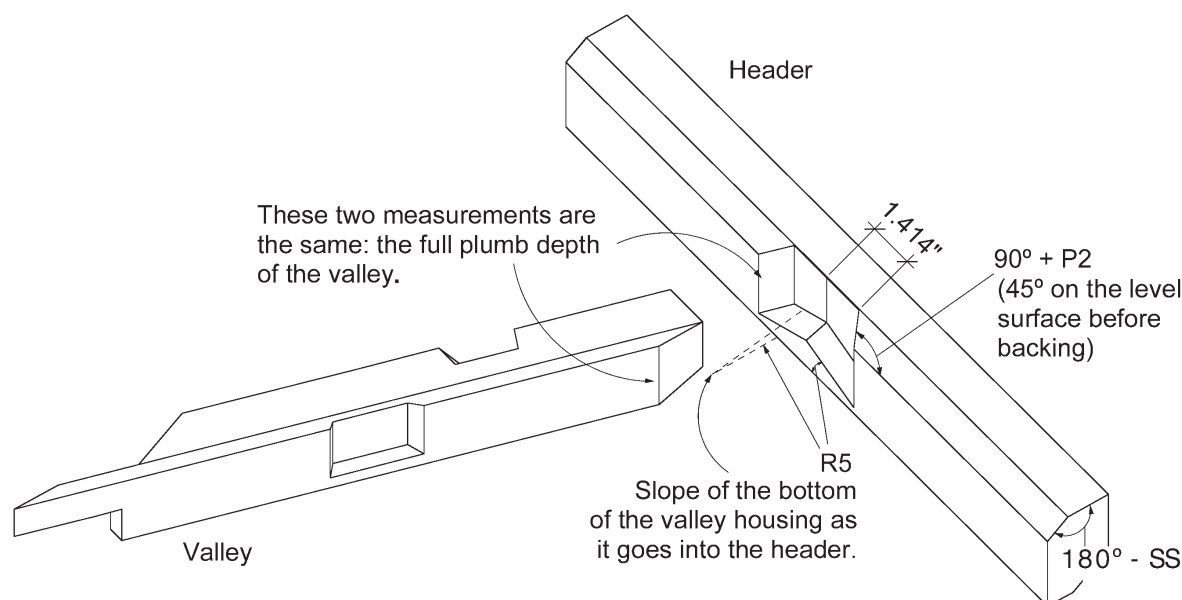

Fig. 9. Sections of header and jack purlin on side of principal rafter.

Fig. 10. Exploded view of valley and header relationship.

MAIN		Tangent		ADJACENT		Tangent	
Angle	Degrees	Rise	Run	Angle	Degrees	Rise	Run
SS	36.8699	9	12	S	36.8699	9	12
DD	45.0000	12	12	D	45.0000	12	12
W	90.0000						
R1	27.9384	6.3640	12	R1	27.9384	6.3640	12
R2m	18.7478	4.0729	12	R2a	18.7478	4.0729	12
R3m	35.9207	8.6932	12	R3a	35.9207	8.6932	12
P2m	38.6598	9.6000	12	P2a	38.6598	9.6000	12
C2m	15.3691	3.2984	12	C2a	15.3691	3.2984	12
C5m	25.1041	5.6223	12	C5a	25.1041	5.6223	12
R4m	41.4591	10.6014	12	R4a	41.4591	10.6014	12
R5m	20.5560	4.5000	12	R5a	20.5560	4.5000	12
R6m	13.0873	2.7897	12	R6a	13.0873	2.7897	12
R7m	12.5491	2.6711	12	R7a	12.5491	2.6711	12
P1m	30.9638	7.2000	12	P1a	30.9638	7.2000	12
P3m	20.0952	4.3902	12	P3a	20.0952	4.3902	12
P4m	30.4655	7.0588	12	P4a	30.4655	7.0588	12
P5m	38.6598	9.6000	12	P5a	38.6598	9.6000	12
P6m	16.3139	3.5122	12	P6a	16.3139	3.5122	12
C1m	34.4499	8.2319	12	C1a	34.4499	8.2319	12
A5m	19.3474	4.2135	12	A5a	19.3474	4.2135	12
A7m	27.9384	6.3640	12	A7a	27.9384	6.3640	12
A8m	8.1943	1.7280	12	A8a	8.1943	1.7280	12
A9m	12.6804	2.7000	12	A9a	12.6804	2.7000	12

Header

90° + P2 (45° on the level surface before backing)

R5
Slope of the bottom of the valley housing as it goes into the header.

180° - SS

Principal rafter

180° - P2

Jack Purlin

180° - P4

90° + P1

90° - P2

Clip angle on bottom of purlin is P3.

P6

90° + P2

P2*

90° - A8

90° - R1

90° - SS

P2

Jack rafter

Valley

90° - R1

Clip angle on bottom of jack is P6.

180° - P2

90° - A9

90° - R2

C5 is the backing angle measured from level on the valley section.

The valley viewed from the other side, showing purlin housing and valley foot.

180° - R6

Fig. 11. Exploded isometric views of joinery with Hawkindale angles indicated and table of Hawkindale angles for 9:12 pitch.

Next, lay out the housing for the foot of the valley on the principal rafter. Measure down from the peak of the principal 19.6875 in. to locate the VRWP, which is the centerline of the valley on the outside edge of the principal. Now we need to do some multiplier gymnastics to find the housing width on the inside face of the principal. The principal is 2 in. wide. Staying in plan as long as we can, we can find the centerline of the valley on the inside by recognizing that the valley runs 45 degrees in plan. If we come over 2 in. in plan to the inside of the principal, and then go "up" the inside edge 2 in. in plan, we will find the centerline on the inside in plan (Fig. 12).
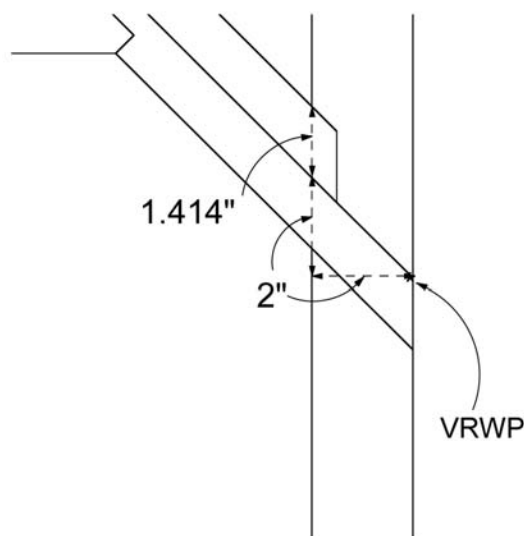
Fig. 12. Finding the plan dimensions of the valley foot housing.

From a line squared over from the outside edge to the inside of the principal rafter stock, we can use our multiplier of common length to common run (1.25) to find the centerline of the valley, 2.5 in. up the inside edge. The 45-degree width of the valley in plan is 2 in. times 1.414; multiply this times 1.25 to get the upper and lower edges of the valley housing on the principal (Fig. 13).
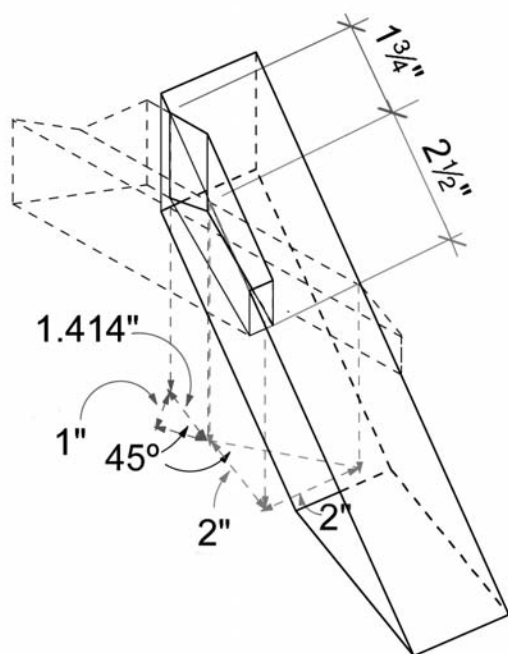
Fig. 13. Finding the upper and lower edges of the valley housing on the principal rafter.

The sides of the housing are again plumb lines down the face of the principal. The height of the housing on the uphill side is (again) the full plumb depth of the valley; take the same measurement you used to lay out the header housing. Use Hawkindale P6 (see Fig. 11 previous page) to run an angle back to the lower line to define the bottom of the valley housing on the principal. This housing is also ½-in. deep. The lower entrance into the principal is a bearing surface, so a 90-degree (square) line defines its shoulder. The valley enters the uphill side at 45 degrees in plan; this translates into Hawkindale P2 in the roof surface (measured from the uphill side as 180−P2 in Fig. 11). Remember that the deck angle (D) in plan relates to P2 in the roof surface, and also to R4 on an unbacked surface on the hip or valley. The principal rafter is now complete.

The valley rafter foot is probably the most difficult joint in the model. Besides the plumb cuts on the sides where it sits in the back of the housing, it has a seat cut angle where it sits on the bottom of the housing, and the "ear" that projects over the principal rafter to support the roof sheathing on the dormer. Establish points for the peak and foot on the top centerline of the valley; this length we've determined as 19.2096 in. from WP to WP. On the unbacked top surface, draw the "side cut" line through the working points; this is angle R4, the same as the table labeled Side Cut of Hip or Valley on the rafter square. This table gives a value of 10⅝ under the 9 pitch. Holding 10⅝ in. on the tongue and 12 in. on the blade, we mark the side cut by running the edge of the blade (12 in. side) through our WP.

At the foot, this is one angle, which represents the side of the principal rafter at the end of the valley. At the peak, this angle runs both ways through the WP to represent the back of the header housing in one direction, and the other to meet the opposing valley coming up from the other side. At the peak, draw plumb lines (9 in 17, or Hawkindale R1) down from the points where R4 meets the arris to define the plumb cuts on the side. Complete the peak cut layout by drawing R4 back to the centerline on the bottom surface.

At the foot we have found the end of the valley and can determine the line where it enters the principal housing and also a line where it ends at the back of the housing. Since the principal rafter is 2 in. wide, and the housing is ½ in. deep, we can use our multiplier of valley length to common run (1.6008) to find the distance to project back up the centerline to find these points. Two in. times 1.6008 equals 3.2016 in.; R4 through this point, parallel to the line at the foot, gives us the line on top where the valley enters the principal rafter. Measuring back from this second line by .8004 in. (½ in. times 1.6008) gives us a line representing the back of the housing. Draw plumb lines down the side of the valley from where all three of these top surface lines meet the arris, and connect them across the bottom (Fig. 14 facing page).

On the "downhill" side of the valley where it enters the housing, we need to cut a bearing surface on the lower part where it rests against the square end of the housing. The top of the valley continues over the principal as the "ear." This angle is 45 degrees in plan but is R4 in the bottom unbacked surface. How far up do we cut this angle on the side of the valley to where the ear begins? We get the answer from the backing angle. The ear is defined by a line projected down from the backing angle on the opposite side of the valley, since the bottom of the ear represents the main roof surface. In this case (a regular valley) it's also twice whatever the rise of the backing angle is (Fig. 14). Cut the ear last, even after the backing angle, but lay it out early, as it's easy to make an error. Last, lay out the seat cut on the bottom of the valley where it sits in the housing; this is best done using Hawkindale R6 (Fig. 11). A paring block set up at right angles to the clip line to guide your chisel would be set to Hawkindale A5.
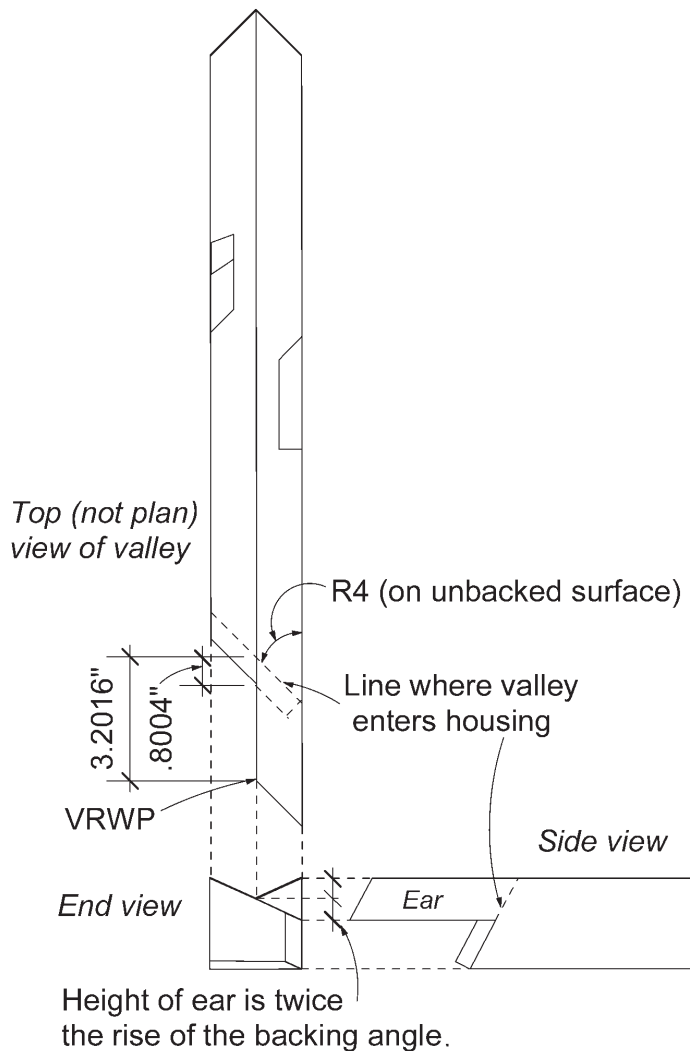
Top (not plan)
view of valley

R4 (on unbacked surface)

Line where valley
enters housing

3.2016"

.8004"

VRWP

Side view

End view

Ear

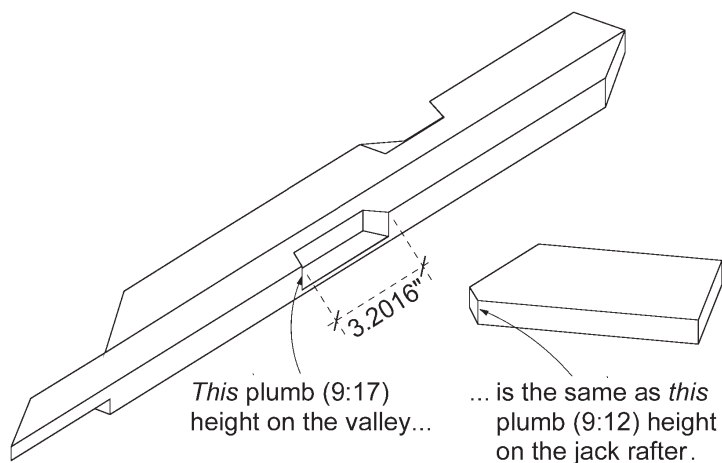Height of ear is twice
the rise of the backing angle.

Fig. 14. Three views of the valley foot.

rafter housing, which is cut in at 90 degrees to the side of the valley and can be laid out as such on the unbacked surface (Fig. 11). This angle becomes 90−A9 on the backed surface. The height of the jack rafter housing on the side of the valley can be found the same way we found the height of the valley housings on the header and principal rafter. Measure a plumb (9:12) line on the side of the jack rafter and transfer that length to the plumb (9:17) lines drawn down from the arris representing the sides of the housing on the valley (Fig. 15). Remember that we have a plumb-sided piece meeting another plumb-sided piece, so the intersection is plumb. Connect these lines at the bottom to complete the housing layout on the side of the valley. On the top unbacked surface, bring the lower shoulder of the housing in at 90 degrees for ½ in., and the upper end of the housing follows the R4 line projected out from the jack rafter valley point.

The jack rafter is laid out from the two WPs with angles we should be very familiar with by now. On the top surface at the foot of the jack, draw angle P2 (Side Cut of Jack—9⅝ on the tongue, 12 on the blade—on the rafter square table) from the WP to the other side. From this point we need to come back up the jack to find where the opposite angle forming the bearing shoulder starts. This will be angle P5, which is the same as P2 in a regular roof (see Fig. 1 on page 4 of TF 71). Since we haven't drawn this joint, we will rely on our multipliers to find the point. The housing is ½-in. deep. The diagonal in plan is ½ in. times 1.414 (the same multiplier as valley run to common run since this plan-view isosceles right triangle is similar) and equals .7071 in. Sound familiar? Multiply this times 1.25 to get the transition from plan length to rafter length. This gives .8838 in. (Fig. 16).

Valley

P5

P2   Jack rafter

.8838"
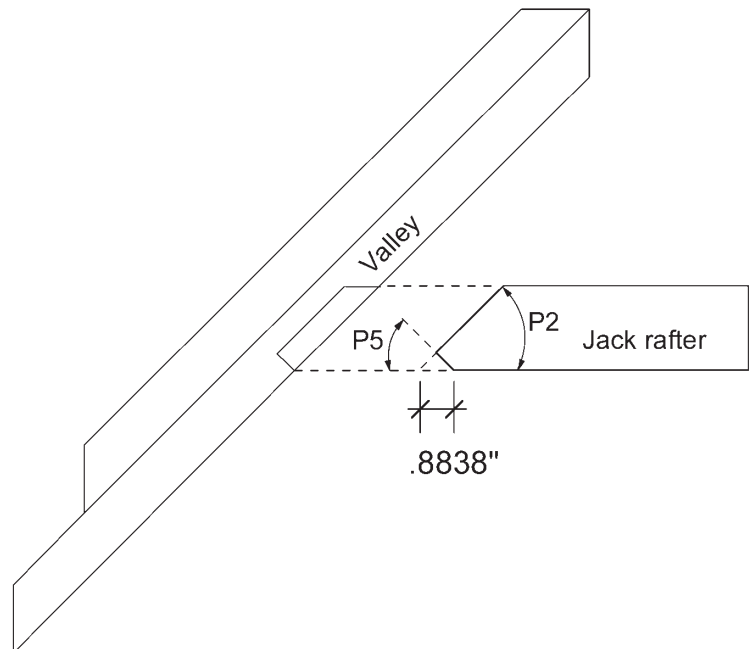
Fig. 16. Jack rafter foot layout.

NOW we're ready to tackle the jack rafter and purlin housings on the valley. Both rafter and purlin run at 45 degrees in plan, so projecting (on the unbacked surface) angle R4 out from their Valley Points to the arris locates one side of their housings. For the jack rafter, a plumb line down from this point is drawn at a 9:17 pitch (R1). Measure down toward the foot of the valley along the arris the width of the jack (2 in. in common run) times our multiplier (1.6008) to get the valley length of the housing: 3.2016 in. This gives us the lower bearing surface of the jack

Come back up the rafter this distance and strike the bearing shoulder line. Drop 9:12 plumb lines down the sides from the arris where these top lines meet the sides. From the points where these lines meet the bottom edge, duplicate the top surface layout on the underside. Since the bottom of the jack rests on a second bearing surface of the housing, we need to trim the bottom surface for a seat cut. This is Hawkindale P6, which happens to be the same as the layout for the valley seat cut on the side of the principal rafter (clip paring guide angle is C5). Strike this angle from where the jack enters the housing on the bottom. Measure up 6 in. to the peak from the lower WP and lay out the simple peak plumb cut at 9:12.

3.2016"

This plumb (9:17)
height on the valley...

... is the same as *this*
plumb (9:12) height
on the jack rafter.

Fig. 15. Jack rafter housing layout.

Last, we need to lay out the jack purlin and its housing. The end of the purlin where it meets the principal rafter is a simple square cut, but the other end is tricky. Since the purlin lies flat in the roof plane, its sides are not plumb, and joinery at the valley is not easily visualized until you do a few of them. Let's use the opportunity to draw a valley kernel, which is constructed a bit differently from the hip kernel we drew in the last article. We will then draw the jack purlin to valley connection and transfer the information from the drawing to the sticks.

DRAWING THE KERNEL. First, we will construct a large 9:12 kernel drawing at the same scale (1:1) as in the last article, except this time the plan view for a valley system will include a ridge instead of eaves and, of course, the ridge runs to the top of the valley. The triangles are the same size as in the hip kernel, just arranged differently (Fig. 17 facing page).

Let's construct a 9:12 valley kernel for a regular pitch roof using the script below. If you're doing this at home, a piece of 27x34 flip-chart paper works well at the 1:1 scale we'll be using. You can also work on a computer or at a smaller scale, but the drawing of the full-scale jack purlin may get crowded if the sheet is much smaller than recommended.

1. PLAN TRIANGLE. Secure the paper with the shorter dimension running away from you, and start carefully at a point 1 in. up from the near or bottom edge and 10 in. in from the right-hand edge. From this starting point, run a level line 12 in. to the left and a plumb line 12 in. up, to form a 90-degree angle. The first line represents the ridge and the second the common run. Connect the two end points to show the valley run. Remember, these lengths have nothing to do with the size of our roof. We are simply constructing a 9:12 model at 1:1 scale, with a rise of 9 and a run of 12.

2. COMMON RAFTER ELEVATION TRIANGLE. From the starting point, extend a level line to the right at 90 degrees to the common run. This line represents the common rise of 9, so make it 9 in. long. Join its endpoint, which represents the peak of the roof, to the foot to make the common length (it should be 15 in.).

3. VALLEY RAFTER ELEVATION TRIANGLE. From the left end of the ridge line drawn in Step 1, extend a line up and to the left at 90 degrees to the valley run. Since the rise of the valley is the same as the rise of the common, this line too should be 9 in. long. Connect the far end, which represents the roof peak, to the foot of the valley run to form the valley length, which should be $19\frac{3}{16}$ in.

4. ROOF SURFACE TRIANGLE. With dividers set to the ridge length and centered on the valley peak, swing an arc. Reset the dividers to the common length and swing a second arc, now centered on the valley foot, to intersect the first arc. Now connect the dots to outline the roof surface. Note that the ridge and the common meet at right angles.

Label all lines and surfaces. Because you will be adding many lines to the triangles, keep the labels outside of the triangles or make them unobtrusive so as not to interfere with the rest of the drawing. If you construct a kernel out of card or poster board, it's revealing to cut it out, score the fold lines and fold it up into a three-dimensional mass model of the roof.

NOW that we have a roof kernel, we can work out the jack purlin-to-valley layout. Figs. 18-21 are numbered to follow the script.

1. THE BACKING ANGLE. Draw the half-valley in plan, and then draw the backing triangle and the valley section (Fig. 18). Note that the backing rise continues above the fold line in the valley elevation triangle since the center of the valley is the fold line and is below the edges. Even though these lines extend onto the

roof surface triangle, they remain part of the valley elevation triangle. Show the purlin entering the valley section and draw its housing (½-in. deep).

2. THE JACK PURLIN. Draw the cross-section of the purlin end in the common rafter triangle (Fig. 19 overleaf). We can't start in the plan as we did in the hip jack rafter exercise in the last article, since the plan doesn't give us the true width of the purlin; its sides aren't plumb. We can get a true view of the purlin in the common rafter elevation. Drop plumb lines from the corners to the common run and extend level lines to mark the purlin in plan. Draw the purlin housing in plan, ½ in. deep. The bearing shoulder is 90 degrees to the valley side in plan, and the other shoulder enters at 45 degrees in plan.

3. THE JACK PURLIN HOUSING. From the points where the purlin meets the valley in plan, raise plumb lines in the valley triangle (Fig. 20 overleaf). The intersections of these plumb lines with layout lines extended from the valley section establish the jack footprint on the side of the valley. Don't forget to bring over the line for the back of the housing. This is the first time we have seen Hawkindale R2 appear, which is the angle of a plane perpendicular to the roof surface and parallel to the ridge or eaves, projected onto the side of a hip or valley. Note that the purlin housing on the side of the valley slants up toward the peak. This is tough to visualize.

4. THE JACK PURLIN LAYOUT COMPLETED. Square up from the mortise (valley elevation) to the valley edge (roof surface) and continue on (square to the common rafter length) to draw the roof surface view of the purlin (Fig. 21 overleaf). If you've done everything right, this width should be 2 in. Take the depth of the housing in the roof surface from the valley section, as we did in Fig. 12 in the last article; it is *not* ½ in. as it is in the plan view. Look at the detail in Fig. 21 to see that you need to square up the proper points from the rear of the housing in the valley elevation to find the points in the back of the housing in the roof surface. This gives us another new Hawkindale, A8, which is the square shoulder of the long side of the jack purlin projected onto the hip or valley backing (laid out as 90−A8 in Fig. 11). We now have all of the information needed to cut the valley housing for the jack purlin—the top and side views on the valley—once we locate the joinery on the valley from the jack purlin valley point. We also have the top view of the jack purlin itself, and see that the square (in plan) bearing shoulder becomes Hawkindale P4 (Fig. 11) in the roof surface, and relates to angle A8 on the valley. The other angle on the top of the purlin is 90−P2. This was P2 on the jack rafter; since the purlin runs at right angles to the way a jack rafter would on the same side of the roof, the angle becomes 90−P2. Note that while P2 and P5 were the same on a jack rafter in a regular roof (but will be different on an irregular roof), 90−P2 and P4 do not share the same convenient relationship on the jack purlin in a regular roof. We are still lacking the side view of the purlin. We can lay out this view in Fig. 21 parallel to the ridge by "rolling" the plan view of the purlin until we are looking at it directly from the side. In the plan triangle, drop plumb lines from one side of the jack-valley intersection to create the side elevation of the purlin. The top of the purlin is 1½ in. from the bottom. To lay out the seat cut (Hawkindale P3) on the bottom of the purlin, first take from the roof surface view the length of the purlin inside the housing and transfer it to the side view of the purlin. Then measure in the valley section the rise of the purlin over this distance.

To make this measurement useful in the purlin side elevation, we need to convert it to the angle of the purlin on the side face of the valley (90−R2). The rise in the valley section is rotated to 90−R2 by extending lines to the purlin housing in the valley elevation triangle, yielding the true rise. This distance is then used to obtain P3 in the purlin side elevation. For greater accuracy, a
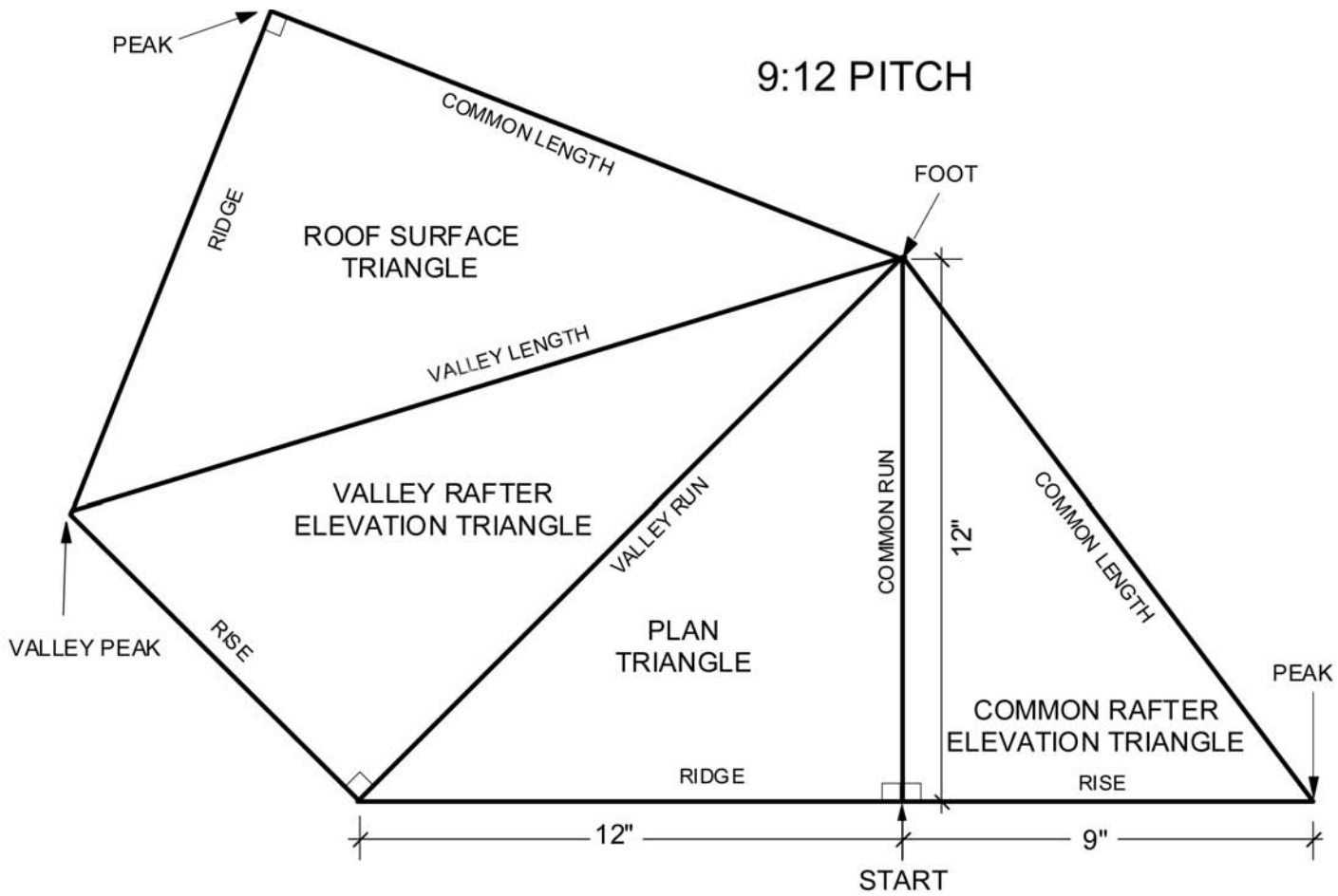
9:12 PITCH

Fig. 17. Drawing the valley kernel.

Backing rise is projected above the fold line in the valley elevation triangle.
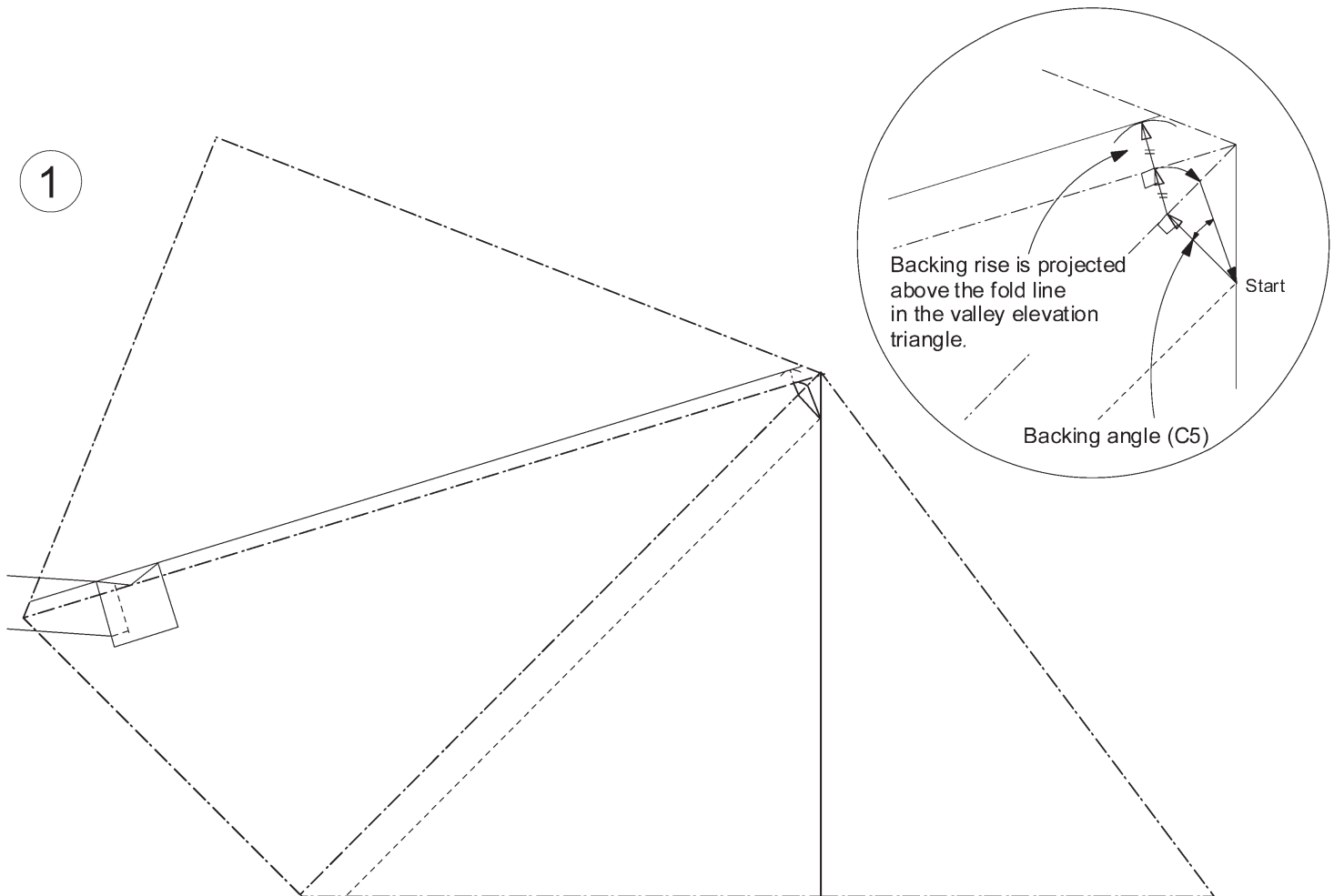
Start

Backing angle (C5)

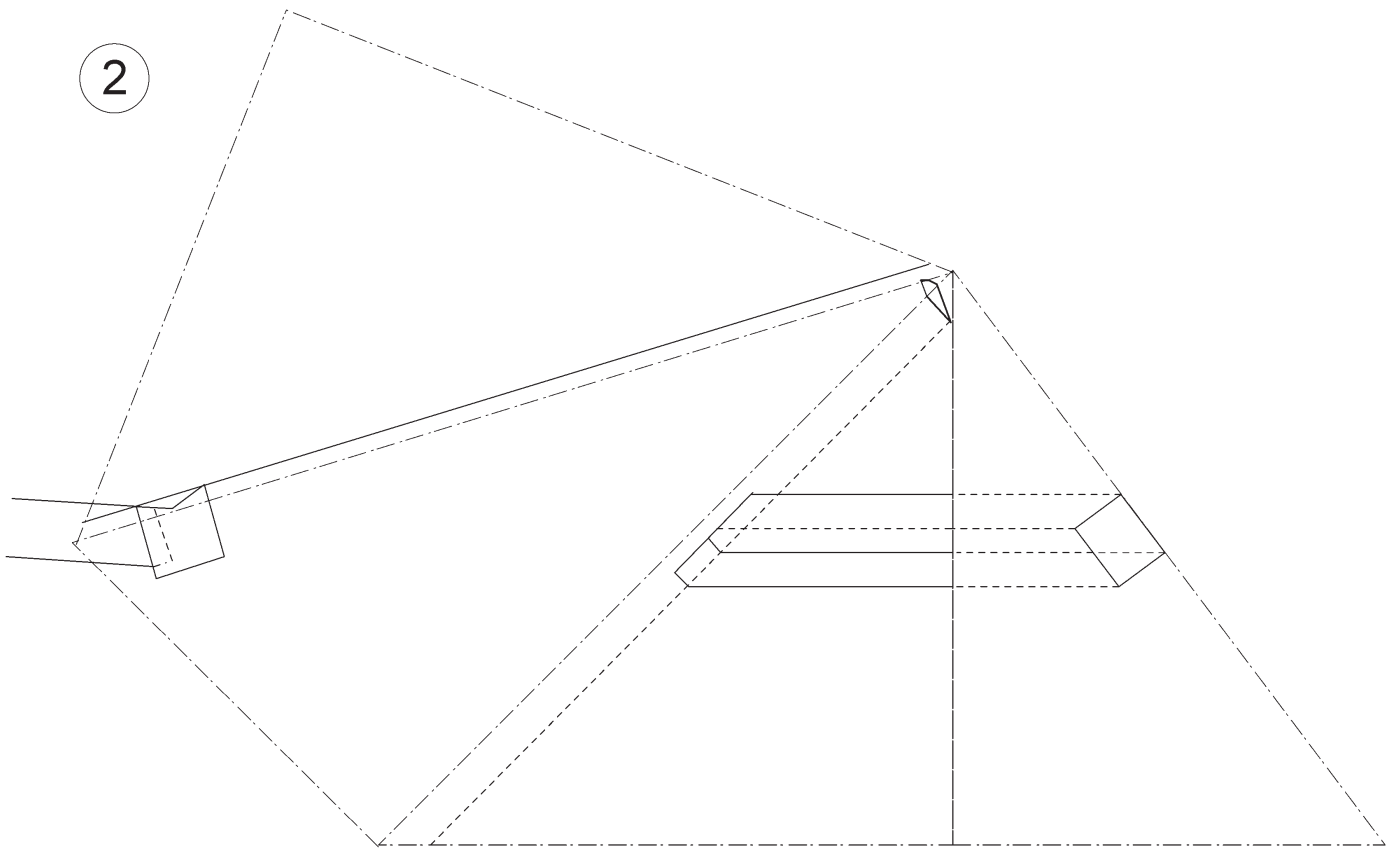Fig. 18. Drawing the valley backing angle and section.

Fig. 19. Starting the jack purlin layout.
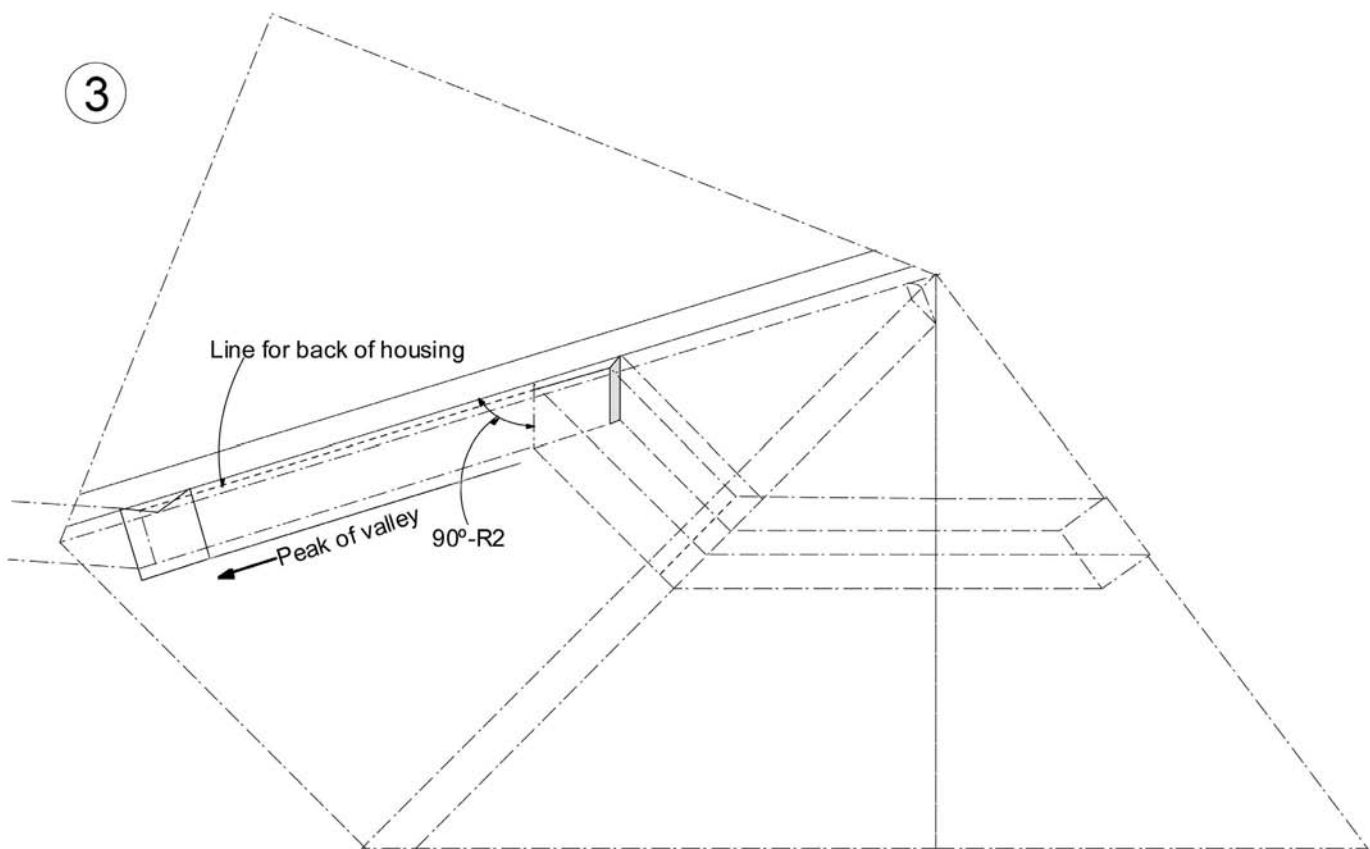
Fig. 20. Drawing the jack purlin housing layout.
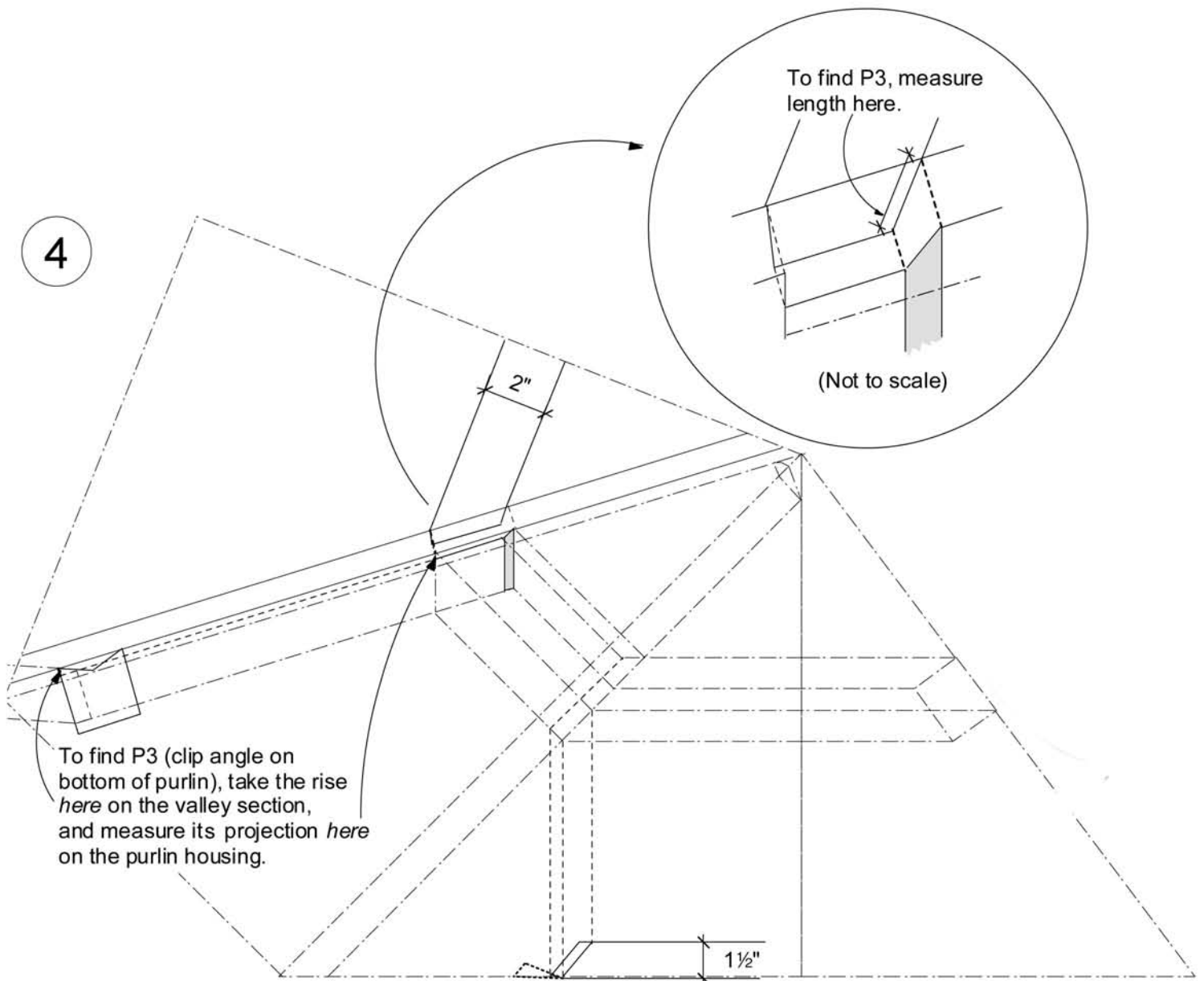
To find P3, measure length here.

(Not to scale)

④

2"

To find P3 (clip angle on bottom of purlin), take the rise *here* on the valley section, and measure its projection *here* on the purlin housing.

1½"

Fig. 21. Completing the jack purlin layout.

This distance is the *rise* of the purlin in the housing (see valley elevation triangle).

P3   Purlin

This distance is the *length* of the purlin in the housing (see roof surface).

longer baseline can be obtained by extending the purlin lines to the center of the valley taking the rise over the full width of the valley. Transfer this distance to the end of the purlin in the side view and connect this point back to the bottom of the purlin where it enters the valley. This is probably the hardest Hawkindale angle thus far to visualize. We are clipping off the backing angle from the bottom of the jack purlin so that it doesn't continue down into the valley at the roof pitch. This is "compounded" by the fact that we need to lay out this clip on the side of the purlin. Thus you can interpret P3 as being C5 (the backing angle) rotated out to 90−P2 (the angle of a jack purlin to the valley). It's hard to draw, much less describe in words, so you can see that once you know how to apply the Hawkindales, they can save you a lot of effort. Once you do a few of these angles, you'll never forget where P3 occurs and how to draw it on the timber!
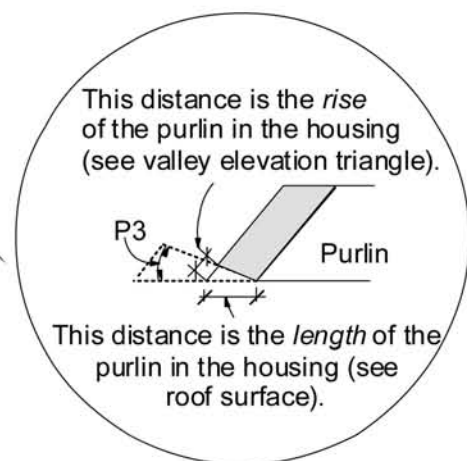
As the final operation in cutting the model, rip the backing angle (Hawkindale C5) of the valleys on the table saw.

—WILL BEEMER

Will Beemer is co-Executive Director of the Guild in charge of education and has taught numerous compound roof courses at the Heartwood School in Washington, Mass.

The 18th-Century Church Designs of Robert Smith

IN THE third quarter of the 18th century, no builder-architect practicing in colonial America enjoyed a wider reputation than Robert Smith (1722-1777) of Philadelphia. Smith was born in Scotland and immigrated to Pennsylvania by 1749. Within a decade, he had emerged as the most prominent figure of his trade in British North America. His talents had been sought out by clients from Virginia to New Jersey, with approximately 50 commissions identified to date, and his buildings influenced the designs of others over an even broader geographic area. Among Smith's leading works are the steeple of Christ Church in Philadelphia (1751-53), Nassau Hall and the President's House at Princeton University (1753-57), a new Philadelphia residence for Benjamin Franklin (1764-66), the Philadelphia Bettering House (1765-66), the Hospital for the Mad & Insane at Williamsburg, Virginia (1770) and the Walnut Street Prison (1773-74) in Philadelphia. Smith also played a leading role in the affairs of the Carpenters' Company of the City and County of Philadelphia, America's oldest trade guild. He provided designs for Carpenters' Hall (1768) and served on the influential Committee on Prices of Work, which set the rates that member carpenters charged their customers.

Robert Smith provided designs for at least seven new churches during his distinguished career, all but two in Philadelphia: Second Presbyterian Church (1750-51), St. Peter's Episcopal (1758-61), St. Paul's Episcopal (1760-61), Zion Lutheran (1766-69), Third Presbyterian (1767-68), Christ Episcopal (Shrewsbury, N.J., 1769-74) and the First Presbyterian (Carlisle, Pa., 1769-73). Dimensions ranged from 38 by 62 ft. for the modest Shrewsbury structure to 70 by 108 ft. for the magnificent Zion Lutheran. Zion was considered the largest house of worship in British North America until well into the 19th century. When viewed as a group, these seven great structures constitute the most significant known body of ecclesiastical commissions associated with one architect in all of colonial America.

Five of Robert Smith's churches survive today, namely St. Peter's, St. Paul's, and the Third Presbyterian (known as Old Pine) in Philadelphia, Christ Church in Shrewsbury and First Presbyterian in Carlisle. Of this total, three have been so totally altered that no trace remains of their interior appointments, and very little exterior detail. Smith's concepts of spatial arrangements and ornamentation can therefore be studied today only at St. Peter's Church in Philadelphia and at Christ Church in Shrewsbury.

For four of the seven documented church commissions, Robert Smith selected a roof truss design based on Plate K from *The British Carpenter* by Francis Price, surveyor of the great Cathedral Church in Salisbury, England (Fig. 1 facing page). Price's book first appeared in print in 1733, followed by a second edition two years later. An expanded third edition came out in 1753. *The British Carpenter* discussed many alternatives for general framing, roof trusses, towers, staircases and domes. It was one of the few architectural treatises of its day intended for practical use by carpenters faced with various structural challenges.

A copy of *The British Carpenter* may well have been among the "Sundry Books of Architecture" owned by Robert Smith at the time of his death (Robert Smith Estate Inventory). Other copies were available locally as early as 1739 in the collections of the Library Company of Philadelphia, by 1753 at the Union Library of Philadelphia, from city booksellers after 1754, and in the library of fellow carpenter John Lort (d. 1795). Francis Price's publication certainly became popular generally among colonial builders and carpenters. One recent survey of architectural guidebooks available in America before 1776 identified 27 citations to it in Boston, Rhode Island, New York and Philadelphia. This number was exceeded by only one other title, *Palladio Londinensis* by William Salmon (Park, 39, 68, 70-71). A copy of "Price's Carpenter," valued at $1.00, was also listed among the 519 titles in George Washington's library at Mount Vernon (Lossing, 376).

The truss model selected by Smith is known today as the raised bottom chord truss. The six primary timber elements of this truss comprise two straight principal rafters, a collar beam, a kingpost and two diagonals that span from the underside of the collar beam near its junction with the kingpost to the foot of the rafters. The primary advantage of this truss is that it accommodates a graceful arched ceiling rising above the level of the wall plates, a feature found in the four Smith churches using this roof framing system. The design also eliminated the need for internal columns or supports and allowed for a low roof pitch, of 30 degrees or less. It made comparatively sparing use of timber and depended on ironwork to achieve structural integrity.

Francis Price advocated the use of iron straps and bolts to give strength to his unsupported long-span truss designs. "I say, if it be objected that there is too much trust reposed on the iron work, may it not be asked, if any common strap, at the bottom of a kingpost, was ever known to break by continual pressure?" Price then went on to describe in detail how this particular truss should be assembled. "First, enter your king-post into the beam; put in your braces; then enter the top of your principal rafters into the kingpost; as at *f*; so by bringing down its bottom, you enter the brace *g*, and beam h; then enter your hammer-beam as at *I*; pin all together, and put on your straps, and your bolts through both beams in a good manner. Then let one think what force can part them" (Price, 19). It is interesting to follow Price's terminology for the individual elements of this truss. He called the long diagonal braces "hammer-beams," a usage at variance with our understanding of the term today, but common in the carpentry trades of England and America into the 19th century.

To secure the straps properly, Price advised "to bolt on your straps with square bolts; for this reason, if you use a round bolt, it must follow the augur [hole], and cannot be helped; by this helping the augur-hole, that is, taking off the corners of the wood, you may draw the strap exceeding close, and at the same time it [the bolt] embraces the grain of the wood, in a much firmer manner than a round pin can possibly do" (Price, 18). In other words, Price recommended the installation of square bolts in round holes in order to prevent them from turning loosely in the timber.

The British Carpenter did not necessarily offer its readers innovative new approaches to timber framing problems. Rather, Price summarized existing English practice and practical experience in a single convenient manual. The raised bottom chord truss had in fact appeared in London years earlier. Sir Christopher Wren, for example, incorporated four of them in the roof framing of St.
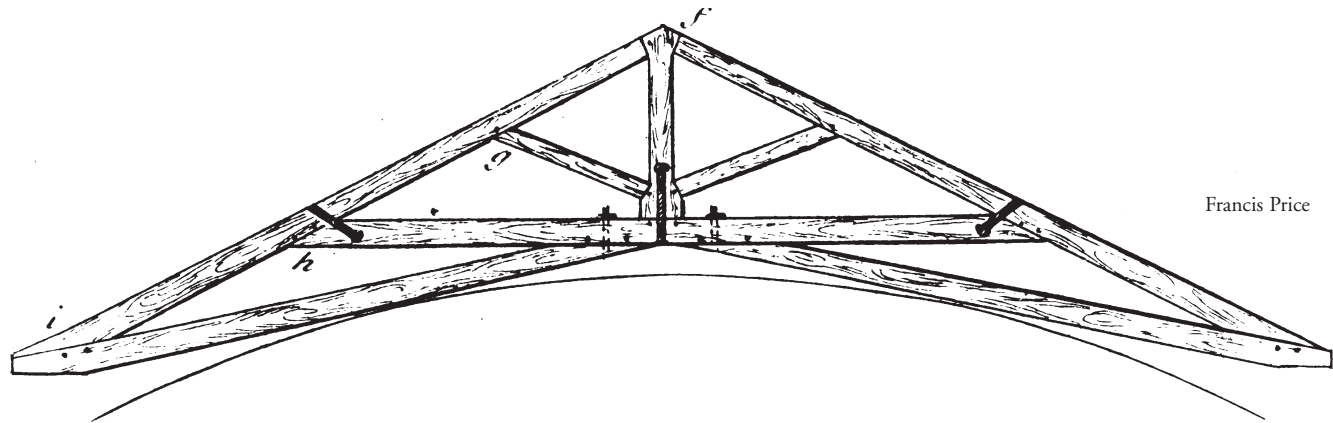
Francis Price

Fig. 1. Detail from Plate K of The British Carpenter, *by Francis Price, first published in 1733. Author's Collection.*

Paul's Cathedral, finished by 1706. Spanning 50 ft., one pair provided extra height for a shallow saucer dome in the ceiling of the vestibule area, and the other pair for a stone barrel vault over the west portico. Wren's carpenters placed three large vertical through-bolts on either side of the kingpost to secure the joints with the hammer beams. They also applied large inverted t-shaped straps on either side of the main three-way kingpost joint with the collar and hammer beams, as well as iron straps around the ends of the heel joints between the rafters and the hammer beams (Fig. 2).
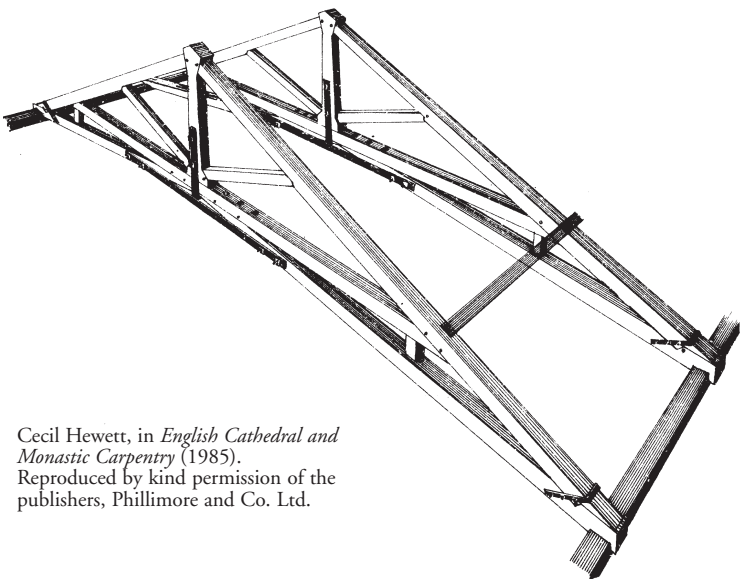
Cecil Hewett, in *English Cathedral and Monastic Carpentry* (1985). Reproduced by kind permission of the publishers, Phillimore and Co. Ltd.

Fig. 2. St. Paul's Cathedral, London, ca. 1706, roof framing over the west portico.

Philadelphia builders before 1750 may not have been as skilled at wide-span timber framing as their design ambitions required. At Old Swede's Church (1698-1700), for example, the outward thrust of the steep gable roof caused the brick side walls to crack and bulge by 1703. Vestibules added at that time against the north and south elevations buttressed the structure. St. Michael's Lutheran Church on Fifth Street above Arch suffered from the same problem after its construction in 1743. The stresses of its enormous gambrel roof proved too great for the brick side walls, apparently because the church was erected in only six months and not enough time had been allowed for the mortar to dry properly. Large two-story porches were built in 1750 abutting the original church on the north and south, providing reinforcement in a manner identical to Old Swede's. St. Michael's 50-ft. steeple was removed at the same time to reduce the load on its walls.

Robert Smith's first church commission in Philadelphia was for the Second Presbyterian Church on Arch Street. A description of

the plan entered into the Trustees' Minutes in 1749 called for a building 60 ft. wide and 80 ft. long. It was then agreed that the Managers would apply to Robert Smith and Gunning Bedford (1720-1802) "to undertake the Carpenters Work of the said House . . . ." (Second Presbyterian Church, Trustees Minutes, vol. 1, 4-5). The church was erected in 1750-51, with installation of galleries, pews and other interior appointments continuing into 1753. The roof truss design remains unknown. But during an 1809 renovation and expansion, the contractor was asked "to lower the present ceiling several feet, making it partly flat, & somewhat ornamental . . . ." (Trustees Minutes, vol. 3, 84). The Second Presbyterian Church thus appears to have featured a high arched ceiling like the four Smith commissions where the raised bottom chord truss is known to have been used. Perhaps it too had such a truss.

After a three-year period in Princeton, N.J., to work on Nassau Hall and the college president's house, Robert Smith returned to Philadelphia, where he became involved immediately with the construction of a new Episcopal church at Third and Pine called St. Peter's Church. In an extraordinarily detailed contract dated 5 August 1758, Smith agreed to erect a church measuring 60 by 90 ft. For this commission, Smith served as general contractor, taking on responsibility for the masonry work as well as all carpentry. He was to be paid 4000 pounds, in installments as construction milestones were reached (Fig. 3).

Fig. 3. St. Peter's Episcopal Church, Third and Pine Streets, Philadelphia, 1758-61. An 1829 lithograph by William L. Breton as the building appeared before removal of the cupola and addition of a tower in 1842. Reproduction courtesy of the Historical Society of Pennsylvania.

The building committee laid out in extreme detail their specifications for such items as depth of foundations, thickness of walls, size of glass window panes, dimensions of lumber and so on. In addressing the roof structure, the contract stated, "The Roof of the said Building shall be Trussed, well framed and bound with Iron, That the frame of a Circular Ceiling shall be made and fixed under the Roof ready for the Plaisterer to lath and plaister on, together with a large Cornice under the Spring of the Arch for the Circular Ceiling . . . ." To assemble and raise these massive roof trusses and secondary framing, extensive scaffolding was erected within the brick walls. Smith's contract concluded: "It is agreeable that the scaffolds be kept up for the use of the Plaisterer" (Richards, 224-226). This clause suggests that the roof truss members may have been laid out and fabricated on the ground, then brought up onto the scaffolding for assembly on a horizontal plane. Raising could then consist of simply turning the truss up into vertical position. St. Peter's stands today as the earliest surviving Smith church, as well as the one least altered. It incorporates the raised bottom chord truss in a clear span of 60 ft.

The 1760s proved a very active period for the building trades in Philadelphia. Robert Smith had hardly completed the shell of St. Peter's Church when he became involved in the design and construction of St. Paul's, an evangelical Episcopal church located on Third Street, only two blocks north of St. Peter's. The initial plan was presented to this new congregation's Vestry on July 28, 1760. Seven days later, the minutes noted that "Mr. Robert Smith Carpenter being present it was mutually agreed betwixt him and the Trustees that he should finish the Roof, Doors and Windows of the Church" (St. Paul's Church, Vestry Minutes, Vol. 1, August 4, 1760). The masonry contract went to John Palmer, a member of the building committee and the mason who had erected the brick shell of the Second Presbyterian Church.

As at St. Peter's, elaborate and comprehensive scaffolding may have been set up within the brick shell for assembling and raising the roof structure at St. Paul's, which, at 65 by 90 ft., was then the largest church in the city. Smith's carpentry crew used the raised bottom chord truss here as well, extending it to a 65-ft. clear span. This represented the widest application in Smith's distinguished career. Although still standing, St. Paul's has been modified extensively several times. The original roof trusses, however, remain in place, representing a milestone in colonial wide-span timber framing (Figs. 4 and 5).

By far the most ambitious of all churches designed by Robert Smith was the great Zion Lutheran church at Fourth and Cherry Streets, erected between 1766 and 1769. Measuring 70 ft. by 108 ft., this massive structure "was the largest and handsomest in North America; the roof and ceiling were supported by eight large columns of the Doric order, which served as the bases of the arches of the ceiling, which were ornamented and finished in a most magnificent manner. No expense was spared in finishing the inside of the church" (Hazard, December 12, 1829). At the time of its completion, Zion Church cost 8000 pounds. Robert Smith and his crews undertook all carpentry and interior finish work, while Jacob Graff Jr., a member of the congregation as well as the local German community, served as mason for the brickwork. The church interior description indicates explicitly that Smith did not use the raised bottom chord truss with high curved ceiling in this structure. Perhaps the 70-ft. span caused him concern. No doubt the double row of four giant Doric columns gave the interior a majestic appearance (Haussman, 41-55).

Unfortunately, this great architectural masterpiece was destined for a short life. Fire broke out in the base of the unfinished church tower on Christmas Day in 1794. By midnight, Zion Church had been reduced to a smoldering brick shell in spite of extensive firefighting efforts to stop the flames. Within days, a complete inspec-
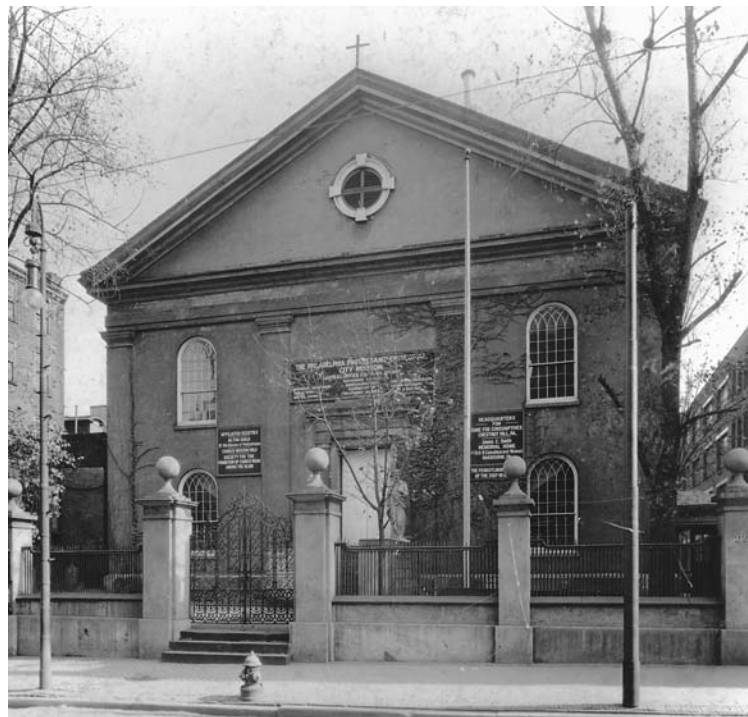
Figs. 4 and 5. St. Paul's Episcopal Church, Third Street, Philadelphia, 1760-61. Interior view below, ca. 1900, shows its appearance following renovations of 1830 and later. The graceful arched ceiling shows the effect possible under a raised bottom chord truss. Ceiling framing can also be seen in the pattern of staining on the plaster surface. At 65 ft. clear span, St. Paul's represented Robert Smith's widest use of the raised bottom chord truss. Photos courtesy of Episcopal Community Services.

tion of the ruins determined that the walls were not essentially damaged. William Colladay, a noted Philadelphia builder, received the appointment to immediately reconstruct the building within them. It was decided not to replace the giant interior columns that had formerly supported the roof. The building committee was therefore instructed to visit other churches in the city to gather information on how a wide-span structure could best be supplied. William Colladay then achieved what Robert Smith did not, a clear span of 70 ft. Zion Church remained essentially unchanged after rededication in 1796, until taken down in 1869 (Haussman, 1942, 105-115).

By the early 1760s, construction of another Presbyterian house of worship on Pine Street was deemed necessary to serve the rapidly expanding southwest part of Philadelphia. On January 16, 1766, the General Committee of the First Presbyterian Church on

Fig. 6. Zion Lutheran Church, Fourth and Cherry Streets, Philadelphia, 1766-69, photographed ca. 1869. Robert Smith's handsome brick exterior walls survived a 1794 fire, allowing the church to be rebuilt within them. Author's collection.

Market Street met to consider the plans. "After some time spent therein, it was determined that the Erection of a new Presbyterian Church (being the third in this City) be undertaken with all convenient speed, not to exceed the dimentions of 80 feet long & 60 feet wide . . . ." (First Presbyterian Church, Philadelphia, Trustees Minutes, January 16, 1766). Robert Smith provided the plans, but ongoing involvements at Zion Church apparently prevented him from taking any role in construction of this new church, known today as "Old Pine" (Fig. 7).
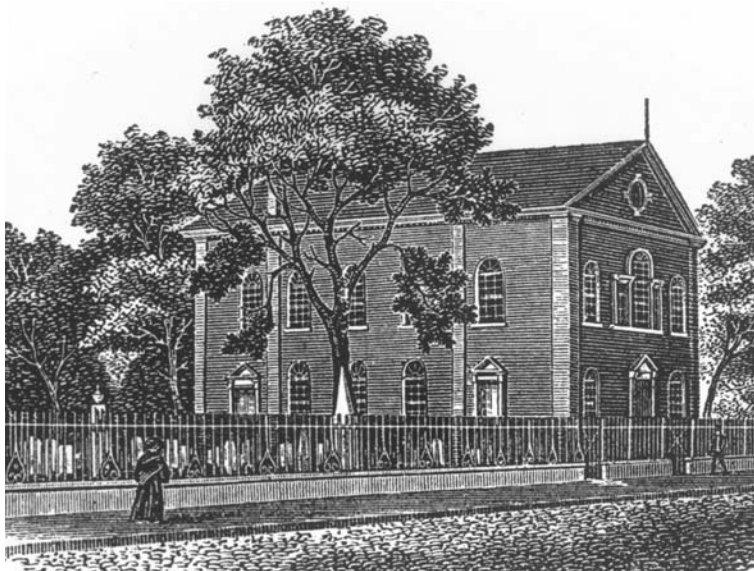
Fig. 7. Third Presbyterian or "Old Pine" Church, Pine Street, Philadelphia, 1767-68. This wood engraving shows the building following façade changes of 1792 but before additional alterations in 1837. Reproduction courtesy of Old Pine Street Presbyterian Church.

Work commenced during 1767 and continued through December 1768. James Armitage, a carpenter affiliated with the congregation, "had Employ^t to a very large Amo^t." But, for the erection of the wide-span roof trusses, the congregation turned to Thomas Neville, another talented Philadelphia builder-architect. A subscription list for this project indicates that Neville "put on Roof

and Ceiling" (Third Presbyterian Church, Subscription List). This notation is confirmed by an undated entry in Neville's own day book in which he recorded that "The Agrement for the Roof & Cealing of the New Presbyterian Meatin House was four hundred & forty pounds" (Thomas Neville Day Book, 1).

Old Pine Presbyterian Church still stands on a lot immediately west of St. Peter's, altered several times beyond recognition as an 18th-century building. But the 60-ft. raised bottom chord trusses remain in place. Comparison of this work with that of Smith at St. Peter's and St. Paul's shows different workmanship standards. Neville's crew, for example, did not surface the timber stock as smoothly as did Smith's. Old Pine also represents the first known instance of Robert Smith serving as architect for a church without taking a role in construction. In fact, Smith did not work as a carpenter or builder again on any of his subsequent ecclesiastical commissions.

In 1769, as his reputation continued to expand, Robert Smith provided designs for two churches radically different from those in Philadelphia. In the spring of that year, the Presbyterian congregation in Carlisle, Pa., paid 5 pounds to "Robert Smith Carpr in Philada for Drawing a Plan of the Meeting House" (First Presbyterian Church, Carlisle, Montgomery Account). This stone church, a prominent feature today on the green of this Cumberland Valley community, measures 50 ft. wide by 70 ft. long (Fig. 8).

Fig. 8. First Presbyterian Church, Carlisle, Pa., 1769-1773, photographed ca. 1880, before additions and alterations changed its appearance substantially. Photo courtesy of Cumberland County Historical Society, Carlisle, Pa.

That the masons were following a set of working drawings is suggested by the contract to complete the walls of the church, in which the workmen were required to construct "the Gable ends agreeable to the plan of the roof . . . ." (Joseph Murray Collection, 43-2-3). The master carpenter responsible for framing the trusses appears to have been Matthew McGlathery (d. 1800) of Philadelphia, who received various payments for work on the building from 1770 through 1772. But instead of a raised bottom chord design, McGlathery installed standard kingpost trusses with flat bottom chords spanning from plate to plate. As a result, the interior features a flat ceiling.

Concurrently with Carlisle, Christ Episcopal Church in Shrewsbury, N.J., completed plans during Easter Week of 1769 to replace their house of worship with an entirely new structure. But this was no easy process. Josiah Holmes, a Church Warden and influential member of the community, objected strongly to the plans under consideration provided by Robert Smith of Philadelphia. He and his carpenter sons Thomas (b. 1743) and

Jacob (1744-1820) prepared an alternative design that reflected conservative carpentry practices in central New Jersey. Surviving framing sketches in the Holmes Family Papers indicate that he preferred two rows of interior columns supporting a barrel-vaulted nave, with galleries placed over both side aisles. The roof trusses depicted resembled those of Old Tennent Presbyterian Church, erected near Freehold, N.J., in 1751-52.

When final decisions regarding the Smith plan came to a vote in Shrewsbury, Holmes became so irate that he resigned from the building committee and the Vestry and as clerk for the congregation. His vituperative letter of resignation was sent in the form of meeting minutes that began "The Gimcrack Vestry . . . Returns their thanks to the Master Gimcrack." This insulting slang term denoted a person who tinkered with mechanical contrivances. Holmes did not believe that the raised bottom chord truss as recommended by Robert Smith would be successful. As he said in his inflammatory draft of the Vestry minutes (Holmes Family Papers, Box 2, Folder 8):

> He thinking it too Great a hardship to be oblig'd and Layed under the Disagreable Necessity of acting against his own Reason, also thinking himself and others Ill used, &c. &c., Declines and Absolutely Refuseth to act either as a Member of said [Building] Committee or as Church Warden until he can at least be better Reconciled to the Method and Proceedings; Determining to have no Manner of Concern in ordering or Carrying on the said work, But only to remain Barely a Spectator according to which Determination his name is Eras'd in the minutes of the Vestry.

The Vestry accepted the resignation of Josiah Holmes with regret, then "Ordered that the building of the Church shall be carried on, and that the Roof &c. shall be framed according to the Draught of Mr. Smith of Philadelphia" (Christ Church Vestry Minutes, Easter Tuesday, 1769). Just to make certain that there was no misunderstanding with Daniel Halstead and other members of the local carpentry crew, the building contract repeated the specification that "the Roof to be built & framed agreeable to the Plan given herewith from Mr. Smith." For the sum of 300 pounds, the carpenters would "Frame, Raisse & enclose with shingles from top to bottom, with a Cupola agreeable to the plan deliver'd herewith, and to make the Window Frames, sashes, Doors, Inside & Outside Cornish and lay the Floors, all in a good, substantial & neat manner . . . ." (Christ Church, Carpentry Articles of Agreement, June 12, 1769). Construction at Shrewsbury continued slowly, and in phases, until April 1774, when the structure was consecrated for worship and declared finished at a total cost of 800 pounds.

At 38 ft. wide by 62 ft. long, Christ Church in Shrewsbury is the smallest of the documented Smith church designs. It is also the only one with timber-framed walls instead of masonry. Perhaps given the small 38-ft. clear span, the carpenters did not believe it necessary to install iron straps either at the complicated center joint under the kingpost or at the heel joints. They did, however, secure the hammer beams to the raised collar with one large iron bolt on either side of the kingpost. Christ Church retains many of its original interior appointments and exterior details (Fig. 9).

WE have seen that four out of seven Robert Smith designs for new churches (and possibly a fifth) incorporated the raised bottom chord truss to create an uninterrupted wide-span space able to accommodate graceful curved ceilings. In fact, this talented builder-architect emerges as one of the few carpenters in colonial America willing to undertake the erection of such wide-span timber trusses. St. Paul's Church, at 65 ft., represents the widest of them all, exceeding by 15 ft. the length of those used by Sir Christopher Wren at St. Paul's Cathedral in London.

Fig. 9. Christ Episcopal Church, Shrewsbury, N. J., 1769-74, photographed ca. 1870. Secondhand stained glass had been installed in the original window openings in 1867, but other elements of the exterior remained essentially unchanged until the addition of a tower in 1874. The building is framed in oak and shingled in white cedar. Photo courtesy of Christ Episcopal Church.

Smith did not merely copy the plate from *The British Carpenter,* as would amateur gentlemen architects. Rather, he made significant improvements in the use of iron. Smith added straps where the diagonal hammerbeams connected with the rafters and the plates, and used two bolts, instead of one, at the junction of the hammerbeams with the collar beam in the three large Philadelphia churches. Like Francis Price, Smith drove the bolts in from below, placing the threaded nuts or wedged and keyed fasteners on the top of the collar.

Finally, Smith strengthened a main stress point in the truss, the kingpost-to-collar beam connection, with a large iron strap that ran along the underside of the hammer beams for approximately 4 or 5 ft. from the center point, in effect creating a large inverted Y-shaped iron yoke when combined with the normal vertical U-shaped strap. The bolts were then inserted through holes drilled in the under strap so that they could not pull through into the timber. These refinements show the eye of an experienced carpenter looking for and fixing potential weak points in a theoretic structural design derived from a book.

If truss configurations and customized iron details used in the known Robert Smith churches can be viewed as defining characteristics, then three more buildings should be considered for some measure of attribution. The first is St. George's Methodist Church in Philadelphia, begun about 1763 by a newly formed German Reformed congregation but auctioned six years later to the Methodists as an uncompleted shell. The evolution of St. George's, a brick structure 53 by 66 ft., was complicated, and in fact the

building was not completed until the 1830s. Original exterior ornamentation shared some details in common with Smith's designs at the Second Presbyterian Church, St. Paul's, Old Pine, Zion Lutheran Church and the Walnut Street Prison. On August 12, 1865, the roof and ceiling of St. George's were destroyed by fire. Photographs taken of the ruin show clearly the use of raised bottom chord trusses, complete with Smith's Y-shaped iron yolk and bolts at the juncture of the hammerbeams, collar beam and kingpost. (See front cover.) These damaged trusses were replicated when the church was reroofed, although with sash-sawn rather than hewn timber. Examination suggests that some of the original iron straps and bolts may well have been reused during the post-fire reconstruction. The replacement roof and its trusses remain in place today.

Recent studies point to Robert Smith as the probable architect for a new church in 1771 at St. Peter's Episcopal parish in Freehold, N.J. Smith was known in the area as he had spent the years 1755 through 1758 in Princeton supervising construction of his designs for Nassau Hall and the college president's house. By 1771, Christ Church in Shrewsbury, 15 miles east of Freehold, had progressed well with their new building according to Smith plans. (The Freehold and Shrewsbury congregations had in fact shared common clergy from 1733 to 1766.) The incumbent minister at Freehold, Rev. William Ayres (d. 1815), was well connected to the Charity School and College in Philadelphia. He had enrolled as a student in 1752, but after 1755 stayed on as a member of the school and college faculty before going to England for ordination about 1766. Robert Smith had served as architect and builder for all work at the college from 1750 through 1777, including renovation of an existing meeting house for classrooms and lecture halls (1750), design and construction of an entirely new College Hall (1762-63) and design and construction of a new residence for the college provost (1774-76). Ayres would have been familiar with these projects.

Little documentary evidence survives pertaining to the original construction of St. Peter's Church in Freehold. A remarkable section drawing entitled "Freehold Church" and dated 1771 indicates that the designs were in hand by that time (Fig. 10). In September of the same year, Ayres wrote: ". . . my hearers in Freehold have erected the frame of the Church . . . they propose to have it enclosed this Fall" (Nelson Burr Transcripts). But construction ceased by 1775 and did not start up again until 1793 when new contracts were let to finish the building and furnish it for worship.

The new structure in Freehold measured 35 by 66 ft. Like its sister church in Shrewsbury, St. Peter's is a timber-framed structure enclosed on the outside with shingles. Roof framing consists of raised bottom chord trusses, in this instance assembled of massive, overweight stock, roughly surfaced. The local carpenters followed closely the truss design as shown in the section drawing of 1771, with some notable exceptions. The drawing specified that iron straps and bolts were to be installed where the kingposts joined the collar beams, and also at the ends of the collar beams and hammerbeams where they connected to the rafters. This particular iron configuration conformed exactly to Robert Smith's customization of the Price truss model. But the carpenters eliminated all iron straps except under the kingpost of the westernmost truss supporting the steeple. A single bolt driven up through the hammer beam-collar beam joints secured that joint from separation. Apparently this crew felt that the 35-ft. span of the building did not require the extensive installation of iron other than where the excessive load of the steeple put unusually heavy stress on the west truss.

In an effort to verify the authorship of the very rare section drawing, it was submitted in 1995 to professional handwriting analysis. The drawing was given a 50 percent probability of bearing Robert Smith's handwriting, mostly because the quantity of
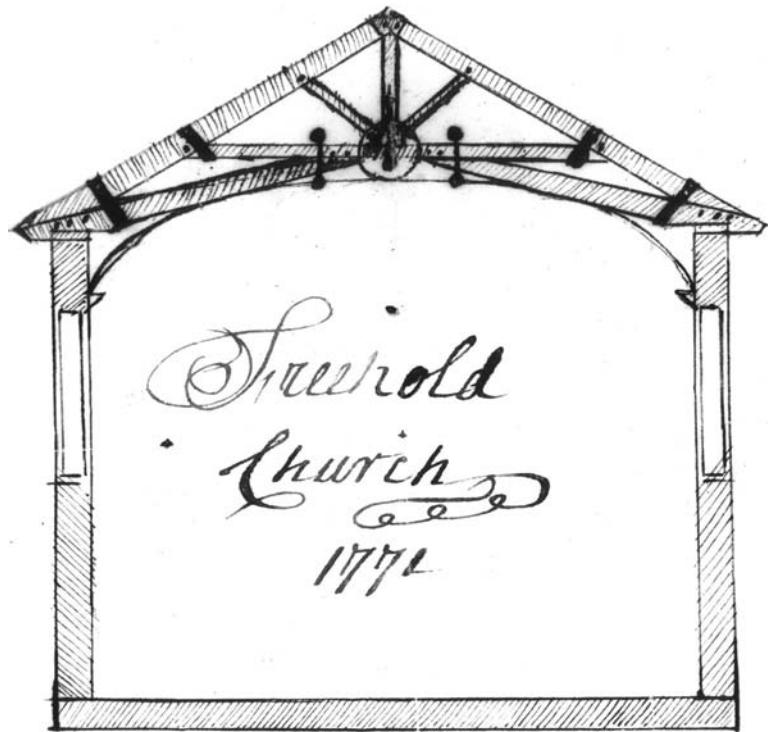
Fig. 10. A rare section drawing dated 1771 showing the roof truss design at St. Peter's Episcopal Church, Freehold, N. J., with Robert Smith's modification of the Francis Price model in the use of iron straps at the heel joints. It also closely resembles Plate VII from the 1786 Rule Book *of the Carpenters' Company. Reproduction courtesy of the Monmouth County Historical Association.*

characters on it for comparison was so limited. Nonetheless, the distinctive flourishes as part of the *F* in Freehold, the first *C* in Church, the numbers *7* in 1771, and the paraph after the *h* in Church were all very consistent with samples of Robert Smith's handwriting dated 1771 from the archives of Christ Church in Philadelphia. The combination of handwriting similarities plus the delineation of structural practices originating with Smith's work make a very strong case for ascribing the Freehold section drawing to Robert Smith's shop, but certainly not to a master draftsman.

In 1771, the German Reformed congregation in Philadelphia decided to replace their hexagonal meeting house on Race Street. Robert Smith and Jacob Graff Jr. examined the old building and rendered their opinions regarding demolition costs and salvage potential. On March 21, 1772, the Church Council "decided unanimously to carry out the design submitted by Mr. Wm Colladay for building the new church" (German Reformed Church, Consistory Minutes, 37). The old building was removed during the same month by Jacob Graff Jr., working in conjunction with Colladay, a master carpenter who had received the contract after competitive bidding (and who would, 22 years later, reconstruct Smith's great Zion church after its fire). These two craftsmen then erected the basic brick shell and roof of the church, which measured 65 by 90 ft. Graff received 606 pounds for the masonry work. Colladay continued as master carpenter for the entire project, which was finished and opened for worship on May 1, 1774. Many details concerning this important Philadelphia church can be found in the construction accounts, most of which were kept in German. Colladay's final bill, submitted in February of 1775, came to 2109 pounds out of a total construction expense of 6017 pounds. Entries for carving and other extraordinary interior detailing suggest that this new house of worship may well have been the most ornamentally enriched of any in the city. Many of its design elements drew from Robert Smith's works, especially from St. Peter's Church at Third and Pine, which it most closely imitated.
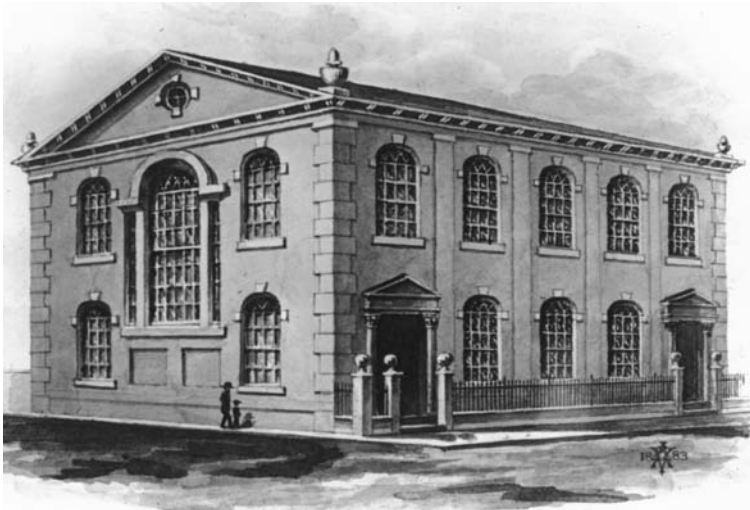
Fig. 11. German Reformed Church, Race Street, Philadelphia, 1772-74. Watercolor view copied in 1883 from an earlier work now lost. Reproduction courtesy of Old First Reformed Church.

Members of the Carpenters' Company played key roles in settling the costs associated with the new German Reformed Church. In February 1775, a committee made up of Gunning Bedford, Joseph Rakestraw, Abraham Carlile and James Worrell "Measured and valued all the Carpenter's Work done at the Calvinist Church in Sassafrass [now Race] Street . . ." (German Reformed Church, Building Accounts, 29). A second group consisting of Joseph Fox, Robert Smith and James Pearson "carefully examined the aforementioned Work, and assisted in settling the prices thereof." Colladay's bill was then accepted for payment by the building committee.

Even though a richly embellished and handsome structure, the German Reformed Church of 1772 was replaced on the same site in 1836 by a restrained Greek Revival Church that is still used for worship by the congregation. An 1830 insurance survey describes, among other things, the roof truss system. "The roof is framed with 8 principal rafters, with collar beams, hammerbeams, &c & constructed for a vaulted or circular ceiling which has a level wooden cornice around it" (Franklin, policy 93). This brief statement makes it very likely that William Colladay framed the roof using a raised bottom chord truss given the reference to hammerbeams. Roof framing elements salvaged from the 1772 building were used in its successor, where they can be seen today. The trusses were reconfigured, however, into massive queenpost trusses with bottom chord timbers that span the 65-ft. width of the new building without scarf joints.

The raised bottom chord roof trusses with Robert Smith innovations apparently proved popular among the members of the Carpenters' Company in Philadelphia, even after Smith's untimely death in 1777 at the age of 55. In 1786, the truss was published as a copperplate engraving in the Company's *Rules for Measuring and Valuing House-Carpenters Work*. Thomas Neville, a close Smith associate for many years, provided the sketches for engraving by Thomas Bedwell in July of the previous year. The version illustrated incorporates all of Smith's customizations, including the use of four outer straps and the central iron yoke. Neville certainly had gained firsthand knowledge of the construction details in his colleague's Philadelphia churches as he had erected the roof and ceiling at the Third Presbyterian Church (Fig. 12).

Neville and Smith had also served together on a Carpenters' Company committee formed in 1774 to prepare a uniform set of prices for its members. The 1786 *Rule Book* recommended the raised bottom chord truss design for clear spans of 60 ft., even though Smith himself applied it in situations ranging from 38 to 65 ft (Peterson, 1971, xvi-xvii, plate VII). It appeared again in *The Young Carpenters' Assistant* by Owen Biddle of Philadelphia, first published in 1805.

The raised bottom chord truss derived from Francis Price remained a standard for high vaulted ceilings for more than 150 years. William Pain, for example, included it as one of five roof designs in Plate VII of *The Practical Builder, or Workman's General Assistant,* first published in London in 1774. Pain did not comment on the structural details in his text. He did, however, add iron straps at the foot of the rafters where they joined the outer ends of the hammerbeams, as had Robert Smith.

The Price design appeared again as an illustration in Plate IX of *Elementary Principles of Carpentry* by Thomas Tredgold, first published in London in 1820, and was included in all subsequent editions through 1871. But Tredgold, a civil engineer, looked skeptically at the stresses in such a structure caused by the oblique positions of the hammerbeams, through flexure and from settlement
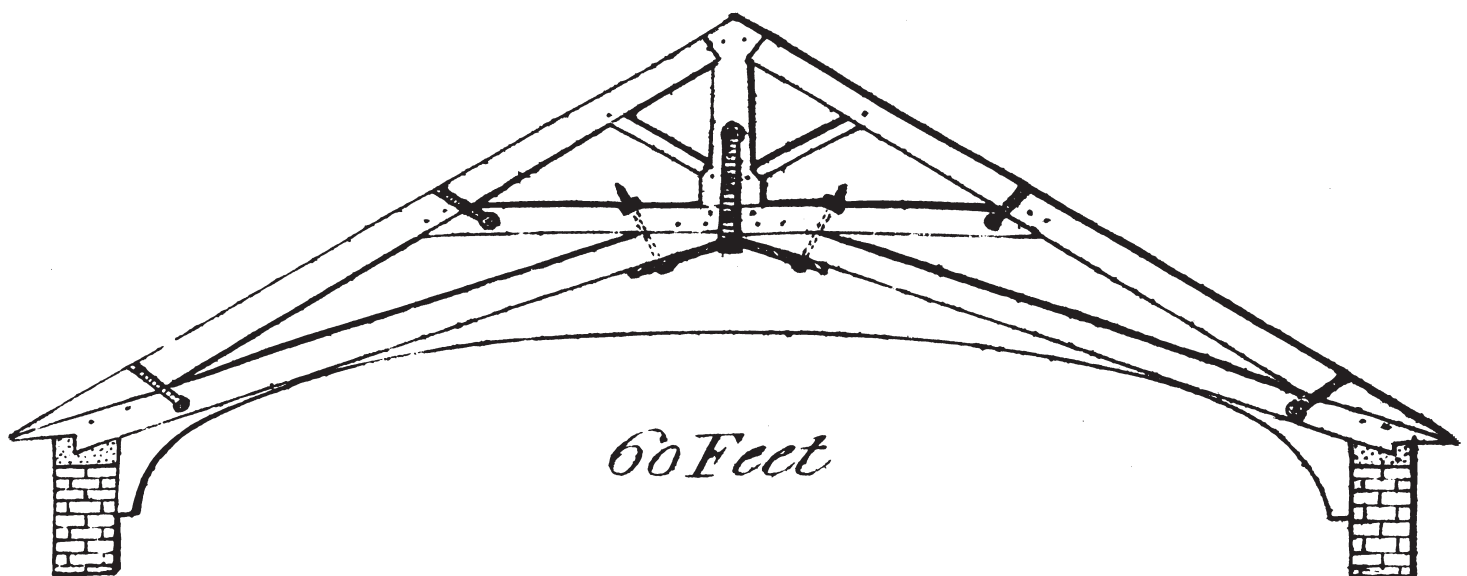
Fig. 12. Plate VII from the 1786 Rules for Measuring and Valuing House-Carpenters Work. *Engraved from drawings by Thomas Neville, it shows the distinctive iron features of Robert Smith, including additional straps at the heel joints and the large Y-shaped iron yoke at the center joint under the kingpost. Reproduction courtesy of the American Philosophical Society.*
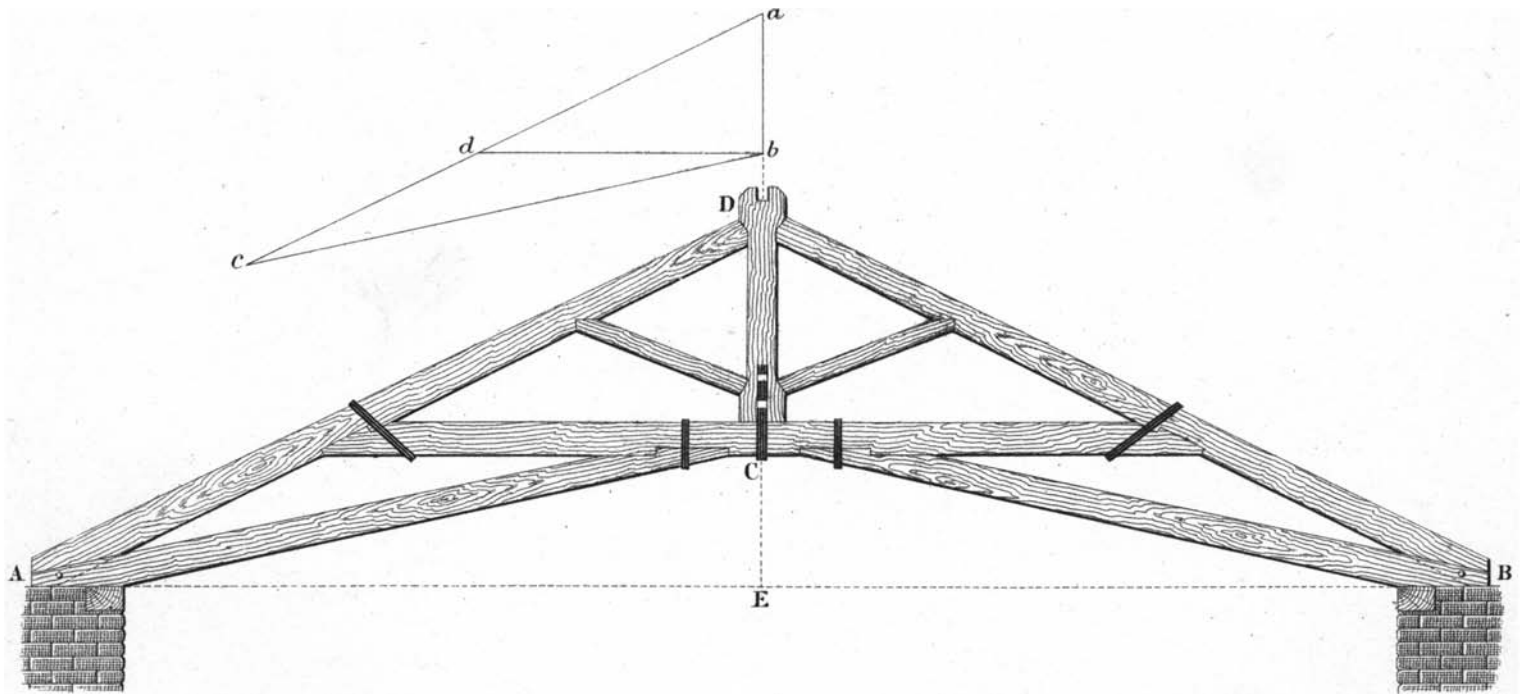
Fig. 13. Tredgold's analysis of the raised bottom chord truss suggested it produced long-term rafter action at the wall head. Author's collection.

due to the number of joints. Tredgold described the physics of the truss, believing that the thrust of the hammerbeams would cause the walls to move out. He also emphasized the difficulty of making a strong joint at the bottom of the kingpost, a condition recognized and improved 60 years earlier by Robert Smith through the addition of more iron. The author then concluded that "having thus pointed out the defects of this kind of roof, we must leave to the reader to judge for himself on the propriety of adopting it" (Tredgold, 93-94). Tredgold apparently focused more on the theoretic aspects of the Price truss without examining its very successful applications on both sides of the Atlantic, albeit with suitable modifications.

Following the death of Robert Smith and publication in the Carpenters' Company 1786 *Rule Book,* the raised bottom chord truss remained a standard wide-span framing solution in the Delaware Valley area until the third quarter of the 19th century. Examples can be found throughout eastern Pennsylvania, Delaware and New Jersey. Curiously, it does not occur commonly elsewhere in the northeastern United States. The massive two-volume 1948 study, *Early Connecticut Meeting Houses*, by J. Frederick Kelly, for instance, illustrates 81 truss designs found in that state, not one of which follows the Price model. So the raised bottom chord truss with long diagonal "hammer-beams" owes its introduction and popularity in the Mid-Atlantic region to the talents of Robert Smith, to those carpenters who followed his plans and imitated his ideas, to the membership of the Carpenters' Company in Philadelphia and to the publications that kept it in print for almost a century after his death.   —JOSEPH W. HAMMOND

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Selected Bibliography

Burr, Nelson R., *Society for the Propagation of the Gospel in Foreign Parts Transcripts, Monmouth,* Acc. 1417, Special Collections, Rutgers University Library, New Brunswick, N. J.

Christ Church Records, Christ Episcopal Church, Shrewsbury, N. J.

First Presbyterian Church Records, Dickinson College Library, Carlisle, Pa., Box 1, John Montgomery Account, 1769-88.

First Presbyterian Church Records, Presbyterian Historical Society, Philadelphia.

Franklin Fire Insurance Company Records, Historical Society of Pennsylvania, Philadelphia.

German Reformed Church Records, Historical Society of Pennsylvania, Philadelphia.

Haussman, Carl F., "History of St. Michael's and Zion Congregation, Philadelphia, Pa.," unpublished ms., ca. 1942.

Hazard's Register, Philadelphia, 1829.

Holmes Family Papers, Monmouth County Historical Association, Freehold, N. J.

Lossing, Benson J. *The Home of Washington: or Mount Vernon and its Associations, Historical, Biographical, and Pictorial,* Hartford, 1870.

Murray, Rev. Joseph A., Collection, Acc. 171, item 43-2-3, Cumberland County Historical Society, Carlisle, Pa.

Neville, Thomas, Day Book, 1762-1782, Wetherill Papers, Day Book DB-1, Van Pelt Library, Division of Special Collections, University of Pennsylvania, Philadelphia.

Park, Helen, *A List of Architectural Books Available in America before the Revolution,* Los Angeles, 1973.

Peterson, Charles E., *Robert Smith: Architect, Builder, Patriot, 1722-1777,* Philadelphia, 2000.

—, *The Rules of Work of the Carpenters' Company of the City and County of Philadelphia, 1786,* reprint, Princeton, 1971.

Price, Francis, *The British Carpenter: or, a Treatise on Carpentry,* third edition, London, 1753.

Richards, Frederick Lee, "Old St. Peter's Protestant Episcopal Church, Philadelphia: An Architectural History and Inventory," 1758-1991, unpublished M.A. thesis, 1992.

St. Paul's Church Archives, Box 1, Folder 1, Episcopal Community Services, Philadelphia.

Second Presbyterian Church Records, Presbyterian Historical Society, Philadelphia.

Smith, Robert, Inventory of Goods and Chattels, April 12, 1777, Orphan's Court Records, Philadelphia City Archives.

Third Presbyterian Church, Subscription List, October 3, 1794, Map Case Drawer, item 32.36, Presbyterian Historical Society, Philadelphia.

Tredgold, Thomas, *Elementary Principles of Carpentry,* third edition, London, 1840.

Kingpost Truss Engineering, An Addendum

The following commentary accompanies the article "Kingpost Trusses," published in the last issue of this journal as part of our continuing historic truss series. The author and the editor regret the delay in coming to publication. The thumbnail truss elevations at the top of the facing page can be seen in their proper size in TF 72.—The Editor.

AS with the scissor and queenpost trusses described respectively in TF 69 and 71, the four kingpost roofs described at length in TF 72 were tested virtually via Finite Element Analysis (FEA), subjected to a standard roof live load based on 65 psf ground snow load, plus dead load of ceiling, floor, frame and roof as indicated. The results of these analyses are presented below. In the axial force diagrams printed on the facing page, compression is indicated by blue, tension by red.

The Lynnfield (Mass.) Meetinghouse (1714) stands out in age, material and morphology. Lynnfield is 83 years older than the next frame in sequence and, on average, well over a century older than its fellows. In its original form, it was framed entirely in oak, unlike any later structure we visited. The pattern of the Lynnfield truss, with its curved and tapered members, harkens back to the late Middle Ages, antecedents it shares with its closest chronological neighbor, the 1797 Rindge (N.H.) Meetinghouse (see TF 71).

The Lynnfield truss model performed well under load. Given mitigating factors like the modest span (32 ft., 4 in.), the stout material (oak) and the lack of a ceiling load, this does not come as a surprise. Predicted deflections remain within allowable ranges. Likewise bending stress, with the exception of the main braces at midspan where they share roof load with the rafters via connecting struts (which carry 6900 lbs. in compression). Here the deeper, stiffer braces take the lion's share of the load, supporting—and minimizing bending in—the rafter above at the cost of a 1650 psi spike in bending stress in the braces. Axial load distribution is ideal, with the major elements handling the bulk of the force (16,600 lbs. tension in the tie beam, 18,000 lbs. compression in the main braces). Tension at the kingpost foot is a mere 4100 lbs. Given the minimal force in the rafters near the peak, above the main brace junction the kingpost goes into compression, signifying the absence of uplift at the peak.

The Strafford (Vt.) Meetinghouse (1799) also evokes older carpentry traditions, with its distinctive strut layout and doubled, divergent upper chords, evocative of scissor trusses. Here long and large section timbers are spruce, the smaller, shorter pieces mixed beech, birch and maple. FEA output for the Strafford truss again shows deflection, shear and bending stress remaining in the fold save for local maximums in the tie beam where it cantilevers beyond the wall to support the flying plate and principal rafter foot. Given ample real world proportions (as opposed to the slender single line geometry of the model), this can be mostly written off as a computer artifact. Resultant axial forces break down as follows: 24,700 lbs. tension in the tie beam and kingpost, 13,400 and 18,200 lbs. compression in the main braces and principal rafters, 6400 and 7200 lbs. compression in outer and inner struts. Contrary to the builder's expectation as indicated by strut lap dovetail ends, the Stafford outer struts are loaded in compression rather than tension.

The major loads at Strafford—in main brace, rafter and tie—are equivalent to or smaller than those for the comparable span, double-rafter queenpost roof at Rindge (TF 71). Perhaps Strafford has an advantage because of its steeper pitch (about 9:12 vs. about 7:12). Offering dual vertical load paths to Strafford's one, the Rindge queenpost retains the advantage in post load. Outboard of the main brace feet at Strafford, tie tension drops from 24,700 to 14,200 lbs. And in the Strafford kingpost, tension falls off above the main braces and below the inner struts, to 10,500 lbs. at the peak and 11,600 lbs. at the kingpost foot joint.

In load sharing between doubled upper chords, the key issue is the relative stiffness of the end joints of the principal rafter versus those of the main brace (see TF 71, 21). The inboard locations of the braces allow them ample relish beyond their mortises into the tie and kingpost, a potential advantage over the principals, which land right at the tie and post ends. Foot joints are often difficult to examine *in situ*. Those we can inspect seem more prone to failure and impairment than most other connections in the truss, for a combination of reasons: the lack of relish beyond the mortise and the large forces involved, coupled with the low angle of attack of rafter to tie, all exacerbated by a high incidence of leaky eaves. The significance of the roof slope is that the geometry of low-pitch roofs channels more horizontal force against potential long-grain shear failure in the tie at the foot joint than it does comparable vertical breakout load on the kingpost at the peak (see TF 72, 19). The point: on both empirical and theoretical grounds, the principal rafter-to-tie beam joint is the likely weak sister in the mix.

All in all, it's a fair assumption that the load-carrying capacity of the Stafford main braces is greater than that of the principal rafters, a conjecture reinforced by the absence of housing or joggle at the head of the kingposts. The Strafford truss was modeled first with the foot joint as a pinned connection, with results detailed above, then as a roller bearing (vertical support but no horizontal restraint), and finally with full vertical and partial horizontal restraint.

Under the roller bearing scenario, tie tension rises to 30,400 lbs., kingpost tension to 27,900 lbs. Main brace compression climbs to 36,300 lbs., while principal rafter foot load falls to a paltry 980 lbs. Strut compression grows to 8900 and 5500 lbs. in and out. The kingpost foot joint carries 13,300 lbs. in tension, while the post peak goes into compression to the tune of 10,700 lbs. (thereby putting the rafter peaks in tension).

The third, and perhaps most realistic, loadcase shows tension of 20,700 and 25,900 lbs. in tie and kingpost, 24,800 and 9300 lbs. compression in main brace and rafter, 8400 and 6000 lbs. in inner and outer struts. Some 12,100 lbs. hang from the kingpost foot, while the kingpost peak is almost a no-load situation, with 530 lbs. compression in the post. Tension load at the tying joint (rafter foot to tie) is a modest 6900 lbs..

The Castleton (Vt.) Federated Church (1833) moves us firmly into the classical kingpost idiom, with a truss spanning an ambitious 60 ft., 7 in. Nesting inside the major triangle are two minor trusses built around princeposts which, fractal-like, echo the parent truss. The central struts rising from the kingpost foot double as struts descending from the princepost peaks, each opposed by an outer strut paralleling the main upper chord (principal rafter).

The Castleton computer model predicts tension loads of 37,900 and 15,500 lbs. in tie and kingpost, 31,000, 17,800, 12,800 and 2700 lbs. compression in rafter, inner strut, outer strut and princeposts. The kingpost pulls tension throughout, carrying 4900 lbs. at the foot joint and 15,500 lbs. at the peak. The princeposts lift 2600 lbs. at their feet and carry a compression load of 8500 lbs. at their heads. Tying joint tension at the eaves is 26,500 lbs. Nothing alarming about these numbers, but there are multiple instances of bending stress up in the 1600 psi range, pretty high for Eastern hemlock, and a 1½-in.-plus sag in the rafters.

Jack A. Sobon
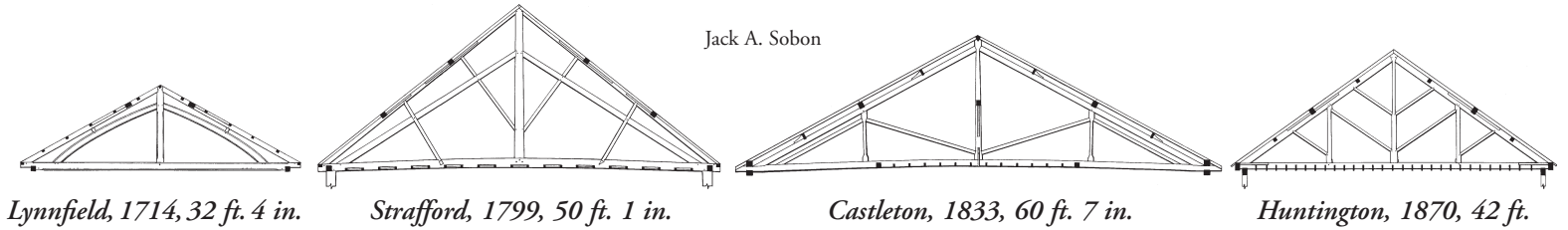
Lynnfield, 1714, 32 ft. 4 in.   *Strafford, 1799, 50 ft. 1 in.*   *Castleton, 1833, 60 ft. 7 in.*   *Huntington, 1870, 42 ft.*

Trying the partial or total foot thrust release (as at Strafford, above) is no help. Deflections increase to over 2 in. and then over 4 in., and bending stresses inflate, first slightly, then off the scale. So Castleton's load-carrying capacity doesn't seem to measure up to expectations engendered by its elegant design and neat construction, although I can't say that we found visible signs of structural inadequacy during our inspection. It may be that the truss was never fully loaded in service (indeed Vermont snow load tables specify a design load of 40 psf in Castleton compared to 50 psf in Strafford, 60 psf in Huntington and 70 psf in ski-country Stowe). Or perhaps, as we have also suggested before, the old-growth hemlock used in Castleton outperforms modern design values.

Maybe it would have helped to adopt a truss pattern more like that of the 1870 Union Meetinghouse in Huntington, Vt., an almost exact copy of a pattern from Asher Benjamin's *Practical House Carpenter* (1830). The FEA model of the Union truss does not disappoint. Predicted deflections are minimal. Bending is modest save at the ends of the princeposts where impacted by strut loads, and even there, stress does not exceed allowable values. Axial loads are among the lowest we have seen: 22,200 and 14,100 lbs. tension in tie and kingpost, 27,800 lbs. rafter compression. Strut compression ranges from 4300 to 5800 lbs. Princeposts feel scant axial force at midspan, 2400-2500 lb. compression at their end joints. Adjacent princerods pull 2500 lbs. Tension at the kingpost foot joint is a mere 2000 lbs.

—ED LEVIN
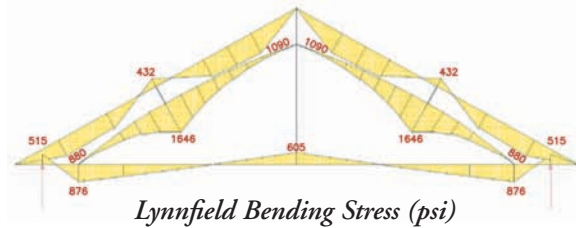
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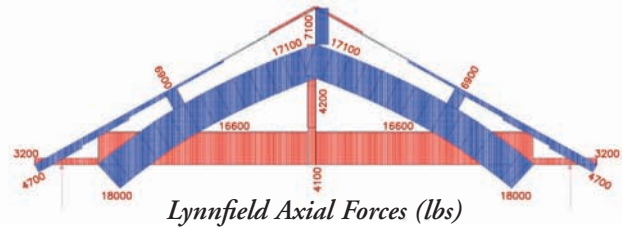
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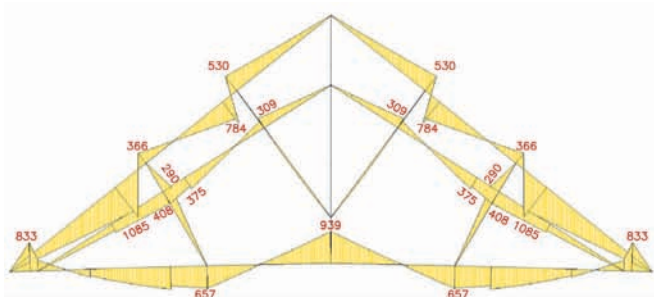
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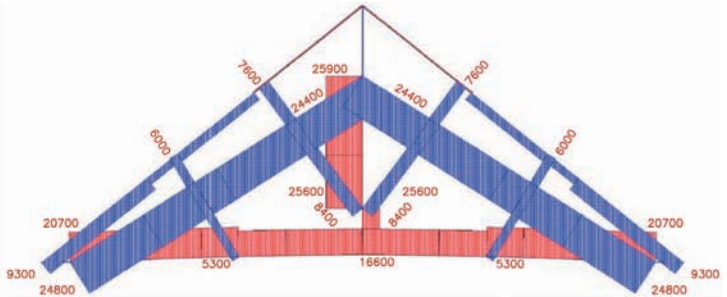
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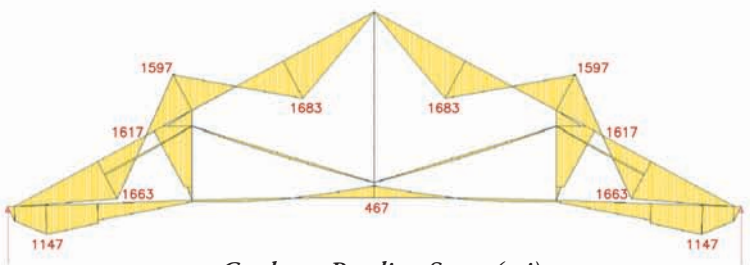
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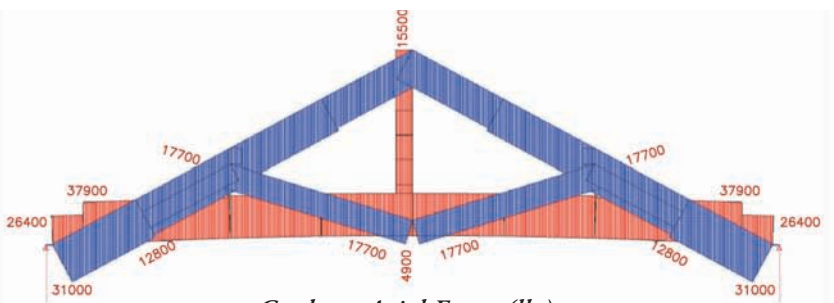
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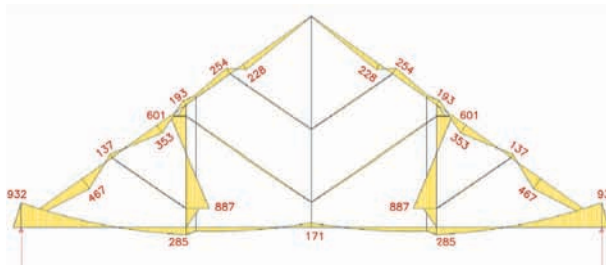
Union Bending Stress (psi)

Union Axial Forces (lbs)

Will Beemer

Model square laid over model joints to demonstrate layout of typical connections among valley, principal rafter, jack purlin, jack rafter and header (or ridge) in a valley dormer. Clockwise from upper left: valley rafter joint to principal rafter; jack purlin joint to valley rafter; seat cut for valley in header; and jack rafter joint to valley. Drawing of completed model and article, page 4.