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Medieval Geometrical Frame Design

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On the cover, aerial view of Tŷ-mawr near Welshpool (formerly Montgomeryshire, now Powys), Wales, dendrochronologically dated to 1460. The house was framed using circle geometry to establish proportions, the fundamental unit of length a diameter of one rod or 16 ft. 6 in. Photograph Crown copyright by the Royal Commission on the Ancient and Historical Monuments of Wales.

Timber Framers Guild, PO Box 60, Becket, MA 01223
www.tfguild.org
888-453-0879

Editorial Correspondence
PO Box 275, Newbury, VT 05051
802-866-5684 journal@tfguild.org

Editor Kenneth Rower

Contributing Editors
Guild Affairs Will Beemer, Joel McCarty
History Jack A. Sobon
Timber Frame Design Ed Levin

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1985

Zabludow Diary

I'VE recently returned from a quite interesting 12-day trip to Poland, where an international group, now including the Guild, plans the replication of a structure representative of the many wooden synagogues systematically destroyed by the Nazis in World War II. Joining the nine Americans in the group were interested persons from Poland, Great Britain, Canada, Germany, Israel, Lithuania, Belarus and the Czech Republic. Our discussions were both enhanced and complicated by the many cultures represented. At times, two translators were required to ensure that all present could follow conversations and provide commentary.

Although all of Poland's wooden synagogues are gone, many of them were documented in drawings and photos before their destruction, leaving evidence of form if not of construction details or of tools and methods used. The group decided early to recreate a synagogue originally built between 1635 and 1650 in the small town of Zabludow. The village has changed greatly since the war and no longer feels like a suitable home for the recreated building. A fire hall now stands on the site formerly occupied by the synagogue. A nearby outdoor museum, or *skansen*, welcomed the opportunity to enhance their own village setting with a new synagogue.

This first expedition was to attempt to decipher construction mysteries by looking at other buildings of that time, similarly built churches of the Catholic and Orthodox faiths and Muslim mosques. As the "international experts," we were given almost limitless access to historic buildings and sites in the area. We often found that ours were the first footprints to disturb many years of dust in church attics and bell towers. We also spent much time in discussion of engineering details. These would have been arrived at through years of practical experience—trial and error—by yesterday's builders. We hope to eliminate that, in particular the error part.

Throughout the trip, there were constant reminders that we were in a Very Different Place. Architecture, urban and rural, contained both elements of modern design and of a past much more profound than ours. The countryside also had a different feeling, very flat, sandy soil supporting small farms with fields of potatoes and cabbage, sugar beets and other unfamiliar crops, and a few cows, perhaps to supply only the farmer's family with milk. Horses could still be seen working the fields or pulling wagonloads of produce, although modern tractors ruled. Largely absent were the high-tension power lines that crisscross our landscape, although we did see alien-looking concrete telephone poles, often topped by gigantic stork nests. The storks were also absent, having already migrated to their winter homes in Egypt.

Many villages appeared to have changed very little in the last hundred years, forming clusters of small, neat houses with sheds in the back yards and barns grouped around the perimeter for fire safety. An area was set aside for everyone's gardens, and workers trudged to their fields beyond the barns, or gathered mushrooms in the forests. Thatched roofs were not uncommon. There was an extensive array of other roof coverings: boards, wooden shingles, terra cotta tiles and concrete tiles and sheets, as well as every type of metal roof imaginable, including a very attractive tile look-alike. Missing were the asphalt shingles we're most familiar with. City or country, cobblestone streets were still found. Many back yards contained attractive underground root cellars to store the potatoes, cabbage and beets that would sustain the inhabitants through the winters. Always there were churches: Orthodox and Catholic, or Muslim mosques, the bells often in a small separate tower at the side of the churchyard. Many private properties had religious shrines at the roadside, with crosses, flowers and perhaps a small sculpture sheltered under a roof.

In many places we visited were reminders of the horrors of the recent past. Still dazed from the long trip, we walked through a section of Old Warsaw and saw grand buildings and whole neighborhoods once reduced to rubble, as portrayed in photographs, now restored to the exact appearance they had once held. It was chilling to stand in a narrow street and contrast two storefronts, one pockmarked with bullet holes, the next indistinguishable except for the absence of holes in the rebuilt façade.

Numerous memorials commemorated the Holocaust, but two that I saw had particular power. The first of these, glimpsed through bus windows along city streets, had railroad ties leading to a railcar of jagged crosses representing those taken to death camps. Another was the twisted steel remains of the dome of the Bialystok synagogue, left to commemorate the more than 1000 Jews who were locked inside the building as it was burned. I have a copy of a photograph the Nazis took of the conflagration from a circling airplane. In the middle of one of our meetings, a very reserved Polish engineer stood and quietly recounted some of the terrible experiences of his childhood, to honor a promise he had made to his mother not to allow these things to be forgotten. There were few dry eyes.

Our travels were concentrated in the northeast of Poland, two or three hours from Warsaw, near the city of Bialystok. This is the center of a region called Podlaskie (pode-lah'-shuh) that before the World Wars spilled over into Lithuania and Belarus, then part of Poland. This land has always been a crossroads, with people (and armies) coming and going. After the destruction of World War II, it's been mostly going, with not much reason for those displaced to return. As elsewhere, the culture of the past is pushed out in the rush to the future, but tourism is a large industry in Poland and may save some of it. There are many people still here who have lived in a pre-industrial society, so the memories are strong.

Although the immediate impetus of the project is the recreation of a wooden synagogue, the larger context is the preservation of the cultural landscape of Eastern Europe. An educational program is envisioned to focus on vanishing cultures, with the technologies of wooden building one of its pieces. Around the world, many cultures are similarly in danger of disappearing, and would benefit.

The powerful emotions awakened by the way the culture represented by the synagogue was systematically eliminated make it an important symbol of loss, and thus a recognizable rallying point for remembrance. We hope to transform all that is negative about that time into a positive force for the future by refusing to let that culture die away.

—Leon Buckwalter

Erratum

The traditional Alsace house pictured on page 24 of TF 69, said to be part of the Ecomusée d'Alsace, Ungersheim, France, in fact stands in the village of Ochfelden as a private residence. The editor regrets the error.

Geometrical Design in Historic Welsh Frames

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Fig. 1 Tŷ-mawr from the southeast.

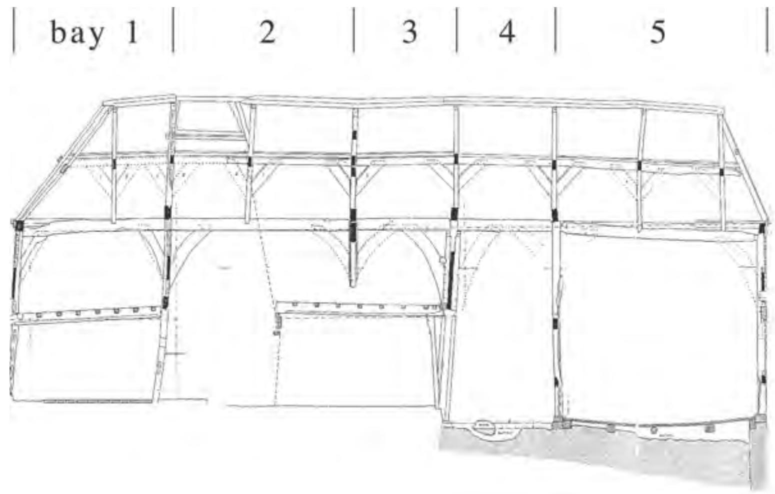

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Fig. 2. Tŷ-mawr's long section and bays from the northwest.

THIS article presents geometrical analysis and findings from three early buildings erected in eastern Wales between the 15th and 17th centuries: Tŷ-mawr, near Welshpool; Gwernfyda, in the countryside eight miles farther west; and The Hall, Llanfyllin, ten miles to the north. All are box-framed hall houses. The text describes the geometrical symbols discovered in the houses and the design systems that arise from each symbol's geometry.

TŶ-MAWR, *The Great House*, was built in open countryside five miles west of Welshpool, the nearest large town, and ten miles west of the English border in the old county of Montgomeryshire, now absorbed into the modern county of Powys. Although English has encroached, the beauty of the Welsh language survives strongly in the names of houses and farms. Tŷ-mawr (pronounced tea-*mour*, to rhyme with hour, and with the *r* rolled) has neighbors called Pant-yr-Alarch, the hollow of the swan, and Allt-y-ceiliog, the steep hillside of the cockerel. The siting of the house, like that of most early Welsh houses, is weather and light specific. Built on a north-south axis with gable end into the southern flank of a steep hillside (Fig.1), it is protected from northerly winter weather blowing down from the Berwyn mountains, while the eastern and western long walls face the dawn and sunset respectively so that the house receives maximum light. The house is constructed on an artificial horizontal platform contained within raised stone plinths that support the oak frame, the plinth being shallow at the northern, uphill gable and around 6 ft. high beneath the southern, downhill gable. In an area of high rainfall, its siting at 90 degrees to the hillside directs surface water past the long side walls and away from the southern gable. Conversely, the northern gable bears the brunt of downhill surface runoff. As its name implies, Tŷ-mawr is large, 25 ft. to the ridge and about 58 ft. long by 28 ft. wide in plan, a building of 5 bays in the typical three-unit plan of the area. Bay 1, the first or service unit, at the northern end, is an inner room for preparation of food. Bays 2, 3 and 4 form the second unit, a large central hall. Bay 4 is a cross-passage with outside doors to the east and west. The cross-passage defines the southern end of the hall and separates it from bay 5, the third unit, often a parlor but also known as the outer room. (Fig. 2). The house is entirely box framed and of aisled construction except for the single base cruck that spans the hall between bays 2 and 3. (In box framing, the walls rise vertically from sill to wall plate and tie beam in the form of a box. In cruck framing, full cruck blades standing as principals rise inclined from sill to ridge, but base crucks rise vertically from sill to wall plate and then follow the roof plane.) The house is listed Grade I by CADW ("Preserve")Welsh Historic Monuments and has been dendrochronologically dated to 1460 by RCAHMW, The Royal Commission on the Ancient and Historical Monuments of Wales. Although the house was clearly of significant social status, its original owner remains unknown.

It is over 30 years since Peter Smith, author of the definitive *Houses of the Welsh Countryside* (London, 1975), and Cecil Vaughan Owen, a friend and co-researcher, discovered Tŷ-mawr derelict, clad in corrugated iron and functioning as a cowshed, its fall from grace complete. The iron cladding clearly saved the core of the house, but the long outer walls of its aisles were long gone and had been reconstructed at some unknown time closer to the nave of the house. The northern gable, built into the hill, had almost collapsed but, as the building was recorded and the debate about its future began, a small geometrical symbol (Fig. 3) was found carved into the inner face of the northern gable's eastern aisle post. It was evident from this position that it was not an assembly mark.

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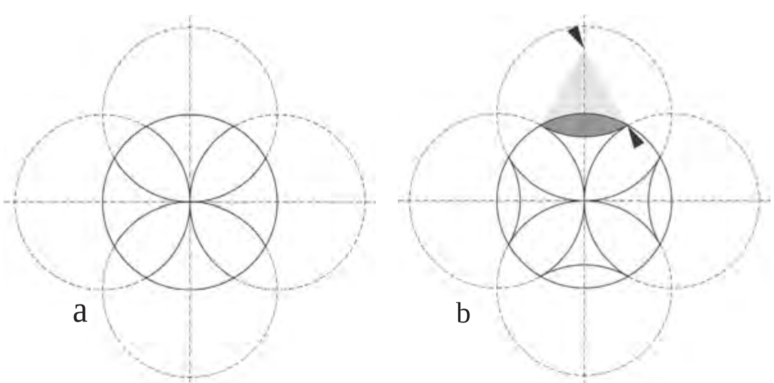
Fig. 3. Video still of Tŷ-mawr's geometrical symbol.

The symbol is critical to an understanding of Tŷ-mawr's design. In the following text, its geometrical construction is first clarified, then applied as an analytical tool to some of the measured drawings of the house and, finally, used to reconstruct the building's design. The symbol's geometry is constructed entirely from arcs of circles: a complete primary circle, four long arcs that span its diameter and four short arcs linking the ends of the long arcs where they meet the primary circle's circumference. The diameter of the primary circle is small, just 2¹⁄₁₆ inches, but it is clear beyond doubt that the symbol represents a symmetrical grouping of compass-drawn arcs. In redrawing the symbol, horizontal and vertical perpendiculars are drawn first, and these are the bedrock of its symmetry. The primary circle is drawn with its axis at the intersection of the perpendiculars. Each long arc is part of a full circle drawn from a point of intersection between the primary circle's circumference and a perpendicular (Fig. 4a). The short arcs follow, drawn from four new points on the perpendiculars, found by placing one pin of the dividers at the end of a long arc and the other on the perpendicular (Fig. 4b). Because every arc of circle is drawn to an identical radius, the short arcs form symmetrical mirror images of the primary circle's circumference to generate a small *vesica pisces* between each pair of long arc ends. The upper vesica is shown in dark shading. In general, the vesica piscis, literally "fish's bladder," is the overlapped area of two circles passing through each other's centers, as seen in Fig. 4a. Approximating the shape of a fish, it was the earliest Christian symbol.



All drawings by Laurie Smith unless otherwise attributed

FIG. 4. CONSTRUCTION OF THE SYMBOL'S LONG AND SHORT ARCS.

The symbol is constructed from nine identical-radius arcs of circle, each of which has its axis on either the horizontal or vertical perpendicular so that the symbol is symmetrical in four directions. The four directions are at right angles to one other and thus the symbol is, perhaps unexpectedly to the modern eye, a source of rectangular proportional relationships. Connection of adjacent long arc ends generates a horizontal rectangle (Fig. 5a) and vertical rectangle (Fig. 5b).

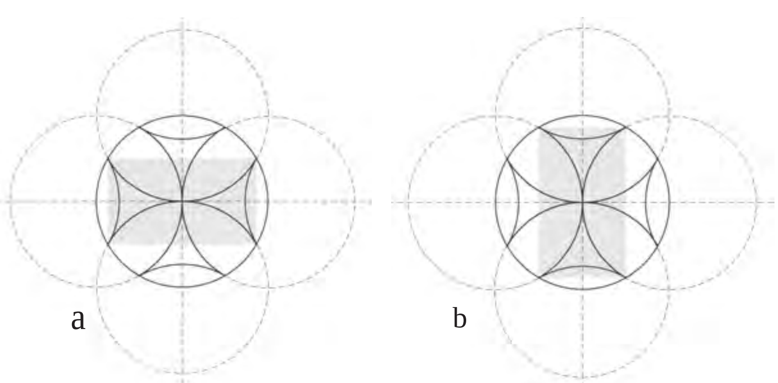


FIG. 5. CONSTRUCTION OF RECTANGLES WITHIN THE SYMBOL.

The rectangles have identical proportions and share the harmonic internal ratio of 1:2 between their short side and diagonal. They are also an accurate source of angles at 30, 60 and 90 degrees (Fig. 6). It should be noted that the precise and elegant proportions of the rectangle are difficult to draw in any other way than by circle geometry. Arcs can be drawn swiftly and simply by compass and connected by straight edge. Critically, the rectangles are proportional rather than dimensional, and no measurement or calculation is needed in their construction. Drawing the symbol at any scale, there is just one dimensional decision to be made: to define the radius of the primary circle. At Tŷ-mawr the primary circle radius is 8 ft. 3 in., the diameter 16 ft. 6 in., exactly one medieval rod (also pole or perch), a measure seldom used today.

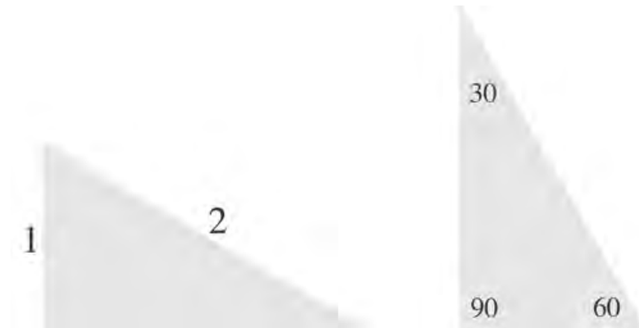


FIG. 6. PROPORTIONAL RATIO AND ANGLES.

With the symbol's construction certain, it became possible to apply its geometry to the measured floor plan of the building in search of potential synchronicity. Because the symbol itself has precision center lines in the form of its perpendiculars, the rational first step was to draw a centerline through the long axis of the floor. Bearing in mind the nature of aisled construction as a nave flanked on each side by an aisle, and also that the original aisle walls were missing, the centerline could only be ascertained from the surviving nave alignments. The nave's length, width and height had survived remarkably intact within the hall, the central and most protected part of the house. Although the hall's base cruck had lost its blades along with the original aisle walls, its upper structure remained, supported between the arcade plates and the ridge.

Conversely, the spere truss between the cross-passage and the hall retained its original form and was in remarkable condition for its 540-year life. (In aisled halls, the spere truss defines the lower end of the hall. It always includes two spere posts which, arch-braced to a tie beam, stand at the outer edges of the nave to form a grand entrance arch to the hall proper.) The spere truss therefore provided the optimum location along the centerline to test the symbol at full nave width. It was immediately evident that the spaces between the rectangle's short sides and the primary circle were occupied by the feet of the spere truss posts, the outer face of the posts defining the outer face of the nave on the circle's circumference (Fig. 7).

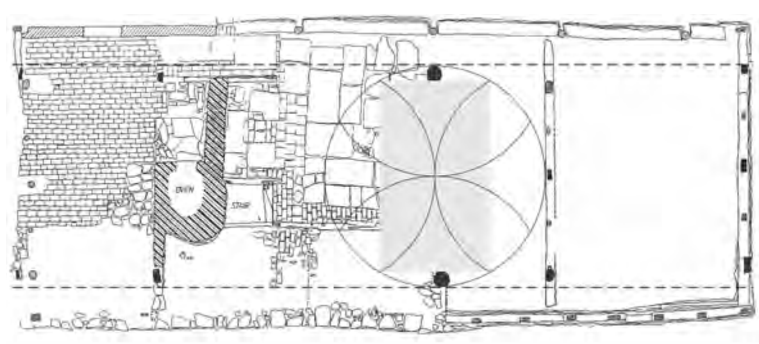


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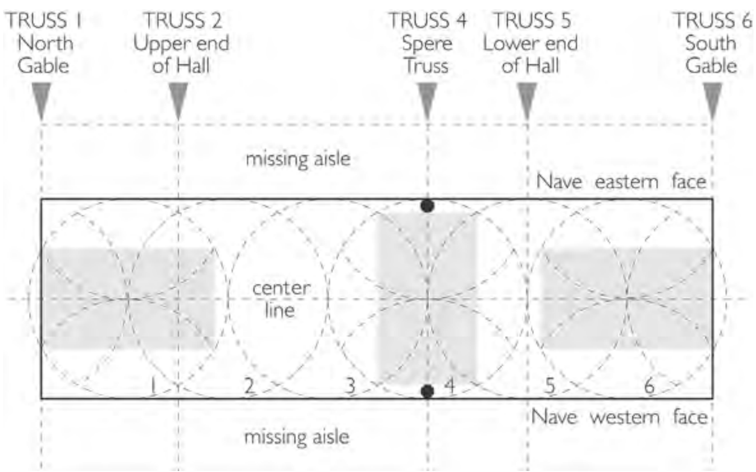
FIG. 7. THE SYMBOL SYNCHRONIZED TO THE SPERE POSTS.

Multiplying the symbol along the centerline also gave precision results, the nave being defined by a six-circle sequence with horizontal rectangles in the end circles pinpointing the gable walls across their short sides (Fig. 8). For clarity, the floor sequence is shown as a diagram. From the six-circle sequence it was possible to determine exact geometrical locations for five of the six cross-walls of the house. The only omission was the base cruck that originally rose from the missing aisle outer walls, an alignment that remained enigmatic. It can be seen in Fig. 8 that truss 2 is located at the intersection of circles 1 and 2 where it bisects the vesica formed by them. Truss 5 is the diameter of circle 5. The symbol is drawn only in the circles at the spere truss and the gable ends. These are the only places where it is necessary as a precision geometrical guide, and this fact begins to reveal the nature of geometrical thought that underlies the design of the house. The fundamental spatial rhythm of the nave is determined by the circle sequence, each circle drawn to pass through the axis of its neighbors, along a common centerline, every circle to identical radius. The symbol, developed geometrically within any circle, provides the potential for finer resolution of the design, every facet of which is aesthetically anchored within the circle sequence. The other characteristic of note is that the symbol is used in the two directions governed by its perpendiculars, so that both the horizontal and vertical rectangles have a role to play in the design.



Montgomeryshire Collections Volume 89 (2001)

FIG. 8. THE SYMBOL GOVERNING A SIX-CIRCLE SEQUENCE.

Having found a positive relationship between the symbol and the floor plan, I next tested the symbol against the cross-section of the house. The spere truss, because it was the least damaged truss in the frame, was chosen again. The measured drawings of the spere truss show evidence of a floor inserted later and the great arch of the truss itself blocked in order to separate the cross-passage from the hall. On computer, all these accretions were stripped away to reveal the truss as built. The symbol was applied at identical scale to that on the floor plan and, developed as a two-circle sequence, gave the exact geometrical height of the truss. Of great importance, it was clear that the roof pitch ran precisely through the centers of the two vesicas on either side of the symbol and that the apex of the ridge beam was defined by the vesica at the top of the symbol (Fig. 9).

The symbol's definition of the roof pitch was a critical discovery in understanding the form of the missing aisles. If the symbol's triangulation is drawn, at the angle of pitch, downward from the ridge until level with the base of the circle's lower vesica, it generates the location of the eaves and therefore the missing aisle walls. The two-circle sequence demonstrates the four cardinal geometrical points within the symbol that determine the roof pitch. The

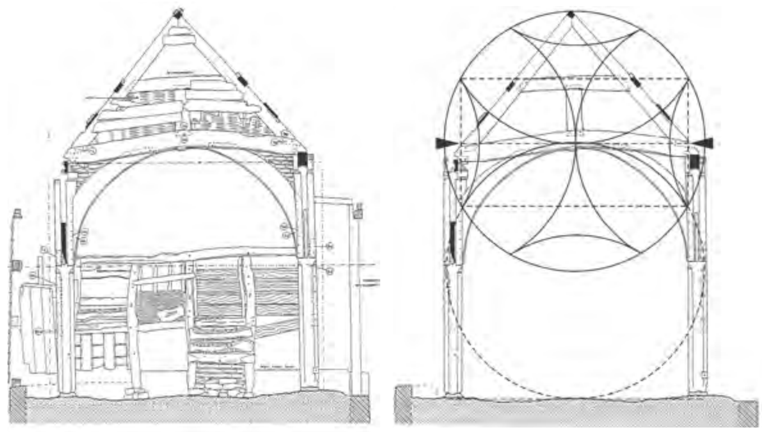


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FIG. 9. THE SYMBOL SYNCHRONIZED TO THE SPERE TRUSS.

design logic is clear: that the highest point of the top vesica and the lowest point of the bottom vesica define the pitch at one circle's height or a diameter of 16 ft. 6 in., identical to the nave width across the spere truss at ground level. The spere posts themselves are half the width of the vesicas, exactly the distance between the circle's circumference and the rectangle connecting the long arcs (Fig. 10).

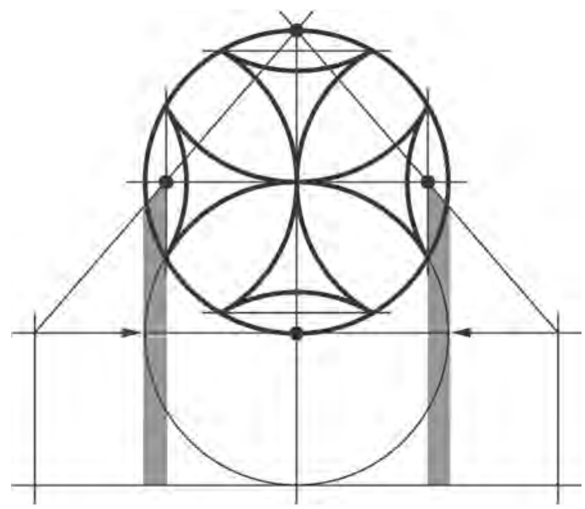

FIG. 10. GENERATING THE SPERE POSTS, LEVEL OF SECTION CHANGE AND THE NAVE AND AISLE WIDTHS.

The figure also shows how the base line of the roof pitch cuts the spere posts at the level indicated by arrows, which marks a critical change in the form of the posts. Below it the posts are massive linear octagons of four flat faces alternating with slightly concave faces (shaded section Fig 11a). Above it they become cruciform, the four directions forming surfaces for the spring of braces to the aisle outer walls, arcade plates, and high entrance arch across the nave (shaded section Fig. 11b). The level itself is marked on all sides of the post by a narrow embattled capital.

The spere post sections are also determined by the symbol. The introduction of a square (set diagonally) into the symbol intersects the long arcs to generate an octagon with sides of equal length (Fig. 11a). The intersection of the long arcs outside the primary circle, shown by an arrow, generates the axis of smaller circles (for clarity, only one is shown), the circumferences of which define the concave face of the lower spere post section. The cruciform upper spere post section is generated by connection of the intersections between the long arcs and the square (Fig. 11b). The spere posts are cut from single timbers, one circle diameter or one rod long.

It is impossible to ignore the pivotal role of the symbol in all the

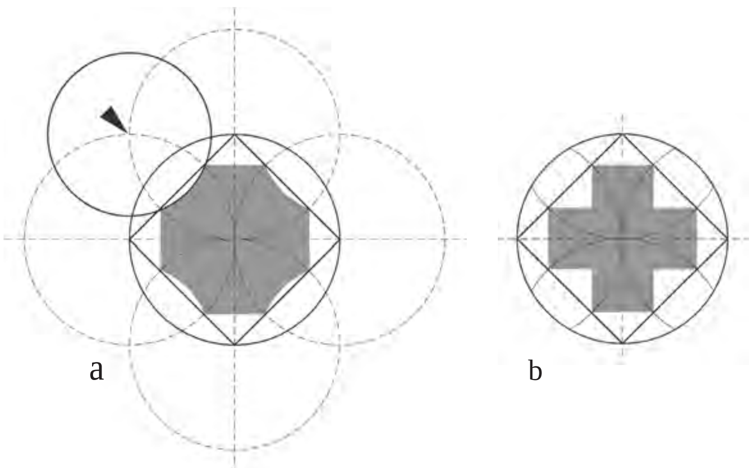

FIG. 11. THE SYMBOL DEFINING THE SPERE POST SECTIONS.

tests shown above. However, while the symbol's application to the spere truss gave the triangulation of the roof pitch and alignments for the aisle walls, it was wise to test the symbol from ground level. The result is shown in Fig. 12, which confirmed the eave level of the roof's triangulation and location of the aisle outer walls. Equally important, it emphasized that the three cardinal points in each vesica were critical to the design process, in this case determining the outer walls of the house at the inside point of the vesicas. The three cardinal points of a vesica are generated where it crosses one of the symbol's diameters: one on the circle's circumference (the vesica's outer curve), another on the vesica's inner curve, both shown in Fig. 12, and the third at its center where bisection along its length also cuts the diameter (shown in Fig. 10).

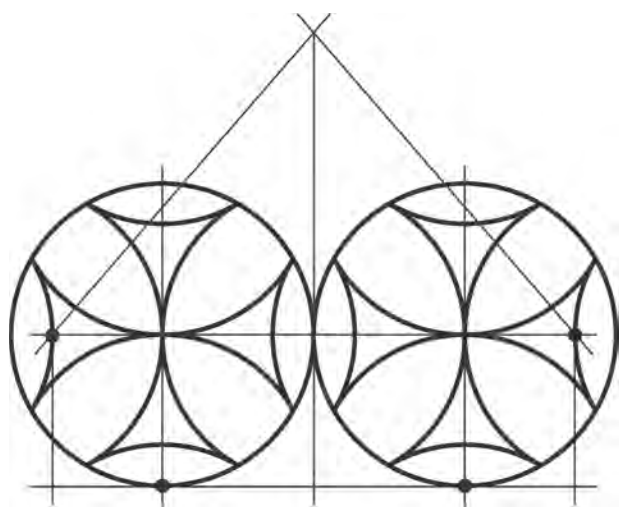

FIG. 12. GEOMETRY DEFINING THE EAVES.

The base cruck truss still remained undefined by the symbol. It was not recorded on the floor plan because its bases were lost with the original aisle walls, but its upper structure was visible adjacent to the spere truss in the long section (frame elevation) of the house. Testing with the symbol revealed that the cruck's location was also determined by a rectangle within the primary circle. It is noticeable that the spere posts have racked to the right in the upper part of the symbol and to the left in the lower, but remain geometrically accurate at the symbol's center. The long section and floor plan are compared to show the symbol's function in both the horizontal and vertical planes (Fig.13).

The placement of the symbol in the long section also shows its influence at ground level, where the symbol's bottom vesica stands on the lower floor level of the house and simultaneously defines its upper level at the service end. The symbol also exerts a powerful

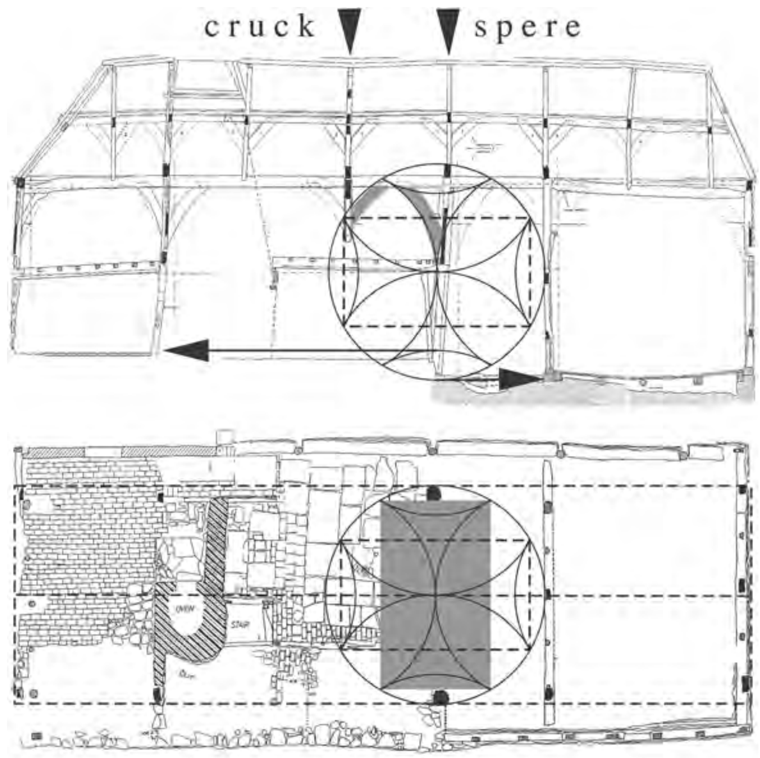

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FIG. 13. THE SYMBOL DEFINING CRUCK, BRACE AND SPERE LOCATIONS.

aesthetic influence on the braces between the spere and cruck trusses: the two surviving original braces (Fig. 13 upper, shaded in) unwaveringly follow the geometry of the symbol's arcs. The small brace following the circle's circumference joins the cruck in the roof plane, and the long brace joins the spere post to the arcade plate of the building's nave.

Reconstruction of Tŷ-mawr's design begins by drawing two perpendiculars and then the primary circle with its center at their crossing. Where the primary circle is cut by the perpendiculars, four identical circles are drawn. These circles intersect at four positions outside the primary circle that can be connected to form a perfect square. Four further identical circles are drawn from the corners of the square to generate a nine-circle grid. All six trusses of the house can be designed individually within the nine-circle grid (Fig. 14). The figure shows the remains of the cruck truss supported by the arcade plates.

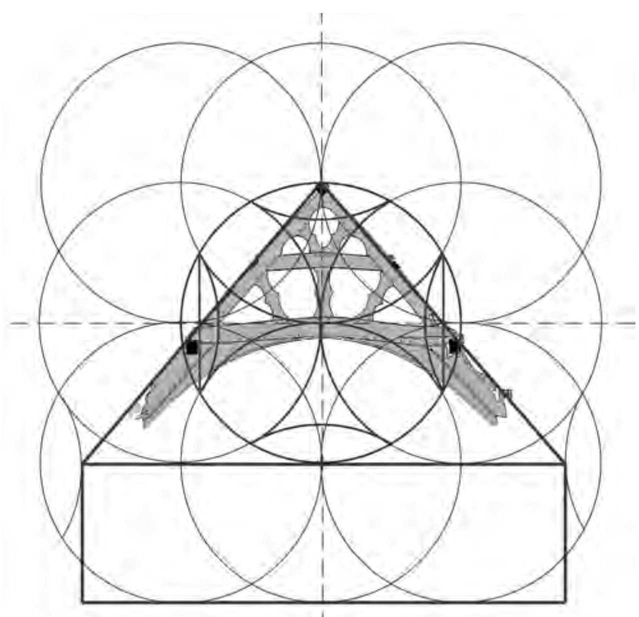

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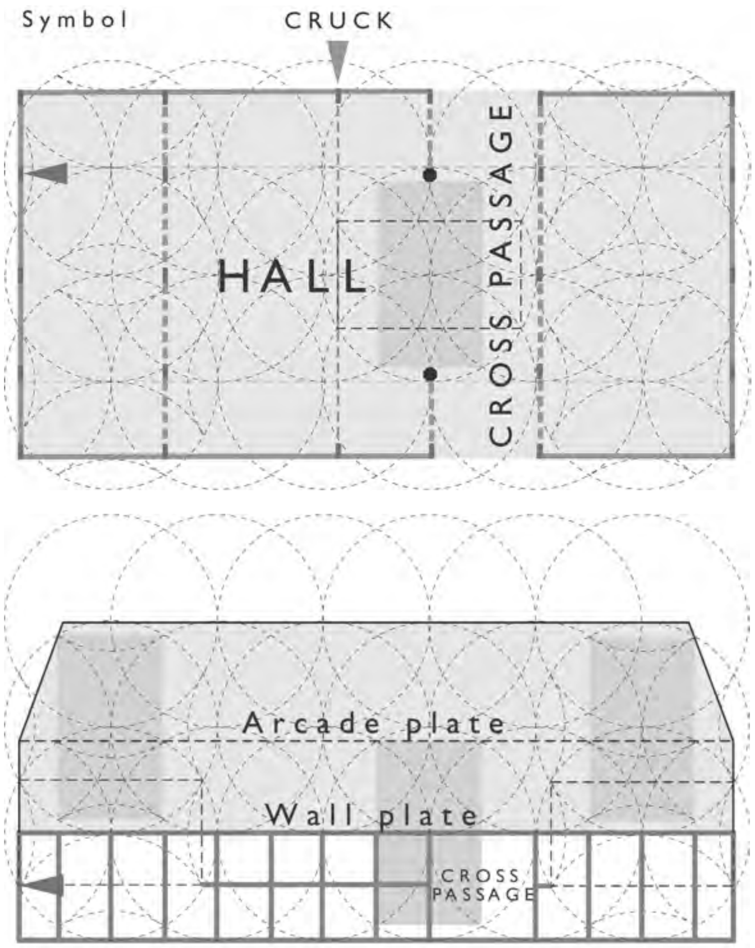
FIG. 14. THE NINE-CIRCLE GRID AND THE THE CRUCK TRUSS REMAINS.

For the full floor plan, the grid is doubled to form an 18-circle grid, six long by three wide (Fig. 15). The figure shows how the symbol's vesicas and their cardinal points, two of which operate here, are crucial to the floor plan's boundary: the gable ends bisect the vesicas and the long walls run as tangents to the vesica's inside edges, and these alignments define the floor plan outline.



Royal Institute of Chartered Surveyors Building Conservation Journal, Spring 2002

FIG.15. AT TOP, TŶ-MAWR'S FLOOR PLAN. ABOVE, THE LONG SECTION.

Looking at the roof above the gable ends in the long section, it can be seen that the vertical rectangles (darker shading) within the end circles control the pitch of the hipped roof, described by lines drawn between the arcade plate ends and the top outer corners of the rectangles. It is also clear that the symbol is carved in a location (marked by arrowheads in the figures) that occupies a specific geometrical position in both the long section and the plan. The placing indicates that the master carpenter was thinking simultaneously in both the horizontal and vertical planes. This indication is borne out by the horizontal and vertical pairs of arcs within the symbol that, if connected, form horizontal and vertical rectangles. The symbol clearly had a function similar to the use of modern protractors to draw accurate angles, but what the symbol also provided, and protractors do not, was a set of related proportions that governed every element of the building's aesthetic. No wonder it was carved into the frame: a design icon, a master carpenter's signature, whatever you wish to call it, but emphatically a key to unlocking the concepts of 15th-century building design. The tragedy is that during modern repairs this unique symbol was lost, rumored to have been burnt in a cleanup of timber waste from the house before its official opening.

Ken Rower

FIG. 16. GWERNFYDA.

GWERNFYDA. *Gwern* means marsh and *fyda* wild bee swarm, so *Wild Bee Marsh* has been my home for the last ten years. (Pronounce *er* as air, *f* as v and *y* as u in udder, and *roll* the *r*.) The house was built in open countryside eight miles west of Ty-mawr as the crow flies and occupies a similar site at the foot of a hill, but long-side across the slope. Though this position is less efficient for drainage, it was clearly chosen in relation to shelter and light. The house is well protected from the prevailing southwesterlies and faces southeast so that the morning and evening sun illuminate the full length of the house. The Afon Rhiw, or mountain river, runs one small meadow away from the house. Only recently drained, the meadow was once the marsh that gave the house its name, and there are still occasional wild bee swarms here. The house has the typical three-unit plan of the locality (Fig. 20, facing page), with a central hall flanked by a parlor at the upper end and a service room at the lower—though, unusual for Wales, it has a narrow bay at the lower end of the hall that functions as a smoke bay or proto-chimney. At the upper end of the hall there is a solid oak post-and-panel wall, showing small mortises where once a bench was fitted to it, and a dais canopy, each an indication of status. In earlier hall-houses, the floor was often of packed earth, and a small dais, a platform not unlike those used for a schoolteacher's desk, raised the trestle table and bench off the earth at the upper end of the hall. The dais canopy, a narrow ceiling that ran across the width of the hall above the dais, was meant to protect those on the bench from the fall of soot and smuts that had risen on the heat of the open fire into the roof space. The house is entirely box framed in oak on a shallow stone plinth and, though well below the social standing of Tŷ-mawr, was clearly the property of a well-to-do yeoman farmer. For a long period, the house was the property of absentee landlords. Their tenants, farming marginal land, could afford little maintenance and none of the fashionable improvements of their time. The original heavy flag roof had given way to thatch before 1900 and, at the outset of World War II in 1939, to corrugated iron, which was, as said at the time and reported by a descendant, "the cheap option in case we get bombed." Since then, weatherboarding has preserved the frame (Fig. 16), the modern boards concealing recycled newsprint insulation so that the house is warm in winter and will therefore be habitable into the foreseeable future. At some unknown time, a tall stone chimney stack was built, incorporating a massive oak lintel carved with two quatrefoils, a phoenix, a running stag and hound, an amphisbaena (double-headed serpent) and a crucifixion (Fig.17).

At the crossing of the hall ceiling beams, there is a boss with the carving of an owl, and "ghosts" of medieval painting survive on some timbers and the few remaining wattle-and-daub panels within the hall. Gwernfyda is approximately two-thirds of Tŷ-mawr's

FIG. 17. MONTAGE OF THE CARVED FIGURES IN THE LINTEL OVER THE FIREPLACE.

size, 48 ft. in length by 20 ft. in both width and height. The house has been dendrochronologically dated to 1552 by The Royal Commission on the Ancient and Historical Monuments of Wales. The house is listed Grade II star, and its description cites "the rare survival of a medieval house in its original form." The original owner of the house remains unknown.

Two geometrical symbols are incised into Gwernfyda's frame, one 8¼ inches in diameter, in the middle of the central, lowest tie in the upper face of the southern gable, the other 2¹⁄₁₆ inches in diameter, on the lower face of the hall's post-and-panel wall. Like Ty-mawr's symbol, neither of Gwernfyda's symbols is an assembly mark. The two geometrical symbols are shown in scale with each other in solid line, but it is clear that both are derived from the daisy wheels that are completed in dashed line (Fig. 18).

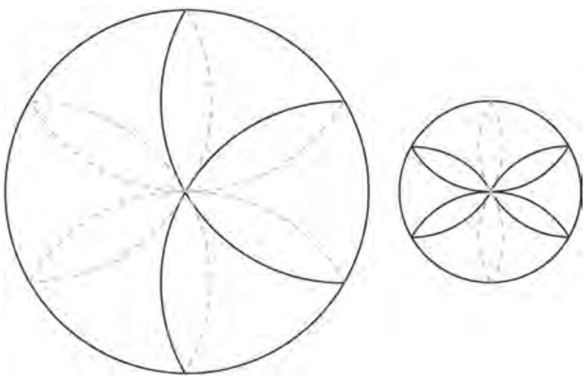
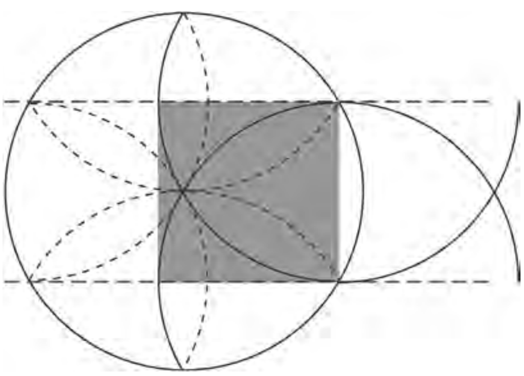


FIG. 18. THE TWO GEOMETRICAL SYMBOLS IN RELATED SCALE.

FIG. 19 (BELOW). THE LARGE SYMBOL USED TO GENERATE A SQUARE.



Considering the large symbol first, some developments can be made (Fig. 19). Horizontal parallels (shown in dashed line) are drawn through four of the daisy wheel's vesica tips to generate two sides of a square, shown shaded, between the circle's circumference and centerpoints of the vertical vesica's upper and lower arcs. Two arcs can also be projected from the square's right-hand side until they intersect.

Inside the square, the two arcs intersect to define the alignment of the dais canopy, shown in white dashed line, and outside the square they intersect at the service gable (Fig. 20a). Diagonals in the left-hand half of the square act as radii to swing arcs to the outer corners of the parlor gable (Fig. 20b). Diagonals in the right-hand half of the square intersect with the square's full diagonals to define the alignment of the smoke bay cross wall, shown in dashed white line (Fig. 20c).

The geometry can be read both as a floor plan and as a long section, the wall plate's top level being on the circle's horizontal center line (Fig. 20d). The parlor occupies the left-hand extension, the hall occupies the square and the service end occupies the right-hand extension.

The master carpenter was clearly aware of the relationship between the compass-drawn symbol and the square geometry that it generates. However, the compass characteristics of the design are dominant, and this is confirmed by the fact that the dais canopy, a feature of status in houses of the 16th century, is placed exactly at the heart of the circle on its vertical diameter.

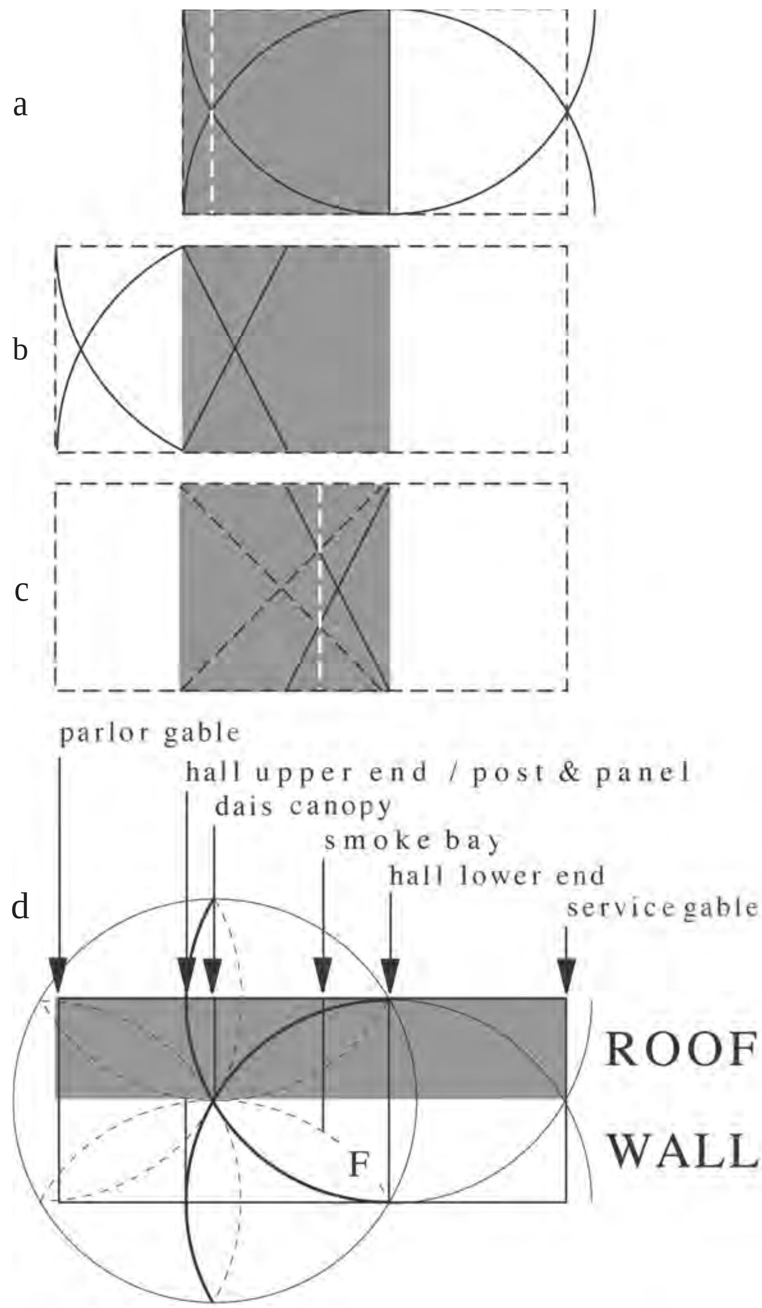


FIG. 20. DEVELOPING GWERNFYDA'S PLAN AND LONG SECTION.

The hall is 20 ft. square in plan, identical to the gable's width and height. The gable's geometry is therefore also governed by the square. In the first stage of the design, the square's full diagonals cut the square in half to generate alignments for the lower wall, roof pitch and collar (Fig. 21a). Two further half-square diagonals cut the collar at the heads of the queen posts (Fig. 21b).

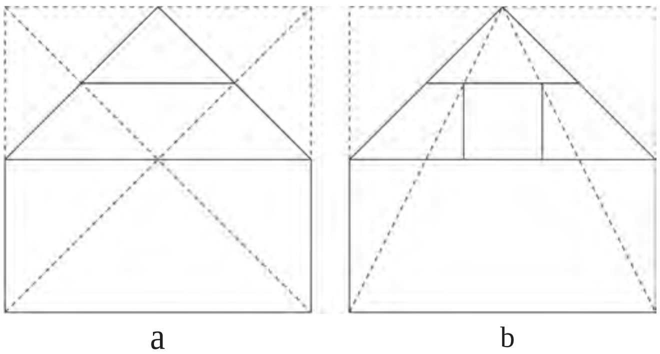


FIG. 21. THE SQUARE AS THE BASIS OF THE UPPER GABLE FRAMING.

Having resolved the primary elements of the roof truss, the design proceeds in the lower wall section. Diagonals are introduced to find the midpoint used to divide the frame into four quarters (Fig. 22a). The quarters are then individually subdivided, by the use of further diagonals, into halves (Fig. 22b). This division of the lower wall frame is a temporary geometrical stage en route to further subdivision.

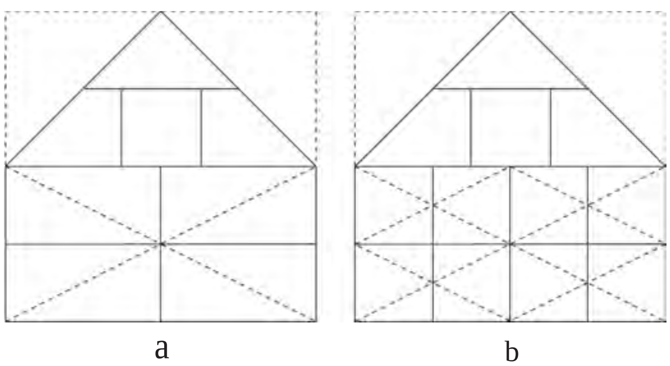


FIG. 22. THE SQUARE AS THE BASIS OF THE LOWER GABLE FRAMING.

The traditional configuration of lower gable wall framing in Gwernfyda's area is three panels high by five long, a subdivision also obtained by the use of diagonals. First, the two horizontal bands established in Fig. 22 are crossed individually by diagonals, then jointly by a single diagonal in the reverse direction (Fig. 23a). Where these diagonals intersect, they divide the lower wall into three horizontal sectors. Similarly, the four vertical bands of Fig. 22 have their individual vertical diagonals intersected by a full horizontal diagonal in the reverse direction to divide the lower wall into five vertical sectors (Fig. 23b).

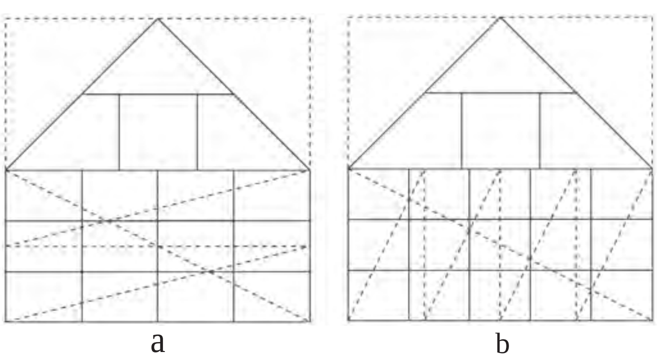


FIG. 23. SUBDIVISION OF LOWER GABLE FRAMING INTO 3X5 SECTORS.

The final stage in the gable geometry is the location of braces in the roof truss. These are again determined by diagonals, this time drawn across the grid of the lower wall's 3x5 paneling. The diagonals define the braces rising from both tie beam and collar to the principal rafters. It is interesting to observe that while the brace diagonals generate roof truss details, they emanate from the lower wall geometry (Fig. 24a) and unite the truss with it.

At Gwernfyda, translating the pure geometry into practical framing was carried out in a pragmatic way. For example, the sill beam, tie beam and the horizontal short wall ties are all placed below their relevant geometrical lines (Fig. 24b), which means that the sill falls outside the pure geometry of the frame. Principal rafters are geometrically correct at the ridge but meet the underside of the tie beam at their lower ends. Similarly, the brace geometry shifts to align with the corner of the first stud in from the corner post (Fig. 24b). The evident purpose of these diversions is to separate the principal rafter and corner post joint alignments to eliminate a compound and therefore weaker joint at a point where the wall plate also makes its appearance. The brace and first stud alignment diversion serves an identical purpose.

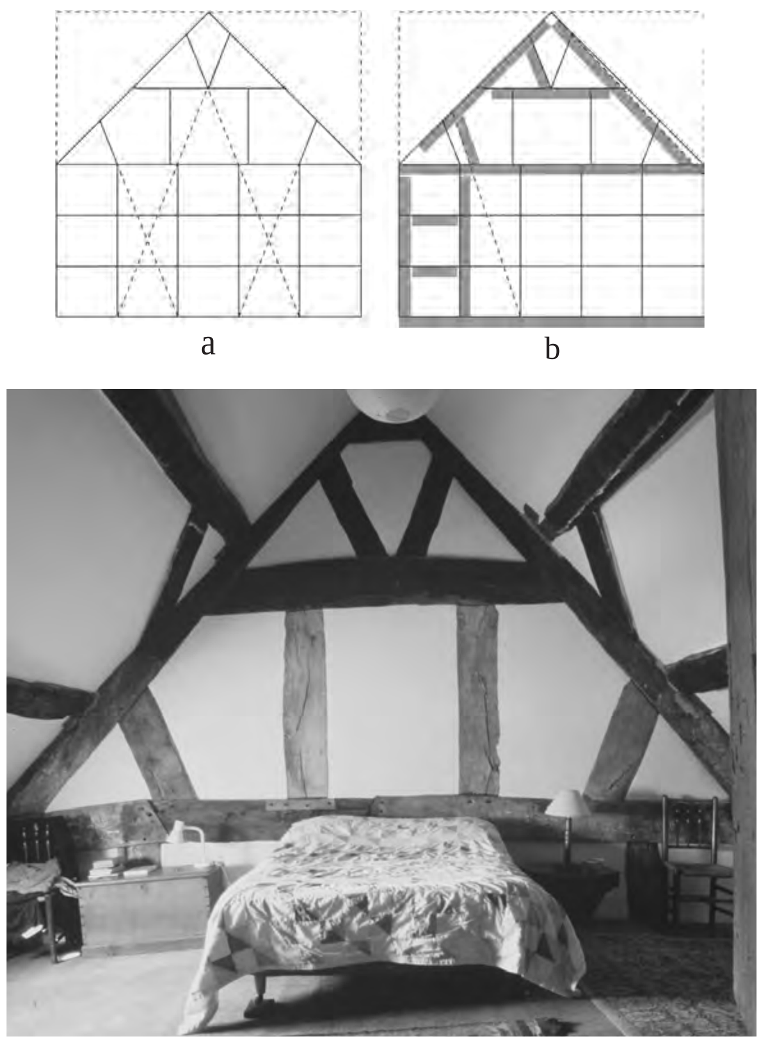


FIG. 24. ROOF TRUSS BRACING AND TIMBER PLACEMENT.

The second of Gwernfyda's symbols is scribed finely into the lower face of the hall's post-and-panel wall, which comprises a sill and wall plate connected by eight posts and, between them, seven panels. The symbol is again daisy wheel based, as in Fig. 18, and depicts four of the usual six vesica petals. If the four vesica tips at the circle's circumference are connected, a rectangle is produced, identical to the rectangle so prominent in Ty-mawr's design. The rectangle has the ratio 1:2 between its short side and diagonal, and these are the exact proportions of Gwernfyda's post-and-panel wall. However long the diagonal is drawn, perpendiculars to it always generate identical 1:2 proportions (Fig. 25).

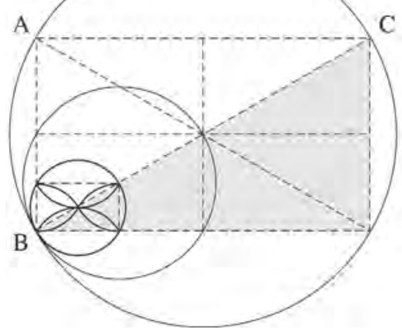


FIG. 25. THE SYMBOL AS A SOURCE OF 1:2 PROPORTIONS.

The previous owners of Gwernfyda, already a listed building, had installed illegal and unsympathetic windows throughout the house, and these had to go. Because there were no historic precedents to follow, the need arose to design modern windows. It seemed appropriate to apply the proportional influence of the symbol so that the new windows could relate to the existing spaces that they would occupy. The horizontal post-and-panel wall symbol was spun through 90 degrees into a vertical position and duplicated to form a two-circle sequence with each circle generating a casement rectangle. The distance between the casement rectangle's short side and the circle's circumference is occupied by the window's outer frame. Perpendiculars in each circle determine the alignment of glazing bars that divide each casement into four panes. Each pane is in identical proportion to the full casement (Fig. 26).

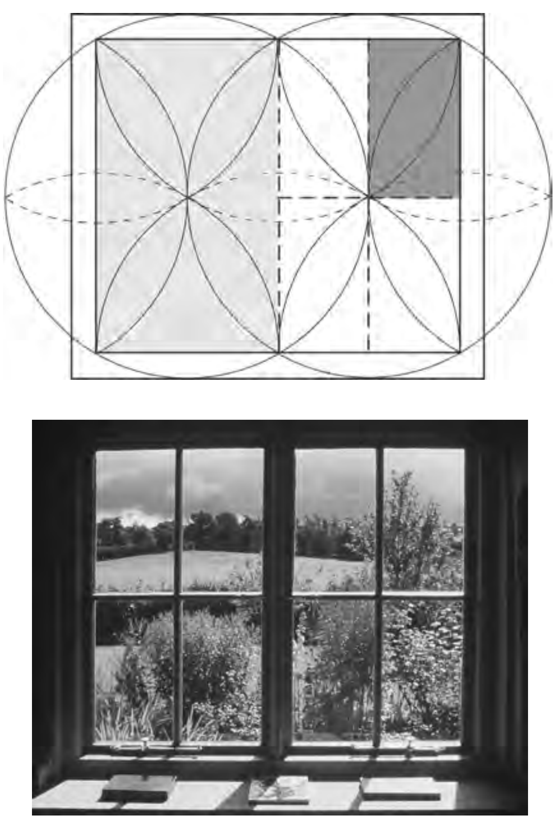
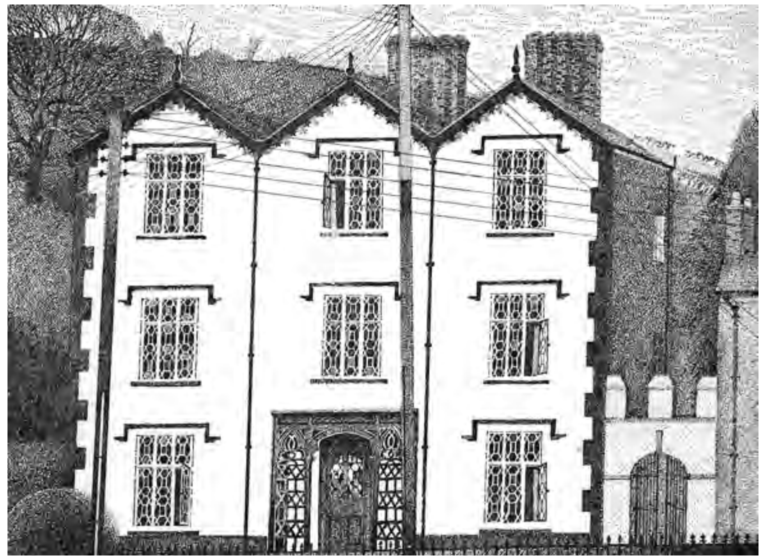


FIG. 26. 1:2 PROPORTION IN GWERNFYDA'S NEW WINDOWS.



Drawing by Laurie Smith

FIG. 27. THE HALL WITH WINDOWS AND PORCH OF 1832.

THE HALL, Llanfyllin. This house has been known by its English name since the 17th century, but it is also known to Welsh speakers in the bilingual town as Plas Uchaf, *The Upper Hall*. (*Plas* is a gentleman's residence, *Uchaf* means higher.) Pronounce *Plas* as in plastic, *U* as i in sit, *ch* as k, *f* as v.

The Hall was built on rising ground on the edge of the small town of Llanfyllin in the old county of Montgomeryshire about 10 miles north of Tŷ-mawr and a similar distance west of the English border. According to a Royal Commission estimate, the house was originally built somewhere between 1500 and 1550 as a timber-framed two-bay hall house sited parallel to the southern slope of the hillside for protection from winter northwesterlies. The house was built on a northeast-southwest axis that allowed morning sunlight from the east and afternoon sunlight from the west into the full length of the house. A cross-wing was added at the southern end of the house in 1599, a date that survives in a carved inscription above the front door inside the current porch. In 1599 the house was approaching its social zenith, boasting a two-story porch, stair tower and a four-hole outside latrine lined with stone and slate (high-quality sanitation, according to The Royal Commission, and flushed out by a small rivulet on its way to Afon Cain, the beautiful river). Its gardens, laid out with a line of yews and box-hedged parterres covering half an acre, stretched down to the town's high street. For a single night in September 1645, King Charles I stayed at The Hall en route for Chester.

In 1832, everything changed. The cross-wing was built over to give a third floor and the house was revamped in the "renaissance" fashion of the time as a three-bay, three-floor "box" with shallow roof and three gables. The new façade was endowed with the latest in pattern-book windows, a front door with related glazing and an oak trellis porch (Fig. 27). The form of much of the original house has been lost, but the service end, the kitchen end to this day, preserves significant elements of a two-bay hall and service room that still retain their medieval character with framing visible internally. In the front of the house, which has Georgian (six-panel) doors in all rooms, the framing is either lathed and plastered or rebuilt in brick and stone. In the modern period, the house was in divided occupation, the formal gardens became allotments and the line of yew trees was felled. The house is listed Grade II. Despite the Hall's well-documented history from 1600 to date, the original owner of the house remains unknown.

The service room of the original building survives almost intact. The wall dividing it from the hall has carpenter's marks, visible mortises, peg holes, sills, wall plate levels and an adjacent wall of framing that make an accurate reconstruction of its missing timbers possible (Fig. 28a, existing and Fig. 28b, "reconstructed"). The adjacent south wall (cross-section on the left in 28a) was rebuilt in 1832 in stone faced with local handmade brick and the roof raised on the same side, while the north wall opposite (cross-section on the right in 28a) survives. It is a fact of frame survival in wet Wales that, while the winter sun is low in the sky, north walls freeze during the winter months and thaw in early spring. South walls freeze at night and thaw in the day so that erosion is severe. North walls survive and south walls do not.

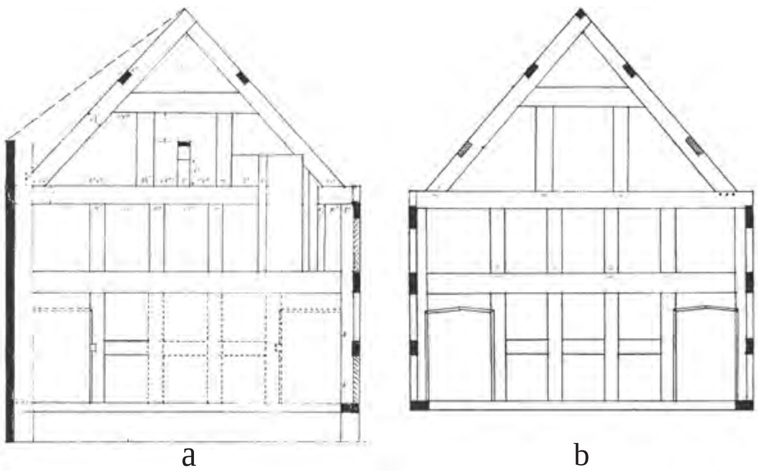


FIG. 28. THE HALL. LOWER END OF THE TWO-BAY HALL.

The hall lower end truss is determined by daisy wheel geometry. The vertical vesicas define the frame's height from floor to ridge, while connection of the remaining four vesica tips generates the planes of the outer walls, the base of the collar and the doorhead level. The circle's horizontal diameter defines the base of the tie beam (Fig. 29).

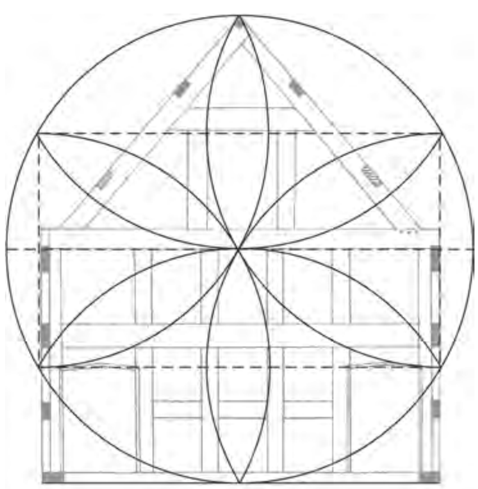


FIG. 29. THE DAISY WHEEL PROPORTIONS OF THE TRUSS.

The daisy wheel is also used at a smaller scale as a proportioning device to determine the combined rectangle of the doors and their doorheads (Fig. 30). The horizontal vesica thicknesses also determine the depth of the lower framing ties between the door jambs.

The Hall's late-16th-century restoration was commemorated by a carving encompassing the date 1599 and the initials C (or G) HMO. In the 1832 remodeling of the house, this carving was fixed above the front door inside the trellised oak porch. I recall standing in this porch 20 years ago and seeing the carving for the first time. The first number 1 of the date and the last letter O of the ini-

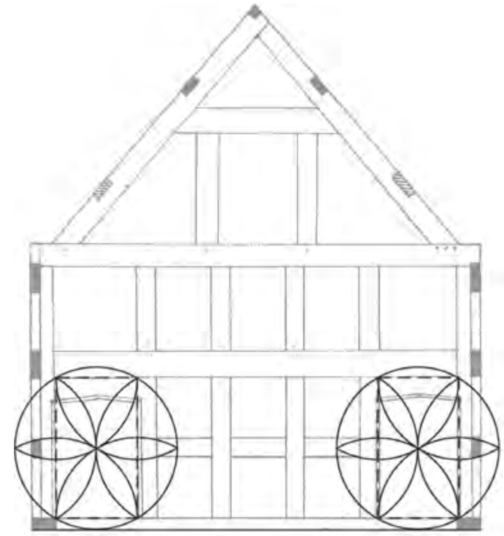


FIG. 30. THE DAISY WHEEL APPLIED TO PROPORTIONAL DETAIL.

tials stood out from the remainder with a geometrical prominence for which there seemed no obvious reason (Fig. 31). But I knew immediately that they held a message.

FIG. 31. THE HALL'S 1599 CARVED RESTORATION DATE.

A full-scale rubbing allowed the 1 and O to be tested geometrically, and established that both resulted from related precision circle-based geometries (Fig. 32). Drawing the geometrical 1 commences with two circles drawn along a centerline so that each passes through the other's center to generate a vesica piscis (32a). Arcs are drawn from either end of the central horizontal vesica until they intersect the circumferences of the circles (32b). The four points of intersection are connected by two lines in the form of an X to generate the two opposed triangles (32c, shaded). Drawing the geometrical O commences in an identical way to generate a vesica piscis (32d). The two points of the vesica and the point of

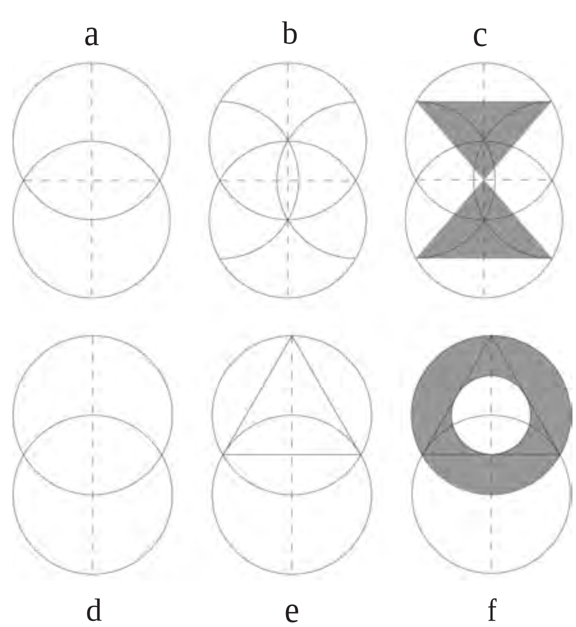


FIG. 32. THE GEOMETRY OF 1 AND O.

intersection between the center line and the upper circle's circumference are connected by three lines to form an equilateral triangle (32e). The O is formed between two circles, the larger passing through the triangle's vertices, the smaller tangent to the triangle's sides (32f). The X was the first clue to meaning. If X was posing as a 1, then what did XO mean? The Hall had been the home of recusant Catholics, forbidden by law to practice their religion in the 16th century. The XO was a sign to those with classical and biblical knowledge that the house was a safe house for Catholics, its meaning hidden in the Greek word in Fig. 33.

ΙΧΟΥΣ

FIG. 33. "ICHTHYS" (A FISH, THE EARLIEST CHRISTIAN SYMBOL), EACH LETTER OF WHICH IS THE FIRST LETTER OF THE GREEK WORDS JESUS CHRIST, SON OF GOD, SAVIOR.

When The Hall was remodeled in 1832, the side of its two-story cross-wing was raised by a further floor and the whole three stories punctuated by a front door and eight pattern-book windows. Windows of this nature were usually of cast iron, but The Hall's were blacksmith forged, the hot iron beaten into narrow strips, angled to the pattern's edict and fire welded. On the inside of the window lattice, half-cylindrical sections of copper were added to hold the glazing in place, the glass puttied on its outer face.

The window design commences from a rectangle that is a square and a half in proportion. The rectangle is divided into three both vertically and horizontally, so that the window has two vertical mullions and a transom across the top of the square. The configuration generates nine areas of glazing, three above the transom and six (in three pairs) below it. The subdivision of the full window is repeated in each of the nine small glazing areas. Diagonals are drawn in the corner rectangles of the nine small glazing areas, and some elements of the horizontal and vertical alignments are removed so that an individual area has 13 panes of glass: one central rectangle, two short hexagons, two long hexagons and four pairs of triangles at the corners. The areas above the transom follow this pattern exactly but, because those below the transom are joined in pairs, the pattern is modified at the join where pairs of small triangles fuse to form diamonds. The double areas below the transom have 24 panes of glass. There are 37 panes in each vertical sector and 111 panes of glass in the full window lattice (Fig. 34). The façade comprises eight of these windows, making 888 panes of glass, and the front door's additional 64 bring the total to 952. The windows are all framed in oak and the trellised porch (Fig. 34 photograph) follows suit in this extraordinary geometrical fugue on a rectangle and its diagonals.

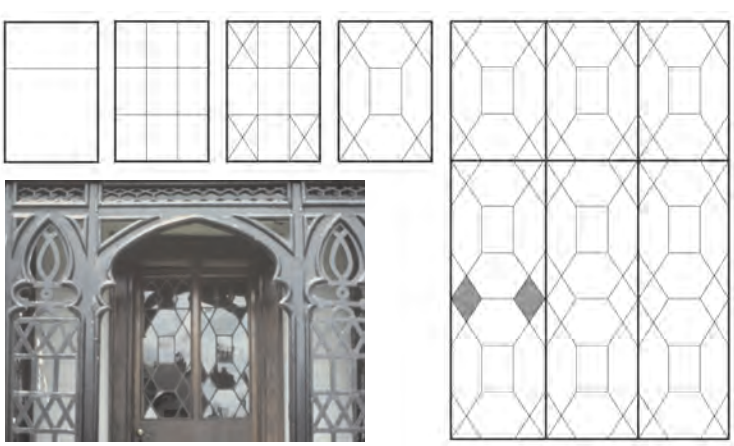


FIG. 34. THE GEOMETRY OF THE HALL'S PATTERN BOOK WINDOWS.

THE three examples I have discussed demonstrate the presence and evolution of geometrical design between 1460 and 1832 in a small area of northeastern Wales. The flow is clearly from circle-based to square geometries. Tŷ-mawr's and The Hall's first phase are pure circle geometries, Gwernfyda is a hybrid circle and square system and The Hall's 1832 façade purely square. The Hall's façade also records the fundamental shift away from geometry as the generative force behind structure toward geometry used solely as a source of pattern. Put another way, the trend marks the conceptual transition from compass and curved line design methods to marked ruler and straight line systems and the detrimental change from proportional to dimensional design.

It is noticeable that Tŷ-mawr, Gwernfyda and The Hall's first phase are all governed in their design by the use of related geometrical modules: carved into the frame at Tŷ-mawr, scribed into the frame at Gwernfyda and deduced from geometrical analysis at The Hall. The use of geometrical modules in the design of buildings has a direct European lineage, probably via the Norman invasion and conquest of the British Isles, from Vitruvius, the Roman architect of the First Century BC and author of the *Ten Books on Architecture*, who wrote:

> . . . . difficult questions involving symmetry are solved by means of geometrical theories and methods. . . . Symmetry is the proper agreement between members of the work itself, and relation between the different parts and the whole general scheme, in accordance with a certain part selected as standard . . . . symmetry may be calculated from the thickness of a column. . . . or . . . . *from a module*.

The italics are mine. The module was clearly alive in Wales, its form a simple evolution from the tangible thickness, or diameter, of a column to its circumference, the circle. The circle was mobile. It could be revolved to transform the direction of any internal geometry. It could be multiplied along a center line to generate harmonically proportioned grids from which linear alignments and rectilinear areas could be established, and it could encompass subgeometries that enabled fine-tuning of the design.

The daisy wheel is ubiquitous in historic buildings; in fact, its absence is more noteworthy than its presence. As demonstrated, analysis of its geometrical properties and their testing against the measured drawings of a building often reveal evidence of its function as a design module governing the building's major proportions and bay rhythm. Many variations of the daisy wheel's basic geometry also exist, and the idiosyncratic symbols found at Tŷ-mawr and Gwernfyda record the presence of individual and intellectually sophisticated geometrical design approaches in operation in eastern Wales between the 15th and 17th centuries. By 1832, when The Hall's windows were installed, medieval geometrical design systems had had their day, but geometry enjoyed a resurgence in the decorative window glazings that were offered nationally as choices in pattern books. —LAURIE SMITH

Laurie Smith (lauriesmith@uku.co.uk), an accomplished artist and scholar living in Wales, has widely studied the geometry underlying historic building design. This article was developed from his talk "Welsh Historic Geometrical Building Design" at the UK Carpenters' Fellowship conference, "Frame 2003," held in September at Amgueddfa Werin Cymru, Sain Ffagan, Caerdydd, Cymru: The Museum of Welsh Life at Saint Fagans, Cardiff, Wales. His drawings shown in Figs. 10 and 12 provided the heraldry for the Fellowship conference, its banners, clothing and literature.

TIMBER FRAMING FOR BEGINNERS

VII. When Roofs Collide 1

ONE of the most difficult problems carpenters face is the framing of pitched roofs, most of which fall into one of four types. A *shed* roof slopes in only one direction and is the simplest. A *gable* roof, the most frequently seen, has two sloping surfaces that rise from the side walls and meet at a ridge running lengthwise, usually over the centerline of the building. A *hip* roof, if it has a ridge of any length, can resemble a gable in part, but at the ends of the building, additional roof surfaces slope upward from the end walls; thus there are four sloping surfaces in a hip roof. Some hip roofs terminate in a point rather than a ridge. In all hip roofs, diagonal hip rafters slope upward from the corners of the building. When a building plan calls for the intersection of two gable roofs, one or more valleys are formed, and the resulting roof is called a *valley* roof. Valleys also occur when gable dormers project out from a roof. All of these roof types are formed with sloping framing members and introduce problems of visualization and measurement that can challenge the craftsman.

Luckily, we've got lots of tools at our disposal to make the problems easier to solve. Computers, calculators, drawing techniques, the framing square, math, geometry—all can be used separately or in combination to make the meeting of timbers visually pleasing and structurally adequate. The basic problem boils down to determining the lengths of the relevant pieces and predicting the angles at which they will meet, and then designing the joinery to hold it all together.

Compound roofs show up in a number of applications. Hip systems, for example, offer a great technique to enclose a space efficiently without high gable ends. Because of its included triangles, a hip roof also forms a stiff cap on the top of a building compared to a gable roof. Valleys, meanwhile, can be problematic to make structurally strong and weatherproof, but they are unavoidable in dormer framing. Some apparently simple effects result in compound cuts. You might be asked to deal with a projecting barge rafter, where the rake overhang gets progressively larger as it slopes toward the peak, and have to work out the angles at the top and bottom, as well as any jack rafter connections along the way. We call the roof forms and the joinery "compound" because, like the angle a compound miter saw takes, the necessary connections typically combine two angles other than 90 degrees.

In this and further articles I will explain the ways of working out compound roofs that I have found most useful. The method I (and probably most carpenters) used first to figure out hip or valley rafters was to repeatedly get up on the ladder after the common rafters were set, and use strings and bevel gauges to sight the angles necessary by projecting the existing roof planes to their intersecting point. This worked okay in stick framing, and I was young and enjoyed running up and down ladders. I still find that jack rafters can be efficiently scribed in place once the hip or valley is installed, but often we don't have the luxury of working out this stuff on site, and we need a method we can use back in the shop.

The framing square, often called a *rafter square*, can be most useful for finding the more common angles needed in compound work. Rafter squares carry tables for the angles as well as lengths of pieces, but these tables are limited to roofs of equal or *regular* pitch with eaves and ridges meeting at 90 degrees (*regular plan*).

I've seen European carpenters use drawing methods similar to those that appear in early carpentry texts in America. These methods are essentially the same as the descriptive geometry and orthographic projection techniques taught in basic mechanical drawing courses, applied to roof framing. Descriptive geometry is the graphical solution to three-dimensional spatial problems. These problems can also be solved with mathematical tools such as trigonometry, but graphical methods achieve the same results, often in less time. Descriptive geometry is an excellent tool for visualizing and reasoning through compound roof problems. Taken further, this geometry can lead to the development of drawings to show the actual full-scale sizes and shapes of the pieces. These developed drawings are, in my opinion, the clearest way to handle problems of *irregular* (unequal) *pitch* roofs and *irregular plans* (roofs meeting at other than 90 degrees). If you can draw it, you can build it. Indeed, we will frequently refer to a small model that the student can build from the drawings.

Finally, these graphical and mathematical methods have both been used to generate a series of formulas and angles used by many timber-framing shops that do compound joinery on a regular basis. These are known in the trade as the *Hawkindale angles*, and are useful provided one can calculate the lengths of pieces independently, and provided one already knows how to apply the angles in their correct orientation. This skill comes with experience, and the results of applying the Hawkindales without being able to visualize what the joint should look like can be disastrous.

We will thus use three methods—developed drawing, the framing square and the Hawkindale angles—each to reinforce the application of the others, as we work our way through hip and valley exercises.

THE BASICS. The two essential pieces of information that we need to solve roof problems are the dimensions of the building in plan (which show the rafter run, roof span and the deck and wall angles at the corners where the roofs meet) and the pitch, or slope, of the roof (Figs. 2 and 3).

Span defines the horizontal dimension the roof covers as measured across the building, and *run* the horizontal or level distance the rafter travels, projected onto the ground (or deck). For an equal-pitch gable roof, the roof span is twice the rafter run.

I'll use *pitch* to refer to the angle of the roof from the horizontal, measured in inches of rise per foot of run. *Rise* is the vertical or plumb distance the rafter travels. Traditionally, pitch was expressed as the proportion of the rise of the roof to its span (or width of the building). Thus a gable roof with a centered peak 6 ft. higher than

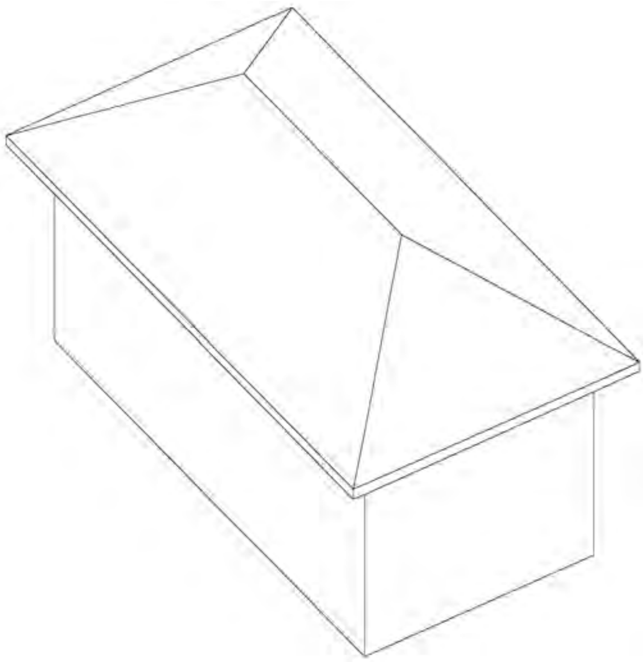


Fig. 1. Isometric view of hip roof.

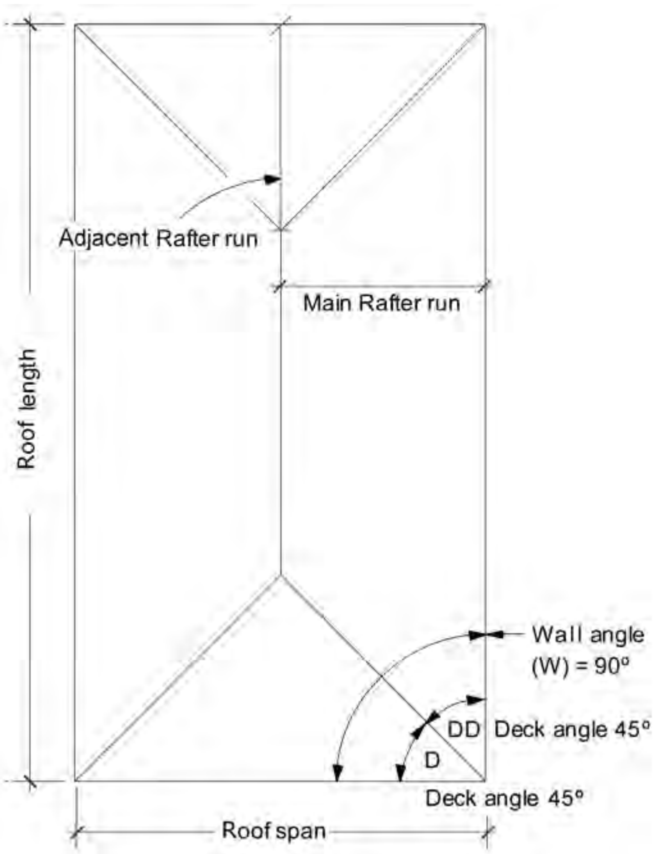


Fig. 2. Plan view of hip roof.

the plates on a building 24 ft. wide would have a one-quarter pitch. Today, pitch is more likely to be expressed in terms of inches of rise per 12 in. of rafter run, and in this case would be called a 6 in 12 pitch, notated as 6:12. We will use this terminology since it ties in well with our use of the framing square and is the observed convention. *Slope* we will use to refer to the degrees of the roof angle from the horizontal. A 6:12 roof has a slope of about 26.5 degrees.

All of our solutions can be derived by understanding the properties of right triangles (where two sides form a 90-degree corner) and the principles of ratio and proportion. Determining lengths of pieces, locations of joinery and angles and dimensions in the joinery can all be done by breaking down the available information and

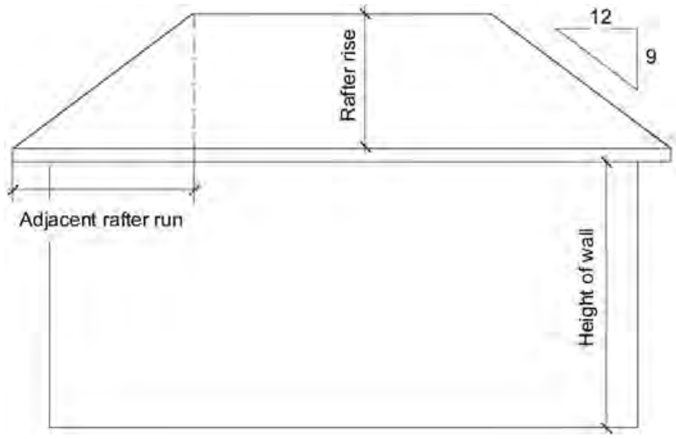


Fig. 3. Long elevation of hip roof.

views into right triangles and then applying ratio and proportion using similar right triangles. Because plumb and level are by definition at 90 degrees to each other, the rise and run of any rafter form a right triangle for which the roof surface is the hypotenuse.

Many of the angles and cuts in compound joinery are plumb or level, and if you know how to strike those lines on the timber using the framing square or bevel gauge, you'll have found a reference line from which to lay out the other angles. All of the pieces in the examples have plumb sides unless otherwise specified.

We will limit ourselves initially to roof surfaces of equal pitch that meet at 90 degrees in plan (the *wall angle*). Thus we have a *regular pitch, regular plan* roof, as opposed to a possible roof intersection with *irregular pitch* (two different slopes) or *irregular plan* (the respective eaves meet at other than 90 degrees), or both. For an irregular pitch, irregular plan roof, you can best rely on drawing techniques to develop the intricacies of the joinery.

For clarity, we will also limit ourselves to simple housed intersections of rafters. All of the necessary angles will be established by the housings, and can be extended if you want to add mortises.

DEVELOPING THE HIP. We'll start with an exercise that represents a hip rafter and a jack rafter rising from a plate to a ridge. A developed drawing represents the various sides of a timber with true sizes and angles for each area of the form. Once completed, its information is transferred from the paper (or floor) to the timber, by placing the timber above the drawing and bringing the points up, or by recording the measurements and carrying them to the timber. To make the drawing, you use the principles of orthographic projection; details can be found in most texts on architectural graphics or descriptive geometry (see the bibliography).

To get a true representation of the dimensions of a line or surface, we must observe it from a right angle. Imagine lines emanating from various points on a surface and projecting out perpendicular to it until they pierce a plane—the picture plane. The image an observer would see is called the view. Thus in the case of the hip roof in Fig. 1, if we looked directly down on it from above, the image we would see projected upward onto a piece of glass between our eyes and the house would be the plan view in Fig. 2, and from it we can get the actual measurements of the perimeter and the span of the roof. We also see the runs of the main and adjacent rafters projected on this surface. (We will use the terms *main* to refer to one roof surface and *adjacent* for the other roof surface intersecting it. Usually the main roof will be the larger surface covering most of the building and the adjacent the smaller surface, sometimes a dormer roof.) If we move around to look at the side of the house (Fig. 3), we get dimensions for the height of the walls and the peak of the roof and, again, the run of the adjacent rafter.

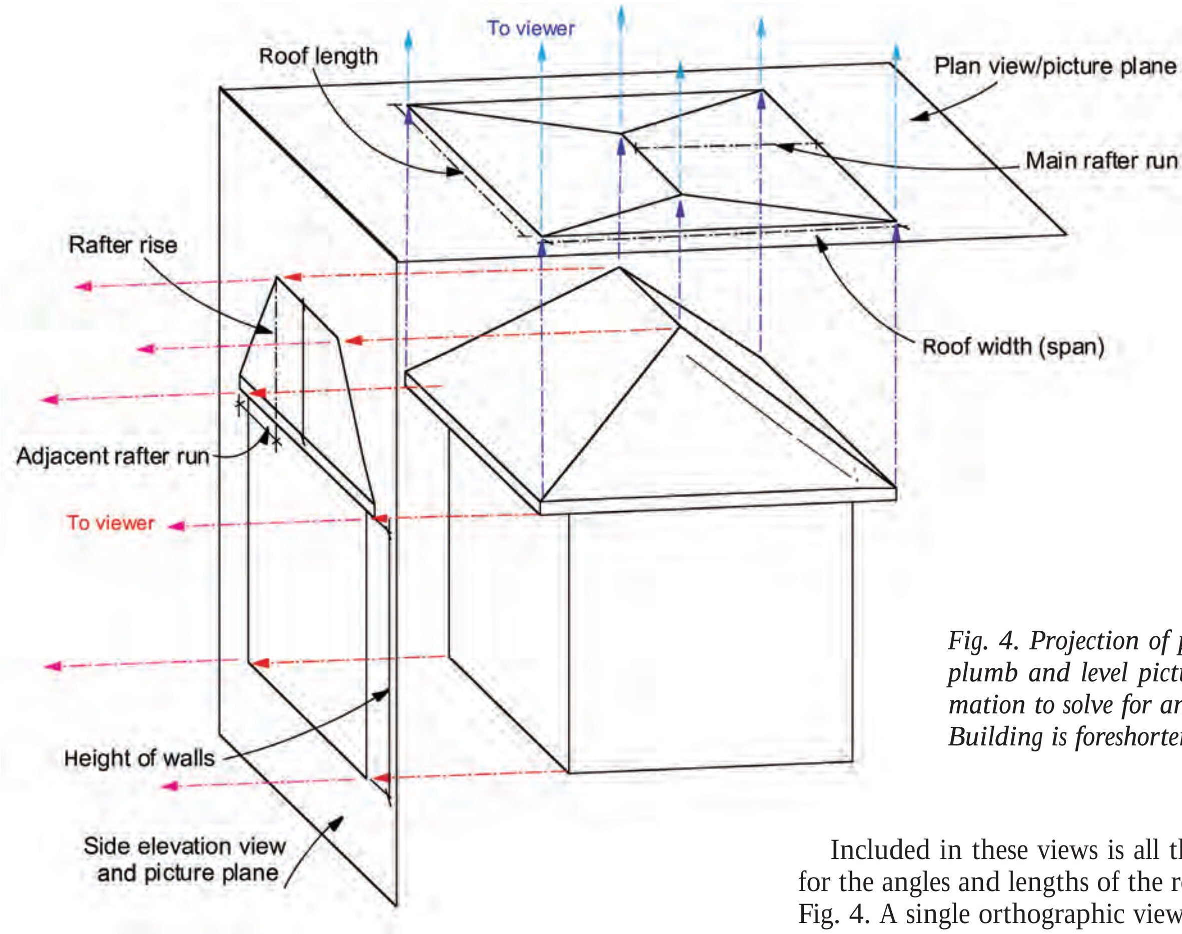


Fig. 4. Projection of plan and elevation views through plumb and level picture planes reveals essential information to solve for angles and lengths of roof members. Building is foreshortened in this illustration.

Included in these views is all the information we need to solve for the angles and lengths of the roof members, as recapitulated in Fig. 4. A single orthographic view cannot fully describe an object, but we can construct other views by recognizing that the projector rays are perpendicular to the picture plane. The side view of the house can be projected from the plan view as shown in Fig. 5 if we unfold the adjacent views onto a flat piece of paper and make sure our projector lines are perpendicular to the fold line. Let's look at our hip and common rafter model to illustrate these principles.

Figure 6, a cutaway view of our hip roof, shows the essential pieces of the roof framing: a hip rafter and common rafter with birdsmouth joints sitting on a ridge beam at the top and a plate at the bottom, with a jack rafter joining the hip. A plan view of these timbers is shown in Fig. 7, with actual model dimensions and sizes of materials shown. The dimensions given are for a small model for which the drawings will fit on 18x24 sheets of paper; this is a convenient size if you would like to try the exercise at home. Fig. 8 shows the model projected up onto the plan view shown in Fig. 7.

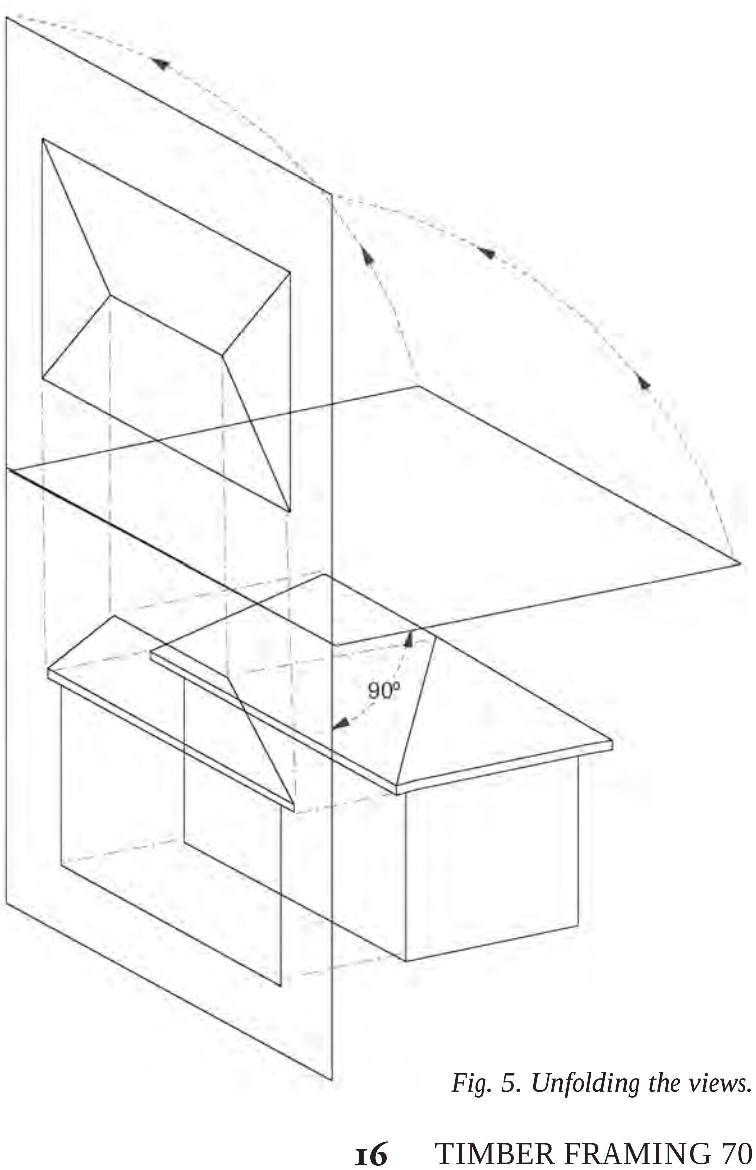


Fig. 5. Unfolding the views.

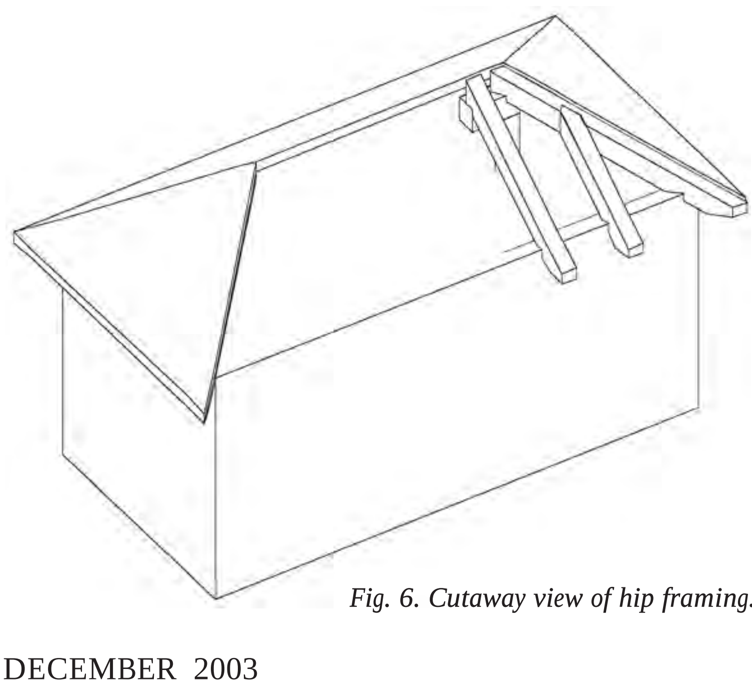
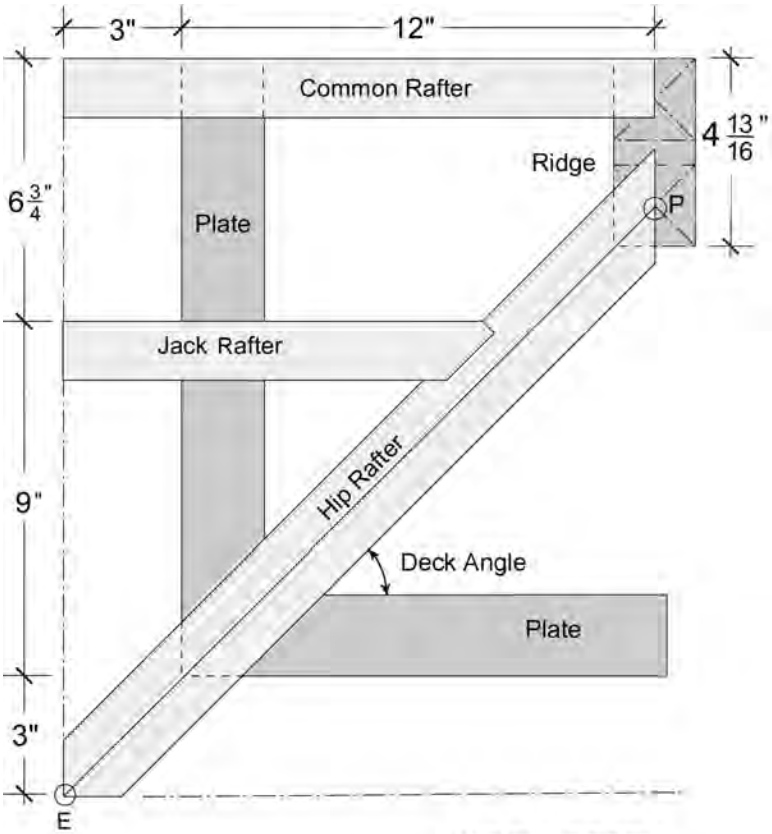


Fig. 6. Cutaway view of hip framing.



DIMENSIONS OF PIECES		WIDTH	DEPTH
	PLATE:	2"	2"
	RIDGE:	2"	2 1/2"
	POSTS:	2"	2"
	RAFTERS:	1 1/2"	2"
	HIP RAFTER:	2"	2 1/2"

Fig. 7. Plan view of hip.

If the carpenter does not have the room to do full-scale drawings of the roof, it's acceptable to do them at one-tenth or one-twelfth scale, and then step off the resulting drawn lengths 10 or 12 times, respectively, with dividers on the actual sticks. The tenths and twelfths scales on framing squares are convenient for this purpose.

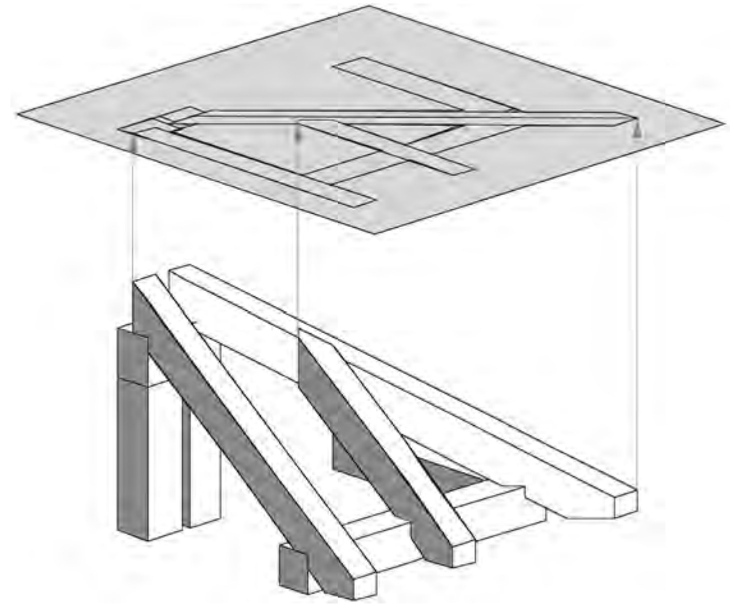
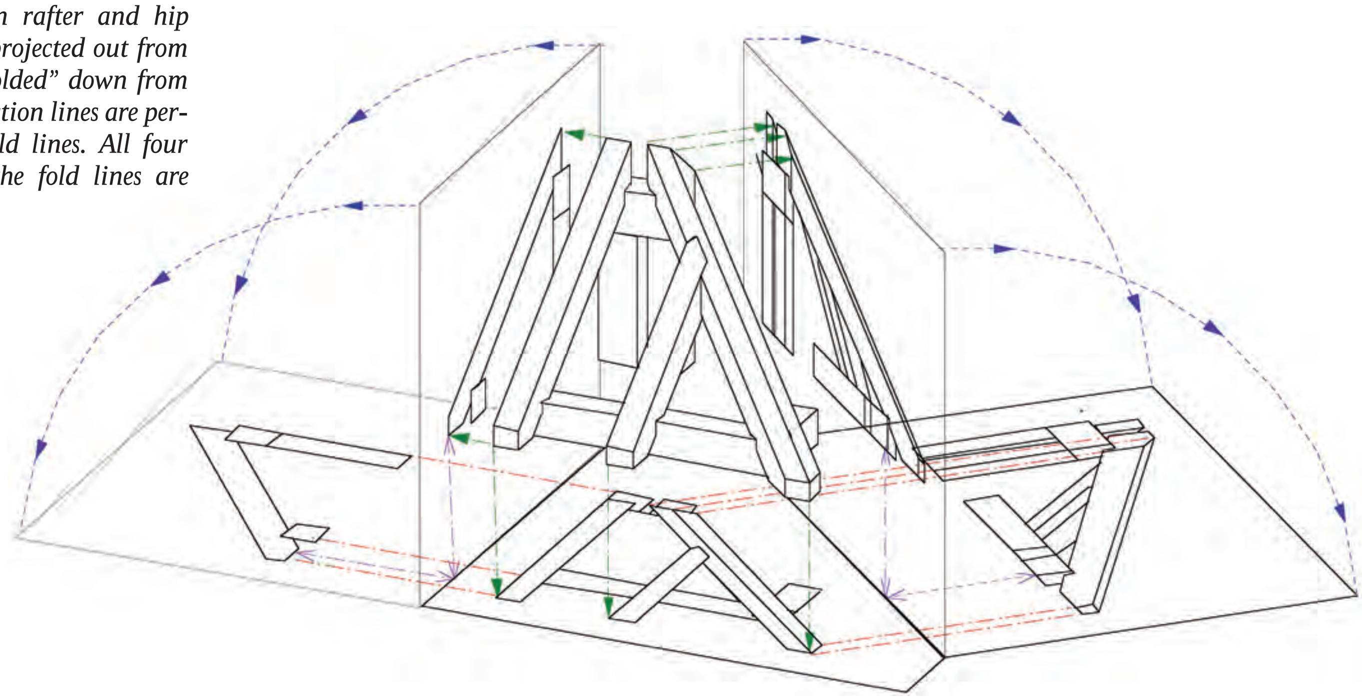


Fig. 8. Isometric view of hip model projected onto plan view. For stability, the model is built with two posts under the ridge .

The plan view gives us the run of each of the rafters, one of our critical pieces of information. As you'll see throughout the coming exercises, the plan view dimensions are used to determine so many of our measurements in the roof as to justify the saying, "Stay in plan as long as you can." In our example, you can see that the run of our common rafter is 15 in. from the centerline of the ridge to the eaveline (12 in. to the outside of the plate plus 3 in. for the overhang). The hip rafter runs at 45 degrees in plan, so this is a regular pitch, regular plan roof (irregularity in *either* pitch or plan will rotate the hip in plan away from 45 degrees). The widths of the common and jack rafters (1½ in.), as well as the plate, ridge and hip (2 in.), will all show up in true dimension in such a view.

To construct the side view, or elevation, of the common rafter, all we need to do is project the necessary points out perpendicular to the fold line, and then figure heights and angles based on our roof pitch, which we have chosen as 9:12. If we envision our plan view as being the projection of the roof down onto the deck, the elevation of the common rafter can be seen as if the rafter were folded down from the vertical onto the plane of the paper (Fig. 9).

Fig. 9. Common rafter and hip elevation views projected out from plan view, or "folded" down from the model. Projection lines are perpendicular to fold lines. All four distances from the fold lines are equal.



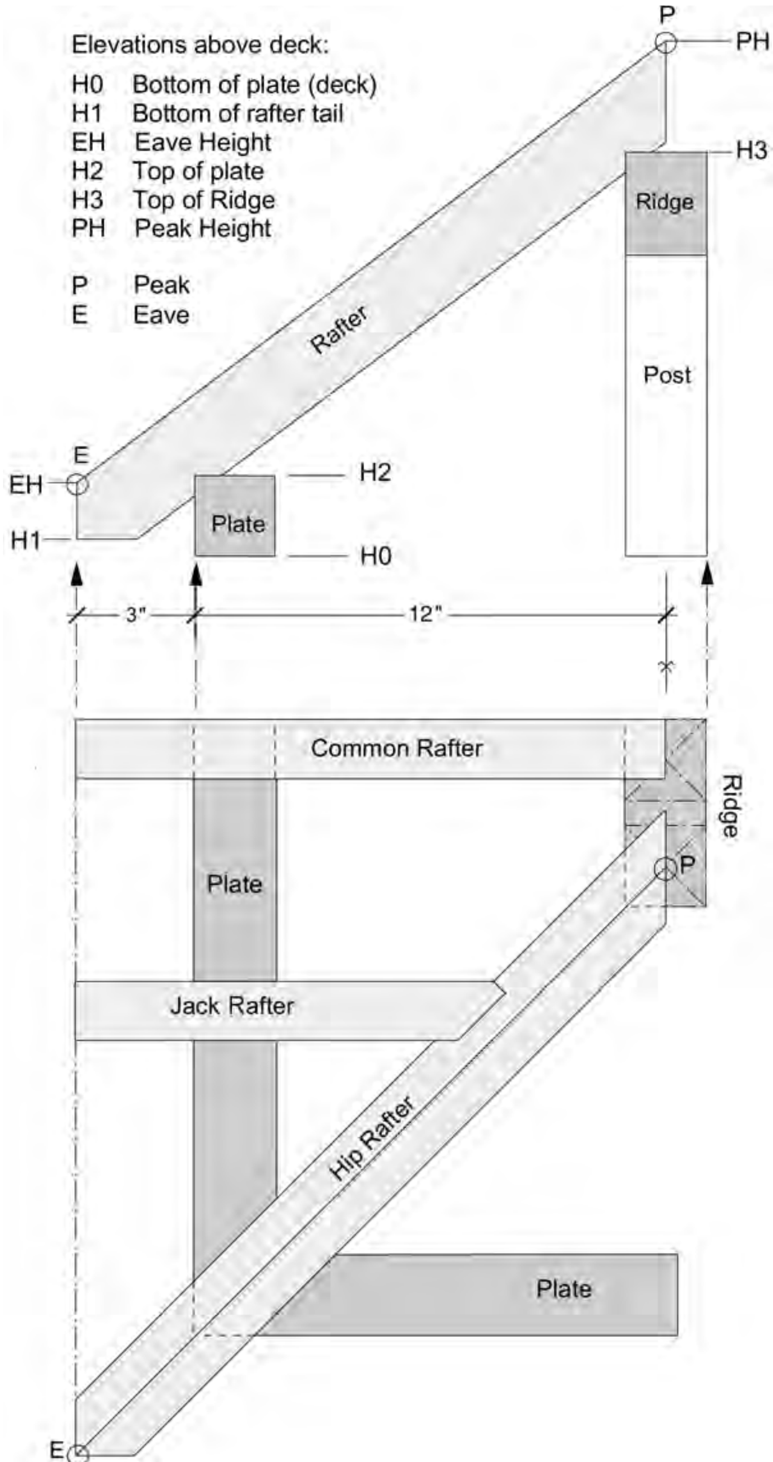


Fig. 10. Developing the elevation view of the common rafter from the plan view.

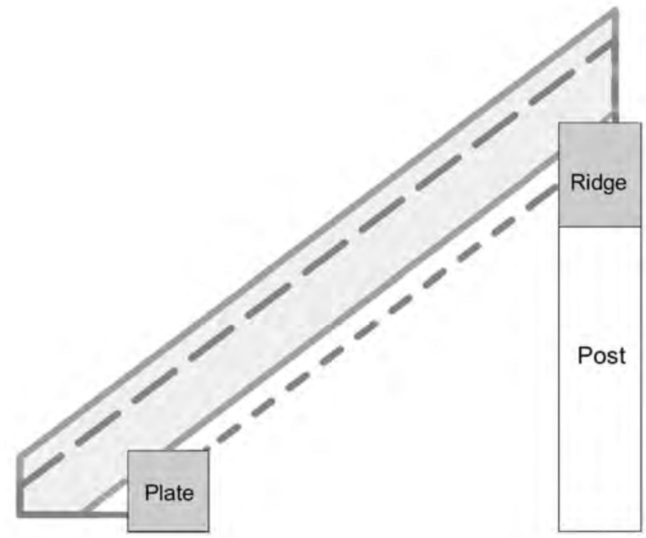


Fig. 11. Proportioning of birdsmouth for strength and bearing.

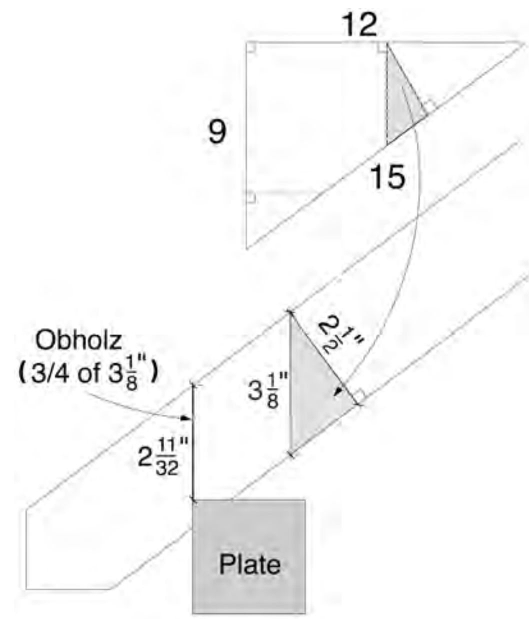


Fig. 12. Calculating the height above plate or ridge remaining after cutting a birdsmouth limited to one-quarter of rafter height. In German carpentry, this distance above the cut is called the obholz.

First draw in the heights that we know (Fig. 10). H0 represents the height of the deck (or bottom of the plate). H1 is the height of the level cut on the tail above H0, which we arbitrarily choose to be ⅜ in. H2 is the height of the plate above H0, which is given as 2 in. (the plate thickness). The other two heights that we need to find, the eave height and the ridge top height, which in turn will determine the final location of the rafter and the height of the roof peak, are dependent on one significant variable: the depth of the birdsmouth.

The deepest birdsmouth possible is desirable for bearing, but building codes usually limit the depth of the birdsmouth cutout to one-quarter the depth of the rafter. This depth is shown by the solid lines in Fig. 11. You might wish to make the underside of the rafter meet the inside edge of the plate to provide maximum bearing for the birdsmouth seat (shown by the broken lines), but this approach could unduly weaken the overhanging rafter tail or the rafter itself at its connection to the ridge.

Note that we are working with plumb heights in this drawing, and so use the plumb depth of the rafter at the birdsmouth rather than the depth perpendicular to the roof plane. The plumb measurement from the roof surface to the seat of the birdsmouth doesn't change from the common to the hip, but the normal-to-roof plane height would because of the different slopes of the two members.

To figure the plumb height above the birdsmouth, we will use one of our basic geometrical tools: similar triangles (Fig. 12). We know as a given that the slope of the roof forms the hypotenuse of a right triangle whose rise and run are, respectively, 9 units and 12 units. A line drawn inside a right triangle perpendicular to any side will result in a triangle with the same proportions as the original. Proportions can be stated as ratios; the proportional relationship of the 9 side to the 12 side is 9:12, the same proportion as 3:4, and it holds true for the new triangle as well as the original.

We can also figure the length of the hypotenuse. This can be calculated using the Pythagorean Theorem, which states that the sum of the squares of the two sides of a right triangle equals the square of the hypotenuse: $A^2 + B^2 = C^2$. Here, $9^2 + 12^2 = C^2$ or 225, of which the square root is 15.

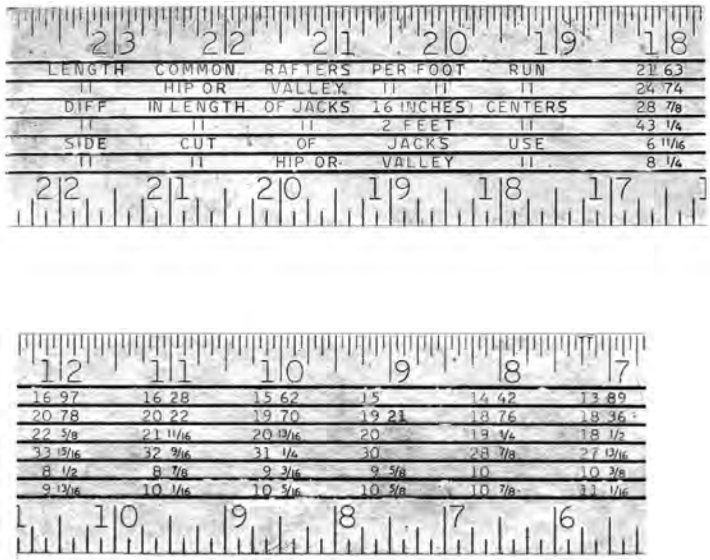


Fig. 13. Finding the length of the common rafter in the table on the rafter square according to the given rise.

The same result is also given on the first line of the table on a rafter square, "Length Common Rafters Per Foot Run" (Fig. 13). If we follow that row over until we are under the 9 (for the rise in 12), we see the number 15. Our triangle then has the proportions 9:12:15 (Fig. 12) or, simplified, 3:4:5.

If we want to know the plumb height of our rafter, we first draw a line perpendicular to the top edge, which describes our known dimension of 2½ in., and we see that the plumb height would represent the hypotenuse of our similar right triangle, the run of which is 2½ in (Fig. 12). The ratio of the hypotenuse to the run is 15:12 (or 5:4), and multiplying this ratio times 2½ in. will give us the plumb height of 3⅛ in. If we want to limit the depth of our birdsmouth to one quarter of this total plumb height, the birdsmouth should then be 25⁄32 in. deep. The height remaining above the birdsmouth would measure 2 11⁄32 in. In English we don't have a word for this part of the rafter—the wood left above the birdsmouth—but it's such an important piece of information that we should. The Germans have a word for it, *obholz*, and I propose that we adopt the term.

We now have this critical variable determined and can proceed with our drawing. Drawing a plumb line 2 11⁄32 up from the outside corner of the plate will locate a point on the top surface of the rafter (Fig.14a). From there, measure over 12 in. level (parallel to the fold line) and square up 9 in. (plumb) to that line to find a second point on the top of the rafter. Connect these lines to draw the top edge of the rafter, then draw a parallel line 2½ in. away to describe the bottom edge (Fig. 14b).

Complete the layout for the plumb cuts at the peak and the eave (*P* and *E*), and the level cut at the eave (H1). (Fig. 14c). The birdsmouths at the ridge and at the plate have the same criteria for depth and are identical (Fig. 14d). The upper birdsmouth sits on the ridge, so its depth determines the height of the ridge (H3); draw in the ridge depth of 2½ in. and you've determined the length of the posts from H0, thus completing the side elevation view of the common rafter we saw in Fig. 10 (facing page).

If we measured the length of the common rafter on this drawing (from P to E) we would find it to be 18¾ in. This length could also be calculated using the top line of the table on a rafter square. The rafter length, the hypotenuse of our triangle, is 15 in. per foot of run, as found under 9 on the square (Fig. 13); since we have 1.25 ft. of run, the length of the rafter would be 1.25 x 15 in. = 18.75 in.

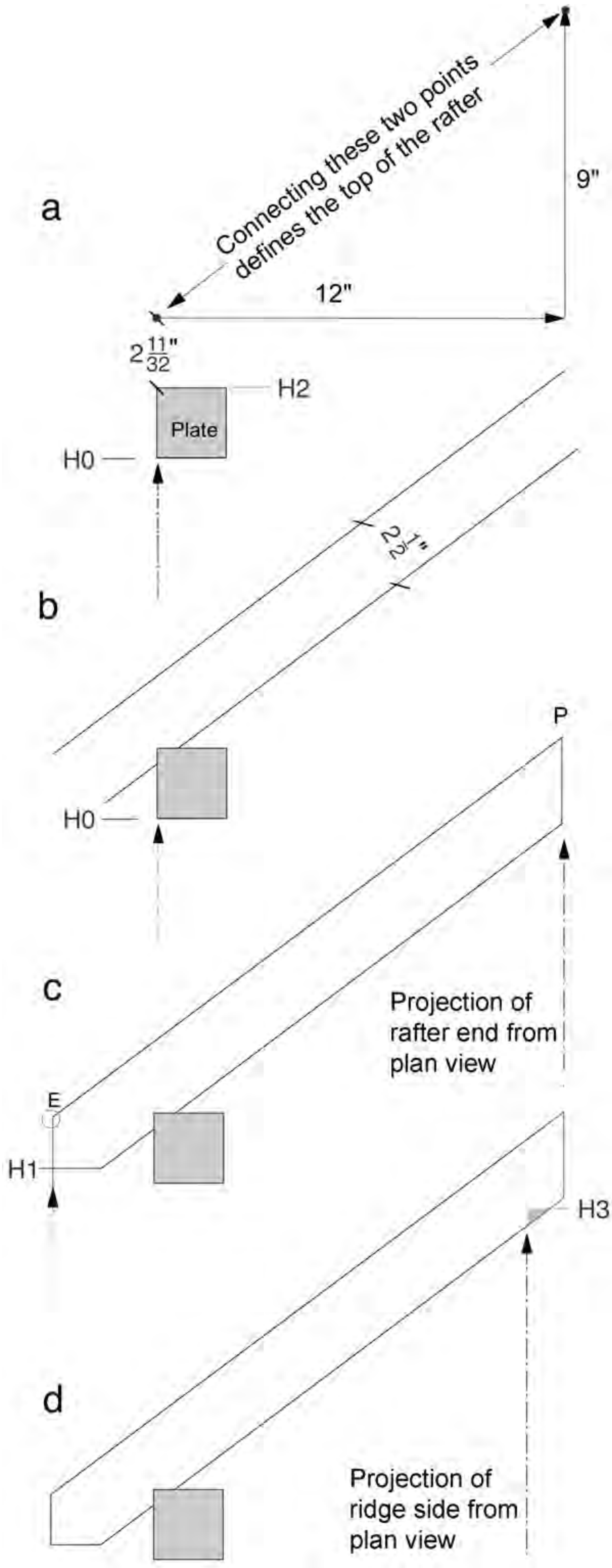


Fig. 14. Stages in the development of the side elevation of the common rafter. Completed view is seen in upper part of Fig. 10.

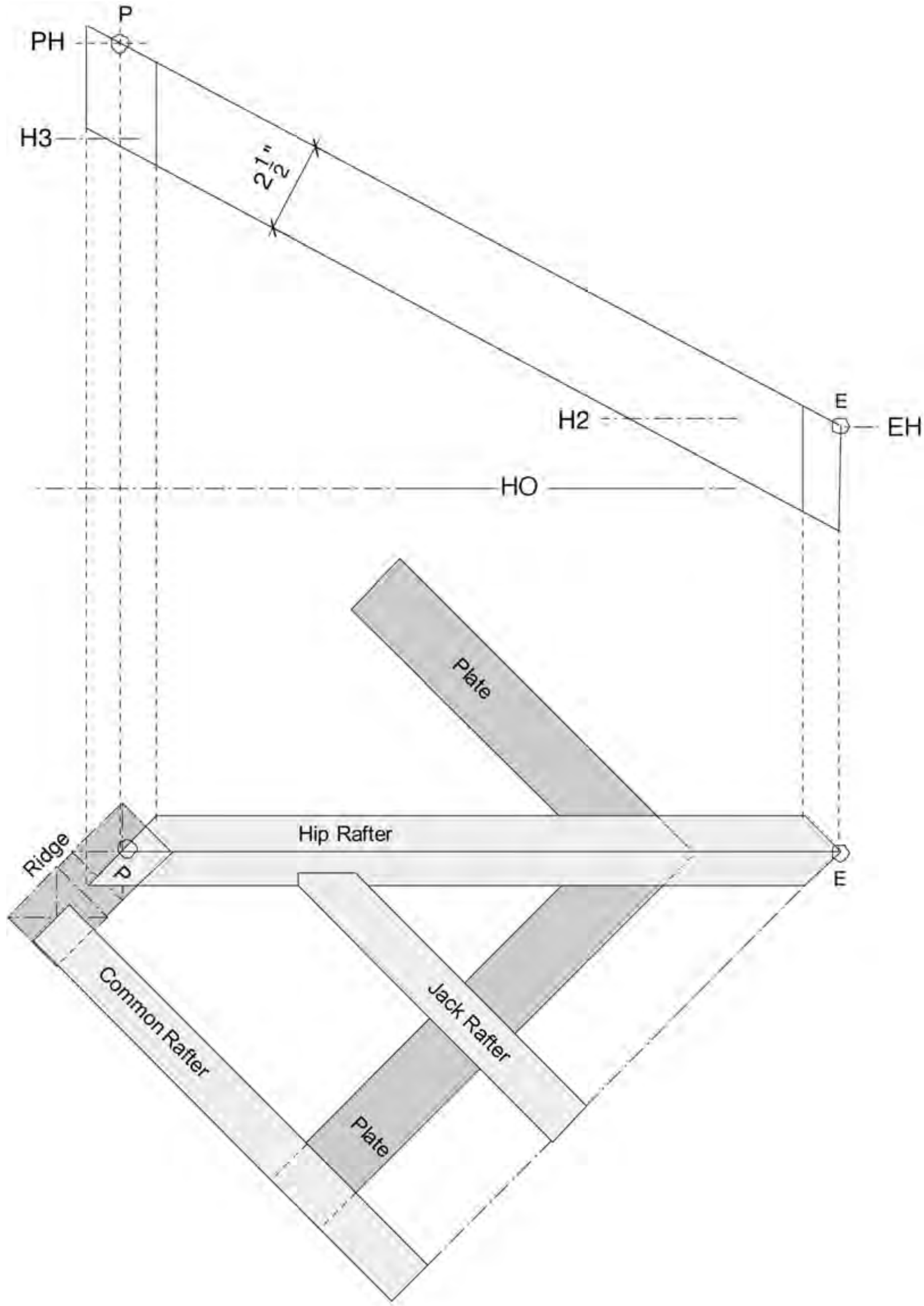


Fig. 15. Developing the side view of the hip. To generate the elevation, points are transferred from the plan view at right angles to the fold line and intersect the pitched lines previously determined by height stations at eave and peak and by the given depth of the hip.

The various heights we have now determined (H0, H1, H2, EH, H3, and PH in Fig. 10, page 18) are necessary to construct the elevation drawing, or true side view, of the hip. An examination of the model depicted in Fig. 8 will show that these heights do not change as we move from looking perpendicularly at the side of the common rafter to looking perpendicularly at the side of the hip. The floor level (H0), the fascia and soffit points on the rafter tails (H1 and EH), the plate height (H2), the ridge height (H3) and the peak height (PH) are the same and describe level lines on both the hip and the common. Since both our common elevation and our hip elevation are folded down from the same drawing (the plan view) and are perpendicular to it, the height dimensions are the same for both. Fig. 9 depicts this operation on the model.

To produce Fig. 15, project lines perpendicular to the fold line onto a new drawing from the critical points on the plan, remembering that projection lines must always run perpendicular to the fold line. Then, using a story pole or dividers, take the height dimensions H0, H1, H2, EH, H3 and PH from the common rafter elevation previously developed (Fig. 10), and transfer them to the hip elevation. Where these offsets intersect the projection lines locates the corresponding points on the new hip drawing.

P represents the peak of the rafter, and *E* the eave; if we connect these two points, we describe the top edge of the hip rafter at its centerline and reveal its slope and its length. This length is not the overall length, but rather the length between two *control points* from which we lay out the rest of the joinery. We can also find these points by calculation, using the pitch of the roof and the run of the piece in question. Control points fall on the centerlines of hips and valleys since any variation in width of the workpiece affects the surface location of the intersection point of another member coming in at an angle.

Plumb lines can be drawn down from points *P* and *E* to define hip or valley ends as well as bottom edges, since we have drawn the true depth of the hip. The length of the hip or valley per foot of common run can also be found on the second row of a rafter square table (Fig. 13); under the 9 we find 19.21. Since we have 1.25 ft. of common run, the hip length is 19.21 in. x 1.25 or 24 in. This agrees with the length shown on our drawing. Note that we use the common run, not the hip run, to figure hip length—a principle that we will use repeatedly to figure lengths and locations of working points for joinery. Remember: *Stay in plan as long as you can.*

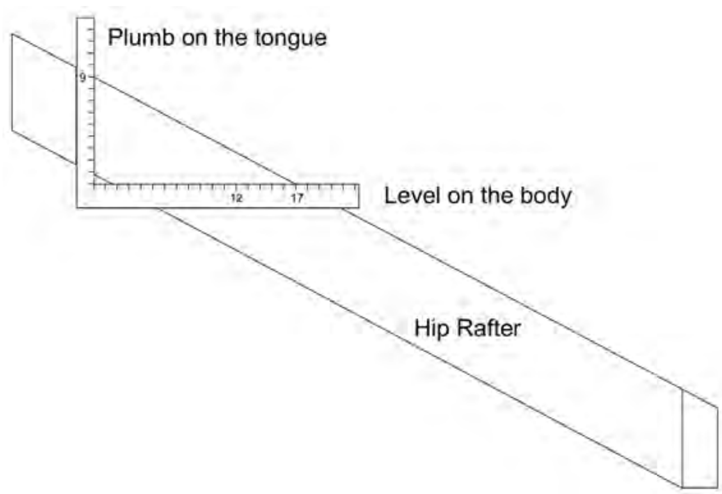


Fig. 16. Drawing plumb and level lines on the hip by holding the pitch on the rafter square.

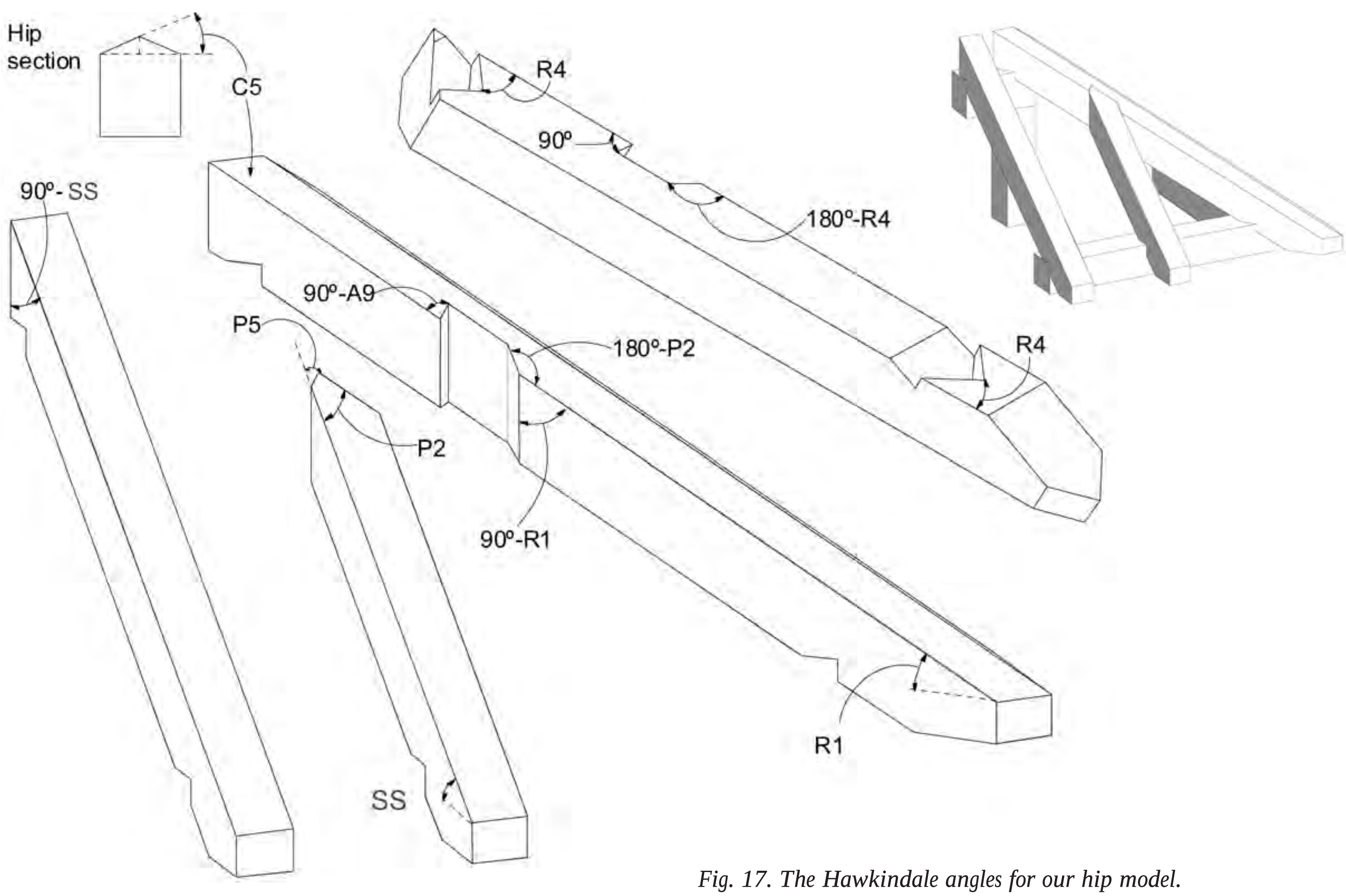


Fig. 17. The Hawkindale angles for our hip model.

ALTERNATIVE METHODS. In Fig. 15 we see the slope of the hip rafter, which can be measured and transferred. Let's now look at the alternative tools to drawing we can use to figure out this information.

To begin with, the framing square can be used to lay out the plumb and level cuts on any rafter at the peak and eave. For the common rafter, if we find the 9 in. graduation on the tongue (the narrow arm) and the 12 in. graduation on the body (the wider arm), and position them simultaneously at the edge of the rafter, the tongue will describe a plumb line and the body a level line, with the intervening length along the rafter edge describing the roof slope.

Now look at the plan view and see that the hip runs at 45 degrees to the common rafter, but has the same rise (9 in.). Hence the pitch of the hip rafter is 9 in. over its run. Now what is the run of the hip? In the plan view, it forms the hypotenuse of an equilateral right triangle whose other legs are both 12 in. long in our model. Using the Pythagorean Theorem again ($A^2 + B^2 = C^2$), we find the hip run is 122 + 122 = 288, the square root of which is 16.97056, or 1⁄32 under 17 in. With the square on the edge of the hip stock, hold 9 on the tongue and 16 31⁄32 (many carpenters call it 17) on the body (Fig. 16). The tongue and body of the square will describe the same plumb and level angles respectively that we found in our elevation drawing. Thus in a regular plan, regular pitch roof, the hip pitch is the rise of the common rafter over 16.97.

In addition to developed drawing and the framing square, we might also use a third tool, the *Hawkindale angles*. They were expanded from a smaller set of angles in a handbook developed for the construction of steel hoppers and buildings—the *Martindale Hip and Valley Roof Angles*, by Frank A. Martindale. The angles we now know as the Hawkindales were developed independently in New Hampshire in the 1980s by machinist and inventor Rees Acheson at Benson Woodworking (who named the angles) and by timber framer Ed Levin at Paradigm Builders. Once they became aware of each other's work, Acheson and Levin worked together to codify the set of angles and refine the trigonometric formulas, which define each angle, based in terms of common pitches and deck angles. By installing these formulas on a spreadsheet or a programmable calculator, one can enter the wall angle and the pitches of intersecting roofs and obtain the various angles needed for compound intersections. Ed Levin has developed such a spreadsheet, downloadable from the Guild website (tfguild.org/tool2.html). Ed and Rees's articles in TF 19 and TF 21 explain the use of the angles and give the trigonometric formulas to build your own spreadsheet, and they provide large-format illustrations of the appropriate joints.

Remember that the Hawkindales give us only angles; there is no information on dimensions or lengths. Once we have located the control points for the joinery along the length of the timber, we can then set a bevel to the relevant Hawkindale angle and proceed to draw the joint. However, it's imperative to know ahead of time what the joinery is supposed to look like. Fig. 17 shows the Hawkindale angles used in our model.

SS is the common rafter pitch.

R1 is the hip pitch.

P2 is the angle in the roof plane between hip and jack rafter; 90°-P2 (not shown) is the roof-plane angle between hip and ridge.

C5 is the backing angle on the hip.

R4 is the angle on the bottom surface of the hip at the plumb cuts parallel to ridge and eave.

P5 occurs on the top surface of the jack rafter where the long side is clipped square to house into the hip.

90°-A9 is the angle on the backing surface of the hip where the square housing for the long side of the jack rafter (see P5 above) is projected onto the roof surface.

FOR regular pitch, regular plan roofs, you need only the main half of the spreadsheet. The same is true for regular pitch, irregular plan roofs if the main and adjacent roofs cover regular polygons. When the plan is regular but the pitch is irregular, you need the main and adjacent values for their respective pitches. But for regular or irregular pitch roofs over parallelogram plans, you have two different wall angles W and WW (such that W+WW = 180°), each requiring its own spreadsheet.

Following are the basic setting angles for any compound roof:
SS is the main common rafter slope.
S is the adjacent common rafter slope.
W is the Wall Angle, the angle in plan between eaves abutting a hip or ridges abutting a valley.
DD, the main deck angle, is the angle in plan between hip and main eave or between valley and main ridge. D, the adjacent deck angle, is the angle in plan between hip and adjacent eave or between valley and adjacent ridge. The sum of the Deck Angles equals the Wall Angle: W = DD + D. So, in regular plan roofs, DD + D = 90°. And in regular plan, regular pitch roofs, DD = D = 45°.

—*ED LEVIN*

HAWKINDALE SPREADSHEET

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

Fig. 18. Spreadsheet of the Hawkindale angles for a regular pitch, regular plan compound roof at 9:12. The master sheet is set up to calculate Hawkindale angles based on Main and Adjacent Pitches (SS and S) and Wall Angle (W), whose respective cells are boxed. A set of trigonometric formulas underlies the calculations.

Fig. 18 shows what the Guild Hawkindale spreadsheet looks like with 9:12 pitch on both main and adjacent roofs. If the two rises were different (an irregular pitch roof), the numbers would all change, including the deck angles D and DD. Note that with both rises at 9, the deck angles for both roofs are 45 degrees, while the wall angle W remains fixed at 90 degrees.

Hawkindales for both main and adjacent roofs are given and in this case are the same. In all cases, R1, the pitch of the hip rafter, is shared by both roofs. Notice that rise and run are given for each angle. This tells you which two numbers on the framing square you would hold at the edge of the timber to draw that angle and its complement—useful data since few of us own protractors of sufficient accuracy.

Even absent the convenient spreadsheet, any angle can be expressed in terms of rise over 12 by obtaining its tangent from a scientific or builder's calculator or a table of trigonometric functions, and then multiplying by 12. And when framing any roof, particularly a compound roof, a useful tool is the *pitch board*, a light-colored board about 12 in. wide on which the angles needed for a particular roof can be drawn and recorded carefully using the framing square as just described, then labeled for repeated pick-up by adjustable bevels, often handier for the actual layout.

Having been given 9 for the rise of both our intersecting roofs, the Hawkindale spreadsheet (it assumes a run of 12) has spit out

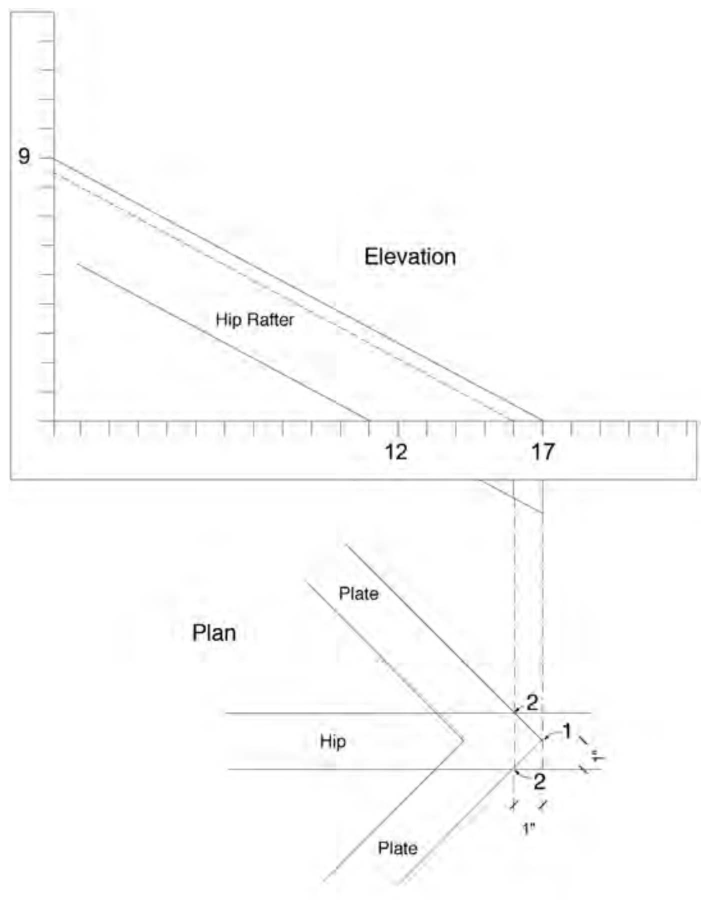


Fig. 19. Finding the backing angle using the rafter square to establish the arris line of the backing on the side of the hip.

the angles SS and S, the main and adjacent common rafter slopes measured from the horizontal, as 36.8699 degrees. We could set a bevel square to this angle and its complement to lay out all of the level and plumb cuts on the side of a common or jack rafter. Because the rises of both parts of the roof are the same and we have a regular plan, the spreadsheet tells us that the deck angles DD and D are both 45 degrees. These would change if the roof pitches were different, and the *m* or main angles would no longer be identical to corresponding *a* or adjacent angles. Likewise, angles D and DD would diverge.

The spreadsheet cell for angle R1 also tells us the slope of the hip and, lo! and behold, it says 27.9384 degrees, the same angle that shows up on our drawing. This angle and its complement can be used to lay out any level and plumb line on the side of the valley. You will see throughout the exercises that the Hawkindales provide a very quick and useful tool once you know how to use them, and we will continue to identify them as they show up.

THE BACKING ANGLE. Let's now return to our drawing of the hip elevation as developed in Fig. 15 on page 20. The next things we will want to find are our *backing angles*, the bevels we will have to rip on the top of the hip for the roof panels to rest on—that is, the angles between the bottom of the hip and the two roof-plane surfaces on the top of the hip. (In our case, the two angles will be the same; they would be different if the roof pitch were irregular.) In Fig. 20, we know that points *E* and *P* lie at the intersection of the roof planes on the centerline of the hip. Find line EE and the line flanking it, which we have brought up to define the plumb tail cut (90 degrees in plan) on the hip. Since the eave height (EH) is level as it goes around the corner of the roof, where these plumb lines intersect EH will define on its *side* where the hip ends at the tail. Thus if we strike a line from this point parallel to the centerline in the elevation, it will reveal the arris between the hip side and its backing. Similarly, if we extend a level line PH out from *P* to where it intersects the plumb line brought up from the long point of the plan-view peak, it will show the same drop, since line PH, like EH, is level. Looking again at the isometric model in Fig. 8 (page 7) may help you to see this.

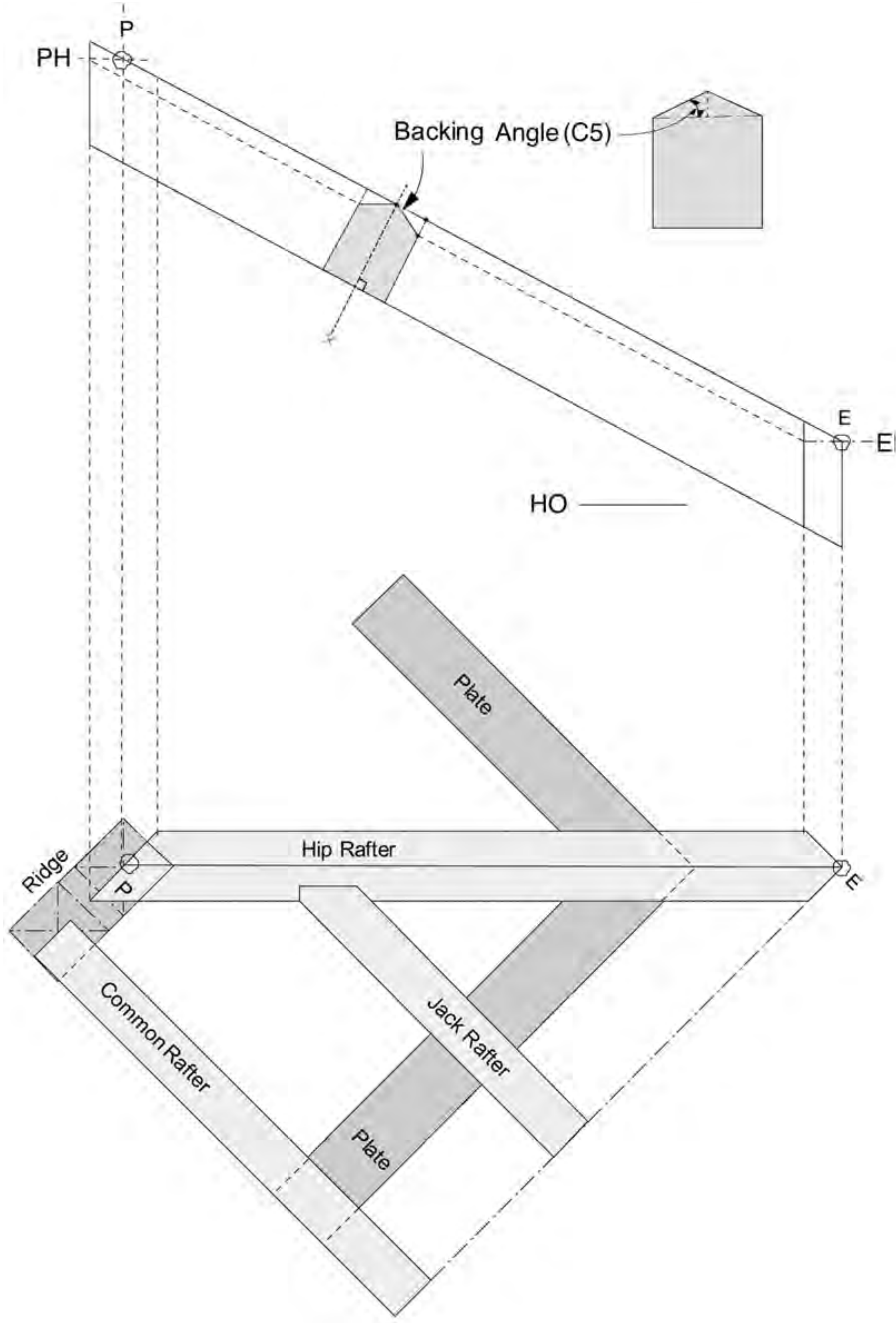


Fig. 20. Backing angles (identical in this case of a regular pitch, regular plan roof) are cut on the top surface of the hip to conform it to the intersecting roof surfaces. The necessary angle can be obtained by developing a view of the backing arris line on the side of the hip and erecting a sectional view of the hip on the same surface, as shown above. The intersection of the arris line with the side and center lines of the sectional view, together with the intersection of the hip top line with the centerline of the section, mark the three points defining the backing angle.

You can also find the backing angle for a regular plan roof on the framing square by setting it up with the pitch of the hip on the edge of the rafter (9 in. on the tongue and 17 in. on the body), and then measuring back from the edge along the body of the square half the known thickness of the hip. This point will show the drop as well. You can see in Fig. 19 (facing page) that this method produces the same results as the first. Point 1 is directly over the outside corner of the plates and points 2 are directly over the points at which the sides of the hip rafter intersect the outside edges of the two wall plates. As before, these points are all level with EH.

We can glance at our spreadsheet here to see that Hawkindale C5, the backing angle, is listed as 25.1041 degrees. This is the angle of the roof surface to the bottom of the hip rafter while looking along the axis of the hip.

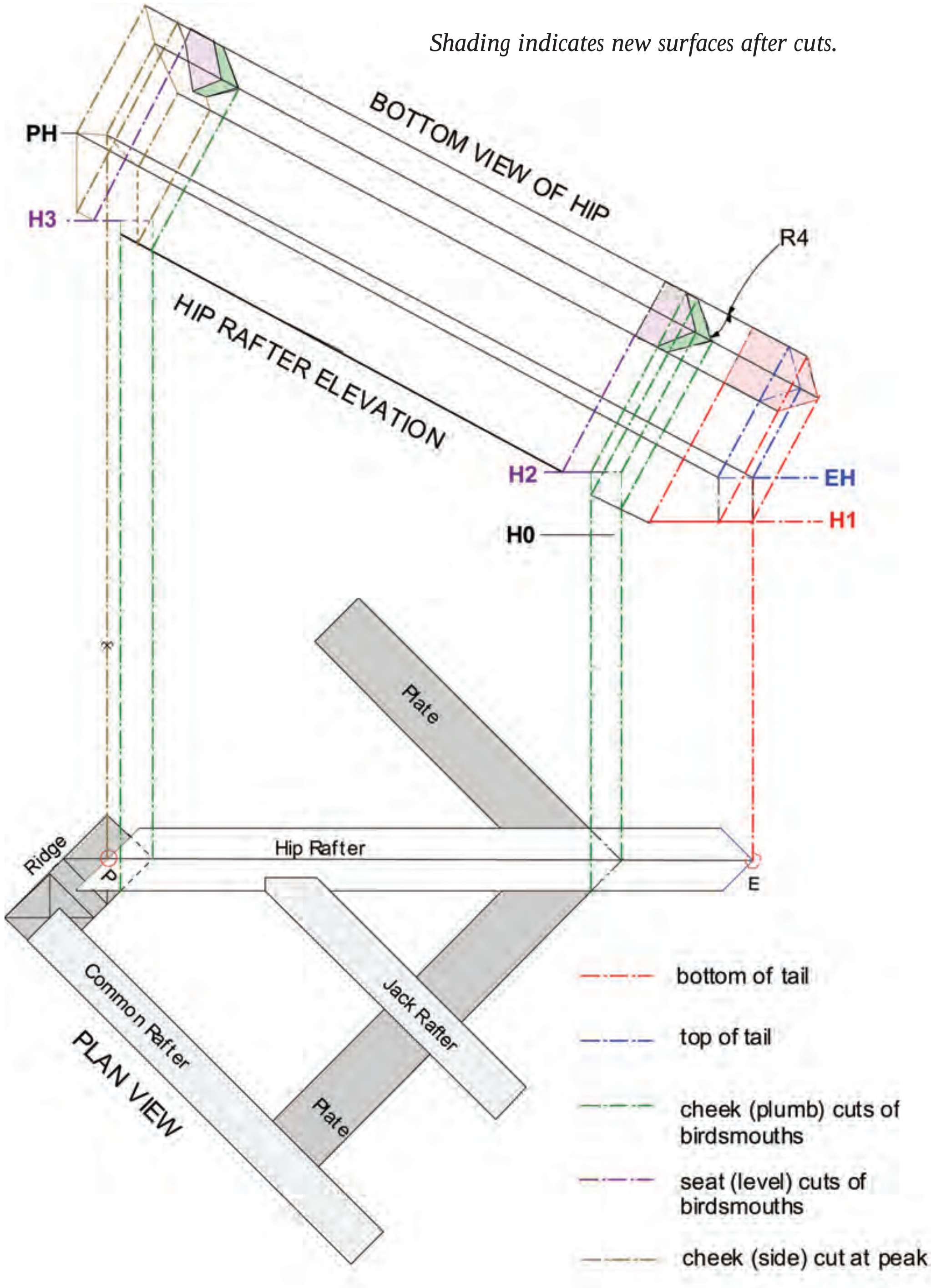


Fig. 21. Finishing the hip drawing. The hip is folded to an elevation view while inclined at its pitch in the roof and folded again to show a perpendicular view of the bottom surface.

WE have drawn lines up from the plan to define the plumb cuts at the ends of the hip, now viewed in elevation or "folded" 90 degrees in Fig. 21. Next we can draw the plumb cuts for the birdsmouths where the hip sits on the plate and the ridge. The birdsmouths wrap around corners, which are 90 degrees in plan but some other angle when projected onto the inclined bottom surface of the hip. Bring plumb lines up to reveal where the birdsmouths exit the side of the hip and where the corners on the centerline appear as hidden lines (since they are inside the hip as viewed from the side). Intersect these plumb lines with the level lines at, respectively, H2 and H3 to complete the side layouts for the lower and upper birdsmouths. The birdsmouths are identical in size and shape, although the ridge end cut will clip the one at the peak. If we know the location of the birdsmouths by calculation, we can also lay out the sides of the birdsmouths by using the framing square held at 9 in. and 17 in. for the plumb and level cuts, respectively, and recognizing that, like the common rafter's, the *obholz* here is also $2\frac{11}{32}$ in. down from the backing line (the roof surface) to the level cut, measured along a plumb line on the side of the hip. Or, using the Hawkindales, we can set a bevel square using R1 and its complement, again observing the *obholz*.

To complete the tail cut layout, draw a level line at H1 on the elevation to intersect the bottom and top edges of the hip and the plumb lines at the tail. We now have all the lines we need on the sides of the hip, and they can be transferred by bringing the timber over to the drawing or by using story poles and bevel squares to take the measurements over to the timber. However, we're still missing some important information before we begin cutting: what are the angles on the bottom and the top?

Continuing with Fig. 21, let's construct one more drawing to represent the bottom surface, so we can see what the birdsmouths will look like in that view. If we want to get a true view of the bottom, we need to be looking perpendicularly at it. Once more, we figuratively "fold" the hip 90 degrees onto its side to view the bottom and project all the necessary points up at right angles to this fold line. The hip is a true 2 in. wide in this bottom view. Taking a fresh perspective, Fig. 22 shows the model hip in its built and its folded positions.

When we bring up the lines that formed 90-degree corners in plan—the birdsmouths and the tail cut—we see when we connect their terminal points on the bottom of the hip that they form different angles on the bottom surface of the hip. This angle is R4 in the Hawkindales, and our table says it's 41.4591 degrees. It's also given on the rafter square table as Side Cut Hip or Valley (even though it's laid out on the bottom). Under the 9 in this row we find $10\frac{5}{8}$ (Fig. 13, page 9). If you're lucky enough to still have the little book of instructions that came with your square (or if you have a new one), it will explain that with the square laid on the bottom surface of the hip, if you hold $10\frac{5}{8}$ in. on one arm and 12 in. on the other, you draw a line along the 12 in. arm to get the desired angle. Note that our Hawkindale chart also shows the rise and run for R4 as 10.6014 and 12. This is the angle formed where the hip meets a plumb surface such as the side of the ridge or a plate (Fig. 23). In other words, it's the deck angle DD brought up onto the unbacked surface of the hip (this would be the bottom or the top before the backing angle was ripped). R4 only appears on hips and valleys and, after the backing cut is made, it becomes another Hawkindale on the roof surface: P2. So D, R4 and P2 are closely related.

Most framing carpenters know that for a regular pitch, regular plan roof, if you follow the 9:17 plumb cuts at the peak and foot of the hip with your circular saw set at 45 degrees, it will cut the 41.4591-degree line exactly. That's because the saw is traveling plumb and, when viewed directly from above, this cut angle is DD, the deck angle, or 45 degrees. In general, whenever you follow a plumb line to cut R4, set the saw bevel to the deck angle DD.

We can complete the bottom view of the hip rafter by bringing up all of the points shown in Fig. 21. Although we don't need all of this information to lay out and cut the hip, it's important to see what the final product is supposed to look like. For example, the middle lines in the birdsmouth layout describe surfaces inside the hip and so serve no cutting purpose. But having them on your drawing helps you visualize the finished piece. In general, if you can see the finished piece in your mind, then you are less likely to cut off a portion you might need later for layout. It's best with the developed drawing method to lay out on the timber as needed lines appear on the drawing, and to go back and forth between various drawings and the timber as things develop. Get all of the lines on the stick before you start cutting. Draw solid lines only for cuts; use dashed lines or tick marks for other layout lines. Cut your most difficult joints first, such as the birdsmouths. The backing cuts are usually made last on both hips and valleys, since it's easier to lay out the joinery and steady the timber on the horses when the top is still square to the sides.

We have introduced the use of the framing square, but be aware that the tables on the square are only useful for regular roofs in whole-number pitches. The Hawkindale angles are very handy and can be used on irregular roofs, but require experience and good visualization skills. The developed drawing technique requires space and time for drawing, but it's a technique that has been passed down for centuries and very good at teaching the novice how to visualize even irregular roof members.

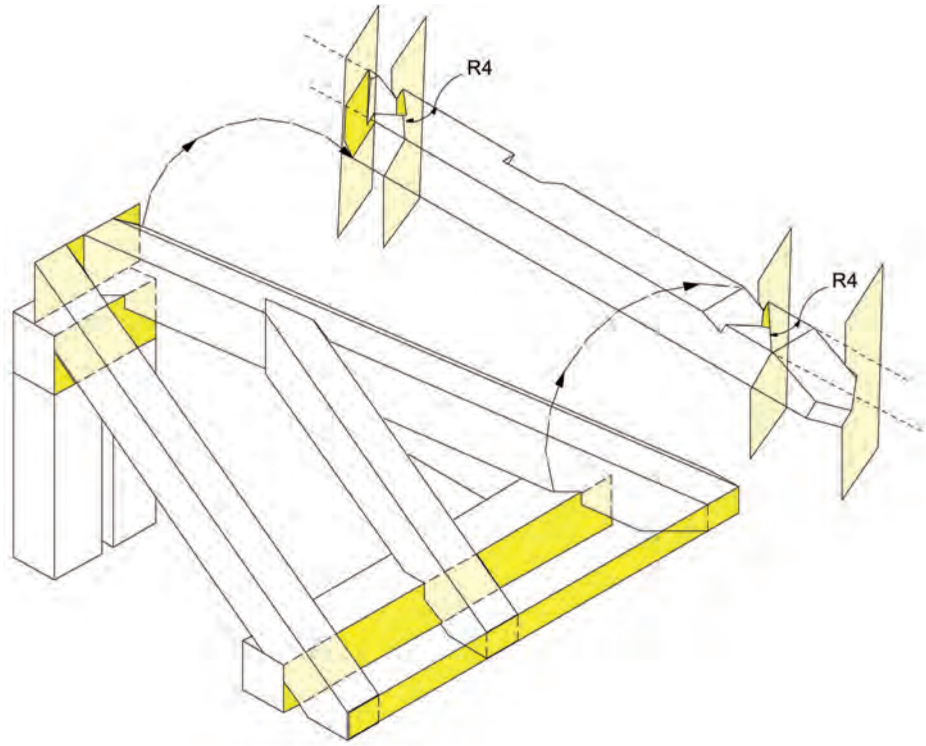


Fig. 23. Hawkindale R4 is formed wherever a plumb plane intersects the unbacked surface (such as the bottom) of a hip or valley. The hip is shown on its back. The broken extension lines represent the timber bottom surface before the end is cut. R4 laid out on this surface gives the cuts for peak, tail and birdsmouths. A plumb line laid out on the side of the hip (pitched at 9:17 for our model) gives the other determinant of the cuts.

We could now continue our drawing and bring up lines to show the intersection of the jack on the hip. I suggest that the serious student try this as well as the rest of the drawings described in this article, using the given dimensions, and perhaps even begin to cut out the model. In the next article we will move on to new tools and methods to make the developed drawing system even simpler. We will use some basic, elegant math to find the lengths of pieces and locations of joinery for the jack rafter, and then develop a *kernel* of the roof with the essential angles to draw just the joinery full scale.

—WILL BEEMER

Thanks to Ed Levin, Curtis Milton, John Miller and the late, great Mark Brandt for help in "developing" this series.

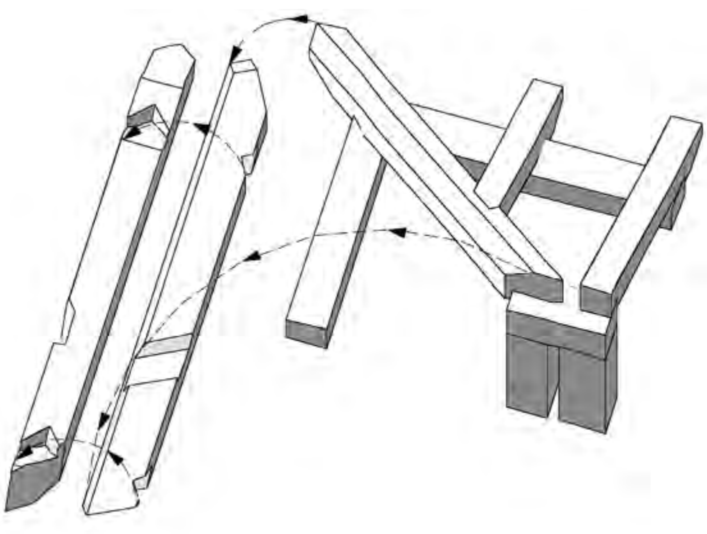


Fig. 22. Perspective view of model hip folded to give developed drawing views shown in Fig. 21.

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There are many books on the use of the steel square. One of my favorites is out of print but available used:
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Buy anything you can lay your hands on in used book shops by Fred T. Hodgson or H. H. Siegele, especially:
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For more on the Hawkindale angles:
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Both of these articles are reprinted in *Timber Frame Joinery & Design Workbook* (pp. 81-95), Timber Framers Guild, 1996, ISBN 0-9706643-1-1.
To download the original publication by Frank L. Martindale that shows the Martindale hip and valley angles for steel construction, go to www.custcad.com, click the Hip/Valley link and download the file martindale.pdf.

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Rudy Christian

Orthodox Church of the Beheading of St. John the Baptist, ca. 1785, in the village of Szczyty-Dzieciolowo, Poland. A deputation of Guild members visited Poland recently to assist in plans for the reconstruction of the 17th-century synagogue at Zabludow. Complex-form wood-framed structures were common in Poland to both church and synagogue architecture of the the 17th and 18th centuries, and surviving churches (there are no surviving synagogues) will serve as sources of appropriate construction detail. *See page 2.*