This Article was originally published in *SPIRE 2007: The Seventy-Seventh Annual Report of the Friends of Salisbury Cathedral*, pp 19-27. Editorial corrections have been made, and Figure 5 has been added, to the article as published.

Within the Spire, Looking Down

by A. Richard Jones

Salisbury Cathedral's spire encloses a unique medieval scaffold which was (or was not) used in erecting the spire. A model of this scaffold inside a cutaway spire has been displayed in the nave for many years, and of course anyone who has taken the roof tour has seen the scaffold close-up. This article is about just two of the many issues which have arisen in an ongoing academic discussion of whether the scaffold was or was not erected at the same time as the spire, providing the working platform the builders used whilst constructing the spire.

For both issues discussed in this article, the argument *against* the use of the scaffold goes something like this: if the existing internal scaffold had been used in constructing the spire, then, because the presence of that scaffold would prevent a crucial operation, it would have prevented the construction, therefore the scaffold *could not* have been used. Logicians call this method of argument *reductio ad absurdum* – disproving a premise by showing it leads to an absurd contradiction.

The argument *for* the use of the scaffold asserts that the previous argument is flawed, for either or both of two reasons. Either the operation is unnecessary, and/or the presence of the scaffold does not, in fact, prevent the operation. Thus construction *could* proceed in the presence of the scaffold, and the argument against the scaffold would be invalid.

The two operations in question are the hoisting of materials and the use of a plumb-line, each said to be prevented by the scaffold’s presence. It is easy to understand that both require a clear path up and down through the scaffolding. In the case of a plumb-line, the clear path could be quite slender, but the hoisting of materials would require a wider clear path. It is also easy to understand that materials must be hoisted, but the necessity for a plumb-line – at least a long one – is far less clear.

The Clear Path

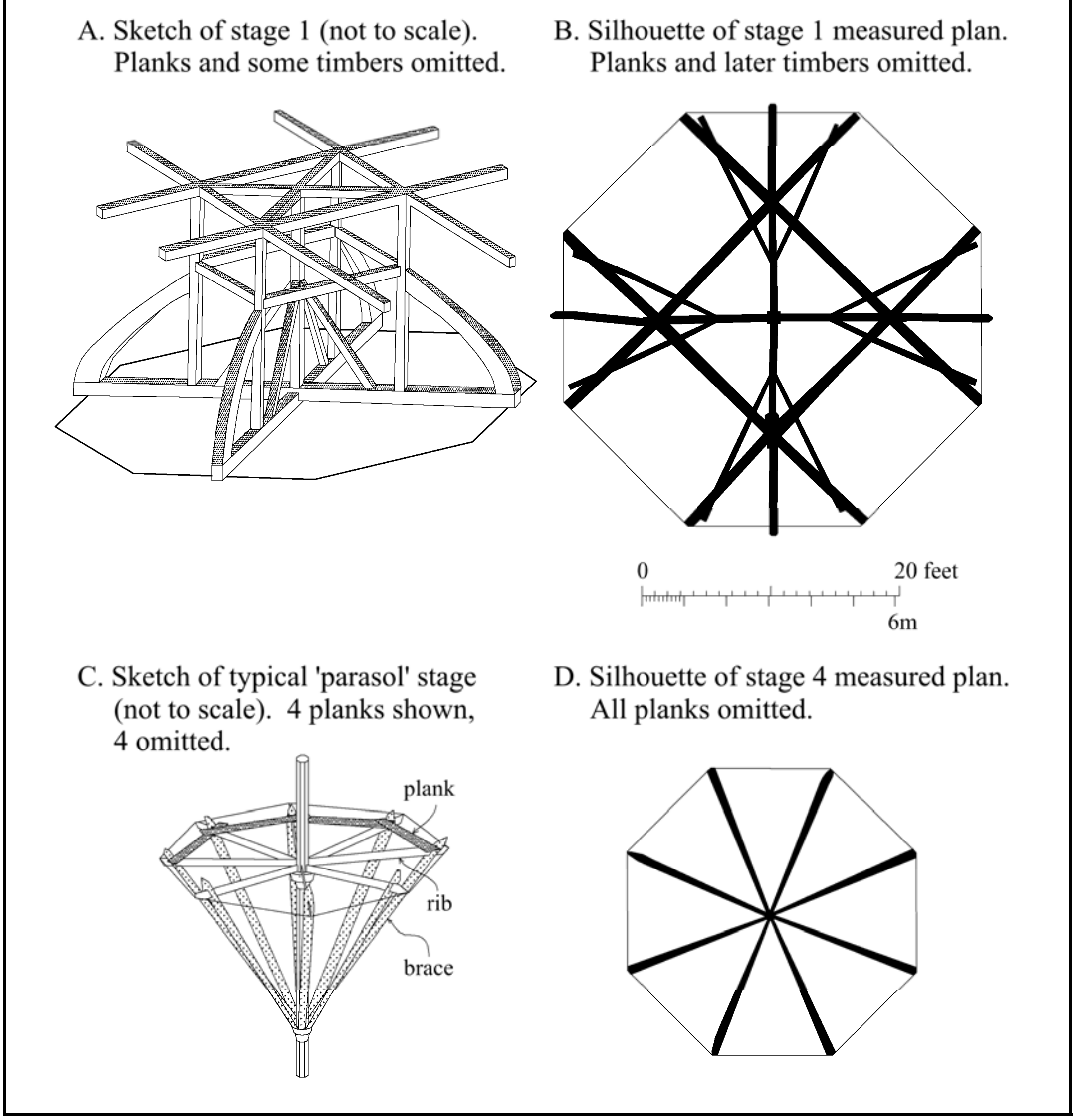
Many photos of the scaffold from below seem to show an impenetrable maze of timbers. Fig.1 is just such a photo taken in July 2006 by Ann Montgomery Jones.

Figure 1. The Scaffold From Below

Actually, such photos are quite misleading, because they show the scaffold at an angle from the vertical, and, in fact, that angle varies throughout the image. The solution to this problem is the so-called '**plan view**' drawing, or just '**plan**,' which can be used to identify clear vertical paths because throughout the plan, each part of the structure is depicted from directly above – an impossibility with a photo. Fortunately, plan views of the scaffold at eight different heights, called **stages**, were drawn during a renovation of the spire in 1993 by Jill Atherton, who retains the copyright. These drawings show the contents of each stage from its top down to the top of the next lower stage at the first eight of the nine stage altitudes: 16, 33, 46, 66, 83, 99, 117, 129, and 142 feet above the modern floor at the base of the scaffold. They were used by permission in preparing Figures 2B, 2D, 3A, 3B, 3C, and 4 for this article, making the task of identifying clear paths fairly simple. The spire continues up to 168 feet, reaching a height of 404 feet above ground level, but the scaffold, except for its center post, is complete at stage nine. The lowest three stages of the scaffold are reminiscent of a timber framed building, as opposed to the remaining six stages, which appear to share their inspiration with the parasol. In all of Atherton's 1993 stage drawings, an octagon of planks appears close to the wall of the spire. For purposes of identifying vertical paths, these planks, and other platforms such as presently exist for walking between ladders, are not considered obstacles, in that they can be moved aside in case of necessity. Planks, platforms, and timbers known to be later additions are all omitted from the remaining discussion.

Fig.2A is a crude sketch, intended only to exhibit the general scheme of the first stage of the scaffold; the timbers as

Figure 2. Salisbury Spire Scaffold Stages



drawn are too stout and some of the horizontal bracing is omitted. Although the structure looks complex from the viewpoint of the figure, many of the timbers are directly below other timbers, so are obscured in a plan view of the first stage from above. Even though the obscured timbers contribute to the visual complexity of Fig.2A, they do not interfere with vertical paths to any greater extent than do the timbers directly above them. In like manner, much of the apparent complexity vanishes as plans of the higher stages of the scaffold are examined.

Fig.2B, a silhouette of the timbers after Atherton's 1993 drawings, accurately shows stage one from above, including the horizontal bracing. All the clear area in Fig.2B is available for vertical paths. It is evident that the timbers of stage one subdivide the area but leave a very substantial amount of open space free for vertical communication. In fact, the lifting wheel in stage one is a greater obstacle than any of the individual scaffold timbers, but is not shown as an obstacle because it probably dates from 1762 rather than being original. Fig.2B shows so many clear paths that it would not matter if some were obstructed by the original lifting machinery.

As each higher stage is considered, it is simple to determine its additional effect on the open space by simply superimposing the silhouette of its plan on the silhouette(s) of the lower stage(s), lined up vertically and oriented the same way, of course.

Fig.2C depicts a typical upper 'parasol' stage. Although it is not evident in Fig.2C, the ribs of the parasol stages were designed so it would be simple to remove a rib (and its supporting brace directly below) to free an entire quadrant for a clear path. Documents and drawings indicate that this was done by securing the rib and the brace to the central post by fitting the rib or brace with ironwork which engaged iron pins protruding upward from collars around the post (the collars *are* sketched in Fig.2C). The ribs and arms could thus be disengaged from the pins when necessary. To connect their outer ends, slots were worked near the outer end of each rib and brace. The rib was passed through the slot in its brace; then, outboard of the brace, a wedge was inserted into the slot in the rib, presumably to ensure that the assembly would not bear upon the newly placed stone of the spire. Another wedge in the arm's slot inboard of the brace could then tighten up the connection. These removable wedges completed the scheme for easy disassembly. Neither the rib nor its brace was fastened to the wall of the spire in any way, but they did rely on the spire's corner for lateral restraint. Note that the stability of the central post would probably be compromised if two adjacent ribs were removed.

Another potential obstruction is the temporary scaffolding that would have been needed between stages. The stages of the scaffold vary from 13 to 20 feet in height; it is patently obvious that nobody has arms long enough to build the wall of the spire up to the next stage, working from the stage below with no additional scaffolding. The use of temporary scaffolding is thus inferred, secured to the then current stage of the surviving scaffold, to raise the level of working along with the stone. Once the level of the stone reached the level of the next stage, that stage could be added atop the growing scaffold, becoming the base for further temporary scaffolding, and the temporary scaffolding below could be removed. It also seems a reasonable inference that any temporary scaffolding would be placed so the clear paths in use would remain clear. Thus, the temporary scaffolding is not deemed a source of obstruction. Even if this inference is wrong, *i.e.*, even if the temporary scaffolding blocked all the clear paths, temporary scaffolding would be required only above the scaffold's last complete stage; materials could be hoisted to the last complete stage of the scaffold and raised up the temporary scaffolding to the working level. Even in this case, the temporary scaffolding would not obstruct the clear paths beneath it, and therefore is not taken into account in delineating clear paths.

Figure 3. Salisbury Spire Scaffold Stacked Silhouettes and Clear Paths

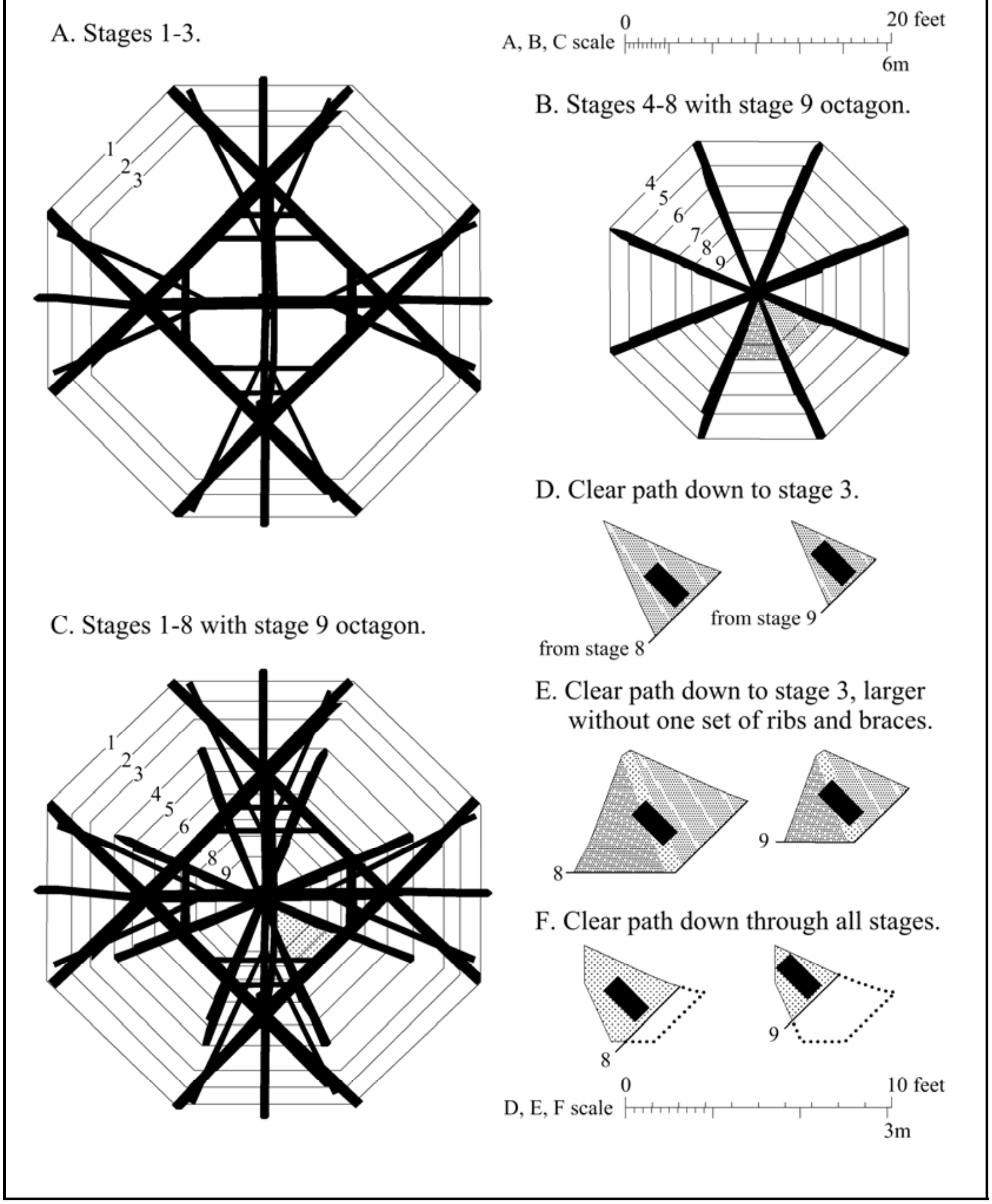


Fig.3A stacks the stage 1-3 plan silhouettes to exhibit the clear paths down from stage 3. Parasol stages 4-8 and the stage 9 octagon are stacked in Fig.3B. Finally, the clear paths down through the whole scaffold are shown in Fig.3C, the superposition of all eight stage plan silhouettes and the stage 9 octagon. Although the plan of stage 9 is absent, the 1993 section drawing indicates it would not enlarge the stacked silhouette. In interpreting this diagram for any given stage, the octagon for the inner wall of the stone spire at that stage must be noted; the clear paths down from that stage are those that that octagon encloses.

Fig.3D and Fig.3E are enlargements of the parasol stage clear paths shaded in Fig.3B; the clear paths down from stages 8 and 9 are drawn as delimited by their respective octagons. In Fig.3D all ribs are present, restricting the clear path to an octant; Fig.3E removes one set of ribs and braces, as their design allows, expanding the clear paths to a full quadrant. The shaded clear path of Fig.3C, down through the entire scaffold, is enlarged in Fig.3F, showing its extent at stages 8 and 9. It is evident that the slender clear path required for a plumb-line is available at many places in the plan, and at all levels.[1] The adequacy of these free paths for lifting materials will be examined next.

Lifting Materials

In the scenario in which the scaffold is built along with the spire and used as the work platform, all the necessary materials for erecting the spire must either be carried up the ladders from stage to stage of the scaffold, or lifted vertically through the clear paths. Lifting is preferred to carrying because it is more efficient in that the weight of the person carrying the material is not also raised, and because lifting machinery allows less effort (although for a longer duration) than carrying.

The feasibility of lifting depends on what is to be lifted compared with the size of the clear paths. The bill of materials – what is to be lifted – for the spire comprises numerous stones, mortar (wet) to set them in, iron cramps to ensure the stability of the stones, lead (molten) to set the iron cramps into the stones, timbers to build the scaffold, and other miscellaneous items. In addition to these permanently-placed items, assorted tools, fixtures, hardware, timbers, and materials for temporary scaffolding between the stages must also be raised.

Stones for the spire would have been measured and cut to their final shape at ground level before being lifted up the spire for installation (as opposed to their being shaped from crude blocks up on a scaffold at some higher level). Although no incontrovertible proof of this statement exists, it is widely felt that it would be unthinkable to do otherwise, because it is by far the simplest and most efficient way to work. Thus, the stones to be lifted would be at their final size rather than in the form of larger, cruder blocks. Three such stones, "removed from the top decorative band of the spire in 1986," according to the sign, are on display near the northeast corner of the cloister.

Figure 5. Spire Stone in the cloister

[1] Further details of the clear path may be seen at http://sarumseminar.org/2007-Spire

These are typical of stones anywhere in the spire, as the thickness of the spire wall is the same scant 9” (22cm) everywhere above stage one. One of the 1993 measured drawings is an **elevation**, *i.e.*, a sideways view, of a **section**, *i.e.*, a cutaway view, of the spire with the south half cut away. This beautifully drawn sectioned elevation shows many of the individual stones in three sides of the spire. One of the largest stones drawn is about 20” (50cm) high, 24” (60cm) wide, and (by inference) 9” (22cm) thick. Using the metric dimensions and a density of two grams/cc, the weight of this stone would be 132Kg or 291 pounds. The stones not shown in the 1993 drawings are probably not substantially bigger, as this weight pushes the limit that two masons can handle.

Fig.3D, Fig.3E, and Fig.3F show how a 24x20x9-inch stone would fit through the clear paths. The stone is oriented on-end, *i.e.*, so that its 20x9-inch face is horizontal, depicted as a black rectangle. This orientation fits easily through all the clear paths. Even the flat orientation (with the 24x20 face horizontal) would fit all the stage 8 paths and also the largest stage 9 path, the quadrant of Fig.3E. It is readily apparent that a stone of this size, or even bigger, could fit through the clear path at any level of the scaffold, and that a stone of this weight would not be a candidate for hand carrying up ladders. The net of this discussion is that it would have been quite possible to lift the stones which comprise the spire via the vertical clear paths through the scaffold.

Considering the very large clear paths of stages 1-3, one could speculate that the builders lifted materials to stage 3, where they stayed until they were lifted once more to a higher stage. This would allow larger blocks to be lifted, as anything that fit the quadrant of the parasol stages shown in Fig.3E could be brought up by lifting it through a large free path to stage 3, then moving it across stage 3 to lie under the clear quadrant in preparation for the second lift. As Fig.3 shows, this scheme would become more desirable at each successive stage. It would be analogous to the ubiquitous assumption that materials lifted from the Cathedral floor were unloaded at stage 1 before they were lifted further up the scaffold.

Mortar would also have been prepared on the ground, close to the supplies of water, slaked lime, and sand from which it was made, again an assumption due to the simplicity and ease of working so achieved. The slaked lime was likely stored under water in a lime pit, also practicable only at ground level. Some of the medieval images collected in Günther Binding’s book, *Medieval Building Techniques*, show mortar being carried into a door at the base of a tower a-building; other images show mortar being carried up a ladder; still others show mortar being lifted in a bucket. Whatever method was used at Salisbury, it would have been compatible with the scaffold within the spire. If carrying in a hod was the method, clear paths would not be necessary; if lifting was used, the buckets presumably would not exceed the size of the largest stones, mortar being similar in weight to stone, so the clear paths that accommodated the stones would also clear the mortar buckets.

Iron cramps – bars around a foot long with legs projecting an inch or two to form a very shallow ‘U’ – are used to secure each stone of the spire horizontally to the two adjoining stones, and also for a few vertical ties. Three of these cramps were examined in the Cathedral shops in March, 1995: two about 10” (25cm) long weighed 2586g (5,7 pounds) and 1590g (3,5 pounds), and a 12" (30cm) long cramp weighed 2416g (5,3 pounds). As varying amounts of the lead in which they were set had adhered to them, the iron cramps themselves weighed less. A cramp is still attached to the right side of the stone in Fig.5.[2] As these cramps are far smaller than the stones, raising them presents no difficulty. A similar argument applies to moderately sized metal **tools**.

The **lead** which was poured around the cramps to set them in place is much more compact for a given weight than the stone, thus should not bulk too large to fit through the clear paths. The answer to the interesting question of whether the lead was raised in its molten state, or was melted near the working level, is completely unknown: no actual evidence exists, and there are good arguments for and against either way of doing it.

Some of the remaining items to raise would need some care, but are not actually a problem. These would be long items, such as **timbers** and scaffolding **poles**, long **tools**, and the very long **ironwork** at the top of the spire. Because their size perpendicular to their long dimension is relatively small, all of these could be raised with their long dimension vertical, and then manoeuvered into proper position once they reached their destination.

As the spire rose, the means of lifting would perforce have risen with it. Nothing at all remains to tell how the **lifting machinery** was itself lifted. A simple scheme, purely speculative, would have been to install a pulley or two on a temporary support above the current working level, with a rope rising from the spire base through the pulley(s) and down again to the base, where a windlass on one side of the rope could haul up materials secured to the other. This would work best if the rope were spliced into an endless loop. To raise this lifting machinery, the pulley(s) would be relocated to a higher temporary support, the length of the rope being increased to match; the windlass at the base would not need to be moved.

In summary, all the materials that would require lifting could be lifted with the scaffold in place. Thus the *reductio ad absurdum* argument against the scaffold is not valid in the case of lifting.

Plumb-lines

The 1993 section elevation mentioned previously shows a plumb-line about four feet to the right of the central post, extending from above stage four to the modern floor. The clear paths identified previously actually allow a plumb-line from stage nine to the base of the scaffold, if one is wanted. On this ground alone, the *reductio ad absurdum* argument against the scaffold is not valid in the case of plumb-lines. If such a long plumb-line is not necessary at all, it would be a second reason the *reductio ad absurdum* argument against the scaffold is invalid.

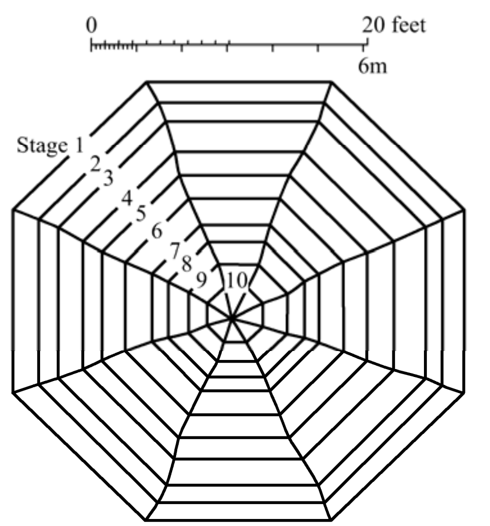
Ideally a box labeled, "*Contains one Acme plumb-line/ comprising a plumb bob and cord/ with instructions for its use in* [Medieval] *Latin,* [Norman] *French, and* [Middle] *English/ Made in England 1325*," would have been discovered with its contents intact.

[2] Neither this sentence and footnote nor Fig.5 appeared in the *SPIRE* article.

Absent any such direct evidence of plumb-line practice, the only actual evidence (known to me) of how medieval builders used plumb-lines comes from the 42 medieval images depicting plumb-lines which appear in Günther Binding's book, *Medieval Building Techniques*, mentioned earlier. Most of these plumb-lines are only a foot or two long, and the longest barely extends below the feet of the person holding it, so must be six feet long at most. Any claim that a much longer plumb-line was required to build the spire must be seen for what it is: an assertion for which no evidence exists, even though the assertion may be informed by experience and conviction. It is true, of course, that absence of evidence is not evidence of absence. However, that is the exact argument a fence salesman would use in flogging a fence to protect your garden against elephants; just because you have seen no elephants, it doesn't prove none are out there. So let us say this: plumb-lines were certainly used in medieval times, but because no evidence of using long plumb-lines has come down to us, it appears that long plumb-lines were either rare or not used at all.

There *is* evidence as illustrated in Fig.4, after Jill Atherton's 1993 drawing 4/20, which superimposes the interior octagons of the nine stages, connecting the vertexes of these octagons with lines representing the interior corners of the spire. What emerges from consideration of this drawing is that the spire has several

Figure 4. Salisbury Spire Octagons



vertical **inflection**s, *i.e.*, changes in vertical direction. Taking these at face value, it is not unalloyed speculation to conclude that the spire was built in four campaigns, the work of each campaign oriented to true vertical, resulting in inflections due to settlement of the prior work. (Note that the inflections in the Tower of Pisa were caused by just such vertical building on previous work that had settled.) It is attractive to believe, though wholly unproven, that each campaign was the work of a year's building season, meaning that the spire was built in just four years.

Twists in the spire would perhaps be more germane to the question of whether a long plumb-line was used. Though inflections may be caused by settlement, it is difficult to imagine any sort of settlement that would twist a structure without twisting its supports as well, probably presaging a catastrophe. It makes much better sense to ascribe any twists to inaccuracies in controlling the construction. Now if a long plumb-line were used, even if not centrally placed, it should have been possible to locate the corners of the ascending octagonal courses of stone so that they would fall on a straight line when projected downwards – in other words, no twist. If twist *did* occur it would imply that long vertical plumb-lines either were not used, or were not used successfully. Unfortunately, in 1993 the ongoing renovation of the spire made some of the measurements that would have allowed drawing twists either impractical or unsafe. Atherton therefore characterises drawing 4/20 as only "a diagram giving a general 'impression' of the spire's shape."[3]

Vertical control without long plumb-lines is not necessarily impossible. After all, if each course of a wall is set vertically above the preceding course, the wall should be vertical. Building this way resembles measuring a long distance with a short ruler: errors can cumulate, but may also cancel out, and much depends on the 'good eye' of the mason. In the case of a sloping wall, it gets a bit harder. Perhaps some kind of template was used to mediate between the sloped masonry and the vertical plumb-line: templates for mouldings were certainly part of the medieval practice of masonry. Or perhaps it was sufficient to cut each stone to the exact angle of the spire, to fit each completed octagonal course of stones on the ground before it was lifted for installation, and to position the stones at the time of laying using water levels, taut horizontal strings, and the good eye of the master mason.

Whatever the case may have been, it certainly is not correct to say that the use of long plumb-lines has been definitively demonstrated. Rather, it remains a somewhat remote possibility. But the claim that, "the spire could not have been built without the use of a long plumb-line," is definitely not proven. This lack of proof, by itself, would invalidate the *reductio ad absurdum* argument against the scaffold, whether or not a clear path for a long plumb-line existed.

Conclusion

This article has demonstrated that there are adequate clear paths from top to bottom of the scaffold both for long plumb-lines (if they were used) and for hoisting, leading to the conclusion that, as far as these two issues are concerned, the scaffold very well could have been used in the spire's construction. The discussion of whether the scaffold was used in erecting the spire should now concentrate on real issues, such as whether the date of the scaffold has actually been established.

Dick Jones is an American member of the Friends who holds degrees in Chemistry and in Electrical Engineering, but worked as a software developer before retiring. In the mid 1990's he became involved in things medieval by taking a class focusing on Salisbury Cathedral, taught by Robert Scott at Stanford University in California. Since that time, Dick has written papers on the building accounts of Westminster Abbey and on several aspects of the spire at Salisbury

[3] Personal communication, March 2007.