Kingpost Truss Engineering, An Addendum

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

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

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

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

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

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

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

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

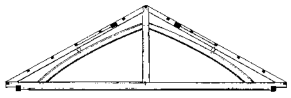
Under the roller bearing scenario, tie tension rises to 30,400 lbs., kingpost tension to 27,900 lbs. Main brace compression climbs to 36,300 lbs., while principal rafter foot load falls to a paltry 980 lbs. Strut compression grows to 8900 and 5500 lbs. in and out. The kingpost foot joint carries 13,300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

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

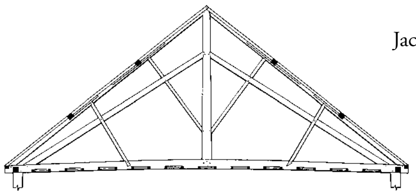
The Castleton (Vt.) Federated Church (1833) moves us firmly into the classical kingpost idiom, with a truss spanning an ambitious 60 ft., 7 in. Nesting inside the major triangle are two minor trusses built around princeposts which, fractal-like, echo the parent truss. The central struts rising from the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

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

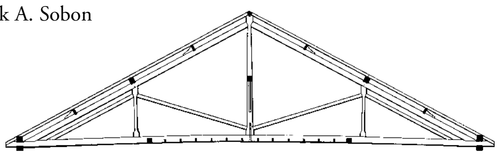
Jack A. Sobon



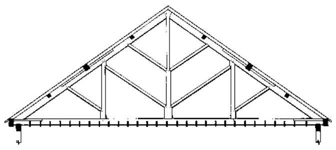
Lynnfield, 1714, 32 ft. 4 in.



Strafford, 1799, 50 ft. 1 in.



Castleton, 1833, 60 ft. 7 in.

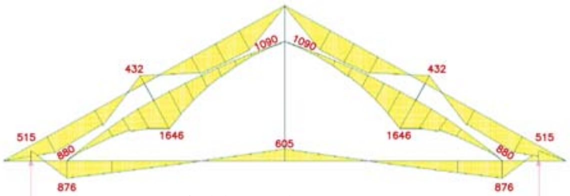


Huntington, 1870, 42 ft.

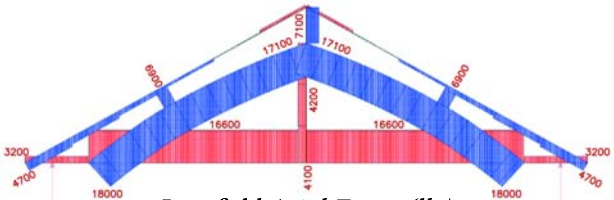
Trying the partial or total foot thrust release (as at Strafford, above) is no help. Deflections increase to over 2 in. and then over 4 in., and bending stresses inflate, first slightly, then off the scale. So Castleton's load-carrying capacity doesn't seem to measure up to expectations engendered by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

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

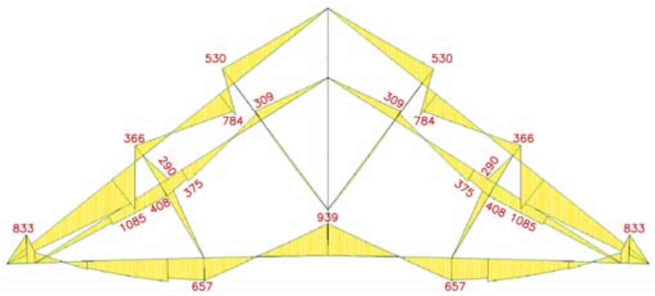
—Ed Levin



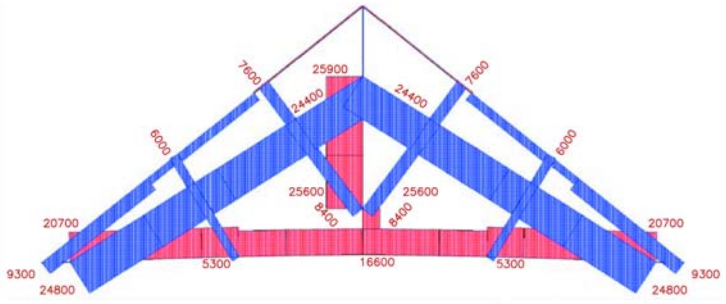
Lynnfield Bending Stress (psi)



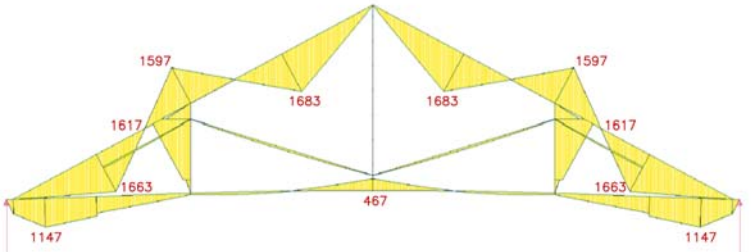
Lynnfield Axial Forces (lbs)



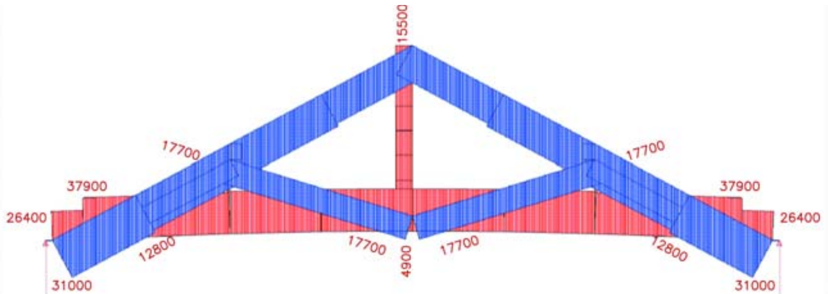
Strafford Bending Stress (psi)



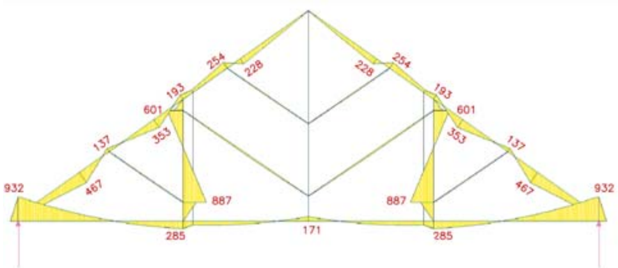
Strafford Axial Forces (lbs)



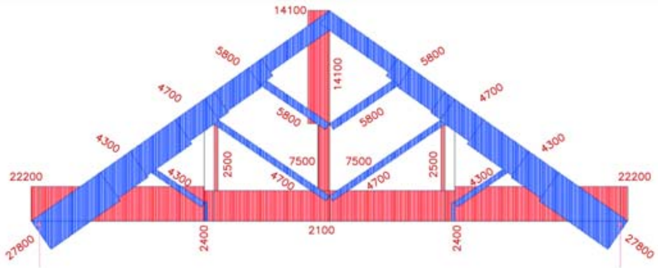
Castleton Bending Stress (psi)



Castleton Axial Forces (lbs)



Union Bending Stress (psi)



Union Axial Forces (lbs)