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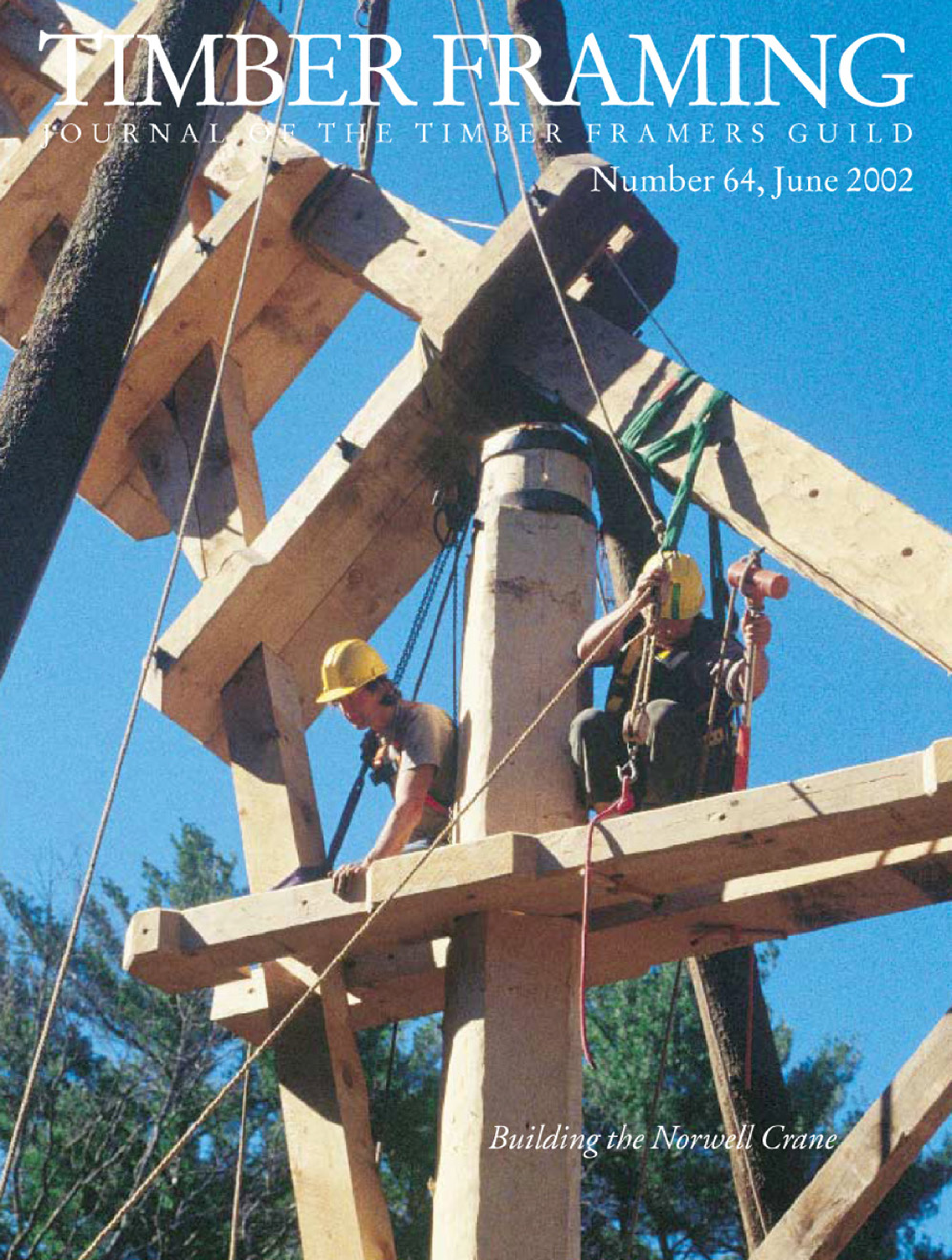


Building the Norwell Crane

Building the Norwell Crane

WHEN the lure came in from the Guild's Joel McCarty, that genial fisher of souls, the e-mail message read: "Lesser Crane of Norwell desperately seeking solution. . . . Who will tell us how large the arm should be in red oak? In Eastern white pine?" The proposed "Lesser Crane" would be a reproduction of an 18th-century French wood-framed portable builder's crane, perhaps 50 ft. tall. The rendezvous would take place at Handshouse, sculptors Rick and Laura Brown's riverside studio in Norwell, Massachusetts, with volunteer timber framers leading art and architecture students from Massachusetts College of Art and Wentworth Institute. Here was another opportunity to leave affectionate families and congenial day jobs to spend a week camping in the cold, working into the night at arcane tasks for no pay. But where else could one have such great times in such good company? I took the hook.

The life of architect and civil engineer Jean-Rodolphe Perronet spanned most of the 18th century, and his *oeuvre* featured stone arch bridges still spanning the rivers of France two and a half centuries later. Perronet documented his work in *Description des projets et de la construction des ponts de Neuilly, de Mantes, d'Orléans, etc.; du projet du canal de Bourgogne, pour la communication des deux mers par Dijon; et de celui de la conduite des eaux de l'Yvette et de Bièvre à Paris.*

Originally published in 1783, the work is in two bound volumes: one of 634 pages of text and the other an atlas with 75 engraved plates measuring as large as 2 ft. by 3 ft. These breathtaking drawings show not only the finished bridges but also works in progress, plus the tools, staging, falsework and machinery used in their construction. The author was both illustrator and designer of many of the latter devices. The portable builder's crane that we were to reproduce was used to lift stone for the Pont d'Orléans, built across the Loire in the 1750s. Bearing a distinct resemblance to its avian namesake, the crane's rotating superstructure pivoted on a fixed base and boasted a 27-ft. central mast carrying a 50-ft. boom, with the entire apparatus standing over 50 ft. tall, reputedly capable of lifting and placing a long ton anywhere along a 40-ft.-dia. circle.

CONSTRUCTION. We took many of our dimensions from Perronet's bill of materials (see page 20), ignoring the 1 percent difference between our inches and feet and, respectively, Perronet's *pouces* (thumbs) and *pieds* (feet).

Base. The massive 16x16x27 central mast is stepped into the cavity formed by four 10x10 sills lapped into a double-cross, and stabilized at midpost by eight paired 6x6 struts that spring from the ends of the cross. These struts rise at 60 degrees, converging on center both in elevation and plan as they climb, thus requiring compound joinery at the connections. The strut feet tenons are pinned into mortises in the sills. Otherwise the base is kept together by gravity.

Superstructure. Principal elements of the superstructure are the long 11x11 boom footed on the main beam, itself a 30x8x22 built up of two 15x8s bolted together, clasping boom, mast and great wheel hangers. A secondary 28x6x14 upper beam (double 14x6) clasps the inner wheel hanger, mast and lower strut. Other secondary members include the 8x8 hangers for the great wheel and the lower and upper struts supporting the boom.

Tertiary members complete the assembly. On the wheel side, diagonal braces to the main beam stabilize the wheel assembly and, along the upper boom, four 28x6 (double 14x6) clasps bind together booms and struts. The entire superstructure pivots on the tip of the mast, bearing laterally and vertically on the turned-down mast where it passes through the main beam just above the base strut connections.

As is typical of ancient lifting engines, the boom on the Perronet crane does not rise or fall, so its point of lift remains a fixed distance from the main pivot (all the points making up the 40-ft. circle). Since crane technology remained essentially unchanged from the late Middle Ages through the Enlightenment, we can infer that this characteristic was not a significant limitation.

Post windmills, similar to our crane in scale and form, feature a tail pole, an extended lever used to turn the entire mill so that its sails face into the wind (see TF44). But there is no evidence of any such lever in the Perronet drawing, implying that the crane must have been both sufficiently well balanced and easily enough rotated on its bearings so that the entire boom assembly could be turned by simply pushing on the wheel (the only reachable portion of the superstructure) or pulling on a tag line.

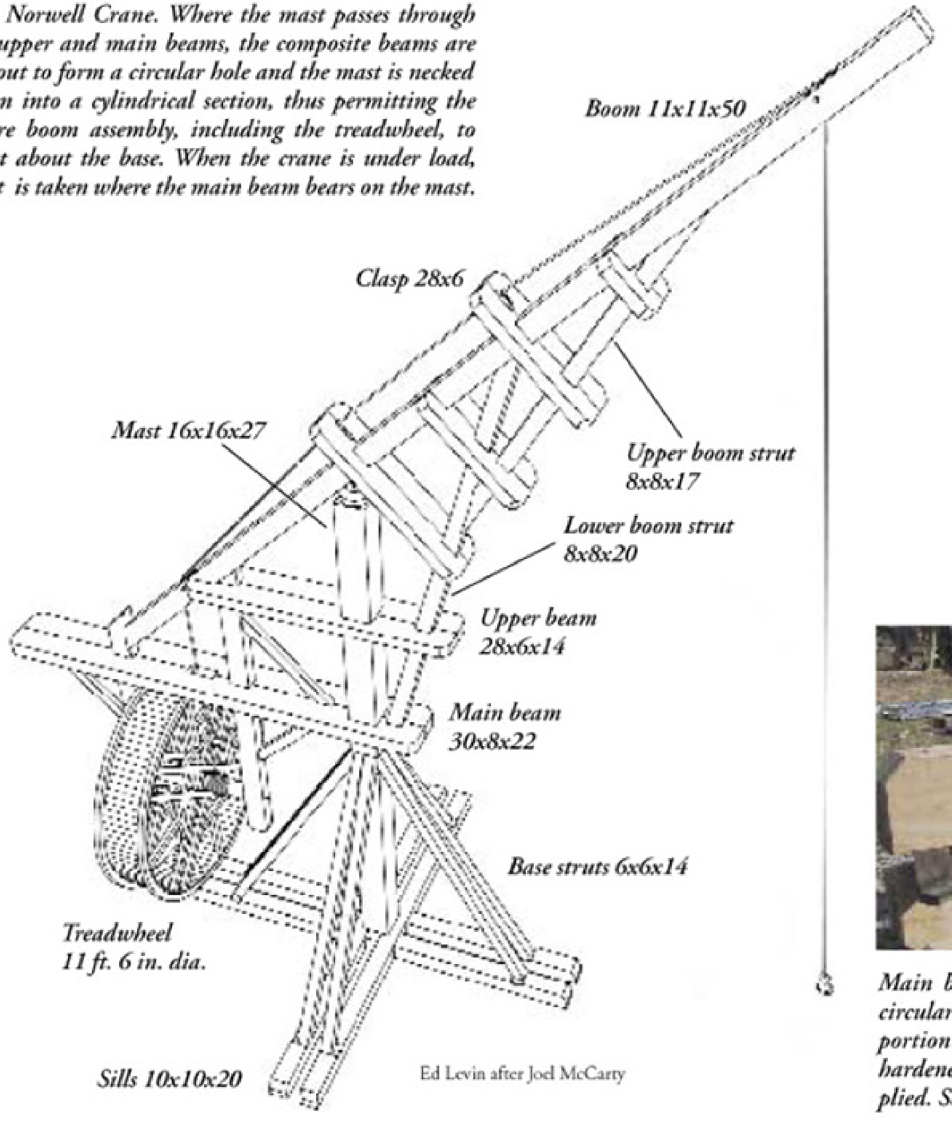
Hardware. The plans and elevations (see page 19) in the Perronet atlas indicate the iron hardware used in the crane, and the bill of materials in the text lists the pieces by weight. The two-part beams and clasps are clearly bolted together and, judging from the pictures, the bolts are unthreaded, with a head on one end and a slot through the rod at the other through which a thin wedge is driven to tighten the bolt. Such draw-wedged bolts are quickly detachable, a convenience for a knock-down portable device. In the bill of materials, nutted bolts are listed for the wheel, which presumably did not get knocked down for transport. The drawing shows the main beam halves bolted together through its joints with boom, hangers and boom struts; the upper beam is bolted through the boom, but adjacent to the strut crossing. (The pivot joints at the mast are, of course, unbolted.) An iron strap reinforces the connection of the inner wheel hanger to the boom.

The drawing does not show bolt locations for the clasps. We concluded that these may have been bolted through the boom crossings, but that no bolts pass through struts so that they can shift axially relative to the clasps (more about this below). The drawing does show iron bearings at the two principal pivot joints, where the mast passes through the main beam and where it terminates at the boom. For the mast tip, our ironcasters produced a 3-in.-dia. gudgeon pin, broached into the wood (itself double-hooped to prevent splitting). This pin engages a bearing welded to a plate fastened to the underside of the boom. Our lower bearing was speculative. Two plates were forged in halves, so that they could be installed around the mast journal and into the half-circles of the two-part main beam. The upper elements, with downward projecting cylindrical rims, were screwed into the underside of the main beam. The lower elements were flanged and fastened to diametrically opposed flat surfaces on the mast. The assembly, which enjoys lubrication, provides bearing against side thrust as well as down pressure.

Wheel. The final element of the crane, the great wheel that serves as the windlass to raise and lower the load, is really two wheels hung on the same axle, joined together by sheathing nailed to the inside surfaces of the rims and used as a runway. To actuate the windlass, the operator or operators climb into the wheel between the spokes and walk around inside, treadmill fashion.

The ratio between the 11-ft. inside diameter of the wheel and the 9-in. outside diameter of the wheel arbor gives a mechanical advantage of 14.7:1. Without indulging in hamster heroics—running as high as possible up the wheel to increase leverage—it should be easy for a wheel-walker to exert leverage equal to half of one's weight. Neglecting friction, a 150-lb. person should be able to lift over half a ton, and two walkers would be able easily to lift the rated long ton of 2200 lbs.

The Norwell Crane. Where the mast passes through the upper and main beams, the composite beams are cut out to form a circular hole and the mast is necked down into a cylindrical section, thus permitting the entire boom assembly, including the treadwheel, to pivot about the base. When the crane is under load, most is taken where the main beam bears on the mast.



Ed Levin after Joel McCarty

Joel McCarty

Main beam before assembly around mast. The circular aperture closes around a necked-down portion of the mast to form a pivoting joint, hardened by steel bearing surfaces not yet applied. See also photos on page 16.

ENGINEERING. The issue of mechanical advantage led us naturally to structural design questions as we chose the timber and had to work out joinery sufficient to resist the resultant loads and stresses. Even without reference to loading, specifying white oak for the sills (to resist ground decay) and for the wheel arbor (to resist wear) seemed obvious calls. Beyond that, the mast, the main beam and the boom stood out as large and critical pieces calling for close attention.

The structural model was loaded with the dead weight of the crane timber frame, plus the mass of the lift (maximum pick 2,200 lbs). The wheel was not modeled; rather its load was accounted for by 500-lb. point loads for the two wheel rims and their shares of sheathing, plus an additional 400 lbs. for wheel operators. Results of interest included member axial and shear forces (which give bearing and tension forces at connections) and member bending stresses. Because of the relatively large stick sizes, shear stresses were not a significant factor.

Apart from the oak sills and arbor, which we could have, it turned out that for everything else we could have any species and grade we wanted as long as it was No. 2 Eastern white pine. (Restricted timber availability may not be a new problem for crane builders. The Perronet drawing shows a scarf joint in the boom in the vicinity of the uppermost clasp, a configuration confirmed by the timber list. Most likely, the builders were unable to find a single tree long enough for their needs, though it's also possible that such an outsize piece would be a nuisance to transport when the crane was knocked down to go to the next job.)

Since our boom could not be made of oak, it was fortunate that FEA model results indicated that Joel's original concern about boom strength was misplaced. The pine boom looked quite comfortable under load. Alas, the same could not be said for the main beam or mast. The problem lay with the first law of structure: Load Goes to Stiffness. In the model, from the top sheave where the lift line transferred pick weight to the boom, the load path of choice followed the boom and forked down the upper boom strut through the lower boom strut, where it delivered a considerable compressive punch to the inner end of the main beam. It chose this route because the struts are positioned to take the load in direct compression, whereas the boom is forced into bending. And, like all framing materials, wood is much stiffer when loaded axially than it is in bending.

Unfortunately, the down thrust of the lower strut imparts a moment to the main beam right at the point where the mast punches through it, greatly reducing the net section of the beam and proportionately increasing the resulting bending stress. Worse, the lean of the strut delivers a hefty side thrust to the even-smaller net section of the mast right where it necks down to pass through the main beam, yielding bending stress on the mast more than double the allowable. Nothing that couldn't be handled by a stout piece of clear oak, the first choice of our English and French forebears, but well beyond the capacity of the available soft pine. What to do?

Virginian and fly fisherman Al Anderson, henceforth to be known as Professor Lift, explains to the crew what's going to happen now that the base and mast have been made ready to receive the rotating assembly.

Photos Ed Levin

Boom with upper and lower boom struts clasped together and offered to masthead, Rick Brown aloft assembling the upper beam, Matt Hincman beneath with bolts. Main beam to complete assembly is yet to come.

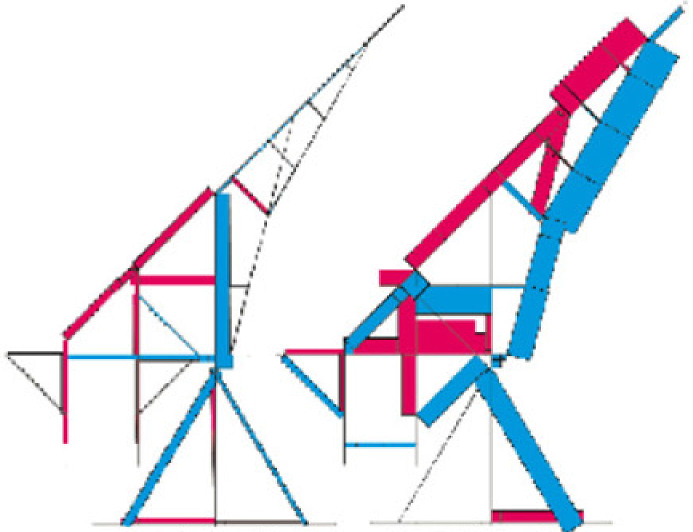
ENTER the Virginian. Helicopter pilot, heavy equipment operator, experienced rigger of church steeples, windmills and trébuchets, framer Al Anderson of Blue Ridge Timberwrights, Christiansburg, Virginia, was our professor of lift. Al had anticipated the crane load distribution problem and had a solution ready to hand. There was plenty of carrying capacity in the crane, he reasoned. It was just that we weren't utilizing the full structure. If there were a way to split the load path between the struts and the mast, we might overcome our material limitations. It was a question of imagination. Where I saw a rigid truss frame structure, fisherman Anderson pictured a flexible giant fly rod supported by a couple of props. What would happen if we pulled out the props and let the rod work on its own? Doubtful, I went back to the computer model and disconnected the struts from the boom. Under full load of 2200 lbs., the unassisted boom tip deflected a foot, and bending stress in the boom soared well beyond acceptable oak values.

Al suggested we reduce the load in steps until we were back in allowable territory. It turned out that the boom on its own could pick 500 lbs. without exceeding bending limits. We checked boom deflection under that load at its points of intersection with the incoming struts. Looking at travel along the lines of the two struts, we measured 5/8 in. of boom deflection at the tip of the lower strut and nearly an inch at the tip of the upper strut. What if we shortened the struts by these amounts? Then the crane should handle dead load plus the first 500 pounds of lift via boom bending and mast compression. Put on additional load and the strut shoulders would come home against their housings and mortises, bringing the struts into play, and the balance of the load should travel down the strut pathway.

So how would this load sharing affect crane performance? The FEA software could not account for the threshold phase shift in a single model, so the answer would have to come from the algebraic sum of two separate models. Looking at the comparative axial force diagrams (facing page), where blue is compression and red is tension, the alternate load paths are clear. In the Stage 1 drawing, the light lift load flows to ground via boom, mast and base struts. In Stage 2, the heavier pick is carried via boom, boom struts, mast and base struts. Note that in many of the areas of significant axial load, the forces are of opposite sign in the two diagrams (by convention, compression is negative and tension positive). That is, where you find compression on the right, you see tension on the left, and vice versa, and in the algebraic sum of the two conditions, they cancel one another out. Meanwhile, in the lightly loaded Stage 1, the center of gravity of the crane superstructure is to the left of the pivot, and thus the rear struts are more heavily loaded. Conversely, Stage 2 overbalances to the pick side (right), with almost all the load channeled via the front struts.

Turning to the paired bending stress diagrams (facing page), look at the most heavily loaded areas in the mast and main beam adjacent to the pivot point. As with the axial forces, you will note that once again bending is of opposite sign in the two diagrams—in Stage 1, the pre-load of the crane's rotating weight plus 500 lbs, the mast bends to the left; in Stage 2, the load represented by adding 1700 lbs., it turns to the right, so once again you get cancellation. The same effect is found in the wheel hangers and parts of the boom.

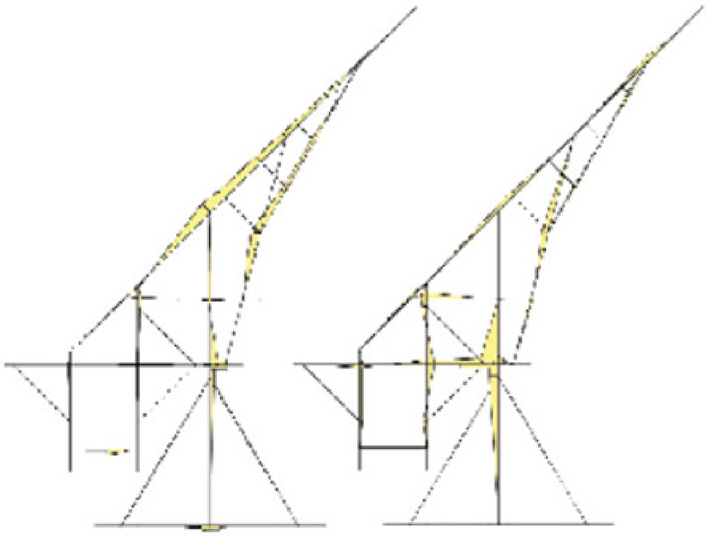
The force of Al's two-stage-load reasoning was relentless. We issued the necessary revisions to the strut shop drawings and put the fly rod scheme into effect.



Stage 1 Axial Force Stage 2 Axial Force

The Clasps. Now what was the role of the clasps, as Al called them, in this scheme? Axial forces in the struts were insufficient to cause buckling. The long lower strut was already sufficiently reinforced by the upper beam. Remove the clasps from the FEA model and there was no discernible effect. On the other hand, if—as we proposed to do—you unlaced the strut upper ends from their mortises, what would keep the struts in place before the joints came home under heavy load? Could the primary function of the clasps be to act as strut retainers while the crane was unloaded or lightly loaded? Was it possible that we had discovered the hidden logic of Perronet's crane?

In addition to shortening the top ends of the upper struts to accommodate the load-sharing scheme, we made one other significant alteration to the apparent crane design, based on our reasoning about how the load should affect the structure. Observe that in both loadcase drawings, the final branch of the load path follows struts rather than the mast. That is the case because we cut short the shoulders of the mast to prevent its bearing on the sills, insuring that the struts (unpegged, remember, in their upper mortises) remained perpetually in compression, lest vibration or motion of the crane cause them to depart their housings. While in our design the mast foot floats above the base, it is restrained from sideways movement by the ample engagement of the mast base tenon into the deep square pocket formed by the sill crossings.



Stage 1 Bending Stress Stage 2 Bending Stress

RAISING and Rollout. The erection of a 50-ft.-tall lifting machine incorporating 15,000 lbs. of timber and iron presented a certain chicken-and-egg problem, which rigger-in-chief Al Anderson puzzled over at length. When not evoking Rodin's *Thinker*, Professor Lift could be found in the impromptu project engineering office, huddling with me over a glowing laptop as we sorted out alternate lifts, loads, centers of gravity, shear leg and tackle configurations.

We resolved to assemble, block up and level the base cross, then pick the mast, using tackle descending from a pair of shear legs, and lower it into the base socket while inserting the eight supporting struts Iwo Jima style. Then we would assemble and raise the boom, struts and clasps, engaging the mast peak bearing. We would leave the rigging in place while adding the wheel hangers, upper beam and main beam and braces. The wheel would go on last.

Our lifting engine (the chicken) would be shear legs harvested from the Brown's woodlot. Like a pair of dividers, shear legs are stable once secured fore and aft in a straight line perpendicular to the spread of the legs. In our case, two stout trees provided tie-offs for the stays, and block and tackle in both stays would enable us to erect the shear legs and then incrementally adjust their lean to relocate the point of lift. We needed 50-ft. poles with 8-in. midspan diameters. A pair of candidate trees was quickly located right across the road from the site. Darryl Weiser felled and limbed them, and reeving and rigging began. For our major lift—the 2-ton boom assembly—we used two sets of tackle, giving us a pair of lift lines. For all but the simplest picks, the procedure was to locate the load's center of gravity and rig to two points roughly equidistant from it on either side. Our ability to adjust the lean of the shear legs put the point of lift just where we needed it. And the double-line lift enabled perfect adjustment of the hang of the incoming load.

Picking the wheel was a breeze; it was moving it to the crane site that was the problem. The finished wheel was assembled vertically, hanging from chainfalls inside the workshop. We had the bodies, and it seemed a simple matter to lay the wheel flat and carry it out through the shop's large double doors. Unfortunately, the wheel's Achilles heel turned out to be its 3x4 white pine spokes, which were halved in thickness at their crossings. The wheel builders assured me that if we tried to lift the 1600-lb. assembly flatwise, the spokes would fracture at these weak points.

There was a puzzled silence while everyone pondered Plan B. The solution proved irresistible. What is it that a wheel does best? The path to the site was fairly level and the surface smooth. Okay, so the wheel was nearly 12 ft. high and a bit unstable, but we had the numbers to handle the load and tipping forces should be easily restrained (as long as we didn't let it lean *too* far). So we took her out for a spin.

When the crane was finished and it was time to strip the rigging and lower the shear legs, we were briefly puzzled again. The legs couldn't simply go back down the way they had come up since the crane was in the way. So, naturally, we used the crane to lower them.

WITH the crane free of rigging and able to rotate freely, it was time to put it through its paces. The builders took turns riding the hook and running the wheel. Then we lifted some dunnage to clear it from the site. I pushed on the wheel and the crane rotated easily. Here was a wooden machine with almost no moving parts, using no fossil fuel and making no noise, that could be run easily by one person. Add a pulley to the lift line and, with 2:1 mechanical advantage, a single operator could pick and move a ton, perhaps even more. My last view as I headed out was of four-year-old Silas Russell hoisting his father Henry into the sky, to the accompaniment of much giggling. I started to think about building a crane model with my seven-year-old Nate. But why make a model when, with just a bit more work, you could have a full-size working crane?

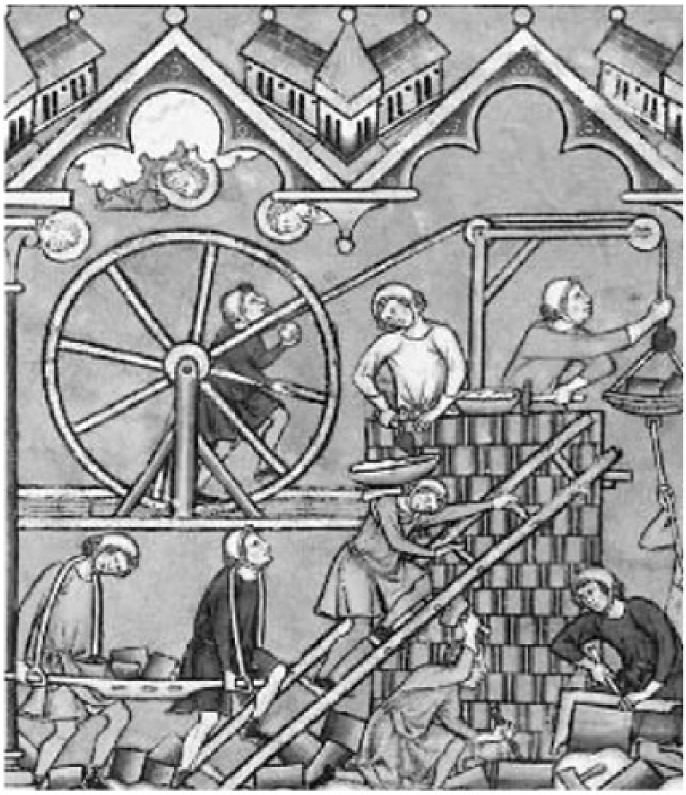
—Ed Levin

A Little Crane History

IN order to add the perspective of an art historian to their expertise in experimental archaeology, architectural design and woodworking, and to include students from another of the group known as the Colleges of the Fenway in Boston, Don Oster of Wentworth Institute of Technology and Rick Brown of Massachusetts College of Art invited me to join their interdisciplinary crane-building project funded by the Davis Foundation.

We began by taking the Great Crane of Bruges as a possible subject of this year's study, inspired by a detail from a painting by Pierre Pourbus published in Mark Girouard's *Cities and People*.[1] The painting is a 1551 portrait of Bruges merchant Jean van Eyewerve, seated before an open window through which we see the Kraanplaats, or Crane Plaza, of Bruges.[2] One can but think that the crane, as tall as a three-story house, made a big impression on the citizens of Bruges because of its size and important contribution to the city's economy.

Bruges was not alone in its respect for massive cranes of this type. A similar large crane that worked the docks in Antwerp appears in the background of at least two paintings, including an *Adoration of the Magi* now in the Philadelphia Museum of Art, and is prominently displayed in numerous city views and plans.[3] More than 40 other cities, from London to Seville, possessed cranes similar to the Bruges example in size and construction in the late 15th century.[4]



The Pierpont Morgan Library, New York. M.638, f.3

Fig. 1. Detail of manuscript (Paris, 1250) illustrated by miniatures depicting Old Testament scenes. The fellow working the treadwheel keeps up his energy by eating fruit, but the hod carrier and the other laborers about to climb the ladder have an uncertain future.

However, last December we learned that students in the technical high school in Bruges intended to reconstruct the crane, or a version of it, in its original location, so the search began for other possible examples for our own project. In addition to their use on the docks of European cities in the late medieval and early modern periods, large human-powered cranes were employed in construction, most notably on the great cathedrals. An enormous wooden treadwheel still rests above the vaulting of Salisbury Cathedral today, and numerous manuscript illuminations depict such machines in use, especially in illustrations of the construction of the Tower of Babel (Fig. 1).[5] Such lifting devices continued to be used on construction sites through the 18th century, only replaced by iron and steel cranes powered by steam in the 19th century.

A number of illustrations of cranes are extant from the 18th century, including one made for Diderot's *Encyclopédie* (Fig. 2).[6] French architect Jean-Rodolph Perronet wrote and illustrated a series of volumes detailing his various bridge and canal projects, including the building of a stone bridge over the Loire River at Orléans 1750-1760.[7] For this project, Perronet designed a wooden crane similar to the one shown in Diderot's encyclopedia. It was

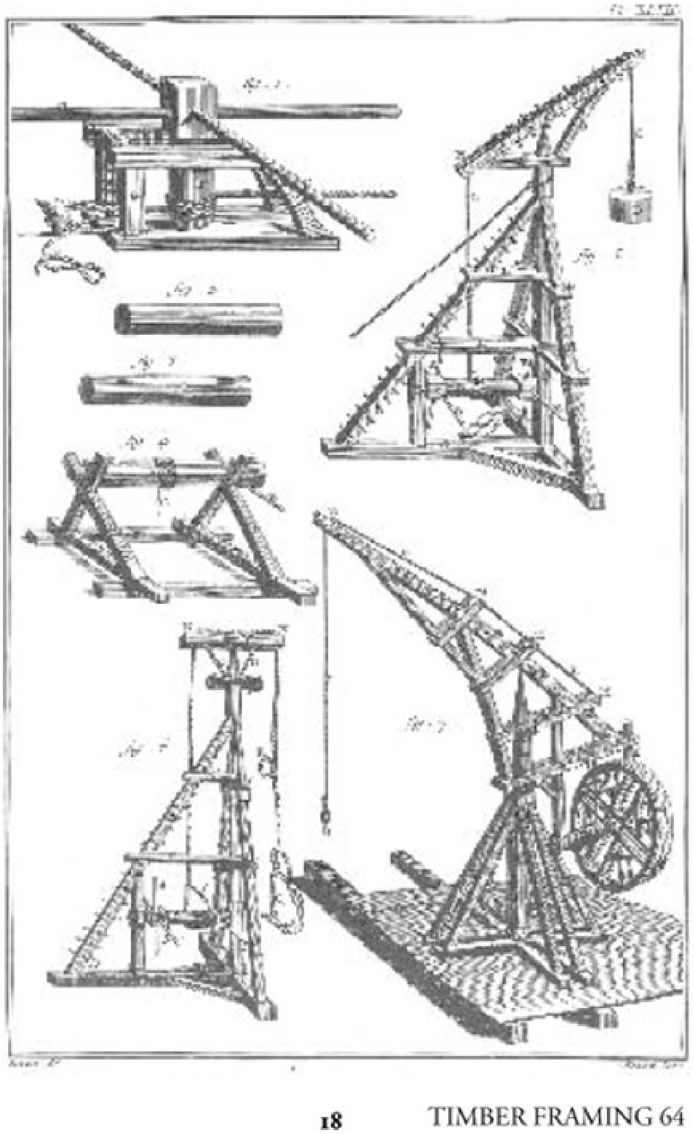


Fig. 2. Plate 47 from Diderot's Encyclopédie *(1751-1772), showing a builder's crane, two hoists and two windlasses. The sharply pointed mast of the crane suggests that no load is taken there, and it is a mystery how, given the fixed location of their windlasses, the hoists could pivot on their pointed masts. (Plate used by permission of Dover Publications, Inc.)*

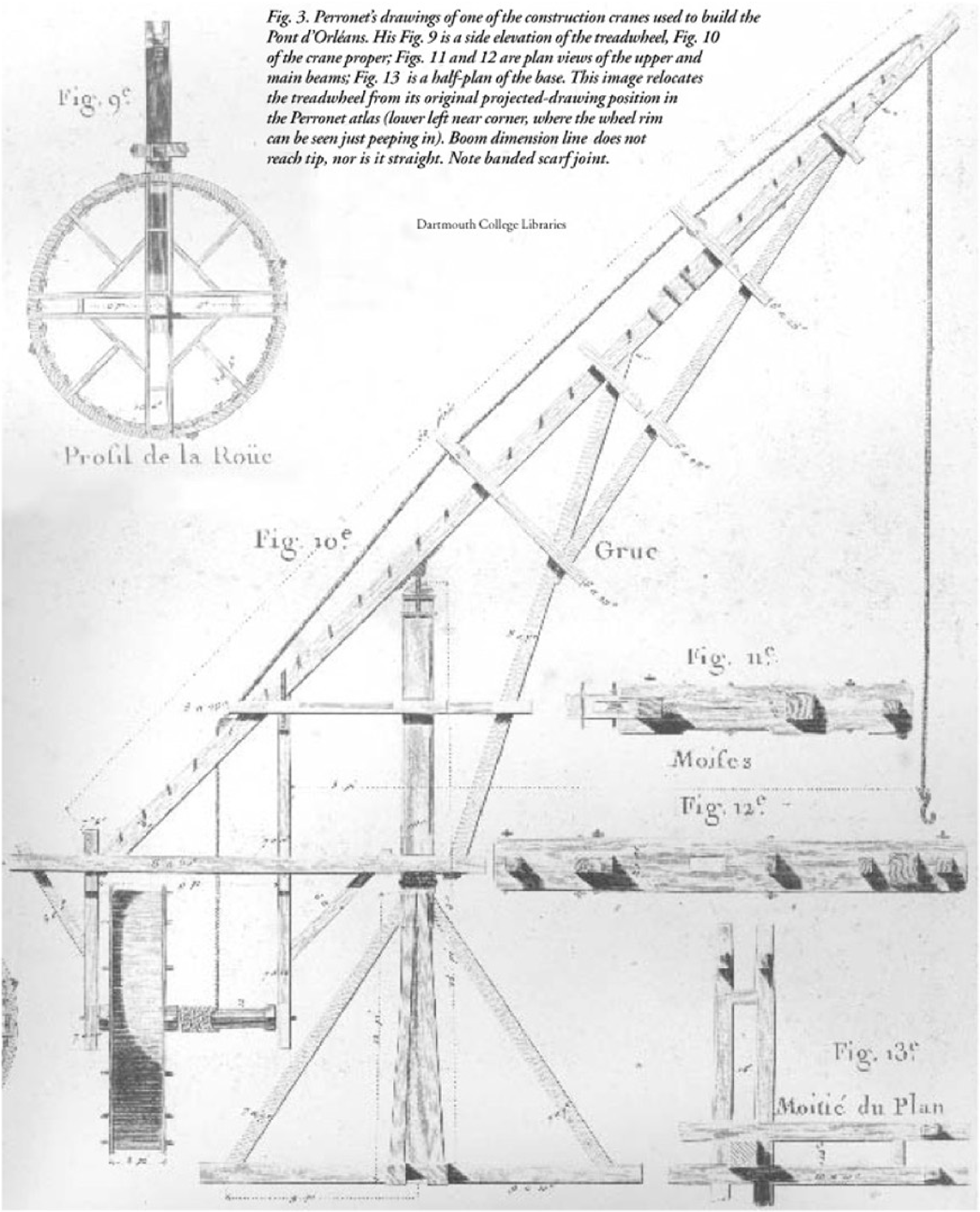


Fig. 3. Perronet's drawings of one of the construction cranes used to build the Pont d'Orléans. His Fig. 9 is a side elevation of the treadwheel, Fig. 10 of the crane proper; Figs. 11 and 12 are plan views of the upper and main beams; Fig. 13 is a half-plan of the base. This image relocates the treadwheel from its original projected-drawing position in the Perronet atlas (lower left near corner, where the wheel rim can be seen just peeping in). Boom dimension line does not reach tip, nor is it straight. Note banded scarf joint.

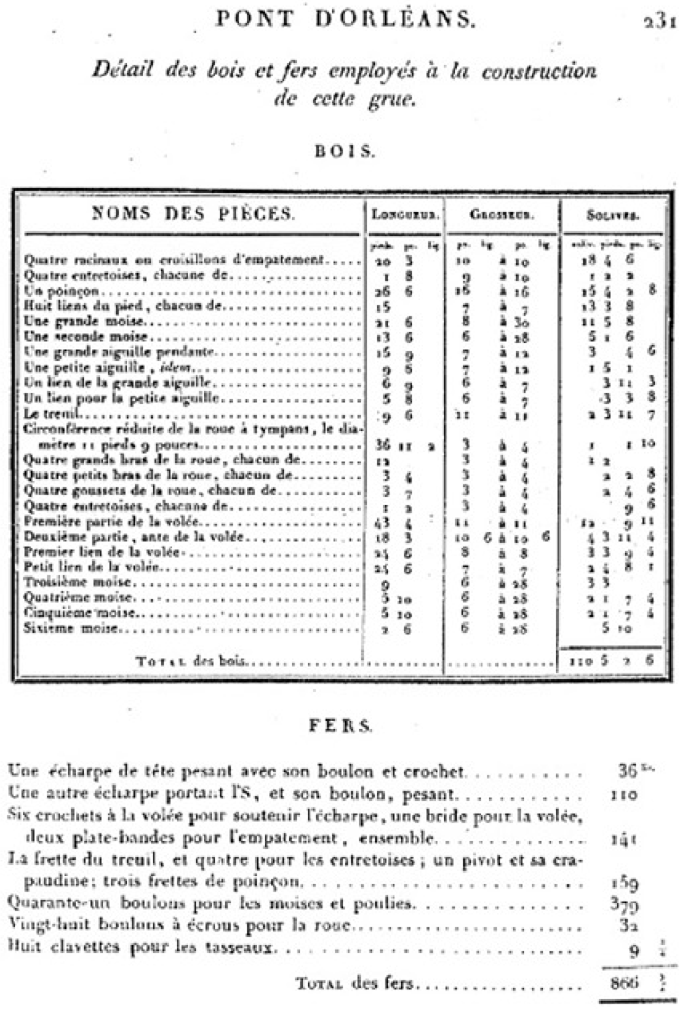
Dartmouth College Libraries

powered by a single treadwheel and used to lift the large stones into place on the bridge. Perronet included a detailed drawing of the crane (Fig. 3) in his book, with dimensions indicated, as well as a bill of materials (both wood and iron) used in the structure, indicating lengths and sections or weights (Fig. 4 overleaf).[8] The drawing provided the information for the crane built this spring.

Information about the construction of wooden wind and water mills, more readily available, and about historical timber framing

John Fenske

Fig. 6. Pont de la Concorde in Paris, designed by Perronet, constructed 1787-1791 and widened in 1930. Perronet introduced daring proportions to the ratio of arch span to pier thickness. Upriver is to the left.



PONT D'ORLÉANS. 231

Détail des bois et fers employés à la construction de cette grue.

BOIS.

NOMS DES PIÈCES.	LONGUEUR.			GROSSEUR.					SOLIVES.			
	pieds	po.	lig.	po.	lig.		po.	lig.	soliv.	pieds	po.	lig.
Quatre racinaux ou croisillons d'empatement	20	3		10		à	10		18	4	6	
Quatre entretoises, chacune de	1	8		9		à	10		1	2	2	
Un poinçon	26	6		18		à	16		15	4	2	8
Huit liens du pied, chacun de	15			7		à	7		13	3	8	
Une grande moise	21	6		8		à	30		11	5	8	
Une seconde moise	13	6		6		à	28		5	1	6	
Une grande aiguille pendante	15	9		7		à	12		3		4	6
Une petite aiguille, *idem*	9	5		7		à	12		1	5	1	
Un lien de la grande aiguille	6	9		6		à	7			3	11	3
Un lien pour la petite aiguille	5	8		6		à	7			3	3	8
Le treuil	9	6		11		à	11		2	3	11	7
Circonférence réduite de la roue à tympans, le diamètre 11 pieds 9 pouces	36	11	2	3		à	4		1		1	10
Quatre grands bras de la roue, chacun de	12			3		à	4		1	2		
Quatre petits bras de la roue, chacun de	3	4		3		à	4			2	2	8
Quatre goussets de la roue, chacun de	3	7		3		à	4			2	4	6
Quatre entretoises, chacune de	1	2		3		à	4				9	6
Première partie de la volée	43	4		11		à	11		12		9	11
Deuxième partie, ante de la volée	18	3		10	6	à	10	6	4	3	11	4
Premier lien de la volée	24	6		8		à	8		3	3	9	4
Petit lien de la volée	24	6		7		à	7		2	4	8	1
Troisième moise	9			6		à	28		3	3		
Quatrième moise	5	10		6		à	28		2	1	7	4
Cinquième moise	5	10		6		à	28		2	1	7	4
Sixième moise	2	6		6		à	28			5	10	
TOTAL des bois									110	5	2	6

FERS.

Une écharpe de tête pesant avec son boulon et crochet	36 liv.
Une autre écharpe portant l'S, et son boulon, pesant	110
Six crochets à la volée pour soutenir l'écharpe, une bride pour la volée, deux plate-bandes pour l'empatement, ensemble	141
La frette du treuil, et quatre pour les entretoises; un pivot et sa crapaudine; trois frettes de poinçon	159
Quarante-un boulons pour les moises et poulies	379
Vingt-huit boulons à écrous pour la roue	32
Huit clavettes pour les tasseaux	9 ½
TOTAL des fers	866 ½

Dartmouth College Libraries

Fig. 4. Perronet's bill of materials. The wooden pieces (Bois) *are listed by length, section and volume, the ironware* (Fers) *by weight. Modern English inches and feet differ by about one percent from French* pouces *and* pieds *of the day. A* solive *is defined as a volume measuring 6 by 6* pouces *by 12* pieds *long. Reasonably enough, the word also means joist.*

and carpentry techniques, guided the fabrication of several small-scale working models by Wentworth and Mass Art students (Fig. 5 opposite). Knowledge of such sources was also available on the construction site, as many experienced timber framers participated. Joel McCarty (of Alstead, N.H.), an executive director of the Timber Framers Guild, Jim Kricker (Saugerties, New York), a millwright responsible for the reconstruction of a number of historical mills and waterwheels, and Henry Russell (Bristol, England), a timber frame preservationist, were among them. All of the experts taught students from Mass Art, Wentworth, and Wheelock as they worked on various parts of the crane during construction in Norwell.

Perronet is an interesting figure, as his career marked the beginning of professional engineering education in France. Before the 18th century, most formal education was provided by the Church. Craftsmen and skilled workers were typically trained through apprenticeships with an appropriate guild. By the 1700s that system had begun to break down, and the French government created new professional schools meant to educate and train a corps of technicians to meet its requirements.[9] The École des ponts et chaussées was formed in Paris in 1747, with Perronet as its first director, a post in which he served until his death in 1794.[10] He was particularly well known for his refined stone bridges, whose sophisticated arches minimized obstruction to the flow of the rivers they spanned. In some cases he employed very long, flat arches on narrow piers, as was the case with the Pont de la Concorde in Paris, built 1787-1791, under which 65 percent of the waterway is open (Fig. 6).[11] In his 1768 bridge at Neuilly (destroyed in 1939), he used piers 12 ft. wide to carry 120-ft. arches, a ratio of 1 to 10, when prior practice had dictated a ratio of no more than 1 to 5.[12] It is not entirely clear how much of Perronet's ability to construct daring but durable bridges derived from his knowledge of recent developments in mathematical techniques and how much is attributable to his varied experience and keen observational skills.[13]

It is somewhat ironic that Perronet's institution, the École des ponts et chaussées, along with other technical schools and societies established at the same time, was in part responsible for bringing about the Industrial Revolution. Of course it was the Industrial Revolution that made timber frame techniques, such as those used to construct this replica of Perronet's crane, obsolete. —MARJORIE HALL

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Notes

[1] M. Girouard, *Cities and People: A Social and Architectural History* (New Haven: Yale University Press, 1985), p. 95.

[2] For a view of the full painting see: P. Huvenne, *Pierre Pourbus peintre brugeois 1524-1584* (Bruges: Musée Memling, 1984), pp.210-214; and see M.P.J. Martens, ed., *Bruges and the Renaissance: Memling to Pourbus* (Bruges, 1998) for this and many other images of the Bruges crane.

[3] J. Van der Stock, ed., *Antwerp: Story of a Metropolis 16th-17th Century* (Antwerp: Hessenhuis, 1993), p. 52, and *passim*.

[4] Many of the cranes are depicted in some detail in the popular city views of the era. See F. Bachmann, *Die alte deutsche Stadt, ein Bilderatlas der Stadteansichten bis zum ende des 30 jahrigen Krieges*, 3 vols. (Leipzig: K.W. Hiersemann, 1941) and G. Braun and F. Hogenberg, *Beschreibung und Contrafactur der vornembster Stät der Welt*, 6 vols. (Plochinger: Müller und Schindler, 1965-70, facs. reprt. of Cologne ed., 1572-1618) for reproductions. A more accessible but abbreviated version of the latter can be found in J. Goss, *The City Maps of Europe: 16th-Century Town Plans from Braun and Hogenberg* (Chicago: Rand McNally, 1992). Forty-two of the city views in Braun and Hogenberg show cranes.

[5] A. Erlande-Brandenburg, *Cathedrals and Castles: Building in the Middle Ages* (New York: Harry N. Abrams, Inc.,1995) illustrates many images from manuscripts that include cranes, and includes a photograph of the Salisbury wheel.

[6] D. Diderot, *The Architectural Plates from the "Encyclopédie"* (New York:

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Fig. 5. Working models of the Perronet crane constructed by students in Boston at Wentworth Institute and Massachusetts College of Art. In the background is the scene from the 1551 Pourbus painting showing the Kraanplaats and the Great Crane of Bruges, the original project model.

Dover Publications, Inc., 1995), p. 108. This modern selection of plates is taken from Diderot's *l'Encyclopédie, ou Dictionnaire Raisonnée des Sciences, des Arts, et des Métiers*, 28 vols. (Paris, 1751-72).

[7] J.-R. Perronet, *Description des projets et de la construction des ponts de Neuilly, de Mantes, d'Orléans & autres; du projet du canal de Bourgogne, pour la communication des deux mers par Dijon; et de celui de la conduite des eaux de l'Yvette et de Bièvre à Paris, en soixante-sept planches* (Paris, L'Imprimerie royale, 1782-83).

[8] *Ibid.*, Pl. XLII, figs 9-13.

[9] C. R. Day, *Education for the Industrial World: The Écoles d'Arts et Métiers and the Rise of French Industrial Engineering* (Cambridge, Mass.: MIT Press, 1987), p. 7. For a more complete discussion of technical training in the context of educational movements in the age of the Enlightenment, see F.B. Artz, *The Development of Technical Education in France, 1500-1850* (Cambridge, Mass., and London: The Society for the History of Technology and the M.I.T. Press, 1966), pp. 60-86.

[10] B. Marrey, ed., *Écrits D'Ingénieurs* (Paris, Editions du Linteau, 1997), p.10.

[11] E. Garrison, *A History of Engineering and Technology: Artful Methods* (Boca Raton: CRC Press, 1991), p.133. Although its roadway was widened in 1930, Perronet's bridge is still in use, as is one he built at Nemours.

[12] S.B. Hamilton, "The French Civil Engineers of the Eighteenth Century," *Transactions* of the Newcomen Society 22 (1941-42), p. 153. The Neuilly bridge served until it was demolished in 1939.

[13] R.S. Kirby et al., *Engineering in History* (New York: McGraw Hill Book Co., Inc., 1956), pp. 220-222.

A Time Machine for Learning

IN June 1969, less than 24 hours before the liftoff of Apollo 11 from Cape Canaveral, I rushed to my hometown airport in Roanoke, catching the last seat on the last flight to Atlanta, hoping to snag a seat on the last plane to Orlando. I sweated every minute as the plane filled, and by luck landed the last seat on the last flight to Florida. I arrived in Orlando during the night, caught a limousine to Melbourne and flagged a taxi full of half-crazed space-flight kooks like myself. Coming upon a beach meadow filled with cars and people, all radios tuned to the countdown that echoed across the water—*3, 2, 1, liftoff!*—everyone stood in awe as the three commanders rushed into the unknown. What would become of them? Why was I here?

I have always enjoyed learning, but the conventional educational process feels to me like a suit that does not fit. Like Mark Twain, I never let my schooling get in the way of my education. I am part of a very large group of curious and eager learners who do not take the direct path to knowing. It is safe to say that many Guild members fall into this category of trailblazing, self-taught, high-risk adventurer learners. Individual vision has its place. In learning and in life it is important to follow your curiosity and to trust your instincts.

When the Apollo 11 spacecraft took off, it was actually pointed in the opposite direction from the moon. The moon was on the other side of the Earth, completely out of view. The known orbits of the moon around the Earth and the Earth's around the sun and the known speeds of the spacecraft and of the Earth's rotation made possible the final perfect alignment. Often the path to a goal is not linear or direct but a sequence toward a constantly moving target.

A year later, while attending college and trying to come to grips with what was important in my life, I came to the conclusion that I would avoid any profession where I could not wear blue jeans to work. Shortly after that decision, I met Laura Smith (she was wearing a pair of blue jeans) and, inspired by my profound denim vision, she convinced me to go to art school. Shortly after that, we got married, we both became sculptors and then educators, and after 31 years we both still wear blue jeans to work.

As teachers, the best thing we can hope for is to prepare young (and not so young) people for a lifetime of learning on their own. Our time is best spent nurturing curiosity and stimulating imagination—which, as Einstein correctly observed, is more important than knowledge. With the right conditions, all we have to do is point toward the window in the wall. The students will do the rest.

Over the last 30 years, I have decided that the creative maker-thinker-doer will be best equipped for problem-solving after developing a sense of history, an understanding of oneself and a craft to forever perfect. The hand, said philosopher Jacob Bronowski, is the cutting edge of the mind.

SO how did we decide to build a 50-ft.-high wood-framed human-powered construction crane? At an exhibition of our Massachusetts College of Art faculty work in Boston a couple of years ago, my friend Don Oster, who teaches architecture at Wentworth Institute, asked me if I thought we could build a wood-

Photos Joel McCarty

The treadwheel, put together in the author's sculpture studio and here suspended by chainfalls, required a subcontract of its own. Below, there was plenty of night work: here the 27-ft. mast is carried to the base where it will be erected by means of shear legs the following day.

framed dockside crane similar to the 16th-century Great Crane of Bruges (Belgium), which he had seen depicted in a painting. This device is a three-story crane, enclosed with siding and a roof, that rotates like a post windmill. Having been to Virginia and to Scotland on trébuchet-building expeditions with the Guild, I answered that I knew a group of people who could make it happen! Putting our heads together, and inviting Wheelock College art historian Marjorie Hall to join us, we composed a proposal to the Davis Foundation of Boston for a grant administered by the Colleges of the Fenway to encourage innovative teaching projects among faculty members of participating institutions. To our amazement, the proposal was fully funded. We then enrolled three individual but related classes centered on the Great Crane of Bruges of 1650. Don Oster's architectural model-making class would produce architectural drawings and models based on information gleaned from northern European paintings of the period. Marjorie Hall's architectural history class would scour paintings, prints and drawings that depicted cranes and research the history of the crane in the social and economic history of the time. My course, Culture and Technology, was to research the technology of the crane and make a 12-ft. working model during an intensive week-long workshop.

A few months later, I presented the idea to Jim Kricker, millwright extraordinaire and perpetual student of historic timber frame technology, whom I had worked with before in Virginia, Scotland and Massachusetts (see TF44, 50, 54). Jim said, "Count me in!" At that moment, the indomitable Henry Russell was en route from England, on his way to New York via Boston, and had independently conceived an interest in building this very crane. Henry showed us his collection of crane pictures and information and enthusiastically joined the team. Soon after, Henry and Jim left for a meeting of traditional timber framers in Virginia. At the conference they found themselves looking at slides shown by Kristen Brennan, a historic preservation graduate student at Cornell University who had recently spent a year in Belgium (see TF60-62). To their surprise, the slides included views of none other than the Great Crane of Bruges. Small world.

Several months into the project we discovered that the City of Bruges had been designated the Cultural Capital of Europe for Summer 2002, a prestigious designation accompanied by funding that provided local historians, educators and builders the means to build their own reproduction of the crane. We were surprised but happy enough for them—after all, it made perfect sense for the crane to be built in Belgium. However, in order not to be doing repetitive research, Henry suggested that we change plans and build a different device, this time a builder's crane used to erect cathedrals, other large buildings and bridges, and designed by the 18th-century French engineer Jean-Rodolphe Perronet. Such a crane could be erected on site and then disassembled and moved to another location. In the case of a bridge, it could be moved across the bridge as construction proceeded. Perronet published a relatively clear drawing and a written description of this crane, several of which he used to build a stone bridge over the Loire at Orléans, France, in the 1750s. Henry Russell and Jim Kricker quickly agreed that this change of plans would give us the opportunity to build the crane *full size*. How did they deduce that? Probably in a telephone conversation with Joel Whynot? McCarty, who by this time had agreed to provide a full set of detail drawings to boot.

WHEN the time came for class recruitment, if I had asked my students, "How would you like to study the history of France circa 1750?" many, if not most, of them would have jumped out the window to avoid answering the question. But when I asked, "How would you like to build a human-powered crane of wood?" their heads popped up like gophers on the first day of spring. They stood in line to enroll. Still interested by the Bruges crane, we started by studying a fragment of a painting by Pierre Pourbus from 1551. Using this image alone as our point of departure, the students' genuine curiosity and desire to build fueled the discovery and learning process. Research and inquiry produced piles of images of cranes, painted by significant artists throughout northern Europe. Information and answers led to more questions. What is technology? What is the relationship between technology and culture? How big is this big crane? Can we build it? In class, architecture student Alexa Riner translated Perronet's French text accompanying his drawings of the crane we would actually build. In disbelief, Alexa had translated a passage describing how it took the French 108 (carpenter-) days to build the crane. "How are we going to build it in a six-day workshop?" she cried. I explained that in 1750 carpenters cut the trees down by hand, fashioned them into finished pieces with axes and hauled them to the building site with draft horses or oxen. I should also have quoted Samuel Johnson, that "Few things are impossible to diligence and skill." And little did Alexa know who would be coming to help us.

Through their research, drawings and many models, the students began to gain an insight into the history surrounding the crane. Issues of patronage, economic systems, the formation of trade guilds and social organization became prominent. The crane was revealed as a symbol of civic pride and economic dominance. Details appeared of process, materials and complementary technologies. The students developed an understanding of the history of lifting engines and the people and societies who built them. The process of learning-by-doing provided a way to get a little closer to what it might have been like to live and build in a particular society at a particular time.

SO in the early days of April our studio and work yard overlooking the North River in Norwell, an old shipbuilding town near the south shore of Massachusetts Bay, took on the feeling of a historic village. Here, Matt Hincman, Mass Art alumnus, directed several students and alumni forging large numbers of bolts and clamps, using coal-fires, anvils, hammers and tongs. There, sculpture student Matt Stone built an iron cupola, and, with George Greenamyer of the Mass Art sculpture faculty, directed a crew of sculpture students who cast iron gudgeons for the axle ends of the large human-powered treadwheel. A team of students and alumni worked with timber framer Chris Madigan and furniture maker and sculptor Ellen Gibson to build this elaborate wooden wheel, almost 12 ft. in diameter, that serves as both counterweight and engine. Timber framer Donna Williams produced the axle while permanently influencing one lucky student with her knowledge of layout and craft. Our two-acre work yard was filled with volunteer timber framers who had traveled from several corners of the country, bringing not only truckloads of the tools of their trade and years of expertise, but also a remarkable willingness to share their knowledge and engage in "discovering" with each and every student.

Henry Russell's determination to hand-hew the 45-ft. boom and the 27-ft. mast worried me, given the limited duration of the workshop. I mentioned the idea of a portable sawmill to West Virginian Darryl Weiser, but he calmly assured me there was no problem. Have you ever seen the West Virginia chain saw method? I had heard of Darryl Weiser but had never seen chain saw performances

Joel McCarty

Jane Eisensmith, Mass Art sculpture student (at left), and timber framer Donna Williams put the finishing touches on the treadwheel axle. Sized surfaces will be enclosed by passing spokes of the double-rimmed wheel; cylindrical portion will wind and dispense the lift line. Axle journals are cast iron with square shafts fitted to broached holes.

Diane Muliero

Iron parts make up little of the bulk of the crane but play a vital role in its operation. Above, Matt Stone's gudgeon pin-casting operation. At right, smiths Erica Moody (thinking), David Cronin (hand in fire) and Ted Hinman (on bellows), heating the iron rings to band the mast and axle.