Joinery

We push 18 popular frame joints to the breaking point

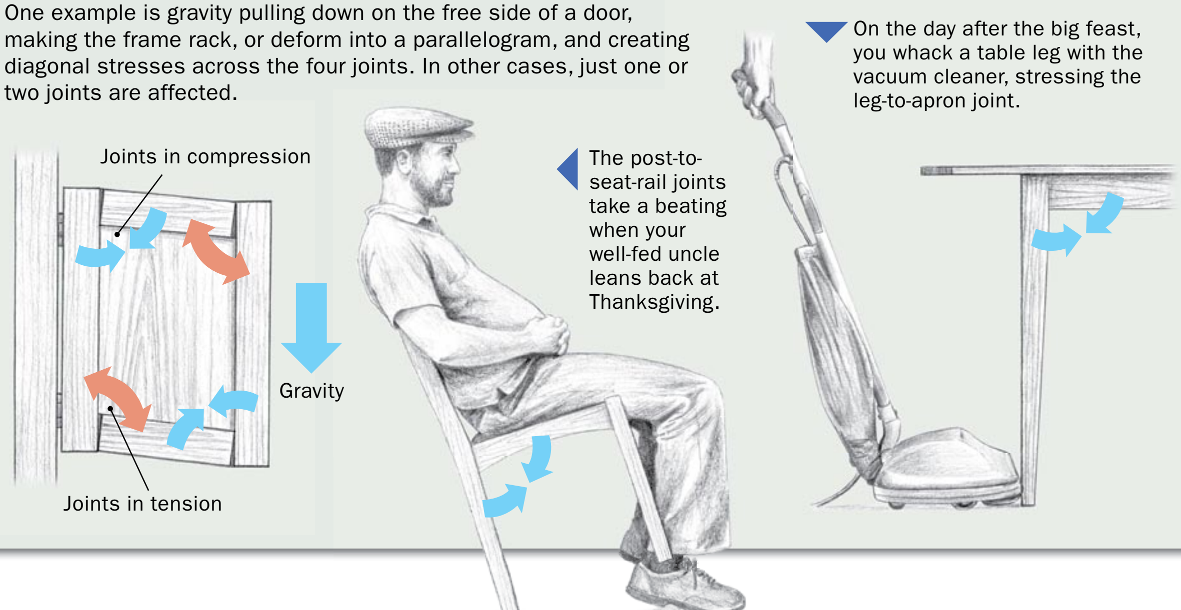
BY DOUGLAS MOORE AND THOMAS McKENNA

WE APPLIED RACKING FORCE

Our test used diagonal compression to simulate racking force, the most common cause of failure in frame joints. The samples were placed in a servo-hydraulic materials testing machine—essentially a hydraulic ram hooked up to a computer to record force and movement.

WHAT IS RACKING FORCE?

One example is gravity pulling down on the free side of a door, making the frame rack, or deform into a parallelogram, and creating diagonal stresses across the four joints. In other cases, just one or two joints are affected.



Photos: staff; drawings: John Tetreault

Shootout

When it comes to making furniture, woodworkers typically base their joinery preferences on aesthetics, efficiency, and available tools. However, joint strength also is a primary concern; after all, we want our furniture to last generations, without embarrassing joint failures. But how do you know which joint is strongest?

In an attempt to provide some insight, *Fine Woodworking* teamed up with a group of research engineers at a lab in Providence, R.I., to break ... er ... *test* a bunch of common woodworking joints.

This sounds straightforward on the surface, but many joints have specific applications within woodworking. So, to simplify things and facilitate comparisons, we focused on a single application that appears in a variety of furniture forms and offers many joinery options: the frame joint. Unlike a standing type of joint such as a dovetail or box joint, which is most often used to attach case or box sides, the frame joint is a flat connection typically used to construct face frames, doors, and other frame-and-panel assemblies. Table and chair joints would also fall roughly into this category.

We made five sets each of 18 different types of joints using cherry, a species used often by furniture makers. All of the samples were ¾ in. thick by 2½ in. wide by 8 in. long, and all were cut by machine to close tolerances. We did break out hand tools to clean up shoulders and to chamfer the tips of tenons slightly so they would slide more easily into their mortises.

Online Extra

Watch a video of the joints being crushed at **FineWoodworking .com/extras.**

All of the joints were glued with Titebond III waterproof Type-I polyvinyl acetate (PVA) adhesive, the peak performer in our recent test ("How Strong Is Your Glue?" *FWW* #192). Per the manufacturer's instructions, we clamped the joints for at least an hour, and let them cure for five days before shipping them to the lab.

The joints were tested to failure in compression using a servohydraulic materials testing machine—essentially a powerful

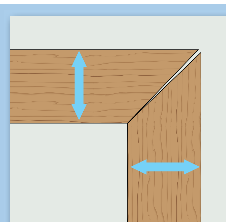
SURPRISING RESULTS

The hallowed mortise-and-tenon joint was not the strongest, even after we fattened the tenon to 3/8 in. thick. Instead, the bridle and half-lap joints, with their broad glue surfaces, withstood the most racking force. The miter was another surprise performer. Bear in mind, though, that none of these joints went through the decades of expansion and contraction that a furniture joint must endure. For other caveats, check the boxes at right. For more on each joint's performance, turn the page.

HALF LAP	1,603 lb.
BRIDLE	1,560 lb.
SPLINED MITER	1,498 lb.
3/8-IN. MORTISE & TENON	1,444 lb.
3/8-IN. FLOATING M&T	1,396 lb.
MITER	1,374 lb.
3/8-IN. WEDGED M&T	1,210 lb.
3/8-IN. PINNED M&T	1,162 lb.
5/16-IN. M&T	988 lb.
BEADLOCK	836 lb.
DOWELMAX	759 lb.
1/4-IN. M&T	717 lb.
POCKET SCREW	698 lb.
DOMINO	597 lb.
BISCUIT	545 lb.
BUTT	473 lb.
COPE & STICK	313 lb.
STUB TENON	200 lb.

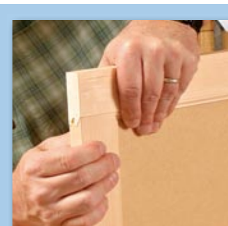
MORE TO THE STORY

The look you want: The half-lap and bridle joints took top honors in our strength test, but these exposed joints don't look right on every project.



Seasonal wood movement: We tested joints right after the glue cured. But seasonal cycles of wood movement will stress the gluelines repeatedly, so joints with built-in mechanical strength, such as the mortise-and-tenon, may have an increasing advantage over time. The miter is especially susceptible to wood movement, actually pulling apart at the tips unless reinforced with a spline.

Ease of assembly: Mortise-and-tenon joints of all types, from traditional to doweled, keep parts aligned properly during glue-ups. Half-laps, on the other hand, must be clamped in a number of directions to squeeze the parts together and to keep them aligned.



How the joint is used: Not every application demands great strength. For a picture frame or even a cabinet door, the ability to withstand 200 lb. of force at each corner might be plenty (and a door with a glued-in panel will resist racking even more). On the other hand, a chair, with its narrow parts and extreme stresses, demands the strongest joints possible.

BROAD GLUE SURFACE ADDS MUSCLE TO BRIDLE AND HALF-LAP

These two heavy hitters ranked one and two in our test, with an average peak load of 1,581 lb., enough to support a full-grown cow. The two joints are similar in their geometry: Both have large glue surfaces and are clamped across their faces, which strengthens the glue bond. When stresses were applied, the joints failed only because the wood sheared across its fibers. Even though the half-lap and bridle joints have great strength, they are exposed joints, and may not look right on every project.

HALF-LAP

Peak load: 1,603 lb.
Rank: 1 of 18

TYPICAL FAILURE

One lap split along the grain, with fibers shearing out across the grain along the glue faces.

BRIDLE

Peak load: 1,560 lb.
Rank: 2 of 18

TYPICAL FAILURE

¼-in.-thick tenon fractured across the grain; stile split just inside the shoulder.

hydraulic ram mounted in a rigid load frame. The test was designed to simulate a racking load, the most common cause of failure in frame joints. As the joints were tested, we recorded actuator displacement and resultant force using a computerized digital data acquisition system. Then we analyzed the data to generate numbers for the average peak strength (the force at which the joint failed) for each type of joint. We also inspected the joints to determine how they'd failed.

Some surprises at the top and bottom

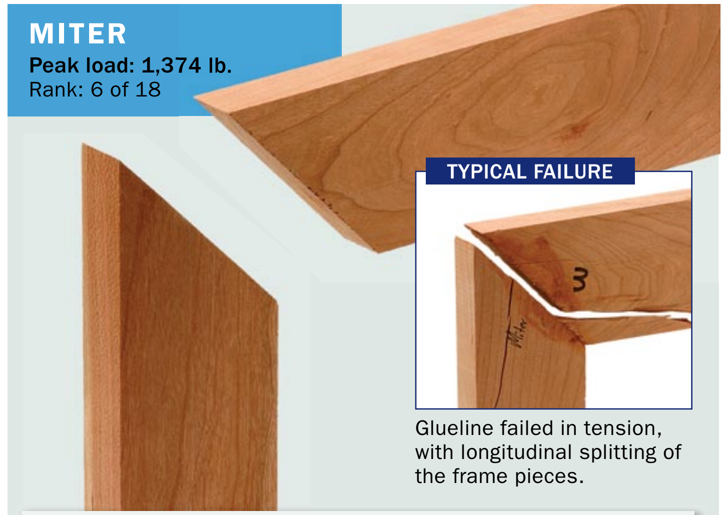
Before the test, we surveyed the *Fine Woodworking* staff and our online audience at FineWoodworking.com to find out which joint

THICK SPLINE ADDS BACKBONE TO THE MITER

Though the miter was surprisingly strong, structural limitations make it hard to recommend the unreinforced miter for furniture-making tasks. When assembled, the joint is angled at the typical 45°. However, as wood expands and contracts over time, the 45° geometry will change (see drawing, below), causing joint failure at the outside corner. The spline creates long-grain glue surface, which helps explain the splined miter's No. 3 position overall.

MITER

Peak load: 1,374 lb.
Rank: 6 of 18



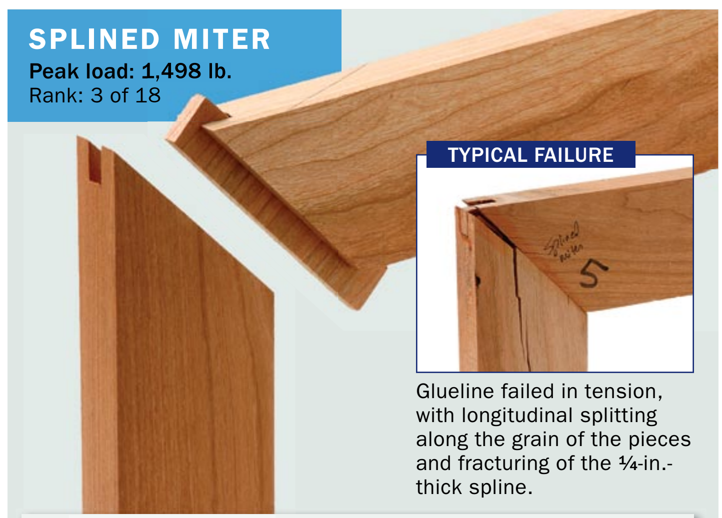
TYPICAL FAILURE

Glueline failed in tension, with longitudinal splitting of the frame pieces.

ANGLE CHANGES AS WOOD MOVES

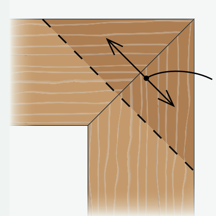
SPLINED MITER

Peak load: 1,498 lb.
Rank: 3 of 18



TYPICAL FAILURE

Glueline failed in tension, with longitudinal splitting along the grain of the pieces and fracturing of the ¼-in.-thick spline.



A BETTER WAY TO SPLINE A MITER?

We didn't think of this variation in time for testing, but a diagonal key adds a broad long-grain glue surface at the miter's weakest point, which should prevent it from failing in the long-term.

A THICKER TENON MAKES A STRONGER JOINT

The ⅜-in. mortise and tenon did well in the test, but the performance of thinner versions was surprisingly average. The results prove that making tenons thicker increases strength: The ⅜-in. tenon was almost twice as strong as the traditional ¼-in. tenon. Adding pins or wedges slightly compromised joint strength; however, they do provide insurance against glueline fatigue in decades to come. A floating tenon acted just like a traditional mortise and tenon in our testing.

⅜-IN. MORTISE AND TENON

Peak load: 1,444 lb.
Rank: 4 of 18

TYPICAL FAILURE

Tenon fractured across the grain; stile split just (about ⅛ in.) inside the shoulder.

SIZE MATTERS

¼-in. tenon: 717 lb.
5⁄16-in. tenon: 988 lb.
⅜-in. tenon: 1,475 lb.

they'd predict to be strongest. Among editors, the pinned mortise and tenon was picked to finish first (it was a close race). Folks who took our online poll predicted the regular mortise and tenon would be king. It turns out, however, that the half-lap joint proved strongest in our test, with the stub tenon bringing up the rear.

Top two have lots of glue—Although we were surprised to find the half-lap and bridle at the top of the heap, in retrospect it was predictable: Both joints have large long-grain glue areas and are clamped across both faces. The only way they can fail is if one or both of the "legs" fracture across the grain.

Thicker tenons are stronger—Most of our survey respondents predicted the trusted mortise and tenon would be strongest, so it's no surprise that two ⅜-in. versions were at the top of the list. What's significant is the margin by which they outperformed their lankier ¼-in. and 5⁄16-in. cousins. We noticed that reinforcing the joint with a pin or with wedges did not help the pieces resist racking forces; in fact, pins and wedges made the joint slightly weaker.

The lowly miter steps up—The miter has always been considered one of the weak links in the joinery world, so we were

WEDGED MORTISE AND TENON

Peak load: 1,210 lb.
Rank: 7 of 18

TYPICAL FAILURE

Tenon fractured across the grain; stile split near glueline.

PINNED MORTISE AND TENON

Peak load: 1,162 lb.
Rank: 8 of 18

TYPICAL FAILURE

Tenon fractured across the grain; stile split near glueline.

FLOATING TENON

Peak load: 1,396 lb.
Rank: 5 of 18

TYPICAL FAILURE

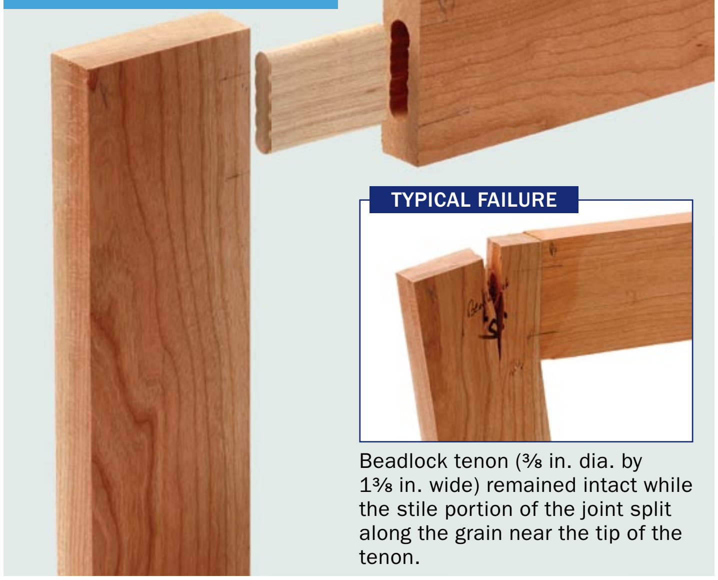
Tenon fractured across grain; stile split near glueline.

STORE-BOUGHT TENONS ARE A BIT WEAKER THAN SHOPMADE

Biscuits, dowels, and premade tenons are all floating tenons of a sort. In general, however, they don't reach as far into the stile as shopmade tenons, allowing the stile to split along the grain without fracturing the tenon. Though we used the manufacturer's dowels and tenons (and followed their directions), we recommend that you choose or make longer ones. Still, these fast and efficient systems made strong joints. When time is money, and you don't need to support a Greco-Roman wrestling team, one of these speedy systems makes a lot of sense.

BEADLOCK

Peak load: 836 lb.
Rank: 10 of 18



Beadlock tenon (⅜ in. dia. by 1⅜ in. wide) remained intact while the stile portion of the joint split along the grain near the tip of the tenon.

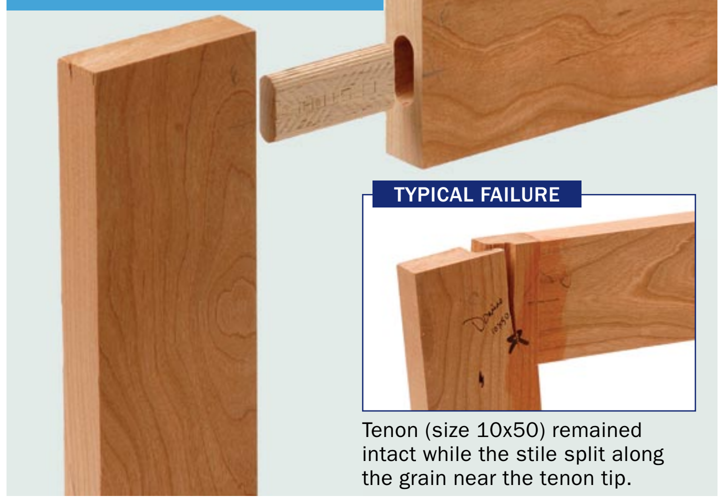
DOWELMAX SYSTEM

Peak load: 759 lb.
Rank: 11 of 18

The three ⅜-in. dowels remained intact while the stile split along the grain near the dowel tips.

DOMINO BY FESTOOL

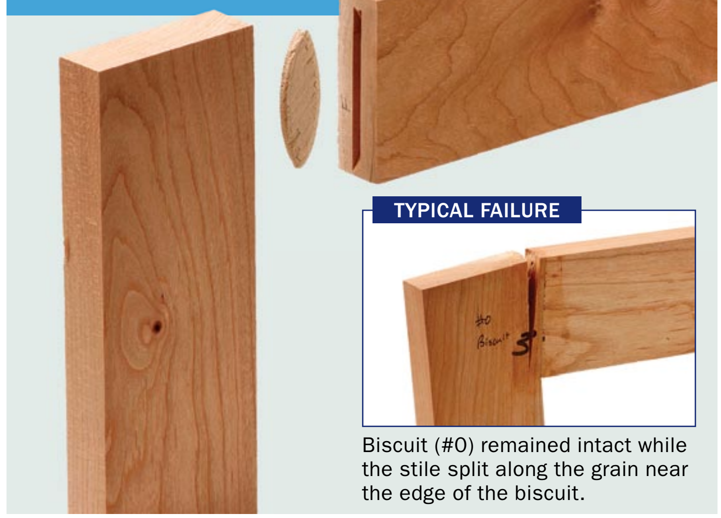
Peak load: 597 lb.
Rank: 14 of 18



Tenon (size 10x50) remained intact while the stile split along the grain near the tenon tip.

BISCUIT

Peak load: 545 lb.
Rank: 15 of 18



Biscuit (#0) remained intact while the stile split along the grain near the edge of the biscuit.

shocked to see two versions nestled near the top. The fact that the splined version did well was less surprising given the reinforcement and increased long-grain glue surface provided by the spline. However, our testing configuration may have stacked the deck for both miter joints, loading the tip of the glueline in tension while compressing the fibers of each leg across the grain.

Even so, as well as the basic miter performed, it's hard to recommend it as a top-notch furniture-making joint without adding a key or spline of some kind. It has no inherent mechanical interlock, so all its strength comes from its glueline. And, as the parts expand and contract, the glueline will be stressed repeatedly and intensely, eventually opening at the outside corner. With a deep key at the outside corner, however, this joint might prove to be very strong over the long haul.

Store-bought systems prove their mettle—We tested several store-bought joinery systems (pocket screws, biscuits, Beadlock, Dowelmax, and Domino) and each put up respectable numbers. We like the fact that they all go together quickly.

Bottom of the heap—The two weakest joints were the cope-and-stick and stub tenon, coming in behind the basic butt joint. These joints are widely used to make production cabinet doors, and they are strong enough for this application, especially when reinforced with a glued-in plywood panel.

GLUE IN A PANEL TO STRENGTHEN STUB TENONS

Most folks expected the butt or miter joint to bring up the rear. But it was the stub tenon and cope-and-stick joints that sank to the bottom of the pile. Even copious amounts of glue did little to help. Both are too weak to be used as-is in large doors. For real strength, stub tenons and cope-and-stick joints need a glued-in plywood panel for reinforcement.

STUB TENON

Peak load: 200 lb.
Rank: 18 of 18

TYPICAL FAILURE

Stile split along the grain near the tip of the stub tenon.

COPE-AND-STICK

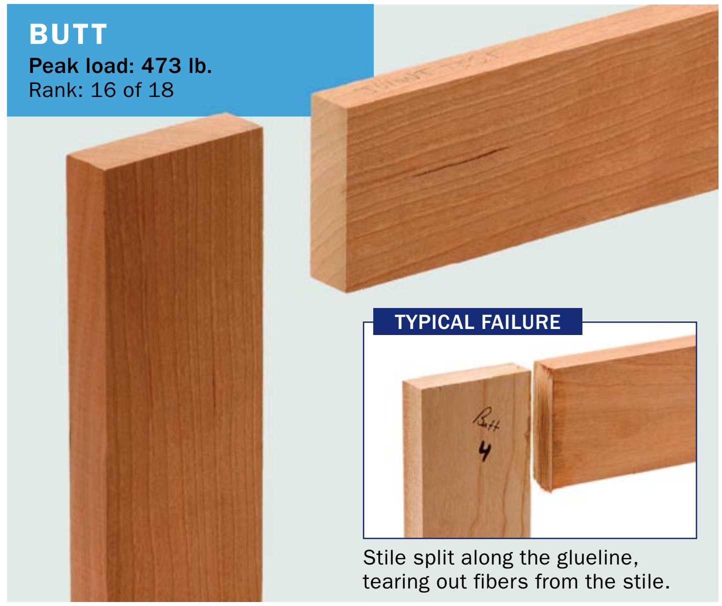
Peak load: 313 lb.
Rank: 17 of 18

TYPICAL FAILURE

Stile split along the grain near the end of the stub tenon.

POCKET SCREWS BEEF UP THE BUTT JOINT

We included the butt joint in the test to serve as a baseline against the others, but it didn't perform badly. Even so, the butt joint isn't suitable for furniture because the small glue surface depends on end grain, making it very susceptible to seasonal stresses. Pocket screws increased the load capacity enough to make this joint a good option for situations where the interior of the frame is hidden.

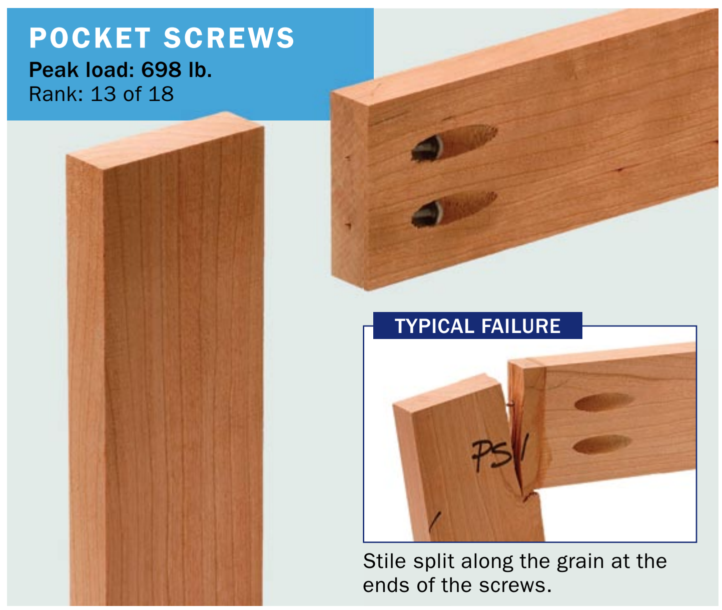


BUTT

Peak load: 473 lb.
Rank: 16 of 18

TYPICAL FAILURE

Stile split along the glueline, tearing out fibers from the stile.



POCKET SCREWS

Peak load: 698 lb.
Rank: 13 of 18

TYPICAL FAILURE

Stile split along the grain at the ends of the screws.

Conclusions

When we looked closely at how joints tended to fail, we found a clear correlation with our test results. The stronger joints forced their component pieces to fail by fracture across the grain or right at the glue joint (miter), while with the intermediate-strength and weakest joints, failure occurred by the splitting of one piece along the grain.

But the numbers don't tell the entire story. A lot of considerations go into the choice of a specific joint: How it will look (exposed joinery vs. the clean appearance of a hidden joint); how it will be affected by seasonal wood movement (is there mechanical resistance to keep the joint together over time?); ease of assembly (fast sometimes is best); and how it will be used (picture frame vs. apron-to-leg joint). So take all those issues to heart when making your joinery choice. □

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