This goes back a few years, but I thought it would be a good addition for the Making Sense of Science archives. –j.j.

The Engineer's Shelves

or

Making Home Improvement More Complicated Through Science

I put up some shelves in my home office last week. It would never do for an engineer's office to have substandard shelving. This called for a bit of planning & forethought. Perhaps even complete CAD drawings to scale. Of course, I'd need to do some calculations based on simplifying assumptions, and solve an equation or two. I wouldn't be an engineer if I didn't at least do that, would I?

The shelves were to be approximately 800.10 mm long (that's around two or three feet, but everything seems more precise when converted into metric), and supported by those long metal brackets that attach vertically to the wall. In the US where stud wall construction is primarily used, I always attach this type of shelf brackets directly to the studs. But this house, like many Australian houses, is all brick. So now I can put the brackets anywhere I want. But where? How far apart should they be, ideally?

Engineers are different from normal people, because they wonder if there is a "best" way to do things. A normal person would say, "I can put the brackets anywhere I want? Great." He then puts them wherever looks good and moves on with his life. But an engineer says, "What is the optimal placement of supports on a two-support beam with distributed loading?" That's pretty much how an engineer talks, too, even when talking to himself.

Let us humor our inner engineer for a moment. If the brackets were too far apart, the shelves would sag unnecessarily in the middle. Too close together, and the edges would droop needlessly. The shelves would probably still hold the same number of books, but they wouldn't be "optimal." Perfection is so rare in life, you must seek it where it can be found. And this is one thing I think I can get exactly right. No extra expense or special parts, just drilling some holes in EXACTLY the right places. How could I resist trying?

First, the engineer makes some basic assumptions about the project. Assumption #1 is that the shelves will be supporting a fairly uniformly distributed load (a.k.a. books). Assumption #2 is that books are all approximately the same linear density (weight per thickness). Thicker books are heavier, but also take up more space meaning that there will be fewer of them, so it all averages out. Assumption #3 is that since there would be loading on either side of each support, the shelf could be treated as if it were composed of three separate beams: two cantilevered beams representing the overhanging ends and one beam fixed at both ends with non-pivoting supports. Pardon me - I was just talking to myself again. Engineer talk.

Next, the engineer reasons. What if the supports could be placed such that the middle and ends of the shelf sagged by an equal amount when full of books? Now move the supports further apart.

The middle would begin to sag more, would it not? And, if you move the supports closer together, the ends would sag more. Is it not therefore the case that when the middle and end deflections are equal, then the shelf has the least amount of deflection under load? (Here's a tip: you can save us all about four pages of calculus by just nodding "yes." Good. Thank you. The other readers thank you too.)

Finally, the engineer calculates. From inside one of the books which were currently laying on the floor, I found formulas for the maximum deflections of cantilevered beams ($w[L_1^4]/[8EI]$) and two-support beams ($w[L_2^4]/[384EI]$) I knew I was keeping all those books for something: to help me make shelves to keep my books on. Setting the deflection of the midspan equal to the deflection of the overhanging ends, one finds that the midspan length L_2 is $\sqrt{\sqrt{48}} = 2.632$ times the overhang length L_1. In other words, for optimal support the distance between supports should be 56.823% of the overall length of the shelf.

The whole shelf is 800 mm long, 56.8% of which is 454 mm. Centering the shelf on the supports leaves 173mm on each end. And that's precisely where I marked and drilled the holes for the brackets. Problem solved.

The next problem was, how many screws were needed to keep the brackets attached to the wall when all the shelves were fully loaded? I remember having to do a problem like that at university. I remember it took a long time, and it was hard. Based on that valuable educational experience, I decided to put in as many screws as I could. No sense "screwing around" with that sort of thing, I say. (Engineers all enjoy a good pun now and then.) Seriously, what's the cost of a screw compared to an hour of engineering analysis? Half this job is knowing what's worth doing and what isn't.

The last problem was to determine how thick and wide the shelves needed to be to support books of average linear density. I approached this problem by going to the hardware store and picking out some 12" x ½" wood that was on sale and, "looked about right." I hope that by saying this I haven't caused the Engineering Profession to lose any of its mystique.

Look, I was getting tired, OK? And after all, it's only some shelves. They may not be perfect in all ways, but By Gandalf, those brackets are spaced absolutely perfectly. It's a good feeling to have done at least one thing - even something not very important – exactly right.

(Editor's note: This TRUE STORY first appeared on the Web in 2001, attracting fans from around the globe. Sadly, the original shelves no longer contain engineering books. I think the ex-wife is using them for cauldrons or dried newts or something.)