The dynamics of linear spaghetti structures — how one thing just leads to another :-) [1]

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1 Introduction

Since our short notes on this topic appeared in New Scientist a few years ago (Nickalls and Nickalls, 1995, 1998), I have noticed a couple of other papers on this topic in recent times—did we inadvertently create a new domain, namely, the *dynamics of linear spaghetti structures*? :-) — and in view of this I have decided to make some quick notes before I forget where all these articles are.

But first, I need to point out that Richard Feynman is really the person responsible for all this spaghetti madness, as I will explain.

2 Feynman

One day I came across the following passage in Sykes' book on Richard Feynman (Sykes, 1994).

> A lot of times he'd get crazy ideas of how physical things worked. He was always putting his theories to the test, and that was a great thing about Richard—whenever you asked a question and couldn't think of the answer, Richard would say, "Well, what experiment can we do to figure it out?"
>
> Once we were making spaghetti, which was our favourite thing to eat together. Nobody else seemed to like it. Anyway, if you get a spaghetti stick and you break it, it turns out that instead of breaking in half, it will almost always break into three pieces. Why is this true—why does it break into three pieces? We spent the next two hours coming up with crazy theories. We thought up experiments, like breaking it under water because we thought that might dampen the sound, the vibrations. Well, we ended up at the end of a couple of hours with broken spaghetti all over the kitchen and no real good theory about why spaghetti breaks in three. A lot of fun, but I could have blackmailed him with some of his spaghetti theories, which turned out to be dead wrong!
>
> Sykes (1994), p 181

[1] www.nickalls.org/dick/papers/spaghetti/spaghetti.pdf

Not long after reading this, I came across a letter on Feynman in *New Scientist* (14 January, 1995). This prompted my son Oliver and me to follow this up with a letter to *New Scientist* about our own fooling around with spaghetti, during which we figured out fairly easily why the third piece is ejected out of the middle (Nickalls and Nickalls, 1995), as follows:

> Your recent letter on Feynman's joke (14 January) reminded us of the passage in the book *No Ordinary Genius* (ed. Christopher Sykes; 1994) in which Danny Hills describes his and Feynman's experiments with spaghetti:
>
> "If you get a spaghetti stick and you break it, it turns out that instead of breaking in half, it almost always breaks into three pieces. Why is this true—why does it break into three pieces? ... Well, we ended up at the end of a couple of hours with broken spaghetti all over the kitchen and with no real good theory about why spaghetti breaks in three."
>
> We can only assume that Feynman was not really trying, since when we investigated this profound and fundamental problem in our own kitchen laboratory, not only did we quickly establish the underlying mechanism, but we even went on to formulate the following general rule for linear spaghetti structures:- If a spaghetti stick is uniformly bent until it fractures and ejects a third piece, then the third piece is always ejected outwards from the convex side.
>
> When the spaghetti fractures for the first time the two remaining pieces then spring outwards, and providing there is a sufficiently weak potential fracture site on the opposite side a second fracture occurs, resulting in a third piece being ejected away from the initially convex side.
>
> The third piece cannot be ejected away from the concave side since this would require a second (and lower energy) fracture on the same side as the first fracture, in which case the spaghetti would have fractured at this site first.
>
> Nickalls and Nickalls (1995)

Pasta puzzle

A few years later this same question appeared in the **Last Word**[2] section of the *New Scientist*, to which we duly responded, giving a bit more detail than previously, as follows (see "answer 2" below).

> **Question**: If you bend a piece of dried spaghetti it breaks into three pieces with the middle piece flying out. Why does this happen?
>
> **Answer 1**: When you bend a piece of uncooked spaghetti, it does not usually break at the apex of the bend where the stresses are highest, because failure in the spaghetti is controlled by defects in the pasta.
>
> The first break will occur at a point near the apex where the combination of stress levels and defect size reaches a critical value. This initially breaks the piece into a long and a short piece. After the break, as the longer side

[2] A section of *New Scientist* in which readers suggest unusual questions, and then later the journal publishes a selection of invited answers.

snaps back, the whipping action sends the tip beyond the neutral point and activates the next defect on the long side. This defect has already been opened up on the outside of the curved spaghetti by the first bending, so it doesn't take much to to finish off the crack by bending it in the other direction.

Because of the whipping motion that section of the spaghetti is travelling forward at that point [in time] of the second break and so the liberated small piece continues in that direction.

If the critical defect does happen to occur right at the apex, which it does only rarely, the spaghetti breaks into only two pieces.

Stephen Claeys, Niagara Falls, New York.

Answer 2: The sequence of events can be determined by looking at the broken ends. When a break occurs the fracture starts cleanly on the stretched convex side, and ends slightly raggedly on the compressed concave side where a small splinter is usually torn away from one side of the break. Careful inspection of the ejected middle piece will reveal evidence of spicule formation at both ends and that these are on opposite sides. This shows that the two breaks which generate the middle piece each occur while the spaghetti is bending in opposite directions, which is consistent with the dynamics of linear spaghetti structures.

Nickalls and Nickalls (1998)

3 Photography

Several years of zero spaghetti-activity went by, until last year when I inadvertently found that one of our previous *New Scientist* notes had been cited by Zaziski (2003) in his chemistry PhD thesis on nanocrystals. Curiosity drove me to look through his thesis (it was available on the web for a while) and find out how and why our fooling around with spaghetti was relevant in a serious scientific work.

Interestingly, his thesis included a nice series of photographs of spaghetti breaking into 3 pieces (Zaziski 2003; see Figure 4.12, and his pages 83–84, and the references 15 & 16 on page 89; he referenced us at the end of his chapter 4). If anyone reading this knows Zaziski then please ask him to send me a copy of his lovely original spaghetti-breaking images. The key images from his thesis are shown below.

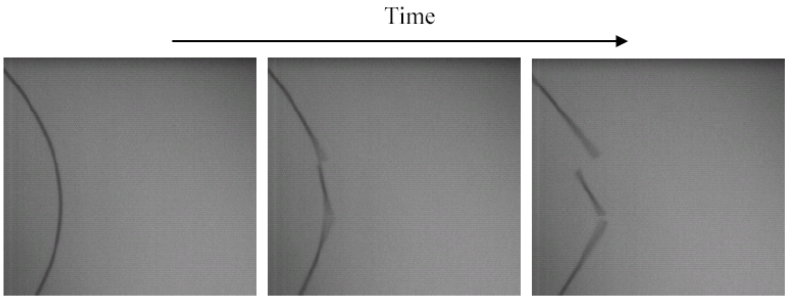

Figure 4.12 Real-time photographs of the three-piece fracture of a spaghetti noodle. The time elapse between frames is 10 msec.

[From Zaziski 2003; pages 83–84]

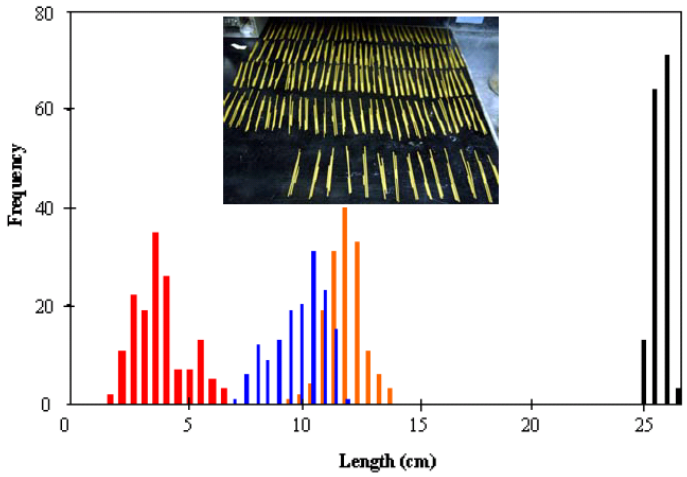

Figure 4.13 Length distribution of spaghetti noodles before (black) and after (red, blue and orange) fracture into three pieces.

[From Zaziski 2003; pages 83–84]

4 More recently ...

In the last few years spaghetti-breaking has become a popular pastime, and articles have even started appearing in the serious science journals. Fracturing appears to be related to interesting waves and oscillations, and not surprisingly the maths and physics turns out to be quite complicated (Audoly and Neukirch 2004, Belmonte 2005, D'Andrea and Gomez 2006). See also the excellent spaghetti breaking videos available on their websites (see below), including those of Feynman's efforts.

5 References

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  [their website also contains several videos of spaghetti breaking]

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