predictably. And that would make it easier to design a cushioning system because you'd be dealing with a single, predictable impact.

Jenna: Yes, but surely, a heavy vertical landing is a huge problem. The force of it would be far greater ...

9.3

Manfred: The first time we launched one of these things, er, we basically just got a plastic washing-up liquid bottle, filled it about half full of water, then pumped it up with an ordinary foot pump.

Interviewer: So it was just ordinary household stuff?

Manfred: Oh, yeah, nothing too technical. And, actually, there was a bit of a coincidence, because the opening in the bottle was just slightly bigger than the fitting at the end of the pump, so there was quite a good seal. So we pumped it up – one of us held the bottle while someone else worked the pump. And we released it, and it went up, literally, like a rocket. I mean, we expected it would shoot up reasonably fast, but we didn't anticipate just how powerful it would be. It just went *whoosh* and totally exceeded our expectations. So you can imagine us, a group of 12-year-olds, we were absolutely ecstatic. And having said that, there was one problem. Once all the water had come out, which happened virtually in a split-second, the bottle – because it was very light – started tumbling over in the air.

Interviewer: So it wouldn't fly straight?

Manfred: That's right. But we quickly came up with a solution to that problem.

9.4

Manfred: What we did was to get a plastic cup, a strong one not a disposable cup, and pushed it onto the end of the bottle, at the top, to form a nose. It didn't go exactly according to plan, at first. It stabilised it a bit, but it still wasn't flying straight. So we tried putting water in the beaker, to act as ballast, and that worked a treat. With the extra inertia, and the fact that it was front-heavy, it went like an arrow. So, so, yes, we sorted that problem out. Then the next goal was to increase the power, to try and reach a higher altitude.

9.5

Manfred: One of the things we did was to experiment with the amount of water inside the bottle. I think, initially, we expected that the more water we put in, the more powerful it would be. But as it turned out, it was the opposite. What actually happened was, if you overfilled it, there wasn't enough pressure to expel all the water. We reduced the amount of water to about a quarter or a third full, something like that, and we also put some tape around the end of the pump, to get a better seal with the bottle. That was really effective. I think we underestimated the pressure we were generating. And, certainly, we were overestimating the strength of the bottle. Because it got to the point where we were firing these rockets up to, I don't know, maybe something like 20 metres high, something like that, so you can imagine the sort of pressure involved. And plastic bottles are hardly up to the job of high-pressure rocketry, obviously. So, inevitably, the bottle eventually blew up while I was holding it. I was rolling around on the ground with sore hands, while everyone else was rolling about laughing. So I learned the hard way.

9.6

Caroline: So how credible is this hoax theory, then? I watched a documentary about it a while ago.

Renato: Well, some of the questions are quite interesting, but from what I've read, they can all be explained, scientifically. You know, like the fact that the stars aren't visible in the sky on the photos. Apparently, it's just due to sunlight on the surface of the moon. It was too bright to see them, that's all.

Caroline: Isn't the flag supposedly waving in the wind, in one of the shots?

Renato: That's right, yeah. They say it's because of the pole shaking after it'd been stuck in. There's obviously no air, so as a result, it kept moving for ages, due to the fact that there was no friction to slow it down.

Caroline: I see.

Renato: Another thing that's been explained is the footprints on the surface. People had said the ground looked wet, so it couldn't have been on the moon. But, apparently, that's the way that type of dust behaves in a vacuum. It sticks together, like mud.

Caroline: Wasn't there some other theory to do with dust when the module landed, that there should have been more dust, or something?

Renato: Well, during the landing, there was supposedly a lot of dust flying up, you know, caused by the blast from the engines. But when the module's actually seen on the surface, there's no crater visible below it. So the theory is that, if it had really landed there, it would have left a crater. But the argument against that is that it had already slowed down substantially by the time it reached the surface, and it was only descending gently, because of the low gravity.

Caroline: So there was only a bit of surface dust blown up?

Renato: That's right.

10.1

Mike: Obviously, a tubular steel tower only gives you sufficient structural strength if you give it adequate protection from corrosion – *the* big problem with offshore installations. So, technically, you could say steel is inappropriate in that environment.

Loreta: They make ships out of it.

Mike: I know, Loreta, but only because there's no cost-effective alternative. But we're not talking about ships, we're talking about fixed structures. The point is, I think we should look more seriously at alternatives to all-steel supports. And the obvious alternative is reinforced concrete.

Loreta: We've already looked into it, though, and it wasn't cost-effective.

Mike: Not in the short term. But we didn't really look into it properly over the long term.

Loreta: But you made the point yourself, Mike, that steel's completely ineffective if it's corroded. And one of the main constituents of reinforced concrete is steel.

Mike: It's protected, though, isn't it? It's embedded inside concrete. That's a much more effective protection than paint.

Loreta: Not necessarily. If we're talking about the long term, as you say, what happens to concrete when it's exposed to the sea for a few years? It erodes. Which means the steel eventually gets exposed. You look at concrete coastal defences. How often do you see the concrete all crumbling away, and all the steel exposed?

Mike: That's due to inconsistent quality, though. You only get that problem if there's insufficient cover. As long as there's appropriate cover at design level, and the construction quality's consistent, then there shouldn't be a problem.

Loreta: Isn't inadequate cover more of a problem in a slender structure, though? You'd probably have less cover, compared with the big lumps of concrete they use for coastal defences.

Mike: Not if ...

Hanif: Just a second.

Mike: Yes, Hanif?

Hanif: Let's just think about what we're trying to resolve, here. The key issue is, what's the most suitable long-term solution? And in both cases, we're saying steel is necessary, either in an all-steel tubular structure or in the form of reinforcement inside concrete. But obviously exposed steel is unsuitable because of the problem of corrosion. So the question is, what's the most reliable way of protecting steel, over the long term? And we have to bear in mind that, just because something requires regular maintenance, such as painting, that doesn't necessarily mean it's unreliable. As long as the maintenance is consistent. The key question is, what's the most economical approach? So painting a steel structure every couple of years is uneconomical only if the cost of painting is more expensive than the additional cost of using concrete at the time of construction.

Mike: So, to determine the most efficient solution, we need to assess the lifespan of a reinforced concrete structure. If we know that, we can determine how many times the equivalent steel structure would need to be repainted over that same period, and what the cost of that would be.

Hanif: Yeah.

Mike: But this is really the point I'm making, Hanif. We can't categorically say that reinforced concrete is inefficient unless we look into it in detail.

Hanif: Of course not. Look, let me make a suggestion ...

10.2

Su: With very tall structures, one of the main loads you need to take into consideration, clearly, is the mass of the structure, its weight. Due to gravity, that mass exerts a downward load, which has to be transmitted to the ground. So that downward force means the structure is in compression, especially near the bottom. Obviously, the closer you are to the bottom, the more compressive force the structure is subjected to. But with tall structures, downward load compressing the structural elements is only part of the problem. Another major force acting on the structure is wind load, which is a horizontal load, exerted by air pressure against one side of the structure. Because the structure is fixed at ground level, and free at the top, that generates bending forces. And when elements bend, you have opposing forces: compression at one side, tension at the other. And at ground level, the wind effectively tries to slide the structure along the ground, and the foundations below the ground resist that. The result of that is shear force between the substructure and the superstructure. The wind generates tensile loads on the foundations of tall structures as well, as the bending action tries to pull them out of the ground on one side, a bit like a tree being uprooted by the wind. So the foundations need to rely on friction with the ground to resist the pull-out force, just as tree roots do. The action of the wind can also generate torsion. You get a twisting force sometimes, when the air pressure is comparatively higher against one corner of a building, although that's less of a problem with chimneys because of their circular profile. With very large masses of concrete, you also have to think about the forces generated by thermal movement. When concrete absorbs heat from the sun, you get expansion; as soon as the sun goes in, there's contraction. That movement can be significant over a large area, especially as the sun generally heats one side of a structure much more than the other. So there are all kinds of different forces acting on a tall structure.

10.3

Andrej: The record speed exceeded the standard operating speed by a huge margin. It was 80% faster at its peak. So you would imagine that the TGV used for the record run was heavily modified. In fact, that wasn't really the case. The train was modified to a certain extent but, with a few exceptions, it was essentially just an ordinary TGV. As you can see from this slide, one of the biggest differences was that the modified train was significantly shorter, in order to make it lighter. There was a 50% reduction in length, down to 100 metres, compared with a 200-metre standard length. The coaches being pulled were perfectly standard – the only differences were that some of the seats had been removed to make way for all of the monitoring equipment that was carried on board. And some changes were made to the bodywork, to make it slightly more aerodynamic, which meant the drag coefficient was reduced by 15%. The wheels on the modified train were marginally bigger than the standard size. The diameter was increased by 19%, in order to reduce the speed of revolution, to limit friction and centrifugal force. And the power of the electric motors was substantially higher than the standard units – boosted by 68%. But none of the changes was fundamental. So my point is, standard high-speed trains can be made to go faster by a considerable amount.

10.4

Narrator: In the late 1940s and early '50s, the United States Air Force carried out a series of experiments to explore how much physical stress the human body could withstand. A key aim was to test how much G-force pilots were able to cope with and see what would happen if they exceeded their limits. Led by Air Force doctor John Paul Stapp, a number of spectacular tests were carried out at Edwards Air Force Base in California, a location suitable for the experiments thanks to its 600-metre rail track, specially designed for high-speed rocket tests. A rocket sled, capable of reaching speeds approaching the sound barrier, was mounted on the track. On top of the sled, named *Sonic Wind*, researchers fixed a seat, intended for an abnormally brave volunteer. Refusing to give the dangerous job to a member of his team, the man in the hot seat was John Stapp himself. Over several runs, Stapp was subjected to progressively greater extremes of force. Each time, he resisted. Eventually, the time came to take the ultimate risk, to surpass what many doctors believed to be a deadly level of G-force. And so on December 10th 1954, Stapp was strapped onto *Sonic Wind* for the mother of all rides.

10.5

Narrator: That day, Stapp was subjected to extremes of force beyond the imagination. When the sled's rockets fired, he shot from zero to over 1,000 kilometres per hour in just three seconds, subjecting him to 20 Gs. When the sled hit the pool of water in the braking zone, it was like hitting a brick wall. Stapp slowed from the speed of a bullet to a complete stop in little more than a single second. Incredibly, John Stapp survived the ride, although so much blood had rushed into his eyes that he was unable to see for some time afterwards. Before the test, doctors had believed that human beings were incapable of surviving forces greater than 17 Gs. When the sled hit the water, Stapp had pulled a crushing 46 Gs.

10.6

Jasmine: I think what he's suggesting in terms of acceleration and deceleration forces is reasonable.

Andrew: Yeah. 2 G sounds about right. Anything less than that, and the track length's going to exceed the size of the site. And if you start getting close to 3 G, or beyond that, then that's probably going to be a bit too much for the average passenger.

Jasmine: I'd say so. His calculations for the total distance for acceleration and deceleration seem about right. The problem I have is with the length of the track. I think his ten-kilometre figure is OK for an ideal world scenario, but it doesn't leave much margin for error.

Andrew: No. Because at full speed, you're going to be covering, what, a kilometre every three seconds. So if there's some kind of problem, you're going to be eating up the kilometres at a pretty frightening rate.

Jasmine: You can say that again. I think he'll need every kilometre of track length he can get on that site. Plus some sort of emergency stopping facility at the end of the line, just in case.

Andrew: Definitely, yeah.

Jasmine: Then I don't know what you think about using wheels, instead of skids.

Andrew: Well, technically, it's feasible to build wheels capable of spinning at that sort of speed, because it's been done on land speed record cars. The only problem is, if you get a wheel failure at the kind of speeds we're talking about, the consequences are going to be unthinkable.

Jasmine: Yeah. I haven't calculated exactly what centrifugal forces they'd have to cope with, but for wheels of about 500 mil diameter, at full speed, I worked out they'd be spinning at over 13,000 rpm.

Andrew: Yeah, that's a lot. Plus, of course, skids should give better frictional resistance under braking.

Jasmine: Possibly.

Andrew: Maybe not?

Jasmine: Well, the friction from wheel bearings spinning at that sort of speed might be higher. And the skids wouldn't be in permanent contact with the rails, don't forget. But, anyway, I think skids are the only safe option.

Andrew: I'd go for skids. Definitely.

Jasmine: And then for the brakes, I think the first point is that, for the initial deceleration, even without applying any brakes, the aerodynamic resistance is going to be huge. In fact, that alone might even exceed 2 G, for a short time.

Andrew: Possibly. It'd depend how much drag there was, which obviously depends on the bodywork design, doesn't it?

Jasmine: Yeah.

Andrew: I don't like the idea of a friction system, against the rails. It would have to withstand a tremendous amount of heat.

Jasmine: Yeah. I think that's a non-starter, at these kinds of speeds. Aerodynamic braking has got to be the best option. Possibly, you could deploy flaps initially, at top speed, then maybe release a parachute as a second stage. Maybe deploy the parachute at, I don't know, what sort of speeds do dragsters reach? They use parachutes, don't they? What do they do? 400 Ks?

Andrew: A bit more, I think. 450, something like that. There's also the option of reverse engine thrust, like they use on aircraft.

Jasmine: In that case, though, you'd still need another system, in case you get an engine failure. But it's a possibility. I think the bottom line is that it needs a combination of systems to make it absolutely fail-safe.