The Lord of the Rings

Introduction

The Lord of the Rings, published in 1954-5 by J R R Tolkein, is a classic work of epic high fantasy. As such, it is not an obvious subject for a Physics-based analysis, but it is nonetheless an interesting one. The plot of the novel involves a classic quest, in which a hobbit, Frodo Baggins, and supporting characters journey through Middle Earth with the goal of destroying a mystical object. Along the way, the characters encounter frequent conflict and battle situations. The novel, and its prequel *The Hobbit*, have recently been adapted as major motion pictures. Previous adaptations include an animated film and radio versions.

Of the major races in the story - hobbits, dwarves, men, elves and wizards - only the last two routinely use magic. The remaining races inhabit a world in which, while magic occasionally intervenes, physical laws govern their lives. Most indications in the novel are that those laws are comparable to those in our own world, with the strength of human men equal to those around us, and the skill of the Dwarves said to be in their metallurgy rather than in any particular mystic properties.

As with any new world, there are several areas that can be explored in a physics context. Here we focus on two:

- Metallurgy and Mithril
- The Great Eagles of Middle Earth

Moria Silver

> *'Mithril! All folk desired it. it could be beaten like copper and polished like glass; and the Dwarves could make of it a metal, light and yet harder than tempered steel. Its beauty was like to that of common silver, but the beauty of mithril did not tarnish or grow dim.'*
>
> *– Gandalf, Lord of the Rings, Book II, Chapter IV.*

Mithril, or Moria Silver, is a hard, shiny metal, light enough to wear as chain mail and yet with the ability to protect against significant impact. Rather to the surprise of his friends, a chain-mail corselet of mithril protected the hobbit Frodo from a severe impact during the rush to escape Moria. The same corselet had, some years, earlier protected Frodo's uncle Bilbo from a similar impact during the Battle of the Five Armies. In both incidents, the hobbit was left bruised, winded and even briefly unconscious, but did not suffer any lasting, severe injuries.

If we focus on the incident in *Lord of the Rings*, we can calculate some of the properties of mithril. The portrayal differs somewhat between book and film. In the former, a 'man-sized' orc cheiftan thrusts a spear at Frodo's chest. In the latter, a twenty-foot-tall cave troll takes the same role, striking Frodo against a wall. In both cases, his survival is attributed to the mithril coat. Taking the movie visualisation as the more extreme example, we can make some order of magnitude estimates.

The cave troll is well-muscled but otherwise proportioned like a human - perhaps the best analogy would be an Olympic-class weight lifter. The average male super heavyweight athlete at the London 2012 Olympics weighed 140 kg and stood 160 cm tall. A similarly built twenty-foot (6 m) cave troll might weigh 7400 kg. Given that the Olympic record for the 'snatch' (i.e. rapid lift) is 212 kg, we might expect the troll to lift a similar multiple of his body mass - an enormous 11.2 tonnes and can assume the weight of the spear to be comparable. The troll thrusts the spear, rather than allowing it to fall $x = 6$ m under gravity. We must assume that he finds this equally efficient and so that the spear would reach a velocity $v = \sqrt{2gx} = 11\,\mathrm{m\,s^{-1}}$. While there may be factors of a few missing from our analogy, we must assume that Frodo absorbed a change of momentum of at least 120,000 $\mathrm{kg\,m\,s^{-1}}$ - equivalent to the impact of a reasonably sized car moving at 60 mph. Treating a Hobbit physically as a young human child (since they are described in those terms in the text), the risk of fatality in such a circumstance would be $>$90%, suggesting Frodo's survival is pretty low. The probability of serious injury is higher still - either Hobbits are considerably more robust than the average pedestrian or Frodo must bounce back from significant internal injuries!

Interestingly, there is one metal in our world which may have comparable properties to mithril in many ways. Titanium has the highest strength to weight ratio of any metal, is silvery, corrosion resistant and has a high melting temperature. Titanium alloys can achieve tensile strengths of 1400 MPa - easily sufficient to absorb the impact discussed above without distortion, assuming that the coat has a cross-sectional surface area of order $1\,\mathrm{m}^2$ and that the impact is absorbed over a fraction of a second. Even assuming a relatively small, 0.01 m^2 impact point, the coat would still not distort significantly. A titanium coat large enough for a Hobbit would likely weigh only ~ 5 kg - not unreasonable when carried across the body.

The Eagles are Coming!

> *'I will bear you' answered Gwaihir, 'whither you will, even were you made of stone.'*
> *'Then come, and let your brother go with us, and some other of your folk who is most swift! For we have need of speed greater than any wind, out-matching the wings of the Nazgûl.'*
> *'The North Wind blows, but we shall out-fly it,' said Gwaihir. And he lifted up Gandalf and sped away south.'* – *Lord of the Rings, Book VI, Chapter IV.*

The race of Great Eagles in Middle Earth is a relatively minor one, which nonetheless plays a pivotal role in both *The Hobbit* and *The Lord of the Rings*. At several points, the eagles intervene, carrying either news or other individuals as required. While their actual size is not quantified in the text, they are sufficiently large to carry a six-foot-tall wizard (or a dwarf and hobbit) over a considerable distance. On screen they are portrayed as enormous creatures, proportioned much like a Golden Eagle, but with wingspans apparently exceeding 10 m. It is interesting to consider whether this is likely to be feasible.

The lifting power of a bird's wings are, broadly speaking, proportional to their surface area (i.e. size of the bird squared). The weight of a bird (or indeed any creature) scales roughly as their volume (their size cubed). As a result, the balance of forces becomes challenging as the size of the bird increases. Large birds are either forced to flap their wings more frequently (thus forcing more air downward and creating more lift, but at the expense of carrying more muscle mass) or adopt a gliding strategy that requires minimum exertion but relies on considerable airspeed.

At constant elevation, the pressure exerted by a moving fluid such as air scales with its velocity as $P \propto \frac{1}{2}\rho v^2$ (Bernoulli's theorem). This pressure must balance the weight of the bird. While wing shape and structure can modify this to some extent, introducing a modifying factor C of order unity, the basic scaling law remains unchanged. A flying creature displaces the air such that the pressure exerted, $\frac{1}{2}\rho v^2 C$ per unit area, balances their weight. Given achievable velocities on launch and known wing profiles, a lifting power of 25 kg per m^2 of wing area has been suggested as a limit on bird flight.

The largest known flying creatures in the past, pterosaurs, had wingspans of 11 m. They likely devised strategies for achieving high velocities at launch and were primarily gliding creatures. They also had different wing profiles and materials to living birds and so may not be good models for Middle Earth's Great Eagles. The largest currently extant bird is the Wandering Albatross with a wingspan of just 3.5 m, although fossilised examples of *Argentavis magnificens* reached 8.5 m wingspans. While resembling the Great Eagles of Middle Earth, this creature appears to have been primarily a glider. It would have required a head-wind to take off and may have lacked the musculature required to flap its wings for an extended period. Despite its large size, the estimated mass of these birds is only ~ 80 kg.

In this respect then, the Eagles of Middle Earth skirt the borders of feasibility. Birds approaching this size certainly have existed, and the limited descriptions in the books, which emphasise 'sweeping' and 'swooping' are not unreasonable. Carrying a grown man, comparable to their own weight, might present difficulties, but could be accounted for by assuming that the birds built sufficient musculature to lift large prey animals. Given a wingspan of 8 m, and a average width of 1 m, a lifting power of some 200kg is not beyond the bounds of possibility, given a high-speed take-off. As shown in the films, the birds are a little more active than might be expected for a bird this large but that can, perhaps, be put down to dramatic license!

Concluding Thoughts

The balance between magic and physics in a fantasy Universe is always a complex one. In the case of Middle Earth though, it would appear that Tolkein's descriptions, and their visualisation on screen, have a physical plausibility which may help explain some of the latest appeal of the classic novels. While the focus is, of course, on the characters' journeys in both the literal and metaphorical sense, a sense of realism shows the depth and complexity of world building.

There are several other points in the books where physical sciences rather than magic plays a decisive role in events - the dwarves' escape from Mirkwood's elves in *The Hobbit*, the breaking of the gates of Minas Tirith, and Gandalf's fireworks, to name just a few. Each of these is an interesting exercise in order of magnitude physics, empahasising both the similarities between our world and Middle Earth, and the differences.

References and Further Reading

The Lord of the Rings and The Hobbit, J R R Tolkein
http://www.allthingsgym.com/london-2012-weightlifting-athletes-statistics/ - Olympic weightlifting statistics
http://assets.dft.gov.uk/publications/pgr-roadsafety-research-rsrr-theme5-researchreport16-pdf/rswp116.pdf – The relationship between speed and fatal injury
http://en.wikipedia.org/wiki/Titanium
http://planetsave.com/2013/06/28/argentavis-magnificens-largest-flying-bird-ever-giant-teratorn-facts-extinction-wingspan-etc/
http://www.youtube.com/watch?v=Vi5pdd7xHNI - Frodo vs the cave troll.