

# Thunderbirds

## Introduction

Thunderbirds was a British children's television series first broadcast in 1965-6. It was distinguished by the use of marionettes to animate the central roles, and the consequent use of filming in miniature. Two feature films were made in the 1960s, and a third, live action movie in 2004. It is currently being redeveloped for television. The descriptions here centre on the original, 1960s version. The plot revolved around a secret organisation known as International Rescue which is dedicated to the rescue of those whose lives would inevitably be lost. To carry out this mission, the founder of the organisation, Jeff Tracy, recruited a scientist called 'Brains' and his own five sons, amongst others, to develop and deploy advanced technology.

Created during the optimistic period of the 1960s, the series puts great emphasis on the use of atomic power, and explores both the positive and negative consequences of new technologies. As such, it is a showcase of devices and scenarios that push the (then current) limits of physical science. Physics topics that can be explored include:

- The speed of Thunderbird One
- The orbit of space station Thunderbird Five
- Moving the Empire State Building
- The scaling laws that govern miniature filming

## Thunderbird One

*'Aircraft approaching from the East. Height: two thousand, five hundred feet. Speed... seven point five thousand miles per hour!'*

*'Seven point five thousand miles an hour?! Have you gone crazy?'*

*- The controllers at London Airport first encounter Thunderbird One*

Thunderbird One is International Rescue's rapid reconnaissance vehicle. Described as a hybrid rocket-plane, it has swing wing capability and increases its wing surface area at low velocities, while presenting a more missile-like appearance at top speed. The best evidence on screen for that speed appears in the exchange quoted above from the first episode, where the speed is explicitly stated as 7500 mph. However, this is during the deceleration phase on approach to the airport. Canonical reference material approved by the creators of the show state Thunderbird 1's top speed as 15000 mph, its maximum altitude as 150,000 ft (30,000 m) and its weight as 140 tons. These impressive statistics beg several questions - notably whether such speeds are possible and what material would be sufficiently robust, while also sufficiently light to construct a craft of this kind.

The altitude at least does not present a problem. Thunderbird 1 is atomic powered, and so does not rely on oxygen for combustion. At the maximum altitude, the thinness of Earth's atmosphere is also helpful, since the friction due to air will be reduced. However, the speed as quoted is something of a challenge. Thunderbird 1's top speed corresponds to a staggering  $6.7 \text{ km s}^{-1}$ , or Mach 20. This is more than twice as fast as existing missiles, which do not have to accommodate a human pilot's acceleration limits.

Dr Phil Atcliffe, an aeronautics engineer at the University of Salford, has written about the aerodynamics of the Thunderbirds machines, and has observed models of the craft at supersonic speeds in a wind tunnel, reaching speeds of Mach 2.25. While the overall design is indeed aerodynamic, he found evidence for shocks caused by extended wingtips, suggesting that reducing their span at high speeds is indeed a good idea - although arguably they should retract entirely into the smooth shell except at low speeds and low altitudes.

Even given a shape well-suited for supersonic travel, Mach 20 presents an additional problem: friction. At subsonic flight, friction scales with velocity squared. At Mach speeds (multiples of the local speed of sound), individual air molecules cannot move out of the way of the vehicle, which must instead push through it. This results in a shockwave, which manifests as the 'Sonic Boom' at Mach 1, and which dissipates energy into heating the air at higher speeds. The recently-retired space shuttle usually orbited at a velocity of 17,500 mph (and thus an altitude of  $h=211$  km since balance of forces gives  $v = \sqrt{\frac{GM}{r}}$  and  $r = R_{\text{earth}} + h$ ). The shuttles reentered Earth's atmosphere at a speed comparable to this, or Mach 25, decreasing to Mach 10 at lower altitudes. The heat of friction at these speeds is sufficient to dissociate molecules and ionise the atoms in the air, causing the craft to be enveloped in a fireball. Thunderbird One would no doubt encounter similar problems, and with a metal hull rather than the ceramic and carbon-composite tiles the shuttle used as a heat shield.

It's worth noting that recent attempts to write a technical manual for the *Thunderbirds* universe has invoked an unknown material known as Cahelium-X, force fields and radar deflection systems to circumvent this problem - a necessary step since the streaking fireball of Thunderbird One would otherwise trace a glowing path pointing straight to her secret base!

## The Orbit of Thunderbird Five

*The electronic eyes and ears of the International Rescue organisation, Thunderbird 5 maintains a geo-stationary position beyond the orbits of commercial and military satellites.*

*- The International Rescue Agents' Technical Manual*

The International Rescue orbiting space station Thunderbird Five provides a surveillance and monitoring platform. Manned by one of the team, it allows distress calls to be intercepted and the progress of rescue missions to be monitored. A computer mainframe automatically filters signals and brings them to the attention of the duty space monitor - usually John Tracy. The orbit of the space station is not explicitly stated during the television series. However, it is conventionally believed to be geostationary.

A geostationary orbit is defined by the balance of gravitational force with centripetal force such that one period of the orbit is completed in one day.:

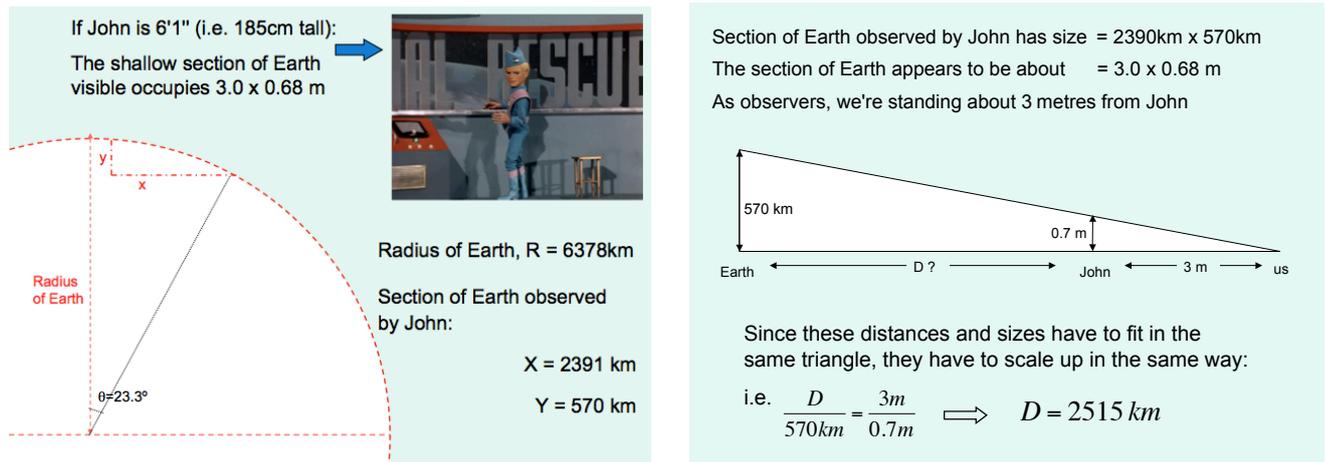
$$\frac{GMm}{r^2} = m r \omega^2 \quad \Rightarrow \quad T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{r^3}{GM}} = 24 \times 3600 \text{ s}$$

Such an orbit occurs at approximately 36,000 km above the Earth's equator - 10% of the distance to the Moon. By contrast, the International Space Station orbits at around 420 km. While it is easier to communicate with a fixed ground station from a synchronous orbit (which, of course, is one of the reasons they are used for telecommunications satellites), the challenge of placing personnel in the correct orbit is substantial. Reaching geostationary orbit requires a factor of 50 times more energy than reaching the ISS - an already challenging task. Given that all food, air and other supplies would have to be lifted from Earth, as well as personnel, the advantages of geostationary orbit would have to be

significant to justify it!

This can be taken as interesting evidence for how computers have changed our vision of the future. When *Thunderbirds* was created, the idea that a computerised, unmanned satellite could be more efficient than a human monitor was inconceivable. Now, it is likely that any organisation such as International Rescue would launch a constellation of satellites, spaced in longitude to ensure line-of-sight contact, rather than a manned station. More likely still, they would piggy-back an existing constellation such as the GPS network.

In fact, internal evidence on screen suggests that the orbit is rather lower than geostationary. Taking John's view through the windows of TB5 as evidence:



## Moving the Empire State Building

*'You are about to witness, folks, one of the greatest pieces of engineering of all time... Today, the Empire State Building here in New York City is going to be moved 200 yards, not piece by piece but as it stands - all 1250 feet of it... Sounds easy doesn't it? But it took ten years of planning and ten years of construction to get this far... She's moving! Yes, she's moving!*

*- Ned Cook, Terror in New York City*

In the twenty-first century of *Thunderbirds*, New York has become run-down and is undergoing a phase of urban regeneration. At one point this requires moving the Empire State Building. According to the engineering plans, this is to be done upright, lifting the structure on hydraulic jacks before sliding a platform underneath, and moving the building on what appears to be some form of maglev system. Maglev systems rely on the repulsive force generated by electromagnets to provide a frictionless contact, over which a vehicle can move. While never widely used, examples exist in small transport systems and other systems are under development. The use of maglev in *Thunderbirds* is more adventurous. As is somewhat the norm for this universe, the attempt does not end well. So, was the attempt doomed from the start, or could better planning and checks have prevented the catastrophe?

Estimating the weight of the Empire State Building is challenging since there is no sensible way to measure it! The canonical figure is 365,000 tonnes, although estimates based on the construction materials and occupancy can be higher. The footprint of the building is about 2 acres, or  $A = 7200 \text{ m}^2$ . Resisting this is a magnetic pressure  $P_{\text{mag}} = \frac{B^2}{2\mu_0}$  where  $P_{\text{mag}}$  is measured in pascals and  $B$  in teslas. So...



Dimensions of the Empire State Building: 443 x 120 x 60m

Weight = 365,000 tonnes

This exerts a pressure:  
 $P = W/A = 3.65 \times 10^8 / (120 \times 60)$

⇒ Supporting this on a magnetic field would require a balance of pressure:

$$P = B^2/2\mu_0 \approx 50,000 \text{ N m}^{-2}$$

⇒  $B = 0.35\text{T}$  or 3500 gauss!

This is not impossible by any means. The superconducting magnets used at CERN reach field strengths of 8 T. However these also need cryogenic cooling and are both heavy and extremely expensive. A more feasible alternative is the more moderate fields (1.25 T) achievable with neodymium magnets.

So if the concept of magnetic suspension itself is not unreasonable, what about the energy requirements?

The machine bracing the building, lifting and moving it appears to double the footprint, and likely doubles the weight, having little effect on the required magnetic field for levitation, but substantially increasing the energy requirements.

On screen the building moves across its own footprint in about 20 seconds, suggesting it reaches a velocity of about 3 m/s. To move the weight of building plus vehicle then, a kinetic energy of  $\frac{1}{2} m_{\text{total}} v^2 = 3.3$  gigajoules must be provided to the system - the approximate output of three of the UK's nuclear power stations at full capacity. As well as kinetic energy, we should also consider the potential stored in the magnetic field. This is simply given by  $\int F dx = \int P dV = \frac{B^2}{2\mu_0} \cdot A \cdot d = 0.04$  GJ, assuming a gap of  $d = 0.1$  m between components of the maglev - a relatively small addition to the already significant energy requirements. While the vehicle is certainly atomic powered, we shall have to assume nuclear power systems become significantly less heavy, bulky and inefficient over the coming decades!

## Scaling Laws and Miniature Filming

*Since the early days of silent films, model effects - or 'miniatures' - have played an important role in creating screen illusion. With the use of models film-makers can create scenes - or even entire worlds - that would otherwise be impossible to capture on film. - Model Futures, RAF Museum London, May 2014*

The use of model shots (or, more recently, computer generated imaging) in filming is now a well established technique. When *Thunderbirds* (and its precursors) was filmed, it was still relatively new - particularly for a British television programme. The Century 21 special effects department were forced to be innovators, developing new techniques. While it is clearly impossible to topple buildings, build aircraft and create explosions on a scale appropriate to real life, the design and filming of miniature simulacra presents its own problems.

**Forced perspective:** Forced perspective is used in several places in the show to place large objects (such as a human hand) in the foreground, while model shots are used in the background. Alternately, models of different sizes can be combined in a single image without necessarily building all to a consistent scale. This relies on the simple observation that objects in the foreground appear larger than those in the background, and that the apparent size is proportional to the distance from the observer. By placing a small object a little closer to the camera than the scene requires, it may appear to be a large object, further away.

*Slow speed filming:* Any interaction between two objects is defined in part by its timescale. An explosion or collision will not appear realistic if the debris moving on ballistic (gravity-influenced) trajectories move more rapidly or slowly than expected. One way to create the illusion of a correct timescale is to film at a higher frame rate, and play it back at a more standard scale.

Modern film cameras can film at thousands of frames per second. Fortunately, the filming requirements of *Thunderbirds* were a little less demanding.

*Waves and Surface tension:* Many of the most exciting scenes in *Thunderbirds* involves action taking place on, or above, water. As such, the height and behaviour of waves can become important for realism. Most of the surface waves we observe are what is known as gravity waves, with their wavespeed scaling with their wavenumber,  $k$ , as  $c = \sqrt{\frac{g}{k}}$ . However, for very small waves, surface tension becomes important, acting as an elastic restoring force. This modifies the properties of the wave such that  $c = \sqrt{\frac{g}{k} + \frac{\sigma k}{\rho}}$  where  $\sigma$  is the surface tension of the fluid and  $\rho$  its density. For scale filming, where the waves are necessarily small to be in proportion to the models, this extra term can be significant. Special effects operators often use chemical detergents (non-foaming, obviously!) to break the surface tension and create a more natural effect!

## Concluding Thoughts

The universe of *Thunderbirds* is a plausible extension of our own, but its technology has evolved in different ways from a common origin in the 1960s. While computerisation and telecommunications have advanced beyond anything imaginable in 1965, we certainly lack the efficient fusion reactors, force fields, artificial gravity and routine spaceflight predicted by the show's creators. Nonetheless, *Thunderbirds* is notable for its optimistic view of technology, and its creativity both in the scenarios it describes, and the way those were filmed and presented.

## References and Further Reading

<http://stupidquestionarchives.blogspot.co.uk/2008/03/empire-state-building-weight.html>

<http://www.manchestereveningnews.co.uk/news/greater-manchester-news/could-thunderbirds-really-fly-967239>

<http://www.grc.nasa.gov/WWW/BGH/hihyper.html> - NASA page on speed regimes.

The International Rescue Thunderbirds Agents' Technical Manual - Graham Bleathman, Sam Denham, Haynes, 2013

Special Effects Superman - the life and work of Derek Meddings by M & P Shubrook, 2008.

The time taken for dust or debris to settle from height  $s$  after an explosion depends on the acceleration due to gravity ( $a$ ).

$$s = ut + \frac{1}{2} at^2; \quad t = \sqrt{(2s/a)}$$

The model of TB2 used in *Thunderbirds* was about 3 feet long – the craft itself was meant to be 250 feet long!

=> For an explosion to look convincing behind it, debris would have to take  $\sqrt{(250./3.)} = 9.2$  times longer to settle than it does under gravity.

Since we can't control gravity itself (unlike International Rescue), the cinematographers had to film 220 frames per second, before playing them back at the standard 24 frames per second rate!