operate at high angles of attack at which it would otherwise stall, and to gain substantial extra lift to support the insect's weight.

How should a MAV be designed? Most insects have two pairs of wings, often linked into a single aerofoil. Flies get by with one pair and so, with care, could the MAV. The wings must be deformable, at the least developing a propellor-like twist, which reverses between the half strokes, like the sail on a tacking dinghy. A simple sail-like wing with a controllable boom and a membrane might be a reasonable initial design. As a minimum, Ellington suggests that the stroke amplitude should be variable and controllable. So should the location, relative to the body, of the area through which the wing sweeps (Fig. 1), because this would influence the line of action of the mean aerodynamic force, which in turn would control the body angle, the stroke plane angle and hence the flight speed. The wings' angle of attack must simultaneously alter, to remain optimal as the speed changes. For manoeuvres, the amplitude of the stroke and the location of the swept area must be independently controllable on the two sides of the body.

Flapping is potentially expensive, as the wings must gain and lose kinetic energy during each half stroke. Insects minimize the cost by storing the energy elastically at the end of each half stroke and returning it at the start of the next. Micro-air-vehicles would need to do the same, operating as resonators oscillating at their natural frequency, which would necessarily be fairly constant.

In any flying machine the ratio of power to mass is crucial. It would be hard to make a machine as light as an insect of the same size. A tiny internal combustion engine or a lithium battery might well provide enough power input. How could power output be maximized? The principal available variables are stroke amplitude and frequency, and wing length. Amplitude should be left adjustable as a means of varying power for manoeuvres and perhaps for carrying loads. Wing length and stroke frequency would be built into the machine's design. Which would have the greater influence on power, and what else may they affect?

Ellington's analysis considers a hovering machine with a basic stroke amplitude of 120°, a lift coefficient of 2, and wings with an aspect ratio (span/mean width) of 7; these values are all well within the insect range. Flapping is assumed to follow simple harmonic motion, and the geometric centre of the wing to be halfway along its length. Using his own aerodynamic equations[6], with a new assumption derived from the spiral vortex, he concludes that longer wings will be far more effective than higher frequency in raising the power/mass ratio, so that a given mass will be supported with less power by using longer wings and a lower frequency. On the other hand, higher frequencies would give higher maximum speeds.

The insects show what can be achieved given a good power source, clever controls, superlative materials and 350 million years of research and development. Ellington's analysis suggests how this might best be copied in a rather shorter time. Over now to the engineers. ■

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Astronomy

Eyes wide shut

David Jewitt

Astronomers like to forget that the roots of their subject lie in ancient superstitions about the influence of the cosmos on everyday affairs. In fact, astronomy and astrology were closely intertwined as recently as four centuries ago, when Tycho Brahe laid the foundations of modern astronomy while simultaneously maintaining a lucrative business in personal horoscopes. Modern astronomers generally scoff at such superstitious beliefs, so it is somewhat ironic that science has in the past few decades uncovered compelling evidence for celestial interference in terrestrial matters.

It is now clear that asteroids occasionally wander from the main belt beyond Mars because of chaotic instabilities caused by Jupiter. Some of these errant asteroids strike the Earth with terrible consequences. On page 165 of this issue, Rabinowitz *et al.*[1] report that the number of threatening near-Earth objects (NEOs) larger than 1 km in diameter is only half the previous estimates. But we still have no effective means of detecting them all, and no form of self-defence.

The Earth bears the scars of previous encounters with NEOs. Hundreds of impact craters, some the size of small American states, have been discovered on the surface of our planet. Each was produced by a

NATURE

100 YEARS AGO

For several years Prof. W. O. Atwater has been engaged in investigations to determine whether the energy given off from the body of a man in the form of heat, or of heat and external muscular work, is equal to the potential energy or heat of combustion of the material actually burned in the body; in other words, whether the law of conservation of energy holds good for the living organism. The latest number of the *Physical Review* (vol. ix., No. 4) contains a concluding account, by Prof. Atwater and Mr. E. B. Rosa, of experiments made with the view of testing this point. … The mechanical efficiency of a man was determined by a comparison of the energy used when at rest and when performing muscular work. The work done, divided by the total energy yielded by the body, gave 7 per cent. as the mechanical efficiency. As, however, a large amount of the energy received was used up in the body, only the excess of energy absorbed in the work experiment over that required when the subject was at rest should be charged against the work done. When this was taken into account the mechanical efficiency of man came out at 21 per cent., which equals or exceeds that of the best compound condensing engines with the highest efficiency boilers.

From *Nature* 11 January 1900.

50 YEARS AGO

As normal blinking is involuntary, it might be expected that blinking would proceed at its normal or at a somewhat reduced rate during sleep, as with breathing and heart-beat. This is not so, however, though little seems to have been published on the subject, especially on the quantitative side. … In all cases so far examined, it has been found that in sleep the eyelids are quiescent, and show no signs whatsoever of blinking movements. During a recent long train journey, opportunity was afforded of examining the problem in its quantitative aspects, the subjects being a young man and his wife, both of whom fell asleep several times during the course of the journey. … The interblink periods of each subject when awake and when in the resting condition were sensibly identical, whereas in sleep bilateral lid movements ceased entirely.

From *Nature* 14 January 1950.

devastating explosion that must have been fatal to life in the surrounding areas on scales from local to global (Fig. 1). The Cretaceous–Tertiary mass extinction of 65 million years ago seems to have been triggered by the impact of an asteroid 10 km in diameter[2]. Ten thousand people killed by 'falling stones' in Shanxi Province, China, in 1490 were possibly the victims of a much smaller and thoroughly fragmented projectile. Still more recently, on 30 June 1908, 1,000 square kilometres of Siberian pine forest in Tunguska were blown flat by a 10-megaton atmospheric blast caused by a 70-metre asteroid.

The gradual acceptance of the evidence for impacts by asteroids (and comets) has led naturally to questions about the magnitude of the threat posed by NEOs to life on Earth[3,4]. Rabinowitz and colleagues[1] provide the most recent and best controlled estimate of the number of large, potentially Earth-threatening NEOs. They report that there are nearly 1,000 NEOs larger than 1 km in diameter and that, given the present rate of discovery, it will take 20 years for 90% of these objects to be found. Should we worry?

The answer depends on the number of fatalities to be expected, but also on personal assessments of risk. The number of NEOs found by Rabinowitz *et al.* is within a factor of two of previous estimates based on less-controlled samples, so published estimates of impact mortality are essentially unchanged. Considering events of all energies there is about 1 chance in 20,000 of being killed by an impact during the course of a human lifetime[4], similar to the likelihood of being killed in an airplane accident. The perception of risk from impacts is smaller than for being killed in a plane crash because planes crash at a steady rate with (relatively) few deaths per event, whereas lethal impacts are rare but kill a lot of people. At the very least, the potential consequences of impact are large enough to cause concern.

In the past decade, thanks to several reported near-miss encounters with small objects, the impact threat has become a subject of intense interest to the general public (spawning the popular movies *Deep Impact* and *Armageddon*). In 1994, the United States House Committee on Science and Technology went so far as to order the US space agency NASA to "catalogue within 10 years the orbital characteristics of all (Earth-orbit-crossing) comets and asteroids that are greater than 1 km in diameter". This particular cut-off diameter was picked in part because 1-km NEOs are thought to be the smallest objects capable of wreaking global havoc (for example, by disrupting the climate and shutting down photosynthesis). Smaller objects cause regional damage but would be unlikely to precipitate a major extinction like the Cretaceous–Tertiary event.

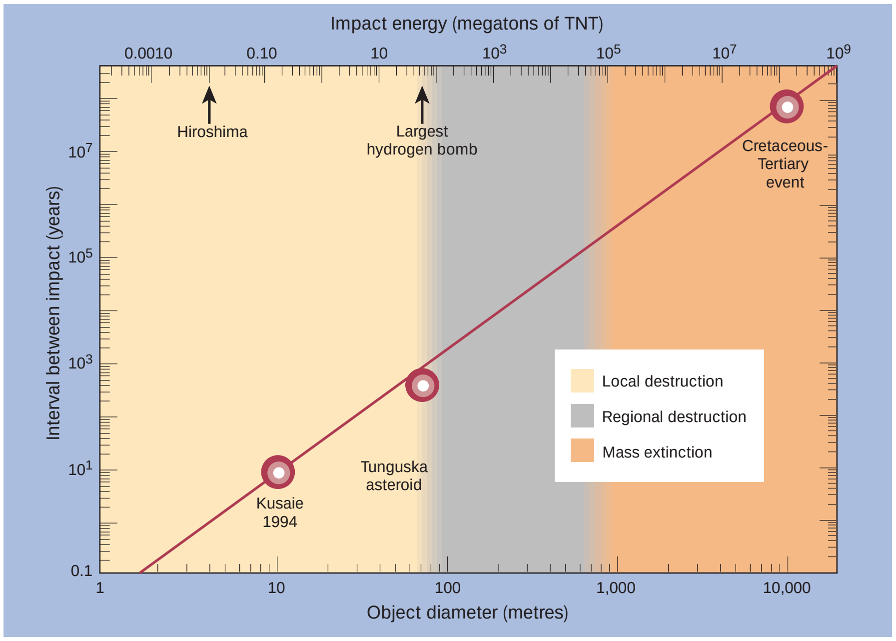

Figure 1 **Previous impacts by near-Earth objects (NEOs). Three well-documented impacts are marked. The dinosaur-killing Cretaceous–Tertiary event was caused by an asteroid 10 km in diameter. Such objects hit the Earth about once every 100 million years. A 50-metre object similar to that which destroyed the Tunguska pine forest strikes the Earth once every few centuries. Atmospheric explosions observed by satellites above the South Pacific island of Kusaie in 1994 might occur every decade. NASA is committed to discovering 90% of all NEOs larger than 1 km in diameter (energy, 100,000 megatons). These objects are capable of wreaking global havoc but are very rare. The vast majority of the dangerous objects (those less than 1 km but more than ~100 metres in diameter) have yet to be discovered.**

Last summer, astronomers devised a new risk-assessment scale, similar to the Richter scale used for earthquakes, to help the public understand the hazard posed by a given NEO. The so-called Torino scale ranges from zero (no chance of a collision) to 10 (certain collision causing global devastation). No known NEO has yet had a Torino number greater than one. This is just as well because we presently have no coherent plan of action should a real threat arise. The simplest option — massive evacuation of the impact site — would be impractical because of the positional uncertainties and large numbers of people involved, and would be ineffective because the damage from large NEOs will be global. One option that has been discussed is the thermonuclear destruction of the incoming NEO (a bad idea because the shower of debris produced by the exploding NEO might be as damaging as the initial object, and would be radioactive). Given enough time, the NEO might be deflected from an Earth-intersecting path by a series of smaller explosions, or by attaching rockets or solar sails that use radiation pressure from the Sun.

The focus on NEOs larger than 1 km ignores the threat from smaller but much more numerous objects. The Earth's atmosphere offers little protection against objects larger than 100 metres in diameter[4]. These smaller objects outnumber NEOs larger than 1 km by a factor of 100, so they are much more likely to strike in our lifetimes. There is a 1% chance that the Earth will be struck by a 300-metre NEO in the next century[4]. Such an impact would deliver a withering 1,000-megaton explosion and cause perhaps 100,000 deaths. If the impact occurred in or near a densely populated region — the eastern seaboard of the United States, for instance, or Western Europe or coastal Asia — the fatalities could easily rise into the tens of millions.

Neither can we take refuge in the fact that 70% of the Earth is covered by oceans. Impact-induced tsunamis could wipe out coastal cities over a wide area. So, to have practical value, surveys should not be limited to the (observationally easy but numerically rare) 1-km NEOs, but should instead catalogue objects at least down to the few-hundred-metre size range[5]. What is needed is a more ambitious survey to completely identify the population of small, potentially threatening NEOs.

The strategy for such a survey has been explored by Alan Harris of the Jet Propulsion Laboratory[6]. He argues that the whole sky must be surveyed on a monthly basis with a sensitivity about 100 times greater than current NASA-sponsored surveys. How can this be done? A large (6–8-metre) telescope is required, with a wide field of view tiled with CCD (charge-coupled device) optical detectors and connected to a massive computer array capable of meeting the huge data-processing demands. The technology exists and tentative designs are beginning to appear[7–9]. Such a telescope, which would have many applications in other branches of astronomy, is projected to cost about $100 million (about half the price of a Jumbo jet). What is missing is any sign that such a facility will be funded by governments and their agencies. Perhaps astronomers can attract the interest of private donors in the search for threatening NEOs. If not, it seems we will have to face the asteroidal impact hazard with our eyes wide shut. ■

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Plant development

Gateway to the chloroplast

Kenneth Cline

Chloroplasts are essential organelles in plants and algae. In plants, they are formed by differentiation of a progenitor plastid, the proplastid. This process involves the import of roughly 2,000 different proteins from the cytosol, across the outer and inner membranes of the chloroplast envelope[1]. Proteins destined for the interior of the chloroplast are made as precursors, and the amino-terminal 'transit peptides' that direct import are removed once the protein is inside. *In vitro* studies have helped us to understand how chloroplasts import proteins[1]. However, models based on these studies have not been examined *in vivo*.

Bauer *et al.*[2] have now addressed the *in vivo* function of the putative import receptor Toc159. (The name Toc refers to the translocation apparatus of the outer-envelope membrane.) On page 203 of this issue they report the identification of a mutant *Arabidopsis thaliana*, known as *ppi2*, that lacks the Toc159 protein. The proplastids of *ppi2* fail to develop into chloroplasts and the plants die at the seedling stage, suggesting that Toc159 is essential for chloroplast development. The lethality of *ppi2* was unexpected because, in other protein-translocation systems, deletion of single receptors is generally not lethal[3]. Perhaps even more exciting is the fact that this study has identified two additional import receptor proteins (Toc120 and Toc132), and this may be the key to unravelling how plastids recognize a strikingly wide range of transit peptides.

Chloroplasts evolved from a photosynthetic bacterium that was taken up by a host cell. During evolution, most of the bacterial genes were transferred to the host's nucleus, so a mechanism was needed to return the corresponding proteins to the chloroplast. Successfully transferred genes acquired coding sequences for peptides that target proteins to the chloroplast, and the evolving chloroplast developed machinery to import these precursor proteins[1]. Because we can reconstitute import into chloroplasts *in vitro* (Fig. 1), various steps of the import process have been dissected and components of the machinery responsible have been isolated.

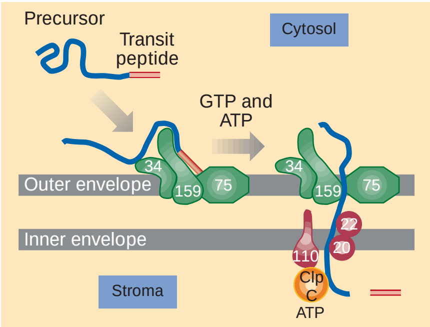

Figure 1 **Model for protein import across the outer and inner chloroplast envelope membranes. A Toc complex of Toc159, Toc75 and Toc34 has been identified by *in vitro* studies, and Bauer *et al.*[2] have now found two additional complexes that contain Toc132 and Toc120, respectively, in place of Toc159. Component proteins in the inner membrane are referred to as the Tic apparatus; for example, Tic110, Tic22 and Tic20. ClpC is a stromal chaperone that may provide the driving force for translocation.**

The identified components, although mostly hitherto-unknown proteins, seem to perform functions common among protein-translocation systems. For example, Toc159, which is found in the outer-envelope membrane, is considered to be a receptor because it interacts directly with the transit peptides of at least two precursors[4], and because antibodies to Toc159 inhibit precursor binding and import[5]. Another protein called Toc75 seems to form at least part of the channel through which proteins cross the outer-envelope membrane[6]. The chaperone ClpC, found in the interior (or stroma) of the chloroplast, may be the ATP-powered motor that 'pulls' precursor proteins through the channels[1].

The diversity of transit peptides promises to make characterization of receptor function in the chloroplast-import system particularly challenging. Transit peptides vary in size from 30 to more than 100 residues, they lack consensus sequences that could serve as address tags, and they have no apparent 'signature' secondary structures. Rather, transit peptides share only compositional features, such as a deficiency of acidic amino acids and an abundance of serine and threonine. The apparent degeneracy of transit peptides is probably due to their origins, which must have been a random process in which the organellar genes inserted themselves into nuclear DNA in-frame with bits of other coding regions.

In this context, the finding by Bauer *et al.*[2] that there are at least three import receptors — Toc159, Toc132 and Toc120 — is highly significant. These proteins are all expressed in chloroplast-containing tissue, they have similar structures, are orientated similarly in the membrane, and are present in outer-envelope translocation complexes. They are unlikely to be functionally redundant for at least two reasons. The first is the severity of the *ppi2* mutation compared with, for example, *ppi1* (another chloroplast-import mutant in which a member of the Toc34 family is disrupted[7]). Whereas the *ppi2* mutation is lethal, *ppi1* plants show delayed chloroplast development but they do survive and eventually appear similar to wild-type plants. Second, although Toc159, Toc132 and Toc120 have highly conserved carboxy-terminal GTP-binding and membrane-anchoring domains, their large cytosol-exposed domains — that is, those domains likely to make initial contact with transit peptides — show considerable sequence divergence.

A more attractive model is that different receptors, with different (possibly overlapping) specificities, accommodate different classes of precursor proteins. Bauer *et al.* suggest that Toc159 may be dedicated to photosynthetic proteins, whereas Toc132 and Toc120 could accommodate non-photosynthetic proteins. The chloroplast belongs to a family of developmentally interrelated organelles collectively called plastids. Plants tailor the type of plastid in each organ by expressing different sets of genes, depending on their metabolic needs. Many proteins are common among plastids, whereas others are specific to a particular plastid. So, a plausible idea is that different types of plastids, such as amyloplasts or chromoplasts, possess different receptor combinations. In support of this idea, transit