



STUART BURGESS



BIO-INSPIRED DESIGN





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Stuart Burgess

Bio-inspired design means looking at biological systems for inspiration to develop better engineering technology for human use. Nature contains such brilliant designs that it is now considered a very important source of ideas for engineering designers.





One early example of copying nature happened when the Wright brothers were designing the first aircraft, **Kitty Hawk**, at the start of the twentieth century. Engineers had been struggling to understand how to perform controlled flight.

However, when the Wright brothers studied bird flight, they saw how birds use their tail feathers to counteract the destabilising reaction moment that occurs when an aircraft makes a turn. This observation led them to design control flaps on their

aeroplane that made controlled flight possible.

I have had the privilege of carrying out several case studies in bio-inspired design over the last 20 years.

From this work I have published around 50 scientific papers detailing recommendations for bio-inspired design. In this pamphlet I will describe three of the most interesting projects I have worked on and summarise the lessons that I have learnt.





DRAGONFLY-INSPIRED MICRO AIR VEHICLE

Engineers are trying to develop very small air vehicles (micro air vehicles), about the size of a dragonfly, in order to carry out reconnaissance in hazardous places like nuclear power plants and damaged buildings.

At my university I have developed a micro air vehicle based on the design of the common European darter dragonfly. My team filmed dragonflies in the lab to study in detail how they flap their wings. We were amazed at how dragonflies can fly forwards, backwards and sideways with great precision and control.

We found that the dragonflies we captured flap their wings at 40 beats per second. In addition, as they flap

their wings, they twist them really fast in order to create a powerful vortex that gives them a strong lift force. We also dissected the dragonflies to see what was inside. We were astonished to find a precision hinge mechanism at the root of each wing that was so precise it was like looking at a Swiss watch!

An interesting feature of the wing hinge mechanism is that it consists of an intricate 4-bar linkage mech-



anism like you would find in a car suspension system. Engineers know that such systems have **irreducible complexity**. This means that all the parts of the mechanism must be in place at the same time to have a useful function.

Such mechanisms cannot evolve step by step but must be planned and designed at the beginning by a Designer.

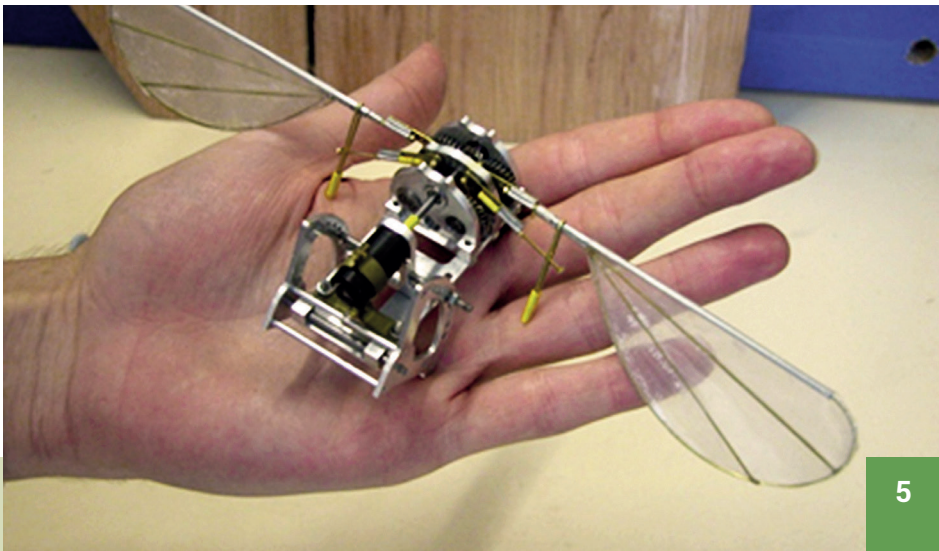
We spent three years designing mechanisms that could produce flapping like the dragonfly. It was very humbling because we could only make the wings flap ten times

per second which was a quarter of the speed of the actual dragonfly.

In our research we found out some astounding capabilities of insects. Some midges can flap their wings over 1000 times per second! We also found that flies can land upside down on a ceiling. This amazing feat involves the fly flipping its body with precision by 180 degrees just before landing upside down!

I had to conclude that insects must have a designer who is far more knowledgeable and powerful than any human designer.

$$P_{aero} = 2 \left\{ 0.5 \rho C_L C_w \cos \beta \int_0^{2/3 L_w} r^3 dr \right\} \left\{ \frac{\omega_{max}^3}{\pi} \int_0^\pi \sin^3 \theta d\theta \right\} \\ + 2 \left\{ 0.5 \rho C_L C_w \cos \beta \int_{0.666 L_w}^{L_w} \frac{(r_1 - r)}{(r_1 - r_2)} r^3 dr \right\} \left\{ \frac{\omega_{max}^3}{\pi} \int_0^\pi \sin^3 \theta d\theta \right\} \\ P_{aero} = \rho C_L C_w \cos \beta \omega_{max}^3 \frac{L_w^4}{18.1}$$





HAND-INSPIRED EXOSKELETON

There is a need for lighter exoskeletons for medical applications to make them manageable for patients to use.

Exoskeletons are robotic devices attached to limbs that strengthen them. When a person has a stroke and their hands become weak, an exoskeleton is able to give strength back.

My research team analysed the design of the human hand in order to produce a bio-inspired design of a hand exoskeleton. We looked carefully at the mechanics of fingers in order to understand how the fingers

are designed. One of the reasons the human finger is so slim and agile is that there are no muscles in the fingers. Instead the muscles that move the fingers are based in the hand and arm. These muscles are attached to fingers via thin tendons that are guided in precision sheaths.

The index finger has seven different muscles that can move the finger forwards and backwards and from side to side.





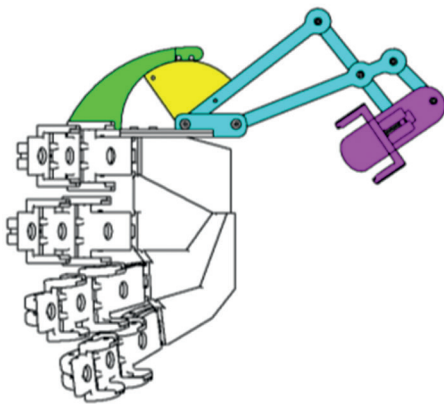
The muscles and tendons are so precise that the fingers can be moved with delicate control and precision. The human hand can hold a grain of sand weighing a fraction of a gram. It can also play notes on musical instruments, playing many notes per second with feeling and emotion. Our fingers can also feel a ridge of just 13 nanometres in height.

Based on our observations we designed and built an exoskeleton. Despite using the best technology, we could not match the precision movement of an actual human hand. Nevertheless, our exoskeleton was able to assist people with weak arms and hands. We tested our exoskeleton on a lady who had had a stroke and

she was very grateful to be able to lift cans of food with the help of our exoskeleton.

Our studies of the human hand showed us that it is a work of art and brilliant piece of engineering.

It is clear that the human hand is designed to do skilful things like play musical instruments and perform craftwork. These things are what would be expected if God had designed man for skilful work and pleasure. However, it is not what would be expected from evolution because this theory predicts humans have evolved only for survival tasks like fighting.





KNEE-INSPIRED ROBOTIC JOINT

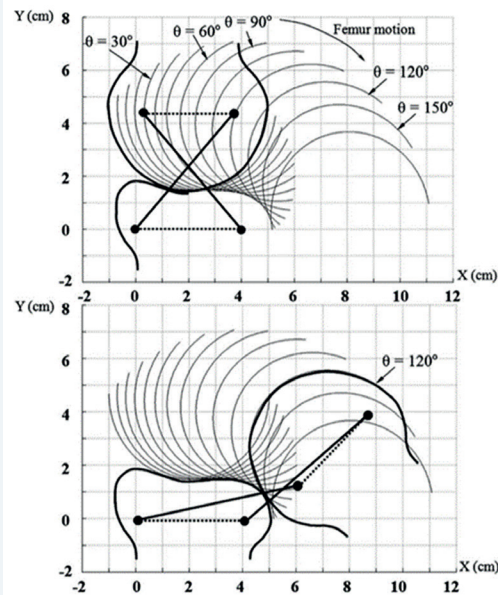
My research team has developed a robotic knee for robots based on the human knee joint.

The human knee joint has remarkable strength and endurance. It is so strong that the knees of soccer players can withstand huge forces as the players twist and turn and slide on their knees.

During the 80-year lifetime of an active person, the knee joint may articulate more than 50 million times.

During a three-hour marathon run, the joint articulates about 20,000 times. Amazingly, the knee joint can maintain and repair itself. Of course, some people have to have replacement joints if they have experienced disease, accident or excessive wear. But in the absence of these problems, the joint is remarkably robust.





One of the secrets of the human knee joint that makes it such a good design is a cam mechanism that causes the femur bone to roll over the tibia bone in a smooth motion. In addition to this mechanism, the ligaments of the knee form a special linkage mechanism that guides the articulating motion of the joint. At the heart of this linkage mechanism are two crossed cruciate ligaments. They form what engineers call an inverted 4-bar parallelogram mechanism.

The knee joint is another example of irreducible complexity because the knee joint can only function when several key parts are present and correctly assembled as a functioning assembly.

In contrast to the human knee joint, replacement joints last only about ten years and do not have as much range of movement, showing the superiority of the human knee joint.





THE SUPERIORITY OF DESIGN IN NATURE

One of the most important lessons of bio-inspired design is that design in nature is always better than human design.

Birds are better fliers than any aircraft. Fish are better swimmers than any torpedoes. Silk is stronger (weight for weight) than any man-made fibre.

The **human brain** is better than any supercomputer. The most powerful supercomputer in the world (IBM Summit) is not able to match the performance of one human brain and yet it is about one thousand times larger and requires about a million times more energy to run.

This is exactly what would be expected if God had designed the world because God is perfect in knowledge. The biblical creation model predicts that nature should be superior to man-made engineering and this is exactly what the evidence shows.

In contrast, according to evolution, nature should be inferior to man-made engineering because evolution is limited to step-by-step change. This is clearly not what the actual evidence shows.





NO BAD DESIGN

Another important lesson of bio-inspired design is that there is no such thing as bad design in nature. There have been claims by some people that nature contains bad design. However, such claims are due to a lack of understanding about what makes a good design.

Some people have claimed that the **human eye** is a poor design because light has to travel through the retina to reach the light-sensitive cells that are located at the back of the retina. However, scientists have discovered that light is guided through cells called 'Muller cells' that act like fibre optic cables. This means that there is no degradation of light as it travels through the retina. In fact, the light signal is improved because reflected light is removed from the signal.

Some people have claimed that the recurrent laryngeal nerve is a bad design because it loops down towards the heart rather than going direct from the brain to the larynx. However, just because the nerve has a loop does not necessarily mean it is a bad design. This is especially so since the loop does not result in any lack of performance.





There are actually very logical reasons for the recurrent laryngeal nerve having a loop.

It is well known in engineering that optimal wiring systems often have loops. One advantage of a loop is that it allows the wiring to make intermediate connections to places that otherwise could not be reached. This is the case with the laryngeal nerve which makes intermediate connections to the trachea and oesophagus. Another advantage is that it allows movement between the parts that are connected. This is the case during the growth of a baby where organs move apart significantly.

The claim of bad design in the laryngeal nerve is based on a lack of understanding of the multiple functions of a wiring system.

The nervous system in the human body is actually an astoundingly sophisticated design.

In an adult there is around 150,000 km of wiring that reaches virtually every cubic millimetre of the body through an immense network of nerve pathways. The nervous system is an example of brilliant design not bad design!





ORIGIN OF DEATH AND DISEASE

When considering design in nature it is normal to question the origin of decay and disease. It is important to clarify that the existence of decay and disease does not mean that design in nature is not excellent.

Even though the human heart is subject to decay and disease, it is still a brilliant design. Design and decay are two different things.

The Bible explains the origin of decay and disease. When God created the world, it was perfect with no death and no suffering. That means that there were no predator-prey relationships in nature. However, this state did not last very long because sin soon entered the world and this changed everything. Genesis Chapter 3 explains how Adam and Eve rebelled against God by eating the forbidden fruit and this led to a judgment that involved a curse on the whole of creation.

Ever since the time of Adam and Eve, everything has been in a state of decay. There is direct scientific evidence for this decay as many species become extinct and as creatures lose their health and beauty after successive generations.

The decay is also what we would expect from the second law of thermodynamics.

Despite the effects of the Fall of Adam, there is still great beauty and wonder in the world that is able to inspire countless engineers and scientists.





EVIDENCE FOR INTELLIGENT DESIGN

The evidence for intelligent design is overwhelming. This should not be a surprise because the Bible teaches that God's attributes are clearly seen in creation:

For the invisible things of Him from the creation of the world are clearly seen, being understood by the things that are made, even His eternal power and Deity; so that they are without excuse. (Romans 1:20)

The book of Job declares that in creation 'God does things we cannot comprehend' (Job 37:5). Modern science has proven the truth of this verse. The book of Job also points out that God is perfect in knowledge (Job 37:16). It is no wonder that engineers are copying designs from creation because God is a perfect designer.

One of the reasons why so many of the founding scientists had a belief in God is that they could see amazing design in creation.

Isaac Newton said that the design of the solar system was so fine-tuned that it must have a Creator. Robert Boyle once said: "Remember to give glory to the One who authored nature."

Today there are still many scientists who can see God's design hallmarks in creation.





THE CREATOR'S REVELATION FOR MAN

Since creation has a Creator, it would be expected that the Creator would leave a testimony of His purposes and instructions for humankind.

This is exactly what we find in the Bible. The Bible is a remarkable book that has been verified to be accurate in its historical accounts.

Since God is our Creator, we are accountable to Him and one day we must all appear before Him. If we have not confessed our sins and obtained forgiveness then we will be judged for our actions and will not be qualified for heaven. However, the Bible explains the good news that God has made a way of salvation. We can be forgiven our sins if we confess them and put our trust in the Lord Jesus Christ. The reason

why this is possible is because Jesus took the penalty for our sin on the cross.

Creation shows that God is perfect in wisdom and understanding. Therefore, we can be confident that the way of salvation described in the Bible is fully effective and perfectly designed.



STUART BURGESS



Professor Burgess is a professor of engineering design in the UK (Bristol University) and the USA (Liberty University) and has written several books about design in nature. He has won several national awards for design including two for bio-inspired design: the Wessex Scientific Medal and the

James Clayton Prize. He is married to Jocelyn (who speaks German) and has 5 children.

Stuart Burgess worked on projects for the European Space Agency including leading the design of the solar array deployment system on the world's largest earth observation satellite, Envisat. He also worked on the design of the European Skylark rocket.

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