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Our Creator - The Master Engineer

by

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I. INTRODUCTION

"In the beginning, God created." The Biblical account starts with God engineering the earth we live in. In His crowning work, God created man "in His image" – also with creative powers. The engineering community has made a career out of exercising this God-given creative power – creating the physical environment that we live and work in. Engineers have the distinguished legacy of following in their Creator's footsteps, thinking God's creative and analytical thoughts after Him. Should we not spend some time reflecting on the Master Engineer as we train engineers to work responsibly in this world?

In the Biblical account of creation (Gen. 1-2), not much emphasis is given to the careful design and detail of the creation process. Man is the only creature that seemed to have some thought and planning to its design. Man was formed from the dust of the ground before being given life, and was very intentionally given a companion, whereas all the rest of creation was simply spoken into existence. Only later on in the Bible is tribute given to the careful planning and engineering of creation.

Scientific study keeps uncovering more and more intricacies in the design of the natural world. The proving ground for the existence of a Creator has been concentrated mostly in the biological realm, which studies nature's chemistry and control mechanisms. Not much reflection on creation has been done from the perspective of engineering, since the natural sciences that engineering is built on – physics, chemistry, mathematics – require only implicit faith in the orderliness of the universe and our ability to understand it. Biology's discoveries of the infinite subtlety in nature's chemistry and control mechanisms is indication that the engineered design of nature is sophisticated, also.

The dichotomy between biology and engineering extends into Christian science classrooms. Examples of God's creations are marveled at in the biology classrooms; after all, they are studying what already exists - the already written book of nature. However, this emphasis on our Creator does not happen in the engineering classrooms – where students are being trained to create a new best-seller based on the available resources. Engineers are studying how to create things that don't exist, and therefore spend classroom time looking at natural laws that govern design, rather than retrospectively looking at things that are already designed. Engineering designs are restricted to available resources, and little attention has been given to mechanical properties of biological materials because biologist and engineers are headed in different directions. Biologists and doctors typically have an aversion to mechanical and mathematical things, and engineering has been going through a phase of using man-made materials rather than natural ones. Thus, the natural world is more and more removed from the engineering discipline.

This paper will try and close the gap between engineering and biology, and look at nature from an engineering perspective. The natural world has much to teach us about our Creator, and about design principles set forth by the Master Engineer. Due to the immense scope of the topic, the discussion is limited to applications in the structural engineering realm – structural design and materials. Hopefully this will be a springboard to encourage those in the physical sciences to look at nature in the light of their discipline, and construct their own applicable illustrations.

II. STRUCTURAL ENGINEERING EXAMPLES IN NATURE

Except for the most primitive forms of life, all living things have a bracing skeleton - internal or external, which gives them stability and form. This structural support system ranges from the vein system that stiffens leaves to the skeletons of vertebrates. Even a very simple and primitive kind of life needs a membrane, a cytoskeleton, with at least a minimum of mechanical strength to contain the living matter and to give protection from outside forces.

The whole world is a lesson book of God's creation, and the examples given are but a fragment of the structural design considerations in creation. This paper will look at spider webs, as well as the support structures of plants and vertebrates, and a mollusk shell.

A. SPIDER WEBS

Much recent attention has been given to the incredible planar orb spider webs. They has been called a miracle of nature - an engineering feat that man has been unable to duplicate! The spider web material and the structure are being examined by researchers.

<u>Material</u>
The strength, toughness and elasticity of spider silk has caught the attention of scientists (university, military, commercial) who are looking for better performing materials. Spider silk is finer than human hair, lighter than cotton and ounce for ounce stronger than steel. It is tougher, stretchier, and more waterproof than the silkworm's strands, which are used for fine garments today. A spider can make up to seven different types of silk, with different strength, flexibility, stickiness, and translucence.

Capture silk is the resilient material at the center of the spider's web, spiraling between the spokes of the web. This miracle fiber can stretch to almost three times its length and return unharmed to the original length when the load is removed. This allows the web to oscillate back and forth after an insect hits it. If the web were stiff, the insect would just bounce off.

Dragline silk is stronger than capture silk, but less flexible. It is used to form the guy lines and framework for wheel-shaped orb webs. It was designed for a different purpose than capture silk, and meets the needs of that purpose. Dragline silk exhibits a combination of strength, toughness, and weight, which is superior to Kevlar - our strongest synthetic fiber. At 30 times thinner than a human hair, it rivals the strength of Kevlar, but is far more elastic and lightweight. It is alleged that if the diameter of dragline silk is increased to half the diameter of a human hair, it can hold two medium-size people. If bundled into a cord as thick as a pencil, it can stop a jet landing on an aircraft carrier.

Understandably, man is trying to duplicate God's design, a design superior to anything that human materials engineers have come up with. Researchers at Cornell (Lipkin, 1996) concluded that "nature has gotten it right. It's our challenge as scientists to find out what nature did." They are working on determining the spiderweb fiber's molecular architecture, understanding the genes that yield silk proteins, and learning how to spin the raw material into threads. Scientists have identified the genetic sequence for the spider dragline silk, which consists of more than 22,000 base pairs. There is disagreement about how much of the sequence needs to be cloned to make proteins good enough to spin into top-quality synthetic threads. They are probing for a material as tough as natural silk, but easier and cheaper to make. There are visions of using this synthetic silk for surgical sutures, suspension bridge cables, endurance fabrics for athletes and the military, bulletproof vests and parachutes. Spider silk withstands very low temperatures before becoming brittle (low glass-transition temperature), making it ideal for the frigid temperatures parachuters encounter. (Benyus, 1997, p. 132)

The manufacturing process that our Creator designed for spiders to use is also amazing. Spiders make silk threads in environmentally benign ways. Proteins are processed from water-based solutions, without using petroleum products or organic solvents. The closest man-made material we have to spider's silk is Kevlar, which uses petroleum-based materials at high temperature and pressure in a sulfuric acid bath - all of which are harsh on the environment.

And leave it to God not to forget any details in creating this exceptional, astounding material. Natural dragline silk glistens in glorious golden tones. Researchers are tinkering with regulatory genes that spiders use for camouflaging their silk, in an attempt to alter the color.

<u>Structure</u>

The structure of the spider's web is another awe-inspiring design. The planar orb web is an extraordinarily efficient structure for capturing fast-flying, massive (on an insect's scale) objects. It is analogous to a fishing net catching a passenger plane!! It is incredible how these webs dissipate so much kinetic energy and capture such large projectiles without being ripped to shreds. Strong and resilient, the web absorbs energy when prey fly into it, stretching with the impact, oscillating, and then retracting into place again. Does the secret lie more in the silky material or in the clever structure?

At University of Oxford (Lin, 1995), computer models were used to structurally analyze a complete spider web. They found, unexpectedly, that air resistance has a tremendous effect on the performance. The small threads of silk (less than one-thousandth of a millimeter in diameter) are viscous in air. They create a drag, like walking through water, or pulling ropes transversely through water. This aerodynamic damping has a tremendous effect on capturing prey, and dissipating energy as the whole web bobs back and forth through the air. A researcher at University of Kyoto (Milius, 2000) has discovered that some spiders tune the web vibration, making them tighter or looser, depending on their hunger level. This is indication that there is even more functionality in the structure.

Researchers (Lipkin, 1995) also looked at how the projectile stresses were balanced across the whole surface of the web, due to its unique geometry. They concluded that the effectiveness and efficiency of the web design has practical applications for tent-like structures with many cables. "Nature has much to teach, not just about aesthetic forms, but about mechanics."

B. PLANTS

Plants have several structural systems. All the structural systems of the plant kingdom are assisted by internal fluid pressure in withstanding mechanical stress, increasing the efficiency of the structural material. Researchers, trying to apply this concept of internal pressure, are investigating portable housing where beams would be inflated with air. (van Dam, 1995) The most obvious structural system in a plant is the stem that holds the photosynthesis factories up where they can receive light. There is a structural mechanism that holds the leaves out to collect the light, rather than allowing them to droop from their attachment point. The plant's roots anchor the whole structural system. The structural systems of plant stems, leaves and roots will be touched on briefly here.

Stems

The stem of a plant is typically a compression member, holding up the weight of the superstructure. In addition, the stem must also resist the bending caused by winds. In doing so, it functions as a cantilever beam, anchored at the base by its root system. The stem materials are optimally designed for this type of loading. They are anisotropic - strong in the longitudinal axis, but weak in any other direction.

Trees, because of their size, carry the largest loads in the plant kingdom. Strong winds create loads more critical than the weight of the tree. Wood is stronger in tension than in compression due to the buckling of the cell walls under compression. Thus, to reduce the high compressive loads from the wind, new wood cells are formed in a tensioned state around the outer ring of the trunk. The bending compressive load from the wind has to overcome this pre-tensioning before the trunk goes into compression. This pre-tensioning reduces, by about half, the critical compressive stress due to the bending from the wind. (Gordon, 1978, p. 282)

The shape of the tree trunk is also cleverly advantageous. If a compression buckling crease does develop in the trunk cells, it would try to propagate perpendicular to the longitudinal direction of the tree. (The shorter length means less energy per depth of penetration.) As the buckling crease tries to propagate, the surface width to buckle increases due to the round cross-section. The surface width of the buckling front increases more rapidly than the strain energy released from the material behind it, thus the buckling front is arrested. No doubt this kind of buckling control is also relevant to the rounded cross-sections of bones. Man has removed this compression crease control from the timber used in construction. Rather than using round sections where the width of the creasing front increases as it propagates, man cuts the wood into rectangular shapes that have a uniform width all the way across, and aren't effective in arresting the propagation of a buckling crease.

Wood is one of the most common building materials for man-made structures. Weight for weight, the strength of timber and stiffness of timber is comparable to commercial steel. This good strength and stiffness, combined with low density, means that wood is very efficient in beams and columns. Wood has an exceptionally high work of fracture, which allows the trees to stand up to the buffeting of the wind, and also makes wood such a useful material. This high work of fracture cannot be accounted for by any of the recognized work of fracture mechanisms which operate in man-made composites. Unlocking the key to this mechanism holds promise for the design and manufacture of artificial composite materials.

Bamboo is stronger than timber, and ounce for ounce stronger than concrete. The energy needed to produce bamboo is approximately half that required for wood due to the fact that it grows quickly -up to 3 feet per day, and sawmills are unnecessary to get it into a form for construction. The production energy is 1/8th that of concrete and 1/5th that of steel for equivalent bearing capacity. (Roach, 1996) The tubular shape makes the most of the material and lightens the weight. The tubular cross-section has much more resistance to compressive loads than a solid cross-section with the same amount of material. The thin walls of the tube run the risk of local buckling of the tube wall, thus the bamboo has nodes to stiffen the tube wall. This is the same type of system that is used to stiffen an aircraft fuselage.

The structural design of other plant stems is also indicative of engineering principles in use. Tulip stems are circular, reflecting the fact that the blooms sit centered on the stems. Asymmetrical daffodils have an elliptical cross section, increasing the moment of inertia in the direction of the off-centered bloom. The elliptical stem also allows the daffodil stem to twist more than the tulip stem. In the wind, daffodils twist to face downwind. Wind tunnel tests showed this reduces the flower's drag by 30 percent, thus reducing the lateral force the stem has to resist. "Studies of lobster antennas, horsetail stems, and twiggy parts of more than 50 plant and animal species reveal a fairly consistent ratio of 'twistiness to bendiness.' …Tulips conform to that pattern, but daffodils proved to have an unusually high 'ratio of flexural to torsional stiffness.'" They were designed to dance in the wind! (Why Tulips Can't Dance, 2000)

A cholla cactus has a tubular supporting structure with oval openings in it. This structural support combines maximum rigidity and strength with minimum expenditure of material and weight. It is reputed to surpass any man-made construction in mechanical efficiency. (Feininger, 1956, p. 26)

Vines, lacking structural rigidity in their stems, are designed to cling to a stronger form. They anchor themselves with root and tendril. The tendrils are sensitive as fingers as they probe the air for a hold. They have an incredibly strong grasp once they curl themselves around their anchoring host. They can work their way into the mortar on a masonry wall, and degrade the structural integrity of the wall.

Leaves

In the competitive struggle for existence, many plants depend on the structural efficiency of their leaves. They must try to expose the maximum area to sunlight, for photosynthesis, at the minimum metabolic cost. Leaves are therefore important panel structures, and must hold themselves out flat to catch as much light as possible. Leaves use several structural methods to increase their resistance to bending. Nearly all leaves are provided with an elaborate rib structure – typically a main rib from which a system of somewhat parallel secondary veins branch off, which in turn are connected by an irregular network of small auxiliary veins. According to tradition, the structure of the Crystal Palace (1851) was patterned after the main leaf ribs of the Victoria Regia lily. The membranes between the veins of the leaves are stiffened by means of cellular construction, and in some cases they are further stiffened by corrugations. In addition to all this, the leaf as a whole is stiffened hydrostatically by the osmotic pressure of the sap.

Roots

Plants, as inanimate structures, need a method of structurally anchoring themselves to the earth. As mentioned above, vines anchor themselves to a more rigid structure; however, they still need a root system to collect minerals and water. Most plants rely solely on their root system for structural anchorage to the ground. There are several types of root systems. Most trees and some plants (dandelions) use a taproot system for their foundational strength. This is similar to pile foundations that human engineers use – e.g. telephone poles. Another type of anchoring system is the multi-root system, where there is not a single dominant root. This system is used for plants that don't have high bending loads (grasses), or where the depth of taproot needed is incredibly large. This is the case for the large Coastal Redwood trees. They do not put down a taproot, but instead rely on interlock with the root system of adjacent trees to resist the sizable bending stress due to wind. Removing some trees in a grove almost invariably leads to wind fall of others due to the disruption of this root interlock system.

C. SKELETONS OF VERTEBRATES

The structural system of vertebrates consists of bones, muscles and tendons. The bones are held in compression by the muscles and tendons. In compression, bone is as strong as granite. Although neither granite nor bone were designed to carry tensile loads, thus the tensile strengths for both are low, bone is amazingly 25 times stronger than granite in tension. (Cameron, 1999, p. 96) This gives a miraculous allowance for the accidental application of tension to the bones.

Bones are sculpted for strength and minimum material. Bones employ engineering principles of the arch to achieve strength, and they reduce weight through elimination of material in places where it is not needed. The variations in cross-sections and densities make them look as if they were designed according to the latest engineering theories, but they're formed to tolerances that human engineers wouldn't dare to specify. The changes in cross-sectional areas are smooth transitions. This gradual gradient alleviates stress concentrations and crack proneness that abrupt changes and interfaces cause. These blending gradients are found all over in nature.

Bones are not designed to resist torsion, or twisting. Large and bulky cross-sections are required to get torsional strength and stiffness. Rather than take on this added weight, the skeletal mechanisms are designed to avoid any torsional loadings. Problems only arise when unnatural torsional loads are applied – like humans wringing the neck of a chicken to kill it or man attaching long levers to their feet and skiing downhill rather poorly, resulting in broken legs. The vertebrae of the chicken are very weak in torsion, as are our legs, but it takes unusual loads to apply these torsional demands. Human engineers came to the rescue, though, (at least for man) designing the modern safety bindings that release automatically in torsion. The chicken is still out of luck! By avoiding torsional loadings, there are significant bulk and weight savings in the bones. As long as they are not subjected to unnatural loads, most animals can afford to be weak in torsion.

D. MOLLUSK SHELLS

Abalones are members of a large class of mollusks having one-piece shells that are suctioned to the oceans' rocky surfaces by the mollusk's muscular foot. The abalone shells are rounded or oval with a large dome towards one end, and a row of respiratory pores. The hard outer shell is rough textured and dull. The smooth inner nacre is delicately swirled with iridescent color, and used for jewelry and mother-of-pearl inlays on furniture. The meat is an Asian delicacy. Nine species occur in North America – all but one are native to the Pacific Ocean.

Abalone shells are among the hardest, most durable materials in nature. Research has shown that the shells consist of alternating layers of hard and soft material. The electron microscope illuminates a highly ordered layering of ultra-thin calcium carbonate (chalk) platelets held together by an organic protein matrix which is one billionth of a meter thick. (Campbell, 1993) The ordered structure increases the strength of calcium carbonate by a factor of 20. The matrix has the strength of the most advanced synthetic ceramics, yet is not brittle like ceramics, which get their strength from powerful chemical bonds. Ceramics fail suddenly and catastrophically when enough force is applied to break these bonds. In the abalone shell, when a crack occurs in a hard layer, it is absorbed by the soft layer and does not propagate. The failure is ductile, due to the platelets sliding on top of one another on the organic layer. This layering method is being investigated for possible new tank armor. (Robbins, 2001)

The highly ordered structure of the abalone shell is due to the shape of the protein chains that form the template for the inorganic platelets to crystallize in. These hexagonal disks are mirror perfect in shape and placement, echoing one another. Even the grains within the disks show mathematical repetition and beauty that characterize natural form. (Benyus, 1997, p. 99)

III. GOD THE ENGINEER

If we recognize the activity of an engineer when we observe mechanical devices, we can also observe the activities of a Designer when we observe similar features in living organisms. The complexity of God-designed structural mechanisms is much higher than man-made designs, the quality is incomparably greater, and the similarities point to a single Designer with a wholistic approach to design.

Some complexities in structural mechanisms and materials have been mentioned above – complexities that man is still trying to understand, complexities beyond the imagination, creativity and ability of human engineers. Natural materials are formed in environmentally benign ways, with a small number of simple building blocks – sugars, proteins, minerals, and water. Precise control is exercised at every level of the process, from the arrangement of atoms into molecules, to the assembly of molecules into intermediate components such as fibers and crystals, up to the final architecture of larger, multifunctional composite materials like wood, bone, or marine shells. The microstructural control that is the norm in nature is still far beyond the capacity of human engineering. Humans start with a vast number of advanced, complex compounds (fibers and resins) that are assembled in relatively simple ways. Man-made ceramics and metals are subject to energy intensive heat and/or pressure to squeeze them together into a hard material. They are plagued with the problem of cracking and brittleness. In recent years we've gotten them down to finer grains (nanometer size) but brittleness is still a problem. Nature's crystals are finer, more densely packed, more intricately structured, and better suited to their tasks.

Quality is evident everywhere in nature, not just in the design process, but also the manufacturing process. Natural structures are often breathtakingly complex and elegant. Dr. Roman Vishniac, superb photographer of nature's manifestations, states: "Everything made by human hands looks terrible under magnification - crude, rough, and unsymmetrical. But in nature every bit of life is lovely. And the more magnification we use, the more details are brought out, perfectly formed, like endless sets of boxes within boxes." (Feininger, 1956, p. viii) This intricacy can be illustrated by the tendon, which shows a hierarchy that is almost unbelievable in its multileveled precision. Tendons are a twisted bundle of cables, where "each individual cable is itself a twisted bundle of thinner cables. Each of these thinner cables is itself a twisted bundle of molecules, which are, of course, twisted, helical bundles of atoms. Again and again a mathematical beauty unfolds, a self-referential, fractal kaleidoscope of engineering brilliance." (Benyus, 1997, p. 100) Man has no hope of achieving this level of intricacy and quality in his designs or manufacturing.

Similarities found in nature point to a single Engineer. The stiffening veins of a leaf and those of an insect's wing exemplify identical membrane stiffening principles, although one is a plant and the other an insect. The humerus of an eagle (a vertebrate) and the shell of a King crab (a crustacean), unrelated animals, have structures that are stiffened in very similar ways - by struts and braces to achieve maximum strength with minimum weight and expenditure of material. These similarities in unrelated things point to a single creative mind in their design.

The Christian perspective of an intelligent design of the universe is gaining more respect in intellectual circles and the culture at large as more and more complexity and specificity is discovered at the most elementary levels of matter and life, especially in the biological sciences. Intelligent design proponents claim that living organisms appear designed because they *are* designed, exhibiting features that natural processes cannot mimic. In observing the structural complexity, quality and similarities in nature, the conclusion is almost inescapable, that there was a very definite structural design process involved.

IV. ENGINEERING PRINCIPLES LEARNED

The overwhelming complexity and intricacy in the design of nature should send all engineers humbly to the feet of the Master Engineer to learn whatever design lessons they can! There is no engineering school that can give them that depth of knowledge, understanding and wisdom. The book of nature gives instruction in physical design principles, economy, functionality, aesthetics, safety, recylability and a wholistic approach to design. These principles, drawn from the Master Engineer's designs, should be engrained in engineering minds and reflected in every design.

A. PHYSICAL DESIGN PRINCIPLES

Structural Design principles are everywhere in nature. The examples are endless – tension structures, compression structures, panels, membranes, all designed in accordance with the known laws of mechanics, and some that are currently beyond the understanding of man.

<u>Known design principles</u>
Man understands that it is more efficient to collect compression forces into as few members as possible. While in tension, diffusing the load into many members to accommodate lighter end fittings more efficiently resists loads. These design principles are illustrated in vertebrate animals. There are a small number of compression members

(bones) centrally located, surrounded by a wilderness of muscles and tendons and membranes carrying the tension. The ends of many tendons are splayed out into branched ends, each branch having a separate little joint to the bone. Thus the weight, and perhaps the metabolic cost, is minimized.

As the size of an animal increases, scaling design principles can be seen in the skeleton. The dimensions of the vertebrae of small monkeys and middle-sized monkeys and gorillas are roughly proportional to the height and weight of the animal, since direct scaling works for compression members. Other bones, which are subjected mostly to bending (ribs, limbs), become disproportionately thicker for larger sized animals. This is due to the fact that the weight of the structure increases as the cube of the dimension, but the resisting cross-section increases only as the square of the dimensions. This is in agreement with the square-cube law for scaling.

Unknown design principles

Man does not have a comprehensive understanding of structural mechanics and materials. He is still trying to unlock some of the incredibly efficient design principles used in nature. This study of nature for better design methods is called biomimicry. Past designs based on nature include hypodermic needle tips shaped like rattlesnake fangs and Velcro, which is based on seed burs. Research is currently being done on spider webs, beetle shells, abalone shells, rat's teeth, animal quills and spines, stems of grasses and grains, water-resistant mussel adhesive, and numerous other God-engineered designs. Nature is a lesson book for engineering design principles.

B. ECONOMY

All of engineering is undergirded with economy. Man's engineering solutions are optimized to use a minimum of materials, labor and time. The monetary cost of the design is typically the bottom line. God's creations reflect a different type of economy. In nature, the 'metabolic cost' is what designs are optimized around – the price of a structure in terms of food and energy. Weight directly affects metabolism, thus natural materials are lighter than man-made structural materials. Perhaps we should be looking at design with respect to economies beyond the monetary cost.

C. MATERIALS SELECTION

Natural materials are carefully matched to the required needs. There is a large range of strengths in biological solids. Muscles are weak, tendons are strong, which accounts for the very different cross-sections of muscles and their equivalent tendons. Biological materials are less dense than nearly all metals, in an attempt to reduce the metabolic cost to the living organism. However, in strength to weight ratios, metals are not too impressive when compared with plants and animals.

Biological materials have the amazing capacity to repair themselves and adapt to changing environmental stresses. The proportions and strength of living structures tend to become optimized with regard to the stress demand. Trees on exposed wind-swept cliffs develop stronger wood than the same species growing in the sheltered valley. Bone, a two-phase composite material, has a porosity that is not fixed. It remodels in response to the mechanical demands placed upon it, economizing the body's metabolic cost by maintaining only the amount of bone needed. Astronauts subjected to only 4 days of weightlessness showed bone mineral losses, which can take several months to regain after normal activity is resumed. (Hawkins, 2001, p. 21) Many natural materials can sense the surrounding environment and adapt.

We can conclude God created materials for a particular application, with mechanical properties that matched the expected loads and functions, while minimizing the weight to reduce metabolic cost to the creature. Man is not capable of creating a new material to match each application, but could do a better job of responsibly using materials that are suited for the application. Man also cannot create structures that adapt their strength to the environmental loads applied. Thus, man has to be much more mathematical and conservative in his approach.

D. SAFETY

Some safety is built into the natural system, in that natural materials can gradually increase their strength to meet demand and in some cases heal the damage due to overloading. Neither of these methods is available to human engineers, though, so we are left with factors of safety to ensure reliability in our designs.

In a wholistic design sense, Christ took on Himself the liability of this world when He created it. The malfunctioning of His creation cost Him His life to redeem it. Human engineers also need to take responsibility for their work. Mistakes and insufficient safety allowances in structural engineering can cause death to the structure's occupants. Engineers carry a large responsibility, and the Master Engineer models our accountability.

E. FUNCTIONALITY

Functionality in God's designs can be clearly seen. The purposefulness of design is executed with clarity of organization, economy of materials and outstanding workmanship.

Each skeleton is designed with function in mind. The burrowing African Hero shrew has vertebrae that are joined together with interlocking prongs, giving a backbone structure strong enough to support the weight of heavy animals that might step on its shallow tunnel. The mole skeleton has robust shovel shaped paws and a wedge-shaped skull, both enabling it to tunnel easily. The pygmy armadillo skeleton has an armored tail plate. This plate corks the hole to its burrow when it flees from an enemy head first into the burrow. The bones of flying or rapidly moving animals are light and hollow. Those of animals that move more slowly, and need more protection from preditors, are heavier and denser.

The arrangement of leaves on the support system of plants may be aesthetically pleasing, but they are placed primarily for function. They are arranged in patterns such that each leaf receives it full share of light. The prickly pear cactus turns its small, thick, fleshy leaves so the narrow edge is facing the sun. This presents a minimum surface to dehydration. The Virginia creeper, a plant that is designed to thrive in the shade, has large, thin leaves, arranged in a natural mosaic to prevent one leaf from shading another.

The tent caterpillar spins its nest in the spring. Although it appears flimsy and loosely woven, this house of silk is strong enough to protect its inhabitants from caterpillar-eating birds and tight enough to keep out the rain. Bald-faced hornets and paper wasps build nests in which the combination of material and structure provide incredible heat insulating properties.

Functionality is the driving force in the design of nature. In man's approach to structural engineering, loads are designed for first, and serviceability / functionality requirements – deflections, vibrations, waterproofness, etc., are looked at secondarily. Nature's design seems to consider functionality at a higher level in the design process. The choice of materials, the fabrication, and the shape of the structure all affect functionality in nature. Thus, the functional aspects had to be a consideration from the beginning of the design process, not an afterthought. Perhaps functionality should be a higher priority in human designs.

F. AESTHETICS

It seemed that God was very concerned with aesthetics. The created world, though fallen, is still beautiful. Man still seeks the environment of nature for regeneration of spirit. This concern for aesthetics can be seen when looking at the minutest detail of nature. God is a lover of beauty. This is evident in the natural world – the array of colors, shades, shapes and textures, all skillfully combined and contrasted. Bright, living colors are used rather than somber browns and greys. There is an immense variety. God is the Master Artist, and this is evident in His designs.

G. RECYCLABILITY

Everything in the natural world is biodegradable. All life is based on a carbon and nitrogen cycle. Carbon combines with oxygen to form one of the gases of the atmosphere. The leaves of green plants absorb this gas, and combine it with water to form sugar. The process is powered by sunlight. Plant-eating animals, needing carbon to build their tissues, obtain it by eating green plants. Flesh-eating animals obtain carbon by eating animals that have fed on plants. Dead organic matter is broken down into its basic components by fungi and bacteria, and in so doing they free carbon to begin once more the cycle needed for all life. Nitrogen has a similar cycle.

The Christian engineer needs to consider the ultimate end of his creation. What happens when the structure or material reaches the end of its life cycle? Does it fill a landfill, while more resources are depleted from the earth for a replacement structure? Or can it be recycled into use again?

H. ENVIRONMENTAL

Natures' processes are not only technologically superior, but also environmentally benign. The bess beetle can turn sugar and protein into an outer shell that is lightweight yet strong, stiff and damage resistant. The spider can spin water-soluble protein molecules into insoluble silk threads that are tougher than Kevlar. The abalone can crystallize chalk from seawater, and turn that substance into a shell that exceeds the strength of most advanced ceramics. Living organisms can turn simple building blocks into materials that are superior to advanced synthetic composites manufactured from the latest high-tech materials. Kevlar, the man-made super material, is produced in vats of boiling sulfuric acid under very high pressure. The process is energy intensive, and the materials used are dangerous to work with and difficult to dispose of. Spider silk, on the other hand, is spun from natural, renewable raw materials, at room temperature and pressure, using water instead of sulfuric acid as the solvent, and the end-product is biodegradable. Perhaps engineers need to develop materials inspired by natural models to replace the petroleum-based plastics and fabrics of this century.

In the current structural engineering realm, metals and concrete require a great deal of energy to manufacture. For light loads, devices made of steel and concrete have much higher energy costs than more sensible materials. Timber is one of the most 'efficient' of all materials in a strictly structural sense. A wooden structure is many times lighter, it uses much less energy per ton to produce, and is a renewable resource. The biggest problem with timber is the time it takes to grow. Plant geneticists have been breeding fast-growing varieties of commercial timber. Weymouth pine has been developed to grow 12 cm in diameter per year, and mature in 6 years. (Gordon, 1978, p. 320) Another advantage of wood is when one is finished with a timber structure, it could be burned to yield up most of the energy which it has collected while it was growing. This is in no way true of steel or concrete.

I. WHOLISTIC DESIGN APPROACH

No living organism can survive without dependence upon other organisms. Each is an essential part of the great web of life. Spiders are one of nature's regulating devices that prevent insects from reaching such numbers that they would destroy all plant life, and themselves die of starvation. But without insects, many flowers and trees would not be pollinated and could not reproduce their kind. Without plants, there would be neither animals nor man, since both depend upon green plant life for their food. In the design of the world, everything is interdependent and balanced. There is a wholistic approach to its design.

The human engineer needs to take a wholistic approach to design as well, and consider the balances required of nature. No engineer has intentionally disrupted this balance, but designs have produced unintended consequences.

Aswan High Dam in Egypt is an example of unintended consequences – things that weren't intended by or foreseen in the design. The dam has increased the salinity of the Nile by 10 percent, has led to the collapse of the sardine industry in the Delta and caused coastal erosion by trapping silt. It has increased snail-borne diseases many-fold by creating stagnant water and has forced the 100,000 Nubians displaced by the reservoir to try to adapt to life as farmers on the newly created arable land. Fertilizer is now required in fields that were formerly enriched by annual floods. Are these consequences balanced by generation of hydroelectric power to furnish half of Egypt's electrical needs? The engineers could not have predicted the exact change in salinity and erosion or the exact human costs to the sardine fishermen and Nubians. (Koen, 1985, p. 7)

The natural world can counteract a certain amount of unintended consequences, it is the cumulative effects that are taking their toll. As a Christian engineer, we are entrusted with the responsibility of caring for the earth (Gen. 2:15, Ps. 8:6). We are compelled to look wholistically at everything we design, not only in the environmental sense, but also the humanitarian sense.

As the world population grows, there will be a higher demand for life-supporting infrastructure. It is estimated that the population of the earth will increase by 50% in the next 50 years! The major growth is projected in less developed countries and urban areas. Sustainability is becoming an issue. There is a need for better, safer, more energy-efficient and more world-friendly life supporting systems. These challenges call for engineers who are out to change their world, to make it a better place, and improve the quality of life for all the people of the earth. The Christian engineer should be the first to start moving in this direction, rather than taking the least cost approach to engineering.

V. IN THE CLASSROOM

In addition to the many technical lessons to be learned from God's creation in the engineering classroom, there are spiritual benefits as well. There is no notion more important to the Christian mind than the notion of God as Creator. Our understanding of anything will be incomplete and maybe quite inaccurate unless we take into account His presence as Creator. It puts us in our place and affects the way we understand what the universe is like. Thus, in the classroom, two things are important: that we point students to the Creator and warn them of about the pitfalls.

A. POINTING TO THE CREATOR

Since the creation act is a starting point for the Christian faith, and a reference point to develop further Christian growth, God used nature's classroom for spiritual formation. Many Biblical characters spent extended time in nature to learn the lessons God wanted them to: - Moses, John the Baptist, David, Paul. The lessons from creation are still important in faith formation and provide a gold mine of opportunities to integrate faith and the profession of engineering.

Faith Formation

Classroom use of examples from God's creation can facilitate initiation of faith for our students. The creation account is the beginning of God's word to man, and the starting point of God's relationship with man. Paul used God the creator as a starting point in evangelism. (Acts 17:24, Acts 14:15) It is an effective point for initiation of faith because "upon all created things is seen the impress of the Deity. Nature testifies of God. The susceptible mind, brought in contact with the miracle and mystery of the universe, cannot but recognize the working of infinite power." (White, 1952, p. 99) We have the opportunity to bring students' minds in contact with the miracles and mysteries of the universe, and thus to the infinite power of God.

Beyond faith initiation, examples from nature can be used to nurture spiritual growth. Nature conveys knowledge of God's character. "For since the creation of the world God's invisible qualities--His eternal power and divine nature--have been clearly seen, being understood from what has been made." (Rom 1:20) The more we study nature, the more we will learn about its Creator. Christ used illustrations from the created works - lilies, birds, seeds - to convey more clearly and impress more deeply His teachings upon the mind of His hearers. [An interesting sidenote is that Christ also used structural examples to illustrate His teachings – the tower of Siloam (Lk. 13:4), structural foundations on rock and sand (Matt. 7:24-27; Luke 6:48,49), consider the cost before building a tower (Lk.14:28)]

Our classrooms are our missionfield. This is where we are responsible for seeing that "no man misses the grace of God." (Heb. 12:15) Since creation is used as a starting point for faith in the Bible, and to promote Christian growth, should it not be used as an anchor point for faith within the science classroom? The Spirit of Prophecy places teachers with the *responsibility* of sharing creation with their students. (White, 1913, p. 456; White, 1958, p. 599)

Integrate Faith and Profession

The classroom use of illustrations from nature, of engineering lessons drawn from God's creations, has the potential of a lifelong effect on students. Hopefully it will bring into harmony their earthly profession and their spiritual life. No longer will these be distinct, separate compartments of their life. Using illustrations from nature would add divinely given responsibilities to the engineering knowledge that students receive in the classroom. They will have guidance from the Creators' examples to guide their engineering decisions and will carry the responsibility of caring for the earth in their creations.

The emphasis on following God's example in engineering would reduce the illusion that success is measured by material acquisitions, social power and prestige, which sometimes is the motivation behind pursuing the engineering profession. It would place a higher calling to the profession, a higher calling to success, and a God-given responsibility to the profession.

B. WARNINGS ABOUT PITFALLS

There are a few things that a teacher must guard against in presenting Creation in the classroom. In order to be faithful to our Christian convictions, we need to ensure that nature is not exalted above God, nor held in place of God (Pantheism). We must also realize that sin has altered God's creation, and our finite mind is not capable of understanding all of God's designs.

Nature exalted above God/God restricted by His Own Laws

One pitfall that engineers could fall into is limiting God to the laws of the physical world. Our engineering designs are based on the laws of physics and the optimization of mathematics – principles that seem to be reliable and constant. We have a lot of faith that these laws will always be in effect and thus our engineering designs will function as conceived. These principles are natural phenomena, the basis of (or maybe a part of) the creation process. It is possible to exalt these natural principles above nature's God, the author of all true science, and think that nature's laws are so firmly established that God Himself could not change them. This was the mindset of the antediluvians who had never seen rain before. They reasoned that the laws of nature had been fixed, which gave them reassurance that rain would not fall. Some miracles of the Bible relate to the abrogation of the laws of physics that engineers design by: the floating axe head, walking on water, the sun standing still. These testify that creation is still under the control of the Creator. The laws of nature known to man do not restrict Him – they restrict only us.

Pantheism / Naturalism

Another pitfall is not tying the wonders of nature to a personal, involved God. In looking at the marvels of nature, there is a risk of becoming so infatuated with the laws of nature and matter as to overlook, or refuse to acknowledge, the continual working of God in nature. We must make a very concerted effort to thwart off that influence, and be very careful that we exalt the Creator in our illustrations from nature. It is not sufficient to just present the marvelous wonders of nature, since there are pantheistic influences and pressures all around. Examples of design in nature must be overtly accompanied with a tie to the Creator – to make sure students are making our intentioned link to a Creator.

Effects of Sin

The existence of evil causes problems for pointing to nature as a perfect reflection of the Creator. Some structural things in nature seem poorly designed. Why do the disks between the vertebrae become less pliable with age, and increase the likelihood of slipped disks? Why do insects hollow out the structural capacity of trees, reducing strength so drastically that they are felled by a storm? Why does muscular dystrophy eat away the functionality of the structural muscles? It does not seem right to blame God for designing this degradation. On the other hand, if God is not responsible for the poor designs, should He be credited with the good designs? The presence of evil in nature does not refute the argument for design, but may raise questions about the nature of the character of the Designer.

Despite the effects of sin, nature is still able to show us the character of God, and it is still intended to be our lesson book. "In the briers, the thistles, the thorns, the tares, we may read the law of condemnation; but from the beauty of natural things, and from their wonderful adaptation to our needs and our happiness, we may learn that God still loves us, that His mercy is yet manifested to the world." (White, 1948, p. 256-7)

Finite Mind

As more discoveries are made in the scientific world, the more we realize the immensity of things we do not understand! Our ignorance and limitations become evident. Just how God accomplished the work of creation has never been revealed to finite man, nor the details of the design. This was made clear to Job (Job 38-39), when God replied to his questionings:

> Where were you when I laid the earth's foundation? Tell me, if you understand.
> Who marked off its dimensions? Surely you know!
> Who stretched a measuring line across it?
> On what were its footings set, or who laid its cornerstone?

The human mind, though fallen, is still adorned and invested with admirable gifts from its Creator. God made us in His image, able to think, reason and create inanimate things but only within a limited scope. "The secret things belong to the Lord our God, but the things revealed belong to us and to our children forever." (Deut. 29:29) We need to realize that we have only part of the picture, and we need God to provide a fuller view of the picture. Fortunately, the mind of Christ is available to us when we receive things of the Spirit of God. (I Cor. 2:6-16)

It is important in any discipline to recognize that our finite minds limit our understanding, and to realize that we are not going to come to correct interpretations of what we see unless we allow the mind of the Infinite God to guide us. "By faith we understand…." (Heb. 11:3) This concept must be clearly conveyed to our students. They need to understand that scholarship is an act of worship, for it is the unveiling of meaning – a value that is near and dear to God. (Sire, 1990, p. 94)

VI. CONCLUSIONS

The created world is a lesson book for engineers. The incredible, awe-inspiring designs in nature point to the wisdom and creativity of their Engineer, and show us how finite our knowledge is. God's wholistic design scheme holds many lessons for human engineers as far as design principles, functionality, materials selection, aesthetics, safety, recyclability and environmental renewal. Beyond conveying technical lessons, bringing creation examples into the classroom will aid in fostering faith and integrating Christian responsibilities with the engineering profession. It is a way of effectively integrating faith and learning in the engineering classroom. Exploring the wonders and mysteries of nature in the classroom also sets up an anticipation for the life to come, where our queries will be answered, our perplexities solved, our understanding enlarged, and our engineering education completed at the feet of the Master Engineer. Ellen White, elaborating on Revelation's description of heaven (Rev. 21, 22), says, "Christ, the heavenly Teacher, will lead His people to the tree of life that grows on either side of the river of life, and He will explain to them the truths they could not in this life understand. In that future life His people will gain the higher education in its completeness." (Nichol, 1957, p. 988) Let us point our students to their Creator, and thus show them the path to a 'complete' higher education.

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