

82 ERIDANI III

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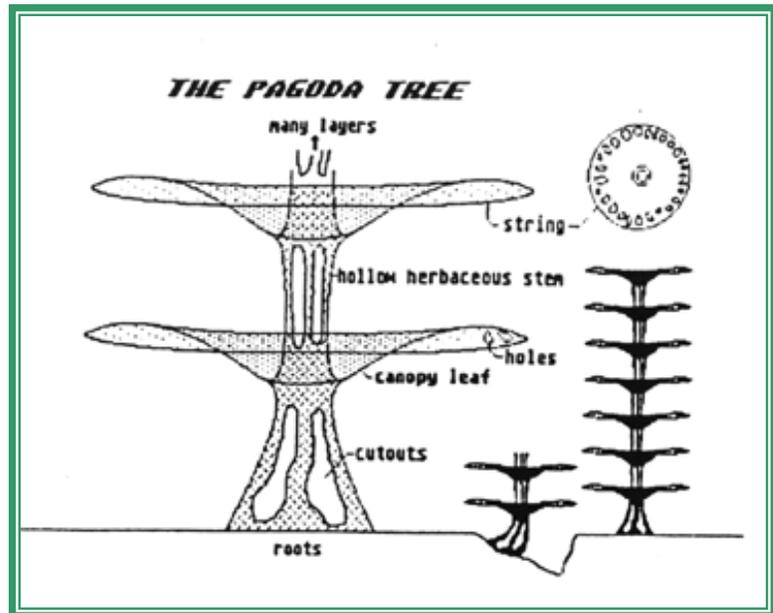
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VEGETATION

Because of the low CO₂ level, plants must develop expanses of flimsy translucent leaf, with a minimum of woody stems; most of the biomass must be devoted to CO₂ fixation (on Earth, the main function of leaves is to collect CO₂, not light; and if CO₂ were less sparse plants could grow happily without leaves, photosynthesis occurring in the green shoots and fruit).

For 82 Eridani III the leaves of rhubarb are too fleshy; ferns too fine and delicate: we want the umbrella canopy of rhubarb, combined with the lightness and intricacy of a fern, whilst retaining the free circulation of air past the leaves.

For example, a range of forms developing from the segmented seaweed, including the Pagoda tree (really an herbaceous plant):



- Each canopy and segment grows to about the same diameter and length.
- Cut-outs in the hollow herbaceous stems lighten the structure (saving biomass) and act as ventilation slots.
- The conical leaf canopies are bound at the edge with a string or fibre in tension so as not to rip and collapse, but ragged holes may appear towards the drooping periphery, improving ventilation; later variants may increase leaf surface area by means of concentric corrugations (simple or fractal).
- The leaf canopies are translucent, because the low CO₂ level means that no single layer can utilise more than a small fraction of the available sunlight.

The stems are stiffened by a large positive internal pressure and ooze sap if cut or damaged. The sap is mainly a concentrated sugar solution; osmotic pressure brings water into it from the relatively dilute mineral solution around the roots. The pressure is enough to carry sap to considerable heights and to support herbaceous plants as tall as forest trees – or taller. The sugar is mostly sucrose and other disaccharides, C₁₂H₂₂O₁₁, because cell membranes are slightly permeable to monosaccharides such as glucose, which would therefore tend to leak out into the soil. The sap also contains some long-chain molecules which set like rubber in contact with air and allow punctures to self-seal. In the often cold climate, herbaceous plants also need the antifreeze properties of the thick sap, so that frosts do not cut them down. Even so, most die down to below-ground tubers in winter;

but after the spring thaw, re-growth is explosive (vegetation on 82 Eridani III cannot easily afford the thick woody trunks that permit earthly trees to stand through an ice-bound winter).

The plant controls the osmotic pressure in the stem cells by means of a sodium pump, coupled to the sucrose molecule, carrying the sugar across the cell membrane (in either direction). A variation in pressure from one side of the stem to the other causes the stem to bend -- or to resist a sideways or asymmetric force. If the plant is crushed to the ground (say, by an avian landing on it) it can recover and spring up again quite quickly. But unlike most earthly plants, it does not turn its stem towards the light; it grows strictly vertically; on sloping ground it bends upright as soon as its first canopy has room to open.

From this primitive plant muscle can develop a true animal muscle (*q.v.*).

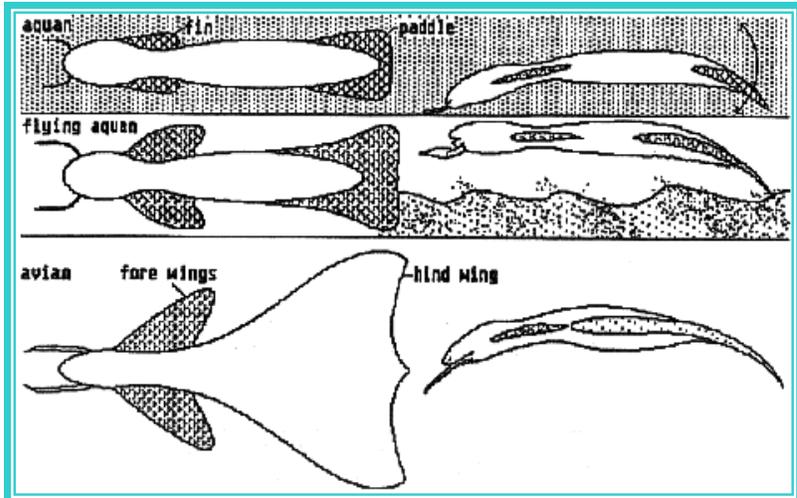
The low CO₂ level also means there is little advantage in trying to use sunlight ultra-efficiently; the plants on 82 Eridani III are rarely light-limited. Thus almost any pigment system will do, including various forms of chlorophyll. The most likely leaf colour is perhaps a dull greenish orange (not uncommon in photosynthetic bacteria, algae and lichens). The long wavelength trap (probably only one) is likely to be around 690nm-700nm, as on Earth (not at a longer wavelength, because suitable redox reactions would then be considerably harder to find); such a trap facilitates the reduction of water, yielding one electron pair for every two photons absorbed.

The low CO₂ level has a further implication: on Earth, plants protect themselves by means of tough or woody stems, by thorns, prickles or sharp branches, or by rapid replacement of damaged tissue; none of these strategies is very practicable on 82 Eridani III. Instead, plants take the route of making themselves unpleasant to eat, or actually poisonous (*cf.* bracken). Consequently, they contain considerable concentrations of various alkaloids and toxins, all designed to discourage grazing. Herbivores then naturally develop resistance. This promotes rapid speciation in the plant populations (and subsequently in the animals that feed on them), whereby a wide variety of plants, differing only in their chemical defences (and almost identical in anatomy and appearance), occupies the same physical habitat in a complex patchwork. A given animal is then able to browse on only a fraction of the plants, and must spend a considerable amount of time cautiously testing the plants and searching for those specimens it can safely eat. This prevents them gobbling up large swathes of greenery without giving the plants time to recover. An earthly analogue is the equatorial rain forest, where the many species of trees are dotted about, only a single tree of each species at a time, each at risk from a different set of insect parasites.

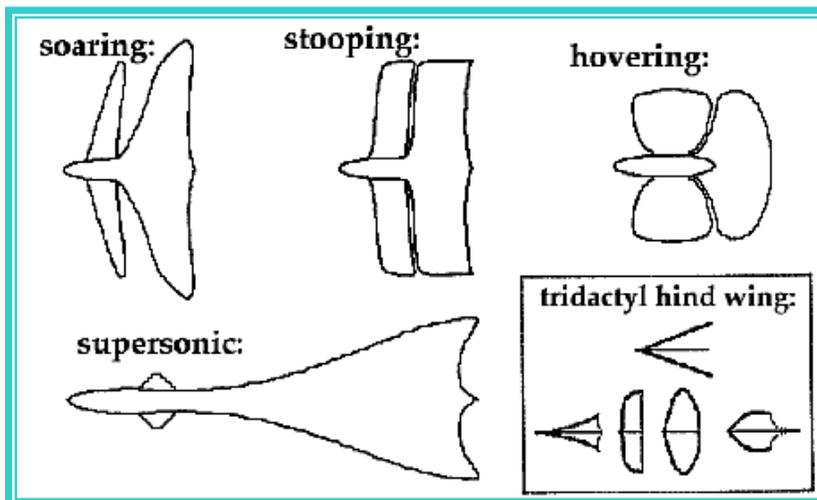
AVIANS

Because of the shortage of time for the evolution of avians, we do not see the development of ornithoids from dinosauroids as on Earth; instead, most flying forms have evolved directly from aquan (fish-like) ancestors.

Consider an aquan, of the same family as the Poncedonus precursors, which increases the size of its paddle and fins until it can leap and glide like a flying fish. In due course, species capable of sustained flight in ground effect fill the niche of a pelagic fisher; air-breathing then develops as a means of extending flight duration and avoiding the energy waste entailed in repeatedly diving back into the water.



The true avian is an air-breather in which the paddle has become a wing large enough for true flight out of ground effect. Its planform is typically a canard delta, the hind wing being flapped up and down in the same manner as the paddle of its aquan ancestor; the fore wings are used mainly for control.



As the avian species diversify, filling a variety of ecological niches, the range of available planforms widens. The original planform evolves into forms specialised for soaring, stooping, hovering, and high-speed flight:

- Soaring forms have high aspect ratio and sharp wingtips.

Dynamic soaring above the ocean swell is utilised by pelagic fishers (*cf.* albatrosses and frigate birds), which have elongated necks and scooping claws.

- Raptors, or eagle analogues, ride thermals and swoop on their prey; they have squarer planforms and a high-lift slot between the fore wings and the hind wing; the forelimbs end in grasping claws. Smaller raptors in particular can penetrate vegetation.
- The hovering form (*cf.* humming bird) is an herbivore or insectivore; its planform is a low-aspect-ratio trefoil with greatly enlarged fore wings, enabling it to hover or even fly backwards.
- High-speed forms are found in migratory non-aquatic (land-based) species; and in avians hunting other raptors and soarers in the open sky. The larger ones can go supersonic.

The diagram indicates how the underlying tridactyl form of the hind wing is modified to provide for the various planforms and permits the addition of a tail or stinger. The wing-spars and longerons are extensile muscle rods (*q.v.*), rubbery rather than rigid.

A wide range of avian ecological niches can be filled with straightforward variations on the basic form, ranging from avians smaller than a humming bird up to multi-tonne dragons (with boost, avians up to at least 100,000 tonnes are theoretically possible, if evolutionarily unlikely!).

The avians of 82 Eridani III are faster than terrestrial birds (very much faster under boost, *q.v.*), and have greater flight-ranges (due partly to the thinner air and lower gravity, and partly to the efficient respiratory system (*q.v.*) and musculature (*q.v.*)). Even where the air is thin, avians can make good use of hydrogen peroxide as a stored oxidiser; under boost, all but the smallest can approach the speed of sound at altitude (though in practise many species do not venture far from the ground), and the largest high-speed types can reach Mach 3.

The range under boost is slightly less than in fully aerobic flight, typically ~3500km versus ~4700km (see under Muscle Boost for analysis). Note that boost, unlike the anaerobic mammalian sprint mode, can be sustained for long periods, providing total outputs in excess of 1MJ/kg-animal (*cf.* ~1kJ/kg-mammal). Avians can make better use of boost than land animals (because locomotion on land is a controlled falling forward, limited by the slowness of falling under gravity, so that very high speeds are difficult to achieve no matter how much power is available).

Prior to the onset of the warm period, a few species of pelagic avians and ice-coast dwellers (*cf.* penguins and skuas) had already developed. This gave the avians an evolutionary head start over the saurian land animals like Ceretridon.

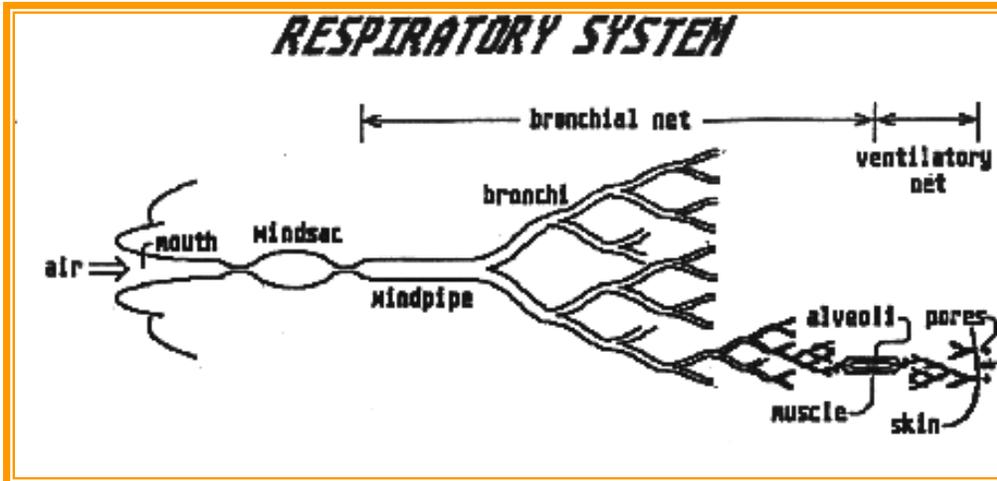
Because avians can readily migrate around the globe, one finds the same body plan on every land mass (this is the aquan body plan, ancestral to the Poncedonus form). Non-migratory and flightless avians then appear on each land mass independently, and thus

show marked evolutionary divergence. The Highlands, including Fire Island, were colonised almost exclusively by avian forms, rather than directly from the sea, and still have few animal species of amphibian ancestry.

The agile and mobile omnivorous avians, with their prehensile forelimbs, are the obvious choice to develop the 82 Eridani III sophont. The paucity of rigid materials in their environment (rubber bones, herbaceous plants, crumbly pumice) will have a marked effect upon their cultural development. Their weapons will cut and stab, rather than bludgeon; their engineering will be floppily efficient, rather than rigid and precise. Spaceflight will come easily to these creatures.

RESPIRATORY AND CIRCULATORY SYSTEMS

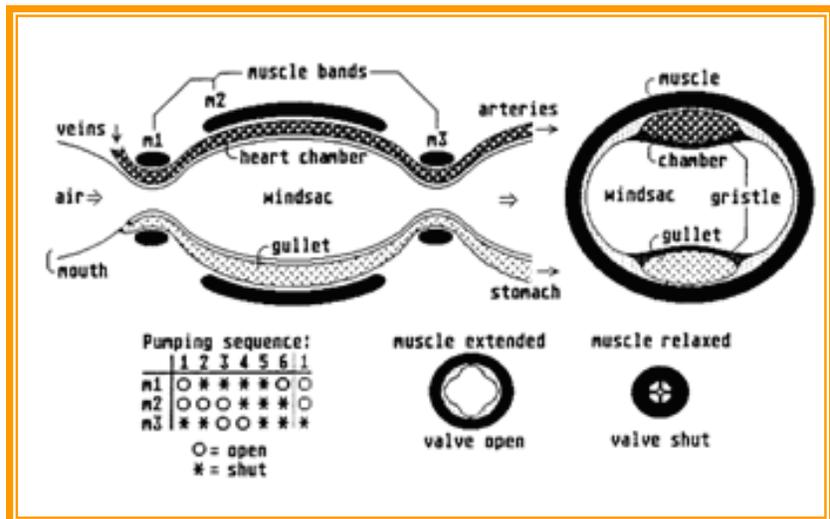
The respiratory system of avians and land animals is derived from a form originally used in aquans for breathing water. In the aquan, aerated water enters the mouth and bronchial passages under ram pressure; primitive aquans had to swim continuously in order to maintain respiration. The extension of the function of the aquan circulatory organ (or heart) in more developed aquans to include that of an in-line respiratory pump permitted the subsequent evolution of air-breathing avians, amphibians and land-animals.



Air (or aerated water) enters the windsac through the mouth; from there it is pumped into the bronchi, which branch repeatedly, delivering air throughout the body.

Some twenty-nine successive self-similar branchings lead to the lowest level, the alveoli, $\sim 10\mu$ in diameter and $\sim 1\text{mm}$ in length, where oxygen is absorbed directly from the airstream into the muscles (plus a limited number of aerobic organs). At the same level, carbon dioxide and water vapour are exhausted into the airstream. Muscles (and other aerobic functions) are concentrated near the skin, so that used air can be respired close to the point of use, through pores connected to the alveoli through some fifteen tributary levels.

For air-breathers, ram pressure is inadequate (though making a significant contribution in fast-moving avians), and an in-line pump (which is also the heart), utilising three major extensile muscles, *q.v.*, has developed. The three muscle bands, m_1 , m_2 and m_3 , operate in sequence. In a creature of roughly human size, expect



~ 1 beat/sec in repose, rising to ~ 10 beats/sec under energetic activity. There is also a

cough mode, utilized to clear the windsac passage, in which m_3 is closed, m_1 open, and m_2 closes violently. At a later evolutionary stage m_1 doubles as a larynx, speech taking the form of a modulation of the heartbeat, mainly between phases 1&2 and 5&6.

The circulatory system is very similar. Here, on the high-pressure side, arteries branch down through some thirty levels down to capillaries within the muscles; glands and internal organs, then re-converge through the same number of levels into veins leading back to the heart chamber. Organs, on the boundary between arterial and venous systems, extract from or release into the bloodstream hormones, nutrients, or wastes. A disadvantage of this division is that messenger molecules have to make a complete circuit (~ 30 secs) before triggering activity elsewhere; thus certain glands have developed the ability to inject substances directly into arteries upstream of the target organs for faster response.

Food is ingested via the gullet, which masticates it and passes it on to the stomach (there is also a regurgitative function using the cough mode). The absence of hard wood (see 'Vegetation') and mineralised bones (see 'Musculature and Skeleton') facilitates the peristaltic grinding and pumping process. After ingestion, a continuing airflow aids digestion and peroxide production in the stomach.

Note that no lung exists as such, and there is no requirement for oxygen-carrying haemoglobin in the blood, which is therefore found to be yellowish in colour (not red). Although heart-and-lung is a single organ, there are fewer critical failure modes than in the more complex mammalian heart-lung system. A fifth network, the lymphatic system, drains fluid at ambient pressure from body cavities and tissues back into the venous system just short of the heart.

Local cooling of active muscles is provided by the evaporation of water from the muscle tissues into the exhaust airstream, permitting extremely high power outputs for extended periods. The bloodstream carries both alcohol fuel and hydrogen peroxide oxidiser ("boost", *q.v.*) to the muscles. All five circulatory networks (bronchial, ventilatory, arterial, venous and lymphatic) obey the same scaling laws. The self-similar space-filling fractal networks are both simple and efficient. Every tissue cell can lie within an arbitrarily small distance of all five networks. Each network grows by budding every branch into two further branches at each round of cell division, until the available space is filled; each then occupies $\sim 3\%$ of the body volume (the ventilatory system, having fewer levels, occupies only $\sim 1.5\%$), or some 15% in total. The ratio of pipe diameters (and lengths and thicknesses) from one level to the next is thus $2^{1/3}$. We have:

Number of pipes at level $n = 2^{n-1} \sim 1/d^3$, each of length $\sim d$

Individual cross-sectional area $\sim d^2$ and thus combined cross-sectional area $\sim nd^2 \sim 1/d$

Hence stream velocity $\sim d$ (slower in capillaries, faster in main channels) and Reynold's Number $Re \sim dv \sim d^2$

Thus drag force (resistance of network) $\sim v^2 A Re^{-1/2} \sim d^2/d/\sqrt{d^2} \sim \text{const.}$ (total drag \propto no of levels N)

Time taken per level $\approx l/v \sim d/d \sim \text{const.}$

Total distance through network $\approx l_1/(1-2^{-1/3}) \approx 4.8 l_1$

Volume per level $\sim ld^2 2^{n-1} \sim d/d \sim \text{const.}$

Total volume of network $\approx NV_1 \approx (\pi/4)Nd^3$

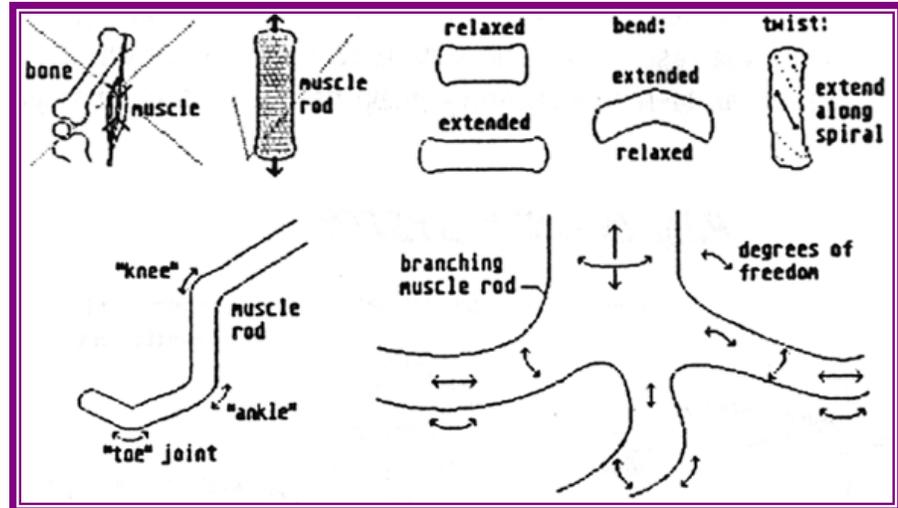
In a human-sized animal, a windpipe $\sim 1\text{m}$ long by $\sim 1\text{cm}^2$ cross-section, passing ~ 1 litre/s at 10m/s , has $C_{D\bullet} \sim N/2$ in laminar flow from $Re \sim 10^6$ at level 1 down to $Re \sim 1$ at level 30. Drag loss (incl. vent. net) $\sim (1\text{kg/m}^3)(1\text{cm}^2)(10\text{m/s})^3 (46/2) \sim 2.5\text{W}$.

Blood pumped at $\sim 2\text{m/s}$ (~ 0.2 litre/sec, total ~ 6 litre) takes $\sim 30\text{sec}$ /circuit and requires a further $\sim 20\text{W}$. The heart muscle m_1 has to be strong: for a windsac $\sim 10\text{cm}$ long by $\sim 5\text{cm}$ dia ($\sim 100\text{cm}^3$ air + 20cm^3 blood) force at 10 beats/sec is $\sim 250\text{N}$.

MUSCULATURE AND SKELETON

Muscles in the animals of 82 Eridani III are extensile, rather than contractile, derived from osmotically pressurised plant cells (see 'Vegetation'). There are certain consequences of this distinction:

The animals possess no mineralised bones and no true skeleton (in the earthly sense); the extensile muscle rod already provides the function of a compression member and its sheath of elastic fibres the function of a tendon.

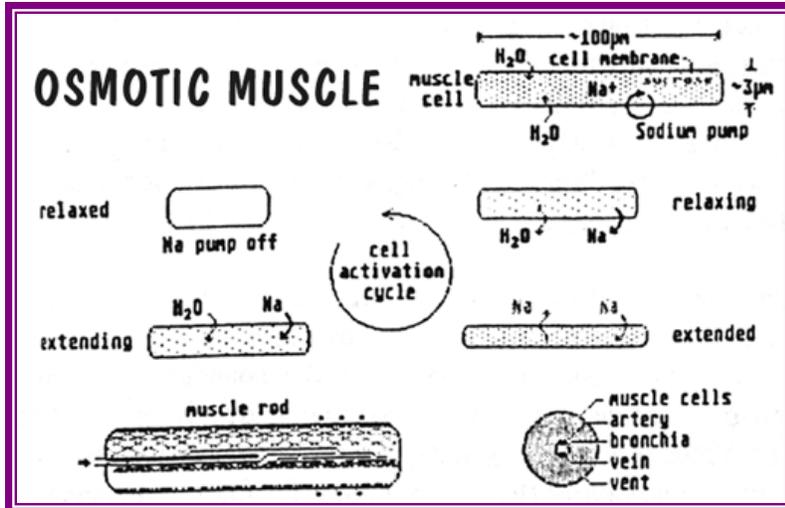


A muscle rod can extend or relax linearly, or, by differential activation of its cell bundles, can bend or twist.

Conventional joints become unnecessary: a single muscle rod can for example simulate the action of a mammalian leg, with knee, ankle and toe joints. Numerous degrees of freedom can be provided, especially where the muscle rod is permitted to branch.

Muscle rods will in general be rather thick (typically somewhat thicker than an earthly animal's bone – but also free of bulging knuckles at the joints); they are strongest in simple extension, but still provide adequate strength in bending and twisting modes. The muscle rods (or perhaps a single rod and many branches) give shape to the animal and comprise its skeleton; most of this skeleton lies close to the skin to simplify cooling of the muscles under boost (*q.v.*) and minimise the volume devoted to the ventilatory net (*q.v.*). Elongated muscle cells are also found woven into closed bands or rings (see 'Respiratory and Circulatory Systems'). As on Earth, the muscles are largely controlled by the central nervous system via nerves, more complex muscle arrangements requiring a correspondingly greater number of nerve endings.

The mechanism of the extensile muscle is that of a sausage-shaped cell elongated by osmotic pressure, still closely related to the primitive form found in the 82 Eridani III vegetation.



The elongated muscle cell has a semi-permeable elastic membrane through which water molecules can diffuse.

In the relaxed state, ion concentrations are equal across the membrane and there is no net diffusion of water molecules.

Ion concentrations within the cell can then be increased over ambient by means of a sodium

pump; extra water molecules diffuse into the cell (attempting to equalize concentrations), thus increasing the internal pressure and causing the cell to extend.

In the extended state, the sodium pump ticks over, making up the loss of sodium ions by outward diffusion.

If the pump is then stopped or reversed, ion concentrations fall and water leaves the cell, which contracts back to the relaxed state.

The osmotic muscle is composed of a sheaf of muscle cells, intimately threaded with a network of capillaries (indeed, five networks). The bronchial net is connected to the ventilatory by alveoli; the arterial flows into the venous; and the lymphatic drains the intercellular spaces. The whole is encased in an elastic protein sheath, like a Chinese finger; and down the centre run the larger vessels, arranged in such a way that all capillaries are equidistant from the origin (that is, all routes through the network are of equal length). The long cells are laid up like a rope, almost parallel, but with an alternating hierarchy of twists; this means that when the muscle is caused to extend, the rod thins down less than the individual cells do; the gaps between them widen, thereby dilating the vessels that carry blood and oxygen to the active cells. Contrariwise, when the muscle is relaxed the capillaries are constricted. Thus blood and air flows are automatically regulated at the point of demand.

The energy driving the sodium pump comes from ATP, which is generated in the enzymatic oxidation of ethanol from the bloodstream; the immediate oxidiser is derived by one of two routes, utilising either oxygen from the air or hydrogen peroxide from the blood. Sucrose, also present in the muscle cells, can if necessary be broken down to ethanol and utilised as fuel; its principal function, however, is to provide stiffness in the relaxed state due to the residual osmotic pressure it affords (as in the corresponding structural plant cells, *q.v.*); sucrose can only cross the membrane by active transport (coupled to the sodium pump), and thus unlike sodium is not lost to the cell by outward

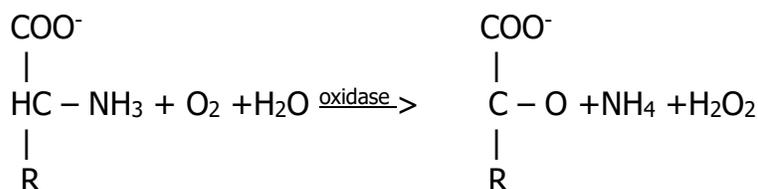
diffusion. Waste heat is disposed of via the ventilatory net by evaporation of water; under boost (*q.v.*), with hydrogen peroxide oxidiser and ethanol fuel supplied by the blood, continuous very high muscle power outputs (at mechanical efficiencies $\sim 70\%$) are thus made possible.

Osmotic muscles can be very fast. For example, if pores account for $\sim 1\%$ of the surface area of the cell, water molecules can diffuse in at an effective speed $\sim 1\text{m/s}$, causing cell extension in $\sim 1\text{ms}$. More commonly, animal muscles function at much lower rates, taking $\sim 10\text{ms}$ or more to extend or contract.

The *hibernation* of certain 82 Eridani III animals may be mentioned here. In winter they excavate burrows and bury themselves in earth. Sucrose is pumped into the muscles of the heart (*q.v.*) to open the valves, then the heart is stopped; slow circulation is maintained by the dilation and constriction of capillaries as muscles throughout the body are gently exercised. Oxygen supplies are augmented by stored peroxide as necessary. Then a boost injection restarts the heart and brings the beast out ready to fight.

MUSCLE BOOST

Since the rate of supply of oxygen to muscles is limited, it is advantageous to provide additional anaerobic energy capable of boosting power output for short periods. In mammals, ATP is used, but only provides ~10kJ/kg-muscle. Nitrous oxide (N₂O) has been suggested as an alternative oxidiser, but as a gas would not be easy to store in the animal or use efficiently. Hydrogen peroxide (H₂O₂) seems a better choice: it can be stored as a concentrated solution in internal sacs, and distributed in more dilute form through the blood. On Earth, in animal metabolisms, it is produced in the oxidation of amino acids by amino acid oxidases:



This is a process likely to occur wherever amino acids are used; the utilisation of peroxide as a special oxidiser should not then be a difficult evolutionary step.

With the osmotic muscle (*q.v.*) and straight-through respiratory system (*q.v.*) of 82 Eridani III, peroxide boost is an effective and advantageous addition.

Most of the surviving animals of 82 Eridani III (including avians and aquans) employ peroxide boost for the roughly tenfold gain in muscle power it affords. Hydrogen peroxide is stored in internal sacs, lined with saturated fats (unsaturated fats would be oxidised) and released into the blood stream (or, sometimes, the air stream) when required. Ethanol (C₂H₅OH), likewise stored in internal sacs, is the principal fuel (though sugars can also be employed):

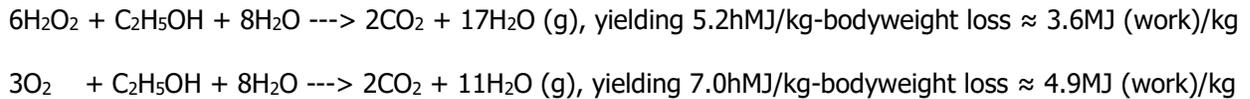


This reaction is equivalent to the two part reactions:



The peroxide thus adds ~50% to the fuel energy, at the expense of some extra reactant mass. However, we must also consider the amount of water needed to remove the waste heat by evaporation. The vaporisation of water requires some 36kJ/mol=2MJ/kg. Now if we assume a muscle efficiency (chemical energy to work) of about 70% (mammalian muscle is up to 80% efficient), the decomposition of hydrogen peroxide needs no additional cooling water (0.3x714 ≈ 6x36), but the oxidation of ethanol (with or without peroxide boost) requires a further eight moles (since 0.3x2040 ≈ (9+8)x36 and 0.3x1326 ≈ (3+8)x36 also)

The overall reactions are therefore:



Clearly, the amount of work obtained per unit loss of body weight is about a third higher under fully aerobic conditions than under boost. Put another way, the total maximum work performed by an animal under boost is about 75% of the maximum it could achieve conventionally, if the stored peroxide were replaced by extra ethanol and water. The rate of doing work can of course be arbitrarily greater under boost, since all the reactants are immediately available. It is evident that boost imposes only a modest metabolic cost, yet provides outstanding benefits.

As an example, consider a migrating avian, having an aerodynamic $L/D \approx 15$ and a propulsive efficiency $\approx 70\%$ (i.e. 50% net efficiency, chemical energy \rightarrow forward thrust). On 82 Eridani III ($g = 7.6\text{ms}^{-2}$) the energy required for flight is $\sim 0.72\text{J/kg/m}$.

Hence, loss of body weight $\approx 0.20\text{kg/kg}/(1000\text{km})$ under boost
 $\approx 0.15\text{kg/kg}/(1000\text{km})$ air-breathing

If the maximum body mass ratio is 2.0 ("replete"/"starving"), the free-air range of the avian (with no wind assist or feeding en route) is $\sim 3500\text{km}$ (37° of arc) with boost and $\sim 4700\text{km}$ (50° of arc) without.

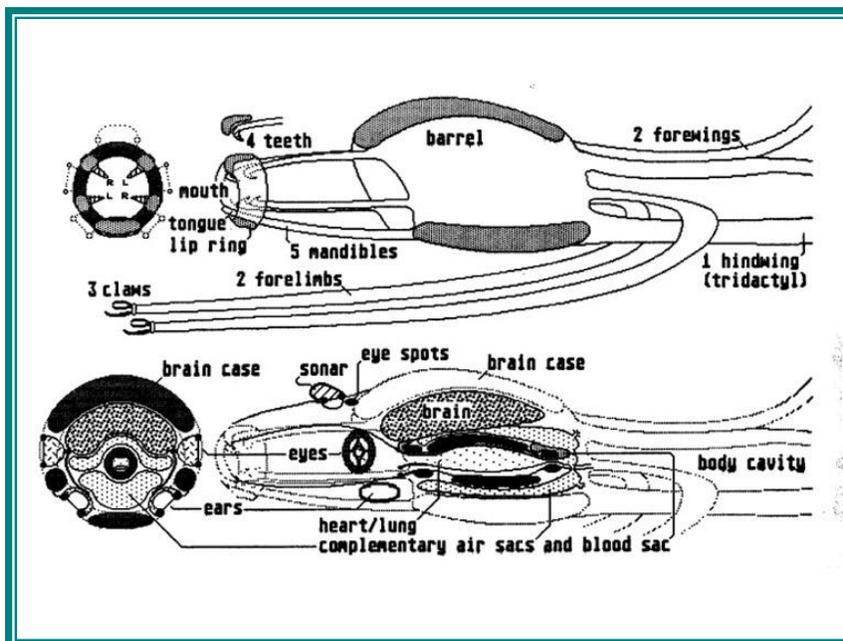
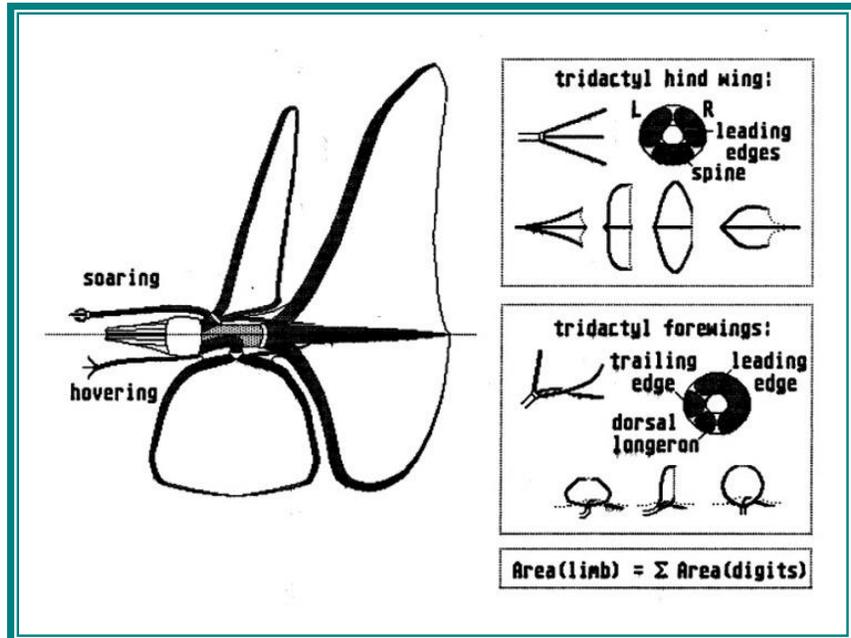
In practise, an avian will continue to get some of its oxygen from the air even in boost mode. An avian of roughly human mass (say $\sim 75\text{kg}$) could handle an air flow $\sim 1\text{litre/s}$ at sea level ($\sim 0.75\text{kg/s}$), yielding $\sim 2\text{kW}$ work. This is already rather better than a human can manage, permitting flight at speeds up to $\sim 40\text{m/s}$. With boost, however, a *blood* flow to the flight muscles $\sim 0.2\text{litre/s}$, carrying $\sim 1\%$ H_2O_2 , yields a further $\sim 14\text{kW}$ work; speeds $\sim 300\text{m/s}$ are therefore possible, at altitudes up to $\sim 45\text{km}$, where the thin air (one hundredth of sea level density) provides too little oxygen. Predator avians may go to $\sim 5\%$ H_2O_2 just upstream of the muscles, hitting a top speed around Mach 3. But at $\geq 20\%$ H_2O_2 , the avian could explode in mid-air!

Certain land animals (and aquans) also inject peroxide directly into the bronchial airstream (or waterstream), enabling them to employ much higher H_2O_2 concentrations and achieve peak boost power outputs up to $\sim 10\text{kW/kg-bodyweight}$ (and accelerate from 0-100m/s in 1s!). However, conditions rarely permit such extreme levels of boost to be used effectively.

PENTAPOD ANATOMY

The myoskeletal pentapods share the same basic body plan with each other (and, indeed, with other myoskeleta, such as Pagoda trees: see under Myoskeletal Embryology). By way of example, we consider the anatomy of a representative avian.

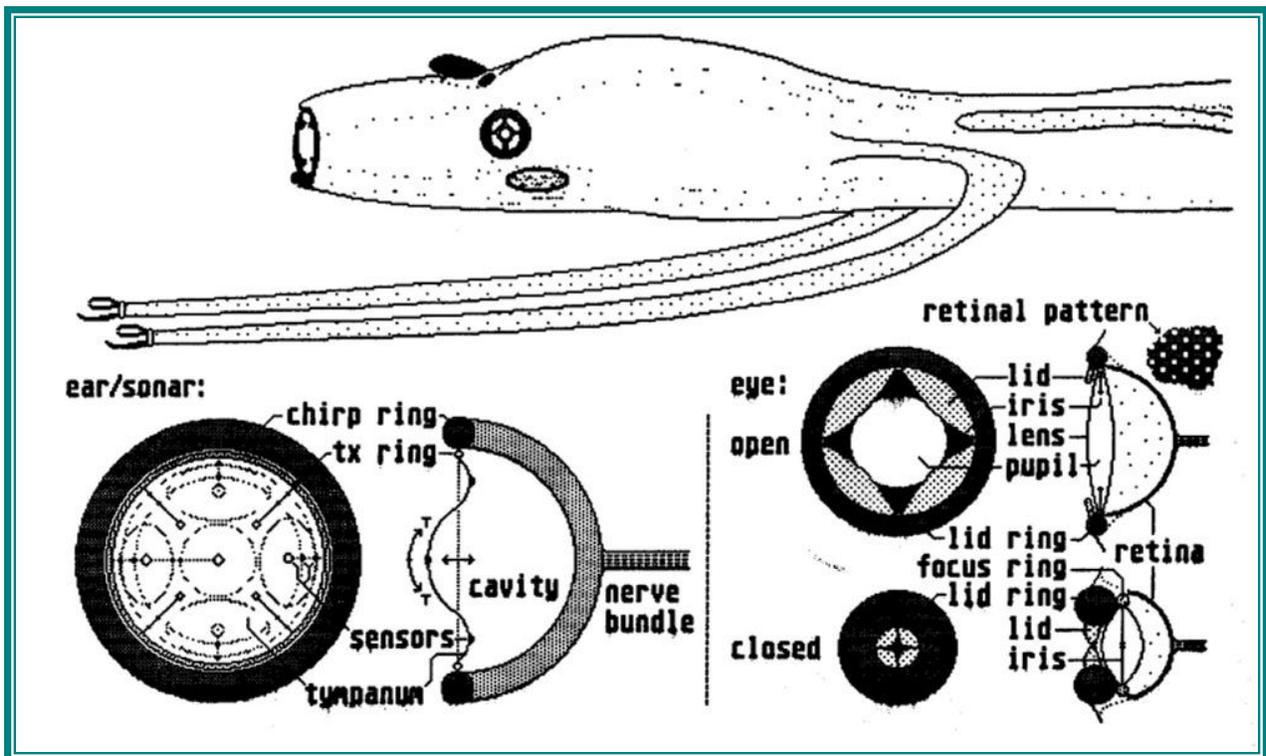
The avian myoskeleton consists of a hoop or barrel, open at both ends. From each end project five myoskeletal limbs; those at the rear are the pentapods that give the phylum its name, comprising the hind wing, a pair of forewings (high-wing canards), and two forelimbs; those at the front comprise the five mandibles of the jaw. Each limb terminates in a muscle ring or collar, from which project three myoskeletal digits; these comprise the main structural elements of the wings, and the grasping claws of the forelimbs. At the collar, the combined cross-sectional area of the digits is made to equal the cross-sectional area of the limb.



Each mandible is also of tridactyl form, but the three digits have been twisted together, fused into inward-pointing screw-action extensile teeth; with alternating left and right hand threads they are almost impossible to disengage by force. The digits of the lower mandible are not twisted but fused into a tongue.

The mandibles connect to the lip ring, an unusually strong muscle which opens and closes the mouth, grips prey or forage in an unbreakable

grip, and drives in the cruel teeth. The brain is housed within the ample protection of the barrel above the complex of the heart/lung pump (see under 'Respiratory and Circulatory Systems'), cushioned by the complementary air sacs and complementary blood sac (which buffer bronchial and blood pressures by maintaining overall constant volume as the pump muscle bands dilate and contract). The brain is also the organ of smell (there is no nose as such); sensitive cells receive air directly through the bronchial net. Taste buds may also be present near the brain in the upper posterior part of the mouth cavity.



Organs of sight and hearing are placed anterior to the barrel, in the five inter-mandible positions. They comprise two eyes, one on either side of the head; and three ears, one on either side below and one above. The upper ear is also a sonar transmitter, surmounted by a dome capable of directing the sonar beam forwards. The two eye spots are anatomically part of the sonar, just behind and to either side of which they lie (in fact, all five organs are in origin anatomically identical, their common structural elements not eliminated by later specialisation). The ear or sonar comprises a loaded cavity, closed by a tympanic membrane stretched across a double muscle ring; the outer, stronger ring tensions – and thereby tunes – the tympanum; the inner ring is much faster, capable of driving tympanum oscillations at up to ~30kHz.

The sonar transmitter produces a strong tone, chirped in frequency by rhythmic extension of the chirp muscle. The ears are narrow-band tunable receivers, sensitive to sound at the resonant frequencies of the membrane (fundamental plus anharmonic overtones). Sound causes the tympanum to resonate; this is detected by sensors placed at the nodal points or around the nodal rings (the sensors are osmotic muscle cells used in reverse,

the increased tension at the nodes sucking water out of the cells, affecting local ion concentrations and thereby modifying the firing rate of the sensory nerves). Signals received or generated by one ear can be fed to the transmitter rings of other ears to improve sensitivity by nulling out unwanted signals, like a background-cancelling microphone.

The eye comprises an aqueous-humour-filled retinal cavity, closed by a lens encircled by a focussing muscle ring. Within the lens is the iris, a thin muscle in the shape of a washer (an eccentric arrangement of muscle cells allowing the iris to shut completely). The heavier outer ring supports the folds of the eyelids; when the lid ring is relaxed, the eye is closed and well-protected. The retina uses a hexagonal array of two types of receptor; two cells have red pigment to every one with yellow.

The upper eye spots are areas of photosensitive nerve cells which have migrated away from the sonar, whose nerve bundle they still share. In avians (and many other pentapods), they are vestigial: they monitor the seasonal intensity of yellow light, triggering the behavioural shifts of migration, mating or hibernation. In aquans (and other pentapods, e.g. Poncedonus), they remain as functional eyes, covered by a non-focussing lens; whereas the lower eyes then function within the water medium, the upper eyes are optimised to function in air, or through the air-water interface, and to detect the presence or movement of predators from above (the avian's migration impulse is presumably related to the ancestral fear/flight reflex thus triggered).

It is important to realise that this same anatomical scheme must apply to the entire pentapod phylum. Seemingly disparate forms, such as Poncedonus or Ceretridon, are sisters under the skin (actually, hermaphroditic siblings: see under 'Myoskeletal Embryology'). Thus, the fins of the aquan and the canards of the avian correspond to the floats of Poncedonus and the forelegs of Ceretridon: but where both aquan and avian have short limbs and long digits; Poncedonus has elongated the limb into an outrigger, leaving the three digits to define the float; and Ceretridon has shortened the digits into toes.

The hindwing of the avian corresponds to the paddle of the aquan and Poncedonus, and the hindleg of Ceretridon. Again, Ceretridon has shortened the digits into toes.

Although the forelimbs, which function as grasping appendages in most species, are attached behind the head, they are normally required to extend forwards. Thus, as in Poncedonus and Ceretridon, they are often found to have fused to the side of head, along the barrel, and even along the middle mandibles as far as the mouth.

Note that the hindwing or hindleg are attached to the barrel in the lower position, whilst the forewings or forelegs are attached in the upper positions. This is apparent in drawings of Poncedonus, Ceretridon, Proto-Ceretridon and Bipedal Ceretridon. In some forms, such as Proto-Ceretridon, the barrel may also be elongated, giving the appearance of a neck.

In aquans and avians, bodily wastes can be ejected (in flight) rearwards from the body cavity, over the hindlimb. In Poncedonus and the Ceretridons, this is impracticable, and the anus is displaced asymmetrically off to one side.

Not all of the myoskeleton needs to be fully vascularised; some parts, such as the barrel, do not need the full flexibility of muscle and consist largely of a stiffer (though still resilient) cartilage. However, since the limbs, mandibles and mouth are required to be as muscular as possible for their size, little or none of their mass can be wasted upon inactive cartilage; they are most effectual when the whole of their length is manipulated, and the whole volume works at the same power density and stress.

Surprisingly, even the myophyta, plants like the tiered seaweed and the Pagoda tree, share the same myoskeletal plan. Consider a Pagoda tree segment: at its base an open hoop (corresponding to the mouth and lip ring) tucks into the top of its parent segment; its hollow trunk has exactly five cut-outs and five beams (the five mandibles); the trunk terminates in the barrel, into the top of which the next segment slots; the canopy spreads from the top of the barrel over five spines (the five limbs), which split into three towards the periphery (the three digits). In the tiered seaweeds, the spines are sturdy and generally obvious; but in most Pagodas they are hardly noticeable, flattening out to form the skeleton (with phloem and xylem) of the leaf canopy; at the canopy edge, the limb collars are linked by pairs of digits to form the ripstop string, the third digit either atrophied or dangling down from the edge.

The growth pattern of Pagoda segments is a clue to pentapod reproduction: the foetus develops within the body cavity, behind the barrel, attached by its mouth to the posterior end of the heart/lung complex; the pentapods give birth by ejecting the podlet forwards through the mouth (Caesarian section, between the upper limbs, may be used by some species, such as Poncedonus). Sexual intercourse of these hermaphrodites is affected by joining mouth to mouth (kissing!) (Avians do it in flight!) and each alternately sucking sperm-laden air through its oviduct. Young are therefore usually produced in pairs, one from each partner, but single arise when only one partner successfully conceives. Vegetative reproduction (clones) and self-fertilisation ('virgin' birth) are also possible. Pairs, singles, clones and selfers (in order of decreasing normality) are liable to be treated differently by society.

The world of an avian differs from ours. Its eyes can see in all directions simultaneously, but because it has no binocular vision, depth perception is absent – the sonar system more than makes up for the lack. Consider an avian of roughly human size. Its eyes have a resolution $\sim 1/3000$ radian, like ours. Its mental map and image processing thus involves $\sim 10^8$ pixels in all; this compares with our monocular maps $\sim 3 \times 10^7$ pixels, which binocular range information bumps up to $\sim 10^{11}$ pixels (we probably don't actually store images – like a computer – in tidy arrays, but the analogy can be useful in indicating the magnitude of the processing tasks). However, if the sonar chirps from ~ 15 kHz to ~ 30 kHz, its range

resolution is about 0.5cm; it has $\sim 2 \times 10^5$ range cells out to ~ 1 km. Its angular resolution (with trinaural hearing) is much poorer, $\sim 1/20$ radian, providing a directional map of ~ 5000 cells. The full sonar map thus contains $\sim 10^9$ cells. Repeated scans, while the avian flies a baseline, enable positions to be triangulated to within ~ 1 cm. If the transmission frequencies and chirp rates are lowered, directionality and range resolution suffer, but the longer wave \sim lengths have a correspondingly longer range; moreover, they are readily diffracted over hills, so the sonar returns are not limited to line-of-sight. Although our avian cannot produce chirped sonar below ~ 2 kHz, it can hoot through its mouth at frequencies down to ~ 100 Hz, while the deep foghorn booms of the greater Ceretridons reverberate around the valleys of Epona.

Sonar is ideal for avians flying at hair-raising speed through the dim corridors of Pagoda forests, where eyesight would be inadequate. Yet if sonar alone would not provide sufficient angular resolution, correlation of the sonar and visual maps can localise objects with great precision, all without placing too great a load on the processing capacity of the avian brain.

The avian also has acute hearing, but of a most distinctive type; at any instant, it hears only the frequency (and its overtones) to which the tympanum is currently tuned. To the resonant frequency, it is ultra-sensitive; to the wrong note, it is all but deaf. To detect sound at an arbitrary pitch, or to scan a broad-band noise, the avian must chirp its tympani, moving the resonant frequencies across the spectrum. Avians can call each other over great distances at an agreed pitch, but while mistuned they can also easily miss important sounds. By contrast, terrestrial mammals enjoy only moderate sensitivity – but over the whole spectrum at once.

An avian could hear the chime of a door bell a dozen miles away, and at the same time fail to notice a foghorn within six inches of its ear. Our music, with its orchestral tuttis and complex harmonies, would be a confusing blare to it; but perhaps we could find common ground in the mellifluous lines of plainsong, the sound of a solo flute or violin, or the change-ringing of a peal of bells (whose overtones are not unlike those of the tympanum). Pentapods, of course, have perfect pitch (to lose it, perhaps through sickness, is a serious handicap). Pentapod cries are like the chirping of birds or the whistling speech of the Clangers (from the sonar), underlain by a rhythmic grunting or hooting out of the mouth (see under 'Respiratory and Circulatory System'). In intelligent speech, meaning is carried by concatenations of leitmotifs at defined pitches.

The organs of hearing have an additional function: that of pressure sensors. The small hole opening forward just below the sonar dome is the avian's pitot tube; it allows the static and dynamic components of pressure to be separated. Thus the pressure altitude and indicated airspeed (as well as rate of climb) are available. The triad of ears then senses orientation relative to the airflow: that is, the degree of sideslip and the angle of attack. The avian thus possesses the flying instruments needed for controlled flight. In aquans, water pressure and depth replace air pressure and altitude, but otherwise the

arrangement is much the same. In land pentapods, these functions tend to atrophy, but the dynamic sense of balance they afford is retained.

Within the pentapod body cavity are to be found various organs, notably the stomach and intestinal tract, spleen-like organs for the production of boost, and sacs for the separate storage of ethanol and hydrogen peroxide. Of particular interest is the milk gland, situated on the back behind the head (that is, posterior to the barrel, between the upper limbs). The subdivided milk sacs connect to an erectile nipple on which the young of the species can suck. The milk is a clear liquid, an aqueous solution of 18% hydrogen peroxide and 15% ethanol (not quite concentrated enough to be explosive). Like mammalian milk, it also contains smaller quantities of protein, minerals, vitamins, antibodies and so forth; mainly, though, it is intended as a source of immediately useable energy. The 18% H_2O_2 oxidises only 4.2% ethanol – the other 10.8% is expected to be consumed aerobically.

In due course we can expect that herbivorous pentapods will be domesticated, not only for their meat, but also their milk. This milk is not for sissies – it is the draft of warriors. Drink deep of it, and you can boost for ever! (At any rate – until metabolite poisons build up, pH control and ion balances deteriorate, nerve function becomes unreliable, and over-driven muscles go into spasm). After a day's hard battle under boost, exhausted warriors could down gallons of milk and rush straight back into the fray, or drink several times their own mass of milk overnight. A clan of berserkers could fight every day; messengers could fly daily to the antipodes; beasts of burden might clock almost as many tonne-miles as a 747: but this is burning the candle at both ends and the middle; and the lifespan of a milk-addict is short indeed.

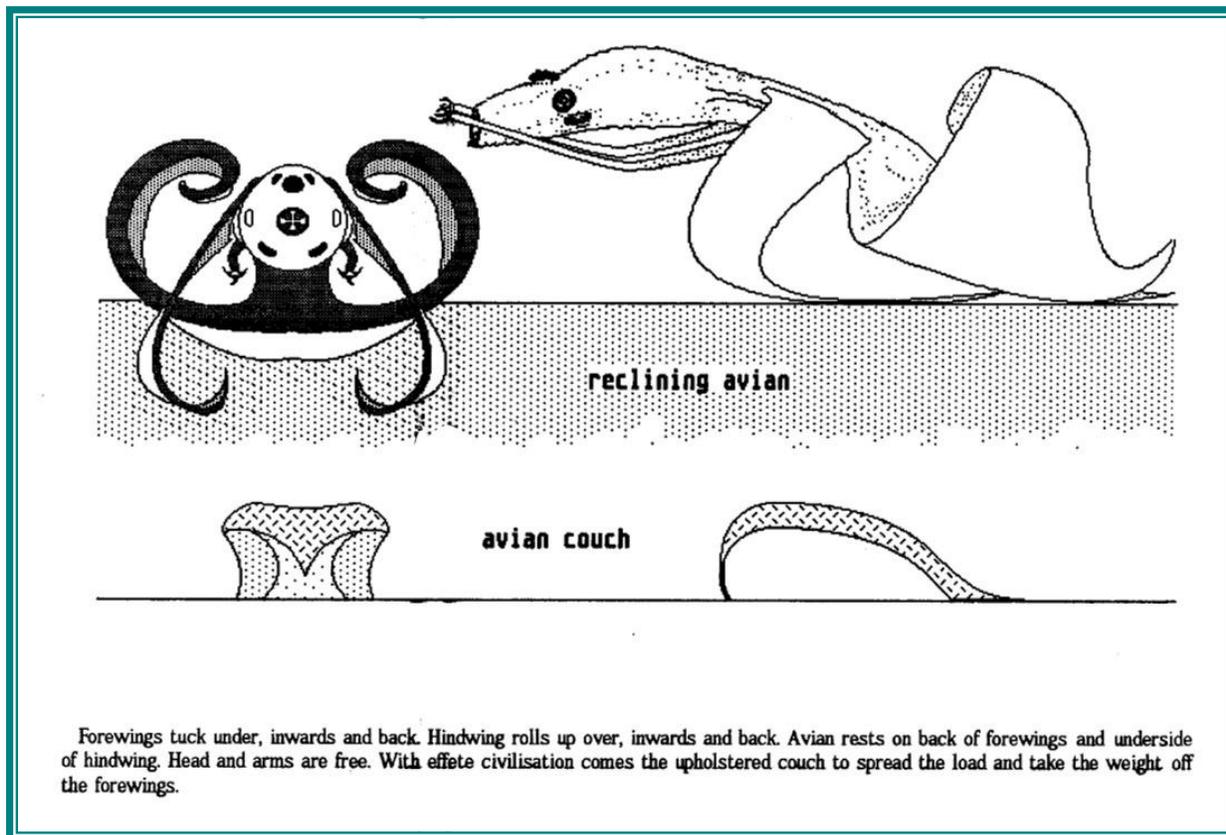
Among pentapod ailments is the Reversed Muscle Action Syndrome, common among overboosters, in which overstrained muscles become trapped in the regime in which a reduction in cell pressure and volume causes already elongated cells to lengthen further; it occurs when osmotic muscle cells suffer both loss of membrane elasticity and excessive helical-net pitch angles.

The integument of an aquan is tough and resilient, not unlike the rubberised fabric of an inflatable, punctuated by the pores of the ventilatory net; its resilience and long-chain-molecule secretions (analogous to terrestrial dolphin skin) help maintain laminar flow and reduce friction. The hide of land pentapods is similar, except that the secretions that help keep it supple are restricted to light-weight oils that evaporate without residue – this prevents any blocking of the ventilatory pores.

The integument of an avian is slightly different. Fur and feathers are impracticable for pentapods, because they would all too easily ice up (like a moustache in the arctic), severely burdening the animal or even choking it to death. This is especially true for avians, who must often fly through super cooled clouds (paradoxically, only in hot

climates would fur be safe). At the same time, excessive heat loss from the wings expanse must be avoided.

Avians consequently have an integument like foam rubber. It is light, highly flexible, porous, and provides good insulation. It protects the wing membrane from damage and provides boundary-layer control of the airflow, preventing laminar separation and reducing drag. It is backed by the tough rubberised fabric of the skin proper, in which the strong fibres are preferentially aligned fore-and-aft to minimise damage from impacts in flight. Beneath the skin is the myoskeleton (although the thick main spar lies along the leading edge, a thin sheet of myoskeleton extends from it across both upper and lower surfaces, allowing muscular control of the whole wing). Most of the wing interior is hollow with just low density elastic foam for shaping.



When resting on the ground an avian supports itself on its folded wings. Its forewings tuck under, inwards and back. Its hindwing contracts and rolls up over, inwards and back. It can lower itself towards the ground by allowing its forewings to contract, or raise itself to the alert position by extending them. Head and arms are free.

The reclining position is to avians what sitting is to humans. A simple upholstered couch can be designed to make it more comfortable, spreading the load and taking the weight off the forewings and spine digit. Intelligent avians reclining at a control desk can have a sonic screen in front of them, visual displays and books to the sides.

A 70kg sophont has a nominal wingspan $\sim 2.5\text{m}$ (from 1.5m to 3.5m fully extended), wing area $\sim 2.5\text{m}^2$ (1.2-3.5 m^2), wingchords $\sim 0.5\text{m}$ (fore) and $\sim 0.75\text{m}$ (hind), wing thickness $\sim 0.1\text{m}$; $W \sim 530\text{N}$, $W/qb^2 \sim (15\text{ms}^{-1}/v)^2$ @ sea level; $C_{Lmax} \sim 3.5$ when $L/D_i \sim 2$, $v_{stall} \sim 12\text{m/s}$ & $P \sim 3.2\text{kW}$; when $b \sim 3.5\text{m}$, $v_{sink} \sim 1.4\text{m/s}$, $P_{min} \sim 740\text{W}$ @ $v \sim 34\text{m/s}$ & $(L/D)_{max} \sim 28$ @ $v \sim 45\text{m/s}$; when $b \sim 1.5\text{m}$, $v_{sink} \sim 4.2\text{m/s}$, $P_{min} \sim 2.2\text{kW}$ @ $v \sim 63\text{m/s}$ & $P \sim 2.6\text{kW}$, $(L/D)_{max} \sim 17$ @ $v \sim 83\text{m/s}$, while $P \sim 14\text{kW}$ @ $v \sim 180\text{m/s}$.

For wingroot spar cross-sections $\sim 40\text{cm}^2$, total wingmass $\sim 35\text{kg}$, osmotic pressures of 35bar support weight up to 13g *Epona*. The arms ($\sim 12\text{cm}^2$) can each similarly push/pull $\sim 4\text{kN}$ or raise $\sim 5\text{kg}$ at arms length. Higher osmotic pressures are possible – see also under 'Structural Materials from Myoskeletal Tissue' for consideration of myoskeletal muscle strengths.

MYOSKELETAL EMBRYOLOGY

The kingdom of the myoskeleta shares a common embryology (leading, not surprisingly, to closely related body plans). In the absence of sexual differentiation – there is no specific XY chromosome pair or equivalent – the myoskeleta are hermaphroditic, reproducing both sexually and asexually. In the sexual mode, each specimen can provide either the egg or seed, or the fertilising sperm or pollen (or, exceptionally, both). In the asexual (vegetative) and parthenogenetic modes a bud grows respectively into a clone or a chromosome-doubled scion of the parent. (As caveat, we note that genetic damage or chromosomal aberrations may lead to specimens unable to fulfill one of the male or female roles, yet still capable of producing viable offspring; sexually differentiated species may thereby develop from time to time, with the damaged gene taking the place of the mammalian Y chromosome).

The development of the myoskeletal embryo starts with the egg, an unusually large haploid cell (or with a bud, an otherwise identical diploid cell). The egg is then fertilised or pollinated by particularly small haploid pollen cells (myoskeletal animals also produce pollen – their spermatozoa are not self-mobile). The fertilised egg is then able to develop into an embryo. The transformation of a bud into an embryo is triggered, not by pollenisation, but by a chemical or environmental stimulus, but is thereafter very similar to the subsequent development of the fertilised egg. The egg or bud now cleaves (division without growth) five times in succession, leading to blastomers of 2, 4, 8, 16 and finally 32 cells. The 32 cell stage is a blastocyst; it comprises a 20-cell dodecahedron, nested around a 12-cell icosahedron, around a 1-cell-sized hole. At this stage, geometry – the nesting of perfect solids – rules the embryo's shape. The twenty cells of the dodecahedron can be thought of as a group of five congregating around each of the poles, plus a staggered band of ten around the equator; this is the origin of the pentapod anatomy. A further two cleavages of the 20 outer cells only surrounds the dodecahedron with a 60-cell ball, three cells in a triangle to each of the twenty; this is the origin of the tridactyl limbs. The hole in the middle, or blastocoele, will eventually become the interior cavity of the developed organism.

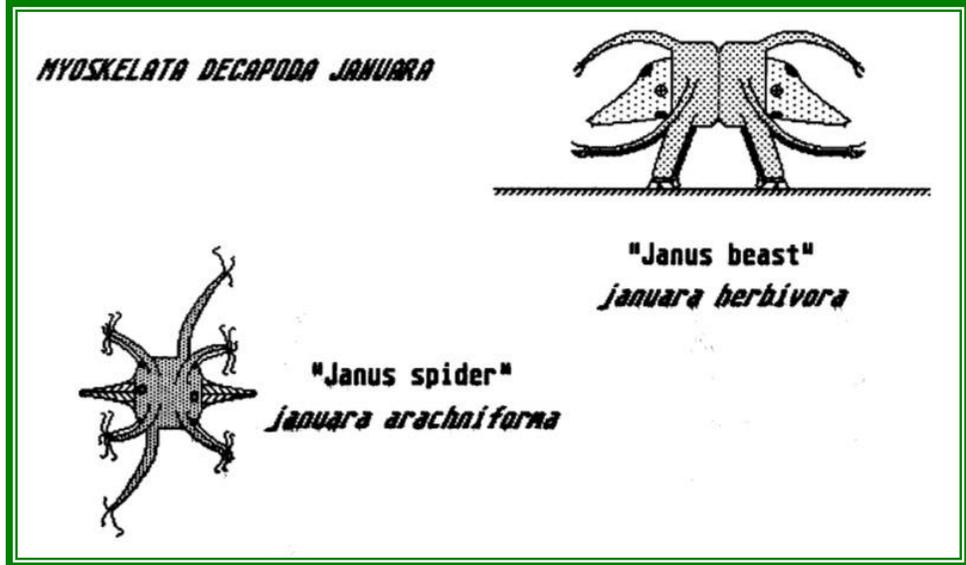
Thus far, development has been geometrically symmetric. But now (except in primitive free-floating organisms) implantation of the embryo within the body cavity of the parent takes place. In the case of the pentapods, implantation occurs onto the posterior wall of the windsac, between the complementary air sacs (see under 'Pentapod Anatomy'); other phyla employ anatomically equivalent locations. The act of implantation breaks symmetry, defining an axis (the vertical axis for Pagodas, fore-and-aft for pentapods). As the blastocyst touches the wall, a chemical messenger causes the nearest of the twelve cells of the inner icosahedron to cleave three times, pushing a pseudopod out between the gaps that cleavage has left in the 20-cell and 60-cell layers; one cell for each of the three layers leaves five, which form a pentagonal ring just beyond the 60-cell layer. This ring, eventually to become the mouth or segment base, sticks to the wall at the implantation site. The cells of the pseudopod develop into a placenta, supplying the growing foetus with nourishment; they are not part of the foetus proper, and are discarded at birth.

After implantation, the embryo begins to grow and the various organs to develop. For example, the remaining cells of the icosahedron (which are still capable of a few more rounds of cleavage) consist of an anterior ring of five (which become the circulatory pump), a posterior ring of five (which branch repeatedly to form the bronchial, ventilatory, arterial, venous, lymphatic and nervous nets), and a single cell at the rear (which becomes the alimentary canal). Initially, there is little difference between the embryos of any of the myoskeleta, and only gradually do the evolutionarily-advanced features appear (ontogeny recapitulates phylogeny).

A crucial point in the growth of pentapod embryos is the second symmetry loss, in which the up-and-down orientation is added to the fore-and-aft. This is controlled by the gravity vector (serious developmental defects could therefore occur if an avian were kept in free fall during this phase of pregnancy). The third symmetry loss (left-to-right orientation) is equally important; without it, their otherwise magnificently developed faculty of spatial perception would be lost. With somewhat faster embryonic growth rates, pentapod gestation periods are typically half those of corresponding terrestrial mammals. At birth, the muscle bands at the implantation site and in the circulatory pump gape wide, squeezing the baby animal out through the open mouth; the size of the body cavity restricts the size at birth to about one third that of the adult animal, or about one twenty-seventh the body weight (equivalent to a 6lb human baby).

The myoskeletal kingdom includes multi-segment plants, such as Pagoda trees. They grow upwards by repeatedly budding a new segment from the uppermost existing one, until the tree's full height is reached, its quota of tiers filled. Each mature segment is the same size (because it goes through a fixed number of cell divisions in development); and each virgin segment is closed at the top by a membrane (the bud site is at its centre). In due season, the topmost segment produces a haploid fruitlet, instead of the usual vegetative bud, and fills the air with pollen. If pollenisation is successful, a daughter segment develops at the treetop; if it fails, the fruitlet develops parthenogenetically instead. Either way, once it is fully grown, the segment is shed, blowing away in the wind like a parachute. On reaching the ground, it takes root, and the whole process repeats. But if at any time a segment should be torn loose, it always has the ability to take root and grow into a complete new plant.

The phylum of myoskeleta decapoda includes the Janus spiders. In the decapods, it is the staggered equatorial ring of ten that develops into legs. The mouth, with its five mandibles, develops as in the pentapods, except that,

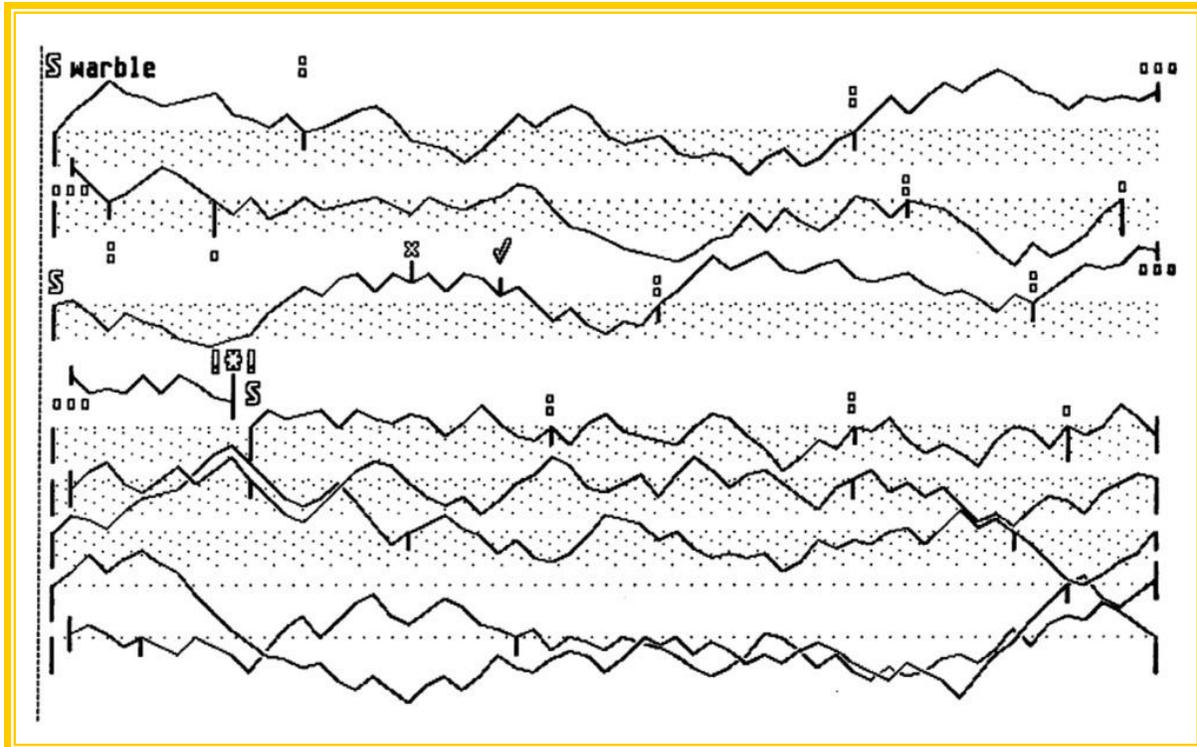


retaining its fivefold symmetry, it rarely has screw teeth. In the Janus order, a second mouth develops at the opposite end; most of this order is relatively small, filling ecological niches similar to those occupied by terrestrial insects. Janus spiders utilise a distinctive ten-legged cart wheeling mode of ambulation. The Janus beast, however, is a large and flighty twice-three-armed quadrupedal herbivore.

SPEECH AND WRITING

The peculiar nature of the pentapod auditory system (see under 'Pentapod Anatomy') constrains the patterns of speech of intelligent avians. They do not hear as we do: they could neither adequately appreciate nor reproduce human speech, not even in the mangled indo-European forms commonly produced by science fiction aliens. Spoken languages built on phonemes, syllables and words (as all human languages are) must be considered inappropriate. Written languages, when they arrive, will inevitably be similarly devoid of phonetic or alphabetic symbols (even pictographs, as employed on Earth, are more closely related to the spoken language than might at first appear).

The formative feature of avian speech is the tuned pitch of the tympani and the corresponding set of anharmonic eigenmodes. Only frequencies within the ears current eigenset are audible; and only those within the sonar's eigenset can be produced (except for the low-pitched bronchial hooting from the mouth). Avian speech thus comprises meaningful sequences of tones – in contradistinction to the broad-band complexities of human speech. There are three main components. First, the bronchial hooting. Most pentapods hoot, producing animal cries of alarm, fear, pleasure, pain, hunger, anger. The sophonts add more subtle emotional responses (such as laughter, amused or contemptuous), but cannot infuse more detailed meaning; it is not true speech. Second, the warble. This is a rapid alternation between two or more of the eigentones within a given set, and is employed for speech protocol (a kind of spoken punctuation, essential to avian speech). It can be produced without retuning or chirping between its rapid tones. The most important warble, without which communication could not even be initiated, is produced on a standard pitch or tuning. Third, the tone sequence or melodic line. This is where the intelligence is actually carried.



The listening avian must always be aware of what pitch its ears should be tuned to (otherwise it would be unable to hear the melody); this is why all speech must commence with a standard warble. The requirement also restricts the range of usable pitches and eigentones. Each speech tone can typically lead to six other tones, three rising, three falling, forming a meandering melodic line. Each of the successor tones belongs in the same eigenset as its precursor (and thus can be heard at the same time), but each change of note is accompanied by a change of tuned pitch. The new eigenset has, in general, only two eigentones in common with the old: the current note, and the previous one. The melodic line can thus either retrace its steps or wander further away from the home key

Speech eigentones are typically some three octaves above the fundamental; suitable eigentones then appear at intervals of order one semitone or $\sim 6\%$ in frequency. Standard pitch is at a nominal 257Hz, close to middle C, and the standard warble between about 2 kHz and 1.4 kHz (about a fourth below); the melodic line therefore centres on 2 kHz. The reason that speech does not employ the fundamental itself is that successive tones would be audible only if placed at successively higher and higher pitches; using the upper eigentones allows the melodic line to stay within the tessitura. Even so, if the median interval between successive notes is about two semitones, the melody's random walk can take it several octaves away within a hundred notes or so; to limit this effect, an anti-persistent bias is introduced, such that an upward interval is somewhat more likely to be followed by a downward one, and vice versa. The bias is achieved by choosing eigentones such that the fundamental pitch deviates less than that of the melody. The full range for adult speech is then about three octaves ($\sim 700\text{Hz}$ to 5600Hz).

Information is carried by the melodic line as follows. Up to four notes (meaning notes) make up a myte (an atom of meaning). There are less than a thousand mytes in all (more-or-less corresponding to basic word roots, prefixes, suffixes and modifiers in English). An unlimited number of mytes (but typically of order five to ten) can be concatenated into a sentence, not unlike the process-absurd-German-word-indefinitely-by-concatenation-creation-of-for-whenever-one-choose-has!

It is grossly impolite to leave a sentence hanging from some random eigentone (because the standard warble would then in general be inaudible), so the last few notes are, when necessary, used to tie up the loose ends and bring the pitch back to standard (not unlike sorting out the parentheses, and commas, of subordinate clauses). The diagram shows the various warbles that may then be used. The S warble, the Standard Sentence-Starting Speaking protocol, has already been mentioned. The full-stop warble is the same, only shorter; it means over. The colon warble is also at standard pitch; it ends a sentence when there's another one to come. Other warbles follow the melodic pitch: the continuation or "er . . . um" warble is a place holder and carries on until the speaker has worked out where to go next; the error warble says "hang on, I got that wrong" and is followed by the sequence to be deleted in reverse order, then by the rather similar carry-on warble; lastly the "!*!" warble, which says "oh, !*!, I m lost! I give up!" and is followed by the standard warble (not necessarily from the same speaker).

A note is about 2.5 bits, a myte about 10 bits. At a tempo ~ 8 notes/sec (demisemiquavers @ $c=60$), the baud rate ~ 20 b/s is comparable to human speech (~ 4 words/sec, 5 letters/word, 1 bit/letter entropy content). Redundancy has already been introduced by the rules governing the choice of eigentones. Why choose from only six tones at a time? It's a compromise. More would increase the number of bits per note, but only logarithmically (doubling the number of tones to twelve adds just one bit per note), while the average note-to-note interval also increases (unless higher eigenmodes are employed, with consequently greater difficulties in discrimination), necessitating a wider range and reducing achievable melodic tempi.

Baby talk employs only the simplest mytes, in the simplest combinations; babies must first learn to handle a simple rise or fall in pitch before they can begin to discriminate the intervals of the full six possible eigentones. Young avians may remain significantly less accomplished speakers than adults for most of their childhood; they tend to avoid the trickier mytes, sticking to those which don't move so far away from the starting key, and keeping their sentences short. But even adults, trying to fly their way through a welter of subordinate mytes, not uncommonly get confused, and find their melodic line drifting out of range, to hoots of derision from the listeners. If the melodic pitch gets too low (≤ 500 Hz) the tympani can no longer be tuned down to the required fundamental. If the pitch gets too high (≥ 8 KHz), the sonar becomes too directional for convenient conversation. A skilled orator (sonator?) is one who can formulate the most complex sentences whilst keeping his melodic line smoothly within the tessitura.

It is worth noting that the sonar, when used as an organ of speech, transmits on the upper eigenfrequencies, not the usual chirped fundamental; it is thus tuned to the same pitch as the ears of the listeners (and speaker). The volume of sound produced this way is of course considerably less than that which can be produced in the fundamental mode; avians can therefore shout by tuning the sonar to higher pitches and producing tones of the correct frequency on progressively lower eigenmodes, down to the fundamental. This is something of a feat of coordination, since, for adequate feedback and frequency control, the ears have to retain their normal tuning; consequently, it is not popular for complex speech.

Hoots of laughter (and other bronchial noises) are normally produced at the current fundamental pitch, though the lower auditory eigenfrequencies can also be used. This is not because of any specific limitation on the frequency of sound production, but because the avian automatically chooses to produce those frequencies that are currently audible.

When considering the melodic line of avian speech, it is important for human beings to appreciate that the intervals are not related to our musical scales or ideas of consonance; in general, they are completely anharmonic, incommensurable within eigensets or between keys. This ultra-chromaticism would make it very awkward (though not impossible) for humans to copy avian speech by whistling, though a computer would have little difficulty.

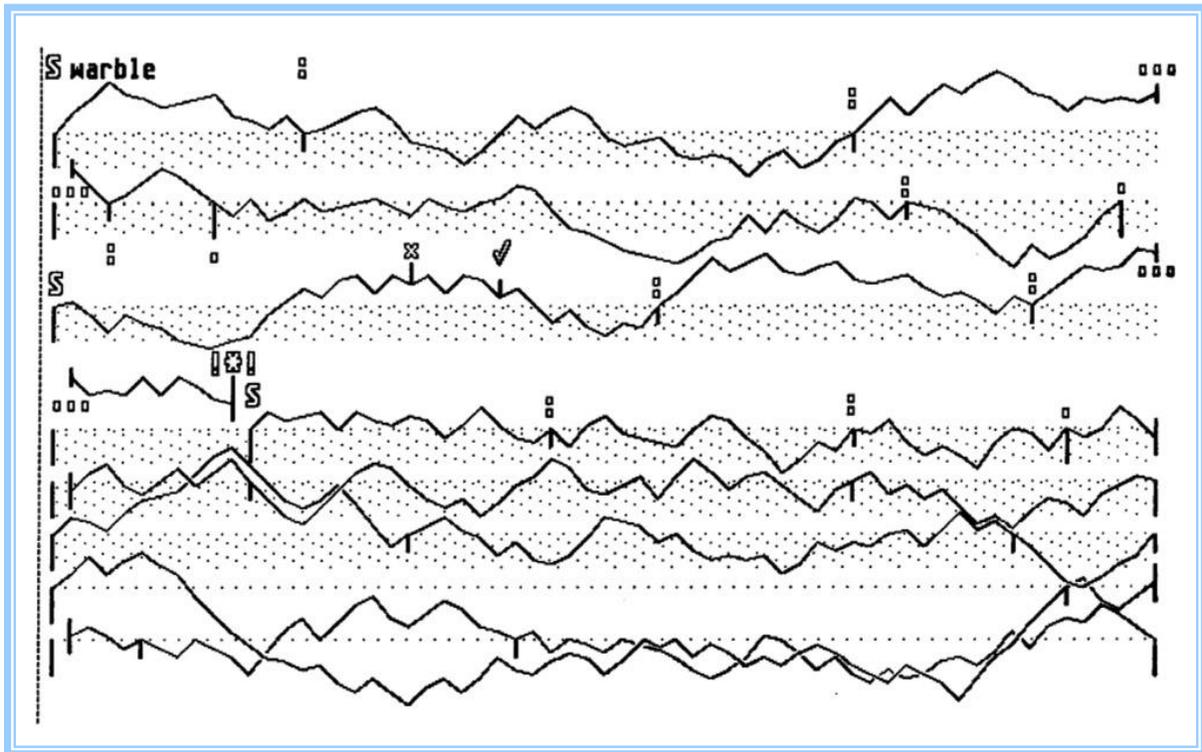
The incommensurability of eigentones strongly constrains the choice of pitch sequences, because of the requirement to be able to reverse any such sequence; in strict mathematical terms, the inverse eigentones do not exist. However, because the resonances have a small but finite bandwidth, sufficiently close matches between the upper eigentones do arise. By tweaking the mass distribution across the membrane, the match of the chosen eigensets can be further improved; presumably it has been so honed by evolution.

It is apparent that facile verbal intercourse among avians hangs upon their ability to tune onto and recognise the starting warble. An avian lacking perfect pitch would have to hunt for the correct frequency by chirping its tympani and would not itself be able to initiate a conversation. Groups of avians engaged in conversation sound like a succession of weird flute solos punctuated (at the end of sentences) by choruses of starting warbles, as everyone tries to jump in. Sophonts being sophonts, it seems inevitable that yet another warble should develop: the interrupt warble, a variant of the “!*!” warble produced by someone other than the current speaker.

Speech has one more facet that should be mentioned: individuality and what we call tone of voice. Speed of delivery, attack, phrasing, dynamics and timbre – most of what makes a musical performance – all enliven avian speech. Timbre is a good example, for it depends largely upon the presence of eigentones other than the principal one; at moderate levels they assist the listener in locking onto the correct pitch; in excess, they

confuse, leaving the listener unable to discriminate successive notes. The strongly anharmonic nature of these eigentones means that avian voices, though unquestionably fluting, don't really sound like flutes – rather more like piccolo sackbuts or regals. There is room for many other variations between individuals. Does the speaker have a staccato delivery – or legato? Does its voice spring cleanly to the next note, or glide, or take in grace notes on the way? Are its warbles rhythmic, or ragged?

Speech is the progenitor of writing. But on Epona there is no written word – for there are no words! There is, however, a written form of the language (or languages) – simply a diagrammatic representation of the melodic line. I repeat the annotated diagram already shown above.



The function of the warbles in avian speech has already been explained; the written forms are similar. Each line begins with a starting warble like a musical clef. Sentences are continued from line to line by means of the continuation warble. The error and !*! warbles would normally only appear in the reproduction of spoken dialogue. The standard frequency is indicated variously by a shaded band or a dotted line; in manuscript it is normally not indicated at all (except by the starting warbles). The clearest print keeps each melodic line well separated.

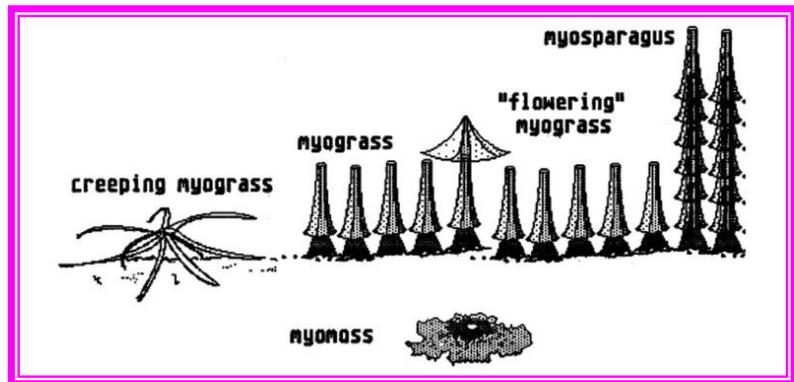
This practise is, however, somewhat wasteful of space; savings can be made by drawing the staves closer together and allowing lines to cross. Provided that crossovers are unambiguous, and starting warbles do not overlap, readability need not suffer.

Avian writing can also be compressed lengthwise (a practise almost invariable in manuscript), leaving a more jagged picture. I have shown melodic lines going from left to right, then top to bottom, with the spine on the left, according to European custom. This is correct, except that avians would naturally hold a book up to their side eye with the spine at the top, like a spiral-bound pad, so that the lines go from top to bottom, then right to left. As with a notepad, the other side of the page is used in exactly the same way, but starting from the back of the book and working the opposite direction.

STRUCTURAL MATERIALS FROM MYOSKELETAL TISSUE

Because the myophyta are almost exclusively herbaceous, with $\geq 90\%$ of their tissue mass composed of water, there is a marked shortage of rigid structural materials on Epona. Wood, as we understand it, is unknown. Moreover, since pentapods have neither horns nor tusks, there is a similar lack of ivory (although limited amounts of chitinous material may perhaps be obtained from springcrops). Wool or fur is also unavailable. This would seem to impose serious constraints upon the development of civilisation.

Fortunately, myoskeletal tissue, which is in ample supply, can be converted into a variety of useful structural materials. Carefully dried under tension or compression, it becomes respectively a rope-like or timber-like material. Both plant and animal tissue can be utilised.



Pagoda trees are the most abundant source of plant material, but here is a pretty picture of some other myophyta that might prove useful.

The basis of myoskeletal tissue is the osmotic cell. Energy-intensive sodium pumps, high diffusion rates and intricate vascularisation may be much more common in animal muscles, and plant tissues may contain rather more water, but otherwise the osmotic cells are very similar. Consequently, similar materials can be produced from both plant and animal myoskeletons.

The sausage-shaped osmotic cell comprises a fluid (mainly water) encased in an elastic membrane, which is composed of a helically wound net of strong relatively-inelastic protein fibres within a softer elastic matrix.

If the membrane has an effective tensile strength $\sim 200\text{MN/m}^2$ and comprises about 10% of the mass, it can contain an osmotic pressure up to $\sim 10\text{MN/m}^2$, obtained with solutions $\sim 10\%$ concentration by volume. A non-tapering herbaceous plant, such as a Pagoda tree, could therefore reach a height $\sim 1\text{km}$. In practise, questions of wind resistance, buckling and excessive demand for carbon dioxide make such heights metabolically uneconomic and evolutionarily unattractive. More sap – and thinner sap – enables plants to grow correspondingly faster, while still permitting them to reach considerable heights.

Consider a typical moderately-large Pagoda tree $\sim 90\%$ water and $\sim 25\text{m}$ high: ten tiers each 2.5m high, with a 5m diameter canopy and 1.25m diameter trunk divided into five 0.25m diameter beams. It masses $\sim 0.33\text{tonne/m}$ $\sim 0.8\text{tonne/tier}$ $\sim 8\text{tonne}$ and is approaching its Euler buckling limit (though this hard to define in these active systems).

At a photosynthetic efficiency of $\sim 5\%$, it could grow to full size in just under two Eponan years; this, however, is not fast enough to obviate the necessity to be able to overwinter underground, dying back to a sweet tough-skinned doughnut-shaped tuber (the bottom tier's mouth-ring) of mass $\sim 800\text{kg}$.

In the pentapods, making allowance for nonzero pitch angles, limited extension ranges, and the rope-like arrangement of osmotic cells and muscle sheath, two-way muscle strengths of order 3.5MN/m^2 are obtained (especially dense muscles, with $\sim 30\%$ solutions and $\sim 30\%$ membrane mass, could push this up to about 10MN/m^2). The myoskeleton is also remarkably effective in torsion; an avian's forearm can twist through six full turns – a considerable advantage when wielding a screwdriver!

If osmotic tissue is allowed to dry naturally (without rotting), it shrinks away into a wrinkled mass of little structural use. However, consider a bundle or rope of osmotic cells (say, a Pagoda-tree beam or the limb of a pentapod) allowed to dry under tension; as the water squeezes out, the fibres of the helical net are pulled into alignment along the rope. When fully dry, the rope will be perhaps three times longer and around six times thinner than in the natural state ($\sim 1/10$ the volume), but will have a tensile strength $\sim 200\text{MN/m}^2$ (1). Thus a Pagoda-tree beam becomes a cable $\sim 4\text{cm}$ in diameter and 10m in length; thinner ropes can be obtained by splitting the beam before tensioning.

If, instead, we allow the beam to dry under compression, the cells are squeezed down into intertwined disks with circumferential fibres. Again the volume is reduced tenfold, but the diameter bulges by only $\sim 10\%$ while the length is reduced by perhaps a factor of twelve, resulting in a material with a compressive strength $\sim 200\text{MN/m}^2$ (2). Our Pagoda-tree beam becomes a block $\sim 27\text{cm}$ in diameter and $\sim 20\text{cm}$ deep.

Now the rope material, even cut into short slices, is relatively weak in compression $\sim 20\text{MN/m}^2$; the timber is even weaker in tension ($\sim 10\text{MN/m}^2$), tearing out like a bale of compressed straw. But by laminating sheets of tensile and compressive material together (such as types 1 & 2 above, or 3 & 4 below) we can obtain composites with strengths in excess of $\pm 100\text{MN/m}^2$.

Osmotic tissue can be processed in a variety of other ways. In general, the idea is to apply a system of forces similar to that which the material will be asked to sustain in actual use. Suitable composites can then be devised for the manufacture of efficient beams, masts, panels, and other structural elements.

Flattening the beam sideways, while compressing (or tensioning) vertically, produces materials (3 & 4) strong in compression (or tension), particularly suited to laminated beam or panel construction, in which the fibres are aligned normal to the imposed stress. Squeezing the beam radially, while keeping its length fixed, produces a material in which the cells are squashed flat and crumpled together; it behaves rather like rubber (5).

If we start with a radial squeeze, then add a lengthwise pull, we end up with a pole which is strong in tension, and reasonably stiff in compression (6). It can be used to make slightly whippy arrows and javelins, etc.

Torsion rods and cables can be fashioned by twisting the beam at the same time as compressing or tensioning it. The material (7 & 8) is then well able to resist torques in the same sense. It will quickly fail under a reversed load. To resist bi-directional torque a composite must utilise components which have been pre-stressed either way. Shear stresses can be embraced in a similar manner, by applying a shear to a compressed panel (9).

Tensile material is stiffer and stronger in compression if it is also squeezed during tensioning (10) (it is then most like wood); but the most flexible ropes are obtained by soaking in water during the tensioning process (11). For the very strongest ropes (12), the soft elastic component of the membrane (and the cell's internal sugar and salt) is carefully dissolved away by a solution of plant or animal enzymes, or other chemicals, thereby attaining a tensile strength $\sim 500\text{MN/m}^2$ (cf. flax $\sim 700\text{MN/m}^2$).

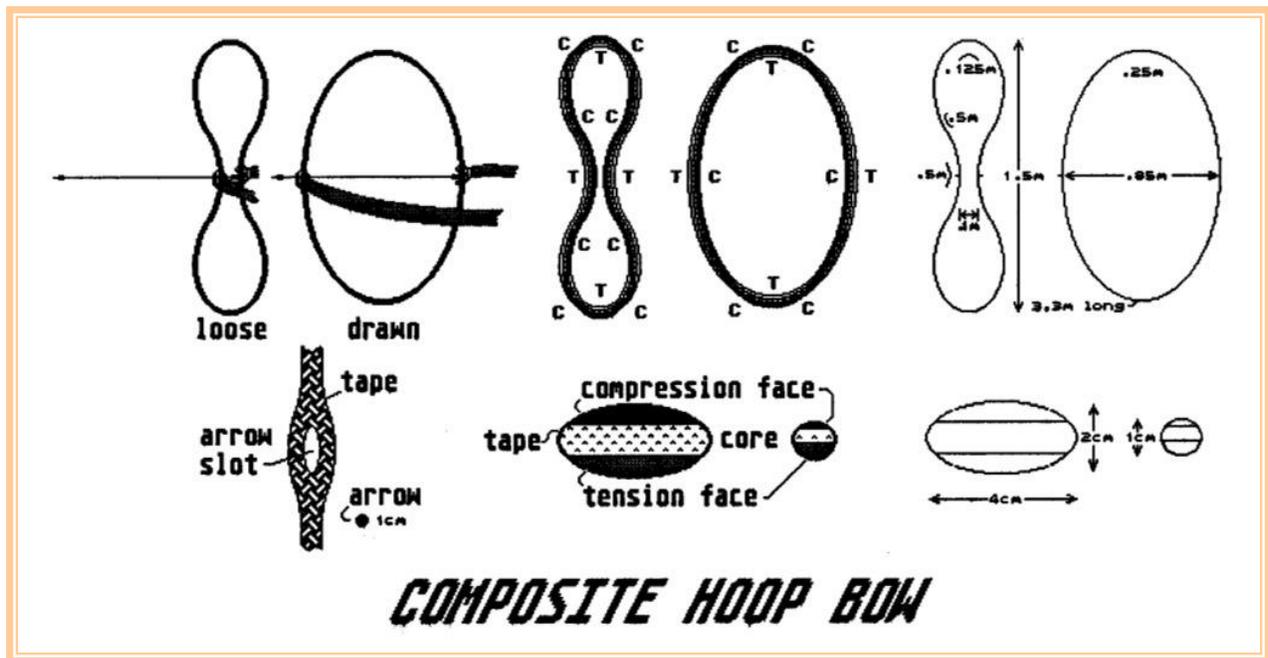
High-quality paper (13) can be produced by soaking combined with agitation to randomise cell orientation. Paper or card (14) can also be obtained by soaking and compressing lengthwise slices of tissue under moderate tension (pitch $\rightarrow 45^\circ$, length $\rightarrow x 2.5$, width $\rightarrow x .75\pi/2 \sim 1.2$, thickness $\rightarrow x 1/30$, so a slice $\sim 2.4\text{mm}$ thick $\rightarrow \sim 80\text{g/m}^2$); this technique, without the soaking, can also be made to produce lengths of tape (either elastic (15) or inelastic (16), depending on applied tension) useful for wrapping composites.

If tissue is dried under low to moderate pressure, at elevated temperatures, various foam materials can be produced: porous foam rubbers (17), which retain their elasticity; and rigid closed-cell foams (18) like cork or balsa, in which the sugars and cell walls are fused together.

It is worth observing that myoskeletal material comes both as beams (in which the osmotic cells are mostly aligned along the length of the beam) and as hoops (in which the cells are mostly aligned around the circumference). There is also a rather complicated intermediate behaviour (rather like a divided back splice) at the union of several myoskeleton components. Advantage can be taken of these forms in the design of structural components.

Myoskeletal material can be derived from both plant and animal sources. That from animals is generally tougher and denser, finer-grained and more cohesive (less friable); it shrinks less in drying, but is harder to get completely dry unless the applied pressure (which for the best results is gradually increased as the tissue dries) is very carefully regulated.

One problem with myoskeletal material is its tendency to swell in damp weather. The softest and most elastic versions are the worst offenders (*e.g. types 5 & 17*), but these will normally be used in situations in which the effect is unimportant. Material that has been densely compressed (*e.g. type 2*), or retains only the helix protein (*e.g. types 12 & 13*), or has been cured at elevated temperatures (*e.g. type 18*), is least affected. Oils and varnish help. Because of its dense vascularisation, material of animal origin is more susceptible to moisture absorption than that from plants.



As an example, consider the composite hoop bow (derived from primitive self-bows formed from Pagoda tree hoops, in which the pitch angle is small, the fibres following the circumference of the cells). A *type-4* compression hoop is moulded around a figure-of-eight form. A lightweight rigid shear-stressed core (*18/9*) is glued to the inner surface of the hoop round the tips, and to the outer surface along the sides. *Type-3* tension strip is then glued to the core; and the whole is tightly wrapped in elastic tape (*15*). The arrows are *type 6*.

The bow has a mass of $\sim 1.5\text{kg}$, of which the tension and compression faces account for 0.5kg each, the core 0.25kg and the tape 0.25kg . When drawn, the bow stores $\sim 2\text{kJ}$ of strain energy (*types 3 & 4* can store up to $\sim 4\text{kJ/kg}$).

An avian can draw this bow – its maximum pull is $\sim 4\text{kN}$ – but even a strong man could not. When perfectly crafted, it can loose a 0.05kg arrow at $\sim 250\text{m/s}$ over a range of up to $\sim 4\text{km}$ (it is thus significantly more deadly than the English longbow or the Greek composite bow, which can only store $\sim 200\text{J}$). Shot from such a bow, a “dumdum” arrow, designed to splinter on impact, would have the stopping power of a sawn-off shotgun, while a steel-tipped bolt might penetrate over 10m of granite! Pity the poor pentapod

whose alcohol and peroxide sacs are ripped apart by a dum dum – and pity the bystander caught in the resulting explosion! (Because of the danger of fire, predators avoid tearing open their victim's peroxide sacs, and sophonts hurl javelins from a safe distance rather than closing with spears; for Eponans, personal space is vital, since a pentapod explosion (up to $\sim 0.6\text{kg-TNT/kg}$) can set off secondary explosions in any other pentapods within $\sim 5\text{m}$, and a football crowd could destroy an entire city!).

The dimensions of the bow ($\sim 3.3\text{m}$ circumferential length, $\sim 1.5\text{m}$ span, $\sim 0.85\text{m}$ draw, and a $2\text{cm} \times 4\text{cm}$ elliptical cross-section) and the various radii of curvature ($.125\text{m} \rightarrow .25\text{m}$, $-.5\text{m} \rightarrow +.5\text{m}$) are chosen so as to limit strains in the faces to $\sim 4\%$ and minimise the total mass for a given strain energy (here $\sim 2\text{kJ}$).

When an arrow is loosed, the bow begins to revert towards its figure-of-eight shape, through a deformation by and large starting at the front and working around to the accelerating arrow. Subtle shaping of the bow and equally subtle tapering of the tension and compression faces (a craft that may well take centuries to evolve) enables the whiplash of released strain energy to be transferred to the arrow with high efficiency. The central portion of the bow, just behind the arrow, is still moving as the arrow flies free, and must decelerate in the $\sim 0.1\text{m}$ gap between the arms of the figure-of-eight, the residual kinetic energy being converted back into strain energy and ultimately dissipated; if the arrow is too light, this energy may break the bow, so an arrow of the correct mass must always be used.

A symmetrical bow can shoot either way – a useful trick in aerial combat – but cannot loose the fastest arrows – an even more important factor. It is usual, therefore, to thin along the trailing arc down to $\sim 1\text{cm} \times 1\text{cm}$ at the arrow (and compensate by paring down the core to nothing and thickening the tension and compression faces along the forward arc towards the arrow slot). This reduces the effective mass behind the arrow to $\leq 0.01\text{kg}$, driving a $\sim 0.05\text{kg}$ arrow to $\sim 250\text{m/s}$ with an efficiency $\geq 80\%$. Naturally, not all Eponan bows can be expected to approach this degree of sophistication.

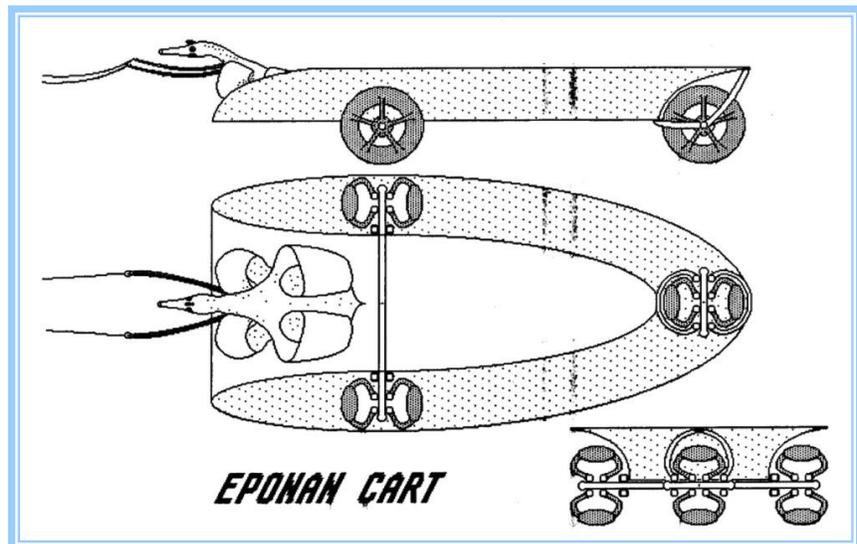
EPONAN ARTIFACTS

The design of Eponan artifacts must be expected to differ from their terrestrial equivalents – if indeed such equivalents exist. An important consideration is the availability of materials (see 'Structural Materials from Myoskeletal Tissue'). Of equal importance are the anatomical, physiological, behavioural and conceptual characteristics of an avian sophont; and the biological and geophysical constructions in their environment that provide inspiration.

One previously mentioned artifact is the composite hoop bow (see under 'Structural Materials from Myoskeletal Tissue'). Its prototype – the hoop of a Pagoda tree – must have been familiar to all primitive Eponans. One day, an unusually bright avian must have come across a dead tier – dried in the sun – and found it could twang the hoop. Perhaps, in the process, the last remaining length of beam went flying off – and the Eponan bow and arrow was born. The further design of the bow was then constrained by the materials from which it could be made, the manner in which it was used, and the physical strength and dexterity of the user. Consider the arrow slot, for instance: a detail, not much used in terrestrial bows, but almost essential for aerial combat.

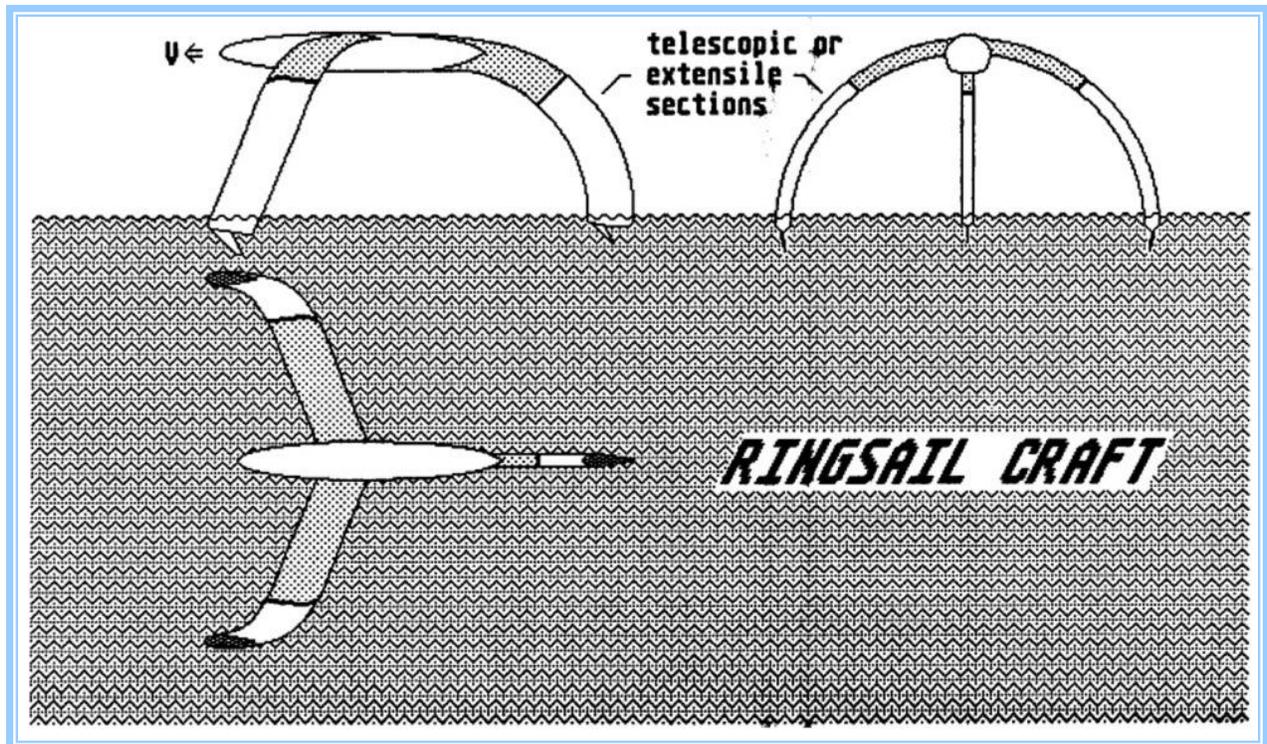
Because the Eponan sophonts are avians, spending little time on the ground and well able to fly great distances with considerable loads, they make only sparing use of roads, vehicles, boats or bridges; these artifacts were therefore not developed until relatively late in Eponan history (although the wheel, reminiscent of a Janus spider, was invented early on).

When land transport came into use it was employed mainly for heavy or awkward loads, which could not easily be carried by air (even by large domesticated dragons). At first, pack animals of the Ceretridon kind were employed; later, the same animals were set to pulling wheeled carts. Note how the tripedal plan of the draught animals has carried over into the design of the wheeled vehicles; and how the wheels themselves, with five spokes on either side of a hoop, follow the characteristic form of the myoskeleta. Such skiamorphs (shadow shapes) are a frequent feature of both human and Eponan artifacts.



The three-wheeled plan does have advantages on uneven ground. After the invention of the steam engine it is retained in Ceretridon-less carriages, goods vehicles and off-the-road vehicles alike. Loading and unloading is usually from the front.

Water transport is often cheaper than land transport. Eponan rafts, originally soggy affairs of lashed up Pagoda segments, came to be made of type 18 balsa material, or turned into marine-ply pontoons (mostly types 3 & 4, with type 18 core). Eponan barges and cargo vessels, also of sandwich construction, are not very different from Earthly versions, whether sea-going or for inland waterways.



However, Eponan sailing craft differ radically from their Earthly counterparts. The hull or fuselage rides clear of the water between the three wingsails that rise from a trio of planing floats. From the front, the wingsails form a semicircular arc; or, when aerodynamically mirrored in the water's surface, a ringsail. Below the surface, fins follow the same arc. The aft wing is a stabiliser and can be given a reduced chord.

This arrangement has the meritorious property of propelling the craft forwards without giving rise to any heeling moment, because the lift force, everywhere perpendicular to the ringsail, is directed through a single point (actually, a line) at the ring's centre. The ringsail has an effective aerodynamic span of $2\sqrt{2}$ times its radius.

Each wingsail is telescopic, able to slide in and out along the circular arc. Its foot can therefore move up and down (by $\pm 0.4r$), allowing it to ride smoothly over the waves,

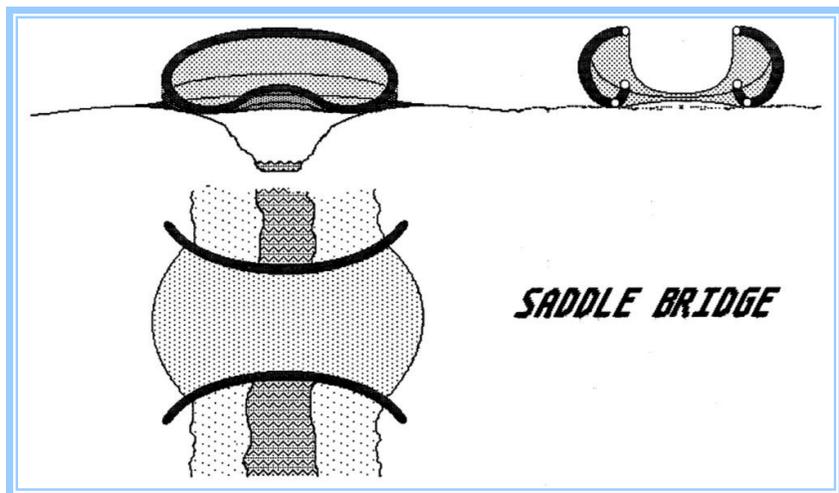
without excessive movement of the hull. In the process, it extracts energy from the wave motion, which can continue to drive the craft forwards even in the absence of wind.

The way in which physical anatomy affects design may seem obvious. However, some of the more subtle factors need pointing out. The avian has highly developed spatial senses (see under 'Pentapod Anatomy'); with its sonar it perceives clearly in 3-D. So complex three-dimensional shapes and trajectories (which humans find utterly confusing) are chick's play to Eponans. Their skill in drawing, painting and sculpting and their mathematical ability in geometry and topology, to us may seem little short of miraculous. (However, they are poor in mental arithmetic: herd animals learn to count, but solitary avians that avoid crowding for fear of blowing up don't need to). Taking as their example the complex Gaussian curvature of the Pagoda canopies, their designs frequently utilise complex curves in 3-D. (Indeed, I have had difficulty in drawing some of their artifacts, in which the subtle 3-D curvatures are not at all easy to grasp).

From the start of their technology, Eponans have an understanding of stress. The very process of creating structural materials from myoskeletal tissue demands it. Not for them the crudities of terrestrial carpentry – in which strength is largely ignored and clumsily-achieved rigidity is all. Eponan designs are habitually efficient but – to our way of thinking – excessively floppy.

The Eponan predilection for structural efficiency and subtlety is sometimes taken to extremes. Bridge design is a case in point.

Minor bridges, spanning brooks or gullies, are often in the shape of a saddle bridge. Originally, they were built exclusively from composite myoskeletal material, but in time, many were rebuilt in masonry or concrete. At every point the convoluted saddle surface has some stabilising curvature; and almost everywhere it has Gaussian



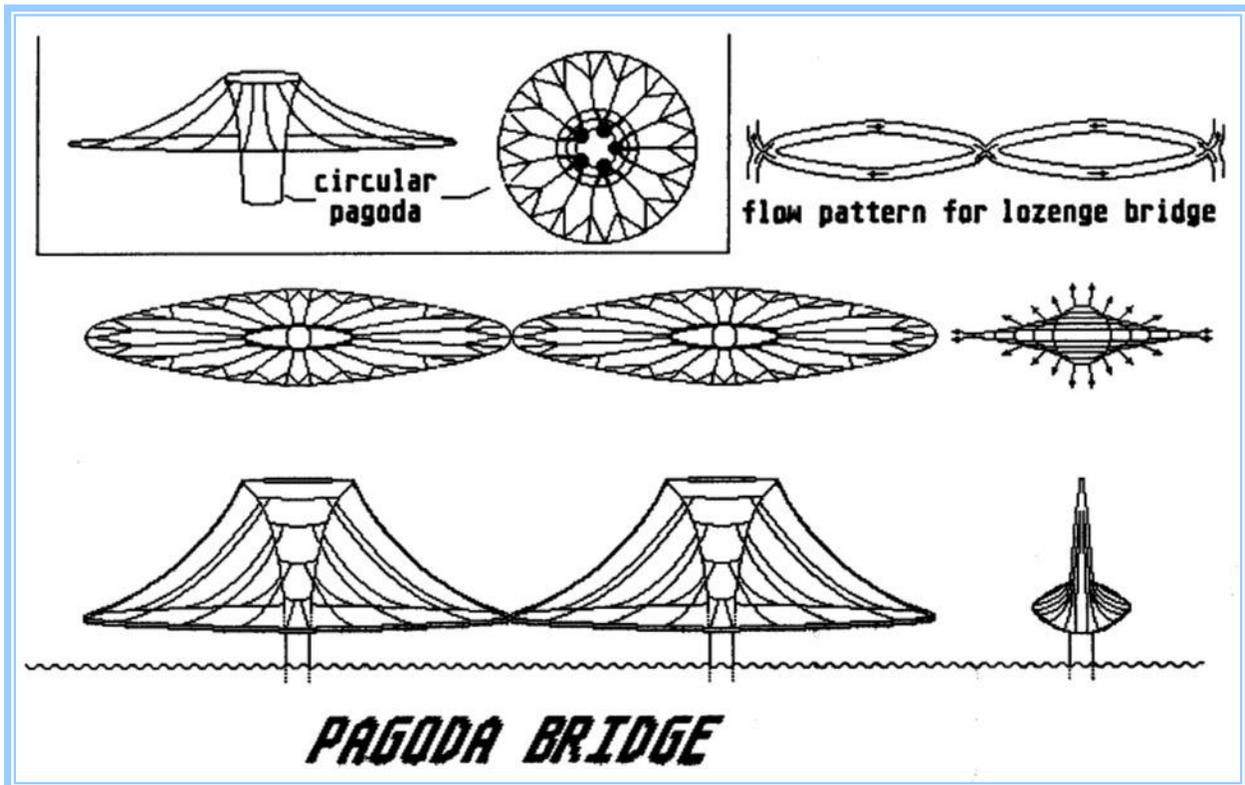
SADDLE BRIDGE

curvature (that is, curvature in two directions at once). The saddle bridge is thus exceptionally sturdy, unperturbed by heavy loads from any direction.

Perhaps, with the earliest floppiest materials, something of the sort was necessary. But in most cases a thick laminated beam (perhaps with a lightweight type 18 core) would be just as good; and a simple arch is ideal for masonry. Since Eponans have long

understood and employed both alternatives, their continued use of the more complex (and hence more costly) saddle bridge can only be put down to a matter of aesthetics.

For long-span bridges the characteristic Eponan design seems to make more sense, though its structural perfection is perhaps debatable.



The Pagoda bridge clearly derives from the idea of a suspended canopy. Its simplest form is circular, used more often in suspended roofs and marquees than in bridges. The rim is in compression; in the absence of a continuous membrane under Gaussian curvature it is stabilised by a multiplicity of criss-crossed cables. The set of cables shown in the diagram is suspended from the top of the tower; a similar set, staggered between them, connects a little lower down. The tower commonly has five main columns; beyond a hoop, each subdivides into three and slants outwards; at the top, a hoop in tension holds the fifteen struts against the outwards tension of the cables. A row of such pagodas (or a single pagoda in mid-divide) makes a bridge, in which the roadway follows the circular rim.

The circular pagoda is not ideal for bridging long spans; the roadway is 57% longer than necessary, carried twice as far from the tower than necessary. Hence its elongation into a lozenge shape, in which the rim is only marginally longer than twice span and is carried at an average distance from the tower of one quarter span. The tower fans out along the line of the bridge, but tapers sideways. Cables hang from the top of the tower to the ends of the roadway, but from progressively further down towards the middle. As in the circular

pagoda, twin sets of cables (criss-crossing at the rim) have vertically spaced loci of attachment to the tower. The rim, carrying the roadway, remains in compression.

The lozenge shape lends itself to a convenient one-way filtering traffic flow, as indicated. In fact, the Pagoda bridge is more often an aqueduct than a road bridge; the circulating flow then allows narrow boats and barges to glide with the current from either end.

In some cases Eponan development has not paralleled Earth's. Eponans never seem to have invented the railway, perhaps because of a lack of hard timber or steel for the rails. There are no Eponan trams: not even Ceretridon-drawn trams. The steam locomotive was never put on tracks. In mining, water chutes or free-rolling wagons were used instead. In fact, horizontal tunnels give avians the willies, so Eponan mines are nearly all either open-cast, or else simple vertical shafts.

But rope-drawn lifts were developed early on. Mostly, they are circular platforms suspended from five cables, moving up and down within the space circumscribed by five vertical columns, bound by hoops at regular intervals. They rarely have walls or balustrades, because avians aren't afraid of heights. Naturally, there are no Eponan escalators – they don't have any stairs at all. Eponan swinging platforms (see 'Avian Architecture') have few Earthly parallels outside of Tarzan movies.

It is often desired to convey large quantities of water over considerable distances. Aerial transport is usually impracticable. So aqueducts turn out to be one of the earliest forms of large-scale civil engineering – even more on Epona than on Earth. Even so, aqueducts freeze all too easily in winter, and can be costly to construct through rolling countryside. For both reasons, it is often preferable to carry water in underground tunnels or pipes. The Romans built so many aqueducts because their pipes of lead or wood could withstand only very low water pressures. Eponan technology was not long in developing plumbing working through falls of up to ~1km. Unfortunately, myoskeletal material always has a tendency to absorb moisture and swell; unless the outside of a water pipe is kept dry, it will eventually fall apart. If a water pipe is laid in sodden ground or under water it is unlikely to last, so aqueducts still have their place. Also, an open aqueduct can carry barges, laden with all kinds of cargo. Chains of pagoda aqueducts are a familiar sight among the low-lying islands and shallow seas of the Sunken Continent; while countless ringsails skitter between them, chased – perhaps – by a thousand lovesick Poncedoni.

AVIAN ARCHITECTURE

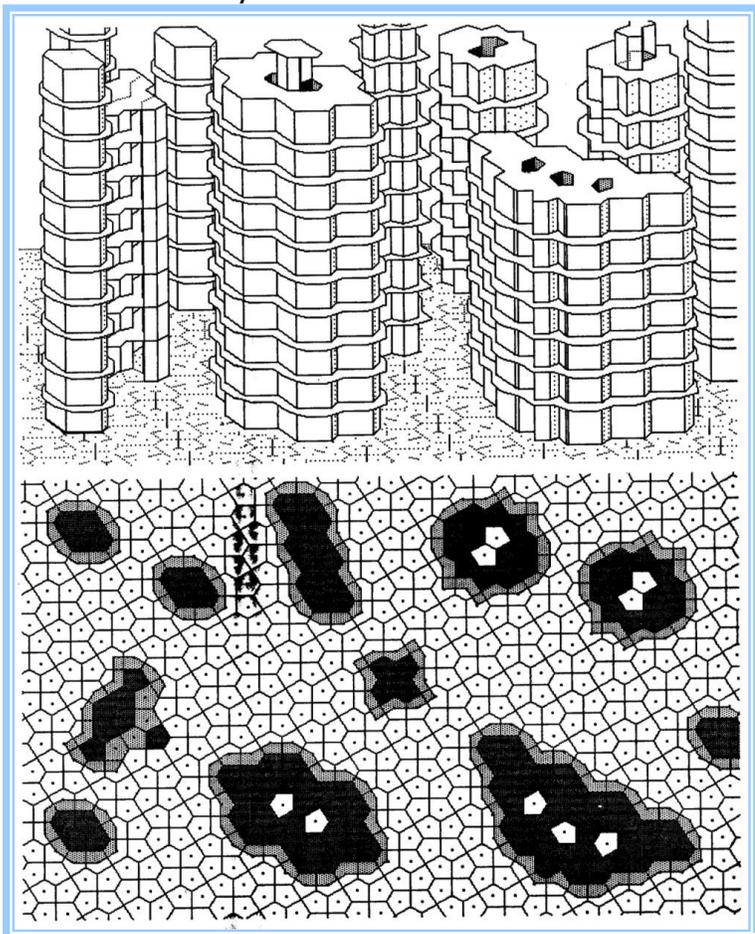
We have seen how the spatial abilities of the avians combine with the subtleties of the Pagoda tree to generate a range of complex and elegant designs.

At the same time, the sameness of Pagoda forests, with every tier of every tree alike, leads to the same sameness in Eponan architecture. Eponans find it almost impossible to conceive of a building with a vertical facade – surely the upper floors have to be identical, like the upper tiers of a Pagoda? On Earth, where every bush and tree has a different shape, variety is the spice of life. On Epona, there is a strong tendency for engineers and craftsmen to build in identical modules and to stick with a single optimum solution. Variety is not widely prized – once you’ve got a good design, why not use it everywhere?

The Eponans saving grace is their lack of sociability! This has made civilisation slow to develop, but has meant that even excellent designs are not always readily accepted by independently-minded others. The tyranny of “Not Invented Here” is even worse than on Earth. Some variety of design has therefore persisted, especially as between races harking back to cliff-dwelling fisherfolk and tree-dwelling landspeople (long after the era of the pre-sophont plains scavengers).

Where primitive sophonts lived in the hollows of the large forest Pagoda trees, it was natural for them to build in a similar style, copying their tiered pentagonal form.

Eponan architecture employs high-rise buildings with pentagonal rooms. Structurally, they are space frames based on a unit of five vertical beams and a hoop top and bottom, with curtain walls and suspended floors (note the neat way of tiling the plane with pentagons – with some irregularities, this is more or less how Pagoda trees crowd together in a forest).

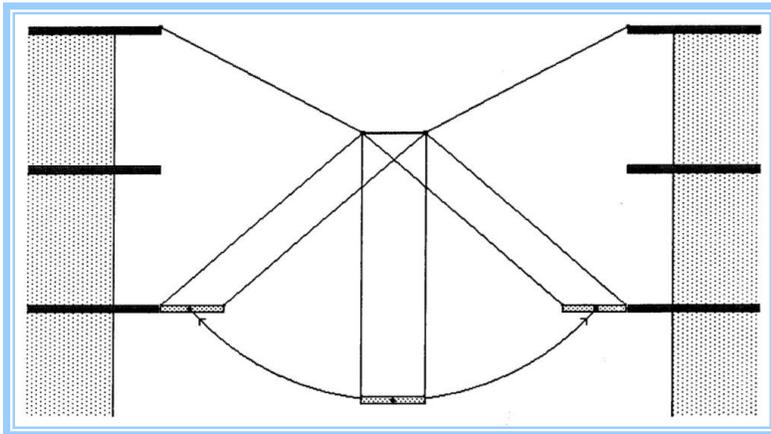


Nesting pentagonal rooms. Balconies for external access. Vertical shafts for internal access. No direct external access at ground level. Few horizontal corridors. High rooms avert claustrophobia. Tall buildings in uniform tiers reflect ancestral Pagoda tree dwellings.

Originally, myoskeletal material was used exclusively (type 20 columns, perhaps laminated with types 3 & 4, hoops wound with type 1 or 16, composite floors often with type 18 cores). Later, masonry might be chosen for the walls and columns, volcanic glass for the floors, sheet glass for the windows. The industrial age added steel girders and reinforced concrete.

The rooms are tall (~8.5m ceiling height, ~9m per tier or storey) and ~4.5m on a side. They are accessed from external unprotected balconies or internal vertical shafts – or from adjacent interconnecting rooms. Interior rooms are commonly left open at both ends to permit flight access between vertical shafts, but horizontal corridors (as we understand them) are not employed. All units in a building are identical in plan, so larger rooms must be obtained by combining pentagonal units (the intrusive supporting columns are sometimes omitted).

At ground level, Eponan houses traditionally have no external access (no doubt originally for protection against predators). The ground floor is the Eponan equivalent of our cellars and attics – used only for storage and services. In larger buildings, it may be provided with a goods entrance. At roof level, in rainy climates, some form of canopy is usually provided over any open shafts.



Within buildings, service lifts are provided within the vertical shafts. Since the avian inhabitants can easily fly from level to level, the lifts are used mainly for heavy goods and machinery. As such, they tend to be constructed as pentagonal platforms filling the shaft from side to side, and normally resting at the top or bottom. Avians whose way is temporarily blocked by a lift

platform must fly through a crossroom to another shaft.

Between buildings, swing platforms perform the same function. Suspended from ropes positioned over the middle of the gap by means of cables or cantilevers, these platforms swing from the balcony of one building to another. When pulled, the release handle gives the slight nudge necessary for a clean docking on the other side.

Naturally, there is more variability in Eponan architecture than these drawings might suggest. Real cities are not laid out on quite so rigid a grid. Not every building has exactly the same ceiling height or room size. And buildings are commonly interspersed with Pagoda trees and other vegetation. In the mountains and on rocky coasts, buildings join

into long irregular keeps like artificial cliffs; there stepped balconies become narrow roof gardens overflowing with vines – exuberant forms of creeping myograss – and glittering streams cascade from the heights.