# Respice-Prospice

## *Learn from the Past—Look to the Future*

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## INTRODUCTION

### Systems Engineering in Perspective…

Systems engineering: the very term is confusing, prone to being misunderstood and misinterpreted. To some, it is clearly engineering, in the classic style: that is, the creation of technological artefacts to meet some need, to serve some purpose. But then, where does the 'systems' bit come in?

To understand where that all-important 'systems' bit comes in, we have to go back to early in the 20th century when researchers found that the behaviour of some 'wholes' (systems) could not be explained rationally by looking at the behaviour of their separate parts (Cartesian reduction). Conversely, adding parts together (synthesizing) to create a whole could result in the whole behaving counter intuitively, and in creating more than would be suggested from 'summing the parts.' Surprise, the ancient Greeks were there before us:

> *"The whole is greater than the sum of the parts*
> *The part is more than a fraction of the whole"*
>
> From Aristotle's Composition Laws.

Systems, then, became the study of wholes – how wholes behave, how to understand wholes, how to model/simulate wholes, and – particularly – how to create wholes where the whole is greater than the sum of its parts in some desired way. After all, Nature does it: we humans are a case in point: our various organs work together in close harmony to create a whole – us – which has remarkable 'emergent properties, capabilities and behaviours.' Emergent properties were identified as properties of the whole that could not be exclusively attributed to any of the rationally separable parts; and, indeed, which had no sensible meaning at the level of those separable-but-interacting parts…

So, systems engineering came into being as a means of synthesizing wholes from interacting parts/subsystems, such that the whole exhibited emergent properties, the most obvious of which was to be that it – the whole – operated and behaved as a unified, unitary entity. Noteworthy is the observation that there is nothing – absolutely nothing – in the development and description of systems engineering that confines – or even *relates* – it to classic engineering. The wholes, and their parts, could be societies, teams, armies, libraries, flocks, shoals, processes, ships, political parties, ecologies, economies… whatever. Oh! And, of course, artefacts comprised of interacting parts, so classic engineering, too.

Three basic tenets, then, provided the foundation for systems engineering: holism, synthesis and organicism:

- **Holism** observes that Nature always creates wholes, and that the whole is greater than (or at least different from) the sum of the parts. Holism 'operates' at the level of the whole…addresses the whole problem, creates a whole solution to that problem
- **Synthesis** requires that the whole be created by selecting the right parts, bringing them together in the right way, causing them to interact, and 'orchestrating' those interactions so as to create emergent properties, capabilities and behaviours

- **Organicism** (originally the organismic analogy) stems from the observation that many wholes, although not organisms, behave as though they are organisms, exhibiting life cycles with growth, decay, etc. (Organizations, enterprises, industries, empires, civilizations, etc.) This evidently comes about, in part, because the parts of some wholes are mutually interdependent, such that each depends on the other for existence, sustainability and growth.
    - In systems engineering, organicism also denotes that the parts are organs in their own right, i.e., that they perform specific functions, and that these functions combine synergistically between parts.
    - So, cooperation, coordination, contribution, concinnity, complementation, etc., are implied by synthesis and organicism… as is non-linear behaviour of the whole – yet another discriminator that distances systems engineering from engineering mechanized artefacts.

All of which leads to a simple definition of systems engineering:

*Systems engineering is the art and science of*
*creating whole solutions to complex problems.*

Bearing in mind the basic tenets of holism, synthesis and organicism, it is possible – and fun, too – to look at past, present and even future 'solutions to complex problems' and see if, indeed, they can be substantiated as systems engineering; or not. Beware imitations: it can be shown that part-only solutions to problems can make matters worse in the long run! And, there are many who might unjustifiably declare themselves to be engaged in systems engineering, if only to add 'lustre to their cluster!'

## RESPICE: SYSTEMS ENGINEERING IN THE PAST

Let us look, first, at past enterprises and see if they 'stand up' as systems engineering.

### The Great Pyramid of Khufu (2528BC) — Deus ex Numeri?

Much has been written about the Great Pyramid of Khufu (Greek *Cheops*) at Gaza, near Cairo. To view it through a systems architect's eyes, it is helpful to employ the same measure that the ancient Egyptians used. For slopes, they did not measure in angles, but instead in *seked*, a measure of gradient. Slope in *seked* is the horizontal run divided by the vertical rise multiplied by seven. The great pyramid slope has a run of 11 units and a rise of 14 units, which equates to 51/2*seked* (7x11÷14 = 51/2*seked*, or 52° in today's units).

Looking at the slopes in Figure 1, shown in *seked*, reveals relationships that are not evident when the same slopes are measured in degrees. So, the northern shaft from the Kings Chamber (KC(N)) has a slope of 11*seked*, exactly half that of the pyramid (twice the *seked* = half the slope) – a bisecting symmetry if you will, but only when measured in *seked* – not in degrees. This shaft pointed, in antiquity at the then Pole Star, Thuban – the only star that remained motionless as the Earth rotated, and hence referred to as the Great Mooring Post in the sky – the Egyptians were a riparian people, used to nautical metaphor. This may suggest that the slope of the pyramid, 51/2*seked,* derives from the slope to the Pole Star… or not.

Similarly, KC(S) at a slope of 7*seked* (= 45°), bisects the vertical (which is not measurable in *seked*, but which is 90° in today's terms), giving a second symmetry. This shaft points towards the so-called Netherworld: the ancient Egyptians had noticed that stars gradually faded and disappeared as the Sun rose in the morning; the Netherworld was where they went when they disappeared. In that direction was a particular star, *al Nitak* in Orion's Belt, which was sacred to Osiris… so the shaft could point at the Netherworld, where *al Nitak* was believed to be. The number 'seven' may have been sacred to Osiris: it certainly occurred only rarely in slopes…

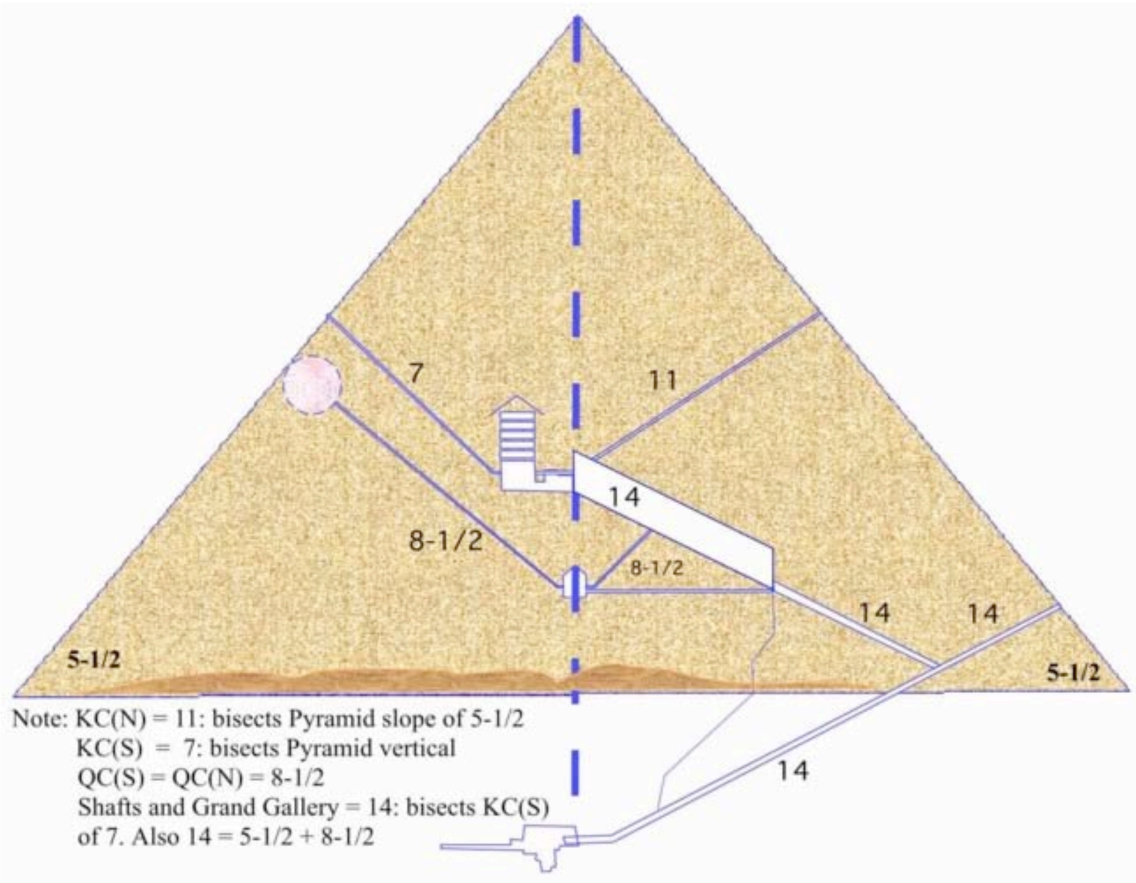


**Figure 1. Great Pyramid of Khufu.** The diagram shows the interior structures in the Great Pyramid. The upper King's Chamber has two small passages, King's Chamber North and South, leading to the outside. The lower Queen's Chamber also has two passages, Queens Chamber North and South that do not reach the outside. All slopes are annotated in *seked* – see text.

All slopes of passages used by people in the Pyramid slope at 14*seked*, which symmetrically bisects the 7*seked* slope of KC(S). That leaves the two shafts from the Queen's Chamber, QC(S) and QC(N), both at 81/2*seked,* so balanced and symmetrical – symbolic, perhaps of the balance between the traditional "Two Lands" of Upper and Lower Egypt? And, 81/2 is the difference between 14*seked* and the Pyramid's 51/2*seked* slope.

Looking at the overall configuration/architecture within the Pyramid, it seems likely that the ancient Egyptians were *either* using simple slope ratios for convenience, *or* vesting some form of magical power in symmetry, in the numbers, and in their interrelationships. In either event, some kind of systems architectural design is in evidence – there was an overall plan, and purpose for the whole. This was not piecemeal design.

To understand that purpose, we have to understand the problem facing ancient Egypt: the country depended entirely for its existence on the annual Inundation of the Nile, which covered the banks of the river with fine, rich silt, from which they could grow their crops. If the Inundation was either too great, or too small, life could be critical in farming terms – and famine might follow.

The King, Khufu, was a god on Earth. When he died, he alone – in the form of his soul, or *ka* – would be able to travel to the stars and negotiate with the other gods who resided there to ensure that the Inundation would happen each every year, and that it would be 'just right.' So, for the People of Egypt, ensuring the continuing existence of the King in the afterlife was a matter of motivated self-interest—of survival.

And the Pyramid? That was to be a 'psychic machine' for projecting the King's *ka* to the stars and back to his mummified mortal remains, stored in the sarcophagus in the King's Chamber. The Egyptians were not quite sure how to achieve this projection, but they considered rope ladders hitched to the Pole Star, ladders up the side of the pyramid, rising on clouds of smoke, or on thunderclouds, and so on. With Khufu, it seemed that the solution may have been partly in the magical configuration inside the Pyramid (so, *Deus ex Numeri?),* and partly in the continual power of prayer provided by a dedicated priesthood.

Which brings us to the overall system, of which the Pyramid was only a part. Figure 2 shows the general arrangement.

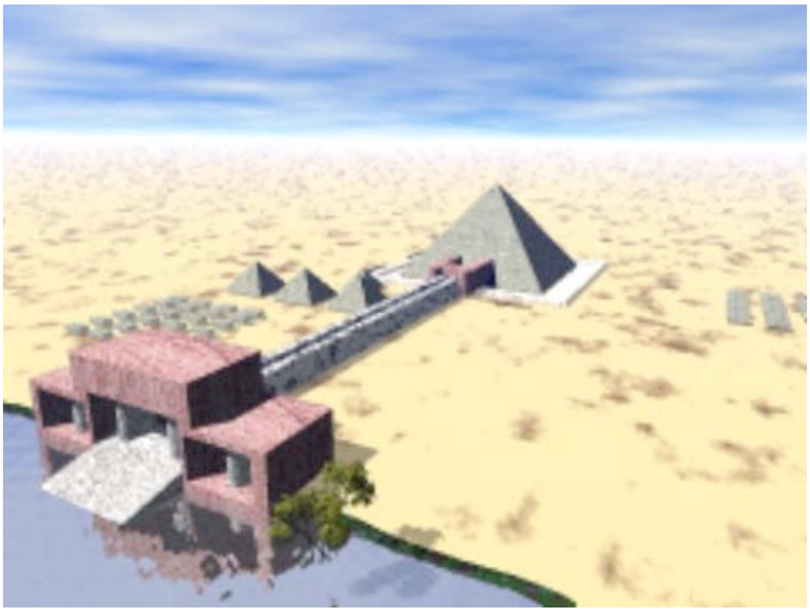

**Figure 2. Pyramid Complex.** Comprised of Main Pyramid; Temenos Wall; 3 Queen's Pyramids; Ka Pyramid; Funerary Temple; Covered Causeway; Valley Temple; 3 boat pits, with boats. Not to scale.

The funerary temple was built against the Pyramid; this was where the priests made their offerings, lustrations and prayers, so providing the continuing psychic power to energize Khufu's *ka* for its continuing workload through eternity.

The valley temple stood at the water's edge – this was where the King's funeral cortege would arrive by boat and enter the complex, but it seems likely that the valley temple would also serve for the King's spiritual sailings upon the Nile, with his wives, using the boats buried in the boat pits which would be magically reassembled and crewed. These sailings were necessary not only for relaxation, but so that the King could watch over his people throughout the length of Upper and Lower Egypt… where the river Nile served as the interconnecting highway.

Connecting the two temples was a covered causeway, inscribed internally with frescoes. This was, presumably, to ensure that the King's spiritual exits and entrances remained concealed from the everyday world, yet infused with the necessary psychic symbols and messages.

The whole shows:

- **Holism**: the various parts were designed to work as an integrated, unified whole, with emergent properties; in that the whole could project the King's *ka* to the heavens and back, and to Upper and Lower Egypt and back. The whole was, indeed, designed to be greater than the sum of the parts, with the expectation that the Nile's Inundation would be regulated accordingly, and the people protected.
- **Synthesis**: the whole was formed by bringing together the various parts (temples, causeways, etc.) in the right way, causing them to interact, and orchestrating their (psychic) interactions
- **Organicism**: the various parts were mutually interdependent; each part had its discrete functions, and interactions between the various functions led to (supposed) fulfilment of the purpose of the whole

So, although it would be over 4,500 years before the term 'systems engineering' would be coined, it is not unreasonable to propose that the Great Pyramid Complex formed a dynamic, unified whole, and that the ancient Egyptians could be classified as systems designers and systems engineers, *par excellence*.

**The Battle of Britain (1940AD)**

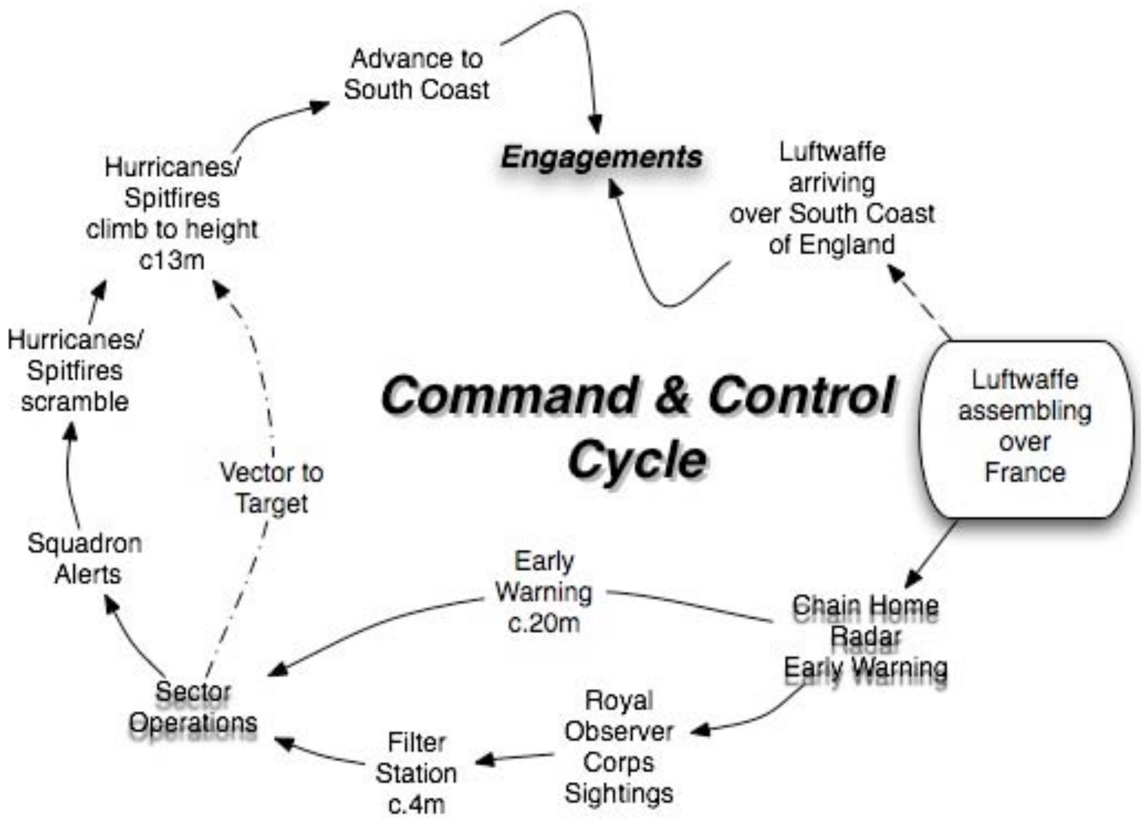


**Figure 3. Battle of Britain: the Command & Control Loop.** The Luftwaffe, based on NW France, sought to suppress RAF fighters in SE England by bombing fighter airfields and factories. The attempt failed… this was the first, significant failure of the German war machine in WWII.

The Battle of Britain also occurred before the term 'systems engineering' was coined. At the time of the battle, the air defence system was already in existence. As Figure 3 shows, there were various interacting parts, all very much mutually interdependent, some of them technological, some of them human activity systems, all socio-technical systems:

- Chain Home Radar for early warning; the radar could detect Luftwaffe bombers formatting over France as the prelude to a raid;
- Royal Observer Corps sighting posts for detecting and tracking raids over land;
- Filter stations to unravel uncoordinated reports from a multiplicity of ROC posts;
- Sector Operations, with its plotters, trackers, communications and control facilities;
- Dispersed squadrons of mostly Hurricanes, with some Spitfires.

Although the whole command & control (C2) system worked, it was initially too slow, with various delays around the loop adding up such that the enemy bombers had time to penetrate into southern England, making good their aim of attacking British fighters and aircraft production on the ground.

The solution was to go around the C2 loop tightening up and improving procedures, introducing the use of brief code-words to describe raids and control interceptions, etc. It worked—just!

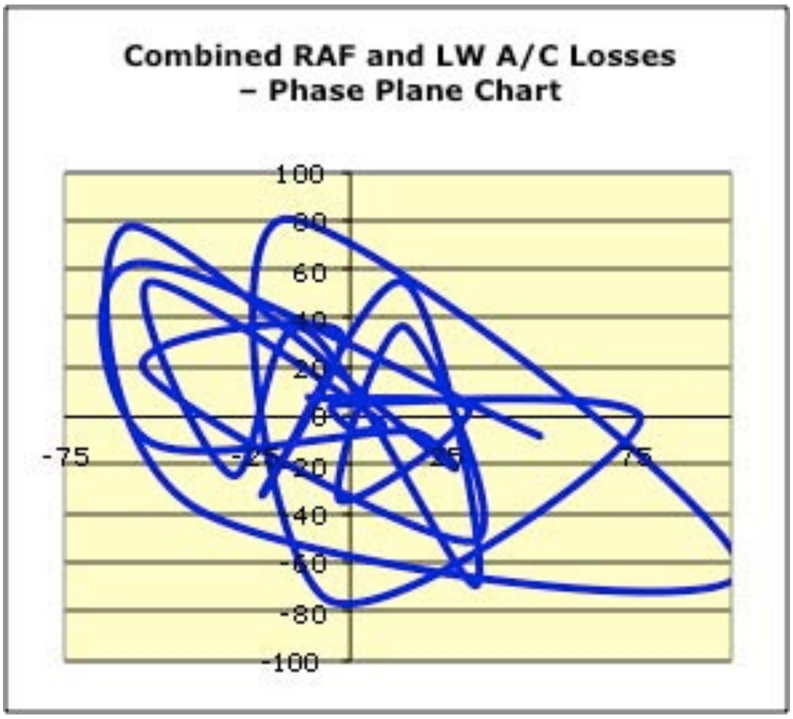


**Chart 1. BoB Phase Plane Chart.** Graph shows the sum of RAF and Luftwaffe aircraft losses during the BoB, on a day-to-day basis. The pattern is confused and unclear, but there is some evidence of a dual attractor within a complex system…

Chart 1 shows how close things were: for those concerned with the enterprise at close quarters it must have seemed chaotic. Deeper analysis suggests that, had the Luftwaffe continued with their assault on the RAF, the latter would have been able to hold out until the Luftwaffe ran out of aircraft after, approximately some 6 months. In the event, after 1 month, the Luftwaffe switched their attack to bombing major cities. Having effectively 'seen off' the besiegers, the RAF was justified in regarding the Battle of Britain as a success. The Luftwaffe certainly felt that it had failed to achieve its mission.

But, was it systems engineering? Let us apply the acid test:

- **Holism**: certainly, the command and control system was considered as a whole, and it had emergent properties of unity, timeliness, coherence and unpredictability; the Luftwaffe, it later emerged, could not understand how the RAF fighters appeared in just the right places to defend and deter the German bombers…
- **Synthesis**: the whole had been formed by bringing together the various parts, and performance was then enhanced by progressively reducing delays around the loop, after the manner of Chinese spinning plates; i.e., orchestrating the interactions.
- **Organicism**: each of the parts had its discrete functions, the functions interacted cooperatively, and these 'organs' were mutually interdependent, forming a unified whole. If any failed, they would all be vulnerable…

So, yes, the Battle of Britain Command & Control System stands as an instance of systems engineering. Note, however, that the basic system was already in existence and operating when the systems engineering took place… this is not what some might regard as conventional systems engineering, which engineers in particular associate with the production of artefacts. Yet, systems engineering it evidently was…

**NASA's Apollo (1960+AD)**

The Apollo missions established the 1960's SE gold standard for systems engineering. So successful was this program that some today deny its existence. Apollo certainly established SE as *the* most powerful problem-solving *methodology*.

Contrary to popular notions, however, this was not classic engineering… although there was plenty of that going on, too. Indeed, Apollo's top level systems engineering had little specifically to do with engineering *per se,* although technology eventually *realized* the design solution!

The central systems design team faced evident limitations in terms of the mass, volume and form that the rocket would lift. Getting to the Moon and back safely had to be accommodated within those limits: too much of *this* meant not enough of *that*; if this took up too much space, then there would not be enough room for that; if this had too great a mass then the C of G/M of I would be outside limits, and so on. The team had to develop a concept of operations (CONOPS) which showed step by step how the mission was going to be achieved – and there were, initially, many options. So, the central team were concerned with function, functional interactions, behaviour – or fit, form and function, as it became known – needed to fulfil the chosen CONOPS. And there was a process of continual compromise, reconfiguration, rebalancing, etc., until the whole could be seen as capable, step-by-step, of pursuing the mission – i.e., of solving the problem of how to put a Man on the Moon. (Curiously, that was not too different from the problem facing the ancient Egyptians!)

Each of the major subsystems (lifter, command module, Moon buggy, etc.) had its own systems design team, which interacted with the central team, such that the subsystems/organs achieved their discrete functions and at the same time cooperated and coordinated their mutual interactions synergistically. Subsystem design teams were, of course, rather closer to their respective technologies…

**Holism**, **synthesis** and **organicism** are central to the Apollo mission designs. They set the standard for creating optimum, whole solutions to complex whole problems.

## CIRCUMSPICE: WHERE ARE WE NOW?

### Systems Science, Systems Thinking

Systems science has been developed over the last 60 years to understand and synthesize systems as wholes: this is as opposed to Cartesian reduction, which takes things apart, seeking to understand the whole by first understanding the separate parts – which works well for simple, linear systems. With the advent of systems science has come a limited understanding and theory of complexity, self-organized criticality, chaos and catastrophe – all concerned with non-linear behaviour.

Systems thinking has developed; that is, thinking about problems and situations as being comprised of interacting systems, and representing such interactive behaviour in non-linear, dynamic computer simulations. This is proving to be at the heart of understanding and addressing complex problems, situations and of designing effective solutions.

### Systems Approach

It is presently *de rigueur* for systems designers, architects and engineers to adopt the systems approach when seeking to understand, analyze, design, and predict the behaviour of wholes/systems.

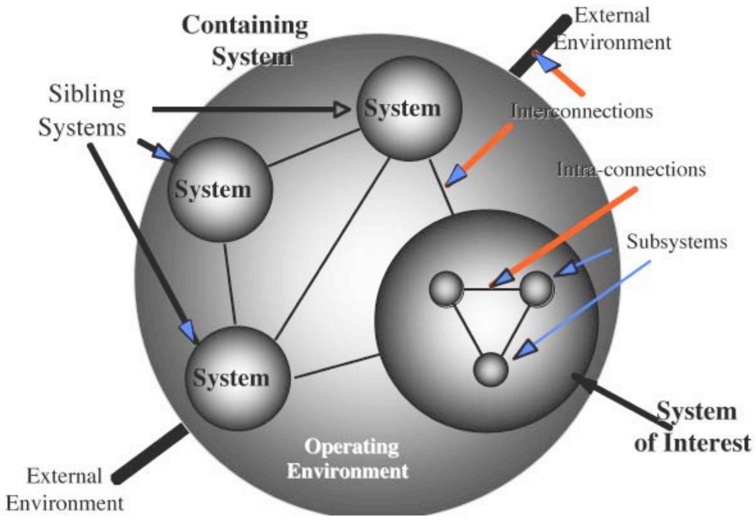


**Figure 4. The Systems Approach.** A System of Interest (SOI) is considered as an open, adaptive whole, interacting with other open, adaptive systems within a wider, containing system. As the diagram shows, the SOI 'contains' a number of open, interactive, mutually-adaptive subsystems, while the containing system is itself an open, adaptive system interacting with other 'containing systems' not shown. The diagram thus represents a hierarchy of systems within systems within systems, all acting, interacting and mutually adapting. (Hitchins, 1992)

Figure 4 shows the so-called 'poached egg' diagram to illustrate the systems approach. A system of interest (SOI) is considered as being an open, interactive, adaptive part of some greater whole. An open system is one that exchanges energy, substance and information with its environment. (Classic engineering treats systems as essentially closed.)

The systems approach has been adopted in many fields of endeavour, including psychology, politics, ecology, economics, and many more. Personality, for example, is studied using the systems approach. The systems approach has lead to the idea that there is a generic or universal *systems methodology*. See Figure 5.

**Systems Methodology**

As the figure shows, the systems methodology is essentially the 'how' of systems engineering. At left is the Problem Space: at right is the Solution Space. Between are a sequence of activities, processes, etc., which progressively develop understanding of the root problem, conceptual remedial solutions, purpose(s) of - and threats to - a conceptual solution, and so on, eventually manifesting the design of a real-world solution. A systems methodology is more than just a problem-solving process, however. It invokes domain knowledge, skills, methods, etc., which are vested in individuals, teams and teams of teams, including their management.

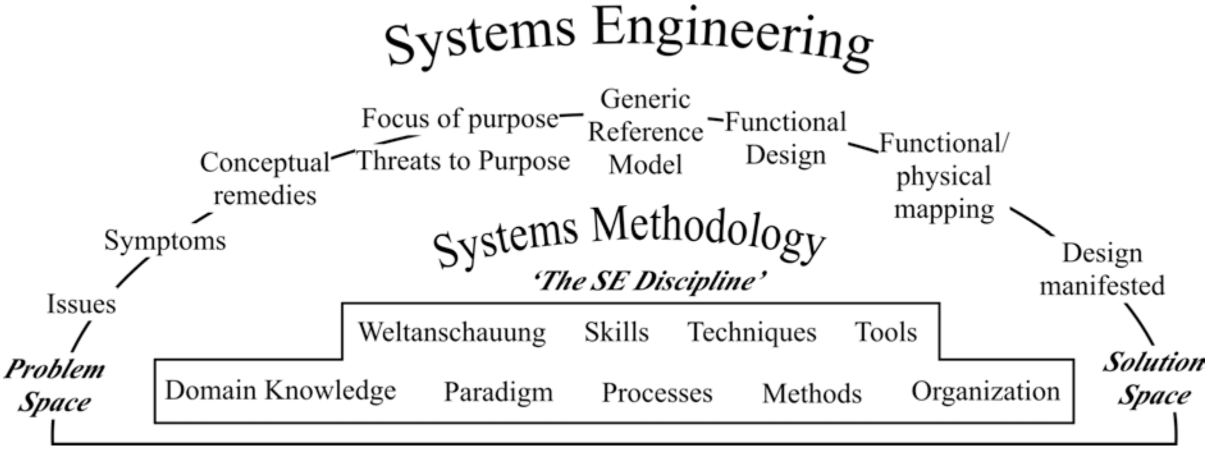


**Figure 5. Systems Engineering Methodology (Hitchins 2008)**

For one systems methodology to be universally applicable may seem unreasonable. However, the systems methodology is not some handle-turning machine – problem in, turn handle, solution out. Instead the methodology depends upon the skill and knowledge of the individuals and teams, and the methods they use – which are selected to suit the problem as a surgeon might select the right scalpel for the required cut. Inherent to the systems methodology are **holism**, **synthesis** and **organicism**: these are built into the processes, procedures and, particularly, into the methods.

**The 5-layer Systems Engineering Model**

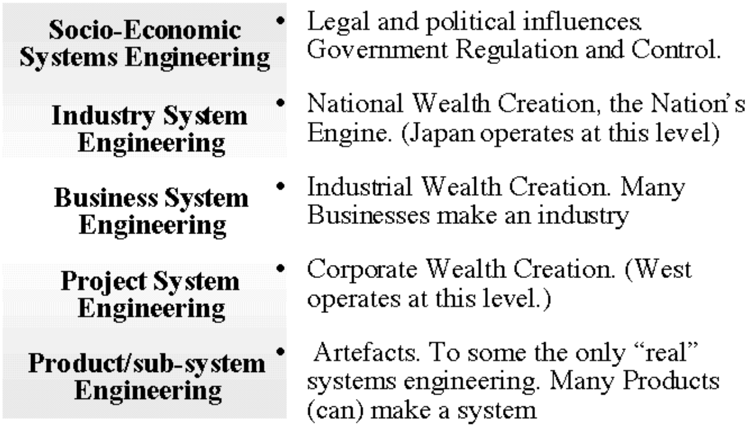


**Chart 2. Five-Layer Systems Engineering Model**

A look at systems engineering today shows the diversity of its application and employment. Chart 2 shows a 5-layer systems engineering model, to illustrate this diversity. The model is of the so-called 'nesting' type, i.e., each model 'fits into' the model above. So, many subsystems make a system; many systems make a business; many businesses make an industry; many industries make a socio-economy. Of course, these are approximations: there is clearly more to a socio-economy than just industries; as there is more to a system than just subsystems. However, the value in the model is that it suggests a wider scope for systems engineering than that perceived by many; it suggests that many who operate in business, industry and economics may be systems engineering, even though they might neither recognize nor indeed relish the term; and, it suggests that there may be a common theme, or methodology running through each and every layer – the so-called systems methodology.

Moreover, examination of, say, industry systems engineering shows that within any industry there is likely to be business systems engineering and, within that, project systems engineering, and within that, subsystems/product systems engineering.

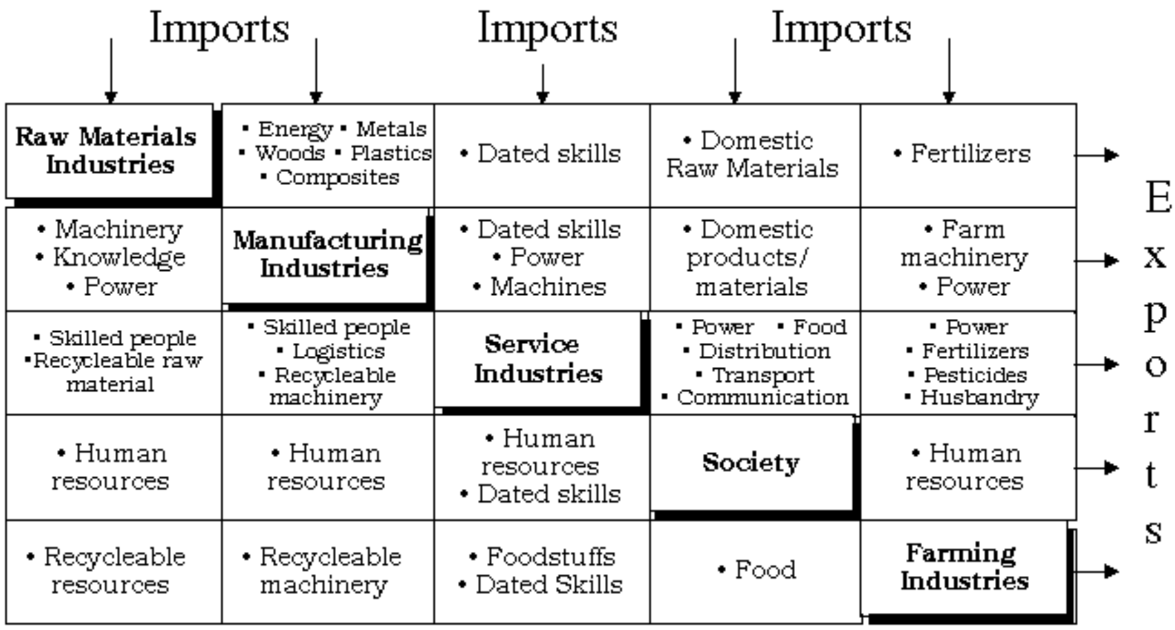


**Chart 3. Socio-economic N² Chart.** The chart could represent a communist-type socio-economic regime, in which the degree of interchange between systems is predetermined and regulated by the state, as in the typical 5-year plan. Alternatively, it could represent a capitalist free-market economy, where the degree of interchange

is uncontrolled, and responds to a sell-buy, profit-and-loss motive. The regulated version has been seen not to work, while the free market version works well, and is robust, but may move towards a state that is less than ideal. The $N^2$ chart can be seen as representing a number of interrelated supply circles –10 in this instance – pointing to an expectation of complex, non-linear behaviour of the whole.

Chart 3 shows a simple $N^2$ chart for a socio-economic system—Level 5 in the 5-layer model. It comprises 5 major groupings:

- Raw Materials Industries
- Manufacturing Industries
- Service Industries
- Society
- Farming Industries

The various groupings interchange goods and service via the interface blocks in the $N^2$ chart. So, Raw Materials Industries give energy, metals, woods, etc., to Manufacturing Industries. The whole set may be self-contained, requiring no input and offering no output, but they may also import as shown if there are shortages, and export if there are surpluses.

### Expanding our horizons…

Systems engineering has emerged over the last 70 years as a distinct discipline, and is in the course of emerging from, even distancing itself from, its classic engineering roots: while there are many today who would claim that systems engineering is simply engineering – level 1 in the 5-layer model of Chart 2 – that was never the case in the past, is not the *de facto* case today, and will not be appropriate for the future. There are too many serious issues facing the world for that to be the case.

## PROSPICE: SYSTEMS ENGINEERING FOR THE 3RD MILLENNIUM

### Problems getting bigger and more complex

World *Problématique* – The Club of Rome has identified a variety of crucial problems—political, social, economic, technological, environmental, psychological and cultural — facing humanity. (See http://www.clubofrome.org/)

“The complexity of the world *problématique* lies in the high level of mutual interdependence of all these problems on the one hand, and in the long time it often takes until the impact of action and reaction in this complex system becomes visible:

- “Environment.
- New Technologies.
- Demography.
- Education.
- Governance.
- Development.
- New Global Society.
- Values.
- Work in the future.
- World Economic & Financial Order.
- Information Society…”

Climate Change and Global Warming currently head the list of global priorities. Increasing global energy demands… feed global warming… fossil fuel supplies dwindle… agriculture is turned over to growing bio-fuels, leading to deforestation, diminution of species, and global food shortages. Global conflict looms… See Figure 6.

Meanwhile the Industrial Revolution lumbers on thru China, India, belching evermore $CO_2$. And stoking the climate change furnace… it has to be faced: prospects post-Kyoto are not good!

SE to the rescue! SE *can* raise its game: SE *can harness human ingenuity to address these problems*. Well, maybe: it still requires people to work together at a global level – and the prospects for that are not promising.

### Major Role for 21st Century systems engineering

All of which suggests a major role for systems engineering in the 3rd millennium, and the 21st century in particular… bring systems thinking to social systems and structures. Simplistic it may be, but Figure 6 captures the essence of the problem. Essentially there are far too many people on the planet, demanding too much food and energy, resulting in global warming and climate change which will, inevitably, prejudice the future of the human species and, unfortunately all other species of flora and fauna in the process. It is not beyond reason to anticipate thermal runaway for planet Earth – it happened to our twin sister planet, Venus.

So one view of the challenge facing humanity is that we must get our global act together.

I.e., evolve towards more sustainable, efficient societies, which will:

- accommodate climate change/global warming…
- nurture individuals,
- preserve liberties and…
- offer exciting environments and lives so that…
- humanity may sustain itself as it continues on its road of social evolution.

Within that broad scope there are alternatives.

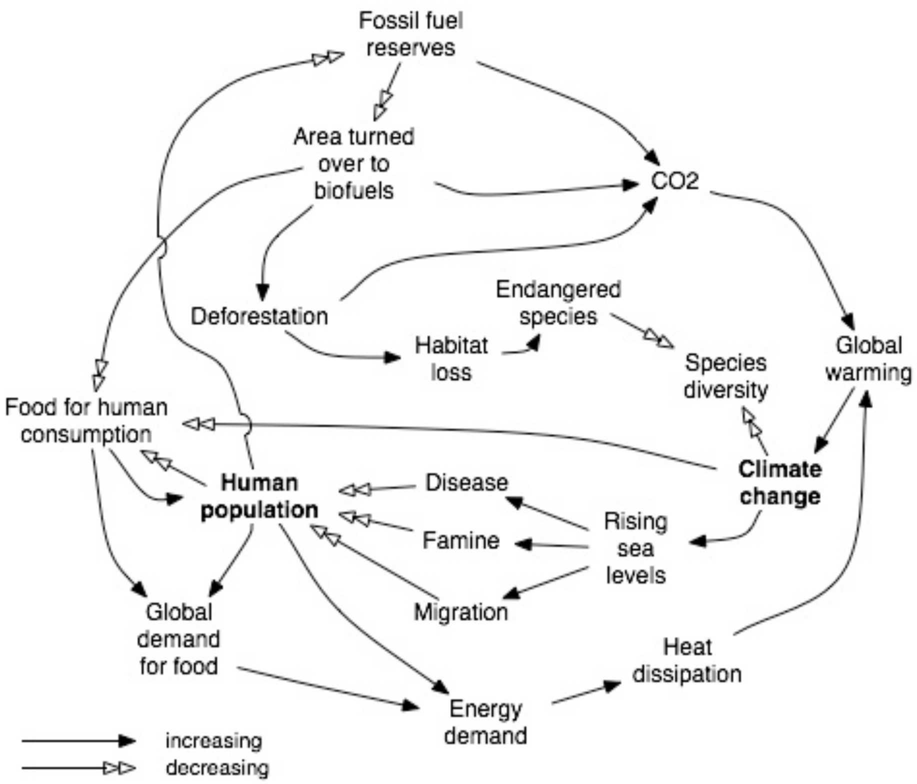


**Figure 6. Interrelated Global Issues...** Overall, a simplistic view of a complex set of interwoven issues…

## Alternative A: Go with the Flow

### A1. Future Landscape

Controlling escalating social tempo – which absorbs energy - necessitates reducing social coupling, but at the same time creating more room for increasing population. The suggestion in Figure 7 is that, to create more room, societies could expand into three dimensions, above and perhaps below ground. The space so created between each habitat is reserved for the natural world, recreating the essential "lung" of the Earth. Each habitat would aim to be self-sufficient and each might act as a tier in one or more global supply chains, Layer 4 on the 5-Layer Model of Chart 2 so both contributing to, and receiving from, the commonwealth. Habitats might form groups, after the style of Layer 5, the Socio-economic layer – see Chart 3.

In Figure 7, the means of interaction between the seemingly isolated habitats is not in evidence. To keep coupling low, it is necessary to minimize interchanges—quite the opposite, it seems, of road expansion schemes. So, while most intra-actions occur within each habitat (tight functional binding) some interactions must occur via communications media—hence the overhead communications sphere. Tangible interchange would occur by tunnel, air vehicle or by road. In any event, such transportation would, of necessity, be non-polluting and would not disturb the recovering flora and fauna on which the planet depends.

Figure 7. A Futurescape

The figure shows each habitat as different in appearance. Conceptually, each habitat has to be largely self-sustaining, but each may achieve this end by different means. It is essential to maintain complementary societal variety, so that different people with different ideas and cultures may develop independently, yet in co-operation.

What would be the population of each habitat? Research into the development of disorder in society suggests that disorder increases with size. Smaller, tight-knit communities appear to suffer fewer problems, being essentially self-policing. On the other hand, self-sufficiency requires some minimum size—and we have the population issue to deal with. The compromise seems to lie somewhere around the 40-60,000 population mark, but it would be foolish to be too specific over such an issue.

There are options to the basic Futurescape of Figure 7. The major difficulty with land-based systems now, and increasingly in the future, is that the land is already in use. Those holding the land will not co-operate with any attempt to change things. Imagine trying to re-engineer London, Paris or New York.

**A2. Littoral Developments**

One obvious option is to move out from the land into the surrounding coastal waters—hence Figure 8. Here the habitats have sprung up from littoral seabed. Again, there is a great diversity between different habitats. Each habitat is self-sustaining, implying internal diversity, yet the whole set is also self-sustaining because of complementary habitat diversity.

Such littoral habitats could produce fresh water and energy beyond their needs. If developed adjacent to desert areas, these excesses could be used to revitalize the desert, making it more habitable and productive. There is, of course, the potential danger from weather and from rising sea levels. Such habitats might be largely submerged, to reduce risks. A semi-submerged hotel is being developed in Florida, perhaps pointing the way?

**Figure 8. Littoral Habitat**

### A3. Mountainscapes

One of the advantages of the littoral development is that the land has not previously been used, allowing expanding population to spread comfortably. Figure 9 illustrates an alternative approach to the same idea of using previously uninhabited territory. In this case, the area chosen is mountainous, and a diverse habitat has been developed under a transparent "bubble." If feasible, the bubble would enable a kind of Shangri-La.

The science and engineering of such a bubble would present a fascinating challenge. It might be a transparent, semi-permeable gas balloon, although the ability of such a solution to resist severe weather is questionable. Alternatively, it might be created using ultrasonic and/or non-visible lasers to create a pressure gradient, with higher-pressure inside, lower outside.

Although such technology may be beyond us at present, the very fact of envisaging such potential futures suggests directions for research. And, the idea of being able to create such protected environments could lead to many other advances—colonizing the Moon and Mars being only two.

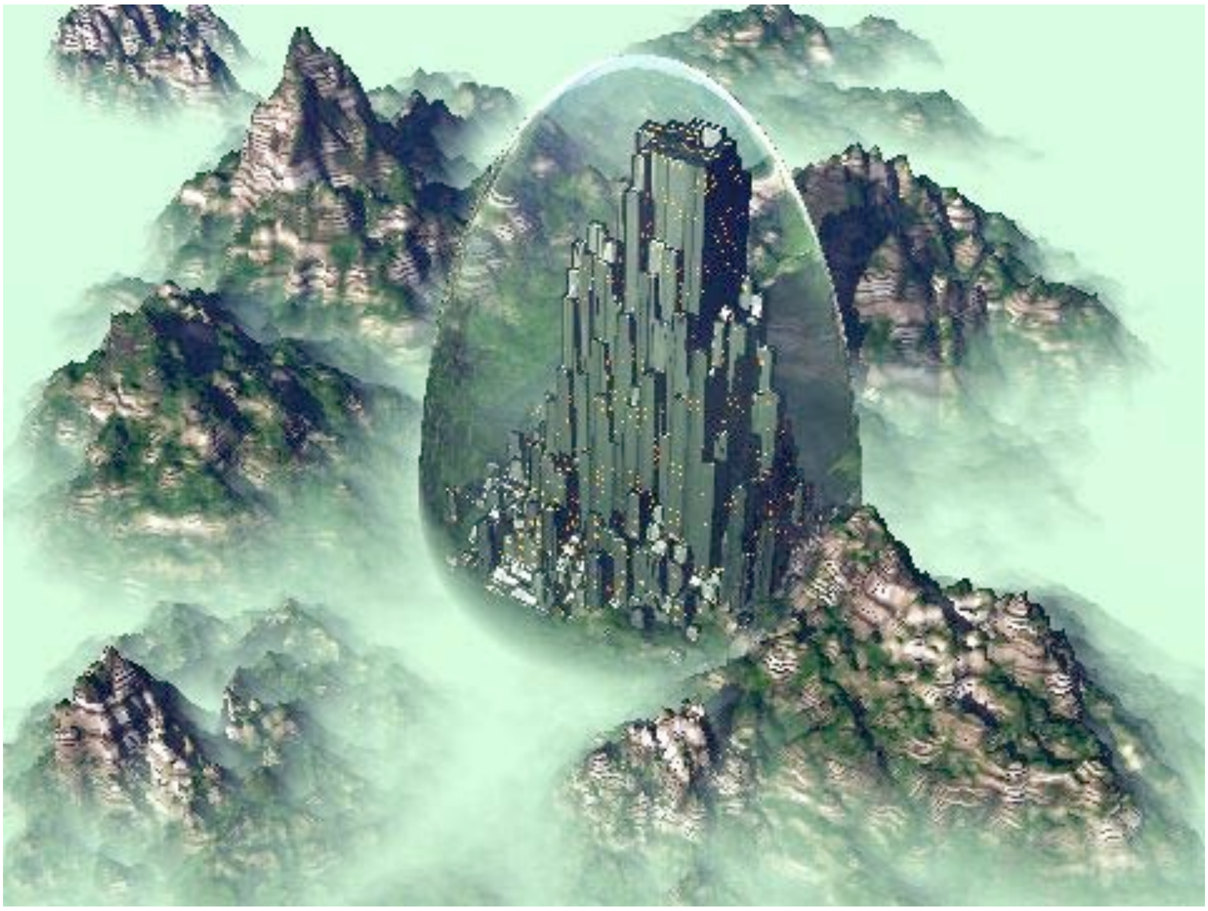

**Figure 9. Mountain Habitat. The bubble creates a moderate environment within the habitat.**

## A4. Desert Living

Figure 10 suggests yet another approach, this time moving into the vast areas of desert presently covering much of the global landmasses. We may think of deserts as hot and arid, but there are cold deserts and vast tundra, too. Deserts may have vast ancient water resources deep beneath them, while tundra has water in permafrost. The figure shows one element in a set of associated elements for living in such conditions without interfering with and damaging their fragile ecosystems. In addition to creating exciting and rewarding habitats for people, such desert habitats may help to sustain and restore natural habitats simply by infusing the local environment with water and water vapour.

## A5. Future Seascape

**Figure 11** takes the use of the sea to its logical conclusion. Self-sufficient habitats are mounted in large free-floating spheres, submerged to a level consistent with wind and weather. In areas where there is danger from tsunamis, depths of submerging might be significant. The spheres can be tethered to the seabed to generate tidal energy. Energy is also available through seawater temperature gradients and directly through sunlight.

The sphere boundary is semi-permeable, allowing osmotic exchange with the environment. Fresh water would be derived by reverse osmosis of seawater, using the weight of the habitat as the necessary force. The water surrounding each habitat inside each sphere is fresh water, and supports fresh water flora and fauna. This water is continually recycled in the mini-climate created inside each sphere, so that clouds, mists, rain and even snow may occur. Gases may pass through the sphere membrane, the behaviour of which can be controlled.

This preserves both the internal environment of each sphere and the external marine environment.

Each of the habitats is clearly different. The view is seen from the inside of one habitat, showing its superstructure. Looking outwards, the near membrane is invisible from inside, although it is filtering out harmful ultra-violet radiation.

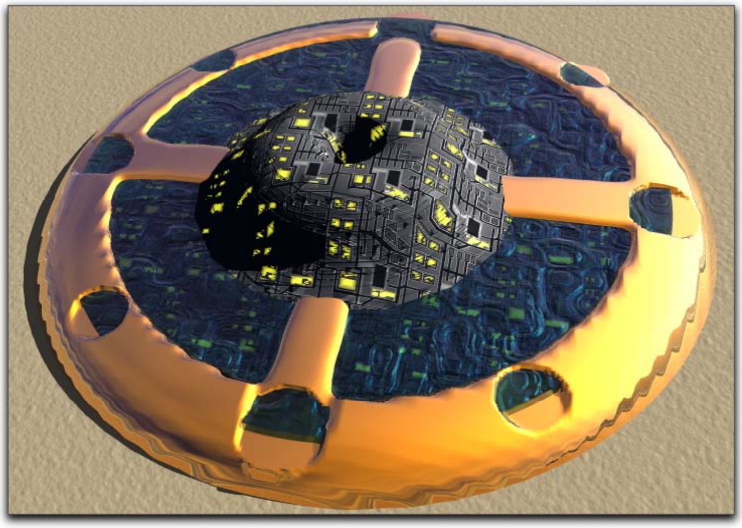

**Figure 10. Living in, and under, the desert.** There is water a-plenty deep beneath some deserts. The figure shows one element in a multi-element habitat. The gold ring contains water, with a central structure of which only the translucent tip is visible. The central living volume has a venturi-shaped upper surface, with the shaft penetrating deep underground. In the shaft, a vertical wind-driven turbine pumps water and ventilates the habitat. Water is used to create local oases, for fresh food and wildlife, as well as to support the human population. Five such elements form a single, self-sufficient habitat for perhaps 1 million people.

- At left is a floating island, with vegetation, trees, farms, plants, insects, etc. By rotating the sphere, different microenvironments can be established and maintain-ed, promoting variety within the sphere.
- Far right is an opaque sphere used for photosensitive processes, waste processing, recycling, etc. This sphere might also extract minerals from the sea, which contains vast amounts of metals in suspensions and solutions, and could contain processing and manufacturing plants.
- The other two spheres are different kinds of population habitats, enabling people to live in the styles, and under the conditions, of their choosing
- Physical interchanges between the spheres are principally by electrically driven submarines to minimize pollution
- The habitats can be seen to co-exist in complementary sets. Research suggests that an ideal number in the set would be about five, all different. Each set of five would be self sufficient, able not only to maintain itself, but to recreate itself too. Within the set, there would be schools and universities, research laboratories, manufacturing, food production, waste management, recreation, etc.
- Opportunities would exist for extracting minerals-in-bulk from sea water, fish farming, farming the sea bed, and even for farming floating sea flora to attract and protect shoals of free-swimming fish, to create sustainable fish stocks in ideal conditions. Such habitats could be, not only self-sustaining, but also highly productive, too. However, that would be a choice for the community.

**Figure 11. Sea Spheres**

Physically, the set of habitats is relatively small, on the other hand. Any travel to work would usually occur within a sphere. Families would live together, with living and working nearby. The nuclear and the wider family would exist within easy mutual reach, but need not be *too* close. And each set of habitats would be connected to other sets through the various lean, volume supply chains that criss-cross the globe. One set might supply specific kinds of food, another specific goods, a third the results of research, and so on. The whole would be mutually dependent for non-essentials or rare commodities.

The whole is a way of living in which the human population can spread out across the 2/3rd of the Earth's surface covered by water without using occupied land and without damaging the essential marine environment

## Alternative B: Global Climate Control

Alternative A faced the prospect of global warming and Climate change head on. But there is another way – one in which climate change is neutralized and global warming does not occur.

Scientists and philosophers have wondered for centuries about climate control. Nature controls climate, why not mankind? Indeed, if our species is to survive over the next, say 10,000 years, it seems that climate control would be a fundamental necessity.

But how? Our world has gone through a bewildering series of climate changes over the last 500 million years. Some of these have been caused by shifting tectonic plates, some by meteoric impact, some possibly by variation on the Sun's output, and some by the solar system passing through radial dust clouds emanating from the centre of the galaxy. On a shorter timeframe, climate change has been brought about by volcanic action, with large volcanoes spewing out vast dust clouds and sulphur dioxide ($SO_2$). The clouds have circled the globe, shielding it from the Sun's radiation on the one hand, and changing the Earth's albedo to reflect more sunlight outwards on the other hand.

The major eruption at Krakatoa is a case in point; it resulted in reduced mean temperatures and glorious sunsets around the globe for some decades after. More recently, the eruption of Mount Pinatubo in the Phillipines in June 1991 indicated that: "the direct radiative effects of volcanic aerosols caused general stratospheric heating and tropospheric cooling, with a tropospheric warming pattern in the winter." (Kirchner et al, 1999). Evidently, volcanic effects on climate may not be as simple as cooling. Apart from other considerations, volcanic emissions do not spread evenly around the globe, so presenting the opportunity for increased turbulence as some areas of the globe receive sunlight while others are shielded.

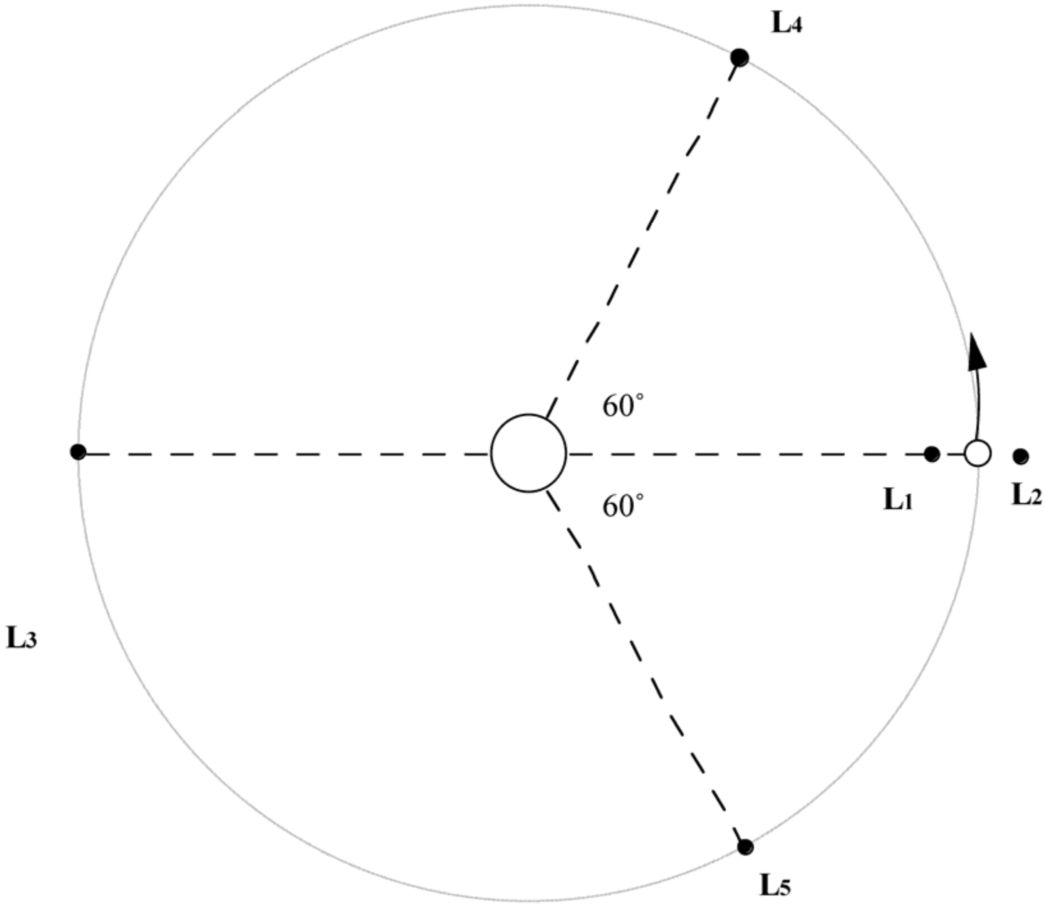


**Figure 12. Sun-Earth Lagrange Points.**

Similarly, studies of the likely outcome from global nuclear war have indicated that a so-called global winter might ensue, which could effectively wipe out much of the Earth's flora and fauna – a Pyrrhic victory indeed for whoever 'won' the nuclear exchange.

A more promising avenue for climate control observes the cooling effect of passing through galactic dust clouds. Such clouds scatter radiation from the Sun, so that less of it reaches Earth directly. The effect is uniform over the globe, so obviating the risk of differential heating/cooling and turbulence. Essentially, the dust clouds "took the heat out of the climate system." Could we emulate that effect in a sensible, risk-free manner?

### B1. $L_1$ Solar Cloud Concept for Climate Control

To understand how this might be achieved, using today's technology and resources, consider first the diagram in Figure 12. It shows the Sun at centre, with the Earth rotating around it. Consider first the point marked $L_1$: at that point the gravitational attraction of the Sun balances the gravitational attraction of the Earth and the centrifugal force of the Earth's rotation around the Sun. An object placed at this point would, in principle, stay there, and so would rotate around the Sun in line with the rotating Sun-Earth radius.

A similar point, $L_2$, exists on the side of the Earth away from the Sun. $L_3$ exists on the opposite side of the Sun, and so is permanently out of view from the Earth. And $L_4$ and $L_5$ are so-called 'gravity wells,' where objects would be trapped. These are the Lagrange Points.

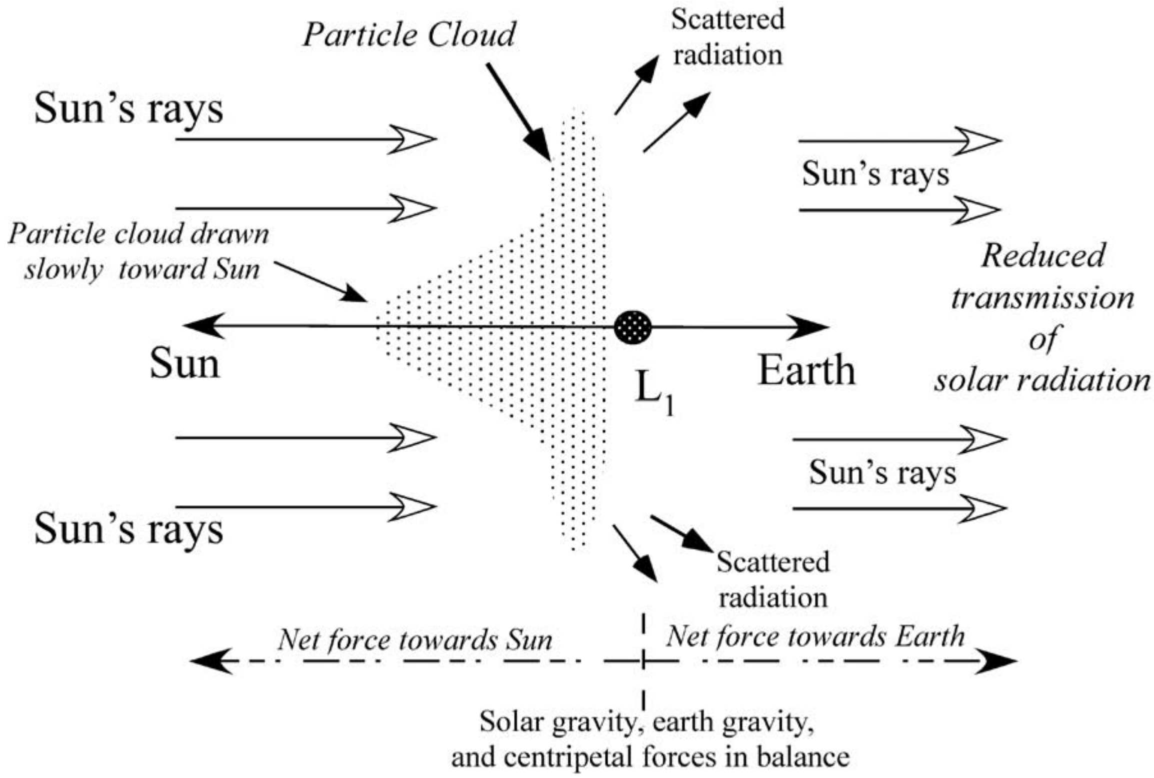


**Figure 13. The $L_1$ Cloud Concept for Climate Control**

Of particular interest to us in this present context is the $L_1$ point. See Figure 13, which shows a view of the $L_1$ point. A dust cloud has been injected just to the solar side of the $L_1$ point. This has the effect of scattering the Sun's radiation, such that the transmission of radiation reaching the Earth is reduced by a small amount. By choosing the dust particle size, it is possible to scatter only infrared radiation, with other wavelengths – visual and UV – passing through virtually undiminished, ensuring photosynthesis on Earth is unaffected

Note from the diagram that the particle cloud, initially a disc, is gradually being drawn out along the Earth-Sun axis, towards the Sun. Over time, this will dissipate the cloud, as the gravitational attraction to the Sun is slightly greater than towards the Earth, because of the initial positioning of the cloud.

Implementation of the $L_1$ Cloud Concept requires some care and caution. While the technology and engineering may be within current capabilities, the effects of injecting a cloud near the $L_1$ point are not absolutely certain. A sensible strategy, therefore, would inject a thin, diffuse cloud in the first instance, and observe both its effect on the Earth's received radiation, and hence on climate, and the time taken for the cloud to disperse. Such observations would allow subsequent injections to be 'tuned' both in terms of the nature and density of the particles and in their point of injection – the latter affecting, particularly, the cloud dispersal time.

The effect of a sequence of such injections on climate would be cumulative, effectively taking the heat out of the climate system – or, rather, countering the global warming effects caused by so-called greenhouse gases, which allow infrared radiation to reach the Earth's surface, but prevent the longer wavelength re-radiated from the heated surface of the Earth from escaping. So, in effect, the $L_1$ Cloud, carefully implemented, should neutralize the effects of greenhouse gases – giving us time to control and limit our generation of such gases, and assuming that we are not already too late…

### B2 $L_2$ Sunshield Concept for Climate Control and Solar Energy Capture

If *Homo sapiens* is to survive into the future as a sentient species, planetary climate control is likely to prove essential in the long term. Figure 14 shows one way in which it might be achieved, while at the same time addressing the global energy shortage that we are presently heading towards.

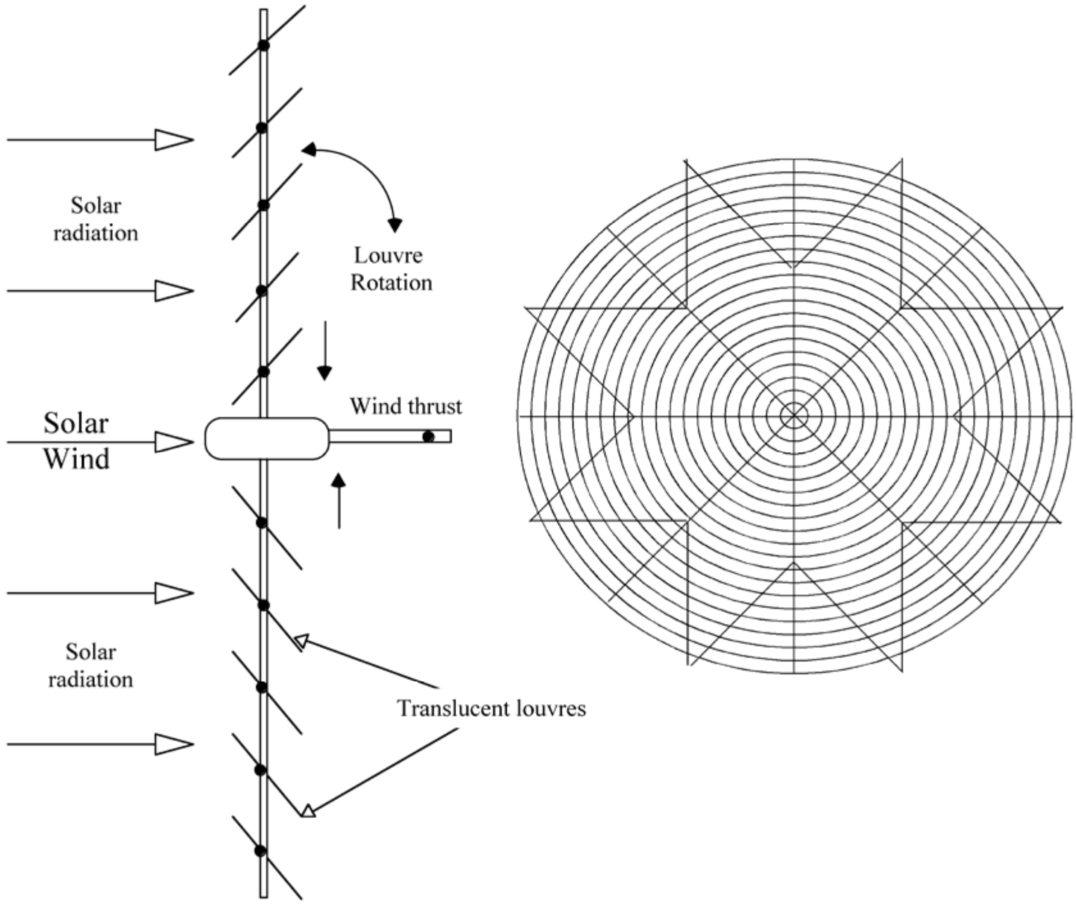


**Figure 14. The $L_1$ Sunshield Climate Control Concept**

Instead of a dust cloud at the $L_1$ Point, a sunshield is envisaged. The sunshield has translucent louvres, the angle of which can be adjusted to capture more or less of the Sun's radiation in the direction of Earth. The whole sunshield effectively 'rests' on the solar wind, being located – like the dust cloud – just on the solar side of the $L_1$ point.

The amount of solar energy passing through the sunshield amounts to some $1.74 \times 10^{17} Js^{-1}$ (i.e., the solar constant multiplied by the cross-sectional area of the Earth). If only 1% of that energy were filtered off by the sunshield, that would amount to $1.74 \times 10^{15} Js^{-1}$. This tremendous power would be spread across the vast web of the sunshield…

If the web of the sunshield were constructed from suitable superconducting materials, then the intercepted energy could be gathered and transmitted, perhaps to the Moon, or perhaps directly to Earth. This would provide a virtually unlimited source of clean, fusion energy.

Similar prospects exist for the $L_4$ and $L_5$ Lagrange points, the so-called energy wells. Large panels could be located at these points to intercept all of the energy radiated in their two directions.

These various sunshield concepts are presently beyond our technological capabilities – but not by much. Perhaps it is time to consider these bolder, more imaginative systems solutions to our global energy and climate change problems. Worth thinking about… meanwhile, not forgetting that a major problem will still exist in the politics of the situation… perhaps systems engineering is needed there, too!

## Conclusions

Our future as a species will involve *global* choices. Making the right choices need Vision—but, *more* than Vision. We need a powerful *systems methodology,* to… recognize & solve our problems and so *achieve* our Vision, anticipating pitfalls and counter-intuitive behaviour along the way — *if*, indeed, we are to *have* a Future! Time for systems engineering to stand up and be counted…

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