Derek Hitchins' Blog.
Systems Scientist
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The *Changing Faces* of Systems Engineering…

…plus ça change? Plus ce *n'est pas* la même chose!

Systems Engineering has been around for a long time—long before it was given that name, back somewhere in the 1950s or 60s. And even then it was about networks, and not what we think of as Systems Engineering today.

Actually, it is not clear what we think of as Systems Engineering— it is easier, perhaps, to identify what is NOT Systems Engineering, and even then you can get arguments. Is Systems Engineering…

- Management?
- Project Management?
- Just Engineering, in the classic sense of electrical, mechanical, electronic, hydraulic, etc., etc.
- Or is it perhaps, something altogether different, like "creating systems"?

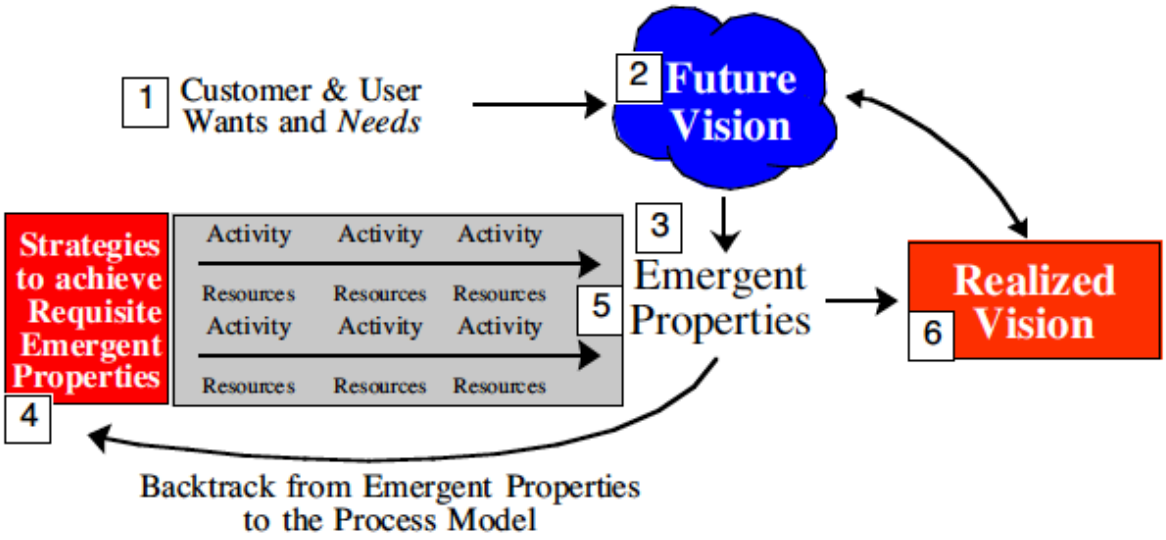
And then there is the issue of "system." What is a "system"? The original notion of "system" was of an overall, complete "something," probably made up of many ordered or disordered parts which, nonetheless appeared and behaved as a single "something," as in the Second Law of Thermodynamics. "System" was a holistic synthesis, a paradigm if you will. And "system" was in many ways the antithesis of reduction, decomposition and analysis. Once the notion of "system" gained cognition, you could see systems all around: political systems; educational systems; gambling systems; societal systems, self-organizing systems, autopoietic systems, galaxies, weather systems—soon everything was a system, even it wasn't really….

Only…the reductionists, unhappy with this *"holistic synthesis nonsense,"* found that if they defined "system" as something restricted and confined to their particular interests, then they could describe their activities as "systems engineering…" and get away with it. Using the term "system" leant "luster to their cluster," as the pre-PC epigram would have it. (Back then, we had free speech, but no swearing—so different.)

Further back in history, we find human ventures that bear the hallmarks of "holistic synthesis." Though not in name, such ventures may have been *de facto* creations of Systems Engineering. Undoubtedly, the most iconic venture of its time was the Great Pyramid of Giza, today the only extant Wonder of the Ancient World.

Reduction had not been conceived back in the 3rd millennium BC. (That would have to wait for René Descartes in the first half of the 17th Century, AD: his reductive approach would eventually become the basis of modern engineering methods.) So,

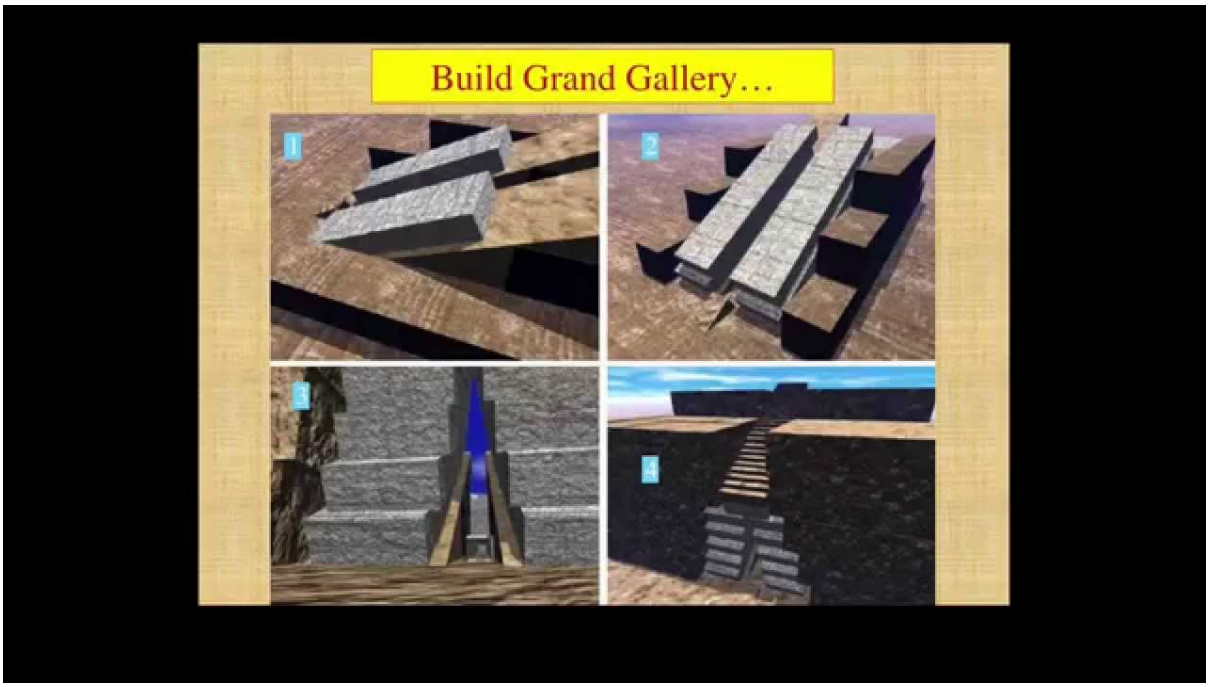
Heminu, the Royal Architect of the Great Pyramid, is unlikely to have employed reduction, but would instead have relied on the only approach available to him—holistic synthesis.



The figure shows a simple outline of the overall systems approach and systems methodology that Hemiunu would most probably have used—couched in modern terms, of course. It is simple, but powerful, and would have taken some 6 steps as shown.

If you are interested, you may see systems engineering—ancient Egyptian style—in the video, which shows much of the Operations Analysis and Functional Design (sic) that would have gone into the concept formulation and systems design of the Pyramid

Systems Engineering the Great Pyramid of Khufu.



complex. This whole complex was seen, not as the large piles of stone we see today, but as a living, breathing organism, a "psychic projector" able to send the interred god-King's *ka* (psyche) up to the heavens where he would negotiate with the other gods for a successful Inundation. And it was designed to operate for "millions of years." The YouTube video takes a little less time…and you might just be surprised.

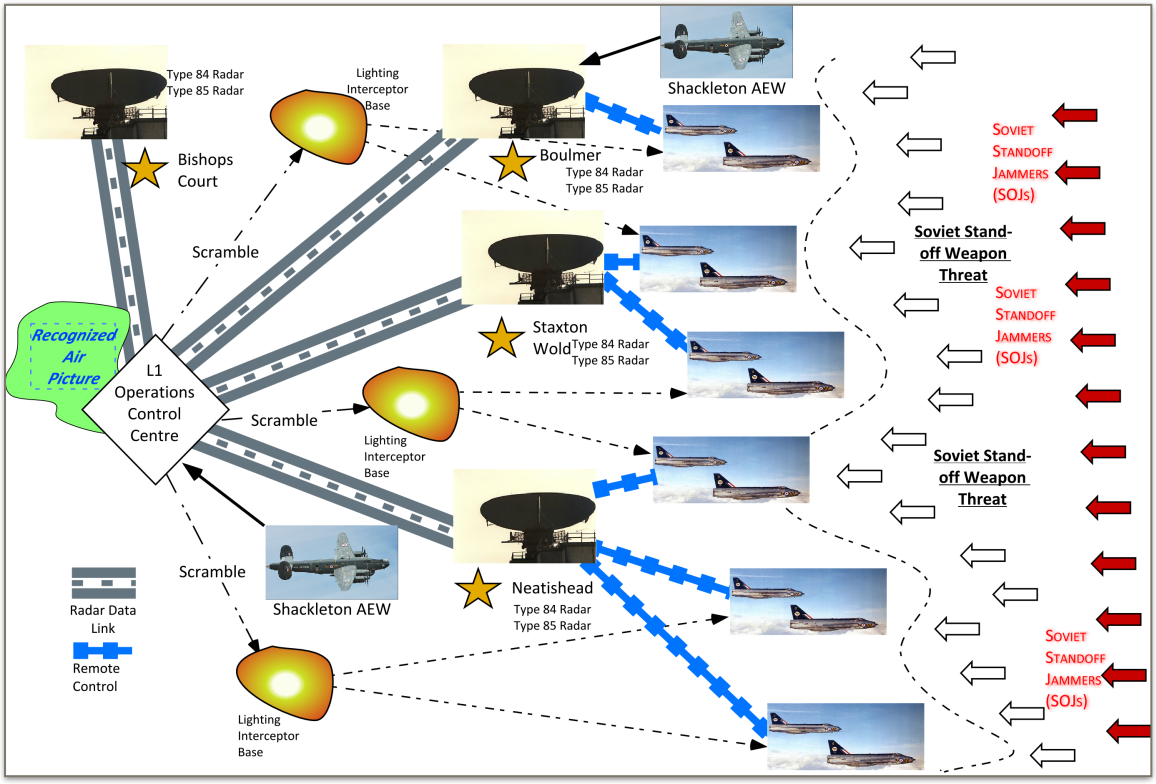
Fast forward to the 1950s UK. The term 'systems engineering' still was not in vogue. The Cold War was, however, hotting up. And the Soviet Union were, allegedly, developing nuclear-tipped standoff weapons, air-launched medium-range missiles that could be carried by a Soviet bomber and launched when the aircraft was some distance off the UK coast. Intelligence sources indicated that as many as 100 such standoff weapons could be launched simultaneously against the UK. And that would be terminal: this was an existential threat. Was it real? Was the Intel sound? Could the UK take the chance? So, the Total Weapon System Concept was spawned of necessity. And Linesman was conceived.

Post WWII UK had a number of centers of defense science excellence, notably Royal Aircraft Establishment Farnborough and Royal Radar Establishment Malvern. Their scientists were tasked with finding some way to counter the Soviet Threat. But how? Operations Analysis (OA) had been developed and proven during WWII. OA was essential from the outset. There were many questions to address w.r.t. the alleged Soviet Threat:

- How could the UK detect the advancing Threat in sufficient time to mount some kind of defense? The innovative Type 85 ***3-D*** radar would be conceived, designed and introduced to help resolve this issue
- The Soviet standoff weapons were too small and fast to intercept using contemporary anti-aircraft artillery (AAA), surface-to-air missiles (SAM) or short range air-to-air missiles (AAM). We would need, inevitably, to intercept the Soviet aircraft *before* they could launch their standoffs—*after launch would be too late*.
- If the Soviets could launch their standoff weapons at, say, 100nm from our coast, then we would need to deploy our interceptions correspondingly earlier.
    - So, we were going to need Airborne Early Warning (AEW); airborne aircraft with long range radars that can "see over the horizon," unlike ground radars. Shackleton AEW aircraft would fit the bill
    - Moreover we were going to need an interceptor that could fly out at phenomenal speeds, faster than anything in the contemporary RAF…and were going to need at least one of these non-existent interceptors for each and every standoff weapon—so, at least 100.
- To compound the issue, Intel indicated that the Soviet Threat aircraft with their standoff weapons would be accompanied by standoff jammers, to render our radars and wireless communications inoperable, or at best operable only at short ranges.

One of many results from the original OA was that we needed an interceptor that could travel at very high speed, up to intercept-altitudes of c.90,000 feet, that could be directed on to its target by a ground controller despite enemy jamming. And so was born the concept of the Lightning interceptor, a Mach 2+ high altitude fighter with infrared (IR) heat-seeking air-to-air missiles.

Total Weapon System Design Schematic—LINESMAN



The Threat is shown on the right approaching from the East. Everything to the left of the wavy line, and facing the threat, is an integral part of one system only—Linesman, UK-wide.

We had the concept. We did not have the aircraft. Happily, English Electric had an experimental aircraft that had the potential to fit the bill— the P1A—but needing copious changes, additions and alterations to make it an integral part of Linesman:

- An advanced interceptor radar with counter jamming capability, the Ferranti AI23B, was fitted into a nose cone in the aircraft's engine air intake.
- Facilities were installed allowing the Lightning to be remotely controlled via exceedingly high-power ground-to-air UHF datalink on to a target, even through heavy jamming.
- A pilot attack sight (PAS) that could show the pilot where ground control believed the target to be, relative to the Lightning, and an intercept profile generated by the AI23B which the pilot could follow to perform the "perfect" interception prior to IR missile launch.

> *A key outstanding issue was known as the Agincourt Problem. At the battle of Agincourt, on St Crispin's Day, 1415AD, it was found that the French crossbows could fire bolts much further than the English longbows could fire arrows. The French bowmen were using their range advantage to target the English knights. Perhaps the English bowmen, who could not reach the French knights, could fire instead at the incoming French bolts, and protect English knights that way? However, an insoluble problem emerged: how to get each English bowmen to fire at a different incoming bolt…there was no way of allocating targets, so bowmen all tended to fire at the same incoming bolt, leaving other bolts untouched.*

Linesman overcame the Agincourt Problem by feeding all of the target information from all of the radars into one central point, the L1 Building. There they formed a singular Recognized Air Picture (RAP). Individual targets from the RAP were allocated to individual Lightnings, whose pilot's were already sitting in-aircraft, on their respective runways, on QRA—quick reaction alert. Target Allocation problem solved. For the time being…

The Total Weapon Systems Concept was holistic synthesis—systems engineering in everything but name. And it is interesting to note that the main thrusts of the work, initially at least, were:

- problem exploration and scoping;
- multiple, competing concept formulation;
- Operations Analysis of, and comparative evaluations between, the differing conceptual solution systems, resulting in…
- A concept of operations (CONOPS), showing the optimum way to go about neutralizing the Threat together with the necessary emergent properties of each of the command centers, sensors, communications, and weapon systems that would go to makeup the whole.
- Total System Design, resulting in…
- …Creative, innovative designs, additions, alterations and enhancements for each and every major part of the Total Weapon System, as it became an integral part of the single system that would become Linesman. And the human element—operators, aircrew, engineers and technicians—was central, and incorporated into the concept and design, not added as an afterthought…

Looking back at the Great Pyramid, and at Linesman, there are striking similarities. Each had a singular overriding purpose: to project/transport the interred King's psyche; to counter a specific existential Threat. Each faced near insurmountable problems in achieving their purpose. Each had to establish a concept of operations (CONOPS), around which to design their overall system. And the systems design was necessarily of the whole system, and not of separate parts which would later be brought together—that simply would not have worked. Moreover, in both cases, the human element was central to the systems design…

The next iconic project to consider is Apollo. It too had one overriding purpose or objective: to put a man on the Moon and to retrieve him safely, as pronounced so memorably by President John F. Kennedy.

NASA drew together experts from around the world to assist with the initial concept development, including some from the burgeoning systems scientists in the UK who had cut their teeth on the Total Weapon Systems Concept. Apollo, however, was to be different. Developing a fully detailed concept for sending a man to the Moon "straight off" was rightly seen as a tall order. So, instead, a series of Apollo Missions was envisaged, each trying out successive parts of the eventual, overall mission. This then was a plan to carefully and gradually work up to the central goal of the mission, which—as it turned out—would be Apollo 11 landing on the Moon.

- Apollo 5, for instance, was the first flight of the live second stage of the launch rocket, Saturn I. It was also the first orbital flight.

- Apollo 8 saw the first circumlunar flight of the Command and Service Module (CSM), with ten lunar orbits in 20 hours. It was also the first crewed flight of Saturn V.
- Apollo 10 was the "dress rehearsal" for the lunar landing. The lunar module (LM) descended to some 15.6 km from the lunar surface.

This cautious, progressive approach was particularly apposite in view of the technology of the period, much of which was analogue and early digital. Digital computers were primitive, slow and bulky by today's standards. Moreover the environment between Earth and the Moon was not well understood, particularly in the effects that radiation might have on the astronauts. There were fears, too, about the surface of the Moon—just how solid was it? Might the lander sink into it? How would that surface behave when the LM blasted off when returning the orbiting CSM?

So, the Apollo program, comprised as it was of a number of related, sequential "sub"-missions, appears different on the surface. However, it seems to have been "holistic synthesis" too, with copious Operations Analysis (OA), simulations and mockups to work out the best way to achieve each phase of the mission, how the CSM and the LM would behave in operation, etc., followed by construction and test of early versions of the various segments and parts.

The human element was paramount. How many astronauts should go on the mission? One? Two? More than two? There were obviously weight considerations. So, could one astronaut manage on his or her own? In the end, as we know, they opted for three, leaving one man in lunar orbit while the other two went down to the Moon's surface. Why? That probably came from OA, too, supported by psychologists.

One man on his own might not have been able to cope. Two men would be better, but then if both went down to the lunar surface, returning to the 'empty' CSM could be problematic. With three men, two could go down, each supporting the other into the unknown, while upon their return to the CSM, the third man would assist their re-entry into the Command Module, and would be able to manage the return to Earth should either or both of the returnees be incapacitated by their expedition.

Because of the postwar situation, with the Soviet Threat continually morphing and expanding, the West needed a highly innovative approach, and one not based on "what had gone before," since 'what had gone before' had never faced the latest, new threat. *Prejudice was out*. Moreover, the defense customer was uncertain how best to respond to the changing threat, so could not be expected to specify any requirements, except in the vaguest of terms.

- First, then, came the notion of expressing the customer's issue as a problem, rather than as any defined requirement: moreover, as a problem to be addressed in a *deliberately abstract way* in order to prevent and preclude prejudice.
- Second, any solution to the customer's problem was clearly going to be complex and sophisticated, in keeping with the morphing threat. Any weapon, aircraft, ship, etc., would become part of an overall offensive/defensive "barricade," and would need, therefore to be both compatible and interoperable with many others.
- Third, since the solution to the customer's problem might be almost anything, it would surely be inappropriate to conceive and design physical structure and hardware: there might not be any…The solution to the customer's problem would necessarily have *purpose*, however, and would necessarily perform functions in pursuit of that purpose:

- So, instead of conceiving structures, conceive functions—many interacting, cooperating functions that together would create…
  - …*synergy,* leading to…
  - …Solution system *emergent properties, capabilities, behaviours,* and…
  - …drive towards the achievement of purpose.

These three provisos became central themes in what came to be known as the "systems approach." By definition, a system was something suitably vague yet precise:

A *complex, organized whole* of material and/or immaterial things

And it was that very ability to be "precise though vague" that was its power—something with which many scientists and engineers found–and still find–difficulty. The notion of system, however, had a rigorous mathematical basis, as defined in Kelvin's First and Second Laws of Thermodynamics, where internal energy and entropy are measures of "system." And there is a host of implications in "organized…" And another host in "whole, complete…"

So, the answer to the customer's problem would be a "solution system," initially at least, a conceptual, formless "blob of protoplasm," but able to perform functions and exhibit properties in the pursuance of some purpose—and, consequently, in the solving of the customer's problem or issue…

Systems engineering would progressively clarify and give definition, identifying the many functions and their interrelationships, before organizing them into functional subsystems, which could then be realized, underpinned and performed by physical entities—people, machines, buildings, weapons, transports, power supplies, etc., etc. And the people would be an integral part of the solution system, performing appropriate functions as part of the whole—not "integrated with the technology" as an afterthought.

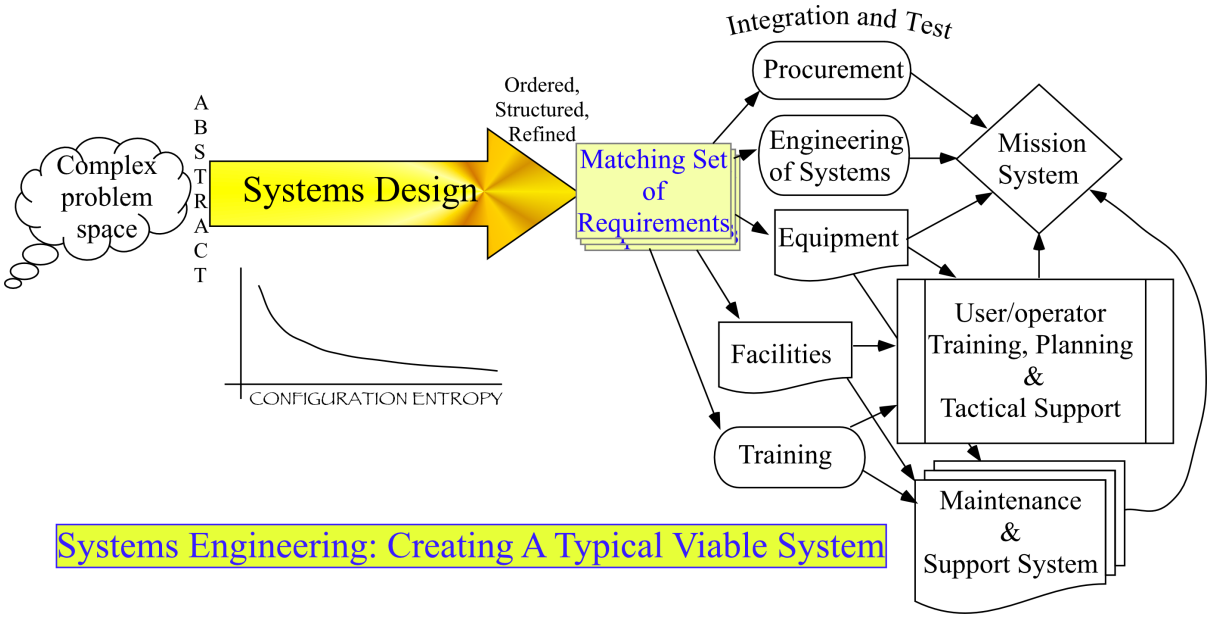
And the so-called ***Systems Design Methodology,*** or simply ***Systems Methodology*** evolved as sequential phases, each with its own proprietary system method, broadly as follows:

- Problem scoping and exploration
- Problem solving, leading to…
- Conceptual Remedial Solutions
- Operations Analysis (OA) of competing Conceptual Solutions
- Preferred Concept of Operations (CONOPS)
- Functional Synthesis of Solution System
  - Dynamic Modeling of Solution System interacting with its Operational Environment to validate and optimize functional design
- Emergence of Functional Architecture and Functional Subsystems (minimized configuration entropy)
- Functional-to-Physical Mapping, leading to…
- Development of Functional-Physical structures into a Viable Solution System
- Matched Set of Requirement Specifications for whole Viable Solution System

The diagram presents the systems design methodology ('system of methods') as ***Systems Design***, in this case for some form of in-service, maintained and supported Mission System, which might be a naval ship, a reconnaissance aircraft, a fighter-interceptor, a

new air traffic management centre, or perhaps an airborne command post, so largely a human-activity system…

Systems Methodology invoked the skills of many disciplines, including–but not limited to–systems scientists, mathematicians, systems dynamics modelers, anthropologists, psychologists, behavioral scientists, ecologists, value engineers, operations researchers, management scientists, cyberneticians, physicists, chemists, physical biologists, archeologists, etc., etc. All were considered to be "systems engineering…"



Systems Engineering: Creating A Typical Viable System

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As the Cold War progressed, supposed threats and supposed counter-threats mounted in sophistication and power, heading inevitably toward Mutually Assured Destruction (MAD). Notable developments along the way, supposedly using the then Systems Engineering, included:

- The ***Aegis Combat System*** is a US Navy integrated naval weapons system, now widely in use by navies around the world
- The production of a number of fine US military aircraft, notable the ***F14 Tomcat, F15 Eagle, F16, YF17–which became–F18 Hornet / Super Hornet, and F111;*** in Europe, the multi-role combat aircraft ***(MRCA)*** which became the ***Tornado***, and the **Eurofighter**, which became the ***Typhoon***
  - The UK's air defense variant of Tornado needed a revised avionics system. Ops Analysis revealed the need for a new CONOPS and many innovative features in the revised avionics system to enable the Tornado, designed as a bomber, to operate as a fighter interceptor…
- Advanced and sophisticated ***Command & Control*** systems: Command, Control, Communications/Computing & Intelligence (C3I), C4ISR, C4ISTAR, etc, where S is Surveillance, TA is Target Acquisition, and R is Reconnaissance.

- Other acronyms sprang into being, as various parties competed to put their *alphabetti-sphagetti* marker on Command & Control, e.g., ***C6ISR*** – Command, Control, Communications, Computers, Cyber-Defense, Combat Systems and Intelligence, Surveillance, and Reconnaissance.

- Joint Tactical Information Distribution System (JTIDS): a highly secure, sophisticated combined digital communications-navigation-identification (CNI) system for NATO tri-service defense operations. It employed frequency division multiple access, time division multiple access, code division multiple access, encryption, multiple transmission and automatic error correction (AEC), so was, and is, a mathematician's delight

…and finally in this list, *Sans Systems Engineering!*

- Automatic Test Equipments (ATEs). These were rather large automated systems for testing the parts of (usually) an aircraft's avionics system.
  - To accommodate US-bought aircraft, ATE was introduced into RAF service without any prior operations analysis (OA) or systems engineering (SE).
  - Retrospective OA/SE showed that a singular ATE, when applied to a large number of LRUs from an advanced military aircraft, was ineffective and uneconomic.

The Cold War came to a head, in retrospect, with President Reagan's Strategic Defense Initiative (SDI) Program, 1983, popularly known as 'Star Wars,' yet another international systems engineering venture, although short-lived At first glance, SDI mirrored the earlier Linesman program (q.v.).

The Soviet Threat this time was from MIRVs, or Multiple-warhead, Independently-targetable, Re-entry Vehicles. The US had introduced MIRVs with their Minuteman 3, but the Soviets had allegedly responded with more capable MIRVs of their own, implying a major threat to continental USA, and upsetting the balance of destructive power between the two.

The SDI program was conceived as a ballistic missile defense system, which had been thought impossible; Operations Analysis showed that it would have to be partly space-based, (hence Star Wars) so as to 'take-out' the Soviet MIRV Threat at, or soon after, launch. While Linesman had been cloaked in secrecy, however, the US appeared to 'leak' details of their proposed weapons systems, including:

- A space-based laser, pumped by a nuclear explosion, giving it sufficient power to destroy missile launch facilities on the ground many hundreds or thousands of kilometers distant.
- "Fighting Mirror," a mirror in orbit, strategically placed so that a remote observer with a telescope could see potential targets on the ground reflected in the mirror and, having identified a suitable target, could fire a powerful laser at the mirror, where the laser energy would be reflected accurately on to the selected target.

News of these fabulous weapons caused international consternation. Never mind that they were many years, if ever, from becoming credible weapon systems—the very notion of such defensive weapons swung the perceived balance of destruction by ICBM against the Soviet Union, which could evidently not afford to match such lavish expenditure.

And so to the end of the Cold War in either 1989 or 1991, according to various definitions and pundits: in the US there was a move to discontinue further ICBM production, with contracts being terminated and staff, including experienced systems engineers of the period, being made redundant and finding new jobs.

It was not long, however, before the US realized that their rebounding industry needed systems engineers—and all of a sudden, there were none. NCOSE, the National Council on Systems Engineering, was inaugurated with a view to fulfilling the resurgent need for systems engineers. And the face of Systems Engineering was about to change once again…

Which may have been appropriate at the time, since the situation had changed radically with the end of the Cold War. According to one NCOSE founder, Systems Engineering was "engineering done properly!" Any idea of recreating the prior 'face' of systems engineering was firmly rejected, and not open to discussion. Which left those experienced systems engineers from the previous era somewhat surprised, disgruntled and perturbed.

Accordingly, the new Systems Engineering was not directly concerned with problem-solving, did not countenance the Systems Approach, or Systems Design, and had no need for a Systems Methodology. And the notion of "system" changed, too…

Back in the 60s, 70s and 80s, the automobile was often used as a standard example on day one of a 'systems' course to distinguish between 'artifact' and 'system.' The car was an artifact, a man-made machine: lifeless and inert, non-viable. Simply, there was no whole; on the contrary, there was an evident empty seat, instruments and controls waiting for the missing driver. Only with the driver did the whole become a viable, autonomous socio-technical system.

However, alternative viewpoints were emerging. The USAF had taken to referring to aircraft as comprising: airframe, undercarriage, engines and "systems," by which they meant all the carried facilities required to assist the crews in the execution of their various tasks. The term seemed to arise because the aircraft manufacturer provided the airframe, flight controls, engines, undercarriage, basic flight instruments, etc., after which various equipments could be installed according to the role of the aircraft, e.g. maritime reconnaissance, troop transport, airborne command post, etc. In each case the significant change with role were to the so-called role systems—and, of course, the corresponding crews.

At the same time, there was a move in the industries that provided these various equipments to call them "systems," not so much in line with USAF practice, more because "system" was considered 'sexier' by salespeople. There was kudos and money in "systems," an echo of the great success of systems engineering in the Cold War. And engineers, long disgruntled by the prior systems engineering, which many did not comprehend, or actively disagreed with, jumped happily on the bandwagon, with so-called mechanical-, electrical-, hydraulic-, instrument-, wireless-, radar- etc. -systems engineering.

The difference between, for example, electrical engineering and electrical *systems* engineering was said to be that the latter took a 'holistic view,' in that it considered the whole of the electrical arrangement: generation; switching & distribution; architecture and configuration; the environment; radiation and interference;

not to mention lifecycle, maintenance, spares ranging, servicing and eventual replacement. Which traditional electrical engineers believed they covered, too…

These "specialist" systems engineering practitioners concern themselves particularly with such things as design for reliability, installation of their systems-cum-artifact-sets into platforms such as aircraft, ships, tanks, automobiles, etc., taking account of the operating environment, so on shock absorbers to absorb vibration and shock, insulated against cold, cooled where necessary, and suppressed to prevent interference. They maintain and service their artifact-sets in operation, replacing and repairing faulty or defective parts. And they adapt and modify components as the needs arise, to replace 'dodgy' parts, to improve software and to continually improve performance over time. All of which was, and is, valuable and highly skilled work—although, it does appear to be straightforward engineering, with little "systems" content (in the earlier sense of that term). We might respectfully call it "engineers' systems engineering."

At a more complex level, avionic ('aviation-electronics') and *navionic* ('naval avionics') systems are to be found in modern aircraft, ships, tanks, etc. These are suites of support "systems" for navigation, radar, communications, automatic flight control, smart instrument panels, mission management, resource management, defensive aids, etc.

As an integral part of Linesman, the RAF's Lightning (q.v.) had had one of the first fully integrated avionics systems, which was so interwoven that the RAF specially trained several engineer officers as so-called "Weapon Systems Diagnosticians"[1] to locate faults in the complex-but-capable avionics system. Not all avionics suites are so fully integrated today—they may be simply a set of relatively independent support facilities for pilot and crew, so: navigation aids, weather radar; autopilot; fuel management, defensive aids, etc., etc. So, less a system, more a set, collection, or configuration, with few interconnections between facilities, which come together at crew members as focal point.

Systems Engineering, beyond these specialist engineering disciplines, and without any descriptive, reductive prefix, is said to be still alive, although with a new and different face to that of 'Cold War Systems Engineering' (CWSE). But what is that face? Two leading examples follow, based solely on their on-line publicity material:

At **NASA,** "systems engineering" is defined as a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system:

1. A "system" is the combination of elements that function together to produce the capability required to meet a need..……
2. *Systems engineering* is the art and science of developing an operable system capable of meeting requirements within often opposed constraints.
3. *Systems engineering* is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, mechanism designers, power engineers, human factors engineers, and many more disciplines are evaluated and balanced, one against another, to produce a coherent whole that is not dominated by the perspective of a single discipline.

[1] I know: I was one…

4. *System Design* processes are interdependent, highly iterative and recursive processes resulting in a validated set of requirements and a design solution that satisfies a set of stakeholder expectations. There are four system design processes: developing stakeholder expectations; technical requirements; logical decompositions; and, design solutions.

NASA's definition and description appear to be of sophisticated 'engineering to order.' Their definition of 'system' appears to be of a complex artifact, with possible human interface. There is no mention of any "Systems Approach." There is little apparent room for the innovation and complexity management, that were the hallmark of CWSE. NASA's SE would not concern itself, apparently, with the creation of human activity systems: intelligence, command & control, management, organization, etc.

Since NASA has a track record for these capabilities, it must be presumed that they are achieved through other means. For instance, NASA's Dragonfly mission to Titan, Saturn's richly organic moon-world, is surely one of the most exciting, innovative ventures ever conceived to date! [See: https://www.nasa.gov/press-release/nasas-dragonfly-will-fly-around-titan-looking-for-origins-signs-of-life]

According to INCOSE, the international Council for Systems Engineering:

1. A "system" is an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not. Systems can be either physical or conceptual, or a combination of both.

2. Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods."

3. 'We use the terms "engineering" and "engineered" in their widest sense: "the action of working artfully to bring something about". "Engineered systems" may be composed of any or all of people, products, services, information, processes, and natural elements.'

INCOSE's definition of system omits 'whole,' (so does not invoke completeness), and seeks to describe 'emergence' without using the term, with which some engineers are 'uncomfortable.' Emergence may be defined as "properties, capabilities and behaviours of the whole that cannot be exclusively attributed to any of the parts." Aristotle characterized it as: "The Whole is greater than the Sum of the Parts."

Unlike many others, INCOSE's definition of Systems Engineering is "transdisciplinary," relates to "engineered systems," and uses "systems principles and concepts," unstated… There is, however, no mention of any *Systems Approach…" 'Transdisciplinary'* may be used to signify 'holistic and a unity of knowledge beyond disciplines…' presenting Systems Engineering as a meta-discipline. (See "Metasystems Methodology," Arthur D. Hall III, 1989.)

As with NASA, there appears to be little room for innovation and complexity management, the keystones of CWSE, so presumably:—

- no problem solving,
- no OA,
- no Conceptual Solution Systems and their tradeoffs,
- no CONOPS,
- no Systems Design Methodology, so presumably…
- no functional architectures,
- no systems dynamics modelling, so…
- …no functional design optimisation

While NASA has a track record evidencing their capabilities in these areas, INCOSE, being a council, does not, as they make nothing…

On the other hand, given INCOSE's recently updated definition of 'engineered systems,' there seem to be no restrictions on their potential to 'engineer' human activity systems, command & control systems, competitive businesses & organizations, social systems, self-organizing systems, integrated transport systems, autopoietic systems…

Summary & Conclusions…

The ancient Egyptians, particularly those of the 4th Dynasty, evidently understood how to create purposeful, complex and secure systems. They had an appreciation for emergence, with their ability to create numinous tombs and temples.

Khufu's Pyramid appears to have been a psychic projector of the king's *ka* or psyche. The architects were uncertain how to energise this projector. Would his *ka* rise up on clouds of smoke from fires? Would he attach a magical climbing rope to the Great Tethering Post—the then pole star, Thuban? In the end, they settled for the 'power of priestly prayers, offerings and lustrations,' to be offered every day for "millions of years."

The prayers may not have lasted, but the structure did. Even today, standing alone in the King's Chamber is an awesome, sobering, even spiritual, experience. Did the innovative Pyramid design actually work? Was the King's *ka* projected to the Netherworld, to negotiate for a successful Inundation? I would like to think so. However, as any innovator knows, you cannot be certain that an innovative new design will operate successfully and reliably.

The Total Weapon System Concept of the 1950s and 60s was a remarkable effort by a war-weakened nation in response to an existential threat. It was holistic design, in the true sense of that much-bandied, little understood concept:

> *Holistic:* characterised by the belief that the parts of something are intimately interconnected and *explicable only by reference to the whole*.

So, the whole was designed as one entity. Which resulted in the parts (radars, interceptors, control centres, etc.) containing active elements which made sense only in the context of the whole. Looked at alternatively, this meant that the parts on their own appeared to have superfluous features, i.e., not directly relevant to their individual operational functions.

Did Linesman actually work? Well, the Soviet Threat never transpired. Although Linesman was shrouded in secrecy throughout its extended development, (or perhaps *because* it was secret) it is possible that the Soviets got wind of this enormous defensive system, and suspected that it would neutralize their threat to the UK, changing the balance of power against them…

So, we don't know if Linesman would have worked in anger—the very knowledge of its existence may have sufficient: that was the Cold War—bluff and counter bluff. However, the radars, interceptors, AEWs, data links, etc., continued to function as parts of UK Air Defence for many years…even today, RAF fighters regularly intercept Russian heavy aircraft entering UK air space. The crews wave at each other. It all seems very friendly…

Would President Reagan's Strategic Defense Initiative have actually worked? Again, the Soviet Threat never materialized. *Would* it have worked? Possibly. But as any innovator knows, you could not be certain that an innovative new design, especially one as "far out" as Star Wars, would have operated successfully and reliably. If Star Wars was a magnificent bluff, it worked—magnificently.

And this notion of questionable credibility seems, in retrospect, to have dogged Cold War Systems Engineering. Innovation was the order of the day, of course, as the Threat kept morphing and switching. New counters were needed, old, unused counters discarded. Meanwhile the cost was mounting, and systems engineering became regarded as 'magic,' yes, but also as "gold plating" and ultimately unaffordable once the Cold War was over.

So, has the face of Systems Engineering changed over the years?

It is not unreasonable to deduce that the 'prior' Systems Engineering has been, in effect, partitioned into three parts:

A. The problem-solving, innovative, conceptual systems approach and functional, optimized systems design, resulting in a 'proven' matched set of requirements for a complete solution system; and…

B. The realization of those customers' requirements that could be physically engineered to create tangible artifacts, lately referred to as 'systems,'plus…

C. The operational lifetime of the engineered systems, their maintenance, continual updating, etc., and eventual replacement

Parts B & C only are presently referred to as systems engineering, so:

Yes, the face of systems engineering has changed.
And, along with that change of face,
the invaluable paradigm that was "system" has been changed too.

Does any of this matter? It may be that governments around the world believe that they can still call upon the power of Cold War Systems Engineering should they need it. After all, the name is the same. That would be a miscalculation: the original CWSE is no longer.

On the other hand, the world is beset by mounting concerns: global warming; overpopulation; global trading, anti-democratic social media; social unrest; medical and

data systems, pandemics; dwindling resources; mounting tension between East and West, Russia and China… Taken together or separately, these are issues and problems on a global scale that would be worthy of a regenerated Systems Engineering by, for and on behalf of, the UN, perhaps. Something greater and beyond that which was CWSE, with problem-solving, innovation, solution optimizing, proven capability, behavior and performance.

Let's face it—we need something! And now would not be too soon…