Systems Engineering, Past, Present and Future

or

Putting Systems back into Systems Engineering

INCOSE Keynote

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Systems Philosophy

- Back in the 30s, 40s and 50s…
- …problems evident with mechanistic and reductionist view, post Industrial Revolution
- Unable to accommodate "life."
  - Chemistry: "dead DNA identical with live DNA"
  - Physics: "entropy increases in a closed system"
    - Second Law of Thermodynamics
  - Life: "obvious example of order increasing"
  - Civilization: ditto
  - Organizations, industries and enterprises: ditto
- Stability in physics—low energy
- Stability in life, etc., above—***high*** energy

Systems Philosophy

- It is not that the Second Law is wrong
- It is because the Second Law applies only to closed systems
- Are there any closed systems in the real world?
- If there were, would we know of their existence?
- So, the idea of "open systems" emerged…

Systems Philosophy—Organismic Analogy

- Analogies were drawn between man-made systems and organisms…
- …the “Organismic Analogy”
- Not to say that enterprises, industries, civilizations, etc., were organisms
- More to say that, like organisms, they “behaved as a unified whole”
- Each had a life cycle, each exhibited growth, stability, and finally death - often sudden, collapsing death.

Systems Philosophy—Holism

- Besides the Organismic Analogy, two other tenets emerged
- Holism:
  - everything within a system is connected/related to—and affects—everything else. Mutual interdependence
  - Viewing, or even considering, parts on their own is irrational
- Systems and their problems have to be viewed as a whole

Systems Philosophy—Synthesis

- Synthesis: systems created by bringing other systems together in some special way
- Not valid to employ reductionism
- Why? Not feasible for a surgeon to dissect a patient into various organs, treat the organs, reassemble, and expect life
- Various parts cannot exist/survive/operate/behave/even be considered in mutual isolation
  - they depend for their very existence on interchanges with the other parts
  - implies that systems are/*have to be* active/dynamic

Systems Philosophy—Emergence

- The notion that, in behaving as a whole, a system may exhibit properties that are not exclusively attributable to any of its parts
  - E.g., self-awareness from the human brain
  - Perception of motion from film and TV
- Commonly referred to as: the whole is greater than than the sum of the parts
- More appropriate—the whole is *different* from the sum of the parts
- Caused by mutual interaction between the parts, each affecting the other—and the whole
- Central to the management of complexity

General Systems Theory

- 1954: Ludwig von Bertalanffy, Kenneth Boulding, Ralph Gerard, A. Rapoport
- GST postulated as a "science of wholeness"
- Embraced the Life Sciences as well as physics, chemistry, etc. Very mathematical
- Models from GST, and ideas of Open Systems and the Organismic Analogy greatly influenced the fledgling discipline of systems engineering

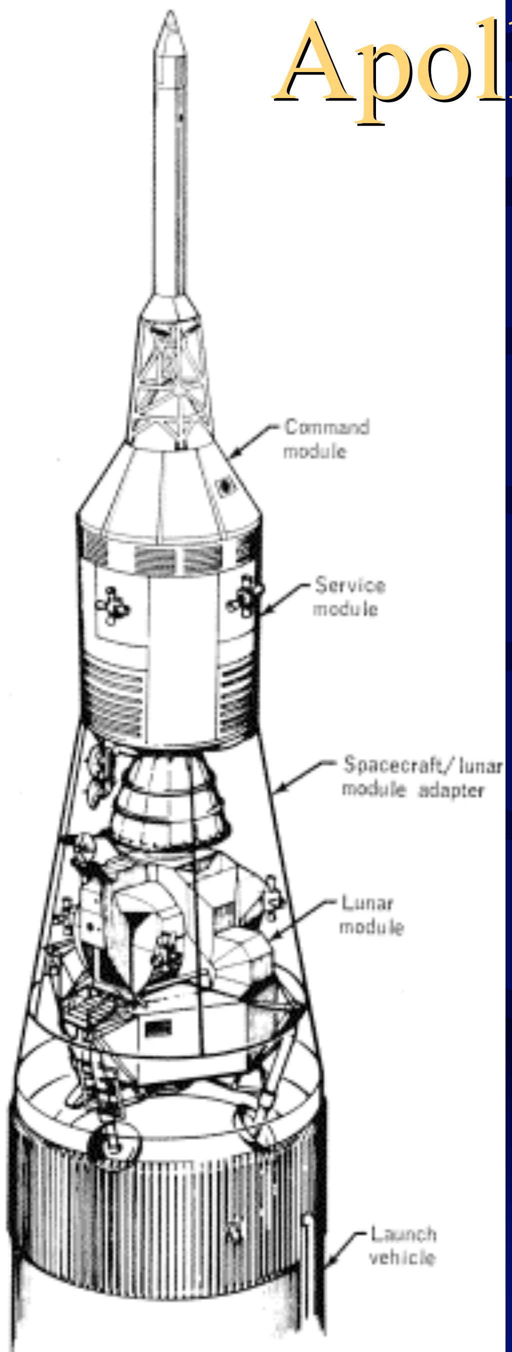
…and so to Apollo

- Astounding early NASA success
- Conception, design, development consistent with Open Systems and Organismic Analogy
- Spacecraft made from many interconnected, interlocking parts
- These parts could separate and operate independently, yet…
- Behave as a unified whole

Apollo

- The various parts had to exist within a fixed budget of overall weight/mass
  - Increase any one, others had to reduce
  - Shared gases, electrical power, lubricants, etc.
- Ditto for shape/form
- Design = 3-D jig-saw puzzle, with variable pieces
- Moreover, the function, fit, form and mass of the various parts had to be “fluid” during design
- Designers abstracted, working with the features of the various parts, not their technology…
  - Major reduction in perceived complexity

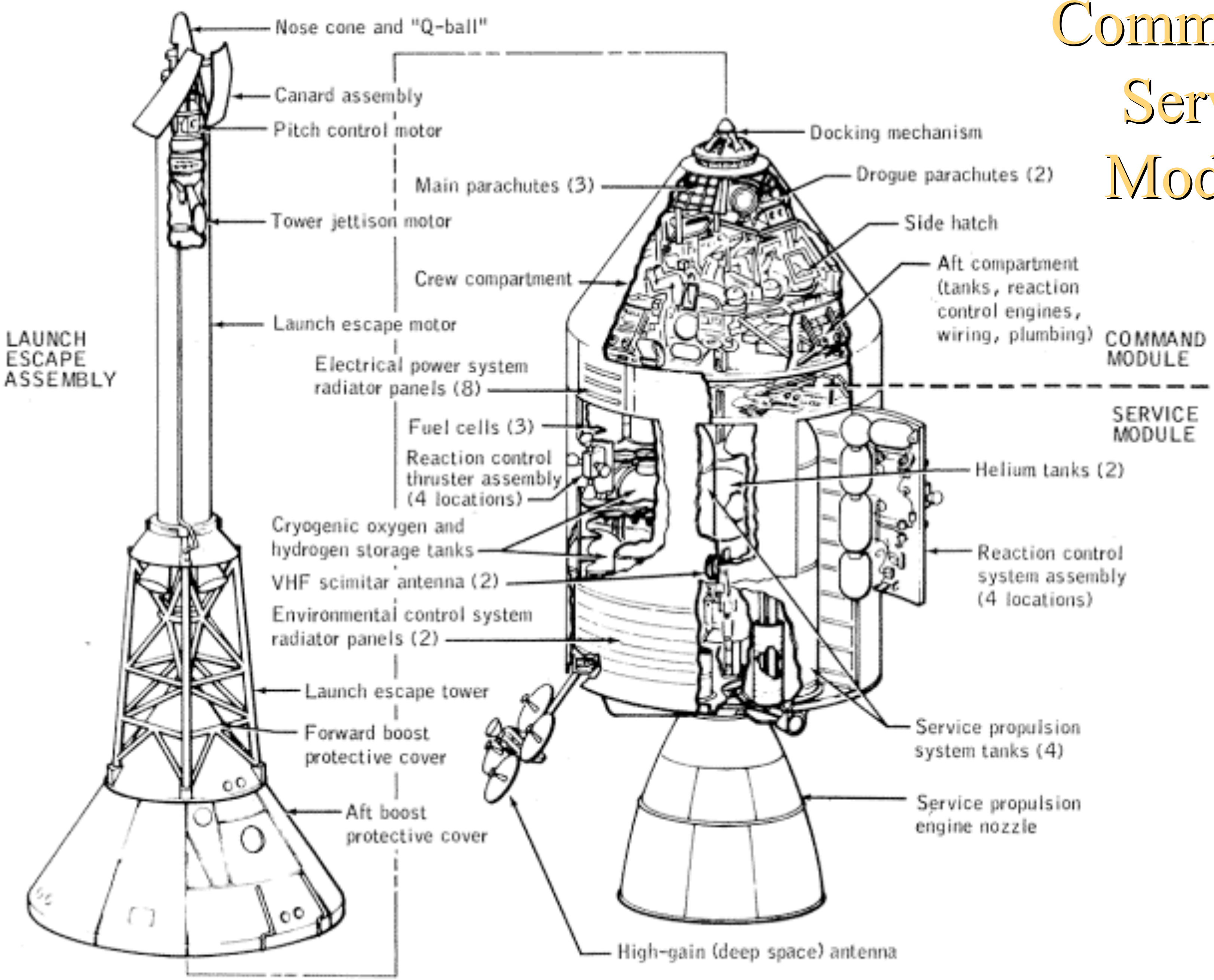
Apollo—Managing Complexity



APOLLO LAUNCH CONFIGURATION FOR LUNAR LANDING MISSION

- Apollo missions carried complex, mutually dependent, yet potentially independent, parts
  - Command module
    - Crew positions
      - Re-entry vehicle
  - Service module
    - main propulsion system
    - stowage for most consumable supplies.
  - Lunar module
    - Descend, roam, return
    - Modularised Equipment Stowage Assembly (TV equipment, lunar sample containers, and portable life support systems), the Lunar Roving Vehicle (LRV), and the Apollo Lunar Surface Experiment Package (ALSEP)
  - Saturn V launch vehicle
- Total complexity managed in 5 parts

Command & Service Modules



APOLLO COMMAND AND SERVICE MODULES
AND LAUNCH ESCAPE SYSTEM

Concept of Operations

- The whole design was tested using step-by-step runs-through of “how things would work”
  - When things went right, *and* when they went wrong
- Result was a Concept of Operations (CONOPS)
- Competing CONOPS progressively eliminated to leave only one
  - The preferred CONOPS - identified the preferred design
  - The design ***realized*** the CONOPS

Systems Engineering?

- Early NASA success set the style and pattern for modern systems engineering
- Clear Mission→Defined Goal →Concept of Operations →System functions/ properties/capabilities/behaviours…
- Subsystems → work with each other → contribute to CONOPS →Mission →Goal

Systems Engineering

- Systems engineering was/is about synthesising a purposeful system from subsystems that are designed and organized to:

A) Function and interoperate

B) Fit each other *and* into the whole

C) Contribute optimally to mission

- too much breaks the budget,
- too little fails to achieve

D) Support CONOPS effectively

- manage risks, neutralise threats

E) Achieve goal

How it works!

- The parts adapt to, co-operate with each other
- … to fit within, ***and*** contribute optimally to, overall system requirement, goal and purpose
- Identical principles characterize systems engineering for:
- …technology systems
- …human activity systems
- …business and enterprises
- …socio-technical systems
- …etc., etc., etc.

Contemporary Notions

- So, where are *systems* in today's systems engineering?
- To some, systems engineering = engineering of systems = applied technology
- To some, systems engineering = doing engineering better
- But–both these notions emphasise engineering, ***de***-emphasise "systems"
- "Systems" make systems engineering unique—**not** engineering
- Potential to forget what NASA learned, and what has been tried and tested many times since

SoS

- Instead of a system comprised of subsystems, we now have "System of Systems" (SoS).
- Not yet clear what SoS really *means*
- If SoS ≅ bottom-up integration, then recipe for failure
  - Bottom-up integration blamed for major disasters (Arthur D Hall III)
- If SoS ≅ piecemeal integration then prepare for poor performance (Gwilym Jenkins)
  - …and Counter-Intuitive Behaviour (Jay Forrester)

SoS

- Of course, you could always tackle a SoS project the systems engineering way…!
  - Identify an overarching Mission and Purpose
  - Establish an overarching CONOPS
  - Determine an overall architecture
  - Adapt/adjust the subsystems to optimize the properties and behaviour of the whole
    - Maximize cost effectiveness, efficiency, quality of service, etc.
- But then, would it be SoS? Or…
- …would it be systems engineering?

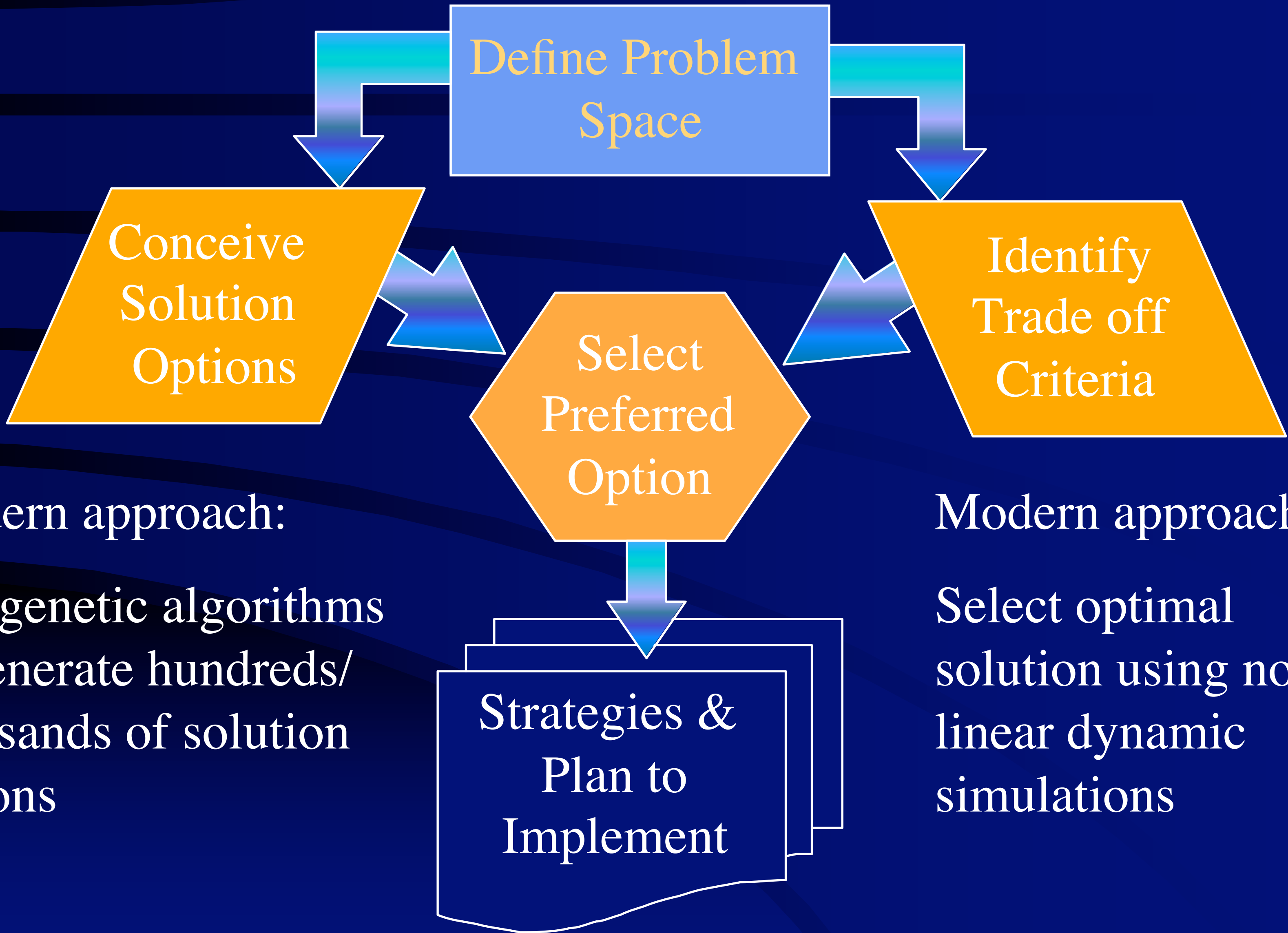
Systems Engineering ≠ Engineering

- Systems engineering can be applied to all sorts of issues—as well as to technology
- Conceive and develop an enterprise? SE
- Improve defence procurement? SE
- Sort out the NHS? SE
- Relieve famine and disaster? SE
- …but if, and *only* if…
- Systems engineering ≠ engineering

Meanwhile…

- … systems engineering is being “sold” as the “engineering of systems”
- …but heck, what’s in a name?
- Well, everything, in this case. SE is philosophically divergent from Engineering
- If a new generation of systems engineers thinks that it’s “just engineering,” we may not develop systems engineering, so much as lose it altogether…

Systems Engineering Paradigm



Modern approach:

Use genetic algorithms to generate hundreds/ thousands of solution options

Modern approach:

Select optimal solution using non-linear dynamic simulations

Apples & Oranges

Engineering	*Systems Engineering*
Reductionist	Synthetic, organismic, holistic…
Closed	Open
Introspective, Isolated	Cooperative, Synergistic
Looks into things to gain knowledge	Looks out from things to gain understanding
Creates complexity	Manages complexity
Technology driven	Process and Goal driven
Linear-predictive	Non-linear dynamic

…and SE’s Future?

- Systems engineering will address many different kinds of systems:
  - Lean Volume Supply, ecological, economic
  - Information-Decision-Action Systems
    - Emergency services, C3I, ATM, etc.
  - Health, social, procurement, logistic systems, etc.
  - Non-linear systems - the new frontier in design
    - Network-centric, biological, nanotechnology…
- Systems engineering will be seen as a major contributor to the management of complexity, the control of disorder, and…
- …the achiever of the otherwise impossible!

INCOSE Future?

Socio-Economic Systems Engineering	Legal and political influences. Government Regulation and Control.
Industry System Engineering	National Wealth Creation, the Nation's Engine. (Japan operates at this level)
Business System Engineering	Industrial Wealth Creation. Many Businesses make an industry
Project System Engineering	Corporate Wealth Creation. (West operates at this level.)
Product/sub-system Engineering	Artefacts. To some the only "real" systems engineering. Many Products (can) make a system

The 5-layer systems engineering framework model