SYSTEM ENGINEERING
UNIT-II

by

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System Building Blocks and Interfaces

System Building Blocks and Interfaces

- The knowledge attained by a system engineer should be sufficient to consider factors such as
  - program risks
  - Technological performance limits
  - Interfacing requirements
  - To make trade-off analyses among design alternatives
- It is possible to provide an important insight into the structural hierarchy of modern systems.
- Such an examination reveals the identifiable types of the building blocks.
- Represent the lower working level of technical understanding that a system engineer should have.
- At this level
  - Technical trade-offs relating to system capabilities must be worked out.
  - Interface conflicts must be resolved to achieve a balanced system.

References

- Alexander Kossiakoff, William N Sweet, “System Engineering Principles and Practice”, Wiley India, Chapter-3(Page number 41).

Hierarchy of a complex system

Concept of hierarchic systems

- Hierarchic systems are common in both natural and man-made systems
  - Physics: atom → nucleus → neutron, proton, electron
  - Organization: Director → Manager → General staff
  - Book: Chapter → Section → Paragraph
- Model of Complex System:
  - Consists of a number of major interacting elements
  - Majority of systems are developed by an integrated acquisition process

System Levels

- ***System Level structure:***

System → Subsystems → Components → Subcomponents → Parts

- 1. SYSTEM.
  - should possess the properties of an engineered system
  - should perform a significant useful operation with the help of human operators and standard infrastructures (example power grid, fuelling station and communication lines)
  - So according to the above conditions, passenger aircraft or a personal computer (with input device, output device, CPU, mouse and keyboard) can fit the definition.

System Levels

- 2. SUBSYSTEM
  - First subordinate level in the system hierarchy
  - Major portion of the system that performs the closely related subset of the overall system functions.
  - May be complex in itself
  - May have properties of the system except being able to perform useful function independently without other subsystems.
  - Involve several technical disciplines.

System Levels

- 3. COMPONENT
  - Refers to middle level of system elements(according to Kossiakoff)
  - Correspond to configuration items in Government system acquisition notations.(example requirement document)

- 4. SUBCOMPONENT
  - The level below the component building block
  - Perform elementary functions
  - are composed of several parts

System levels

- 5. PARTS
  - Lowest level
  - Perform no significant function except in combination with other parts.
  - Great majority comes in standard sizes and types
  - Can be bought commercially.

Refer to Table in the next slide to see the hierarchy of various systems .

System Design Hierarchy

Systems	Communication systems	Information systems	Material processing system	Aerospace system
Sub-systems	Signal networks	Databases	Material preparation	Engines
Components	Signal receivers	Data displays	Power transfer	Thrust generators
Sub-components	Signal amplifiers	Cathode ray tubes	Gear trains	Rocket nozzles
Parts	Transformer	LED	Gears	Seals

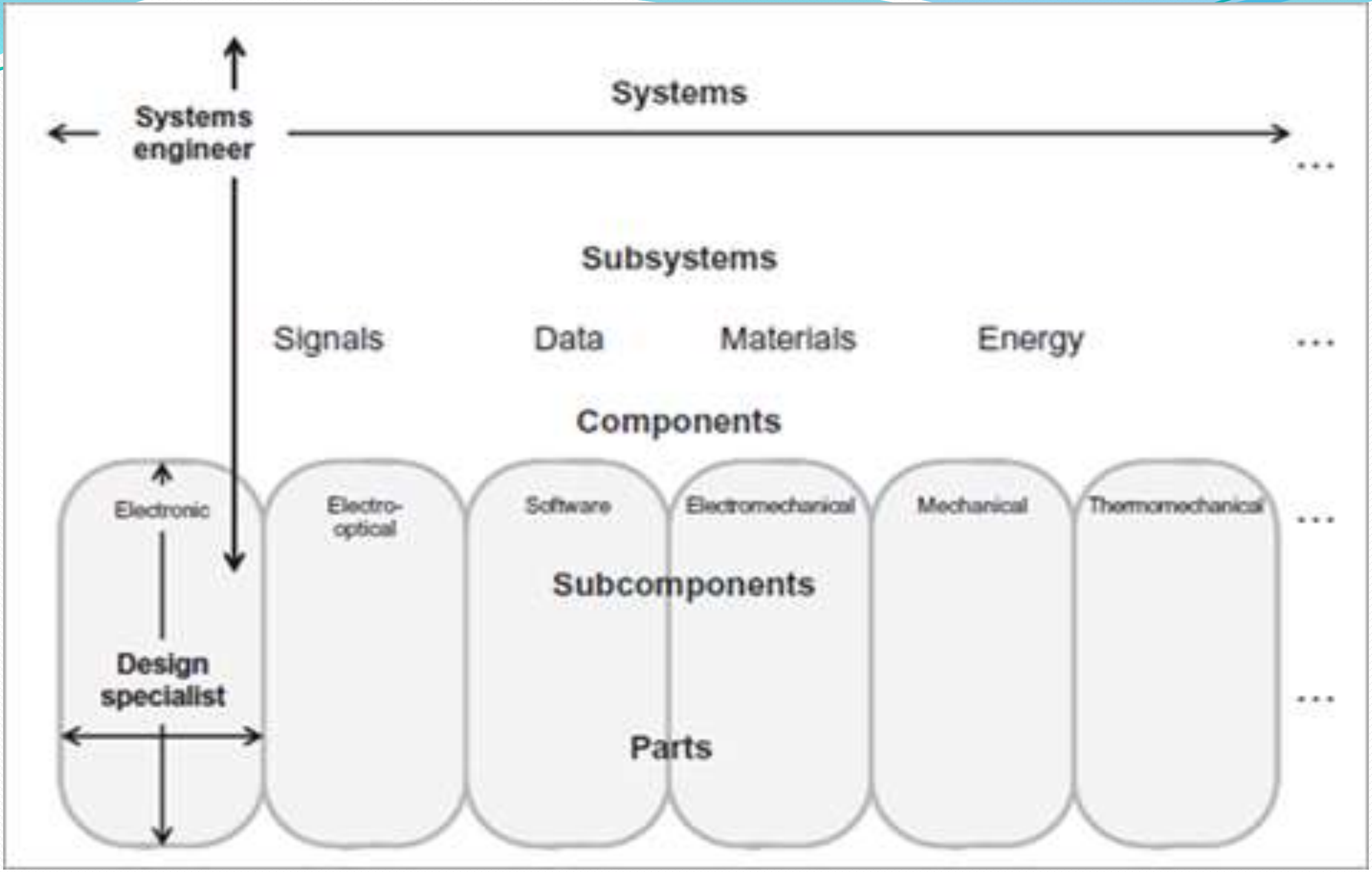
Domains of System engineer versus Domain of design specialist

- • System Engineer's Domain:
  - Extends down through the component level
  - Is as detailed as a system engineer usually needs to go
  - Extends across several system categories

- • Design Specialist's Domain
  - Extends from the part level up through the component level
  - Overlaps the domain of the systems engineers at component level
  - Is usually limited to a single technology/discipline

Domains of system engineer and design specialists

- At this “overlap” area, the system engineer and design specialist
  - Must communicate effectively
  - Identify and discuss technical problems
  - Negotiate workable solutions that will not put the system design process into risk.
  - Make sure that the capabilities of the system as a whole should not be at risk.



Knowledge domains of systems engineer and design specialists

References

- Alexander Kossiakoff, William N Sweet, “System Engineering Principles and Practice”, Wiley India, Chapter-3 (Page numbers 42-45).

System building blocks

Building blocks

- **Building Blocks –The Concept**
  - A library of commonly occurring system elements
  - A means for classifying system constituents according to:
    - functional characteristics
    - physical characteristics
  - A useful tool for modeling system architecture and its synthesis
  - Useful for visualizing potential architectures of system concepts

Functional Building blocks: Functional elements

- Three basic entities on which system operates
  - ***Information:*** Content of all knowledge and communication
  - ***Material:*** the substance of all physical objects
  - ***Energy:*** energizes the operation and movement of all the active system components.
- So we have four **System functional elements**
  - ***Signal elements:*** sense and communicate information
  - ***Data elements:*** interpret, organize, and manipulate information
  - ***Material elements:*** provide structure and transformation of materials
  - ***Energy elements:*** provide energy and motive power

Functional building blocks: functional elements

- **Criteria** used to ensure that each element is neither very simple nor extremely complex
  - ***Significance:*** each functional element must perform a distinct and significant function.
  - ***Singularity:*** each functional element should be largely within the scope of a single engineering discipline.
  - ***Commonality:*** the function performed by each element can be found in a wide variety of system types.

Signal Functional Elements

Functional Element	*Physical Examples*
Input signal	TV camera
Transmit signal	Radio transmitter
Transduce signal	Antenna
Receive signal	Radio receiver
Process signal	Image processor
Output signal	TV display, speaker

Data Functional Elements

Functional element	*Physical Examples*
Input data	Keyboard
Process data	CPU
Control system	Windows, UNIX
Control Processing	Word Processor, analysis program
Store data	Magnetic disk
Output data	Printer, display

Material Functional Elements

Functional element	*Physical Examples*
Support material	Airframe, auto body
Store material	Container, enclosure
React material	Autoclave, smelter
Form material	Milling machine, foundry
Join material	Welding, riveting
Control position	Auto tool feed, power steering

Energy Functional Elements

Functional element	*Physical Examples*
Generate thrust	Rocket, turbojet
Generate torque	Gas turbine
Generate electricity	Power plant, solar cells
Control temperature	Furnace, refrigerator
Control motion	Transmission, power brakes

System Functional Elements

TABLE 2-1 System Functional Elements

Class Function	Element Function	Application
Signal—generate, transmit, distribute, and receive signals used in passive or active sensing and in communications	Input signal	TV camera
	Transmit signal	FM radio transmitter
	Transduce signal	Radar antenna
	Receive signal	Radio receiver
	Process signal	Image processor
	Output signal	TV tube
Data—analyze, interpret, organize, query, and/or convert information into forms desired by the user or other systems	Input data	Keyboard
	Process data	Computer CPU
	Control system	Operating system
	Control processing	Word processor
	Store data	Magnetic disk
	Output data	Printer
Material—provide system structural support or enclosure, or transform the shape, composition, or location of material substances	Support material	Airframe
	Store material	Shipping container
	React material	Autoclave
	Form material	Milling machine
	Join material	Welding machine
	Control position	Servo actuator
Energy—provide energy or propulsive power to the system	Generate thrust	Turbojet engine
	Generate torque	Reciprocating engine
	Generate electricity	Solar cell array
	Control temperature	Refrigerator
	Control motion	Auto transmission

Physical building blocks: Components

- They are the physical form of the functional elements consisting of hardware and software.
- Have the same characteristics of significance, singularity and commonality.
- Referred to as ***component elements*** or simply ***components***
- Some **Components**
  - Electronic, electro-optical, electro-mechanical, mechanical, thermo-mechanical, software.

Physical Building blocks

Category	Component Examples
Electronic	Receiver, transmitter
Electro-optic	Optical sensing, fiber optics
Electro-mechanical	Electric generator, data storage, transducer
Mechanical	Container, material processor, material reactor
Thermo-mechanical	Jet & rotary engine, Heating & AC
Software, firmware	Operating system, applications

Component design elements

TABLE 3.3. Component Design Elements

Category	Component	Functional element(s)
Electronic	Receiver	Receive signal
	Transmitter	Transmit signal
	Data processor	Process data
	Signal processor	Process signal
	Communications processors	Process signal/data
	Special electronic equipment	Various
Electro-optical	Optical sensing device	Input signal
	Optical storage device	Store data
	Display device	Output signal/data
	High-energy optics device	Form material
	Optical power generator	Generate electricity
Electromechanical	Inertial instrument	Input data
	Electric generator	Generate electricity
	Data storage device	Store data
	Transducer	Transduce signal
	Data input/output device	Input/output data
Mechanical	Framework	Support material
	Container	Store material
	Material processing machine	Form/join material
	Material reactor	React material
	Power transfer device	Control motion
Thermomechanical	Rotary engine	Generate torque
	Jet engine	Generate thrust
	Heating unit	Control temperature
	Cooling unit	Control temperature
	Special energy source	Generate electricity
Software	Operating system	Control system
	Application	Control processing
	Support software	Control processing
	Firmware	Control system

Applications of System Building blocks

- Identifying actions capable of achieving operational outcomes
- Facilitating functional partitioning
- Identifying subsystems and component interfaces.
- Visualizing the physical architecture of the system
- Suggesting types of component required for a particular technology
- Helping software engineers to gain hardware knowledge.

References

- Alexander Kossiakoff, William N Sweet, “System Engineering Principles and Practice”, Wiley India, Chapter-3 (Page numbers 45-50).

The System Environment

System Boundaries

- Its not easy to identify what is part of the system and what is part of the environment
- So we have certain ***Determining criteria***
  - ***Developmental control:***
    - does the system developer have control over the entity's development?
    - Does developer has a role in defining the requirements or not?
    - Is funding a part of developer's budget or some other organization?
  - ***Operational control:***
    - Will the entity be under the operational control of the organization that controls the system
    - will the tasks and missions performed by the entity be directed by the owner of the system?
    - Will another organization have operational control at times?

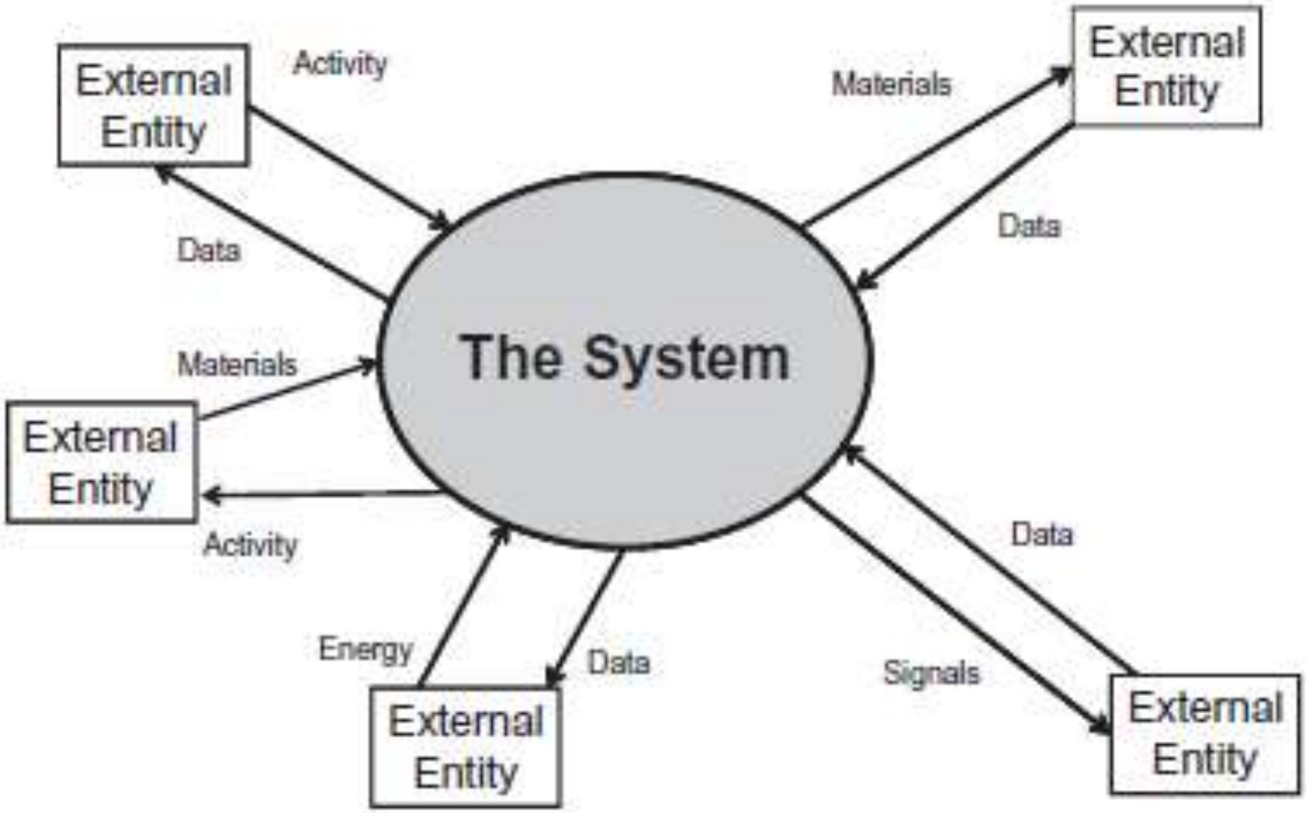
System Boundaries

- ***Functional allocation:***
  - Is the system engineer "allowed" to allocate functions to the entity in the functional definition of the system
- ***Unity of purpose:***
  - is the entity dedicated to the system's success
  - Once fielded, can the entity be removed without any objection by some other entity?
- Human users and operators are often treated as external entities
  - Focus is on the operator interface
  - Still important in a functional aspect
- Example
  - Network of roads and service stations → automobile

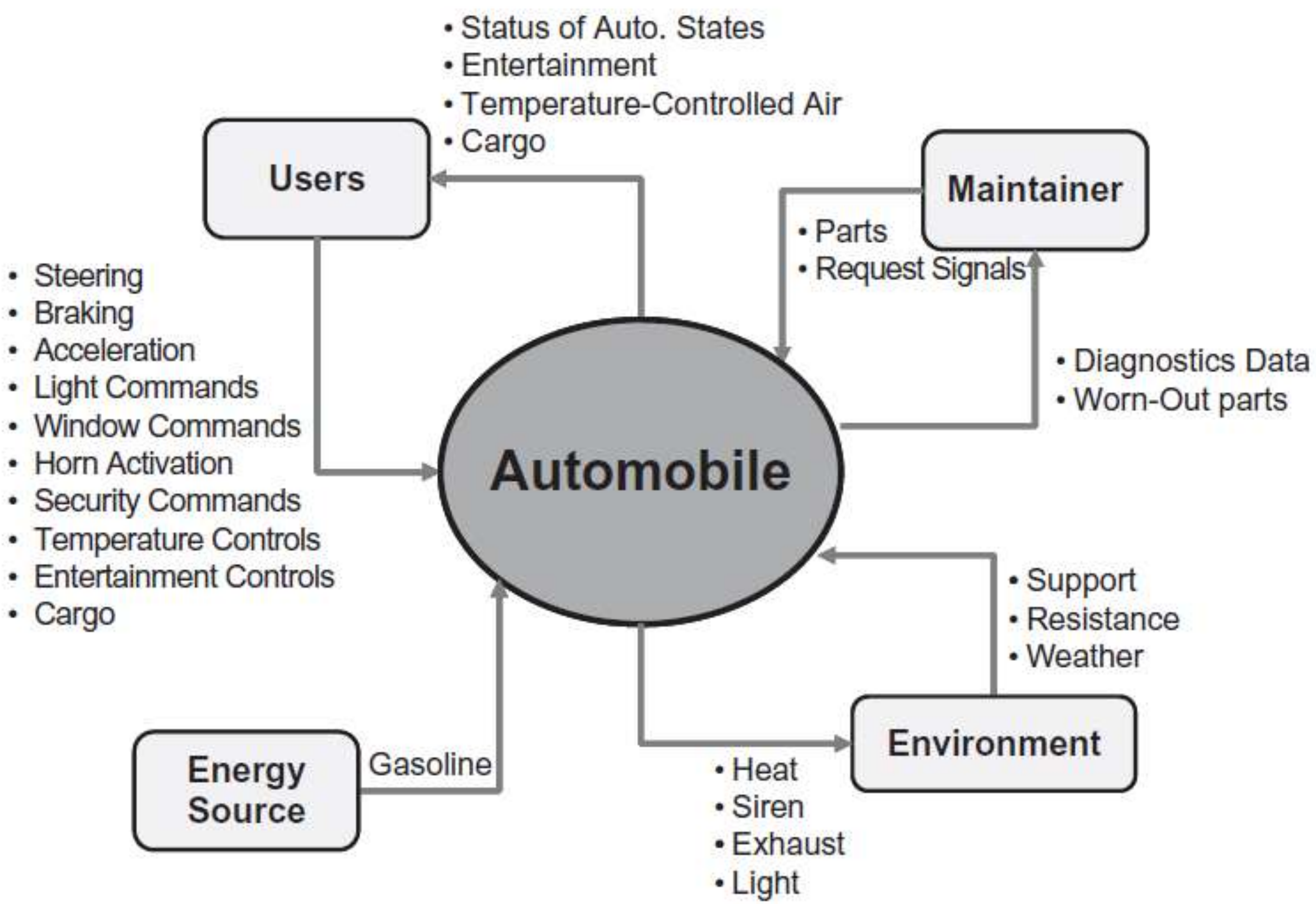
Context Diagram

- Display the external entities and their interactions with the system
- ***External entities***: sources for inputs into the system and destinations of outputs from the system
- ***Interactions***: represented by arrows, the direction or flow of a particular interaction
  - Application or company-specific labels can be used
  - **Five categories:** *data, signals, materials, energy* and *activities*
- The ***system***: represented by an oval, circle or a rectangle in the center with only the name of the system within it.

Context Diagram



Automobile: Context Diagram



Types of environmental interactions

- ***Inputs and outputs***
  - The primary purpose of most systems is to operate on external stimuli and/or materials in such a manner as to process these inputs in a useful way
- ***System operators***
  - Emphasize on human-machine interface
  - Complex to define and test
- ***Operational maintenance***
  - Affects system readiness and operational reliability
  - Provides access for monitoring, testing and repair requirements

Types of environmental interactions

- ***Threats***
  - Either natural (e.g., salt water) or man-made (e.g., thief)
- ***Support systems***
  - Part of the infra-structure on which the system depends for carrying out its mission
- ***System housing***
  - provides protection
- ***Shipping and handling environment***
  - Transportation from the manufacturing site to the operating site

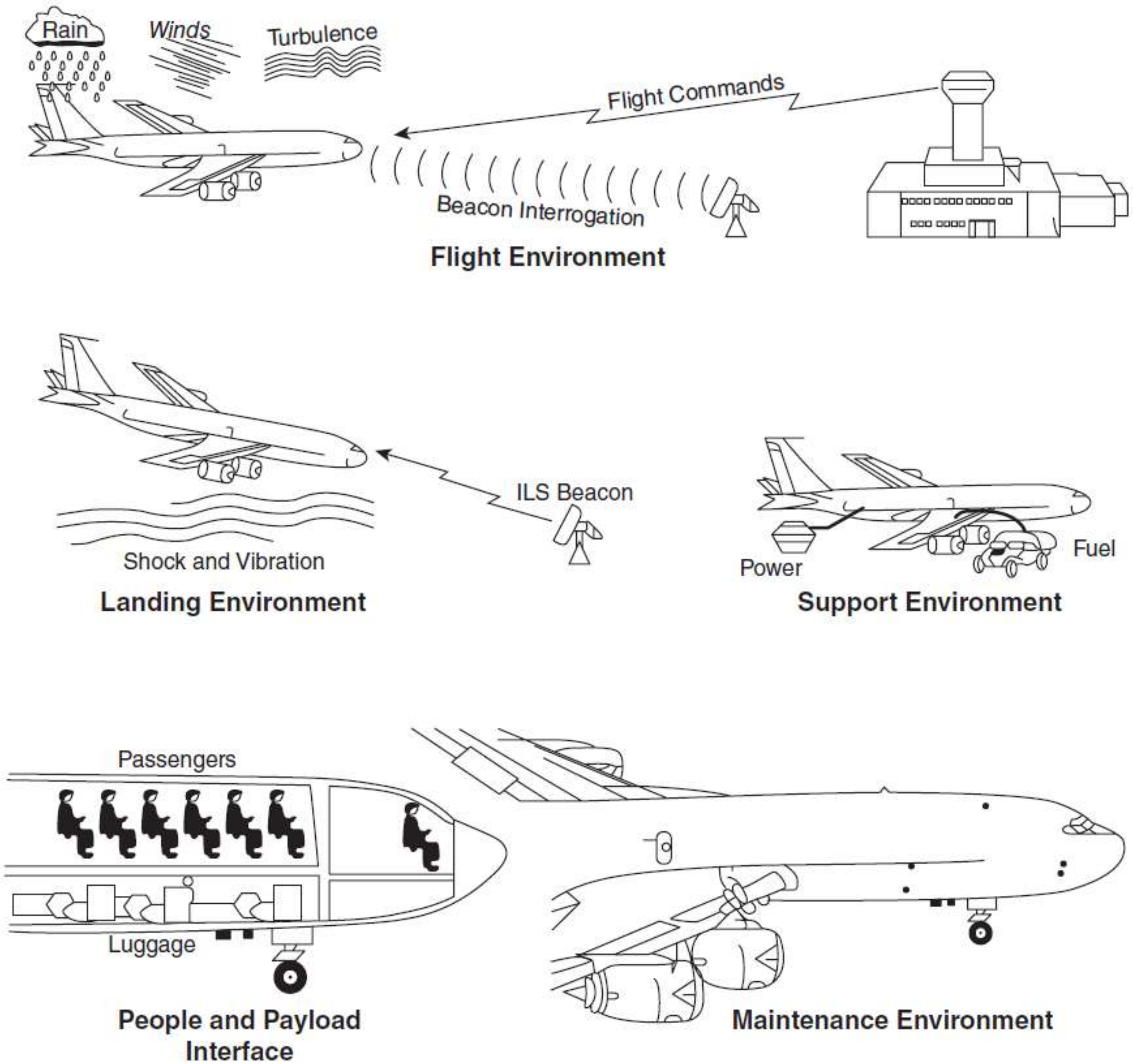


Figure 3.4. Environments of a passenger airliner. ILS, instrument landing system.

References

- Alexander Kossiakoff, William N Sweet, “System Engineering Principles and Practice”, Wiley India, Chapter-3 (Page numbers 51-58).

Interfaces and interactions

Interfaces: External and Internal

- There are different ways in which the system interacts with its environment including other systems.
- All interactions occur at various boundaries of a system
- Such boundaries are called system's ***external interfaces***
- Proper interface control is necessary for successful system operation
- Management of interfaces involve:
  - Identification and description of interfaces as system concept definition
  - Coordination and control of system integrity throughout the system development lifecycle.
- Inside the system, the boundaries between individual components form the ***internal interfaces***

Interactions

- Take place through the ***interface*** connecting the two individual elements
- The interface between the car driver's hands and the steering wheel
  - Enables the driver to guide(interact with the car) by transmitting the force that turns the steering
  - The above activity in turn turns the car's wheels
- The interface between the car's wheel and the road result in the movement of the wheel by transmitting driving traction to the road

Interface elements

- ***Connectors*** which facilitate the transmission of electricity, fluid, force etc. between the components.
- ***Isolators*** which inhibit such interactions
- ***Converters*** which alter the from of interaction medium
  - These interface are in form of components or subcomponents which can be called as interface elements.
- Though interfaces are relatively simple, a large fraction of system failures occur at interfaces only.

Examples of interface elements

Type	Electrical	Mechanical	Hydraulic	Human-machine
Interaction medium	Current	Force	Fluid	Information
Connectors	Cable switch	Joint coupling	Pipe valve	Display control panel
Isolators	RF shield insulator	Shock mount bearing	Seal	Cover window
Converter	Antenna A/D converter	Gear train piston	Reducing valve pump	Keyboard

References

- Alexander Kossiakoff, William N Sweet, “System Engineering Principles and Practice”, Wiley India, Chapter-3 (Page numbers 58-60).

Complexity in modern systems

System of Systems (SoS)

- The *U.S. Department of Defense (DoD)* defines *SoS* as
  - A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities.
- Categories
  - ***Virtual***
    - Lack a central management authority and central agreed-upon purpose
  - ***Collaborative***
    - Components interact more or less voluntarily to fulfill agreed-upon purposes
    - standards are adopted but there is no central authority to enforce them
    - The central players decide whether to provide pr deny service thereby providing some means of enforcement and maintaining standards.

System of systems (SoS)

- ***Acknowledged***
  - Have recognized objectives, a designated manager and resources
  - Constituent systems retain their independent ownership, funding, development and sustainment approaches

- ***Directed***
  - Integrated SoS is built and managed to fulfill specific purposes
  - Centrally managed during long term operation to fulfill specific purposes
  - Can fulfill new purposes if the owner adds them.

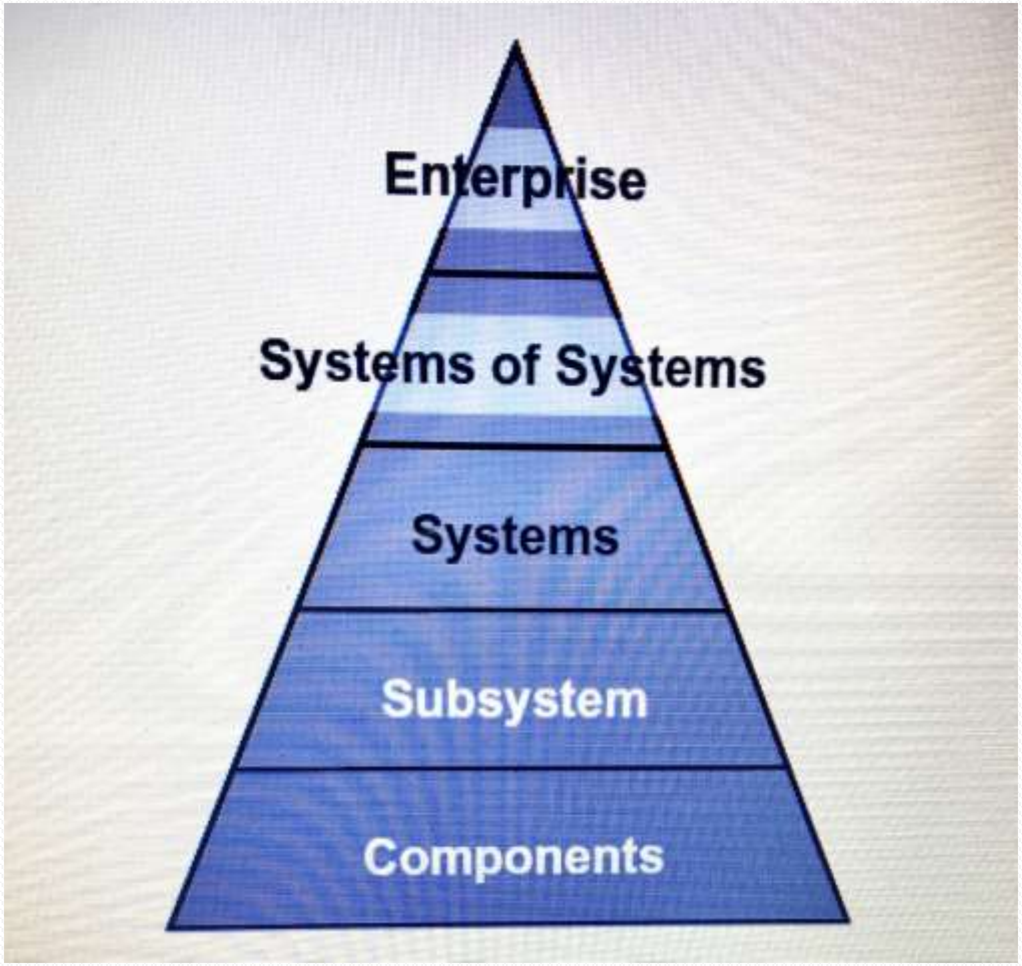
System of Systems (SoS)

- Characteristics
  - Operational independence of the individual system
  - Managerial independence of the individual system
  - Geographic distribution
  - Emergent behavior (not necessarily related to the component system)
  - Evolutionary development
  - Self-organization
  - Adaptations
- Examples
  - Airport, Air traffic control, satellites, radar and aircraft.

Enterprise systems engineering

- Consists of multiple SoSs
- Definition
  - anything that consists of people, processes, technology, systems, and other resources across organizations and locations interacting with each other and their environment to achieve a common mission or goal
- Examples
  - Government agencies and departments
  - Cities and countries

Enterprise systems engineering



Pyramid of system hierarchy

Enterprise systems engineering

- The enterprise typically includes the following components that must be integrated together
  - Business strategy and strategic planning
  - Business processes
  - Enterprise services
  - Governance
  - Technical processes
  - People management and interactions
  - Knowledge management
  - Informational technology infrastructure and investment
  - Facility and equipment management
  - Supplies management
  - Data and information management

References

- Alexander Kossiakoff, William N Sweet, “System Engineering Principles and Practice”, Wiley India, Chapter-3(Page numbers 60-64).

THANK YOU