Advanced Systems Engineering and Human Factors Engineering for Unmanned Aerial Systems

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Global Technica

- Systems Engineering
- Software Engineering
- Human Factors
- Industrial Engineering
- Advanced Visualization
- Usability Testing
- Analysis of Complex Systems

- Software Architecture
- Software Engineering
- Modeling and Simulation
- User Interface Design
- Cognitive Modeling
- Virtual Environments
- Mobile Applications

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Outline

- Systems Engineering Presentation
- Human Factors Engineering Presentation

What is a System?

- A purposeful collection of inter-related components working together towards some common objective
- A system may include software, mechanical, electrical and electronic hardware, and be operated by people
- System components are dependent on other system components
- The properties and behavior of system components are inextricably inter-mingled components

What is a System?

A system is a set of interrelated components which interact with one another in an organized fashion toward a common purpose

System components may be quite diver

- Persons and Organizations
- Software and Data
- Equipment and Hardware
- Facilities and Materials
- Services and Techniques

What is Systems Engineering?

- Designing, implementing, deploying and operating systems which include hardware, software, and people

What is Systems Engineering?

Definition of Systems Engineering (NASA SE Handbook)

Systems Engineering is a robust approach to the design, creation, and operation of systems

Systems Engineering consists of:

- Identification and quantification of system goals
- Creation of alternative system design concepts
- Performance of design trades
- Selection and implementation of the best design
  - balanced and robust
- Verification that the design is actually built and properly integrated in accordance with specifications
- Assessment of how well the system meets the goals

Systems Engineering and Composites

- Composites are newer and less understood than metallic materials
- NASA Standard 5001A (Rev A)
  - NASA factors of safety 1.4 for metals
  - Factor of safety 2.0 for composites
  - As a result composites are generally overbuilt and do not allow engineers to realize lighter structures
- If it does not break and the structure is lighter then then everybody wins
  - Analysis software allows engineers to realize the lighter total weight of composites by not overbuilding
  - www.firehole.com
- The properties of the materials can drive the requirements and certainly drive the design
  - Metallic mesh embedded in the fuselage for electrical grounding and lighting strike protection

- Focus of Systems Engineering
  - From Original Need
  - To Final Product
    - The Whole System
    - The Full System Life Cycle

- Focus of Component Engineering
  - On Detailed Design
  - And Implementation

Need

- What needs are we trying to fill?
- What is wrong with the current situation?
- Is the need clearly articulated?

Operations Concept

- Who are the intended users?
- How will they use our products?
- How is this different from the present?

Functional Requirements

- What specific capability will we provide?
- To what level of detail?
- Are element interfaces well defined?

System Architecture

- What is the overall plan of attack?
- What elements make up the overall approach?
- Are these complete, logical, and consistent?

Allocated Requirements

- Which elements address which requirements?
- Is the allocation appropriate?
- Are there any unnecessary requirements?

Detailed Design

- Are the details correct?
- Do they meet the requirements?
- Are the interfaces satisfied?

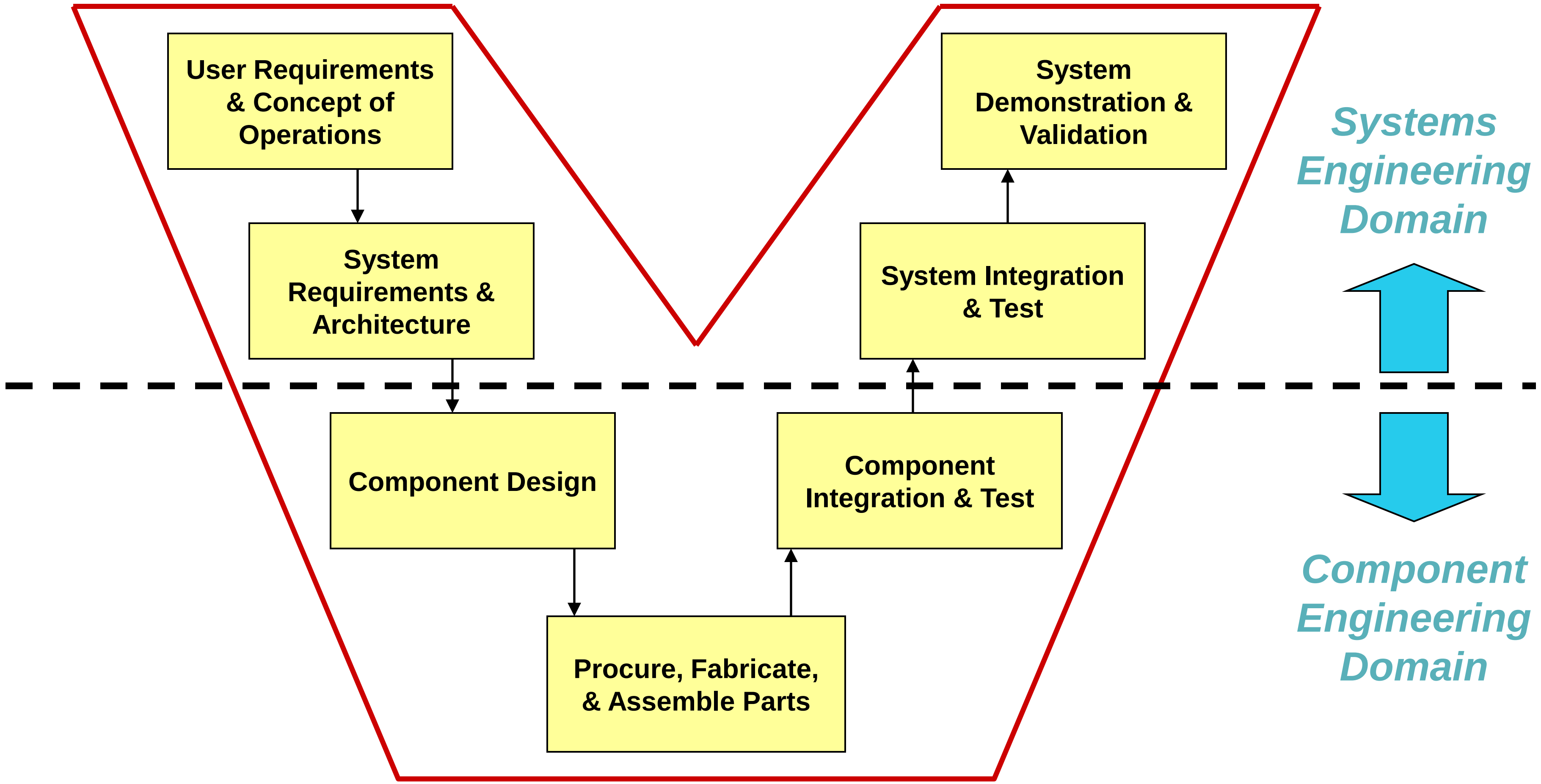
Implementation

- Will the solution be satisfactory in terms of cost and schedule?
- Can we reuse existing pieces?

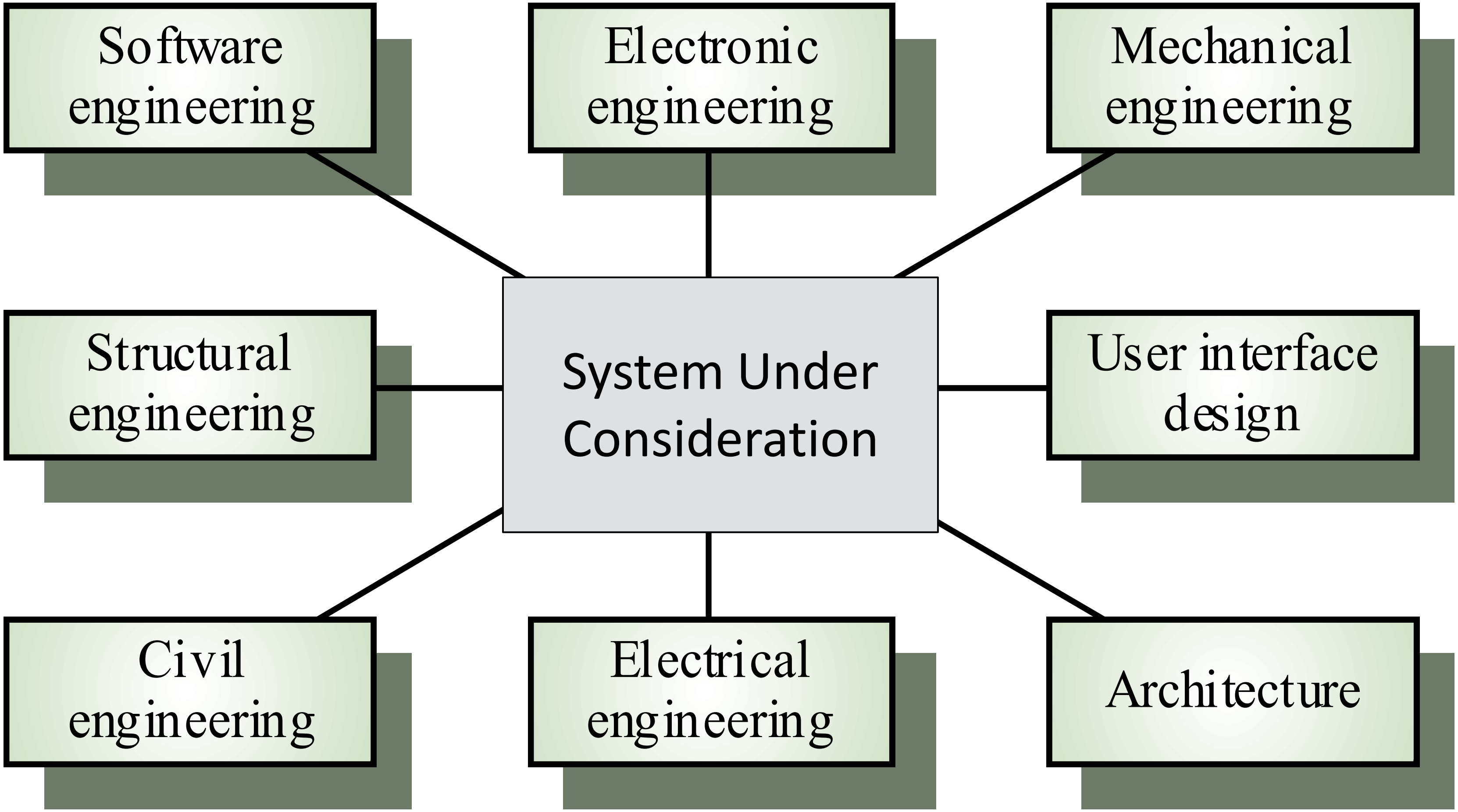
Test & Verification

- What is our evidence of success?
- Will the customer be happy?
- Will the users' needs be met?

The Systems Engineering "V"



Interdisciplinary Involvement

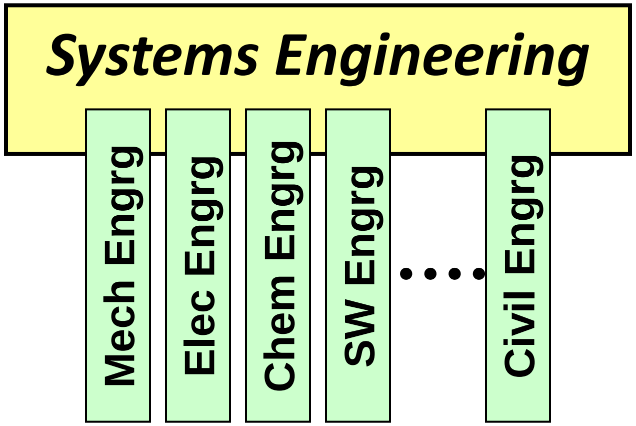


Role of Systems Engineering in Product Development

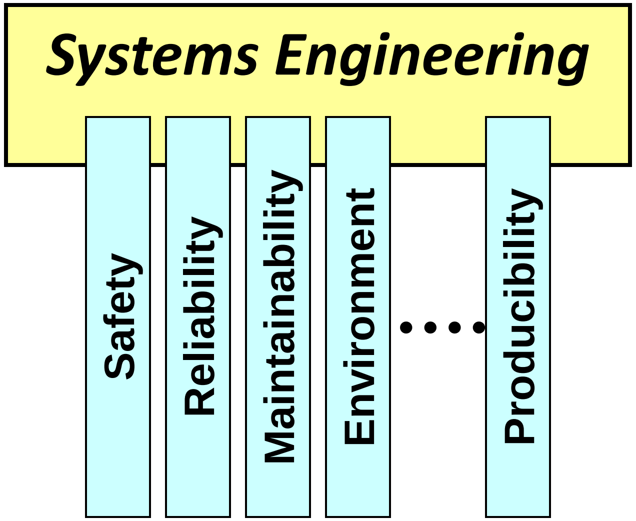
Integrates Technical Effort Across the Development Project

- Functional Disciplines
- Technology Domains
- Specialty Concerns

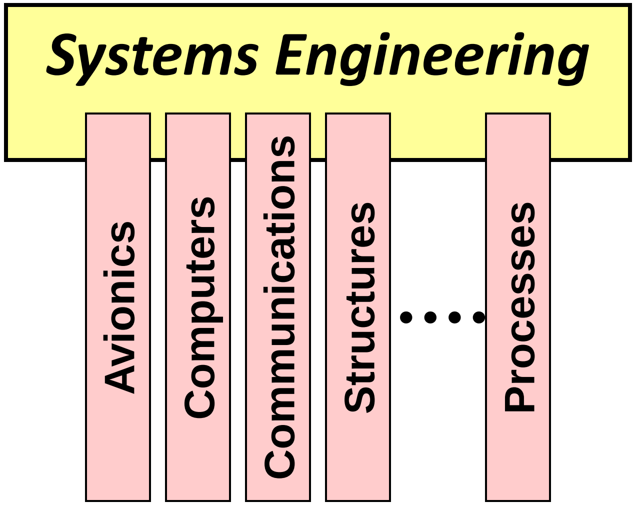
Technology Domains



Functional Disciplines



Specialty Concerns



Building Blocks of Systems Engineering

- Math & Physical Sciences
  - Qualitative modeling
  - Quantitative modeling
  - Physical modeling
  - Theory of Constraints
  - Physical Laws
- Management Sciences
  - Economics
  - Organizational Design
  - Business Decision Analysis
  - Operations Research
- Social Sciences
  - Multi-disciplinary Teamwork
  - Organizational Behavior
  - Leadership

Unique to Systems Engineering

- Body of Knowledge
  - Problem definition
    - Concept of operations
    - System boundaries
    - Objectives hierarchy
    - Originating requirements
  - Concurrent Engineering
    - System life cycle phases
    - Integration/Qualification
  - Architectures
    - Functional/Logical
    - Physical/Operational
    - Interface
  - Trades
    - Concept-level
    - Risk management
    - Key performance parameters

Problems of Systems Engineering

- Large systems are usually designed to solve complex problems
- Systems engineering requires a great deal of co-ordination across disciplines
  - Almost infinite possibilities for design trade-offs across components
  - Mutual distrust and lack of understanding across engineering disciplines
- Systems must be designed to last many years in a changing environment

Software and Systems Engineering

- The proportion of software in systems is increasing
- Software-driven general purpose electronics is replacing special-purpose systems
- Problems of systems engineering are similar to problems of software engineering
- Software is often seen as a problem in systems engineering
  - Many large system projects have been delayed because of software problems

Emergent Properties

- Properties of the system as a whole rather than properties that can be derived from the properties of components of a system
- Emergent properties are a consequence of the relationships and interaction between system components
- They can therefore only be assessed and measured once the components have been integrated into a system

Examples of Emergent Properties

- *The overall weight of the system*
  - This is an example of an emergent property that can be computed from individual component properties
- *The reliability of the system*
  - This depends on the reliability of system components and the relationships between the components
- *The usability of a system*
  - This is a complex property which is not simply dependent on the system hardware and software but also depends on the system operators and the environment where it is used

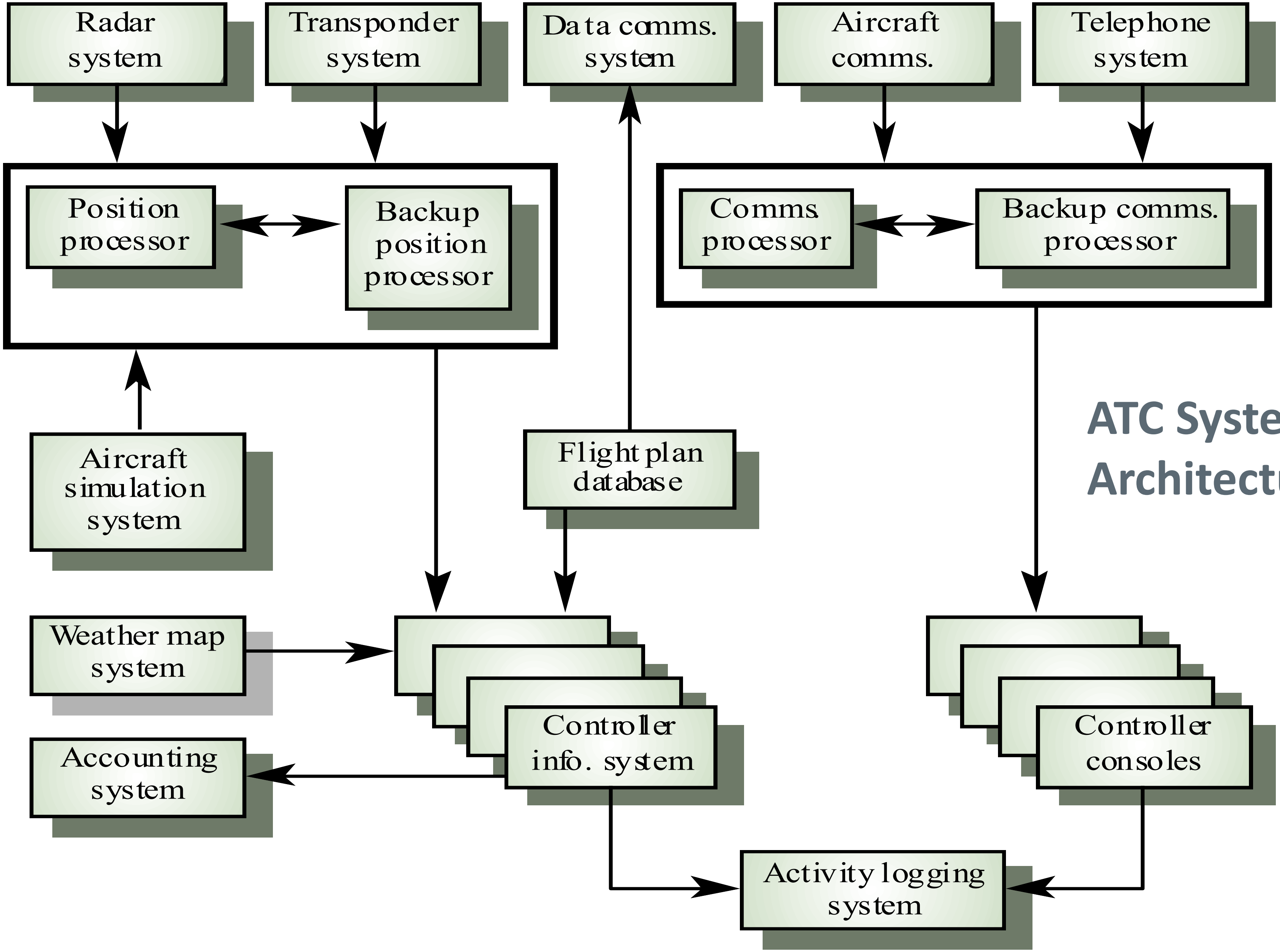
Types of Emergent Properties

- Functional properties
  - These appear when all the parts of a system work together to achieve some objective
    - A bicycle has the functional property of being a transportation device once it has been assembled from its components
- Non-functional emergent properties
  - Examples are reliability, performance, safety, and security
  - These relate to the behavior of the system in its operational environment
  - They are often critical for computer-based systems as failure to achieve some minimal defined level in these properties may make the system unusable

System Architecture Modelling

- An architectural model presents an abstract view of the sub-systems making up a system
- Includes the major information flows between sub-systems
- May identify different types of functional components in the model
- Descriptive verses Analytical Modelling and Simulation

ATC System Architecture



System Components

- Sensor Components
  - Collect information from the system's environment
    - e.g. radars in an air traffic control system

- Actuator Components
  - Cause some change in the system's environment
    - e.g. valves in a process control system which increase or decrease material flow in a pipe

- Computation Components
  - Carry out some computations on an input to produce an output
    - e.g. a floating point processor in a computer system

System Components

- Communication components
  - Allow system components to communicate with each other
    - e.g. network linking distributed computers
- Co-ordination components
  - Co-ordinate the interactions of other system components
    - e.g. scheduler in a real-time system
- Interface components
  - Facilitate the interactions of other system components
    - e.g. operator interface

All components are now usually software controlled

The Systems Engineering Process

- Usually follows a 'waterfall' model because of the need for parallel development of different parts of the system
  - Little scope for iteration between phases because hardware changes are very expensive
  - Software may have to compensate for hardware problems

- Involves engineers from different disciplines who must work together
  - Potential for misunderstanding
  - Different disciplines use a different vocabulary
  - Much negotiation is required due to different opinions as to what is most important
  - Engineers may have personal agendas

System Requirements Definition

- Three types of requirement defined at this stage
  - Abstract functional requirements
    - System functions are defined in an abstract way
  - System properties
    - Non-functional requirements for the system in general are defined
  - Undesirable characteristics
    - Unacceptable system behaviour is specified
- Should also define overall organisational objectives for the system

System Objectives

- Functional objectives
  - To provide a fire and intruder alarm system for the building which will provide internal and external warning of fire or unauthorized intrusion

- Organisational objectives
  - To ensure that the normal functioning of work carried out in the building is not seriously disrupted by events such

    as fire and unauthorized intrusion

System Requirements Problems

- Requirements often change as the system is being specified
- Engineers must anticipate hardware/communications developments over the lifetime of the system
- It is hard to define non-functional requirements without an impression of component structure of the system

The System Design Process

- Partition requirements
  - Organise requirements into related groups
- Identify sub-systems
  - Identify a set of sub-systems which collectively can meet the system requirements
- Assign requirements to sub-systems
  - Causes particular problems when COTS are integrated
- Specify sub-system functionality
- Define sub-system interfaces
  - Critical activity for parallel sub-system development

System Design Problems

- Requirements partitioning to hardware, software and human components may involve a lot of negotiation
- Difficult design problems are often assumed to be readily solved using software
- Hardware platforms may be inappropriate for software requirements so software must adapt and compensate for this

Sub-system Development

- Typically parallel projects developing the hardware, software and communications
- May involve some COTS (Commercial Off-the-Shelf) systems procurement
- Lack of communication across implementation teams
- Bureaucratic and slow mechanisms for proposing system changes may mean that the development schedules need to be extended due to the need for rework

System Integration

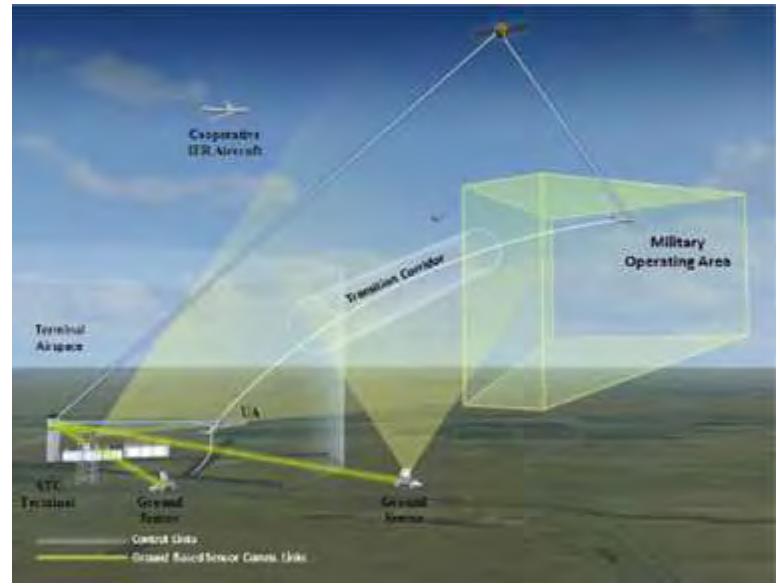
- The process of putting hardware, software and people together to make a system
- Should be tackled incrementally so that sub-systems are integrated one at a time
- Interface problems between sub-systems are usually found at this stage

System Installation

- Environmental assumptions may be incorrect
- There may be resistance to the introduction of a new system
- System may have to coexist with alternative systems for some time
- There may be physical installation problems
- Operator training has to be identified and implemented

System Evolution

- Large systems have a long lifetime and they must evolve to meet changing requirements



- Evolution is inherently costly
  - Changes must be analysed from a technical and business perspective
  - Sub-systems interact so unanticipated problems can arise
  - There is rarely a rationale for original design decisions
  - System structure is corrupted as changes are made to it

- Existing systems which must be maintained are sometimes called legacy systems

System Procurement

- Acquiring a system for an organization to meet some need
- Some system specification and architectural design is usually necessary before procurement
  - One often needs a specification to initiate a contract for system development
  - The specification may allow for buying a commercial off-the-shelf components which may be cheaper than developing a system from scratch
- Requirements may have to be modified to match the capabilities of off-the-shelf components
- The requirements specification may be part of the contract for the development of the system
- There is usually a contract negotiation period to agree changes after the contractor to build a system has been selected

Systems Engineering Key Points

- System engineering involves input from a range of disciplines
- Emergent properties are properties that are characteristic of the system as a whole and not its component parts
- System architectural models show major sub-systems and inter-connections and are usually described using block diagrams
- System component types are sensor, actuator, computation, coordination, communication, and interface
- The systems engineering process is usually a waterfall model and includes specification, design, development, and integration
- System procurement is concerned with deciding which system to buy and who to buy it from

Systems Engineering Summary

- Has Unique Focus
  - End product and system purpose
  - Stakeholder needs and expectations
  - Full system life cycle
    (Conception through Retirement)

- Has Unique Approach
  - Integrates disciplines and technologies
  - Balances many conflicting considerations

- Has Unique Methods, Tools & Models for:
  - Organization and management of information and requirements
  - System analysis and simulation
  - Assessment of performance and risk
  - Verification and validation

Human Factors for Unmanned Aerial Systems

What is Human Factors?

- Taking into account the capabilities and limitations of human operators during design, manufacture, and operation to optimize safety, efficiency, and reliability
- The application of psychological principles to the design of human-machine systems
- Human factors professionals develop models of human sensory, cognitive, and motor performance that can aid designers of human-machine systems
- “The study of how humans accomplish work-related tasks in the context of human-machine system operation”
- “An interdisciplinary science concerned with influencing the design of manned systems, equipment and operational environments so as to promote safe, efficient and reliable total system performance”
- “Designing human tasks within a specified system context to maximize physical and mental performance and thus minimize human errors.”

Human Factors Benefits

Enhanced Safety

Reduced error rates

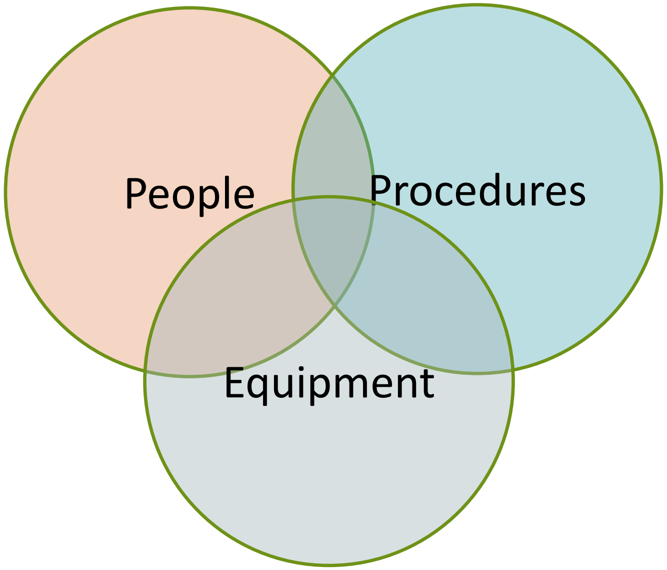
Improved performance

Improved efficiency

Reduced life-cycle costs

Human Factors Areas

- Clinical Psychology
- Anthropometrics
- Experimental Psychology
- Computer Science
- Cognitive Science
- Medical Science
- Organizational Psychology
- Educational Psychology
- Industrial Engineering
- Safety Engineering



History of Human Factors in Design

Late 1800s - Early 1900s: The Industrial Revolution

- Frank and Lillian Gilbreth
  - study of human motion and workplace management
  - skilled performance, fatigue, workstations & equipment for physically disabled
  - forerunners of "human factors" research

1900-1945: Workplace was "Task Oriented"

- people adapted to the job and equipment required
- tests developed for better worker selection and training
- BUT, still an "efficiency gap" that called for a paradigm shift by fitting job/tools to the person

History of Human Factors in Design

1945-1960: “Human Factors” Profession is Born

- first engineering psychology labs established in US & Britain
- first ‘Ergonomics Research Society’ formed in Britain
- first book on human factors in engineering design
- first scientific journal in 1957 – ‘Ergonomics’
- International Ergonomics Society launched in 1959

1960-1980: Rapid Growth

- up to 1960, human factors research was limited to military
- interest and need fed by the space race
- expansion beyond military and space research to industry and workplace (e.g. computers, automobiles, and other consumer products)

History of Human Factors in Design

1980-Today: Computers, Disasters, & Lawsuits

- **Computers** - desire for “people-oriented” technology grew through ergonomically designed computers, user-friendly software, and office design
- **Disasters** – Three Mile Island, Chernobyl, and various high-profile chemical plant explosions were linked to lack of attention to “human factor” considerations
- **Lawsuits** – courts came to recognize the need for experts in explaining human behavior, responses, defective design, and effectiveness of workplace warnings and instructions

Human Factors and Experimental Psychology

- Experimental Psychology is the scientific study of mind, brain, and behavior
  - Why do humans think and behave the way they do?

- The study of human behavior in the context of technological systems

How should we design a system to accommodate the way humans think and behave?

Human Factors and Cognitive Psychology

We are thinking beings and the nature of work is changing

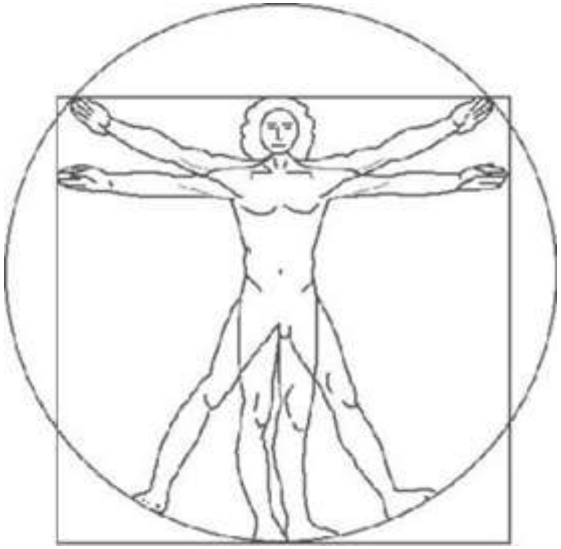
Cognitive issues must be considered

- Memory (accuracy, retrieval ability, storage capacity)
- Visual and auditory capabilities/interpretations
- Attention capacity
- Response time to stimuli
- Interpretation of stimuli
- Coding interpretation
- Problem solving abilities
- Decision making
- Language comprehension
- Disabilities
- Cognitive load
- Levels of Automation

Design in Human Factors

- The emphasis in Human Factors is on design
- How should systems be designed to optimally accommodate human operators
- Human Factors should be proactive
- Is usually driven by a need or requirement
- Can cost more initially,

however ….

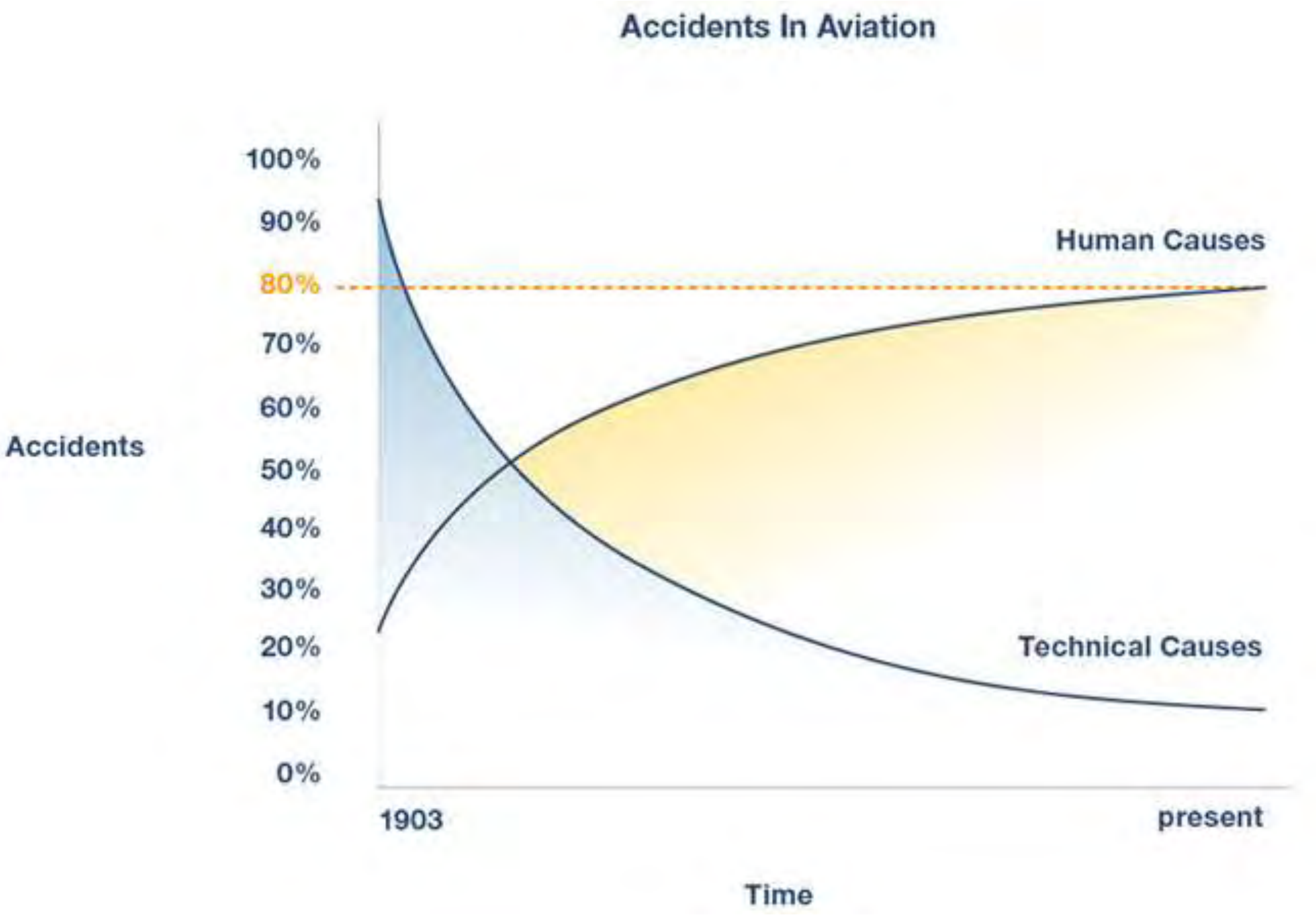


Good human factors design yields returns in improved safety, performance, reliability, and efficiency

Design Considerations in Human Factors

- Safety
- Performance
- Reliability
- Task to be accomplished
- Environment
- User Population
- User Culture
- Efficient processes and workflows
- Right people in the right job

Aviation Accident Causes



Aviation Accident Causes

Significant accident causes and percentage present in 93 major accidents: (Graber & Marx)

– Pilot deviated from basic operational procedures	33%
– Inadequate cross-check by second crew member	26%
– Design faults	13%
– Maintenance and inspection deficiencies	12%
– Absence of approach guidance	10%
– Captain ignored crew inputs	10%
– Air traffic control failures or errors	9%
– Improper crew response during abnormal conditions	9%
– Insufficient or incorrect weather information	8%
– Runways hazards	7%
– Air traffic control/crew communication deficiencies	6%
– Improper decision to land	6%

Causes of Aviation Accidents Related to Maintenance Engineering

What are the types of things that negatively effect human performance and may lead to human error?

- Fatigue
- Boring repetitive jobs
- Lack of spare parts and tools
- Personal life problems
- Substance abuse
- Loud noises
- Poor communication
- Poor instructions
- Unrealistic deadlines
- Smelly fumes
- Poor training
- Incomplete or incorrect documentation
- Poorly designed testing for skill and knowledge

Attributes for Increasing Safety

- Proficiency
- Vigilance
- Assertiveness
- Procedural Compliance
- Communication
- Teamwork
- Decision Making
- Experience
- Leadership
- Situational Awareness
- Company Safety Culture
- Workload Management

What is Ergonomics?

Ergon = work

Nomos = laws

“The laws of work”

Ergonomics

- Ergonomics is the study and optimization of the interaction between people and their physical environment by considering their physical, physiological, and psychological characteristics

1. ***User Orientation:*** Design and application of tools, procedures, and systems must be user-oriented, rather than just “task” oriented
2. ***Diversity:*** Recognition of diversity in human capabilities and limitations, rather than “stereotyping” workers/users
3. ***Effect on Humans:*** Tools, procedures, and systems are not “inert”, but do influence human behavior and well-being
4. ***Objective Data:*** Empirical information and evaluation is key in design process, rather than just use of “common sense”
5. ***Scientific Method:*** test and retest hypothesis with real data, rather than “anecdotal” evidence or “good estimates”
6. ***Systems:*** object, procedures, environments, and people are interconnected, affect one another, and do not exist in “isolation”

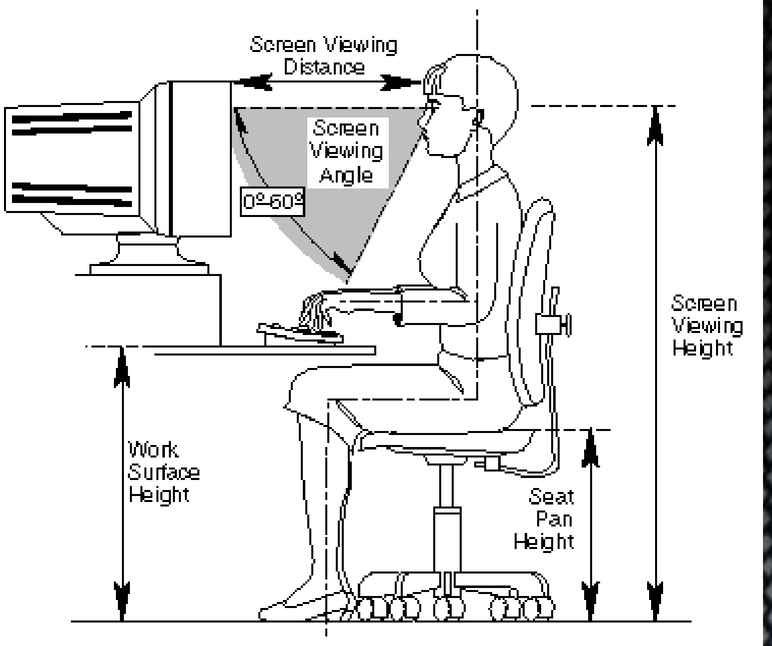
What is Occupational Biomechanics?

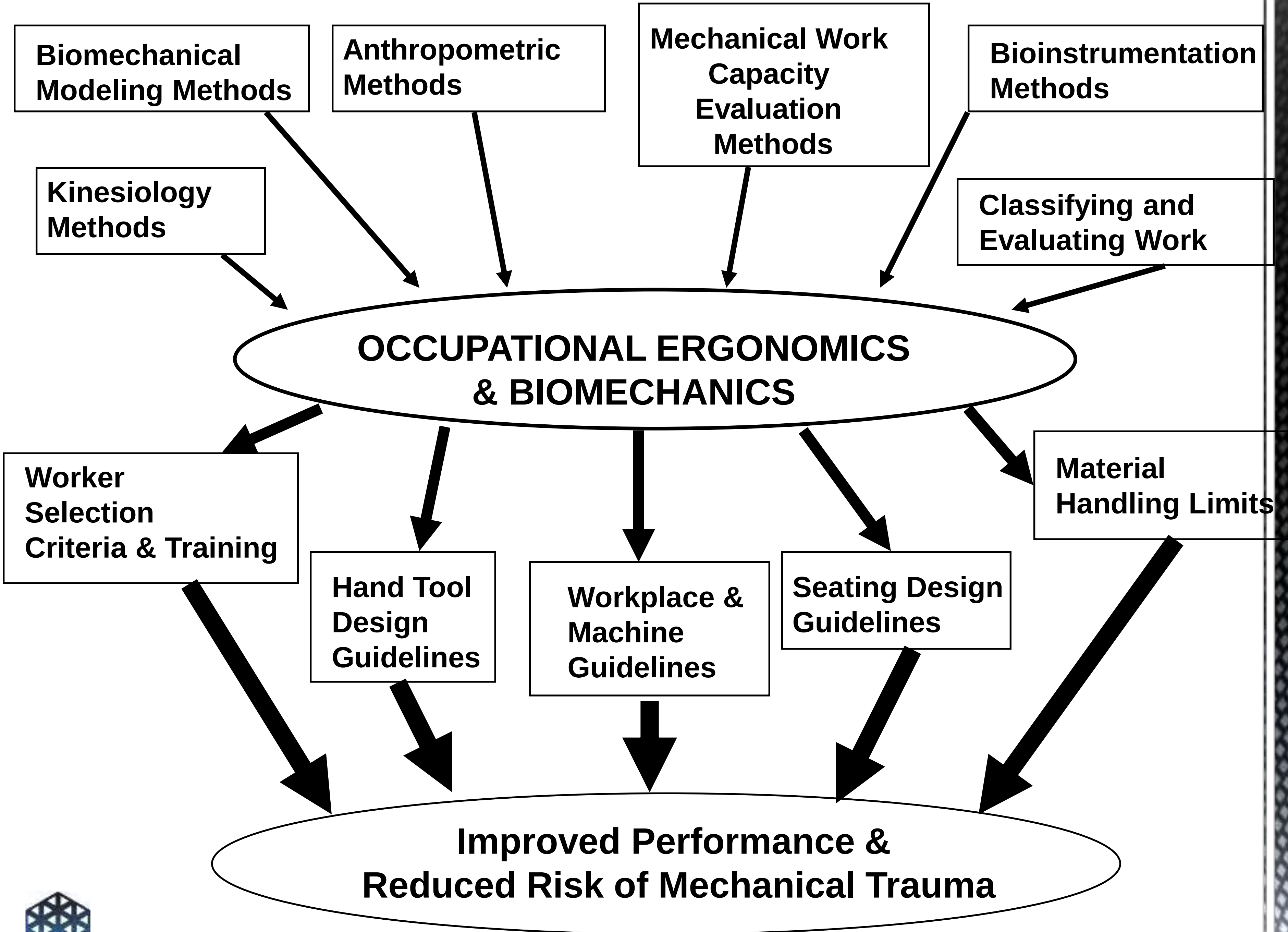
Biomechanics

"Biomechanics uses the laws of physics and engineering concepts to describe motion undergone by the various body segments and the forces acting on these body parts during normal daily activities"

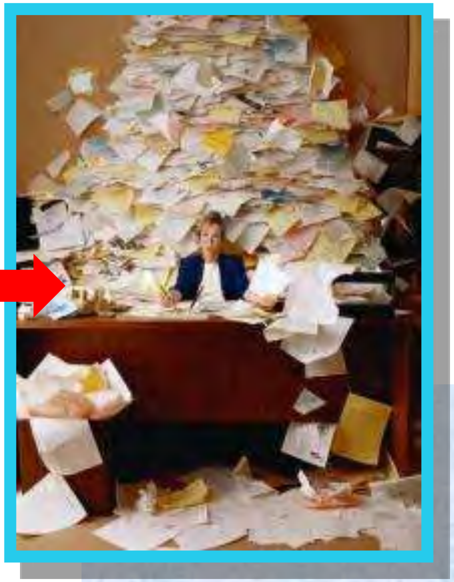
Occupational Biomechanics

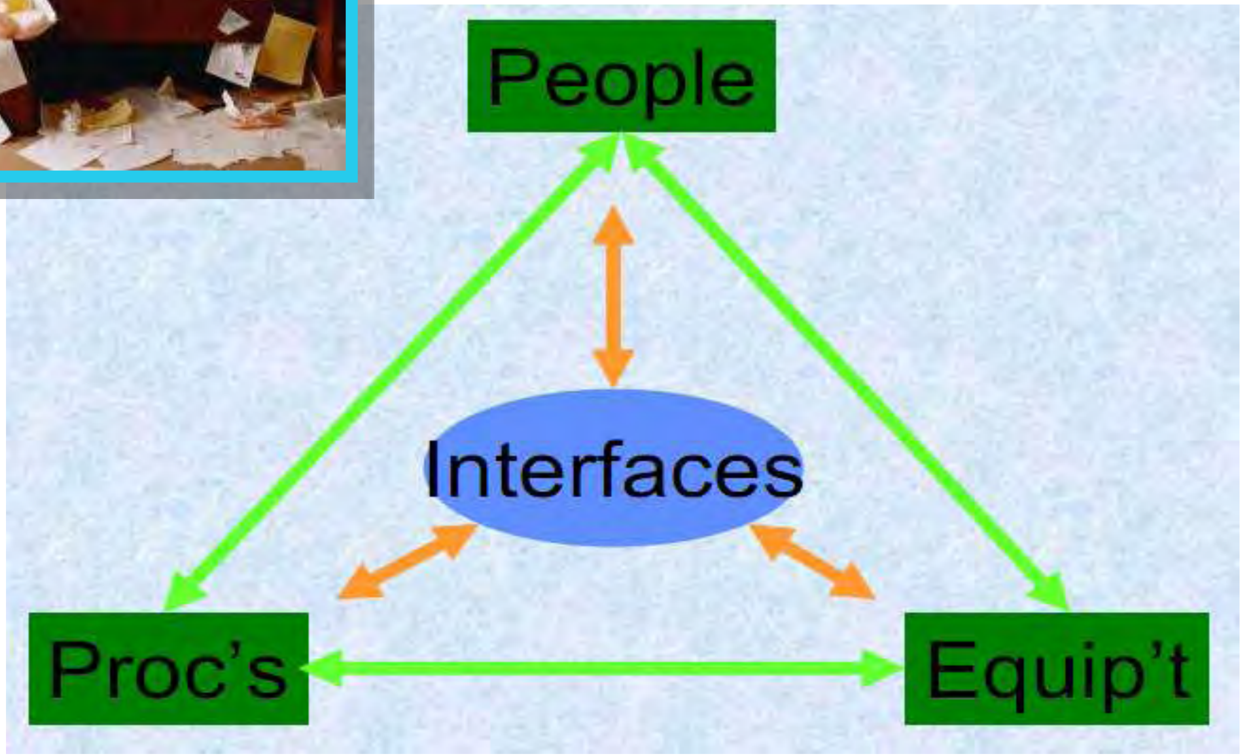
"Occupational biomechanics is the science concerned with the mechanical behavior of musculoskeletal tissues when physical work is performed."




Biomechanical Modeling Methods
Anthropometric Methods
Mechanical Work Capacity Evaluation Methods
Bioinstrumentation Methods
Kinesiology Methods
Classifying and Evaluating Work
OCCUPATIONAL ERGONOMICS & BIOMECHANICS
Worker Selection Criteria & Training
Hand Tool Design Guidelines
Workplace & Machine Guidelines
Seating Design Guidelines
Material Handling Limits
Improved Performance & Reduced Risk of Mechanical Trauma

Human Computer Interaction

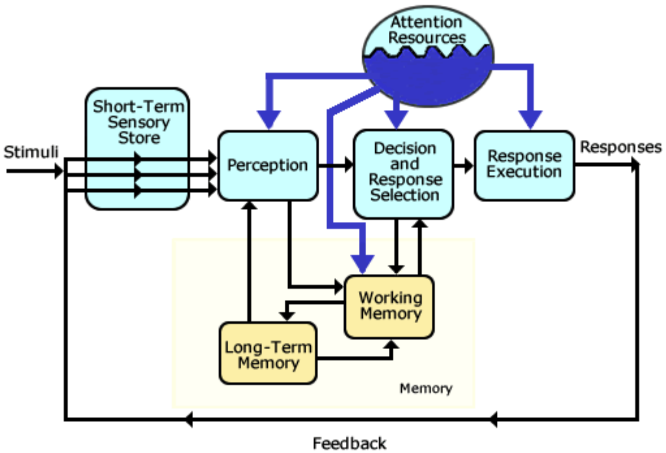


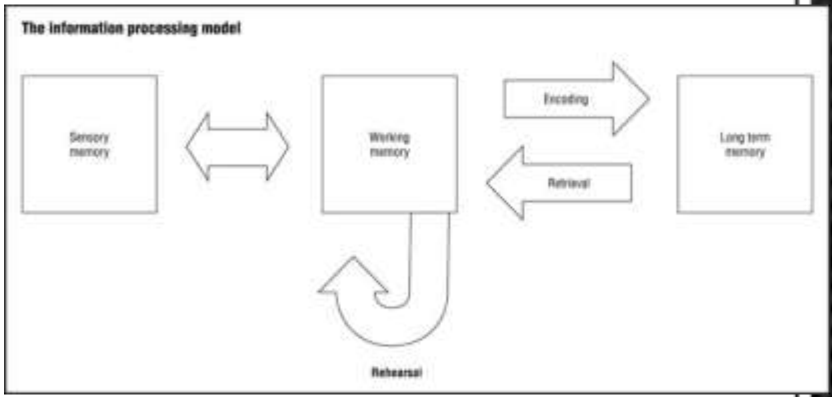


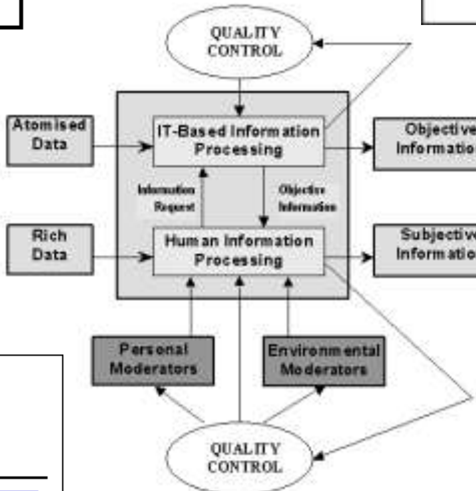
What Is Mental Workload?

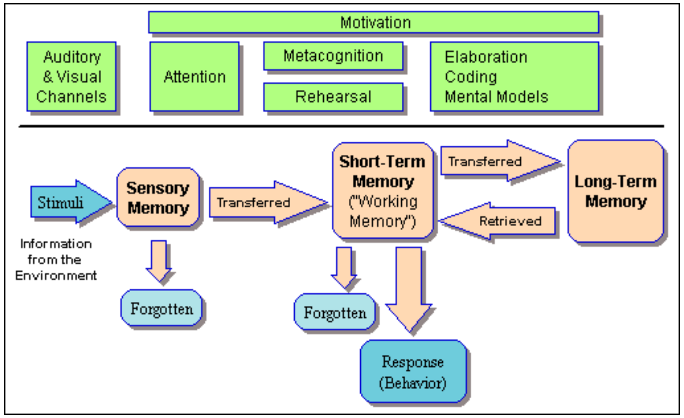
- Mental workload is the portion of operator's limited mental capacities actually required to perform a particular task
- Mental reserves are the difference between capacity required and capacity available
- Mental effort is the voluntary matching of mental capacities with that needed for task success
- Increase in Mental Workload often precedes Performance Failure

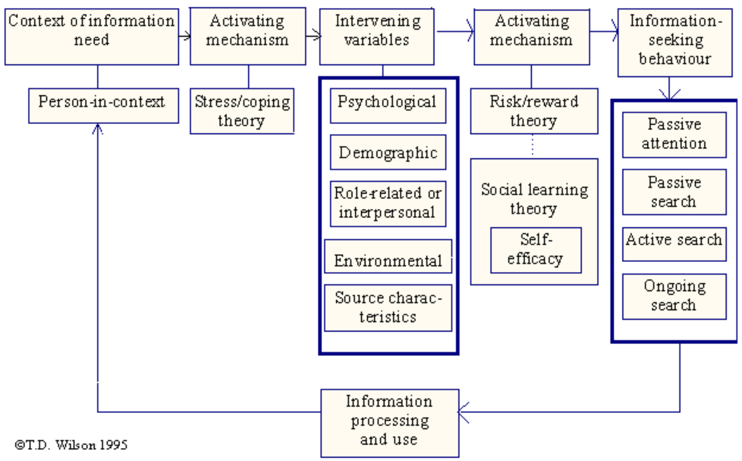
Information Processing Models











Workload and Vigilance

Vigilance is a Long-Standing Problem

Sources of Performance Influence Include:

- Event Rate
- Signal Salience
- Stress/Workload/Fatigue
- Glare, Noise, Temperature, Vibration, Drug Effects, etc.

Memory Load

- Successive vs. Simultaneous Comparisons

Individual Differences

- Introversion/Extraversion, Age, Sex, Expertise

Current and Emerging Interaction Styles

Current

- Command Language
- Question and Answer
- Form-based
- Windows
- Icons
- Menus
- Mouse
- Direct Manipulation
- Natural Language

Emerging

- Virtual and augmented environments
- Tangible interfaces
- Ubiquitous, pervasive, handheld
- Lightweight
- Passive
- Wearable
- Context aware
- Affective computing
- Multi-modal interfaces
- Brain-computer interaction

Human Factors Design Philosophy

- Make the right way the easiest way
- Make the right way the only way
- Provide safeguards to prevent it from being done the wrong way
- Give the operators feedback if it was done the wrong way

Attributes of Good User Interface Design

Well-designed interfaces provide a good match between the user's needs, skill level, and learning ability and will lead to satisfied and productive users

A good interface will be easy to learn and easy to use, and will encourage the user to experiment and try out new features within the system without getting frustrated

Well-designed interfaces will also help towards 'selling' the system to both managers as well as the users themselves

Principles of Interface Design

Strive for consistency
Consistent sequences of actions should be used in similar situations; identical terminology should be used in prompts, menus, and help screens; and consistent commands should be employed throughout.

Enable frequent users to use shortcuts
As the frequency of use increases, so do the user's desires to reduce the number of interactions and to increase the pace of interaction. Abbreviations, function keys, hidden commands, and macro facilities are very helpful to an expert user.

Offer informative feedback
For every operator action, there should be some system feedback. For frequent and minor actions, the response can be modest, while for infrequent and major actions, the response should be more substantial.

Design dialog to yield closure
Sequences of actions should be organized into groups with a beginning, middle, and end.

Offer simple error handling
As much as possible, design the system so the user cannot make a serious error. If an error is made, the system should be able to detect the error and offer simple, mechanisms for handling the error.

Permit easy reversal of actions
This feature relieves anxiety, since the user knows that errors can be undone; it thus encourages exploration of unfamiliar options. The units of reversibility may be a single action, a data entry, or a complete group of actions.

Support internal locus of control
Experienced operators strongly desire the sense that they are in charge of the system and that the system responds to their actions. Design the system to make users the initiators of actions rather than the responders.

Reduce short-term memory load
The limitation of human information processing in short-term memory requires that displays be kept simple and sufficient training time be allotted for codes, mnemonics, and sequences of actions.