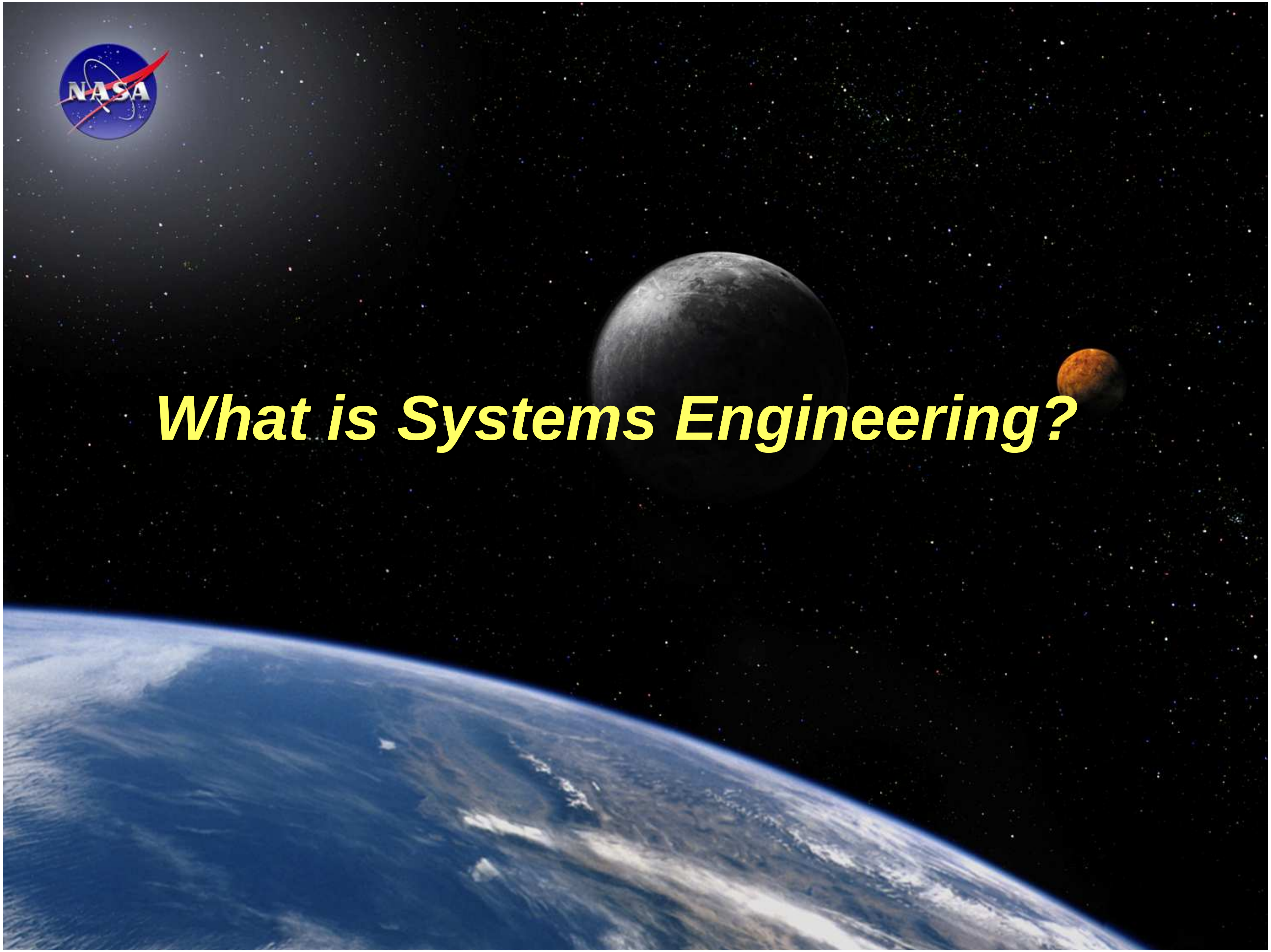

NASA
What is Systems Engineering?

What is a System?

Simply stated, a system is an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objectives.

What are examples of a system in the aerospace industry?

Personnel

Facilities

Processes

Hardware

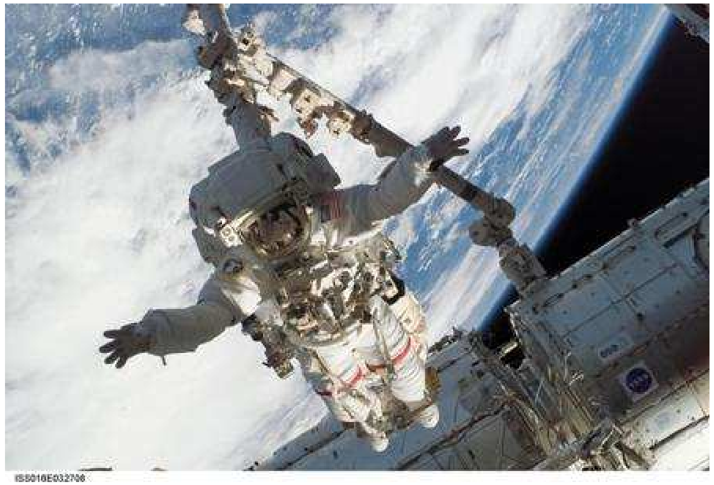
Examples of Systems

- Space Shuttle Main Engine vs. a collection of parts

- Space Shuttle Orbiter with engines and avionics

Examples of Systems

- Space Shuttle Orbiter with solid rocket boosters and external fuel tank
- Space Transportation System (STS) with payload, launch pad, mission controllers, vehicle assembly facilities, trainers and simulators, solid rocket booster rescue ships…



- "System of Systems"
  - STS + International Space Station + TDRSS communication satellites +…

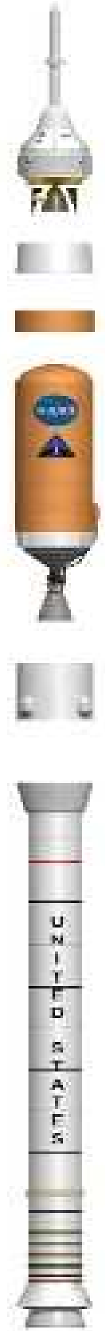
What is Systems Engineering?

***Systems engineering* is a robust approach to the design, creation, and operation of systems.**

The approach 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*
- verification that the *design* is properly built and integrated, and
- assessment of how well the system meets the goals

This approach is iterative, with several increases in the resolution of the system baselines (which contain requirements, design details, verification plans and cost and performance estimates).



Ares 1

System, Systems Engineering, and Project Management

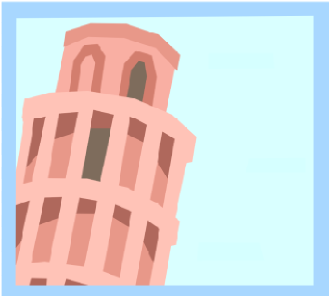
- **System – The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.**
- **Systems Engineering – A disciplined approach for the definition, implementation, integration and operation of a system (product or service).**
- **The discipline of systems engineering uses techniques and tools appropriate for use by any engineer with responsibility for designing a system as defined above. That includes subsystems.**
- **Project Management – The process of planning, applying, and controlling the use of funds, personnel, and physical resources to achieve a specific result**

Original Reasons for Systems Engineering

Vasa, Sweden, 1628

Photo from Dec 1999 Civil Engineering magazine

- Systems of pieces built by different subsystem groups did not perform system functions
  - Often broke at the interfaces
- Problems emerged and desired properties did not when subsystems designed independently were integrated
- Managers and chief engineers tended to pay attention to the areas in which they were skilled



- Developed systems were not usable
- Cost overruns, schedule delays, performance problems

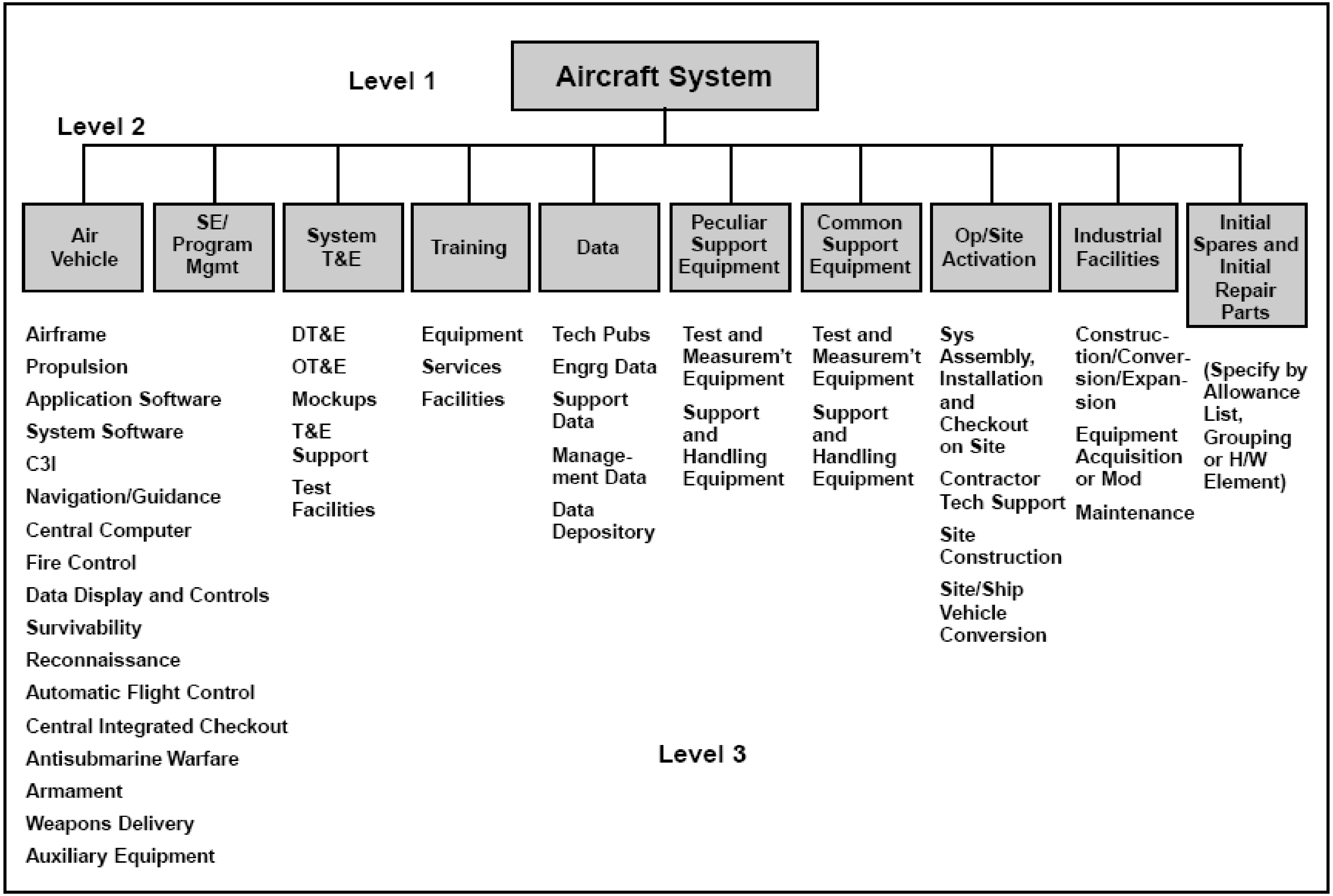
Systems Engineering is Built on the Lessons of the Past

- Systems engineering is a relatively new engineering discipline that is rapidly growing as systems get larger and more complex.
- Most of the foundations of systems engineering are built on the lessons of past projects.
- Every project should have a "debrief" at the end to record lessons learned data.
- These learned lessons can be used by future projects so they do not repeat mistakes and ensure they incorporate successes.

Systems Engineering Process Models Begin with Reductionism

- Reductionism, a fundamental technique of systems engineering, decomposes complex problems into smaller, easier to solve problems - divide and conquer is a success strategy.
- Systems engineering divides complex development projects by <u>product and phase</u>.
- Decomposing a product creates a hierarchy of progressively smaller pieces; e.g.,
  - System, Segment, Element, Subsystem, Assembly, Subassembly, Part
- Decomposing the development life of a new project creates a sequence of defined activities; e.g.,
  - Need, Specify, Decompose, Design, Integrate, Verify, Operate, Dispose

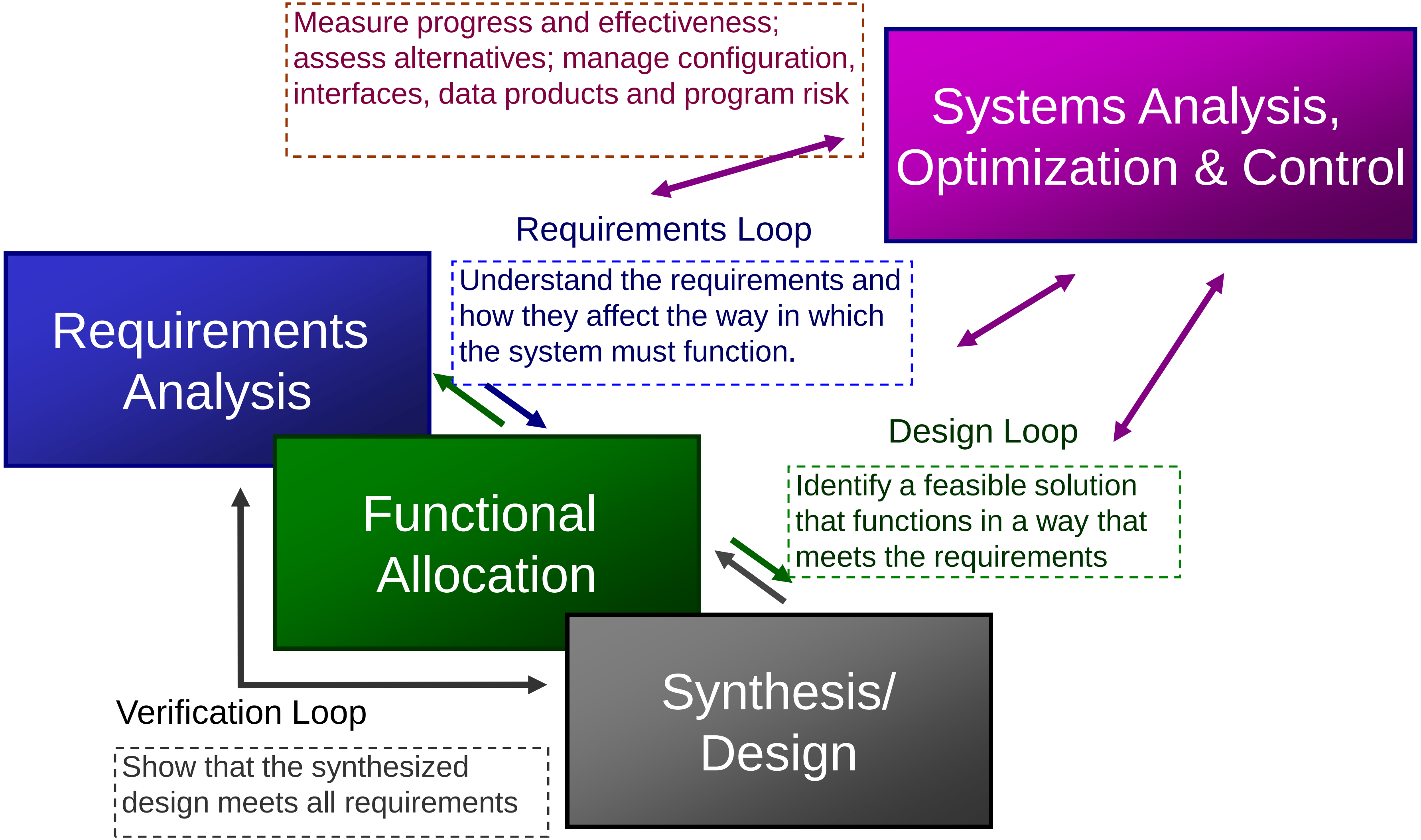
Subsystem Organization Structure



Group Effort – Display Product

Write the subsystem organization structure for a display product that will accept remote information and display it on the screen. This is the ECGR6185 project.

Systems Engineering Process also Includes Requirements Analysis



Requirements Development

Write the requirements for a quadrotor vehicle system which will inspect a power plant cooling tower.

Use requirements language, and organize by subsystem:

Vehicle:

Req-V0001: The vehicle shall be able to fly for a minimum of 30 minutes.

Req-V0002: The vehicle shall be able to fly for a maximum of 60 minutes.

Base station:

Req-B0001: An operator shall man the base station at all times while the vehicle is aloft.

With Process Comes Systems Engineering Practices

Set up a plan for each of these ***EARLY!***

Design Budgets
- Power
- Memory/data
- Communications
- Mass
- $$$
- Other resources

Documentation Organization
- Requirements (**!!**)
- Materials Lists
- CAD drawings
- Safety documents
- Interface controls
- Configuration management

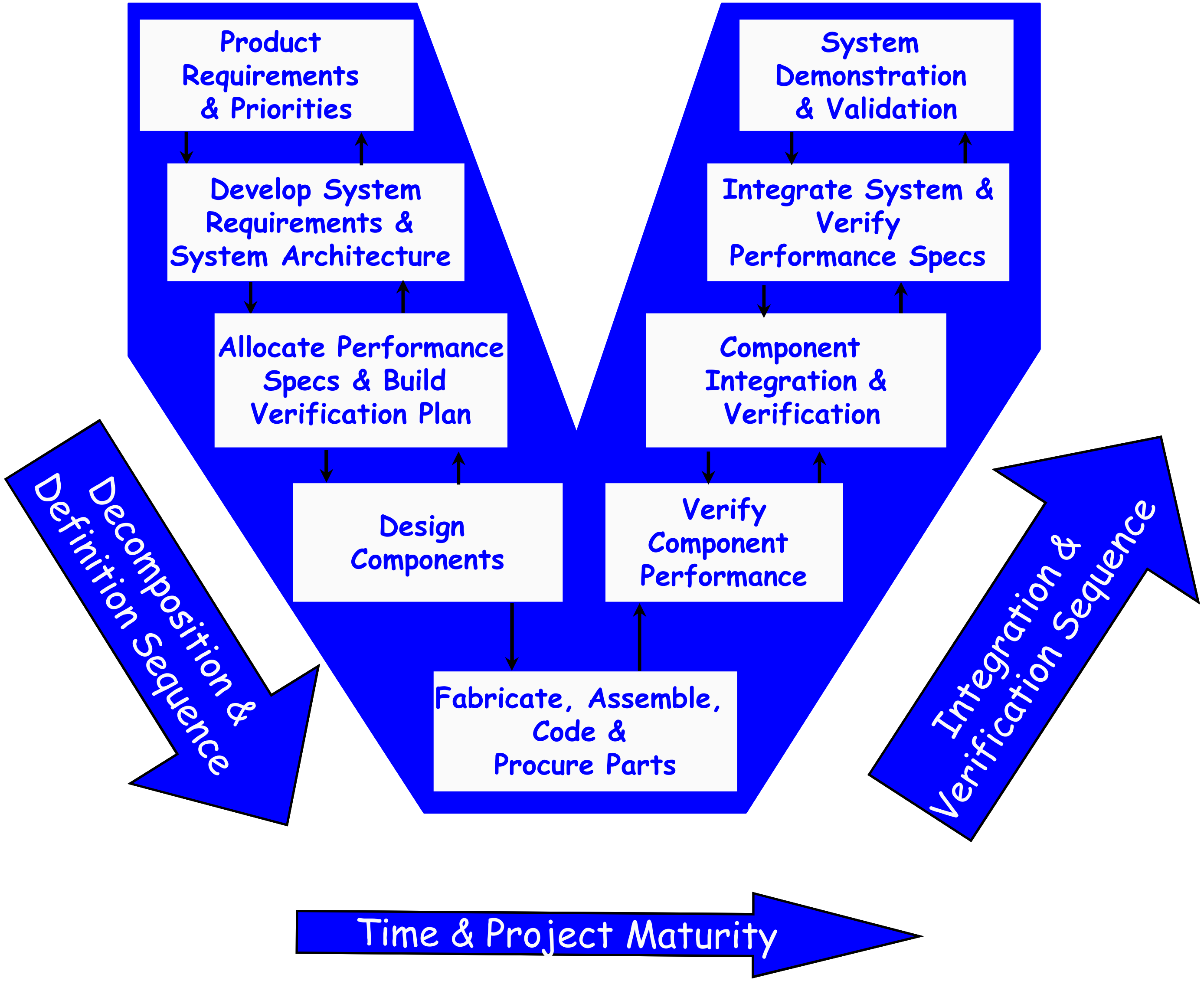
Acquisition strategies
- Purchase
- In-house
- Contribution
- Other

Interface Control
- Harness & Connectors
- Structural connections
- Software protocols & signal processing

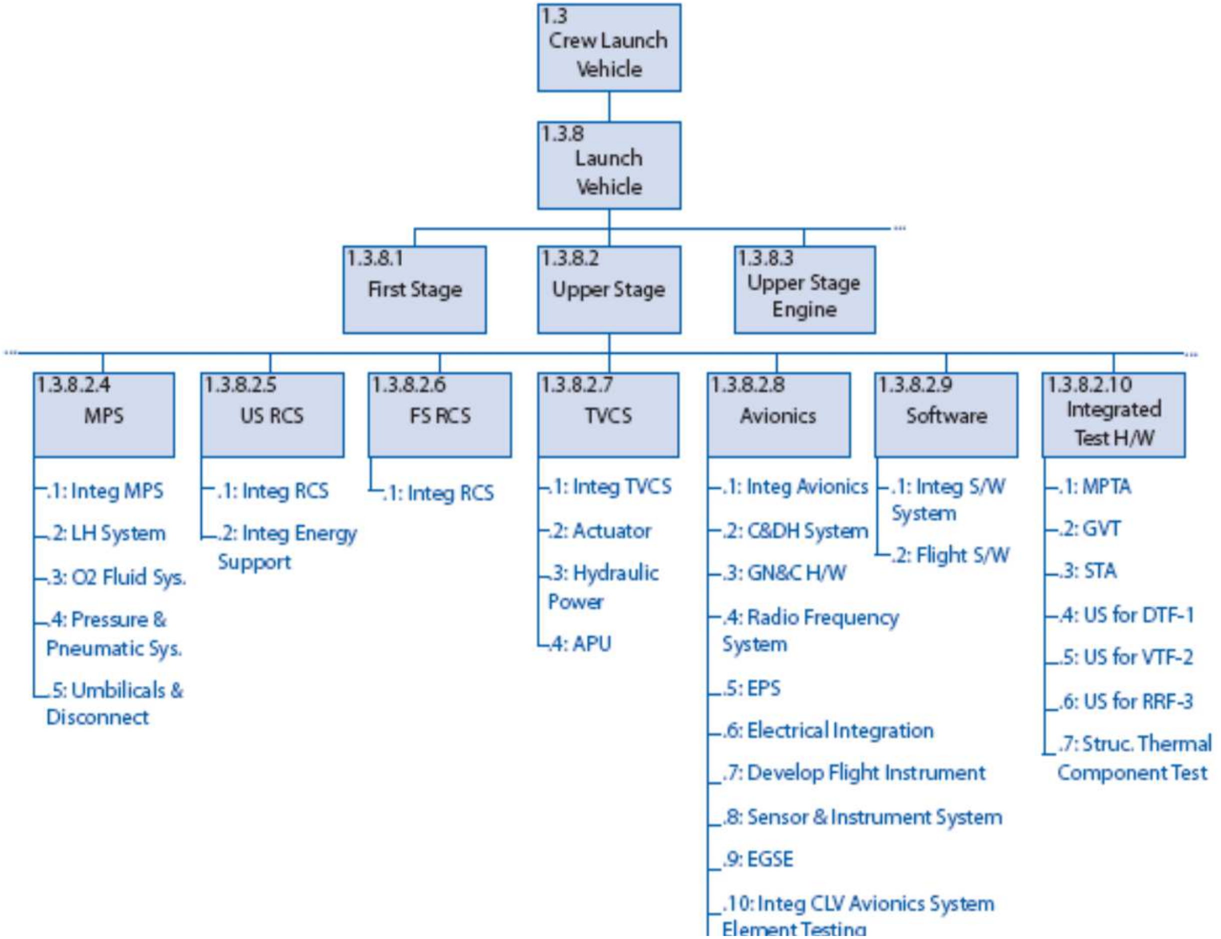
Identify design drivers
- Cost
- Schedule
- Performance

Execute a risk management plan

The Systems Engineering 'Vee' Model Extends the Traditional View with Explicit Decomposition and Integration



Production and Work Breakdown Structure



Allows the systems engineer to systematically divide an entire project into a set of major production areas including, sub-areas, and sub-sub areas.

WBS for Display Product

Write the WBS for structure for a display product that will accept remote information and display it on the screen. This is the ECGR6185 project.

Trade Studies

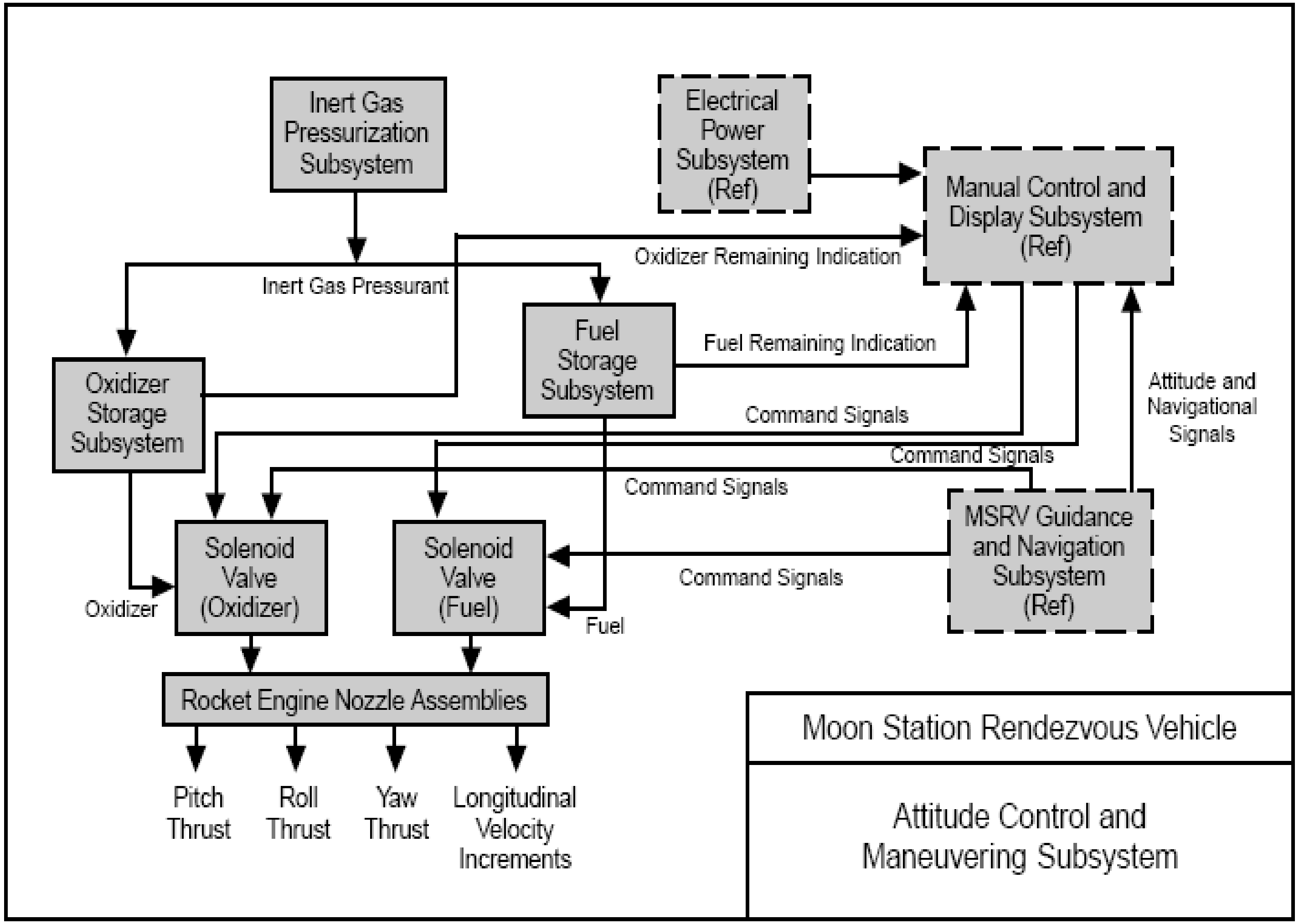
- **Trade study is a tool used to help choose the best solution among alternatives.**

- **Numerical values are given based on weight factors and a normalization scale for the evaluation criteria.**

Decision Factors / Alternatives	Range Wt. = 2.0		Speed Wt. = 1.0		Payload Wt. = 2.5		Weighted Total
	U	W	U	W	U	W	
Transport System 1	.8	1.6	.7	.7	.6	1.5	3.8
Transport System 2	.7	1.4	.9	.9	.4	1.0	3.3
Transport System 3	.6	1.2	.7	.7	.8	2.0	3.9
Transport System 4	.5	1.0	.5	.5	.9	2.25	3.75

Key: U = Utility value
W = Weighted value

Functional Block Diagrams



Schematic Block Diagram Example

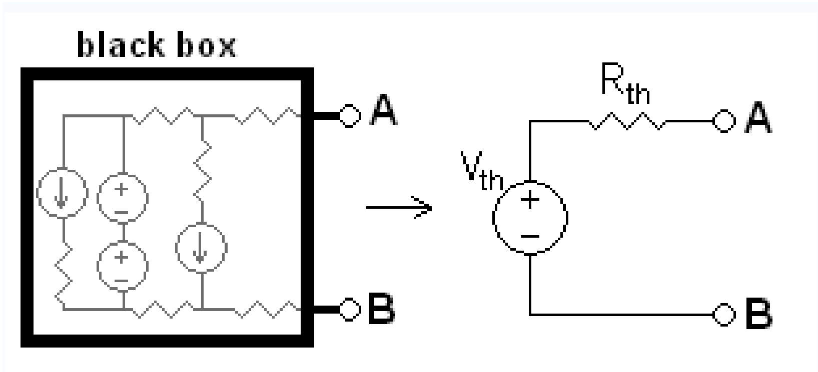
Schematic Block Diagram (SBD) depicts hardware and software components and their inter-relationships.

Developed at successively lower levels as analysis proceeds to define lower-level functions within higher-level requirements.

Useful for developing Interface Control Documents *(ICD's)*

Interface Control Document

-- Allows Disparate groups to work integrate sub-systems without complete working knowledge of what is inside of the “black box
-- In this way, independent teams can develop the connecting systems which use the interface specified, without regard to how other systems will react to data and signals which are sent over the interface.
-- An adequately defined ICD will allow one team to test its implementation of the interface by simulating the opposing side with a simple communications simulator.



Interface Control Document

TNC Interface V1.0				
Pin			Description	MCU Pin
1	CTS	Clear to Send	RS-232 level flow control signal out of the TNC. Indicates whether the TNC is allowing or holding off data input on pin 3.	PE4
2	RXD	Receive Data	RS-232 level data out of the TNC.	PE0
3	TXD	Transmit Data	RS-232 level data into the TNC.	PE1
4	RTS	Request to Send	RS-232 level flow control signal into the TNC. Indicates the MCU wants to send data to the TNC.	PE3
5	GND	Ground	Common signal and frame ground.	GND
6	DCD		No connection.	N/C

Table 4: MCU/TNC Interface

Power and Mass Budget Analysis

C&DH Mass Budget V1.0			
Part	**Mass (kg)**	**Quantity**	**Mass Total**
Memory	0.0030	1	0.0030
ATmega2561L	0.0010	2	0.0020
3V relays	0.0003	4	0.0012
I2C ADC's	0.0010	3	0.0030
I2C GPIO	0.0010	1	0.0010
Circuit Board	0.0250	1	0.0250
Crystal	0.0010	1	0.0010
Miscellaneous	0.0100	1	0.0100
Thermistors	0.0010	8	0.0080
Total	**0.0433**		**0.0542**
Contingency			**10%**
Total Plus Cont.			**0.0596**

Table 5: C&DH Mass Budget

Weight and power growth are major enemies of many products.

Power and mass budget analyses insure product growth is bounded and eventually mandates comes in “under weight” and “overpowered”

Power and Mass Budget Analysis

C&DH Power Budget

C&DH Power Budget V1.0										
		Voltage Range			Current	Power Max	Power Mode			
Part	Quantity	Min	Max	V used	mA	mW	Safe	Idle	Normal	Transmit
Memory	1	2.7000	3.6000	3.0000	4.0000	12.0000	0.1000	0.1000	1.0000	1.0000
ATmega2561L	2	1.7000	5.5000	3.0000	5.5000	33.0000	16.5000	16.5000	16.5000	16.5000
3V relays	4	1.0000	5.0000	3.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
I2C ADC's	3	2.7000	5.0000	3.0000	0.2250	2.0250	1.0125	1.0125	2.2050	2.2050
I2C GPIO	1	2.3000	5.5000	3.0000	0.1040	0.3120	1.0000	1.0000	1.0000	1.0000
Circuit Board	1	~	~	~	~	0.0000	0.0000	0.0000	0.0000	0.0000
Crystal	1	~	~	~	~	0.0000	0.0000	0.0000	0.0000	0.0000
Miscellaneous	1	~	~	~	~	0.0000	0.0000	0.0000	0.0000	0.0000
Thermistors	8	1.0000	5.5000	3.0000	0.3333	7.9992	8.0000	8.0000	8.0000	8.0000
Total					**10.1623**	**55.3362**	**26.6125**	**26.6125**	**28.7050**	**28.7050**
Contingency						**15%**	**15%**	**15%**	**15%**	**15%**
Total Plus Cont.						**63.6366**	**30.6044**	**30.6044**	**33.0108**	**33.0108**

Table 6: C&DH Power Budget

Example – a Display Product

Customer: Large offices, university faculty

Problem 1: How do I inform if I am running late, or will be available in my office later in the day?

Problem 2: Can I mount and operate an inexpensive product outside an office?

Tools:

- Electrical hardware – wireless and wired communications equipment, servers, power (batteries, AC)
- Tools – 3D printers, PCB development systems, software tools
- Software – Create OS, buy OS, use a free OS.

Write Requirements as a Group

Module Summary: What is Systems Engineering?

- *Systems engineering* is a robust approach to the design, creation, and operation of systems.
- Systems engineering is a ubiquitous and necessary part of the development of every space project.
- The function of systems engineering is to guide the engineering of complex systems.
- Most space projects struggle keeping to their cost and schedule plans. Systems engineering helps reduce these risks.
- Systems engineering decomposes projects in both the product and time domain, making smaller problems that are easier to solve.
- System decomposition and subsequent system integration are foundations of the Vee and the NASA systems engineering process models.