



Prof. Paolo Gaudenzi

Università di Roma "La Sapienza"

Scuola di Ingegneria Aerospaziale

Dipartimento di Ingegneria Aerospaziale e Astronautica

***Metodi avanzati di progettazione di
strutture spaziali per sistemi abitati***

***Advanced design methods for manned
space structural systems***

2° Int. Workshop AGROSPAZIO. RICERCA e TERRITORIO

Sperlonga 25 maggio 2006

MOTIVATIONS

TRYING TO INVESTIGATE ABOUT SOME FUNDAMENTAL QUESTIONS:

DO WE UNDERSTAND THE COMPLEXITY OF A LIFE SUPPORT SPACE SYSTEM?
THE SPACECRAFT AS A COMPLEX SYSTEM

WHAT DO WE NEED FOR THE ENHANCEMENT OF DESIGN PROCEDURES FOR SPACE EXPLORATION?
CONCURRENT ENGINEERING PROCEDURES

WHAT ARE THE DRIVING CRITERIA FOR AN OPTIMAL DESIGN OF A SPACE SYSTEM AND FOR THE SUCCESS OF A SPACE MISSION?
DESIGN BY USING SYSTEM BUDGETS

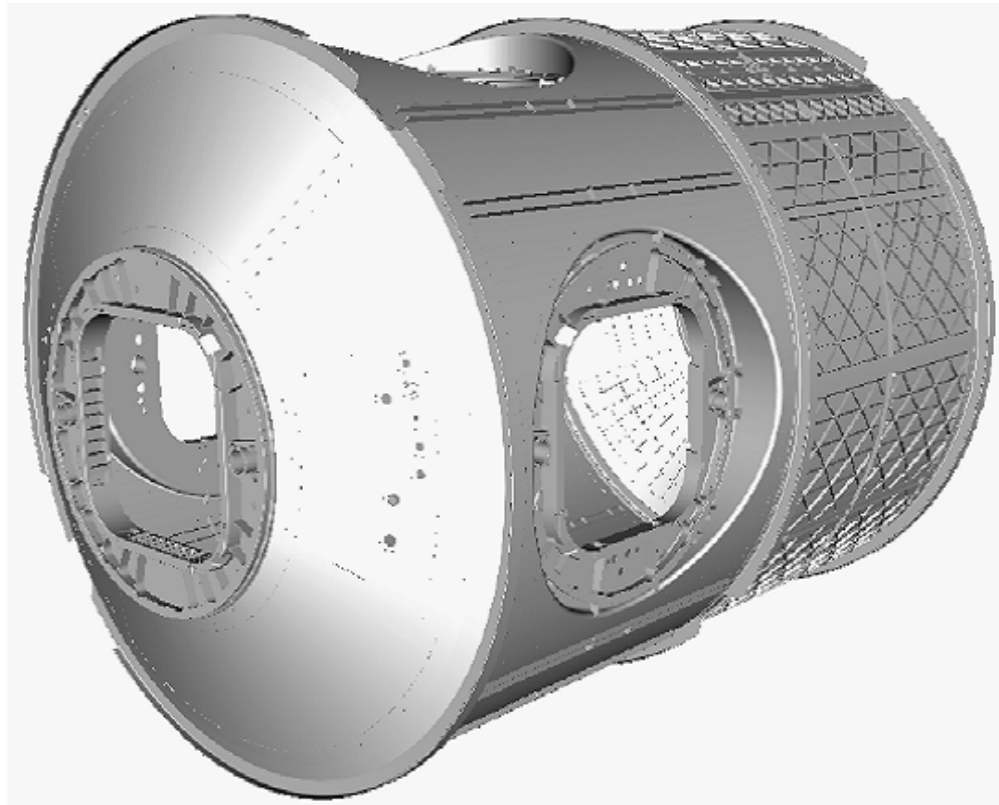
HOW CAN WE ASSURE THE SAFETY OF THE ASTRONAUTS?
SYSTEM HEALTH MANAGEMENT TECHNIQUES

THE SUBSYSTEMS OF A LIFE SUPPORT SPACE SYSTEM

- **Mechanical systems (Strutture primarie e secondarie)**
- **ECLSS (Controllo ambientale)**
- **Flight crew system (Interfacce con l'uomo)**
- **Electrical Power System (Distribuzione di potenza)**
- **Audio & Video**
- **TCS (Controllo termico)**
- **Wire harness (cablaggi)**
- **Computers & S/W**

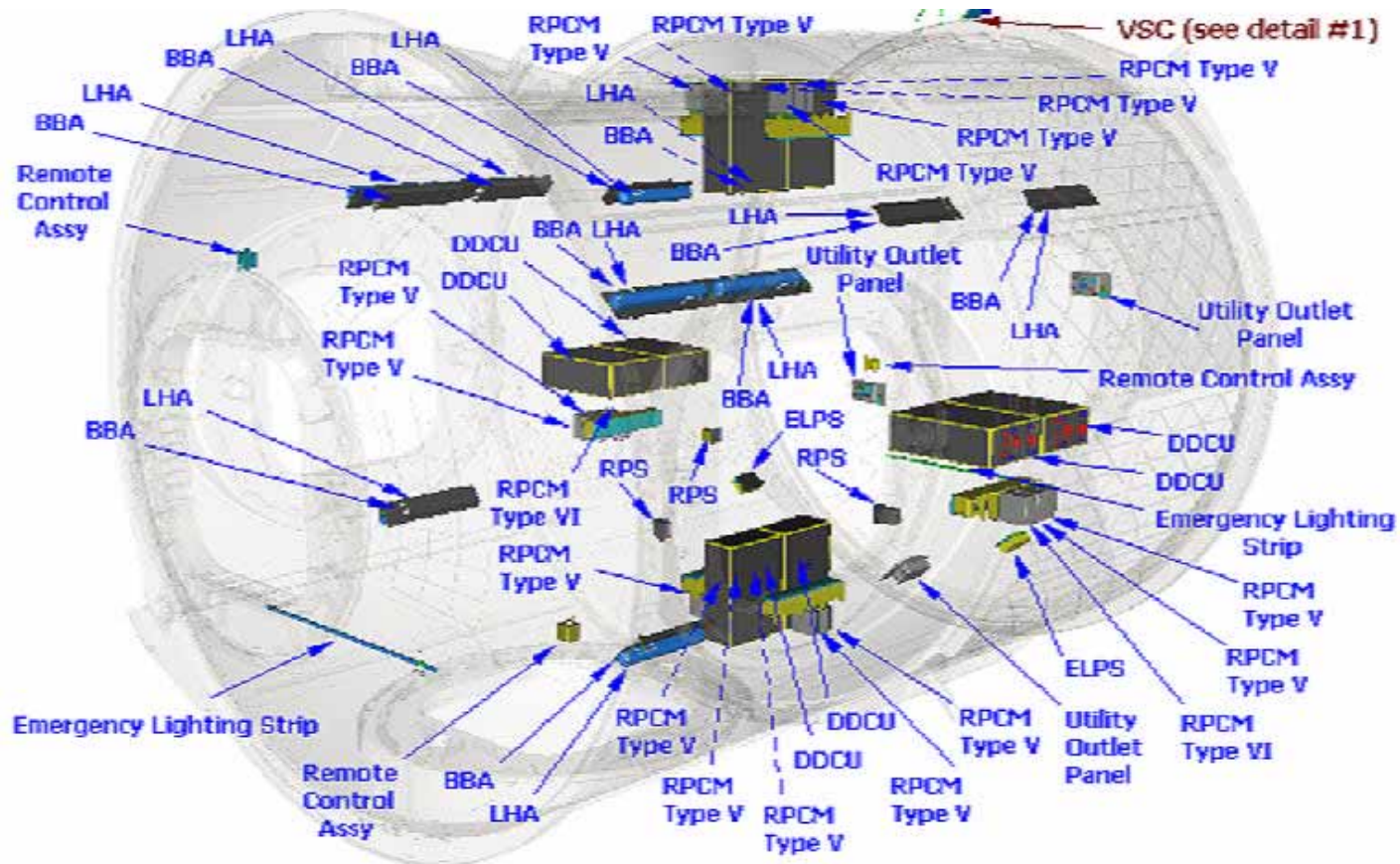
A TYPICAL MANNED SPACECRAFT SYSTEM: THE ISS NODE 2 SUBSYSTEMS

THE SUBSYSTEMS OF A LIFE SUPPORT SPACE SYSTEM (2)



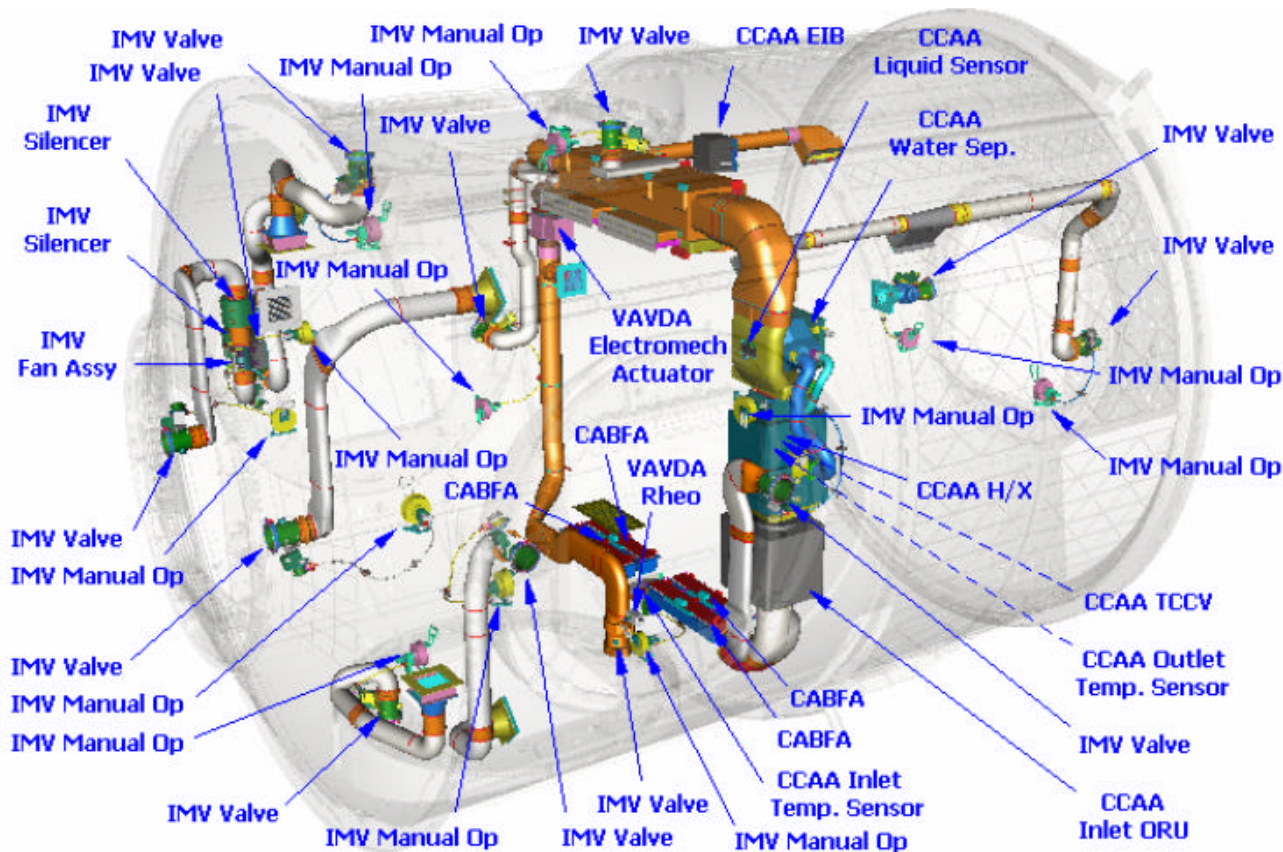
ISS NODE 2 PRIMARY STRUCTURE courtesy of Alcatel Alenia Space Italia

THE SUBSYSTEMS OF A LIFE SUPPORT SPACE SYSTEM



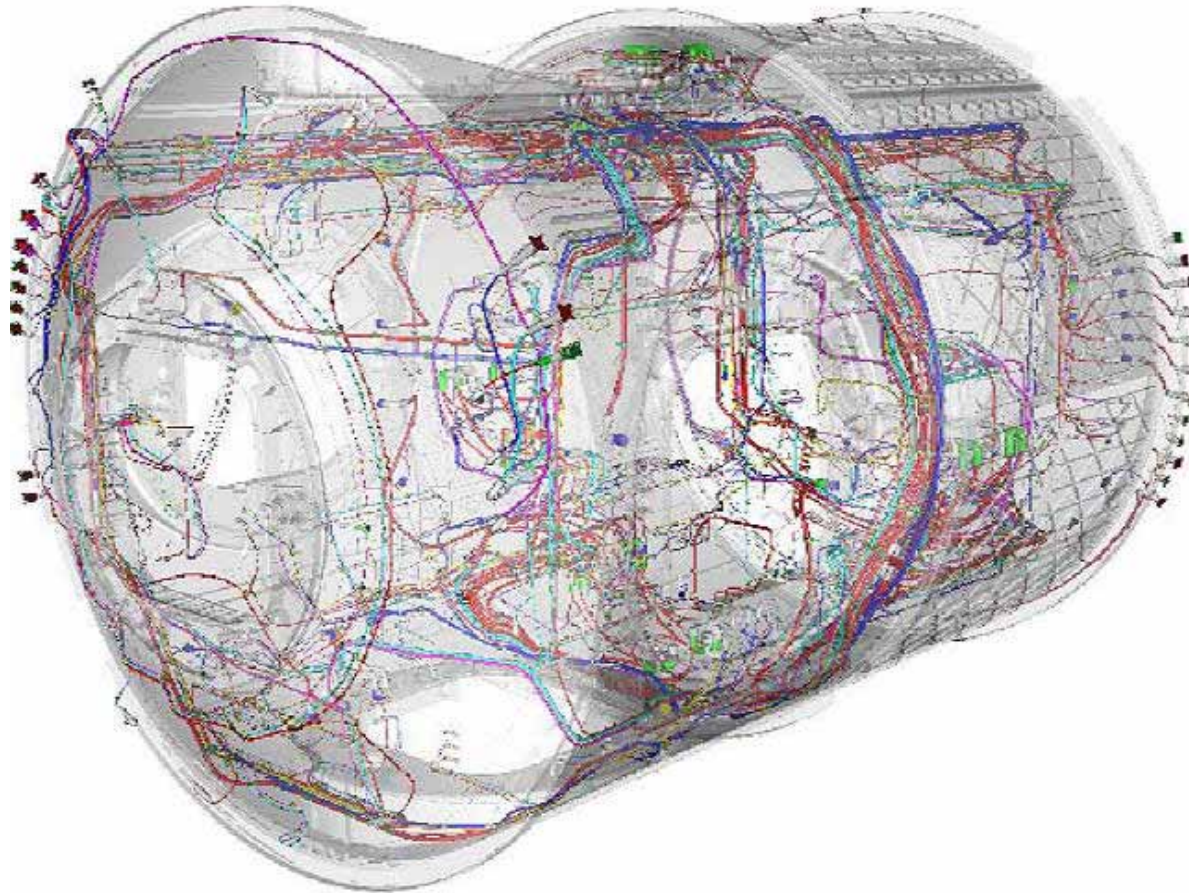
ISS NODE 2 ELECTRICAL POWER SYSTEM courtesy of Alcatel Alenia Space Italia

THE SUBSYSTEMS OF A LIFE SUPPORT SPACE SYSTEM



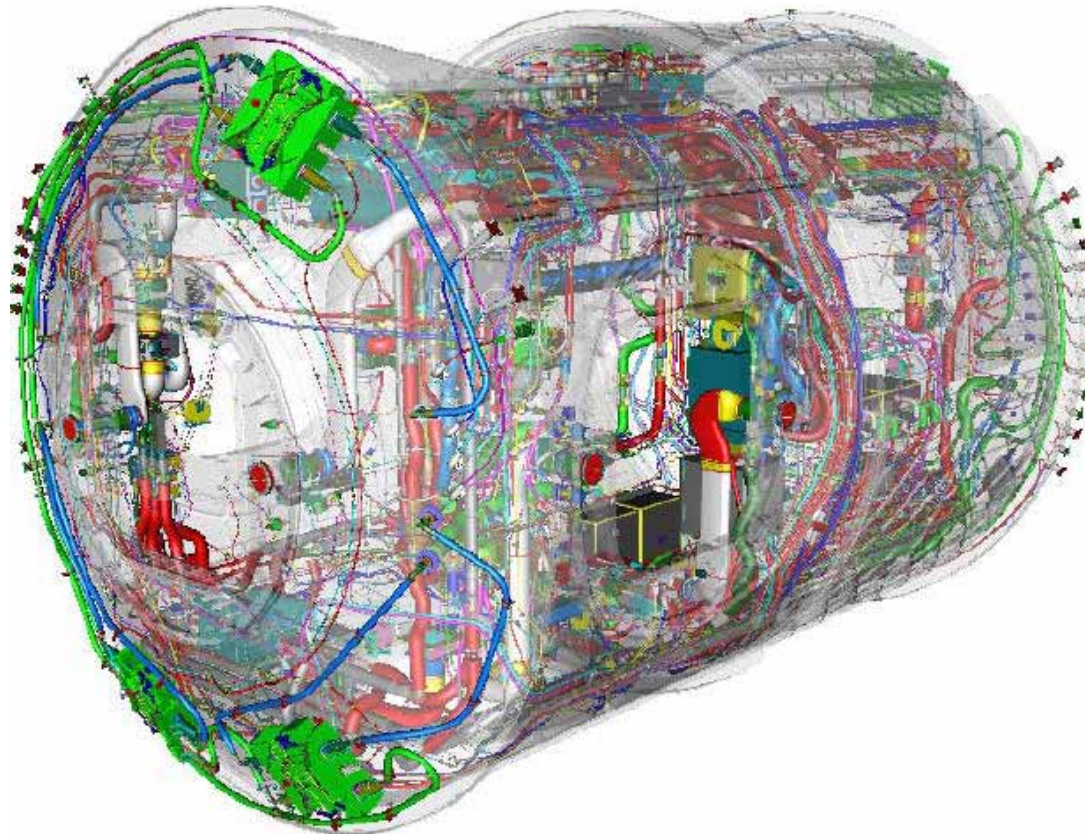
ISS NODE 2 ECLSS TEMPERATURE AND HUMIDITY CONTROL
courtesy of Alcatel Alenia Space Italia

THE SUBSYSTEMS OF A LIFE SUPPORT SPACE SYSTEM



ISS NODE 2 WIRE HARNESS courtesy of Alcatel Alenia Space Italia

THE SUBSYSTEMS OF A LIFE SUPPORT SPACE SYSTEM



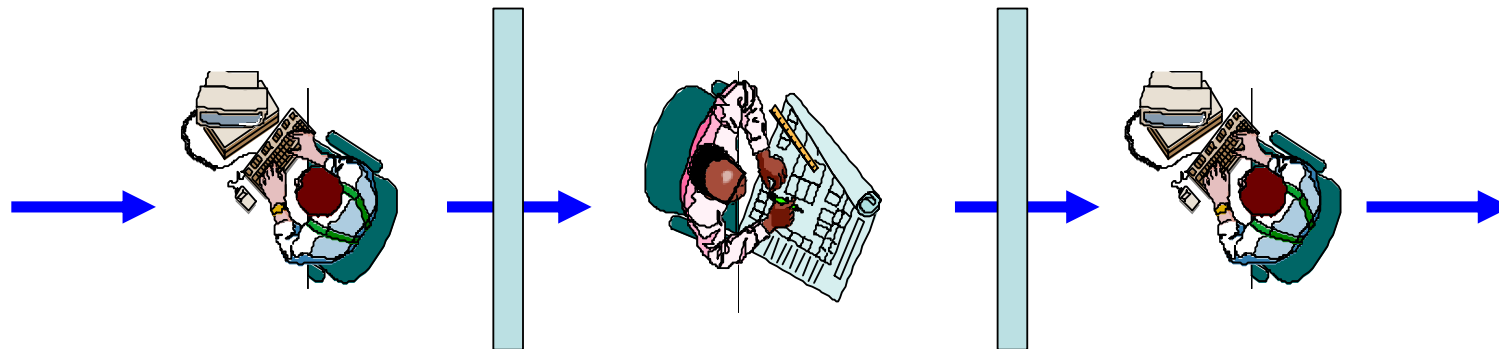
ISS NODE 2 OVERALL CONFIGURATION courtesy of Alcatel Alenia Space Italia

THE MANNED SPACECRAFT AS A VERY COMPLEX SYSTEM



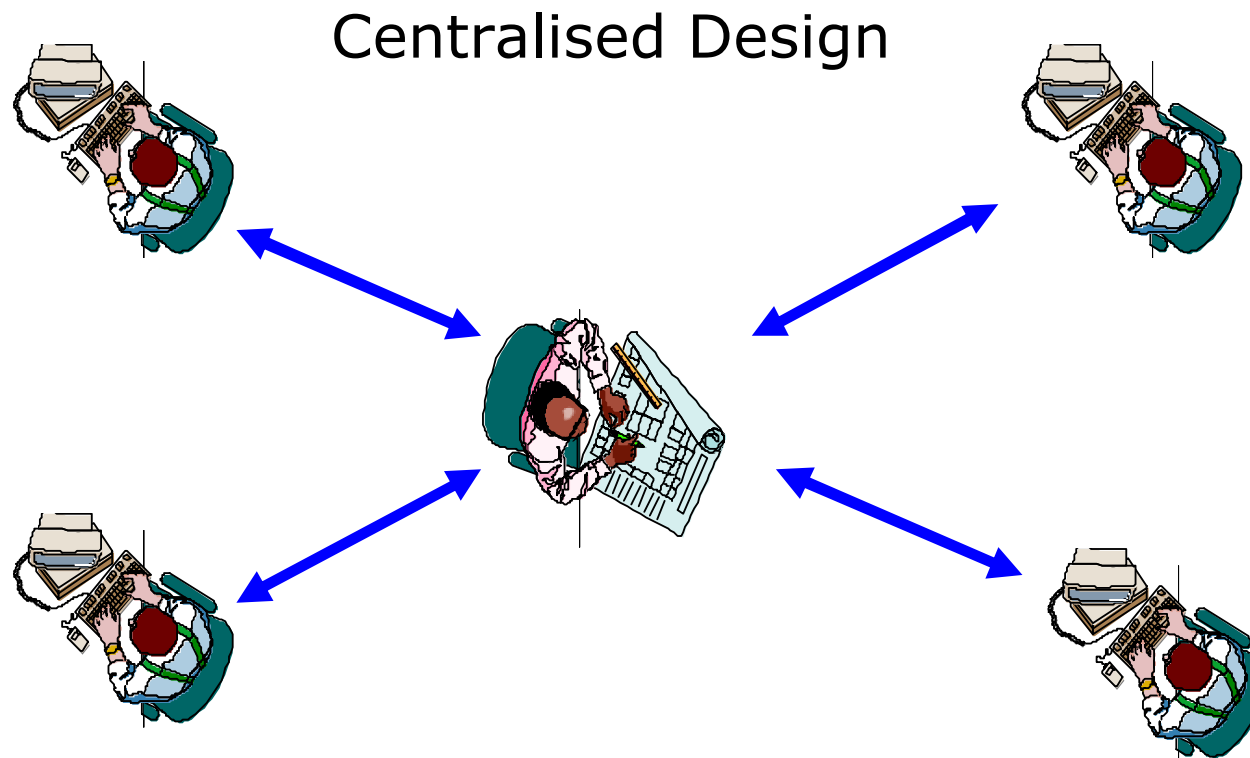
TRADITIONAL DESIGN PROCEDURES

Sequential Design (“over-the-fence” approach)



- **Presence of communication gaps between the “designer” (who produces design information) and the “user” (who utilises the design information).**
- **Designers and users belong to several families of specialists.**
- **Long iterative design cycles: long design times**

TRADITIONAL DESIGN PROCEDURES (2)



TOWARDS INNOVATIVE DESIGN PROCEDURES

WHAT DO WE NEED?

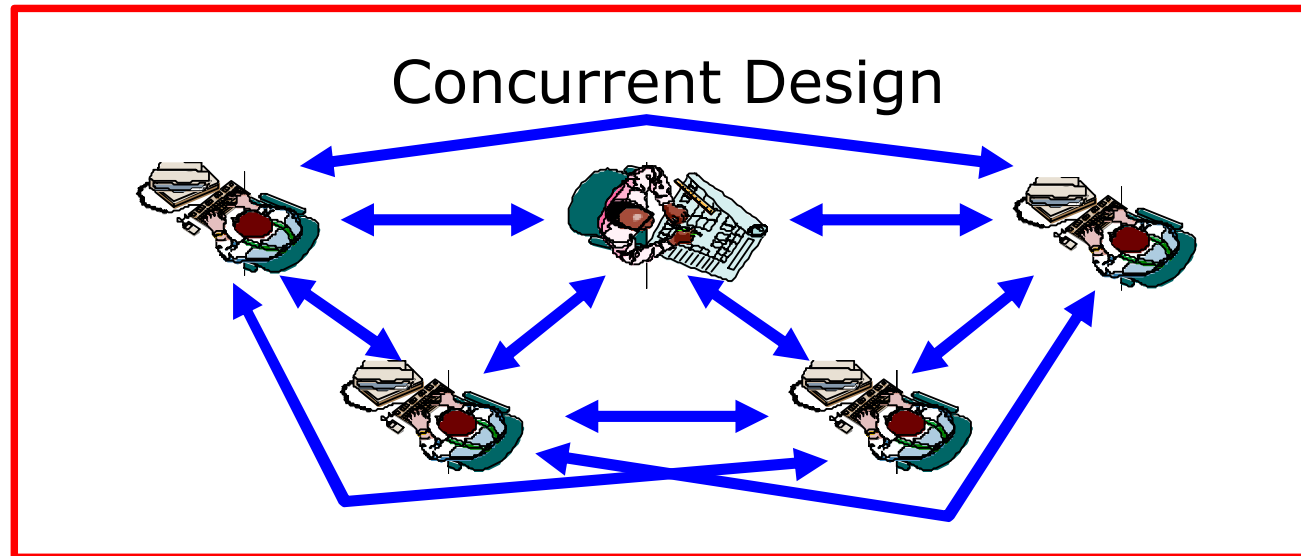
An **integrated design environment** for interdisciplinary applications especially conceived for the assessment and conceptual design of future space missions (i.e. pre-phase A / level 0 studies)

team orientated (concurrent)
collaborative engineering

integration of tools, project data, mission and system models

model driven, on-line- real-time design
co-operation, interaction, iterations

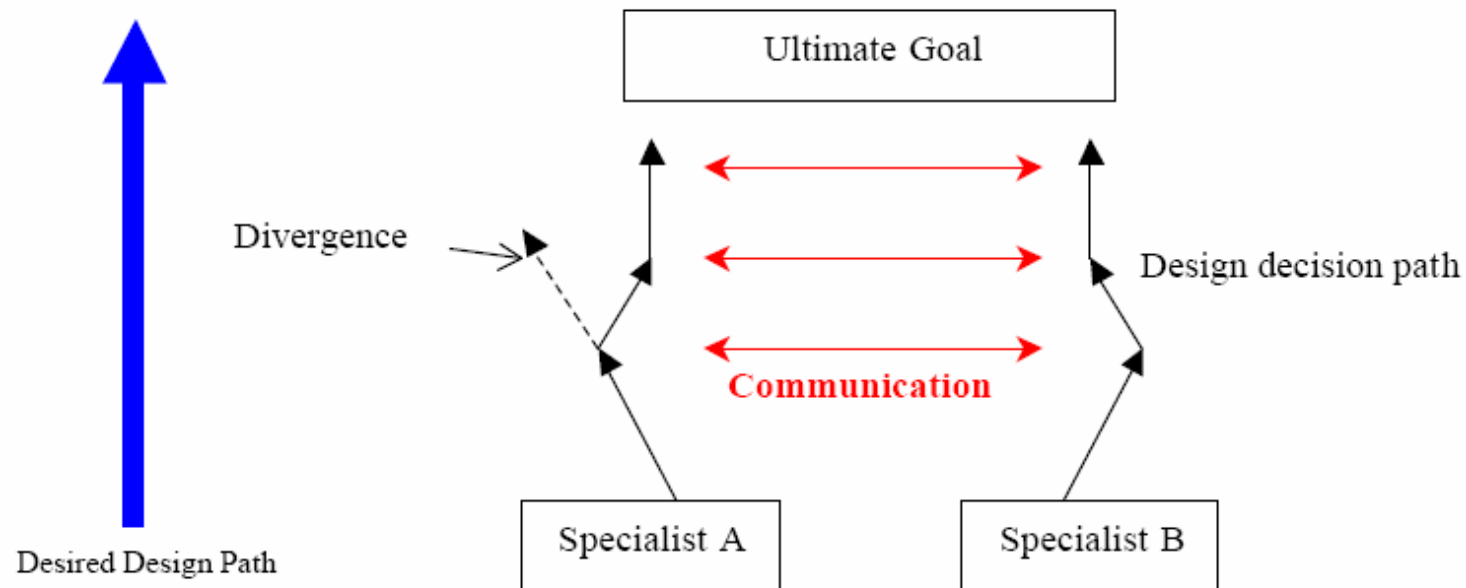
ADVANCED DESIGN PROCEDURES: CONCURRENT ENGINEERING



“Concurrent* Engineering is a *systematic approach* to integrated product development that emphasises the response to *customer expectations*. It embodies *team* values of *cooperation*, trust and sharing, in such a manner that decision making is by *consensus*, involving all perspectives *in parallel*, from the beginning of the product life-cycle.”

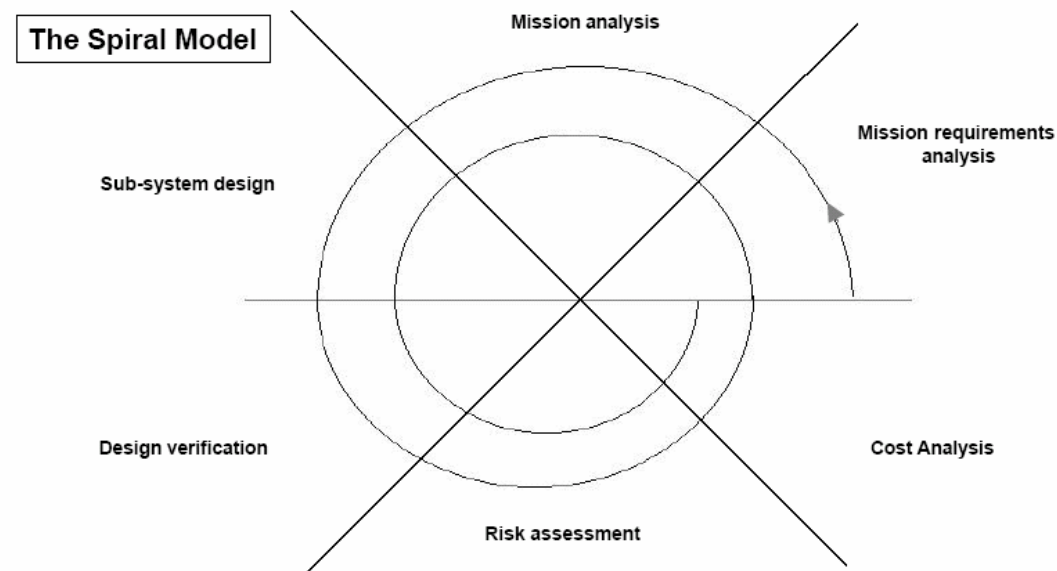
Courtesy of Esa CDF Massimo Bandecchi.

Why Concurrent Design?



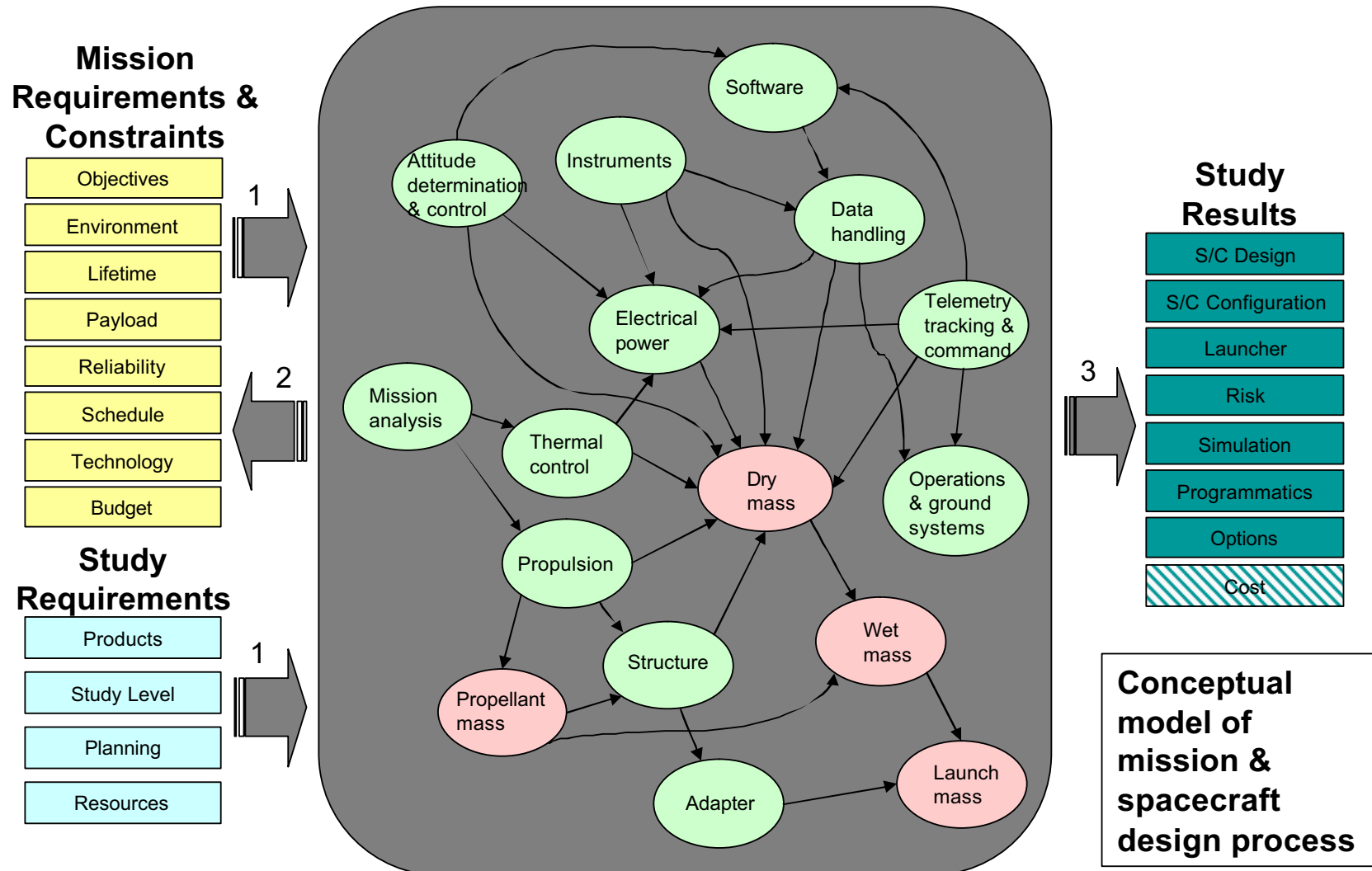
All the design team members can constantly follow the same design path, avoiding the occurrence of incompatible approaches

Iteration of the Design



Spiral Model

Successive iterations by the domain specialists converge to one or more design options to meet the mission requirements



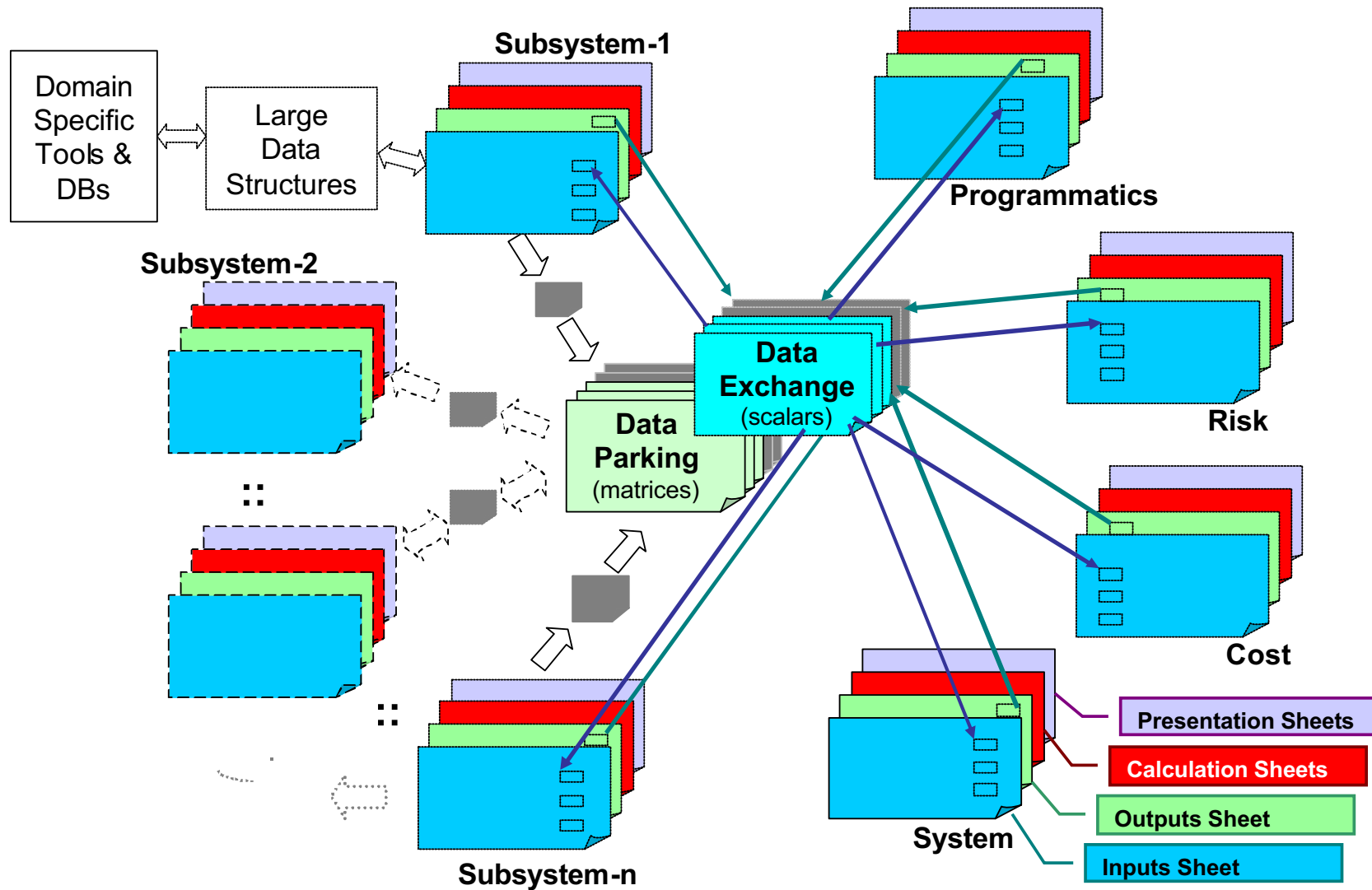
CDF: Design Process (from ESA)

Subsystems Design

- Definition of Subsystem Input and Output parameters for the assigned mission
- Analysis of subsystems features
- MS Excel Workbook Implementation

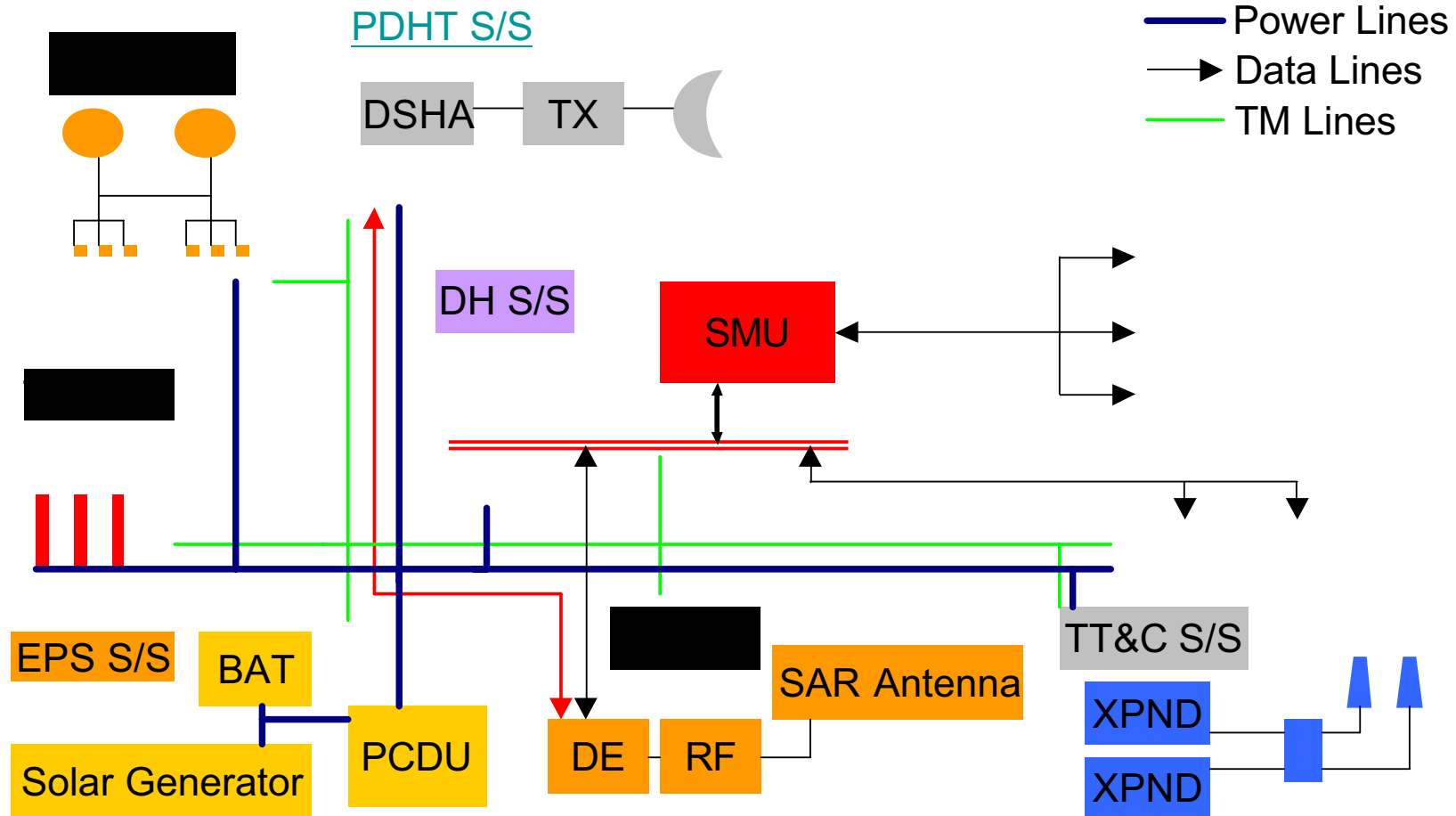


Subsystem design



Integrated Design Model

System Functional Architecture



System Mass Budget

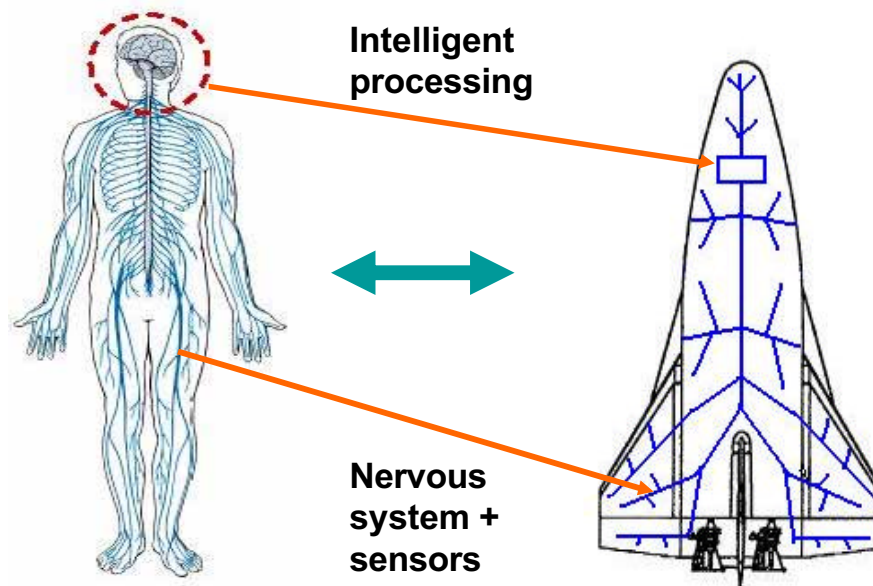
MASS BUDGET		FINGERSAT		Current Working Values					
				Target Spacecraft Mass at Launch		1050 kg			
				Below Mass Target by:		22 kg			
	Input Mass	Input Margin	<i>FGR</i>	Without Margin	Margins % kg		Totals kg	% of Total	
SST	170,00		Structure	168,6 kg	6,4	10,8	179,4	18,54	
SST	40,50		Thermal Control	29,8 kg	20,0	6,0	35,8	3,70	
DI	10,00		Mechanisms	10,0 kg	0,0	0,0	10,0	1,03	
DI				0,0 kg	0,0	0,0	0,0	0,00	
SST	8,10		Communications	7,0 kg	5,0	0,3	7,3	0,76	
SST	32,00		Data Handling	26,4 kg	10,0	2,6	29,0	3,00	
SST	45,00		PDHT	47,8 kg	5,2	2,5	50,3	5,19	
SST	50,00		AOCS	37,3 kg	5,0	1,9	39,2	4,05	
SST	13,50		Propulsion	14,6 kg	6,5	1,0	15,6	1,61	
SST	117,00		Power	100,2 kg	8,2	8,2	108,4	11,20	
DI	45,00		Harness	45,0 kg	0,0	0,0	45,0	4,65	
SST	310,00		Payload	297,0 kg	12,0	35,7	332,7	34,38	
DI				0,0 kg	0,0	0,0	0,0	0,00	
DI	20,00		Supports & Miscellanea	20,0 kg	0,0	0,0	20,0	2,07	
DI	10,00		Balancing Mass	10,0 kg	0,0	0,0	10,0	1,03	
				Total Dry (excl.adapter)	813,68 kg	8,5	69,0	882,7	91,21
SST	80,00		Propellant (main)				85,1	8,79	
DI	0,00		Pressurant				0,0	0,00	
	60,00		Adapter Mass			(incl. Sep. Mech.)	60,0	6,20	
				Total WET Mass			967,8	100,00	
				Total Launch Mass			1027,78		

Budgets: mass, power, link (unmanned), life support items (air, water, food, ...)

STRUCTURAL HEALTH MONITORING SHM for RLV IN THE FRAME OF HEALTH MANAGEMENT SYSTEMS FOR MANNED SPACE VEHICLES

Structural Health Monitoring

**Real-time knowledge of structural "health"
through a distributed sensor system integrated
into the structure + a diagnostic system (like
human nervous system)**



BENEFITS

- Increase of reliability and safety
- Minimisation of turnaround time and cost
- Extension of components lifetime

HEALTH MANAGEMENT SYSTEM (HMS)

- Systems and processing architectures necessary to perform a vehicle health assessment and to provide instructions on mission and maintenance actions
- Post-flight HMS → Ad-hoc inspection and maintenance
- In-flight HMS → Recovering actions or failure alert

HMS - STRUCTURAL HEALTH MONITORING

Active Piezoelectric Sensors (APS)

- **Principle** : Active damage detection based on Lamb-wave propagation (pulse-echo and pitch-catch) and on local E/M impedance method; possible use in a phased array of sensors and for passive damage detection.
- **Application** : Every kind of defect
- **Advantages** : **Large area coverage**, they can act simultaneously as **actuators and sensors**, lightweight, small size, low cost, non-invasive
- **Limitations** : Sensor durability and survivability to be demonstrated, **temperature limitations**, EMI, risk in flammable environments
- **Development needed** : Improvement of miniaturized embeddable sensors, methods for optimized sensor placement, temperature resistance improvement, wave propagation modelling in composites

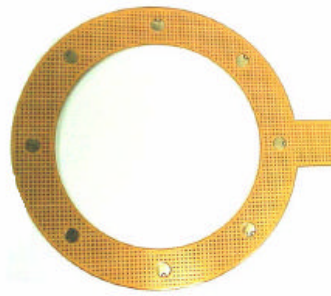
SMART Layer® (Acellent Technol.)

SMART Layers

- Thin dielectric film with PZT network
- Easy layer installation
 - Embedding
 - Surface mounting
- Various possible shapes



3D



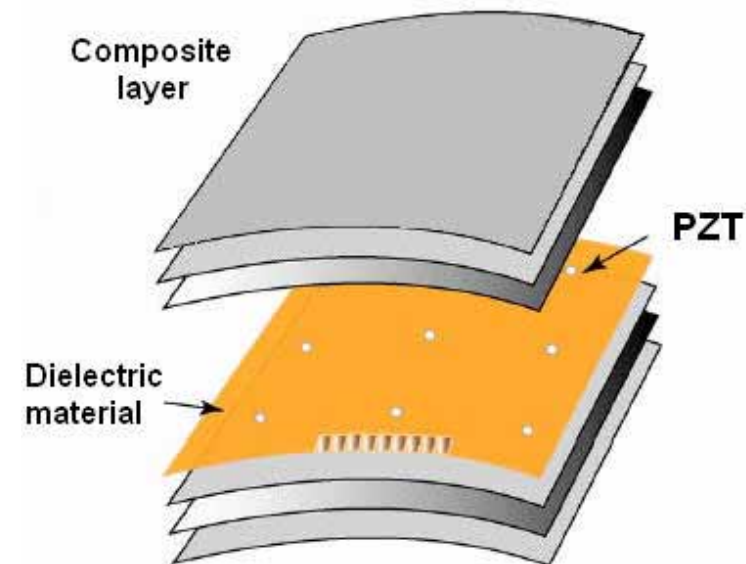
Circular



Rectangular

- Incorporation of other types of sensor (moisture, fibre optics,...)

- **Strain, temper. monitoring**
- **Impact detection**
- **Crack growth monitoring**
- **Debonding**
- **Cure monitoring**



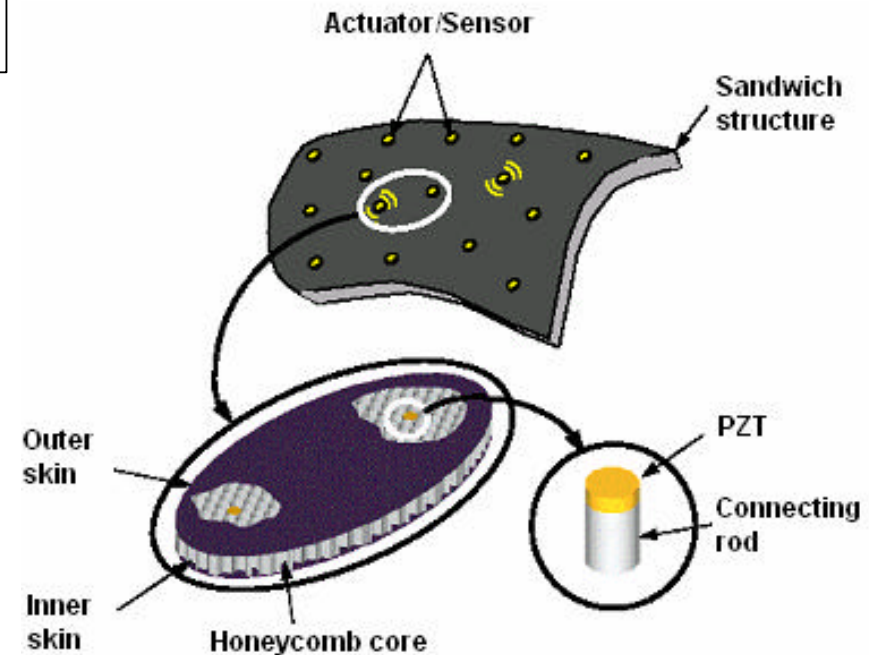
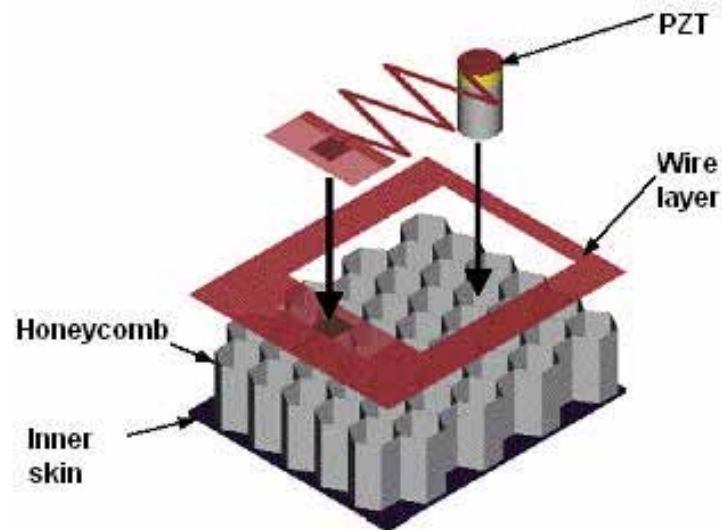
Embedded SMART Layer

APS – PZT embedded in honeycomb

(Stanford University)

- Application to cryogenic fuel tank
- High actuation energy - axial and radial
- Very sensitive to core-skin

- Investigation of temperature effect on signal
- Easy sensor installation



APS – Other piezoelectric systems

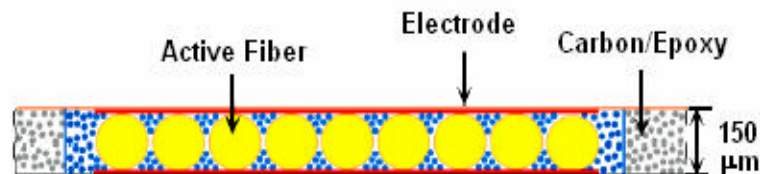
Piezoelectric Wafer Active Sensors

- Phased array of sensors (Univ. of South Carolina)
- Large area monitoring with Lamb wave technique
- Local area monitoring with E/Me impedance measurement
- Passive damage detection

Piezoelectric Fibre Composites (PFC)

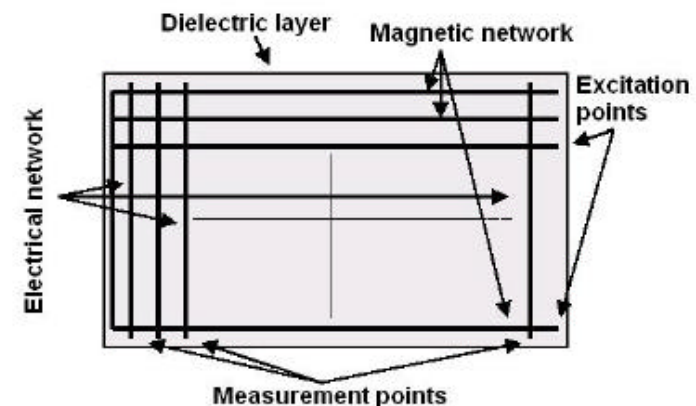
- Suitable to be embedded in CFRP

(Indian Institute of Technology, 2004)
(NASA-Langley)



Electromagnetic sensor network + PZT sensors

- Combination of electrical measurement + Lamb wave technique



(ONERA)

CONCLUSIONS

TRYING TO INVESTIGATE ABOUT SOME FUNDAMENTAL QUESTIONS:

DO WE UNDERSTAND THE COMPLEXITY OF A LIFE SUPPORT SPACE SYSTEM?
THE SPACECRAFT AS A COMPLEX SYSTEM

WHAT DO WE NEED FOR THE ENHANCEMENT OF DESIGN PROCEDURES FOR SPACE EXPLORATION?
CONCURRENT ENGINEERING PROCEDURES

WHAT ARE THE DRIVING CRITERIA FOR AN OPTIMAL DESIGN OF A SPACE SYSTEM AND FOR THE SUCCESS OF A SPACE MISSION?
DESIGN BY USING SYSTEM BUDGETS

HOW CAN WE ASSURE THE SAFETY OF THE ASTRONAUTS?
SYSTEM HEALTH MANAGEMENT TECHNIQUES