National Aeronautics and Space Administration

GSFC Systems Engineering Seminar

Concurrent Engineering, the GSFC Integrated Design Center, and NASA's Concurrent Engineering Working Group

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GSFC, Code 592

January 10, 2012

yesterday's dream, today's concept, tomorrow's reality

OUTLINE

- Introduction to the GSFC Integrated Design Center — 15 min
- Introduction to Concurrent Engineering — 60 min
  - <u>Processes</u> — <u>15 min</u>
    - Task Ordering — (5 min)
    - “Basic Research”: DSM Optimization: Partitioning, Tearing; Socio-Cognitive Analysis — (5 min)
    - “Applied Research”: The Gezintos Gezoutos Project — (5 min)
    - Agile Concurrent Engineering (ACE) — (5 min)
  - <u>Facilities and Tools</u> — <u>15 min</u>
    - Micro-Comm Platform (The Room) — (2 min)
    - Macro-Comm Platform (Data Exchange Platforms, ISDP)
    - Contingencies and Margins — (5 min)
  - <u>People</u> — <u>30 min</u>
    - Teamwork in High Performance Concurrent Engineering Teams
- Overview of the CEWG — 15 min

Acknowledgement

The IDC, the CEWG, and this presentation, wouldn't be possible without all the fundamental contributions over the years by the following *(not in any particular order)*:

- Mike Ryschkewitsch, Bruce Campbell, Mark Steiner, John Martin, Tammy Brown, Jennifer Bracken, John Oberright, Dennis Evans, Mike Roberto, Ellen Herring, Kris Brown, Carmel Conaty, Bill Hayden, Dave Everett, Jim Morrissey, Cynthia Firman, Anel Flores, Debbie Amato, Robin Mauk, Frank Kirchman, Martha Chu, Scott Applebaum, Sue Olden, Donya Douglas, John Woods, Bruce Thoman, Dawn Daelemans, Dave DiPietro, Hanxin Wu, Adrian Colburn, and way too many other talented Code 500 IMDC, ISAL, MDL and IDC engineers and managers to list,

- … as well as our valued Customers who supported us throughout the years, especially Bonnie Norris and her Team, Peter Hughes and his Team, the Code 400 Programs and Code 600 Science Communities

- … and JPL's Team-X, especially Keith Warfield, Jairus Hihn, and Debbie Wheeler, and Aerospace Corp.'s CDF, especially Dan Nigg

GSFC Integrated Design Center

- **Rapid development of science instrumentation and mission architecture concepts**
  - Multi-disciplinary concurrent collaborative space system engineering design and analysis
- **Benefits**
  - New Business Support
  - Cross-organization Support
  - Core Competency Maintenance and Enhancement
  - Technology Infusion
- **Serving a diverse group of customers**
  - All NASA centers and enterprises
  - Other Federal Agencies
  - Academia and research institutions, national and international
  - Industry, national and international
- **Services custom tailored to customer needs**
  - End-to-end concept studies
  - Focused-studies
  - Independent technical assessments
  - Technology and risk assessments

Birth of the IDC

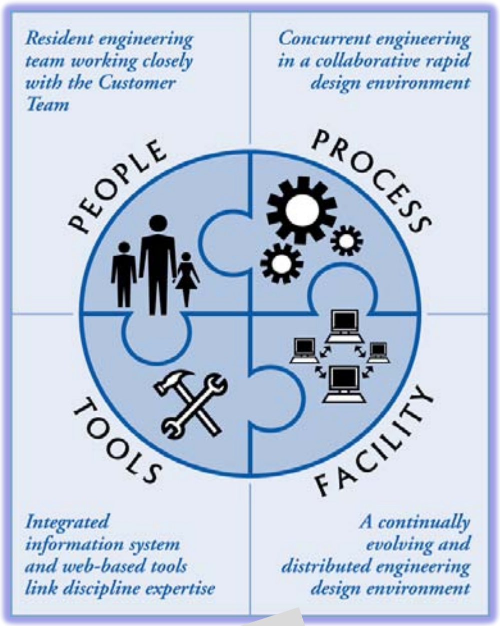
- In 1997, around the time when full cost accounting arrived to NASA, the method by which GSFC gains new business has changed to a competitive process
  - Less assignment/dedication of particular mission areas to GSFC within NASA
  - More need for formal proposals to win new work
  - The old “project” based approach was too slow and cumbersome

- Goddard decided to restructure the new business process, people, and facilities to ensure GSFC’s competitiveness and ability to win new work:
  - Code 100: Deputy Center Director for new business, New Opportunities Office, LOB’s, Technology Management Office
  - Code 400: Project Formulation Office
  - Code 500: **Integrated Design Center**

Evolution of the IDC

yesterday's dream, today's concept, tomorrow's reality

IDC



Over 500 Studies conducted since 1998

1997
Mission Design Lab (MDL)
formerly named Integrated Mission Design Center (IMDC)

1999
Instrument Design Lab (IDL)
formerly named Instrument Synthesis & Analysis Lab (ISAL)

2001
Integrated Design Center (IDC)

2010
Early Concept Engineering / Architecture Design Lab (ADL)

2011
Mission Concept Engineering / Stewardship Engineering Services

2010
CEWG, Reviews, Techn. Authority, Talks, Outreach, etc.

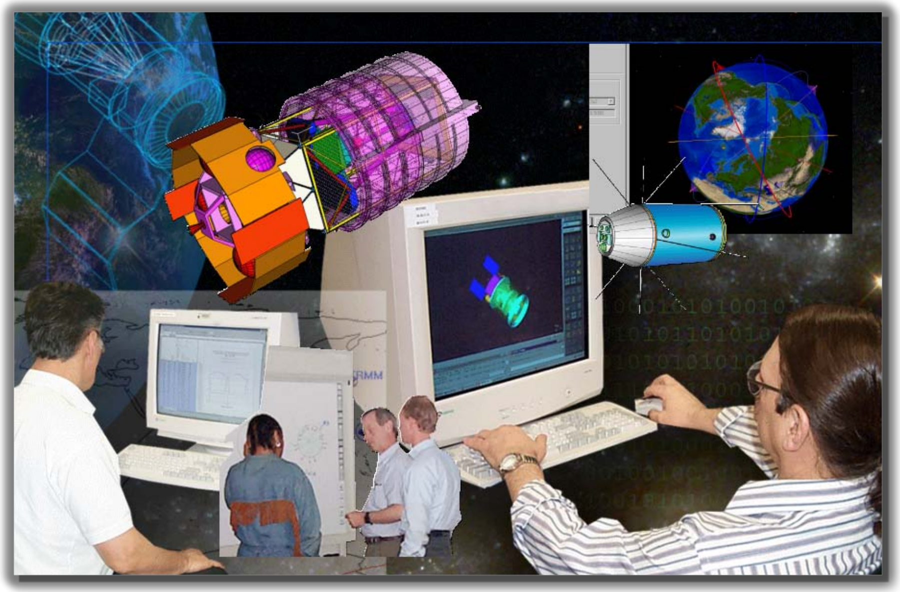
MDL – Capabilities and Services

Capabilities:

– Complete mission design capabilities include LEO, GEO, libration, retrograde, drift away, lunar, and deep space orbit and spacecraft design
– Single spacecraft, constellations, formation flying, distributed systems
– Ground system concept development, including services, and products
– Expendable, non-expendable launch accommodations
– Controlled and uncontrolled de-orbit as well as controlled recovery modules, etc.

Services:

– End-to-end mission concept development
– Existing mission or concept evaluations
– Trade studies and evaluation
– Technology, risk, and independent technical assessments
– Requirement refinement and verification
– Mass/power budget allocation
– Cost estimation



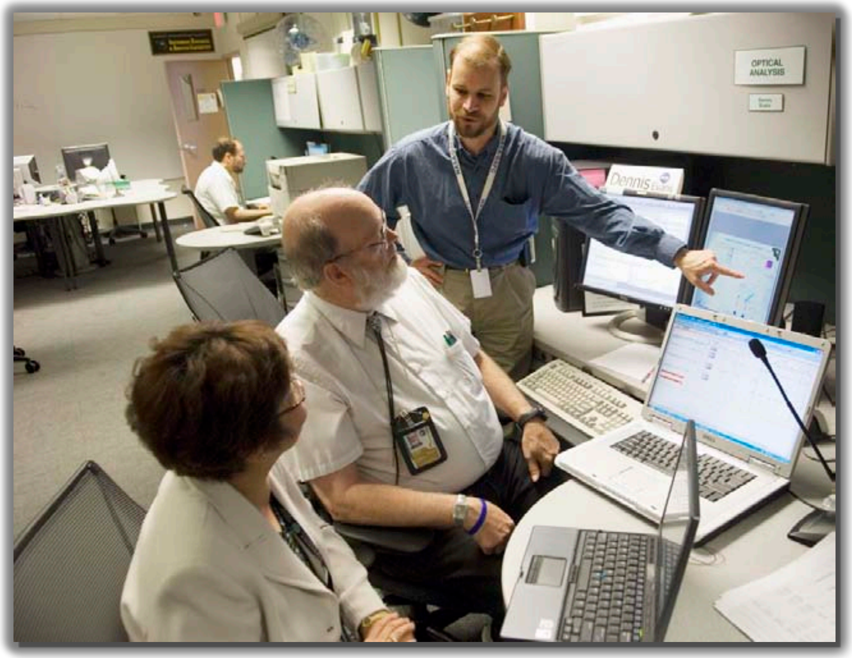
IDL – Capabilities and Services

Capabilities:

- Instrument families covering the entire range, with spectrum support from microwave through gamma ray
  - Imagers, Cameras; Spectrometers; Lidars; Cosmic Ray and X-Ray Telescopes; Solar Physics Instruments, Spectroheliographs; Passive or Microwave Radiometers; Infrared Cosmology Instruments and Telescopes; Geo-chemistry experiments; Planetary Orbiter Instruments and Planetary Sondes and Lander Instruments; Optical Molecular Sensors; Large Weather Satellite Instruments
- For LEO, GEO, libration, retrograde, drift away, lunar, planetary, deep space, balloon, sounding rockets and UAV
- Non-distributed and/or distributed instrument systems

Services:

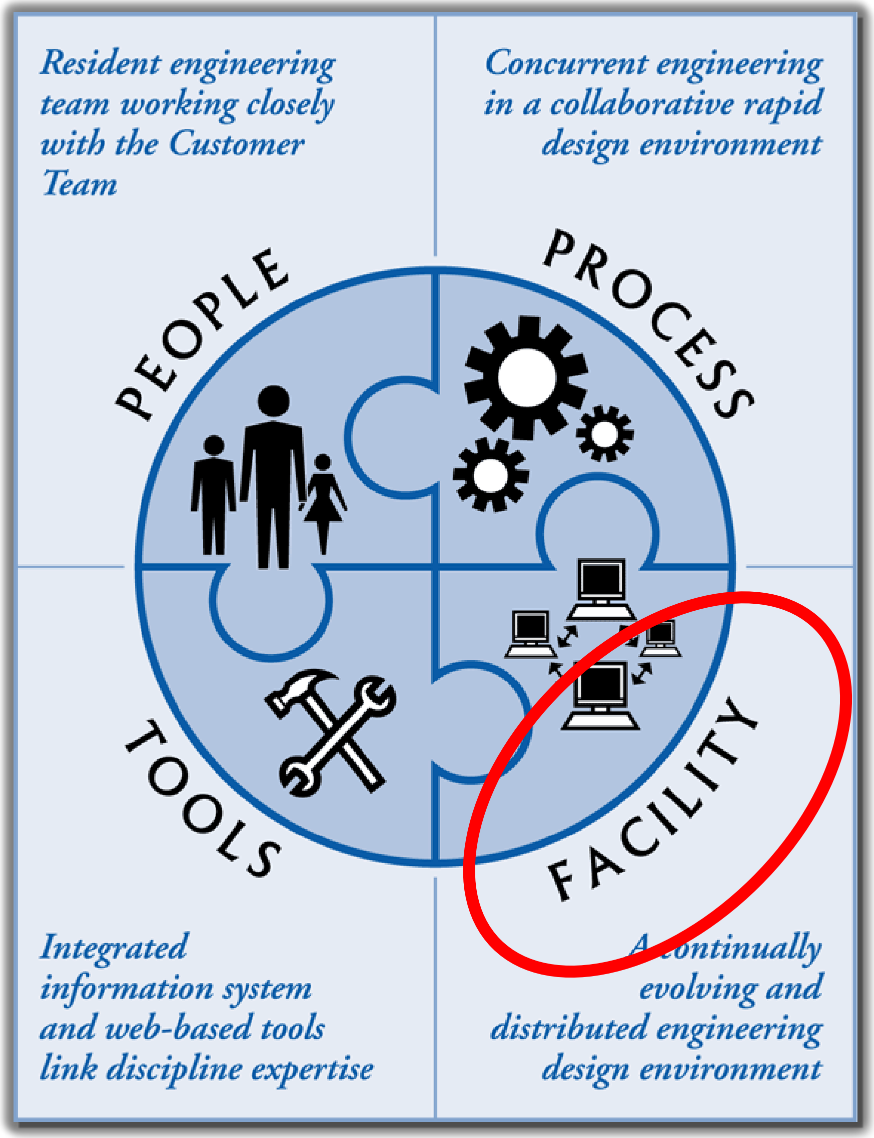
- End-to-end instrument architecture concept development
- Trade studies and evaluation
- Existing instrument/concept architecture evaluations
- Technology, risk, and independent technical assessments
- Requirement refinement and verification
- Mass/power budget allocation
- Cost estimation



IDC Lab Disciplines

IDL	Common	MDL
• Optics	• Systems	• Command & Data Handling
• Electro-optics	• Engineering Mechanical Design	• Mission Operations
• Detectors	• Electronics/Avionics	• Propulsion
• Cryogenics	• Thermal	• Flight Dynamics
• Lasers	• Software	• Electrical Power
• Microwave Systems	• Integration & Test	• Orbital Debris
• Instrument Electronics	• Contamination	• Launch Vehicle
• Data Systems	• Radiation Environment	• Ground Systems
• Structures	• Reliability	• Attitude Control
• Electro-mechanisms	• Cost Estimation	• Communications
• Orbit and Fine Guidance		• End of Mission Life

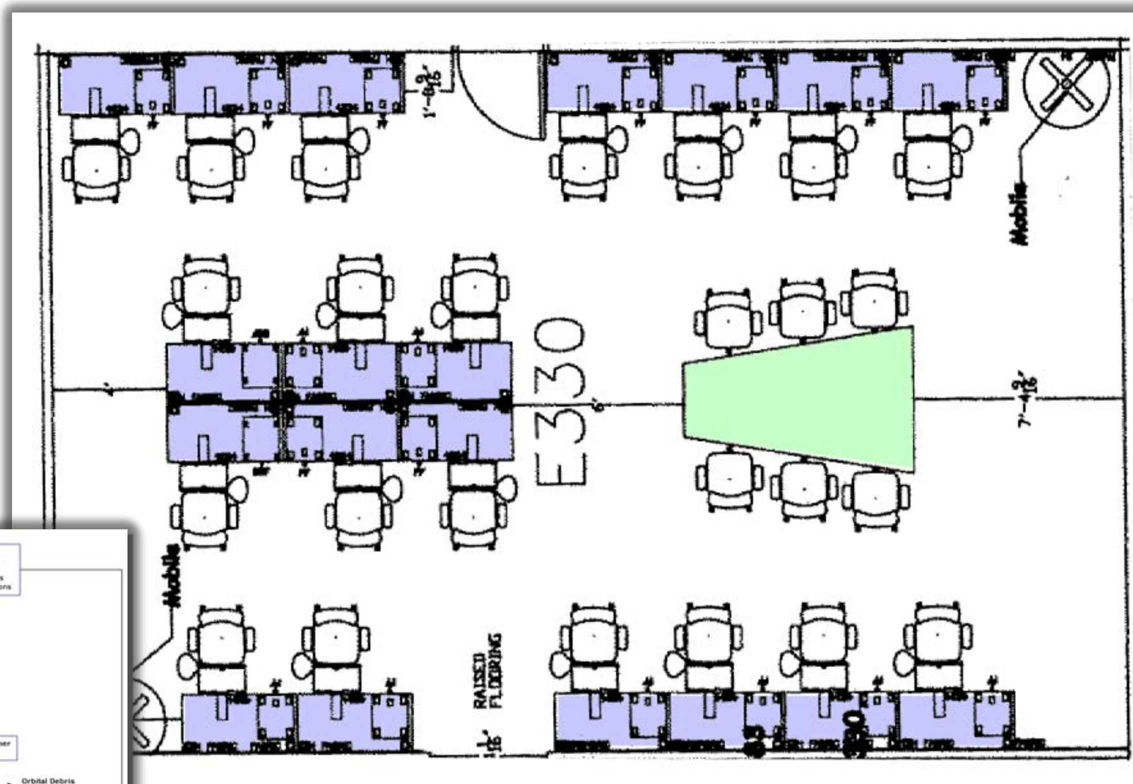
IDC Facility

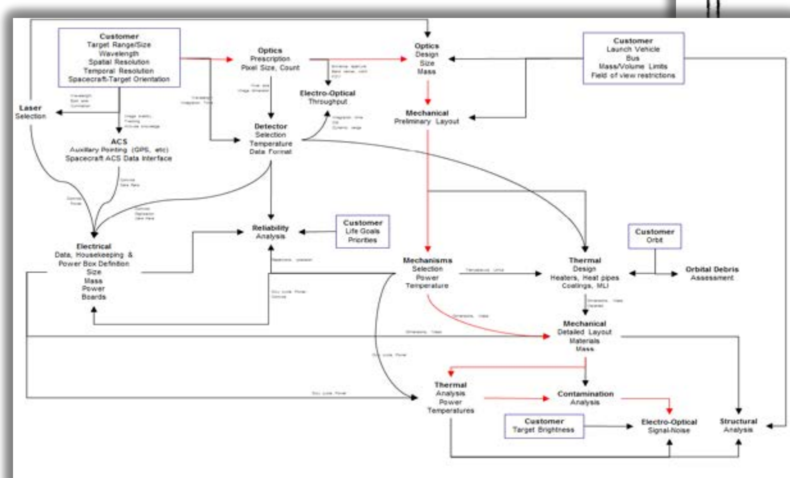


Facilities Designed for Concurrent Collaboration

- All required engineering disciplines co-located in the same facility cooperating at the same time DEDICATED to the study for the study duration
- Customer team embedded as a part of design team

Current IDL





Mission Design Lab (MDL)

Lab Lead | MDL Systems Engineer

- Reliability
- Structural
- Mechanical Systems Engineer
- Thermal Engineer
- Contamination
- Mechanical Designer
- Avionics
- Radiation Environment
- Power Systems Engineer
- Communications Engineer
- Integration and Test
- Flight Software
- Ground Systems
- Missions Operations
- Attitude Control
- Team Lead
- Deputy Team Lead/ Systems Engineer
- Launch Vehicle
- Mechanical Systems Engineer
- Mission Cost
- Orbital Debris
- Flight Dynamics
- Propulsion

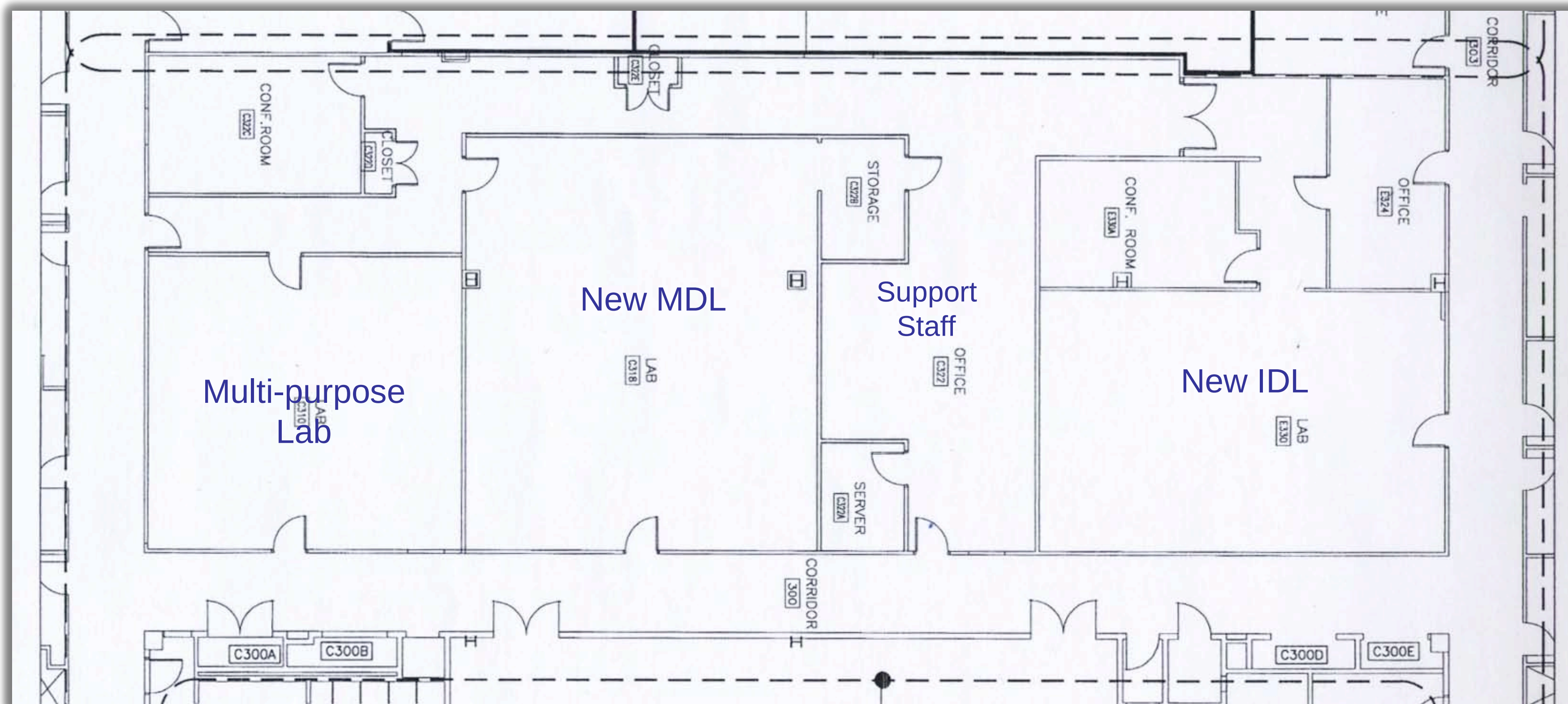
Instrument Design Lab (IDL)

Lab Lead | IDL Systems Engineer

- Reliability
- Structural
- Mechanical Systems Engineer
- Electro-mechanical Engineer
- Cryogenics
- Thermal Engineer
- Contamination
- Mechanical Designer
- Electro-optics
- Optics
- Detectors
- Lasers
- Microwave Systems
- Team Lead
- Deputy Team Lead/ Systems Engineer
- Instrument Systems Engineer
- Instrument Cost
- Radiation Environment
- Avionics/Electronics
- Integration and Test
- Flight Software
- Fine Guidance
- Orbital Design

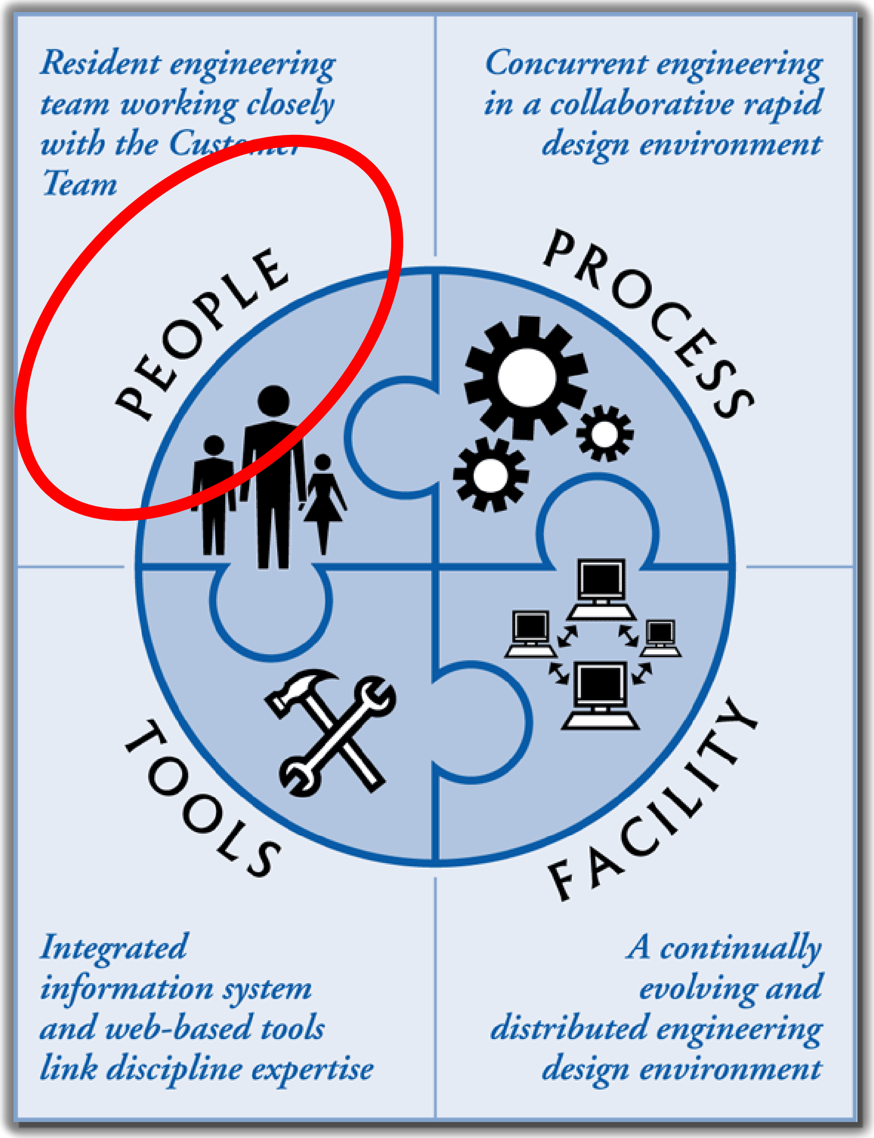
Customer Participation During An Actual Design Session

IDC Recent Expansion



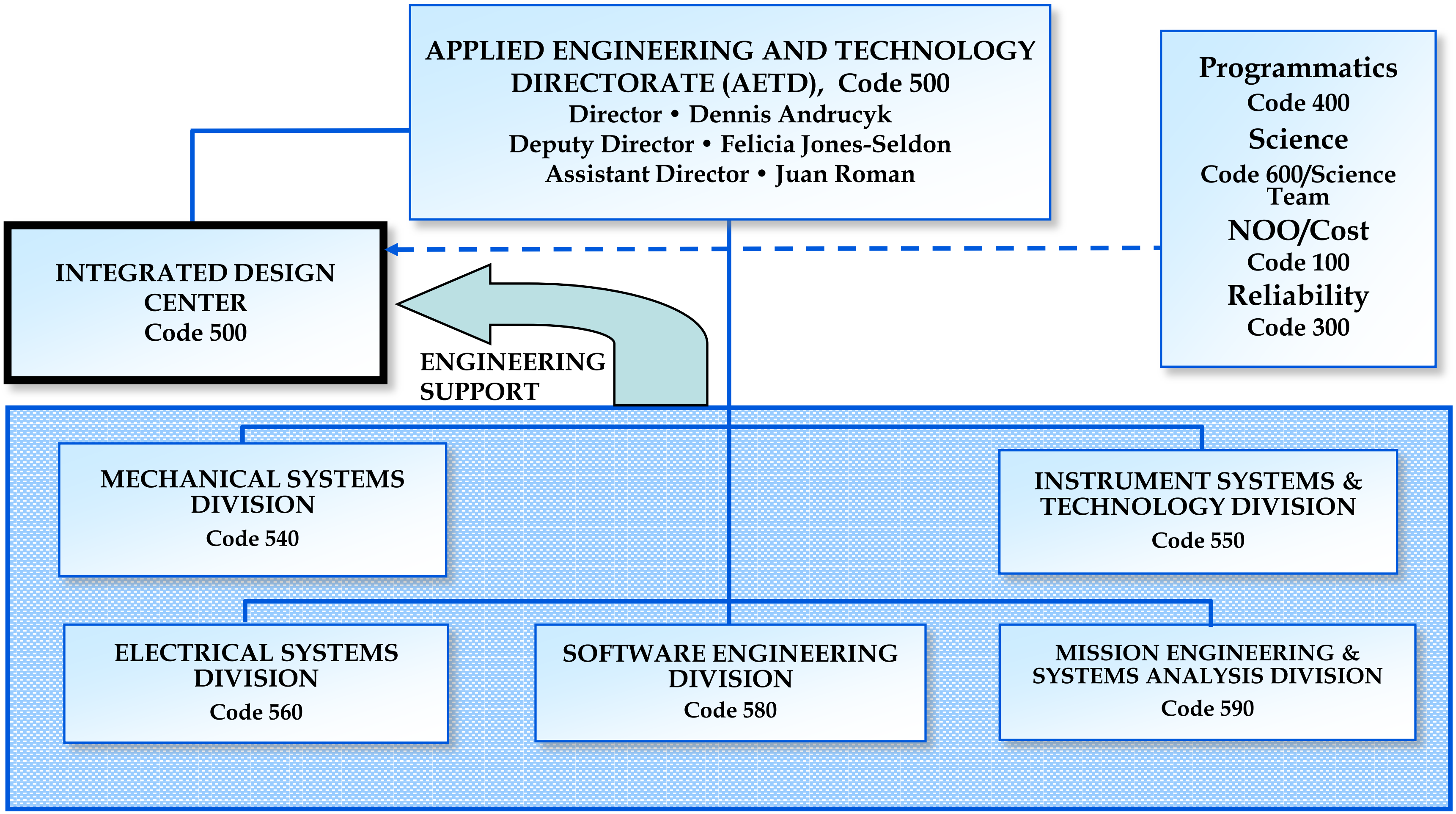
MDL Facility Video

IDC People



Resident engineering team working closely with the Customer Team
Concurrent engineering in a collaborative rapid design environment
PEOPLE
PROCESS
TOOLS
FACILITY
Integrated information system and web-based tools link discipline expertise
A continually evolving and distributed engineering design environment

Organization



Center commitment to provide required expertise as needed for each study

Disciplines and Engineers in the MDL (not a complete list)

Mission Design Lab (MDL)

Reliability Aron Brall 302/SRSTE Belkacem Manseur 302 302	**Mechanical Designer** David Peters 543 547	**Ground Systems** Steve Tompkins 581 Stephanie Nickens 581 Cindy Adams 584 581	**Deputy Lab Lead/MSE** TBD 592 592
Structural Analysis TBD 542	**Avionics/Electrical Systems** Ed Brinker 561 Jack McCabe 561 Terry Smith 561 561/565	**Flight Software** Kequan Luu 582 David Hardison 588 Carver Audain 582 582	**Launch Vehicle** Larry Phillips 592 592
Mechanical Systems Engineer TBD 543	**Radiation Environment** David Batchelor 561 Tony Sanders 561 561	**Missions Operations** Stephanie Nickens 581 Steve Tompkins 581 Cindy Adams 584 584	**Mission Costing** Larry Phillips 592 Sharon Seipel 605 592
Electro-Mechanical Systems TBD 544	**Power Systems** Bob Beaman 563 David Jung 563 563	**GN&C/ACS** Doug Freesland 596/ACSE Dave Olney 595 Scott Miller 424/OSC 591/595	**Orbital Debris** Ivonne Rodriguez 592 592
Thermal Engineer Kim Brown 545 George Daelemans 545 Eric Grob 545 545	**RF Communications** Ron Vento 567 Brian Gosselin 567 567	**Lab Lead** Mark Steiner 592 592	**Flight Dynamics** Michael Mesarch 595 Frank Vaughn 595 Greg Marr 595 595
Contamination Philip Chen 546 546	**Integration and Test** Harvey Safren 568 568	**Mission Systems Engineer** Frank Kirchman 592 592	**Propulsion** Rick Caverly 454/OSC 597

Disciplines and Engineers in the IDL (not a complete list)

Instrument Design Lab (IDL)

Reliability
Aron Brall/300/SRSTE
Belkacem Manseur/322
Ming Li/300/SRSTE
302

Structural
Jeff Bolognese/542
542

Mechanical Systems Engineer
Mike Clark/543
Dan Helfrich/543
Drew Jones/543
543

Electro-mechanical Engineer
Ken Blumenstock/544
Gary Brown/544
Paul Grimm/544/Bastion
544

Thermal Engineer
Mike Choi/545
Kim Brown/545
Eric Silk/545
545

Contamination
Dave Hughes/546
Philip Chen/546
546

Mechanical Designer
Dave Palace/547
Bobby Nanan/547
547

Electro-optics
Eric Young/551
Brad Greeley/551
551

Optics
Dennis Evans/551
Bert Pasquale/551
551

Cryogenics
Judy Gibbon/552
Rob Boyle/552
Theo Meunch/552
552

Detectors
Carl Kotecki/553
Sachi Babu/553
Thomas Stevenson/553
553

Lasers
Antonios Seas/554
Steve Li/554
Jeff Chen/554
554

Microwave Systems
Brian Gosselin/567
Terence Doiron/555
Fernando Pellerano/555
555/567

Team Lead
Tammy Brown/556
Sue Olden/586
556

Instrument Systems Engineer
Scott Appelbaum/462/Qwaltec
556

Deputy Team Lead/ Systems Engineer
Martha Chu/586
556

Instrument Cost
Sanjay Verma/605/QSS
Bill Lawson/605
556

Radiation Environment
Tony Sanders/561
David Batchelor/606
561

Avionics/Electronics
Joe Novotka/565/QSS
Terry Sullivan/560/MUNIZ
John Staren/567/QSS
565

Integration and Test
Harvey Safren 568
568

Flight Software
Ann Koslosky/582
J.P. Swinski/582
Dave Hardison/582
582

Fine Guidance
Doug Freesland/417/ACSEN
Dave Lorenz/428/SGT
Dave Olney/595
595

Management

Dawn Daelemans, Code 501
IDC Project Support

Bruce Campbell
Code 500
IDC Manager

Gabe Karpati
Code 592
IDC Senior Systems Engineer

Mission Design Lab (MDL)

Mark Steiner Code 592
Lab Lead

Frank Kirchman, Code 592
MDL Mission Systems Eng.

Discipline Engineering Team
Codes 300/400/500/600

Infrastructure

Carlos Dutan, Code 585
IDC IT Team Lead

Henry Cao
Dawn Cooper
Nancy Iacona
Facility / IT / SW
Support

Instrument Design Lab (IDL)

Tammy Brown, Code 556
Lab Lead

Martha Chu, Code 556
DLL, Instrument Systems Eng.

Scott Appelbaum/462/Qwaltec
Instrument Systems Eng.

Discipline Engineering Team
Codes 300/500/600

IDC organized for efficiency and to provide maximum support to studies

Key Personnel / Contacts

IDC Manager: Bruce Campbell/500, 301-286-9808

IDC Resources/Support: Dawn Daelemans/501, 301-286-5036

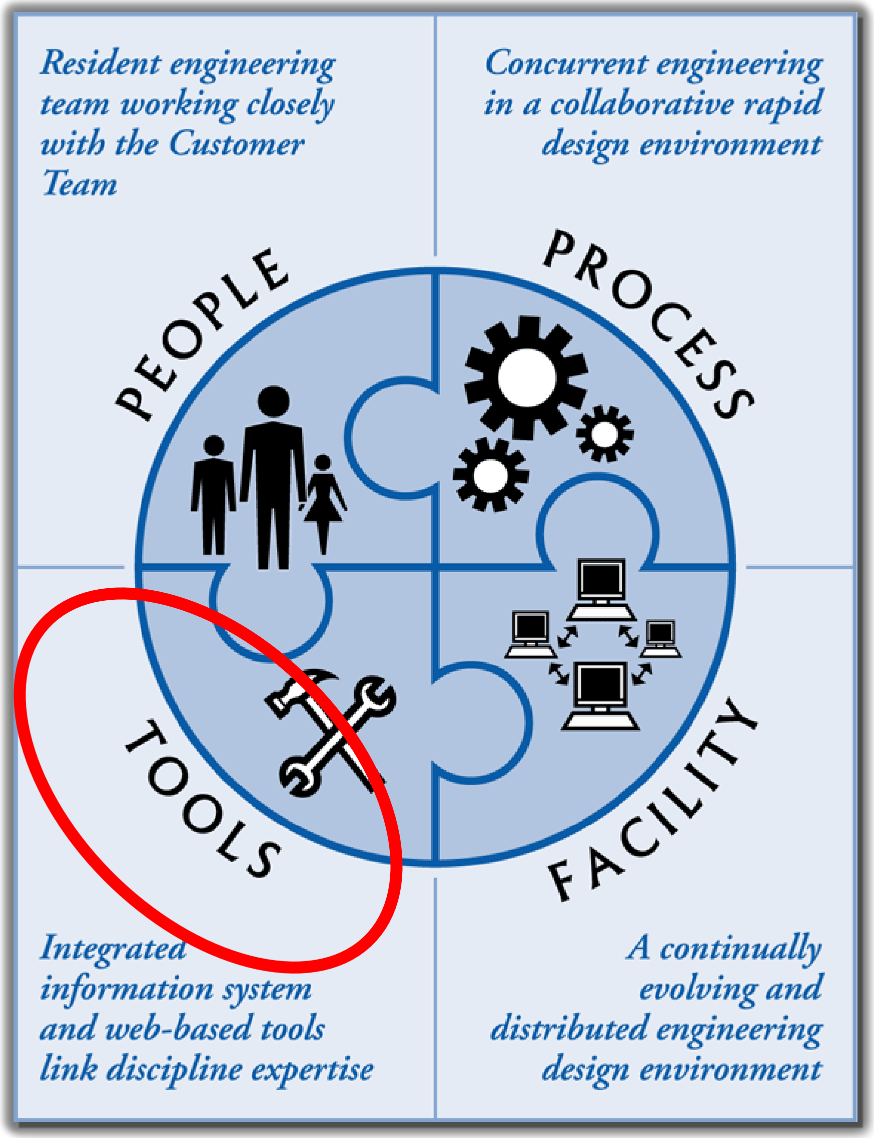
Mission Design Lab

Lab Lead: Mark Steiner/592, 301-286-4285

Instrument Design Lab

Lab Lead: Tammy Brown/505, 301-286-5753

IDC Tools



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TOOLS
FACILITY
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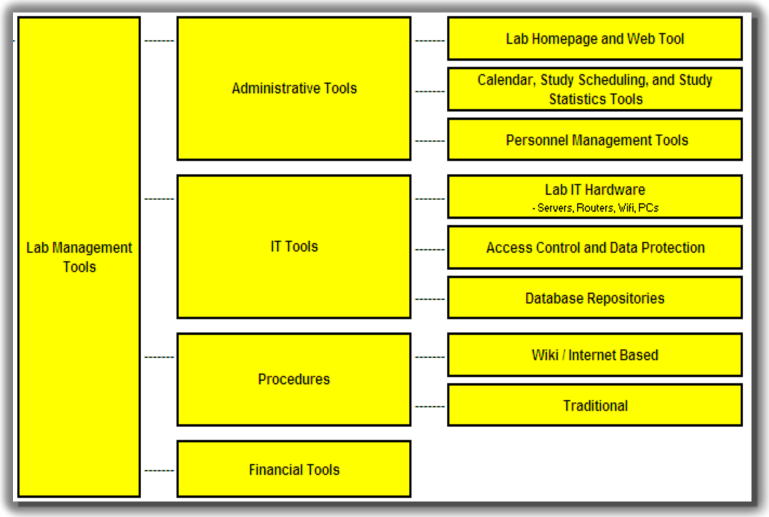
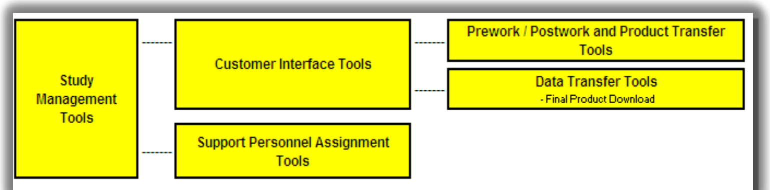
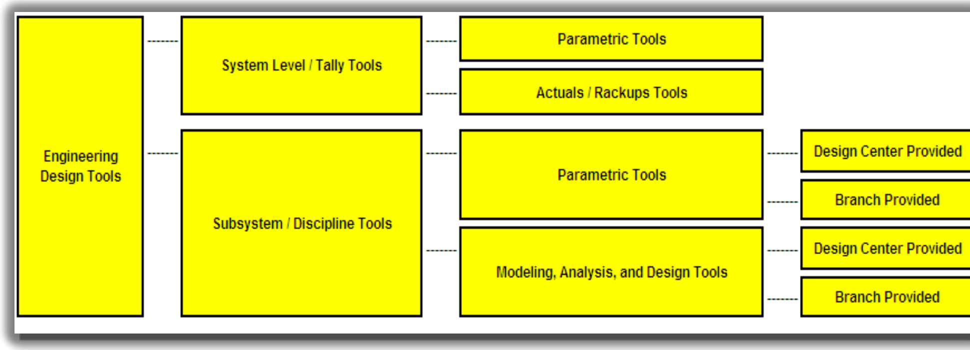
Concurrent Lab Tools Taxonomy

Management Tools

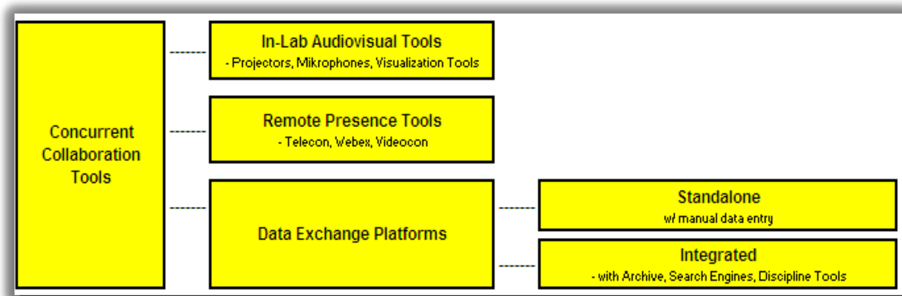




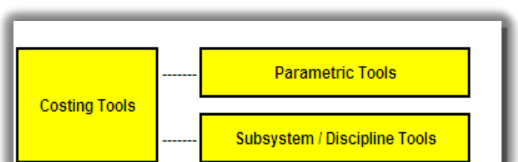
Design Tools



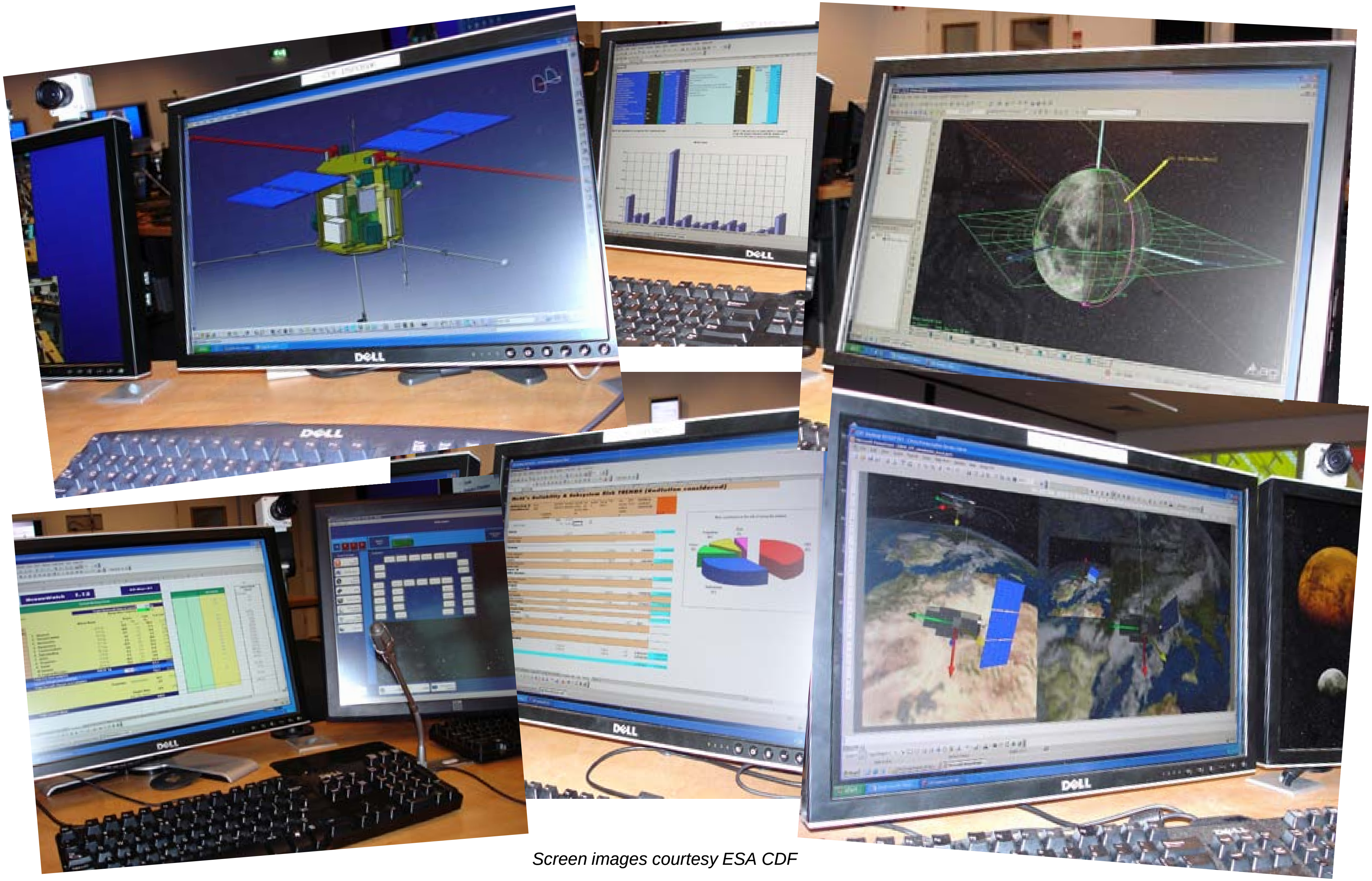
Collaboration Tools



Costing Tools



Concurrent Engineering Tools



Screen images courtesy ESA CDF

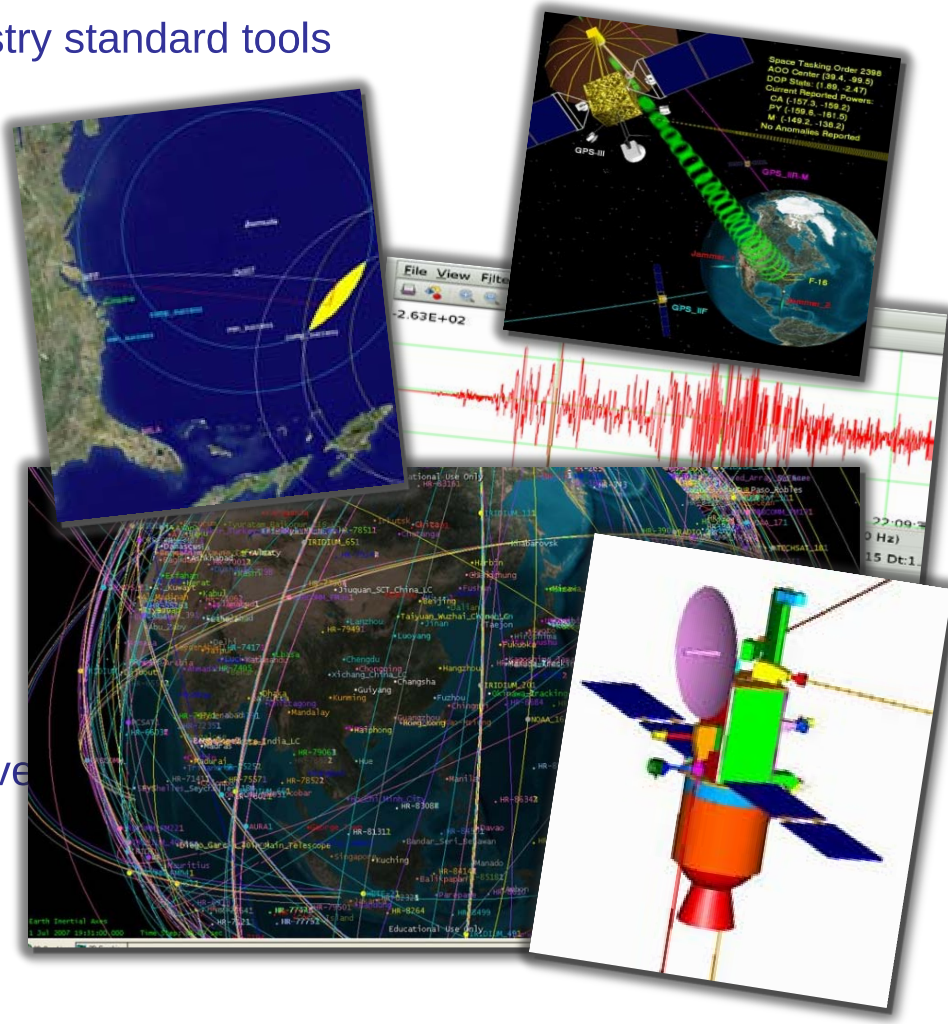
http://idc.nasa.gov

Engineering Design Tools

- **<u>Applications</u>**: a mix of Commercial-Off-The-Shelf (COTS), Government-Off-The-Shelf (GOTS), and Homegrown Engineering Software
- Discipline workstations incorporate industry standard tools

- Satellite Tool Kit	- FreeFlyer
- IDEAS	- Pro-E
- FEMAP	- SolidWorks
- MathCAD	- SINDA
- Mathematica	- Code V
- CAGE/CLASS	- ZEMAX
- MATLAB/Simulink	- AutoCad
- PASTRAN/NASTRAN	- TSS
- Agora / 42	- Price-H

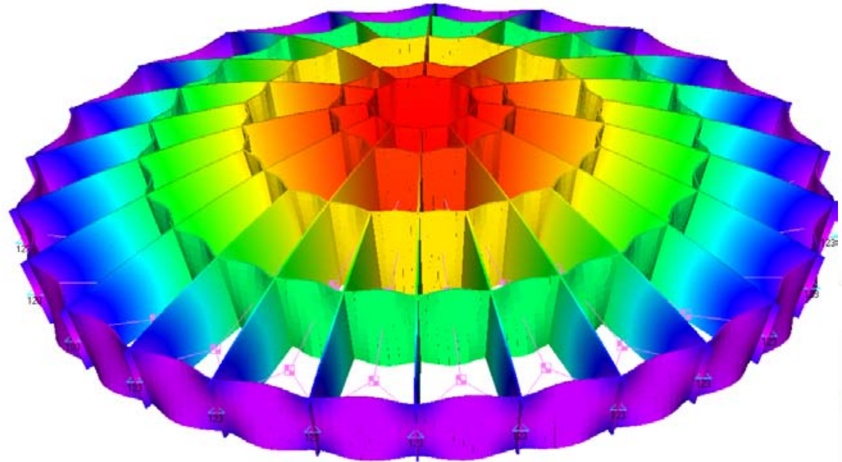
- **<u>Internal Databases</u>**:
  - – Pre-Work Databases
  - – Instrument and Mission Design Archive
  - – Discipline Component Catalogs
  - – Spacecraft Bus Catalog
  - – Launch Vehicles Catalogs, etc.

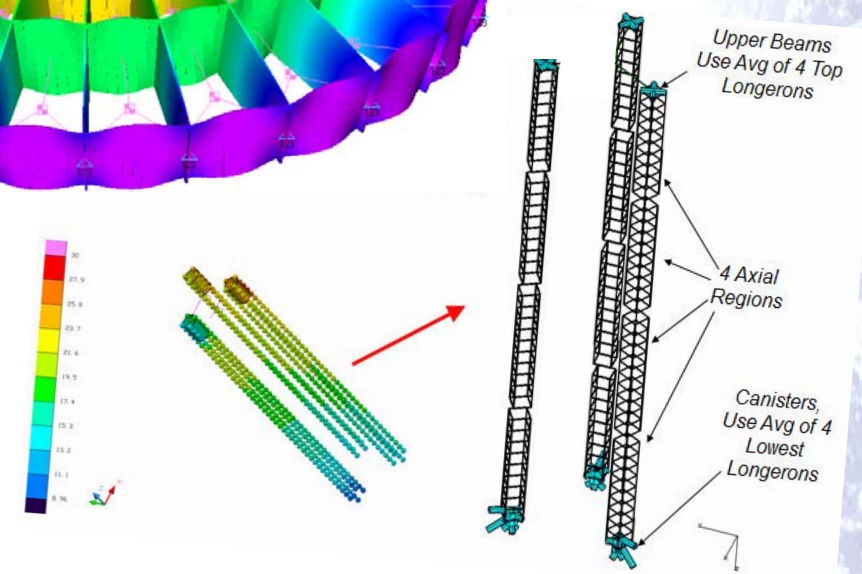


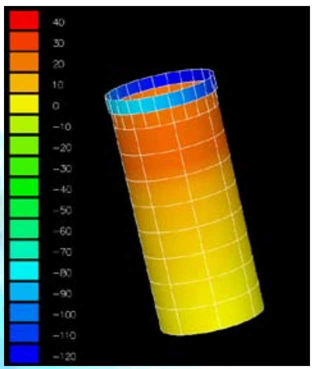
Screen images courtesy JPL Team-X

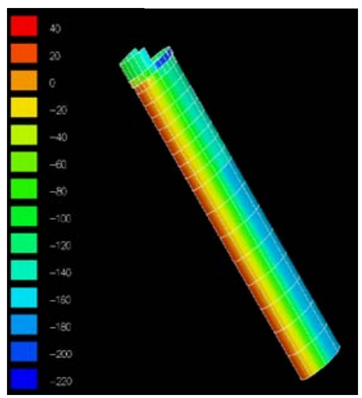
Use of Modeling in Concurrent Engineering

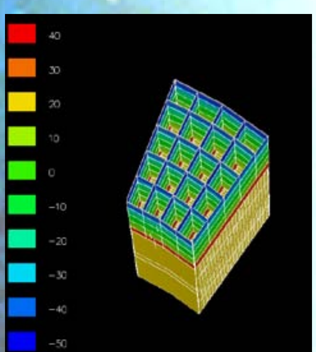
- **Engineering Models**
- **Integrated Models**
- **System Models**

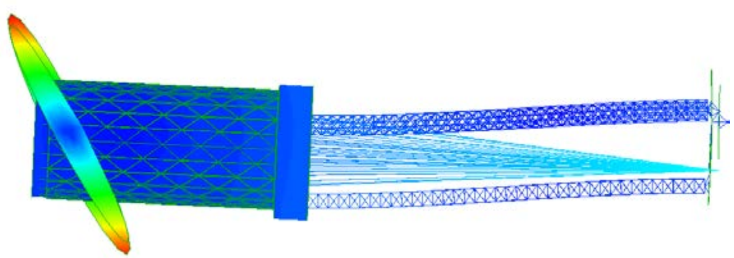


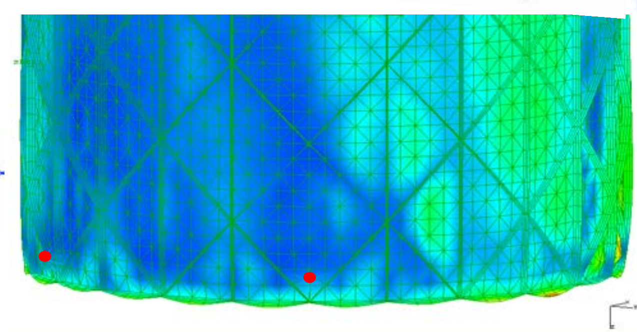




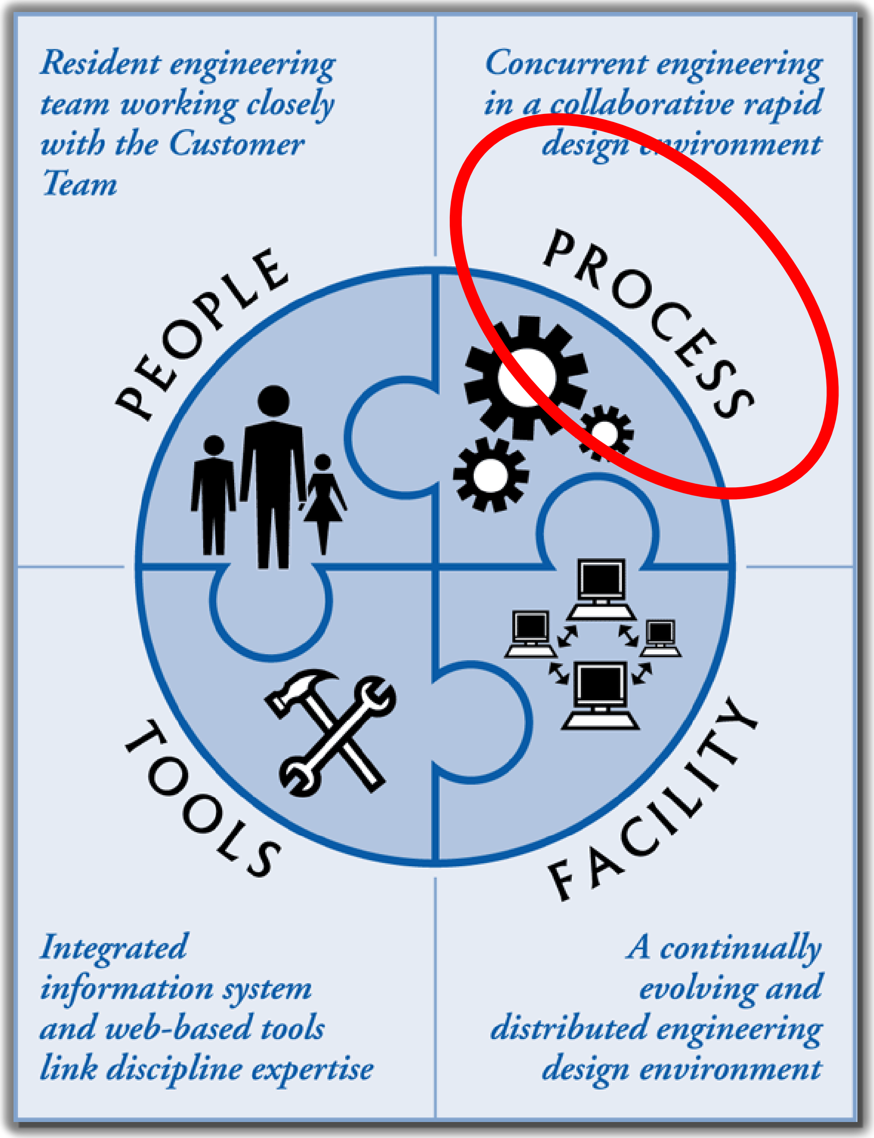








IDC Study Process



Study Scheduling

Initial contact and scheduling

- 2 - 3 months in advance of desired study start

Planning and preparation

- Initial planning meeting approx. 1 month before study
- Pre-work meeting 1 - 3 days before study

Study execution

- Pre-work Activities (1 - 2 days)
- Study activities (typically 1 week)
- Post-work Activities (1 - 2 days)

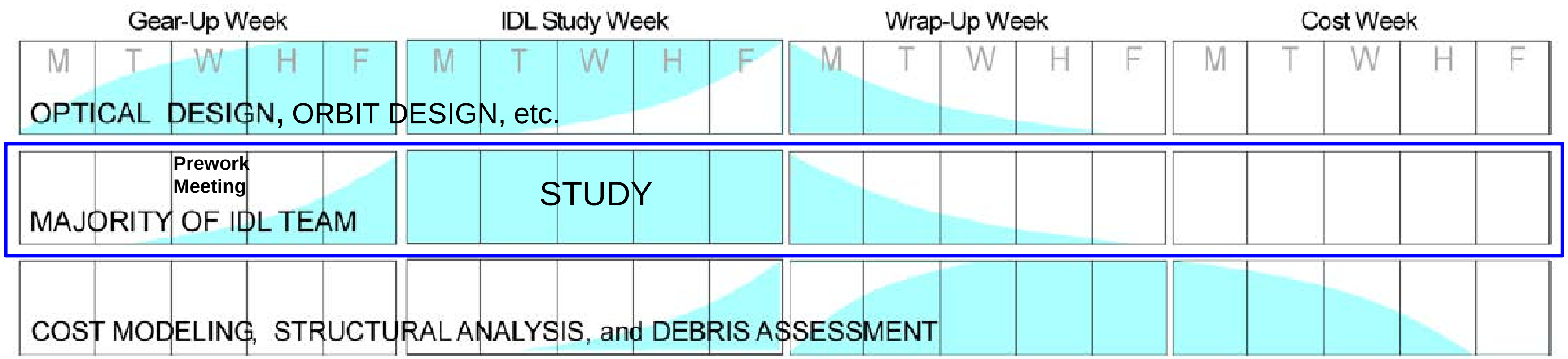
Study products

- Provided 1 - 4 weeks following study execution (depending on cost estimation requirements and post-work engineering)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1 Planning Meeting	2	3 Prior Study Pre-work Meeting and Engineering Activities	4	5	6
7	8 ←	9	10 Prior Study	11	12 →	13
14	15 Prior Study Post-works Next Study Planning	16	17 Pre-work Meeting	18 Pre-work Engineering Activities	19	20
21	22 Kick-Off (A.M.) Study	23 Study	24 Study	25 Study	26 Study Final Report (P.M.)	27
28	29 Post-work Engineering Activities, Upcoming Study Planning	30	31 Next Study Pre-work Activities	1	2	3 Final Product Delivery…>>>

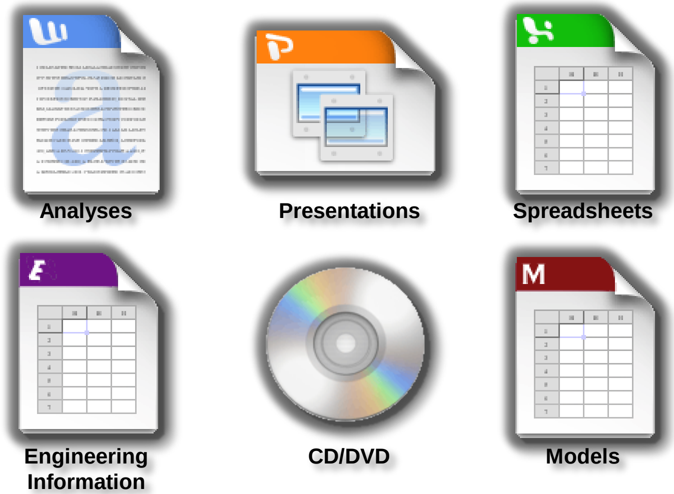
Study Execution

- Study begins with a "**Prework Meting**" where the customer gives a detailed **Kickoff Presentation** to the entire Lab Team
- Study execution
  - Typically **5 days** duration
  - Iterative, collaborative design sessions
    - **Daily Tag-Ups at 9:30 and 1:30 -** full attendance required
    - **Sidebars** to resolve minor issues
- At the end, a live "**Presentation**" of the study results to customer team



- Planning **identifies long duration tasks** such as complex optical analyses (IDL) or orbit designs (MDL), and the Lab may **start** it **ahead** of the study

IDC Products



IDC Engineering Disciplines

- Mission Systems
- Mission Design/Flight Dynamics
- Avionics/Electronics
- Attitude Control
- Propulsion
- Thermal
- Integration & Test
- Launch Vehicle
- Ground Systems
- Cost Estimating
- Instrument Systems
- Optical
- Lasers
- Microwave/RF
- Detectors
- Electrical
- Mechanical Configuration
- Thermal
- Flight Software
- Cost Modeling

Each discipline prepares material that addresses

Product Areas

- Requirements
- Baseline Design
- Alternative Designs and Trade Studies
- Functional Diagrams
- Interfaces
- Detailed estimates of
  - Mass
  - Power
  - Data Rate
- Technical Risk Assessment
- Issues and Concerns
- Conclusions and Recommendations
- Models & Background Information
- Parametric and Grass-roots Costs

Products

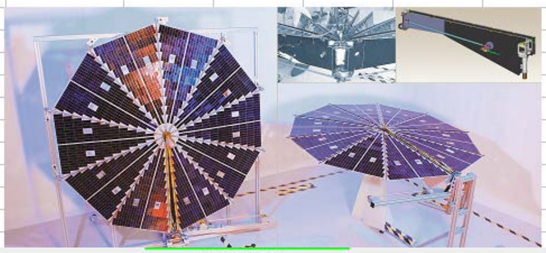
SMAD given %ages	Mass based on SMAD Percentages	Mass	Mass based on historical data	% of S/C	(mission)		
26.7%	0.0	Instrument	0.0	31%	0.00	#DIV/0!	Payload Mass (given) 0
21.7%	0.0	Structure	0.0	16%	0.00	#DIV/0!	
27.9%	0.0	Power	0.0	18%	0.00	#DIV/0!	Historical
	0.0	Harness	0.0	7%	0.00	#DIV/0!	instrument % of S/C = 31.1% 0.0
7.5%	0.0	C&DH	0.0	6%	0.00	#DIV/0!	
	0.0	Comm	0.0	4%	0.00	#DIV/0!	SMAD
8.0%	0.0	ACS	0.0	9%	0.00	#DIV/0!	instrument % of S/C = 26.7% 0.0
3.7%	0.0	Propulsion	0.0	6%	0.00	#DIV/0!	
3.4%	0.0	Thermal	0.0	3%	0.00	#DIV/0!	0 Propellant actual
		solar array mech			0.00	#DIV/0!	
	0.0		0.0		0.00	Total S/C (DRY)	*30% 0
	0.0	Propellant	0		0.00		0.00
	0.0		0.0		0.00	Total S/C (WET)	
		support structure (ex: PAF, launch					*30% 0
						Total lift-off Vehicle Capacity	0
							0
							#DIV/0!

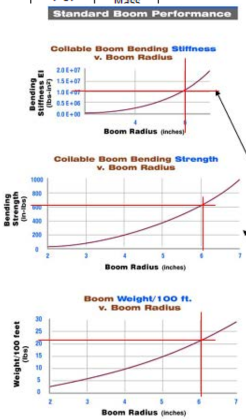
Commercial Bus Densities

Vendor / Bus	Mass (kg)	Density (kg/m^3)	P/L Capability (kg)	P/L Capability to Bus Mass
Ball BCP2000	608.00	5		
Ball BCP600	203.00	12		
Orbital / PicoStar	52.70	6		
Orbital / MicroStar	58.60	3		
Orbital / LeoStar	263.00	1		
Orbital / MidStar	580.00	1		
Orbital / StarBus	566.30	1		
Surrey / Minisat-400	206.70	1		
Surrey / MicroSat-70	70.00	5		
Surrey / NanoSat	8.50	1		
Spectrum Astro	129.00	1		
Spectrum Astro	133.00	1		
Spectrum Astro	354.00	4		
TRW / T100	184.10	1		
TRW / T200A	242.40	1		
TRW / T200B	278.00	1		
Lockheed / LM900	492.00	1		
(mission)	0.00			
AVERAGE COMMERCIAL BUS	260.55	3		

UltraFlex Solar Array Calculator

Watts/m^2	225	26	solar array area required
watts/kg	150		
		39	total mass
# of wings	2	19.50	mass per wing
$M/kw	1.5		
nre ($M)	2	10.78	cost of UltraFlex Array





Continuous-Longeron Able Boom

d=longeron diameter				
0.125	inches			
R=boom radius				
6	inches			
L=boom length				
433.07	inches	11.00	meters	30.48m=100feet
ε=max bending strain of longerons when completely coiled				
0.015	(ε=d/2R=F/E)	s-glass	0.375	(calculated ε, white paper gives .015 as "given" value)
E=young's modulus of longeron material				
7.50E+06	psi	s-glass		
ρ=density of longeron material				
0.075	pci	s-glass		
F=coiling stress of Longerons (F=εE)				
1.13E+05		s-glass		
Bay Length=1.25R				
7.5	inches	s-glass		
1.03E+07	Bending stiffness EI=1.5πER^4ε^2			
610.17	Bending Strength M..=7.44ER^3ε^4			
25.15	Shear strength V..=1.84ER^2ε^4			
130.40	Torsional strength T..=1.59ER^3ε^4			
7.44 lbs	3.37 kgs	Boom weight Wb=9πρR^2ε^2L		
8.27 inches	210.08 mm	Retracted height Hb=3L(ε+.005)/π		
26.27 inches	667.28 mm	Cannister height Hcan=HB+3R		
19.56 lbs	8.87 kgs	Cannister weight W...=.04εLR+.5R^2		
27.00 lbs	12.25 kgs	Total package weight		

Formulars & data from AEC-ABLE white paper located from the internet at: http://www.aec-able.com/Booms/Resources/Boom Information.pdf

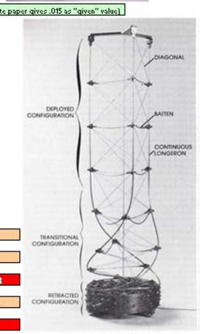


FIGURE 1
Continuous-Longeron Boom

HONEYCOMB PANEL MASS CALCULATOR

HONEYCOMB ACCESSORIES

Baseline

Power Components

BASELINE - MASS [kg]

NANOSATS PAYLOAD

1st DISPENSER BUS SUBSYSTEMS & STRUCTURE

2nd DISPENSER BUS SUBSYSTEMS & STRUCTURE

3rd DISPENSER BUS SUBSYSTEMS & STRUCTURE

TOTAL MASS 3 DISPENSERS [kg]

CONTINGENT WORST CASE

3 DISPENSERS LOADED w/ A TOTAL OF 22 "Cont. Mass" N.S. -- WET TOTAL

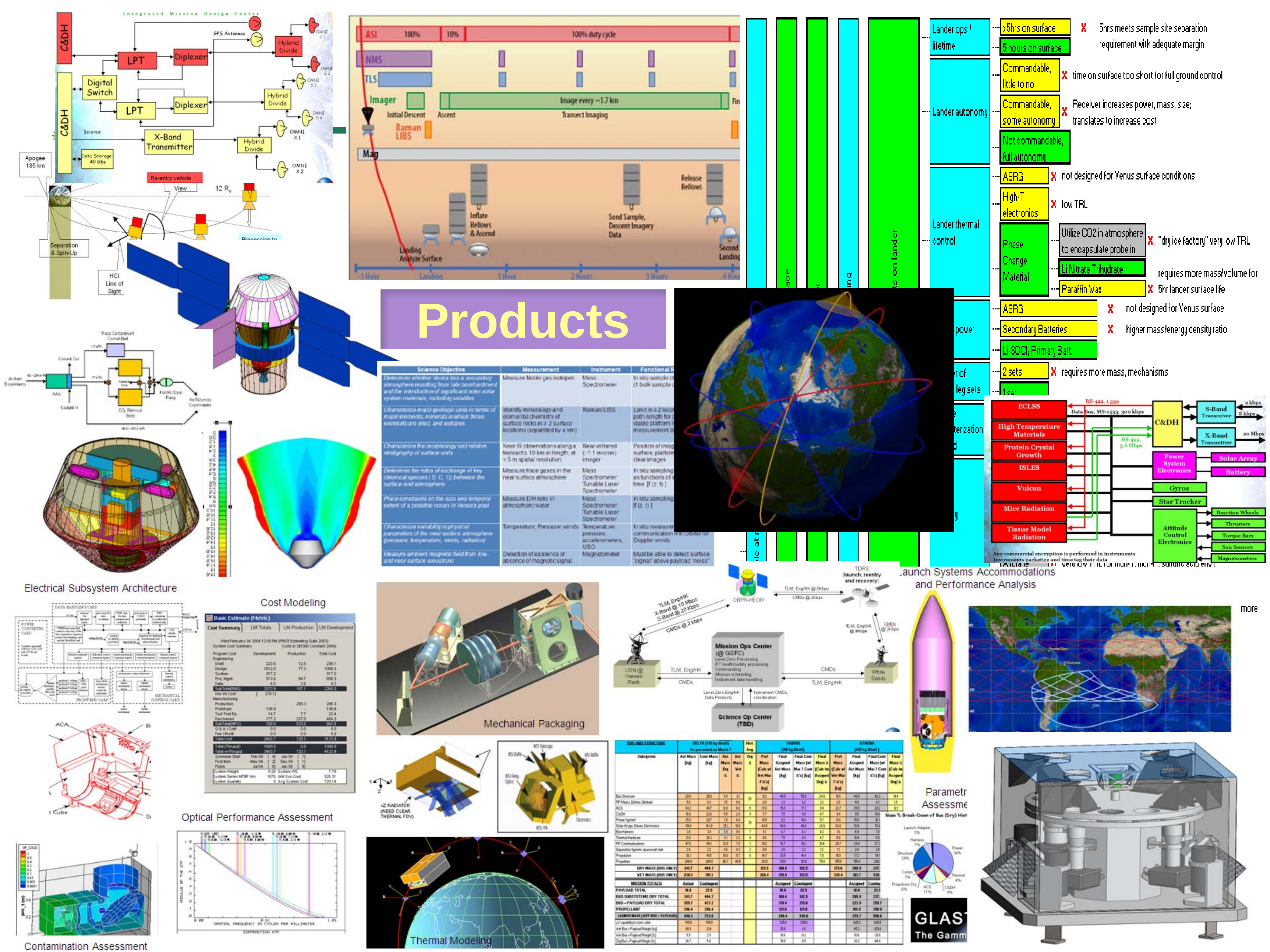
secondary structure	0.00	1	0.00
Fasteners	0.00	1	0.00
Solar Array			
main panel			0.00
outer panel			0.00
yoke			0.00
hinges			0.00
Fasteners	0.00	1	0.00
Comm antenna mast			
arms			0.00
mount al alg			0.00
drives			0.00
Fasteners	0.00	1	0.00
Separation System Ø steel, al alg, cres			0.00
steel, al alg, cres			0.00
Counter Weights steel	0.00		0.00
	SUB-TOTAL		0.00
TOTAL STRUCTURAL COMPONENTS			0.00
	0.00	Actual structural mass as % of dry mass =	#DIV/0!

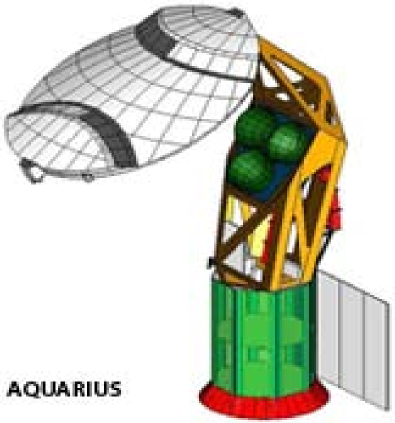
Orbit Calculations

From Wertz and Larson, "Space Mission Analysis and Design", Third Edition 1999

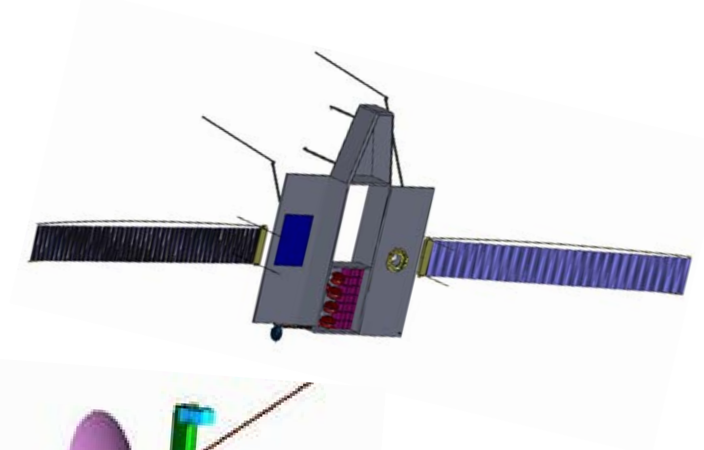
Parameter	Units	Input	Output
Orbit Parameters			
Launch date		4/1/2008	
Perigee	km	550	550.00
Apogee	km	500	500.00
Inclination (i)	degrees	28.00	28.00
Ascending Node Local Time	hours:min	23:53	
Longitude (geostationary)	degrees east		
Semi-major axis (a)	km		6903.1365
Eccentricity (e)	unitless		0.00
Orbit Period	seconds		5707.9567
Orbit Period	minutes		95.132612
Mean motion (n)	rad/s		0.0011008
Mean motion	arcsec/s		227.05
Circular Orbit Parameters			
Velocity	km/s		7.5988113
Earth angular size from satellite	degrees		135.0
Angle of horizon below horizontal	degrees		22.5
Pertubations			
Node Rate	deg/day		-6.670339
Perigee Rate	deg/day		10.946586
Node Rate per orbit	deg/orbit		-0.4406714

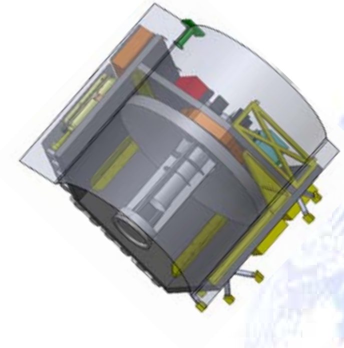
Products

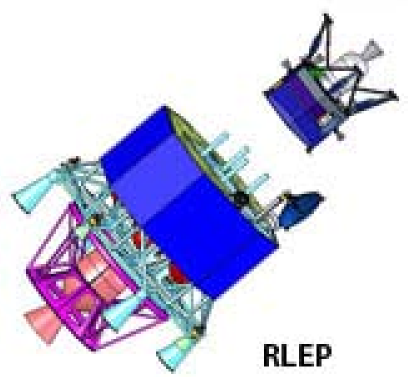

Lander ops / lifetime
>5hrs on surface
5hrs meets sample site separation requirement with adequate margin
5 hours on surface
Lander autonomy
Commandable, little to no
time on surface too short for full ground control
Commandable, some autonomy
Receiver increases power, mass, size; translates to increase cost
Not commandable, full autonomy
Lander thermal control
ASRG
not designed for Venus surface conditions
High-T electronics
low TRL
Phase Change Material
Utilize CO2 in atmosphere to encapsulate probe in
"dry ice factory" very low TRL
Li Nitrate Trihydrate
requires more mass/volume for
Paraffin Wax
5hr lander surface life
Secondary Batteries
higher mass/energy density ratio
Li-SOCl2 Primary Batt.
2 sets
requires more mass, mechanisms
Electrical Subsystem Architecture
Cost Modeling
Mechanical Packaging
Optical Performance Assessment
Contamination Assessment
Thermal Modeling
aunch Systems Accommodations and Performance Analysis
Mission Ops Center (@ GSFC)
Science Op Center (TBD)
more



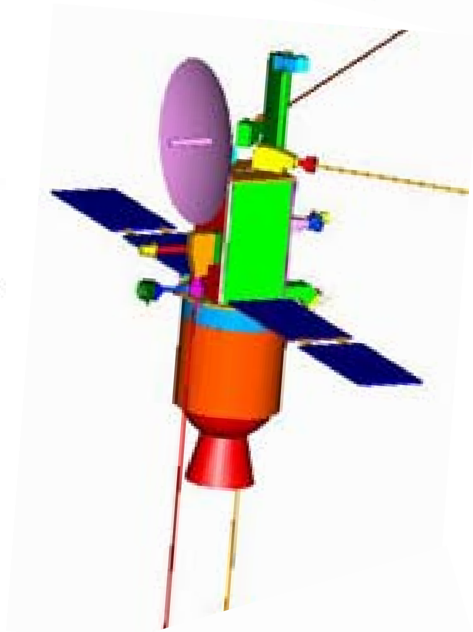
AQUARIUS

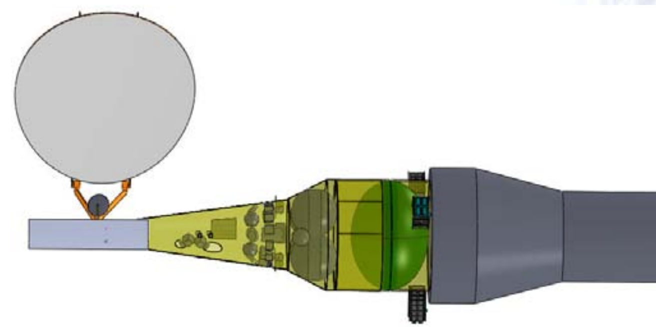


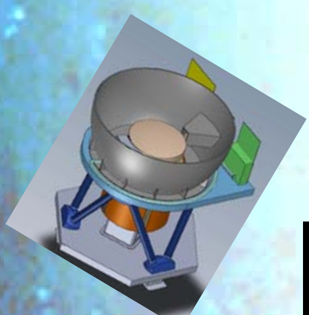


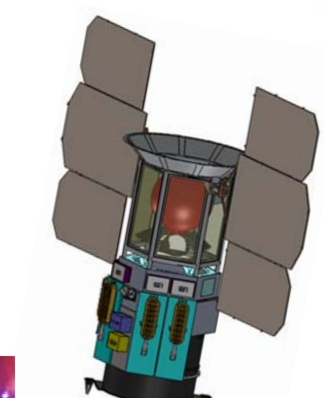


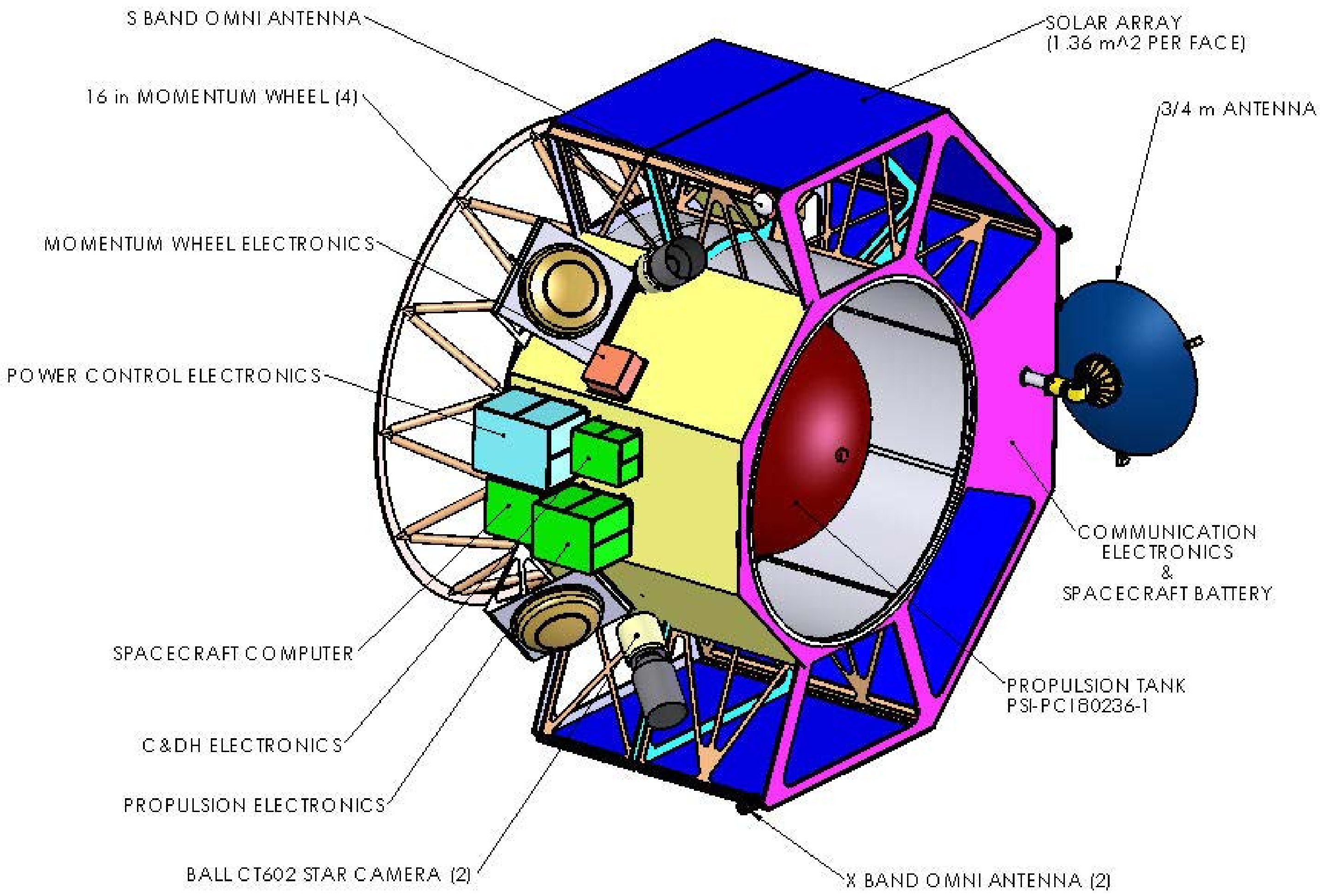
RLEP



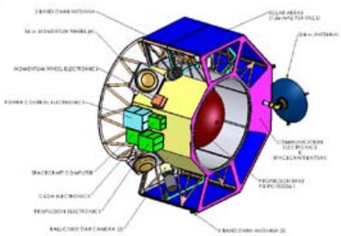


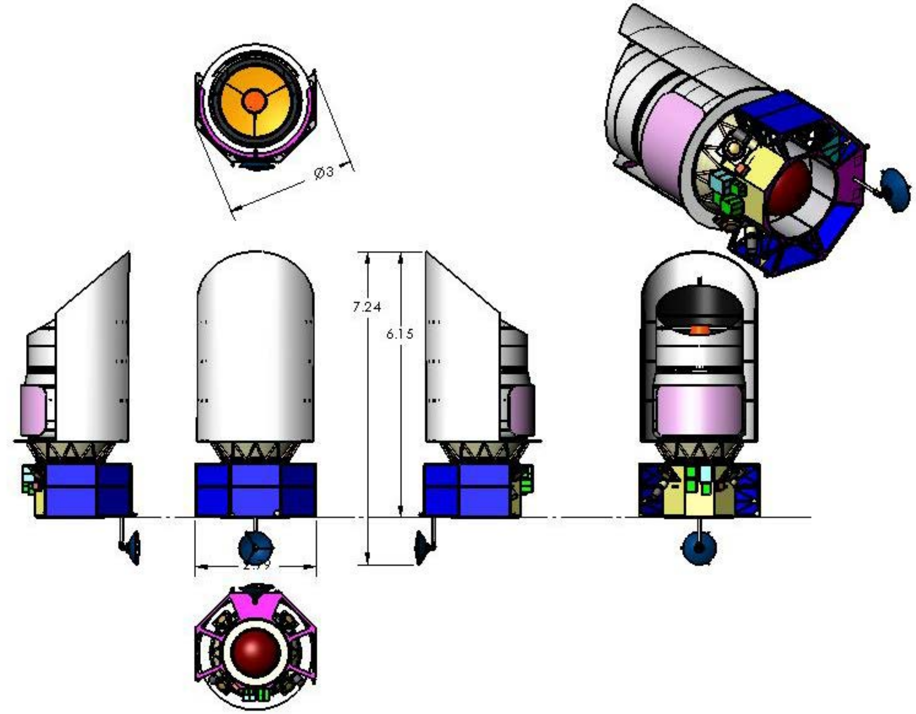




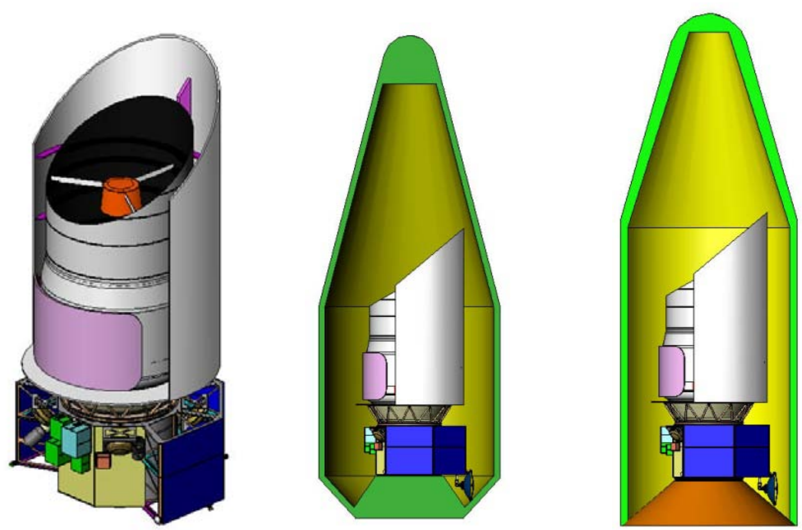


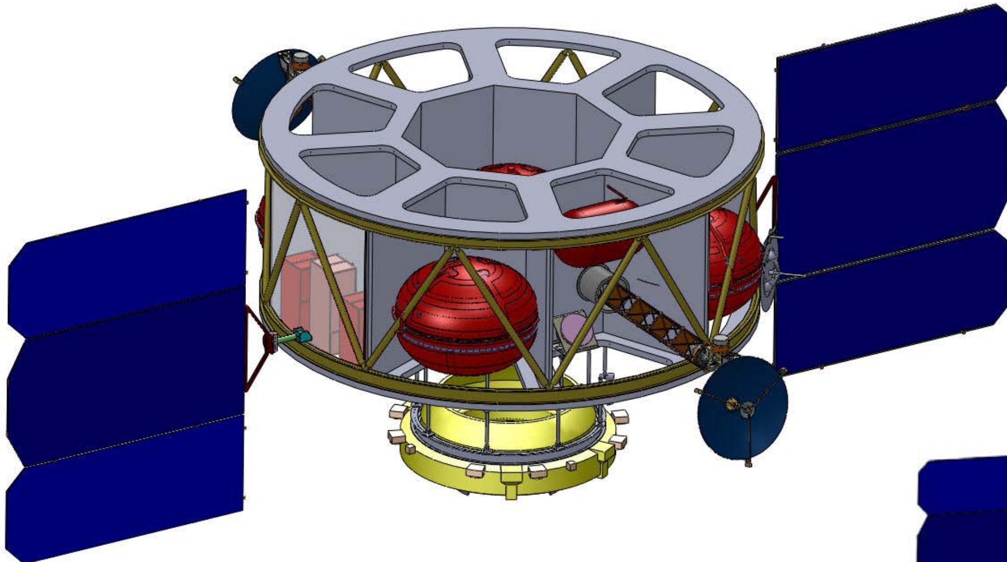
S BAND OMNI ANTENNA
16 in MOMENTUM WHEEL (4)
MOMENTUM WHEEL ELECTRONICS
POWER CONTROL ELECTRONICS
SPACECRAFT COMPUTER
C&DH ELECTRONICS
PROPULSION ELECTRONICS
BALL CT602 STAR CAMERA (2)
SOLAR ARRAY
(1.36 m^2 PER FACE)
3/4 m ANTENNA
COMMUNICATION
ELECTRONICS
&
SPACECRAFT BATTERY
PROPULSION TANK
PSI-PC180236-1
X BAND OMNI ANTENNA (2)

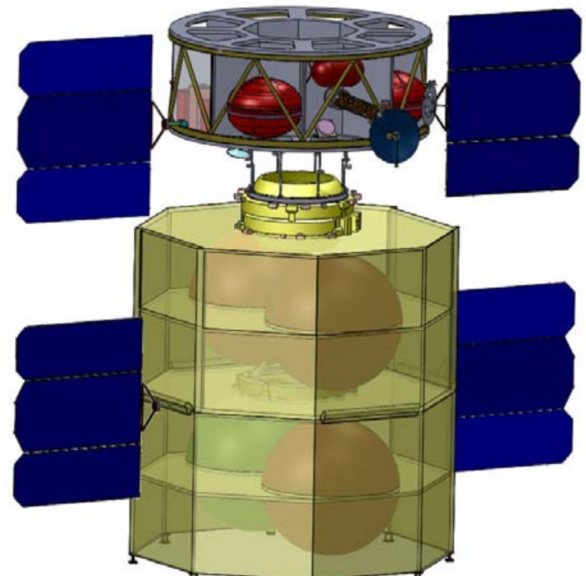


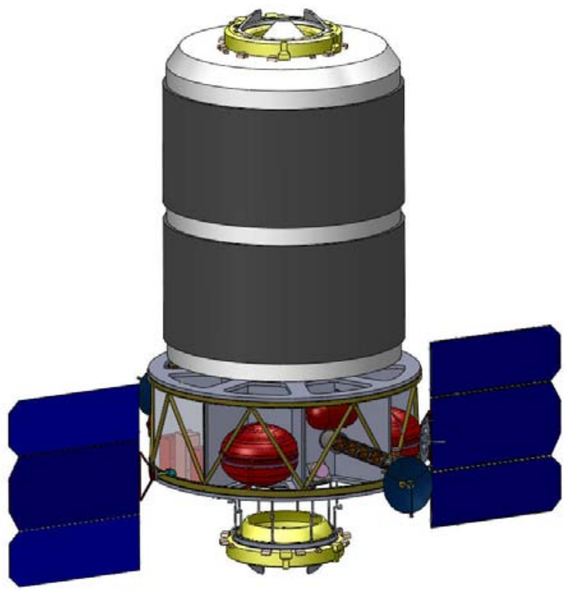


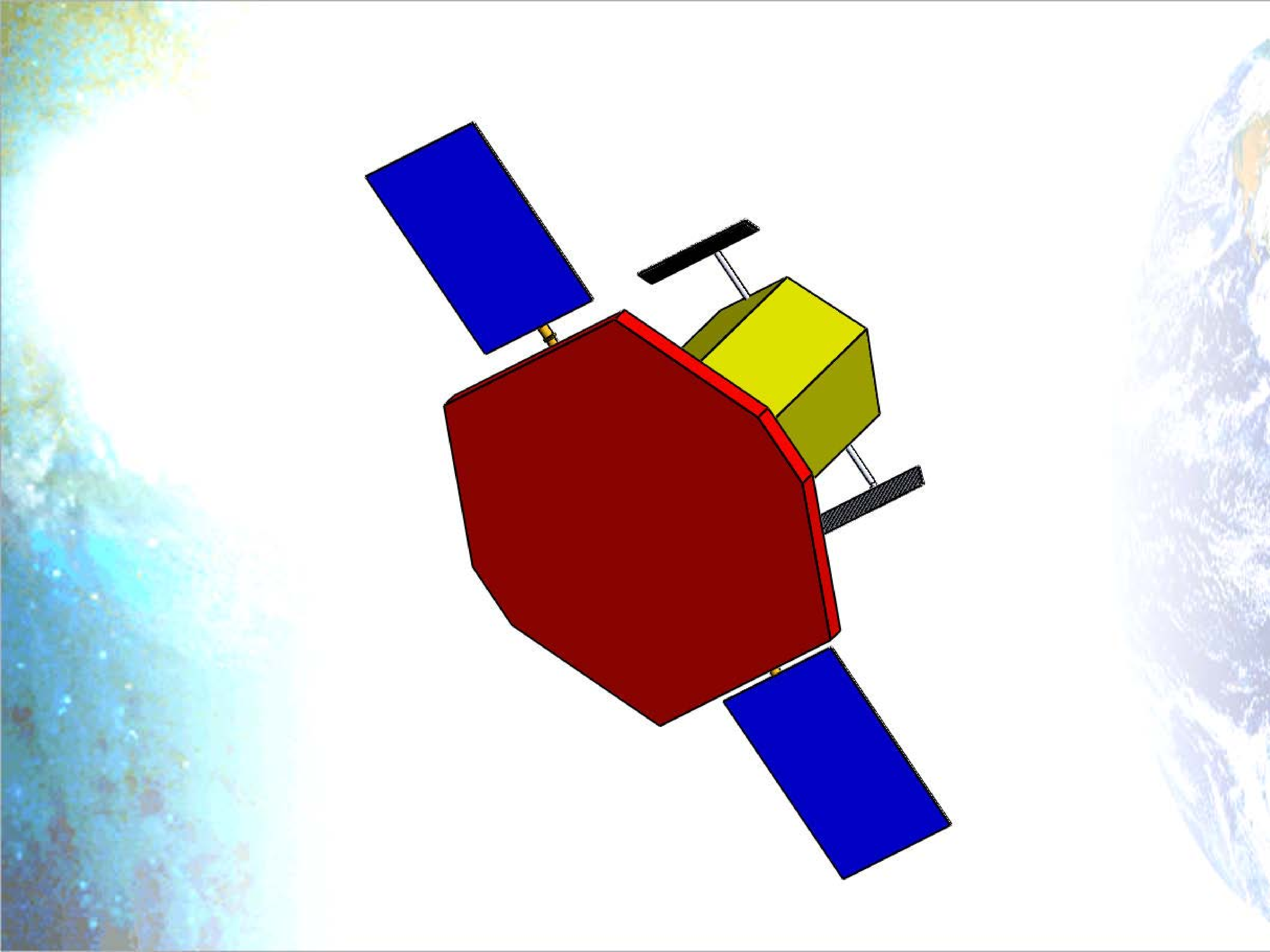
Ø3
7.24
6.15

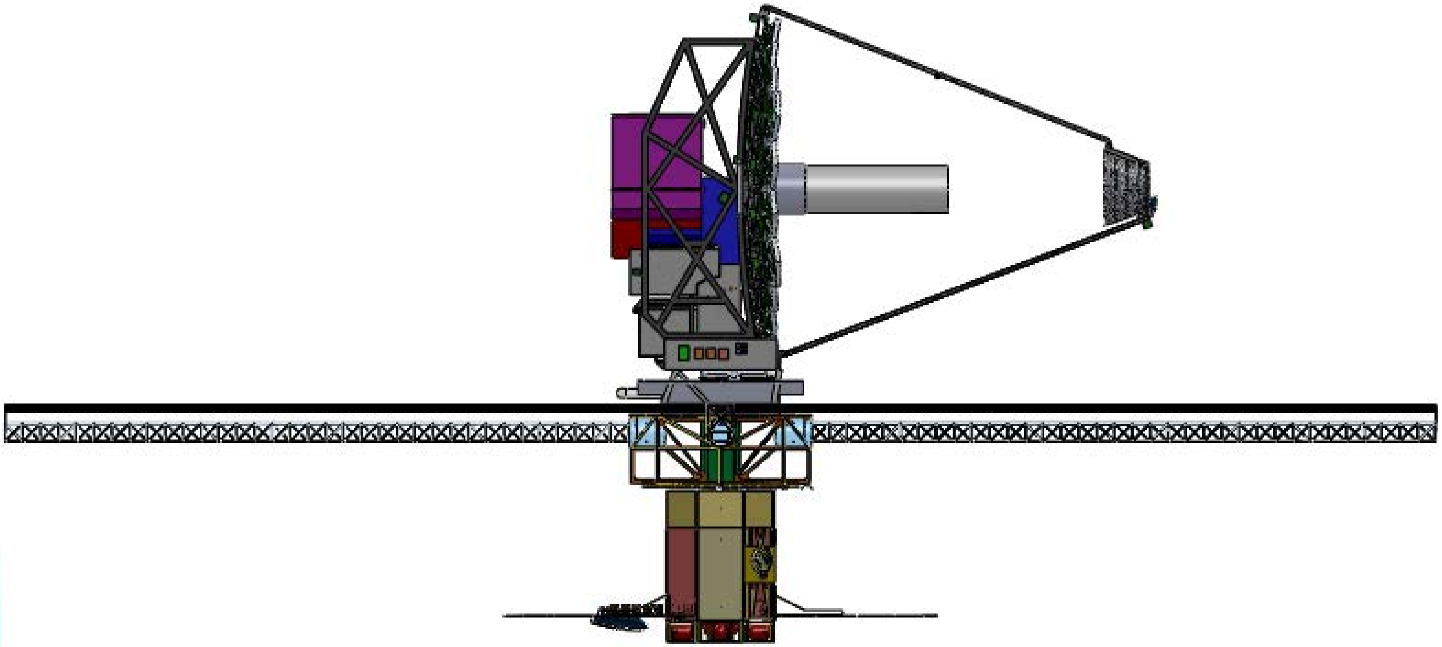


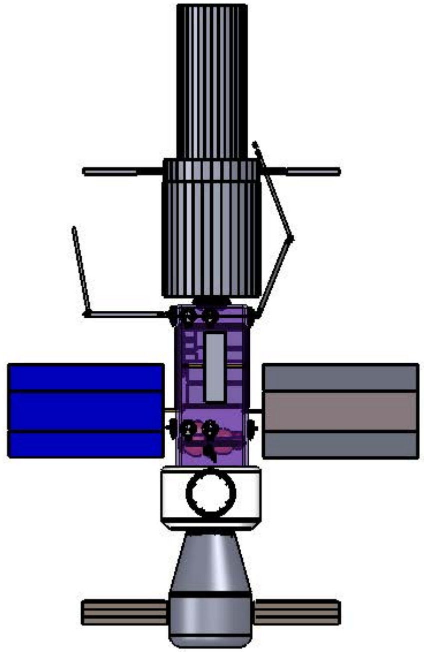


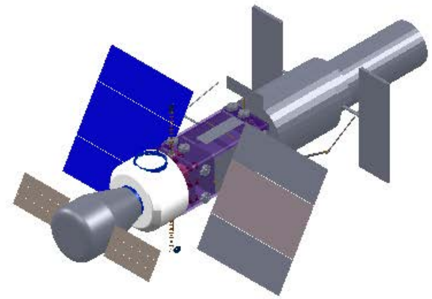


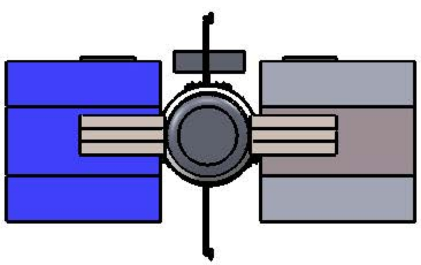


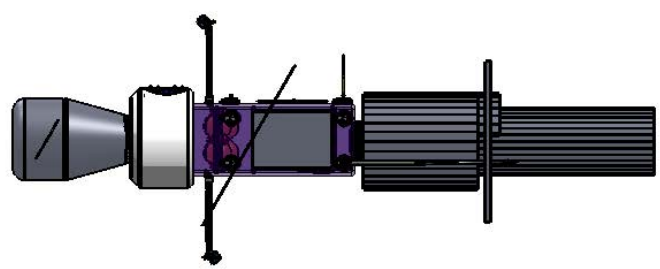




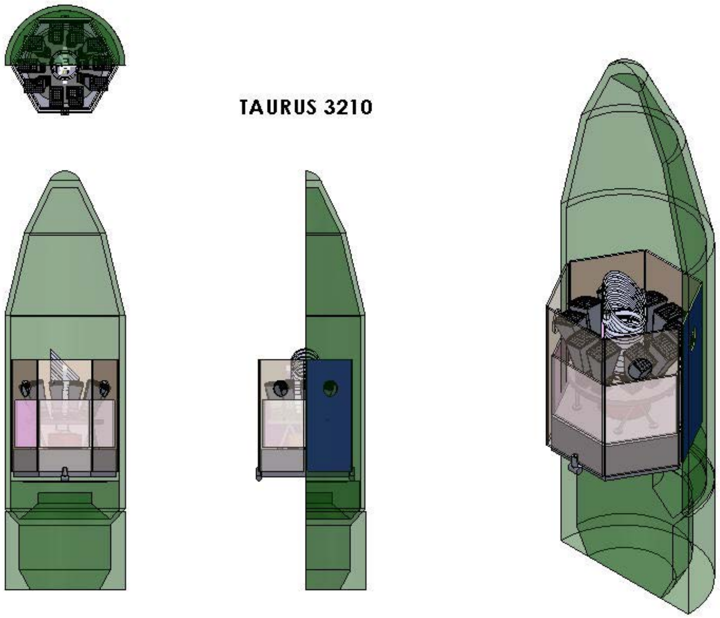




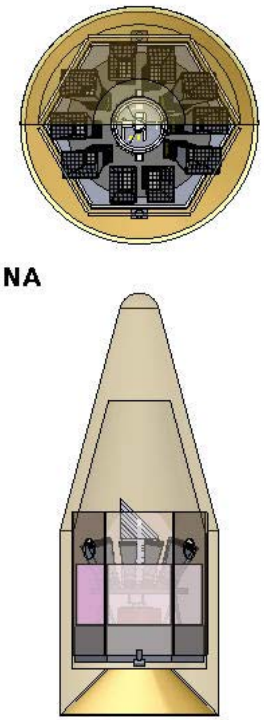




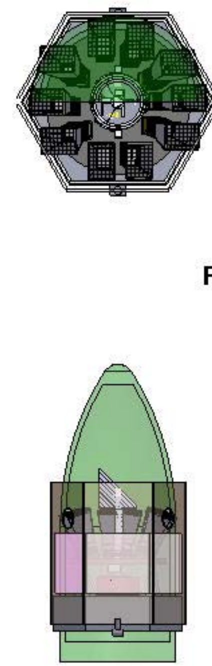
TAURUS 3210

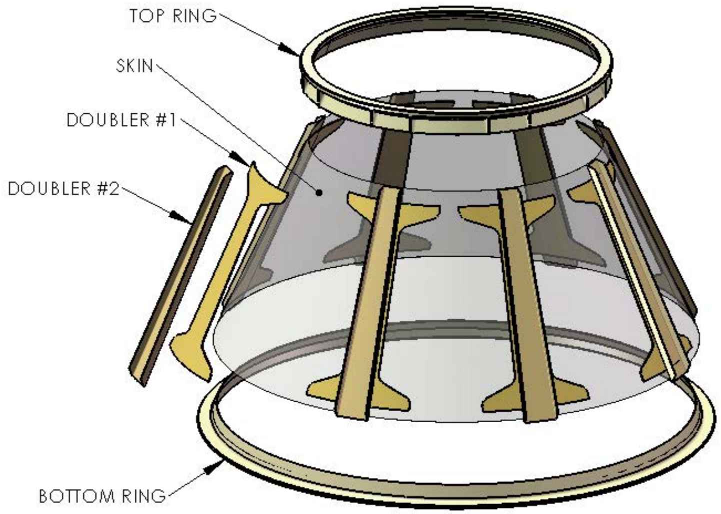


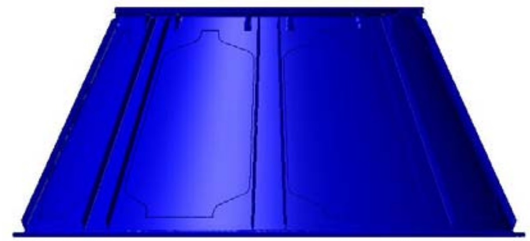
ATHENA

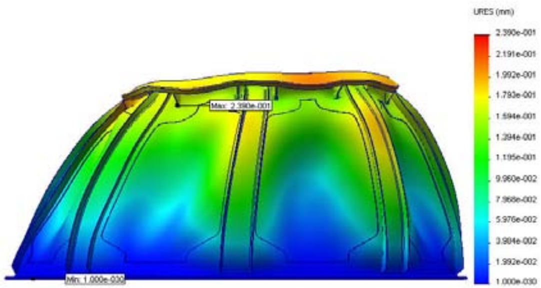


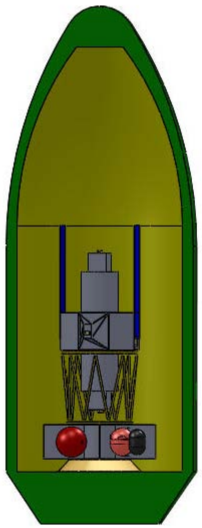
FALCON-1e

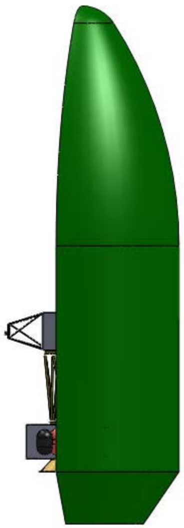


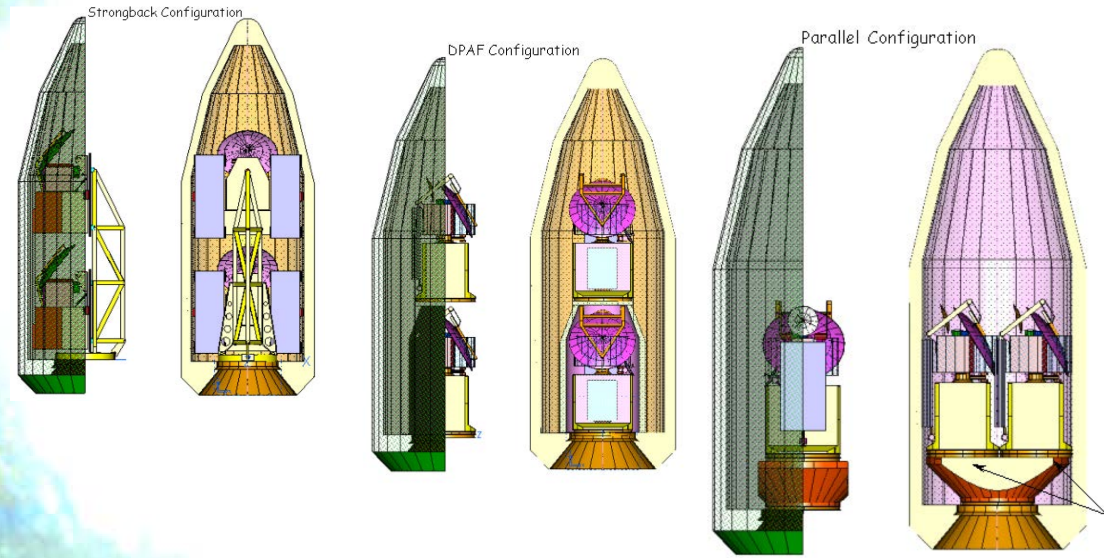

TOP RING
SKIN
DOUBLER #1
DOUBLER #2
BOTTOM RING

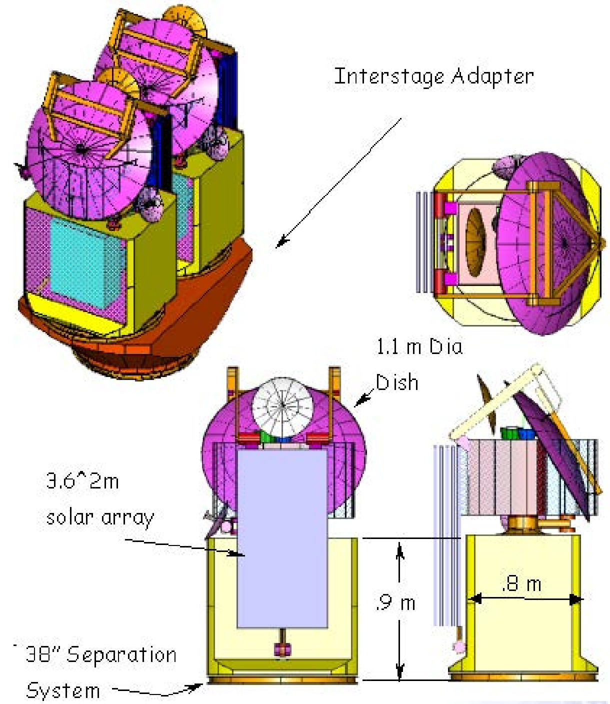


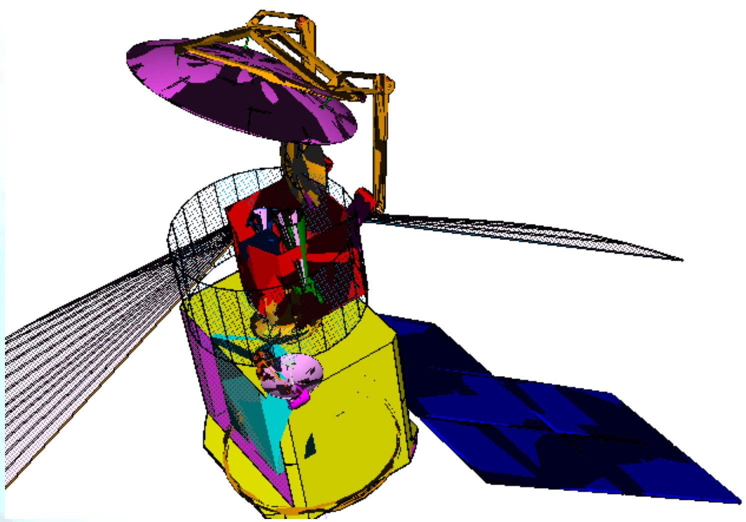

URES (mm)
2.390e-001
2.191e-001
1.992e-001
1.793e-001
1.594e-001
1.394e-001
1.195e-001
9.960e-002
7.968e-002
5.976e-002
3.984e-002
1.992e-002
1.000e-030
Max: 2.390e-001
Min: 1.000e-030

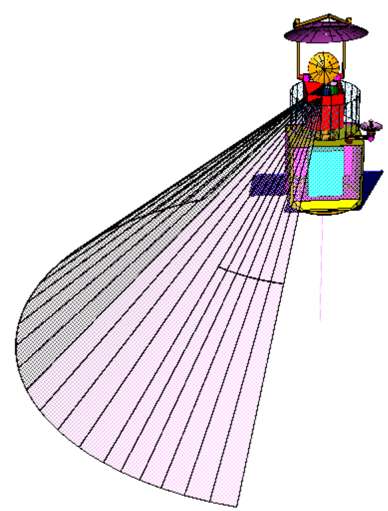





Strongback Configuration
DPAF Configuration
Parallel Configuration


Interstage Adapter
1.1 m Dia
Dish
3.6^2m
solar array
.9 m
.8 m
38" Separation
System





Introduction To Concurrent Engineering

Concurrent engineering is increasingly recognized as a distinct branch or method of engineering

Concurrent engineering has its own:

- facilities, unlike any other engineering discipline
- processes and information flow, unlike any other engineering discipline
- tools, unlike any other engineering discipline
- and even basic and advanced research, unlike any other engineering discipline

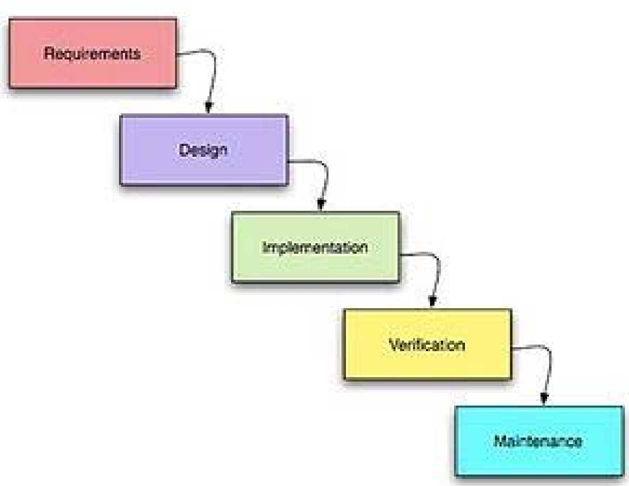
..all supporting the thesis that Concurrent Engineering is in fact a novel distinct branch or method of engineering

What is Concurrent Engineering?

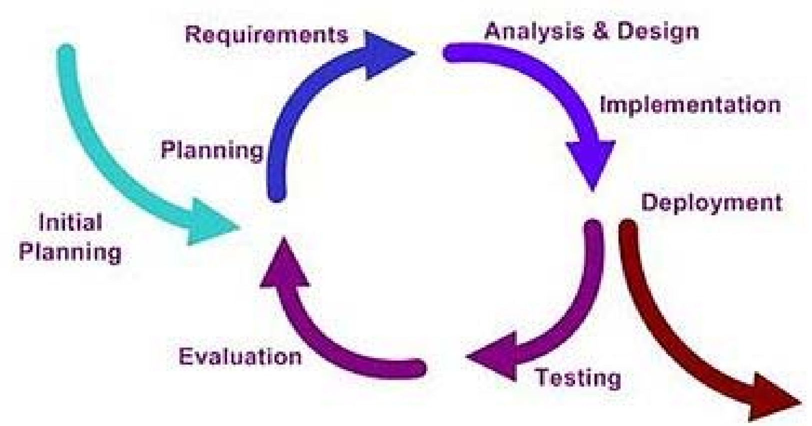
CEWG's definition:

"Concurrent Engineering is a systematic approach by diverse specialists collaborating simultaneously in a shared environment, real or virtual, to yield an integrated design."

- **This approach is intended to cause the developers to consider from the very outset all elements of the product life cycle, from conception to disposal, including cost, schedule, quality and user requirements.**



vs.



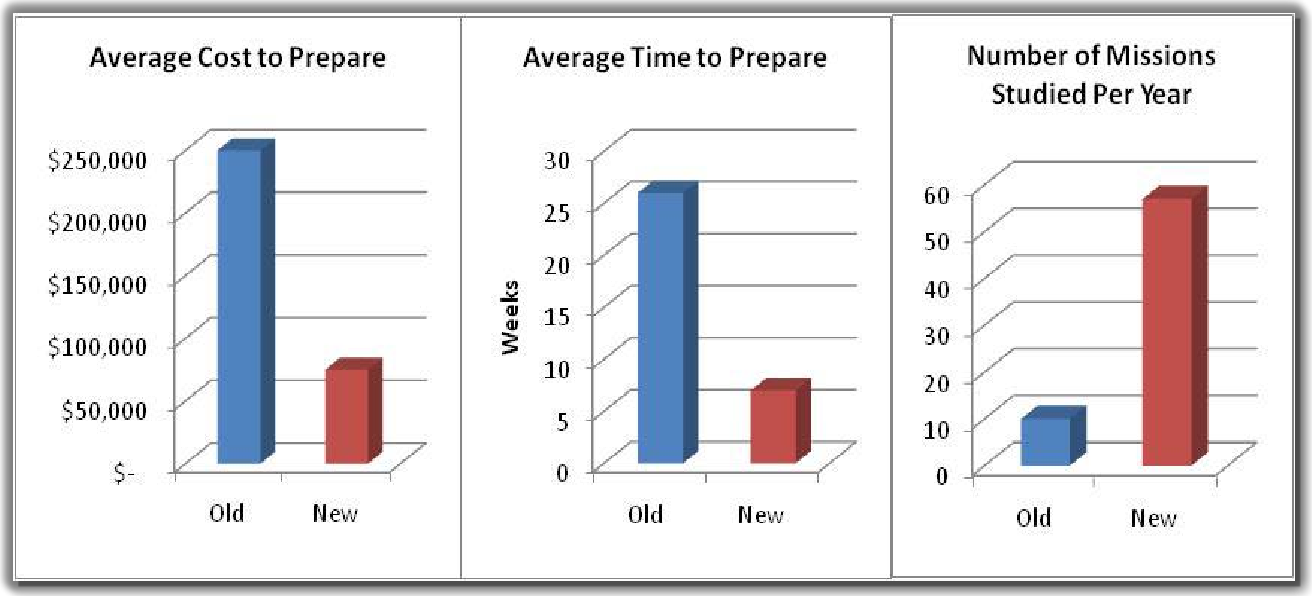
Concurrent Engineering on Wikipedia

Concurrent engineering is a work methodology based on the parallelization of tasks (i.e. performing tasks concurrently).

Introduction

The concurrent engineering method is still a relatively new design management system, but has had the opportunity to mature in recent years to become a well-defined systems approach towards optimizing engineering design cycles.[1] Because of this, concurrent engineering has gathered much attention from industry and has been implemented in a multitude of companies, organizations and universities, most notably in the aerospace industry.

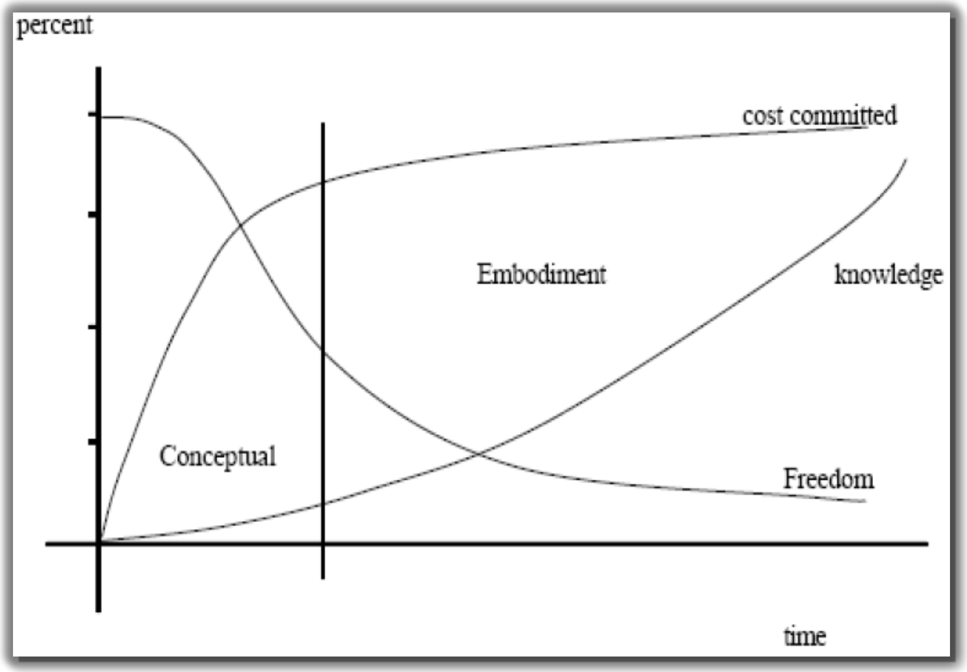
One of the most important reasons for the huge success of concurrent engineering is that by definition it redefines the basic design process structure that was common place for decades. This was a structure based on a sequential design flow, sometimes called the 'Waterfall Model'.[5][6] Concurrent engineering significantly modifies this outdated method and instead opts to use what has been termed an iterative or integrated development method.[



Origins, Present

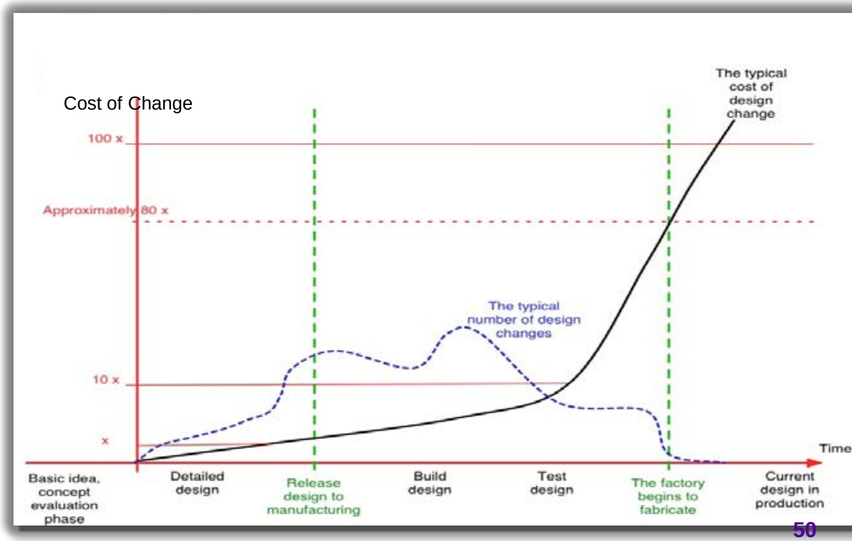
- CE methods started in WWII
  - American Aviation Corporation’s P-51 Mustang fighter aircraft was designed in 102 days; went concept to production in 9 months !!!
- CE methods have been in active use since the ‘80s
  - Origins go back to the “TQM” circles
  - Catalyzed by the emergence of CAD design capabilities
- Today CE is widespread
  - Automotive Design (Ford, BMW, Volvo)
  - Aircraft Design (Boeing 777, Airbus, Rolls Royce)
  - IT world (Agile programming)
  - Space X Engineering _and_ Manufacturing (!)
  - Architecture / Civil Engineering
  - Space Industry
    - CEWG has 15 US member institutions
    - ESA: 19 concurrent labs at ESA; bi-annual training conferences; standard study product data format information transfer between institutions; ECSS-E-TM-10-25 EU Space Standard on Concurrent Engineering

The Need for Upfront Knowledge

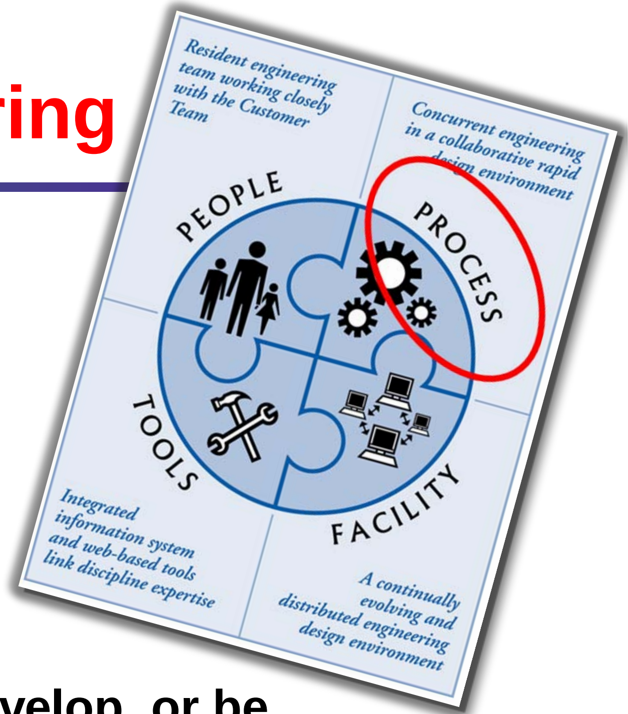


Courtesy: National Research Council

- A significant concern in designing complex systems implementing new technologies is that while knowledge about the system is acquired incrementally, substantial financial commitments, even make-or-break decisions, must be made upfront, essentially in the unknown.

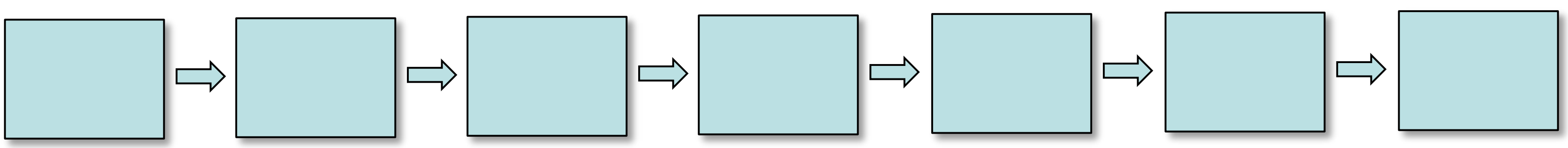


Process: Engineering the Engineering



Old Style Stovepipe Design

- **Dictionary definition of stove pipe** *(v.)*: **"To develop, or be developed, in an isolated environment; to solve narrow goals or meet specific needs in a way not readily compatible with other systems."**
- **It is a serial effort:**

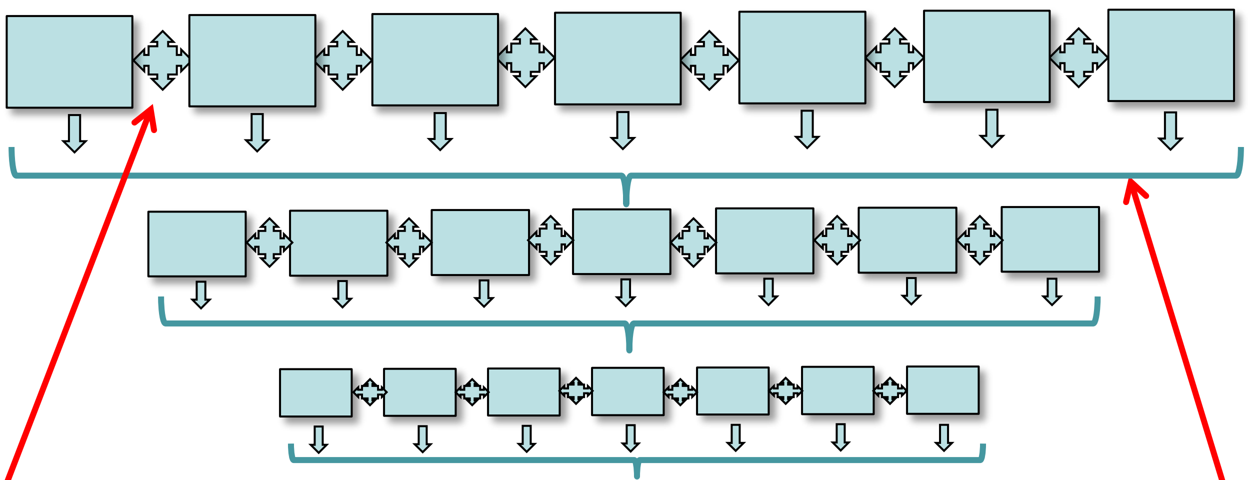


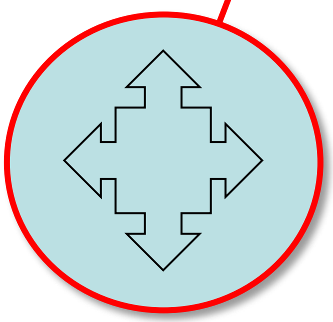
- **Characterized by slow paced communication**
  - A single iteration takes months

Concurrent Engineering Process

Concurrent Engineering is a massively parallel effort

- Study products / results in days / weeks



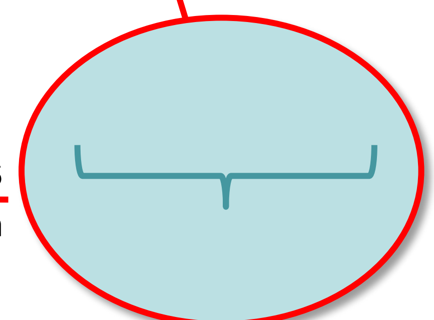


Micro-communications

Constant bit-by-bit synchronizing of essential information between the players involved

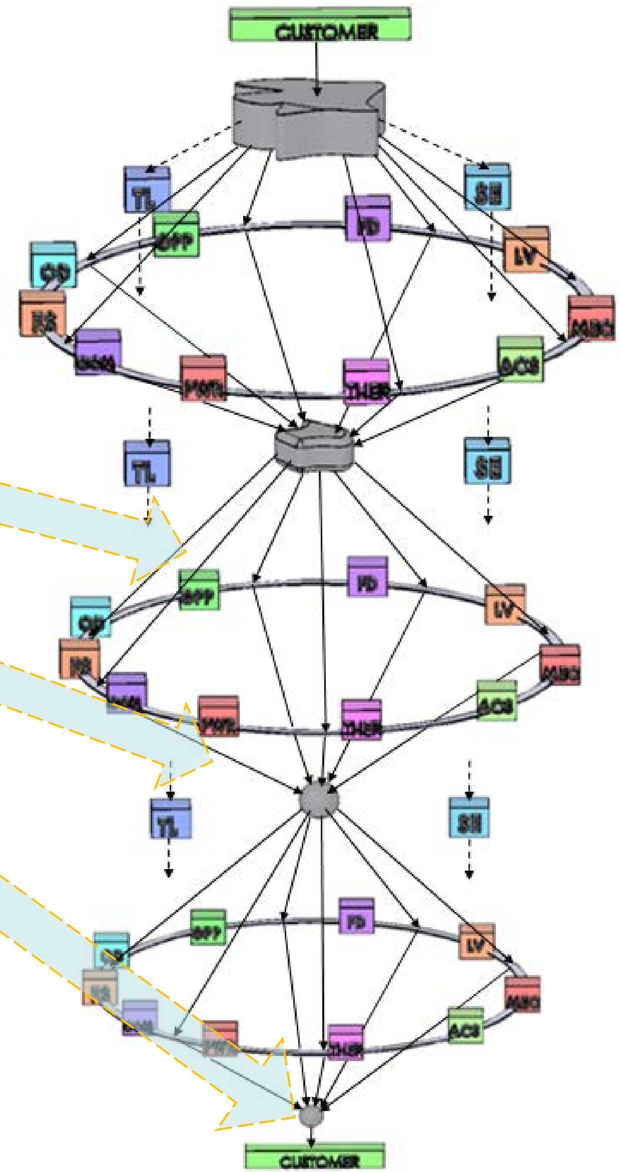
Macro-communications

Synchronizing of high volume information within the entire team

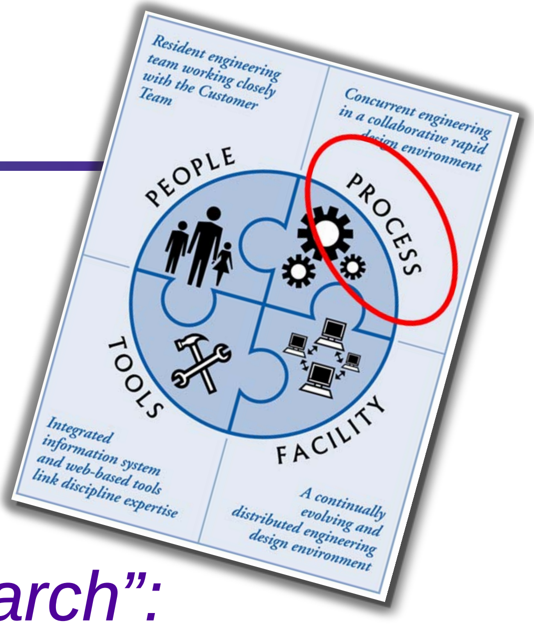


Task Flow Diagram

- Integrated collaborative design process is essentially parallel processing based on continuous intensive interactions between the client, the Team Leader, the System Engineer, and the discipline engineers
  - All parties exchange information in pseudo-real time with virtually all other parties, using IT Data Exchange Platforms: PRIME (MDL) and EditGrid (IDL)
  - Initial system requirements assessed through **concurrent analysis**
  - The customer and the IMDC engineering team work together to establish a straw man concept by **collaborative synthesis**
- The straw man concept is gradually refined with subsystem and system dependencies incorporated in a series of **iterations** of concurrent analyses and collaborative syntheses
- The iterations are repeated until **convergence** in a coherent and consistent final mission concept *baseline*
- The process concludes when the final baseline design provides sufficient information to allow development of credible performance and cost models with contingencies
- **Self-consistency** is assured via Tag-Ups ("mini-red team reviews") and the Final Presentation



Information Flow

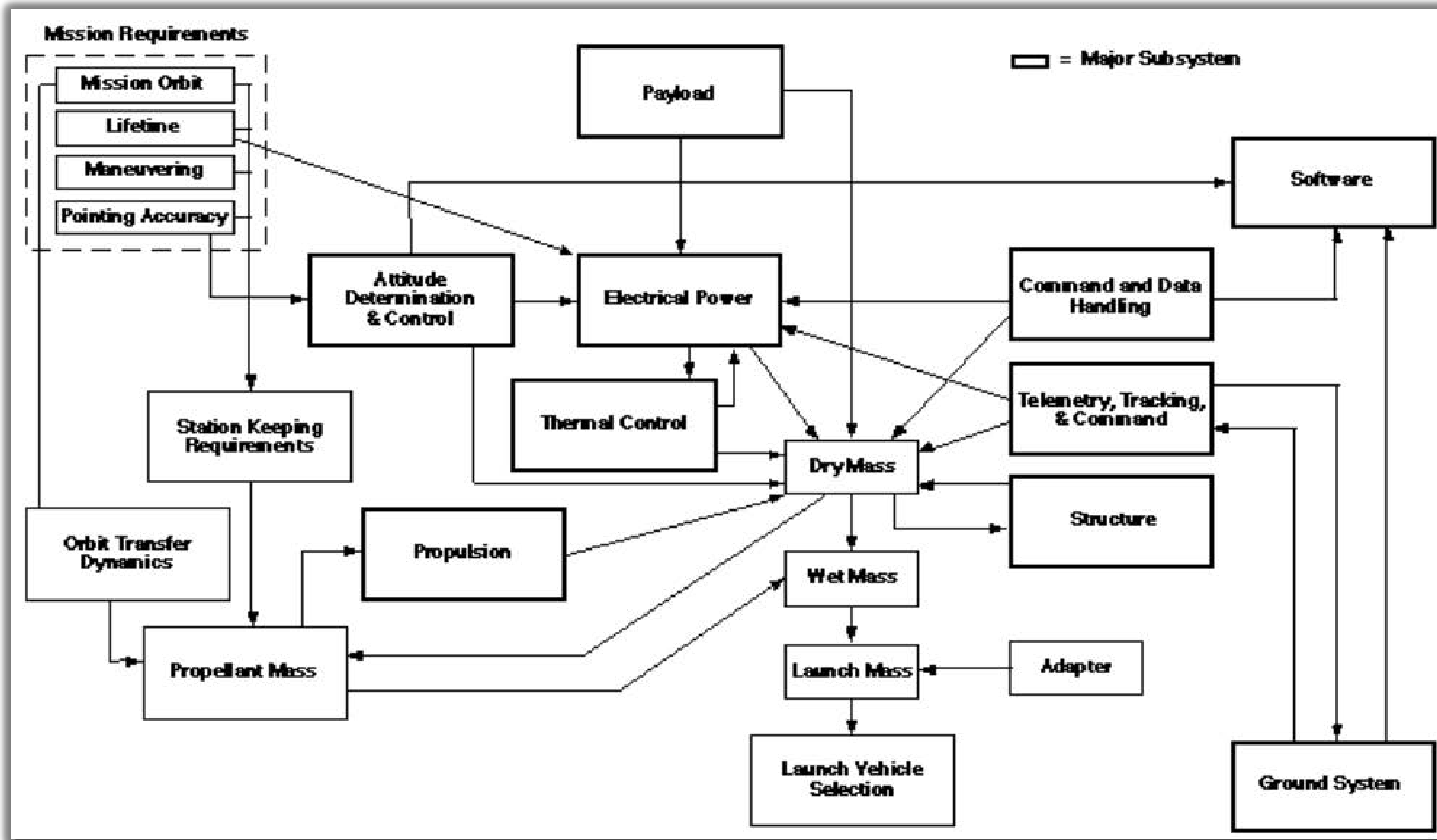


Information Flow "Basic Research":

DSM Optimization: Partitioning and Tearing
Socio-Cognitive Analysis

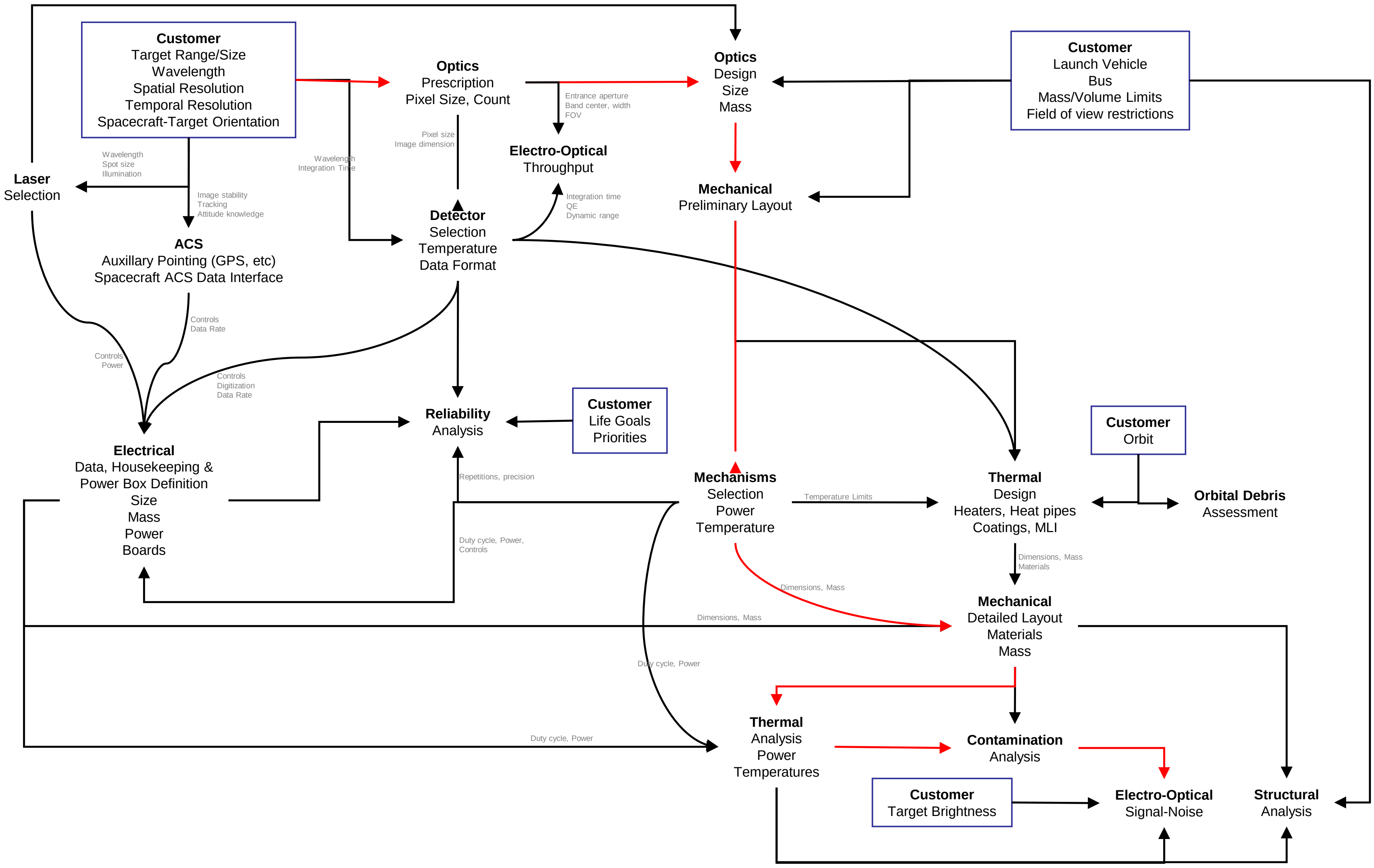
(by Mark Avnet, MIT)

Concurrent Systems Interdependencies



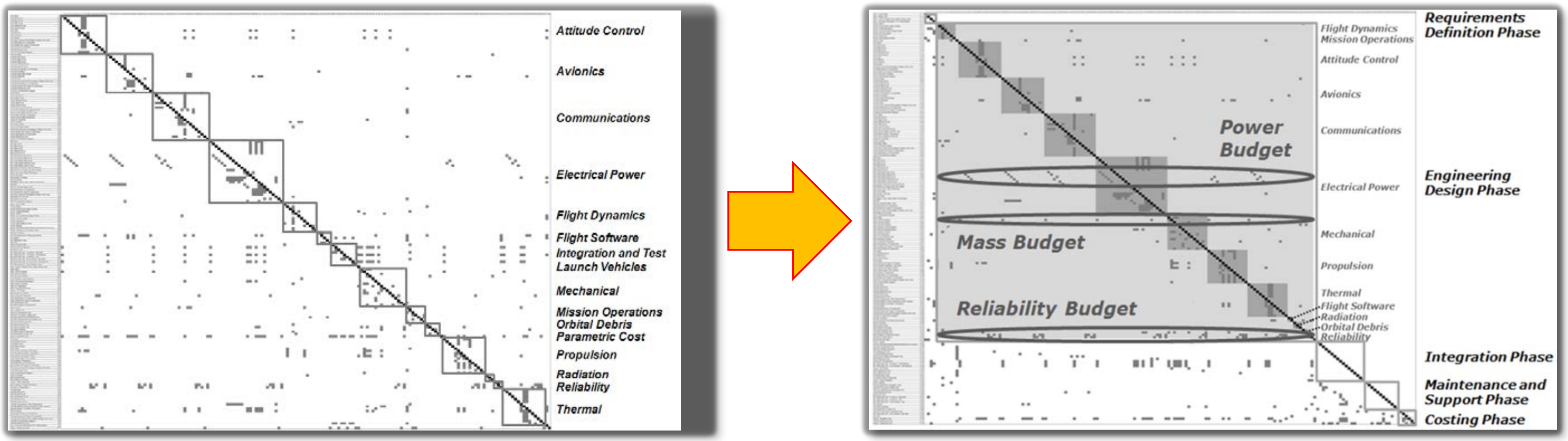
Courtesy: "The Aerospace Corporation's Concept Design Center" By Aguilar, Dawdy, Law

Concurrent Information Flow



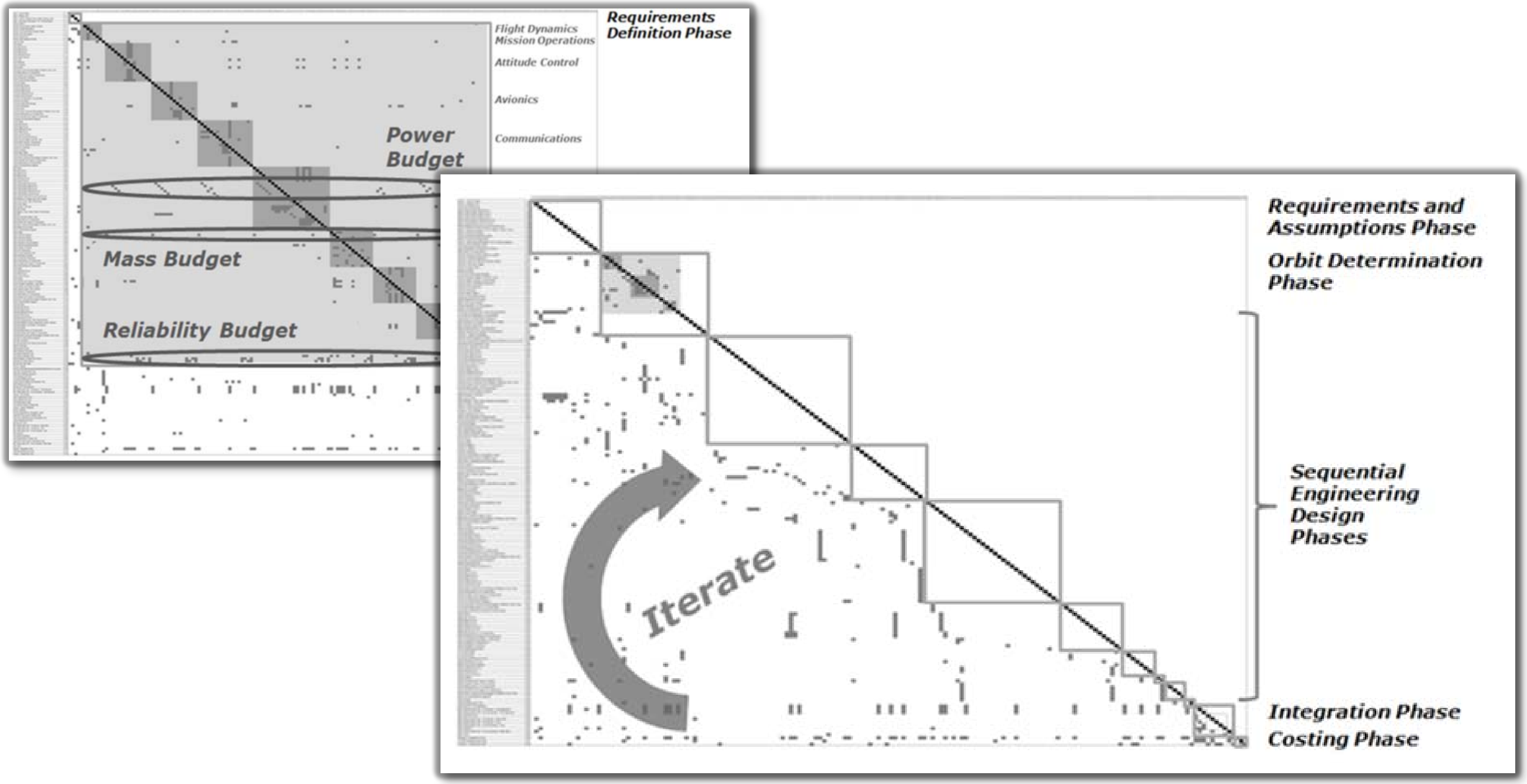
Optimizing the DSM by Partitioning

- **<u>A concurrent design session has numerous complex precedence relationship</u>** issues (i.e. the simultaneous determination of parameters)
  - Three types of tasks: series, parallel, and coupled (information can be “hung up“ in circular dependency loops)
- The Design Structure Matrix is a parameter by parameter input / output matrix, used to explore information flow relationships and design dependencies



- Partitioning adds the temporal order to the DSM, it places the parameters in the order in which they can be determined
  - By reordering design parameters, partitioning clearly identifies dependencies which can then be optimized

Further Optimizing the DSM by Tearing



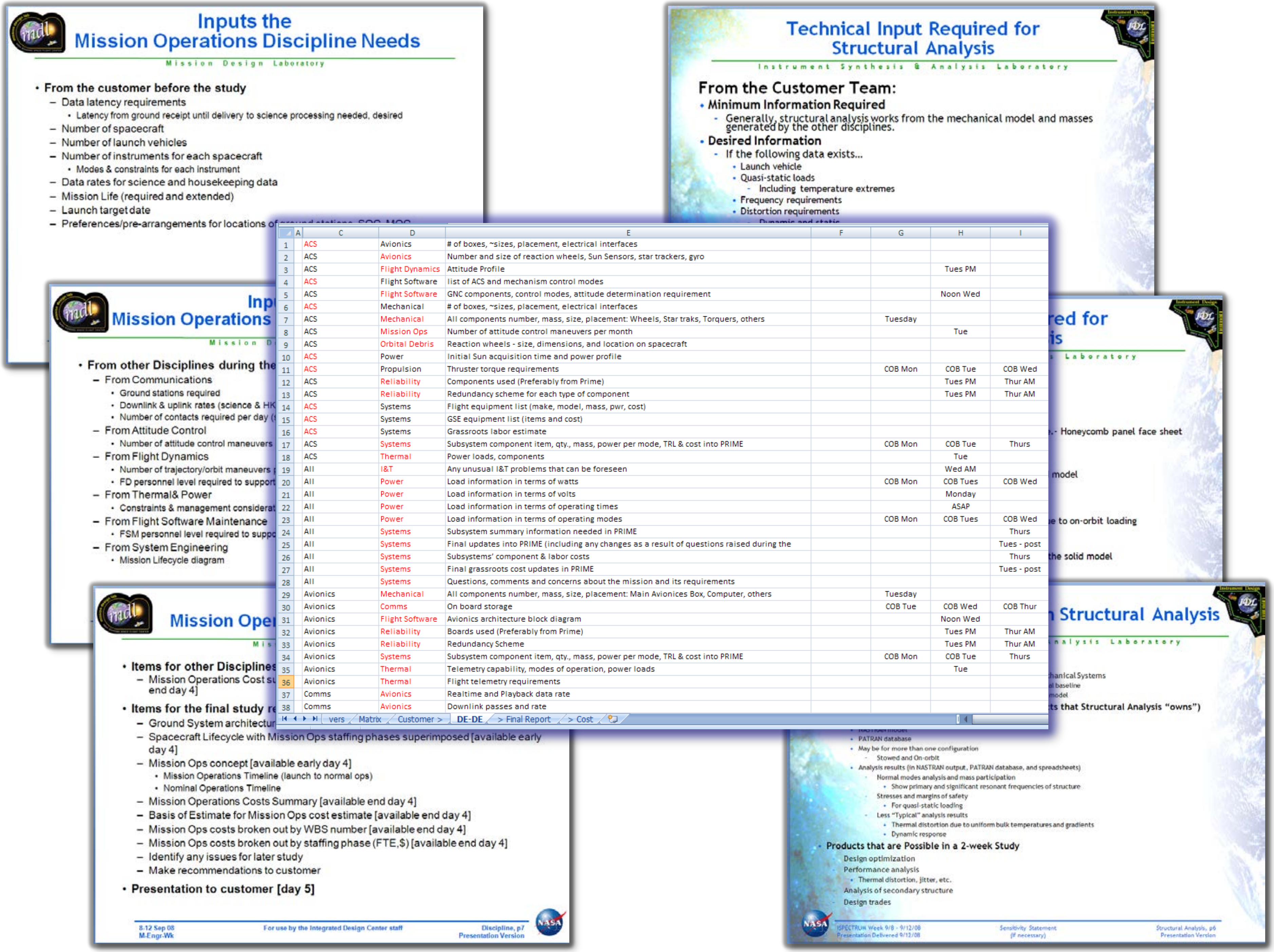
- The goal of **tearing** a DSM is to identify the dependencies that, if removed, would "cut through" circular dependencies, allowing a clear starting point
  - Results in a "lower triangular" DSM (as shown)
- Once identified, circular dependencies can be decoupled by "tearing", i. e. by guesstimating a number of key starting parameters to allow the iteration to proceed

Process – Data Flow

Information Content "Applied Research":

The Gezintos-Gezoutos Project

(by George Polacek, DoD)



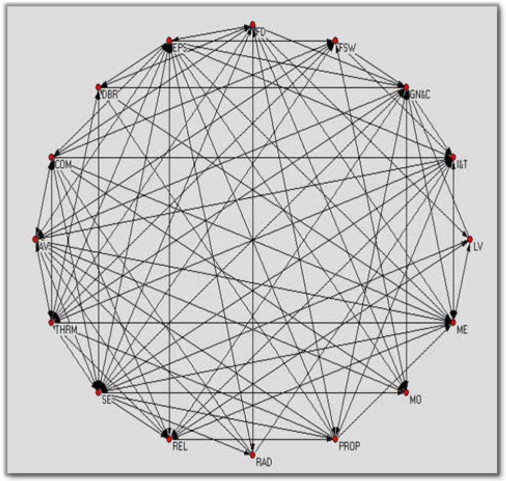
	C	D	E	F	G	H	I
1	ACS	Avionics	# of boxes, ~sizes, placement, electrical interfaces				
2	ACS	Avionics	Number and size of reaction wheels, Sun Sensors, star trackers, gyro				
3	ACS	Flight Dynamics	Attitude Profile			Tues PM	
4	ACS	Flight Software	list of ACS and mechanism control modes				
5	ACS	Flight Software	GNC components, control modes, attitude determination requirement			Noon Wed	
6	ACS	Mechanical	# of boxes, ~sizes, placement, electrical interfaces				
7	ACS	Mechanical	All components number, mass, size, placement: Wheels, Star traks, Torquers, others		Tuesday		
8	ACS	Mission Ops	Number of attitude control maneuvers per month			Tue	
9	ACS	Orbital Debris	Reaction wheels - size, dimensions, and location on spacecraft				
10	ACS	Power	Initial Sun acquisition time and power profile				
11	ACS	Propulsion	Thruster torque requirements		COB Mon	COB Tue	COB Wed
12	ACS	Reliability	Components used (Preferably from Prime)			Tues PM	Thur AM
13	ACS	Reliability	Redundancy scheme for each type of component			Tues PM	Thur AM
14	ACS	Systems	Flight equipment list (make, model, mass, pwr, cost)				
15	ACS	Systems	GSE equipment list (items and cost)				
16	ACS	Systems	Grassroots labor estimate				
17	ACS	Systems	Subsystem component item, qty., mass, power per mode, TRL & cost into PRIME		COB Mon	COB Tue	Thurs
18	ACS	Thermal	Power loads, components			Tue	
19	All	I&T	Any unusual I&T problems that can be foreseen			Wed AM	
20	All	Power	Load information in terms of watts		COB Mon	COB Tues	COB Wed
21	All	Power	Load information in terms of volts			Monday	
22	All	Power	Load information in terms of operating times			ASAP	
23	All	Power	Load information in terms of operating modes		COB Mon	COB Tues	COB Wed
24	All	Systems	Subsystem summary information needed in PRIME				Thurs
25	All	Systems	Final updates into PRIME (including any changes as a result of questions raised during the				Tues - post
26	All	Systems	Subsystems' component & labor costs				Thurs
27	All	Systems	Final grassroots cost updates in PRIME				Tues - post
28	All	Systems	Questions, comments and concerns about the mission and its requirements				
29	Avionics	Mechanical	All components number, mass, size, placement: Main Avionices Box, Computer, others		Tuesday		
30	Avionics	Comms	On board storage		COB Tue	COB Wed	COB Thur
31	Avionics	Flight Software	Avionics architecture block diagram			Noon Wed	
32	Avionics	Reliability	Boards used (Preferably from Prime)			Tues PM	Thur AM
33	Avionics	Reliability	Redundancy Scheme			Tues PM	Thur AM
34	Avionics	Systems	Subsystem component item, qty., mass, power per mode, TRL & cost into PRIME		COB Mon	COB Tue	Thurs
35	Avionics	Thermal	Telemetry capability, modes of operation, power loads			Tue	
36	Avionics	Thermal	Flight telemetry requirements				
37	Comms	Avionics	Realtime and Playback data rate				
38	Comms	Avionics	Downlink passes and rate				

Information Exchange Matrix

To	AT	COM	DDR	EPS	FD	FSW	GN&C	INT	LV	ME	MO	PROP	RAD	REL	SE	THERM
AT		[illegible]		[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COM	[illegible]			[illegible]	[illegible]					[illegible]			[illegible]	[illegible]	[illegible]	
DDR				[illegible]	[illegible]		[illegible]			[illegible]		[illegible]			[illegible]	[illegible]
EPS	[illegible]	[illegible]			[illegible]		[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FD		[illegible]	[illegible]	[illegible]					[illegible]	[illegible]		[illegible]			[illegible]	
FSW	[illegible]	[illegible]		[illegible]			[illegible]				[illegible]				[illegible]	[illegible]
GN&C				[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
INT	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LV					[illegible]					[illegible]				[illegible]	[illegible]	
ME	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		[illegible]			[illegible]		[illegible]	[illegible]	[illegible]
MO		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]								[illegible]	
PROP					[illegible]		[illegible]							[illegible]	[illegible]	
RAD					[illegible]										[illegible]	
REL	[illegible]	[illegible]		[illegible]			[illegible]		[illegible]	[illegible]		[illegible]			[illegible]	[illegible]
SE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
THERM	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]		[illegible]	[illegible]	

Information Exchange Matrix Network Analysis

- View the IE Matrix as a directed network of interactions
  - Each discipline is a node in the network
  - Each exchange is an arc from information source to destination
  - Arcs do not indicate details about the information

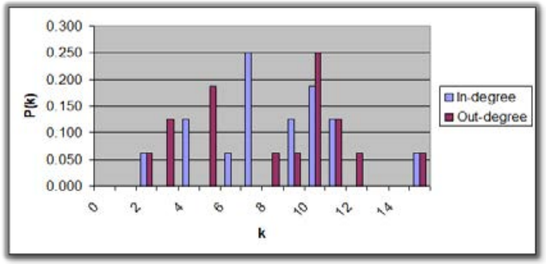


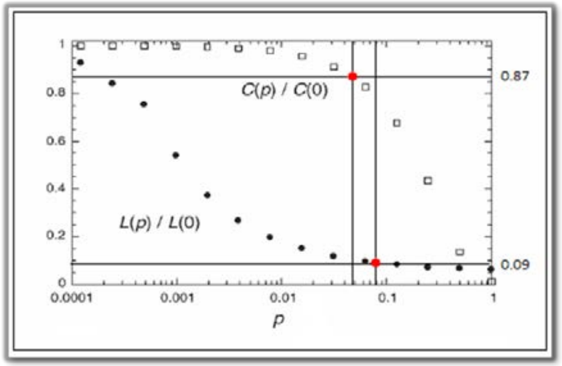
- Several highly connected nodes exist.
  - Act as information hubs for the team
- "Average" node interacts with more than half of the other nodes.
  - No highly isolated nodes.
  - Indicates highly collaborative team.

Node	No. of inputs	In-degree	No. of outputs	Out-degree
AV	11	0.733	8	0.533
COM	7	0.467	10	0.667
DBR	7	0.467	3	0.200
EPS	10	0.667	12	0.800
FD	7	0.467	10	0.667
FSW	7	0.467	5	0.333
GN&C	9	0.600	11	0.733
I&T	11	0.733	2	0.133
LV	4	0.267	5	0.333
ME	10	0.667	11	0.733
MO	6	0.400	3	0.200
PROP	4	0.267	10	0.667
RAD	2	0.133	5	0.333
REL	9	0.600	10	0.667
SE	15	1.000	15	1.000
THRM	10	0.667	9	0.600
avg =		0.538		0.538

Does the MDL information exchange network have characteristics similar to a stereotypical network such as a Small World or Scale Free type network? This can be determined by examining several other network characteristics:

- Probability distributions of the input and output arcs;
- Characteristic path length and the clustering coefficient





Conclusions:

- The data does not exhibit an exponential or "power law" distribution.
- The data does exhibit high clustering and a short average path length.

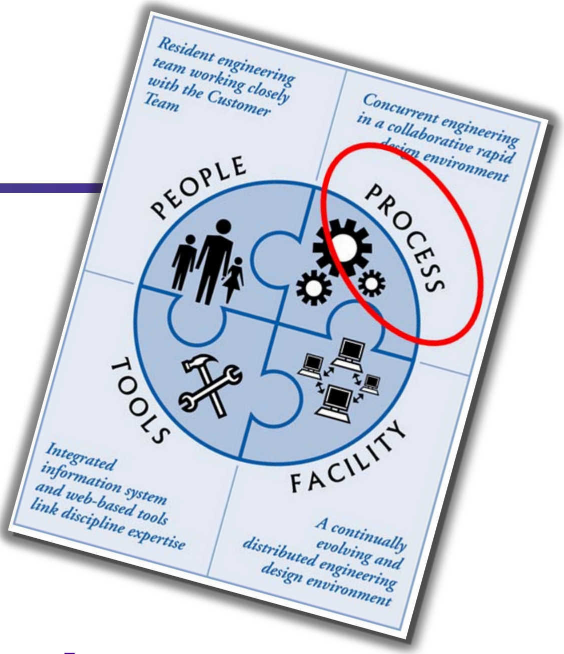
Taken together, that indicates, the MDL network is "Small World" type network..

Related Publications

- More information on the foregoing:
  - **Karpati, G.; Polacek, G.; Avnet, M.; Panek, J.; Campbell, B.; “Information Exchange In a Concurrent Engineering Lab, and The Tools That Enable It”; AIAA Space 2011 Proceedings; 2011**

- Closely related additional publications:
  - Avnet, M.S., and Weigel, A.L., “An Application of the Design Structure Matrix to Integrated Concurrent Engineering.” *Acta Astronautica* 66: 937-949, 2010
  - Avnet, M.S., “Socio-Cognitive Analysis of Engineering Systems Design: Shared Knowledge, Process, and Product.” Engineering Systems. Massachusetts Institute of Technology, Cambridge, MA. Ph.D., 2009
  - Karpati, G.; Martin, J.; Steiner, M.; Reinhardt, K.; “The Integrated Mission Design Center (IMDC) at NASA Goddard Space Flight Center”; IEEE Proceedings, 2003, Volume 8, Issue , Page(s): 8_3657 - 8_3667; March 8-15, 2003
  - Hihn, J.; Chattopadhyay, D.; Karpati, G.; McGuire, M.; Borden, C; Panek, J.; Warfield, K.; “Aerospace Concurrent Engineering Design Teams: Current State, Next Steps and a Vision for the Future”; AIAA Space 2011 Proceedings; 2011

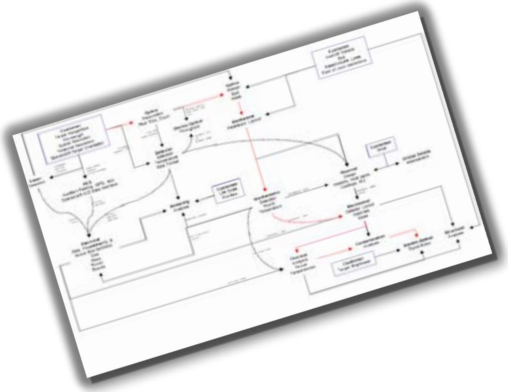
Process - ACE

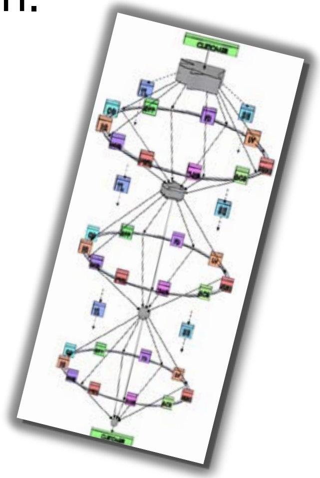


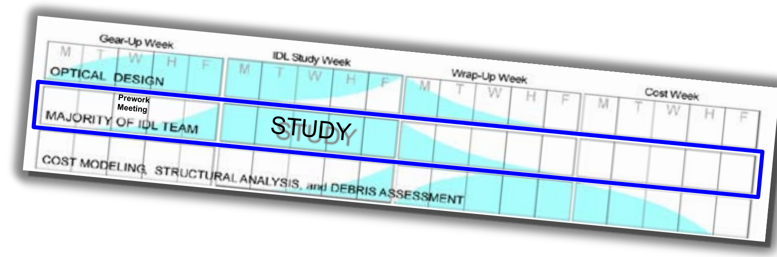
Agile Concurrent Engineering

Raising the Bar: the Need for Agility

- A typical study in a standard concurrent engineering lab todays is comparable to a well rehearsed dance, where a process is fine tuned to a well defined standard flow and duration.







- The problem is: <u>not all customers need the exact same well rehearsed process</u>
  - Some have a higher number of questions, but don't mind less in-depth.. answers
  - Some want to focus on narrow questions, but need accurate in depth answers
  - Some have less resources, need a lesser or shorter study
  - Some have adequate resources, but want to apportion it to a custom-tailored study series to cover all of their needs (to a depth as permitted by the resources)

Agile Concurrent Engineering (ACE)

The answer to varying customer needs is <u>Agile Concurrent Engineering (ACE)</u>

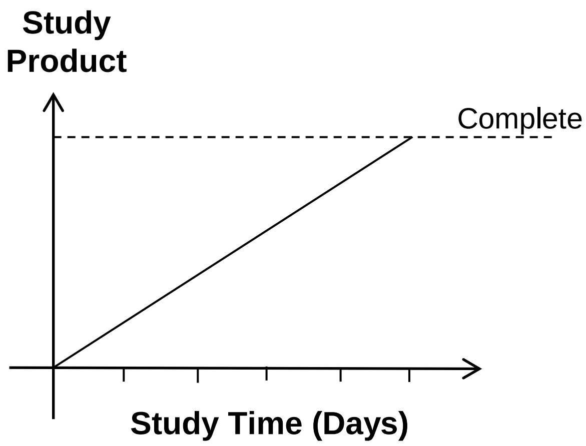
- ACE **custom tailors a lab's (formerly rigid) concurrent design process** to adapt it to varying customer needs
  - Adjusts the scope, depth, duration, and cost of the studies
  - Adjusts the expected study products:
    - Variable analytical depth
    - Hence, variable study product quality and accuracy.
      - (As ACE study durations vary, so do the uncertainties associated with study products. Obviously, a longer study that tackles only a few questions allows the concurrent engineering team to conduct deeper analyses than a shorter study that tackles a higher number of issues.

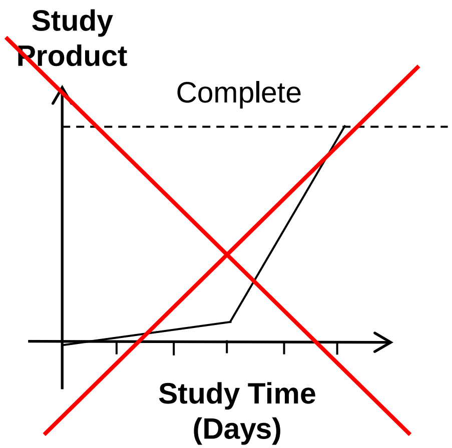
- ACE requires more careful in-depth <u>planning</u> with the customer, to (1.) apportion the study resources and durations, and plan study flow; as well as to (2.) align expectations

- ACE requires the Team Lead's and Systems Engineer's exceptionally <u>knowledgeable leadership</u> during study execution. They will have to adjust and manage the (once rigid) study processes in real-time.

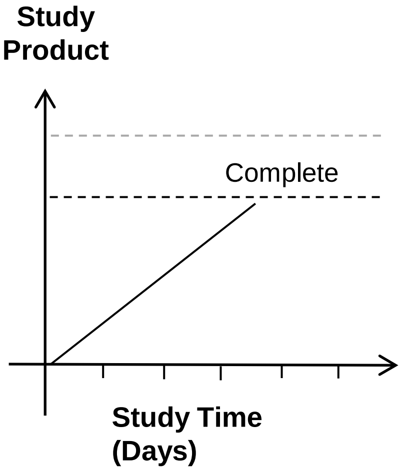
Standard Study Process vs. ACE

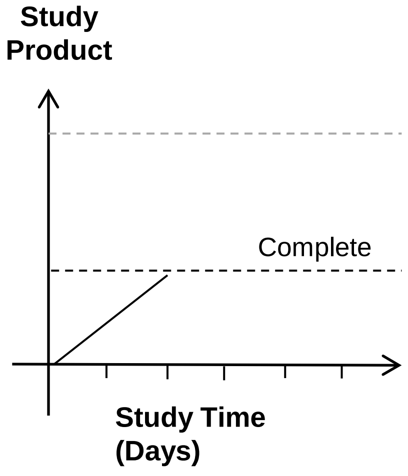
Standard CE Study

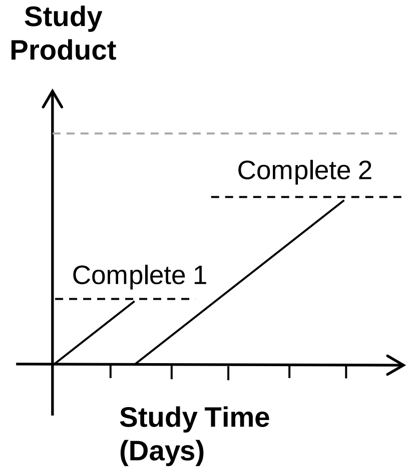


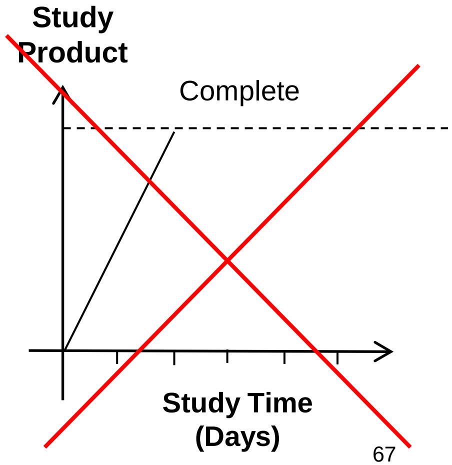


ACE Study









Study Product Quality

STAR WARS

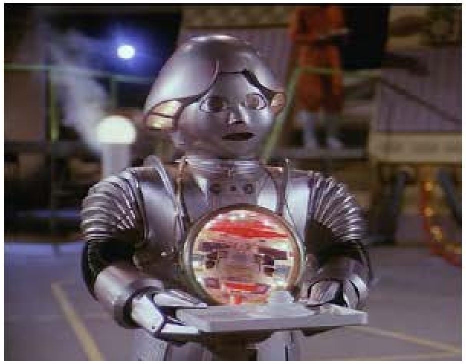
- PRODUCT: well worked, very presentable
- DETAILS: well refined, sometimes intricate
- STORY: compelling and convincing
- WHEN: Expect this in a 2 week IDL study, provided all other contributing factors are near-optimal: good and detailed customer input, no changes in study direction, no workload creep, no unexpected surprises

STAR TREK (Original Series)

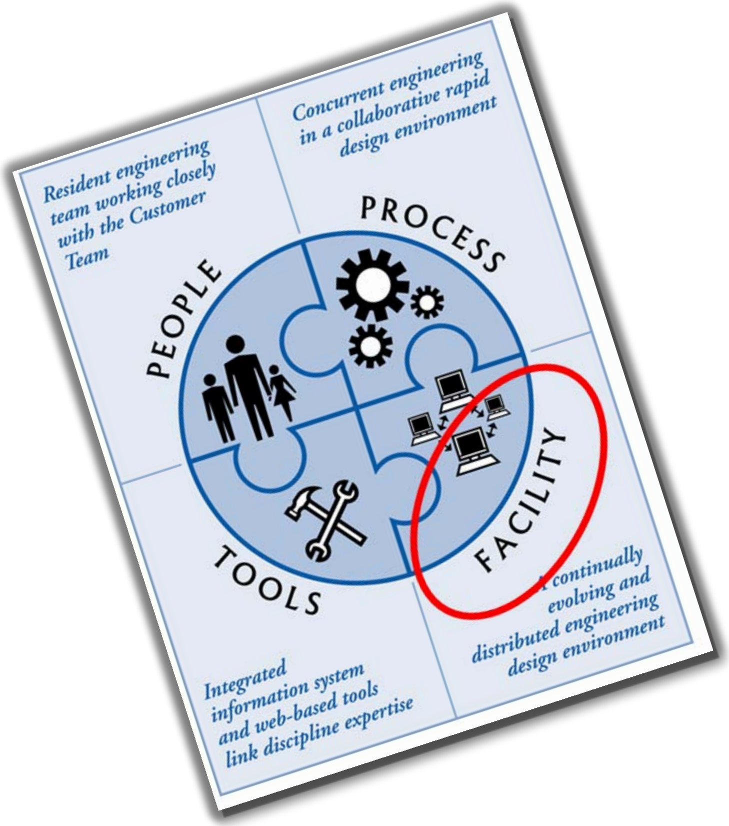
- PRODUCT: A bit simpler, a bit rougher around the edges
- DETAILS: Much less details, generally a bit crude
- STORY: The story is still interesting
- WHEN: Expect this in a 1 week IDL study, provided all other factors are near-optimal OR in a longer study if some of the quality factors misbehave

BUCK ROGERS

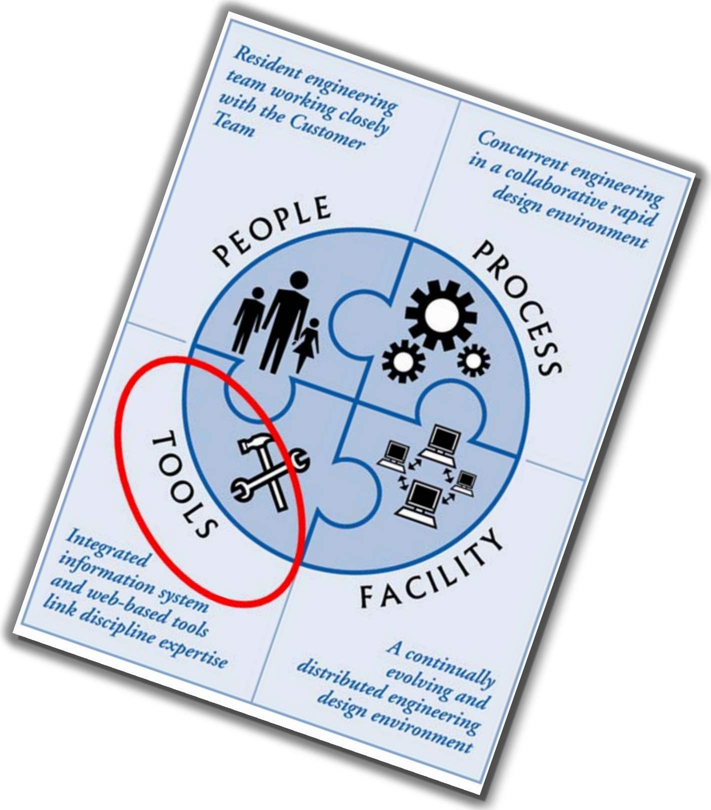
- PRODUCT: Major simplifications, approximations, prorating
- DETAILS: Definitely crude and sketchy
- STORY: Simplistic, needs much future refining
- WHEN: Expect this in a < 1week IDL study OR in a longer study if some of the quality factors seriously misbehave



Facilities and Tools

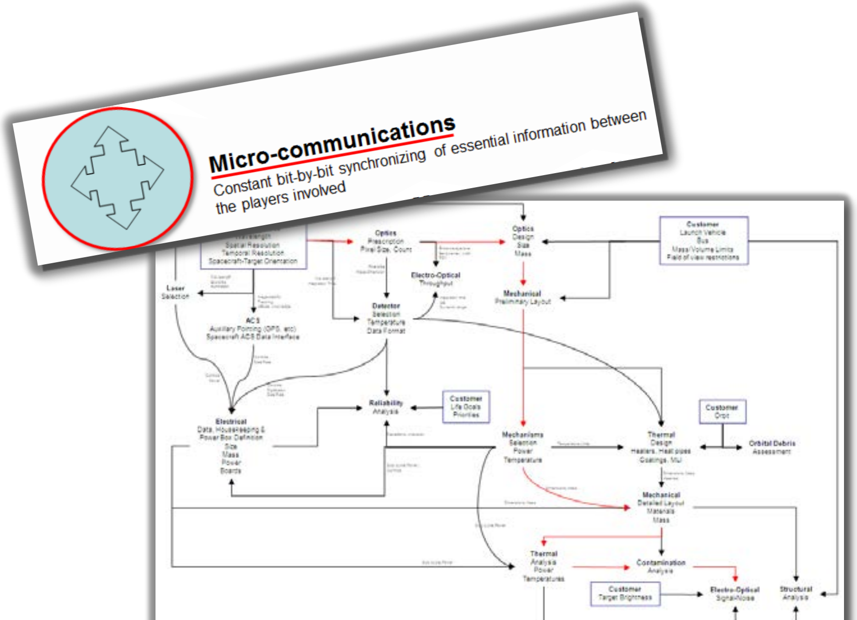


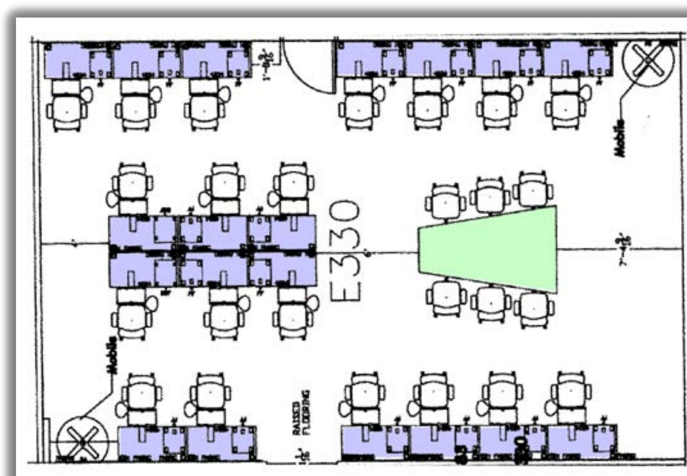
Platforms



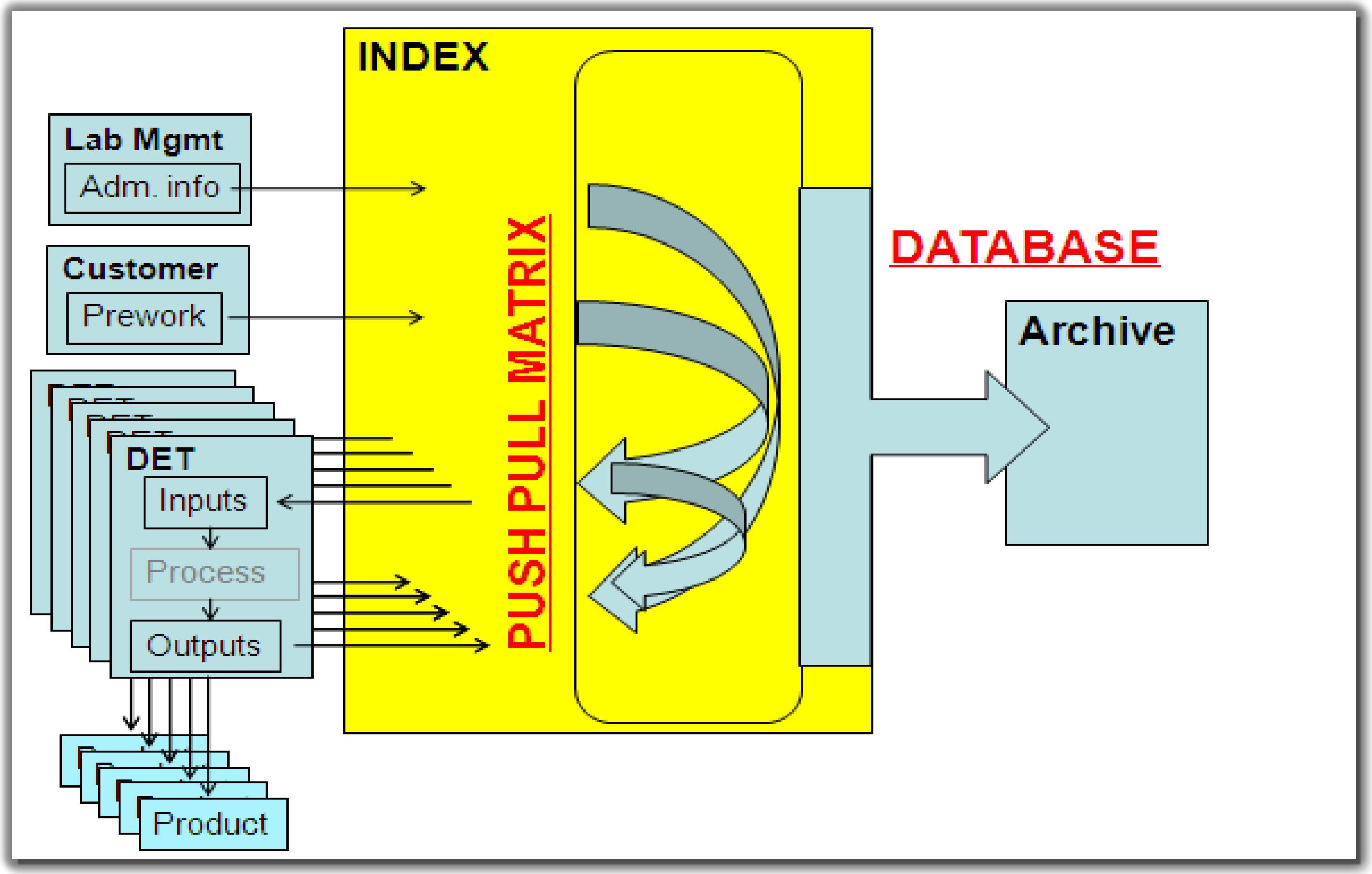
The Study Room
is the Platform for Micro-Communications

- The most essential means of information exchange in a concurrent lab, the **backbone** that makes solidly parallel engineering actually possible is, to this day, the **old fashioned person to person verbal communication**.
  - Spontaneous informal exchanges, trading questions and answers, or providing up-to-the minute verbal updates
  - Also includes more substantial discussions and debates.
  - The layout of seating arrangements in the MDL is carefully planned to conform to the principal pathways of information flow and thus facilitate the verbal exchanges.
- **All required engineering disciplines co-located in the same facility cooperating at the same time DEDICATED to the study for the study duration**



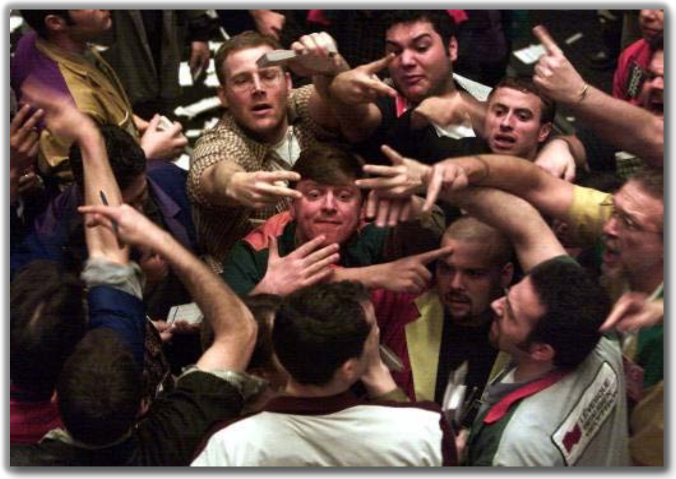


Data Exchange Platforms
handles Macro-Communication

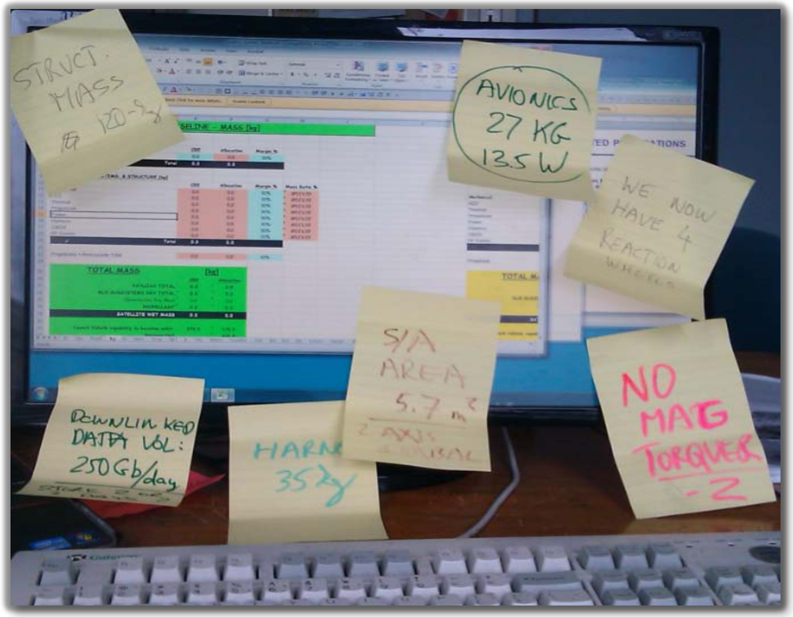


"Low Tech" Information Exchange

- **In the early days of the MDL**, information sharing, even for purely numerical information, consisted exclusively of **verbal exchanges**.

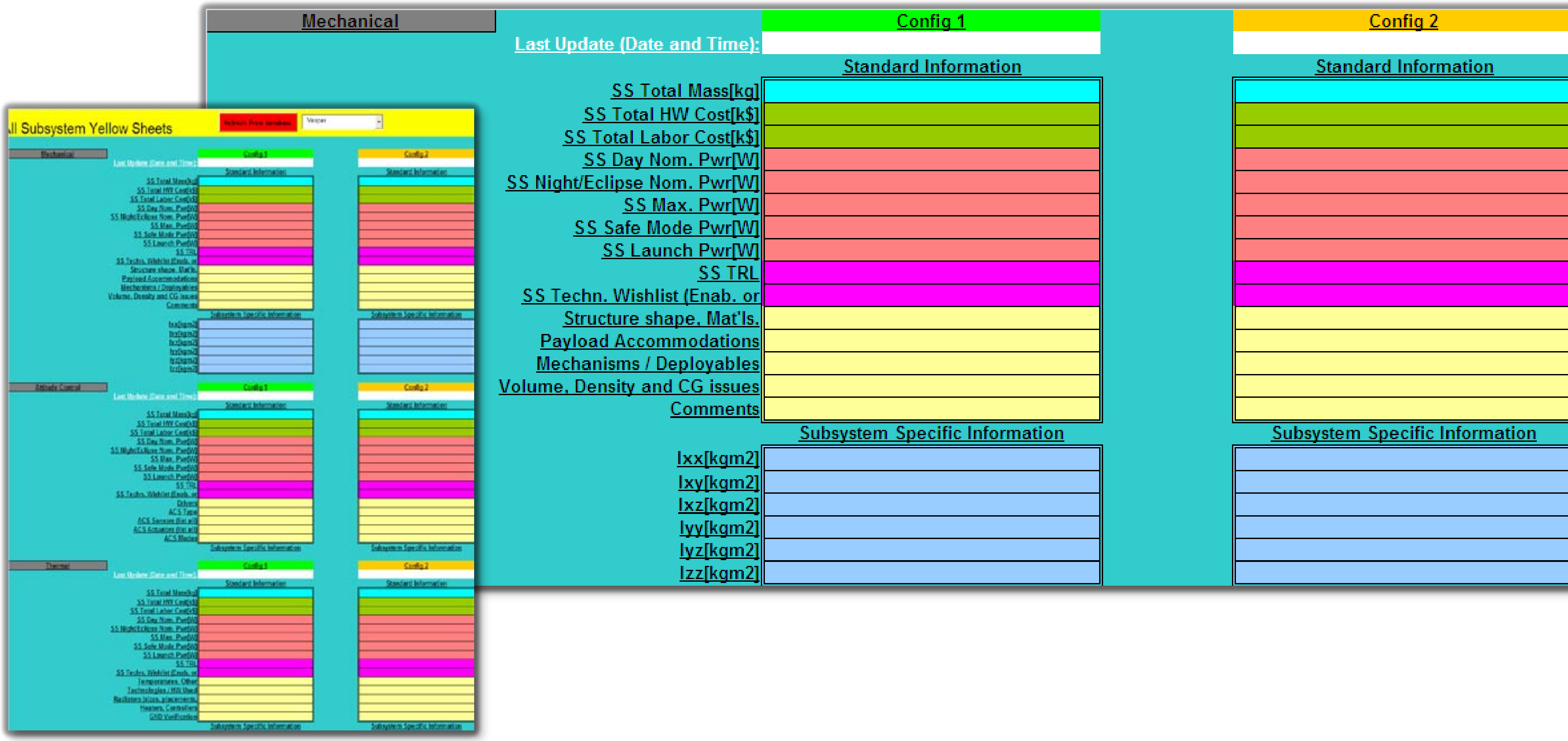


- Over time, that evolved into to **more transactions in writing**, especially for numerical content.
  - Eventually semi-standardized in that only easily recognizable stick-on "**yellow sheets**" were used.
  - Before the daily tag-ups where the Systems Engineer manually transcribed all the Subsystem yellow sheets into Excel, to get updated resource tallies.



EXIX – Subsystem Inputs

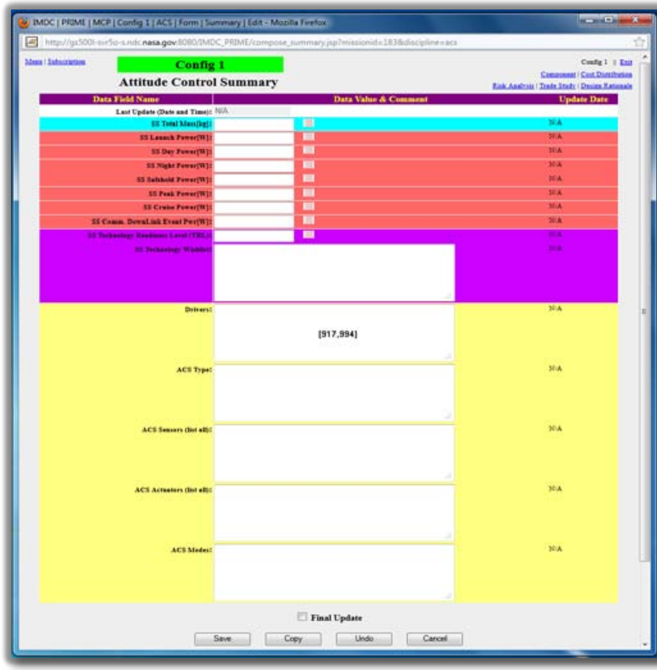
- Each Discipline had a **uniquely formatted** Excel Spreadsheets to enter his/her values
- **Range (area) copies** from Discipline spreadsheet to SE spreadsheet
- **Automated** the opening up of the DE Yellow Sheet files and the cut-and-paste using VBA
  - Initially, EXIX experimented with hyperlinks for file access, but hyperlinks proved to be too fragile. Any change in a file's path-name broke the link and brought down the exchange.
- Simple file management system and naming convention allowed the VBA program to physically address, open, then close, each DE Yellow Sheet file.

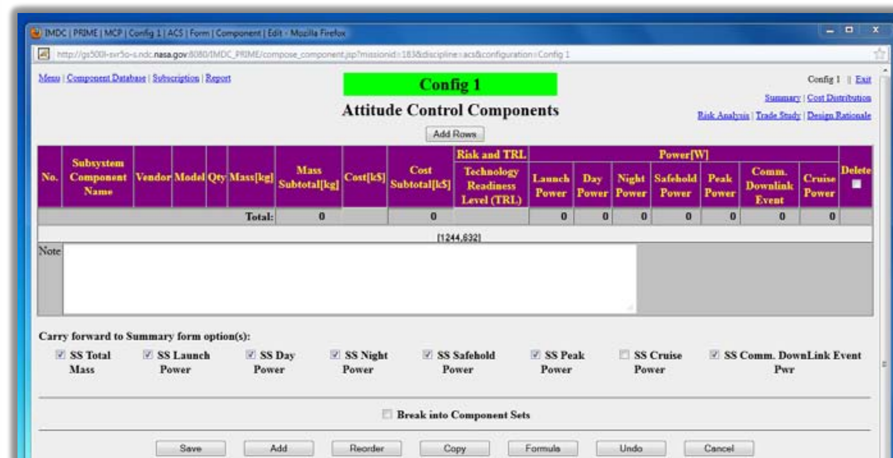


EXIX – Automatically Compiled Tables

PRIME – User Layer

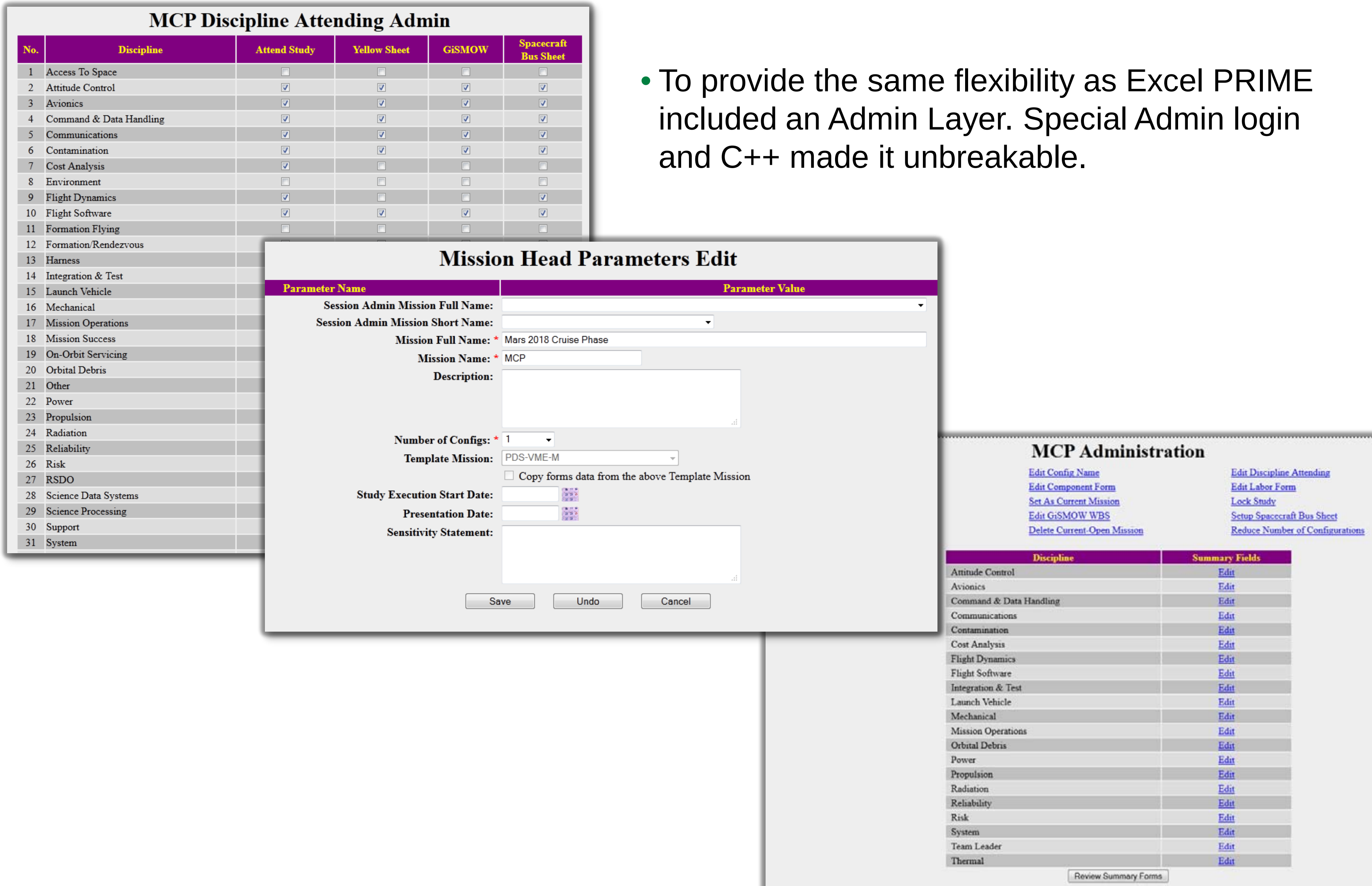
- PRIME (Process Reasoning and Information Management Environment) looks and feels exactly like the EXIX, with the functions and appearance (colors, cells, gridlines, and all) copied verbatim.
- A advantage of PRIME was that all study data collected was reposited in a central Study Database, available for search and reuse.





PRIME – Admin Layer

- To provide the same flexibility as Excel PRIME included an Admin Layer. Special Admin login and C++ made it unbreakable.



INDEX Overview

- **INDEX** is the next generation data platform planned for the IDC.
- It is the **physical manifestation** of the **dataflow structure** defined by the **“Gezintos-Gezoutos”** (inputs and outputs) Project

Key Requirements:

1. **INDEX shall handle all information for all Disciplines, not just for the Systems Engineer**
2. **From the information in INDEX alone, the exact study product shall be precisely recreatable without ambiguity**
   - INDEX contains all essential information produced by a concurrent engineering study. The relation between the totality of information processed during a study and the ISDP is comparable to the relation between a “wav” sound file and its “mp3” version.
3. **INDEX shall be useable in distributed concurrent engineering as the interface data structure for the data exchange**
   - The interface consists of a single table, in which all information is exchanged between the distributed parties

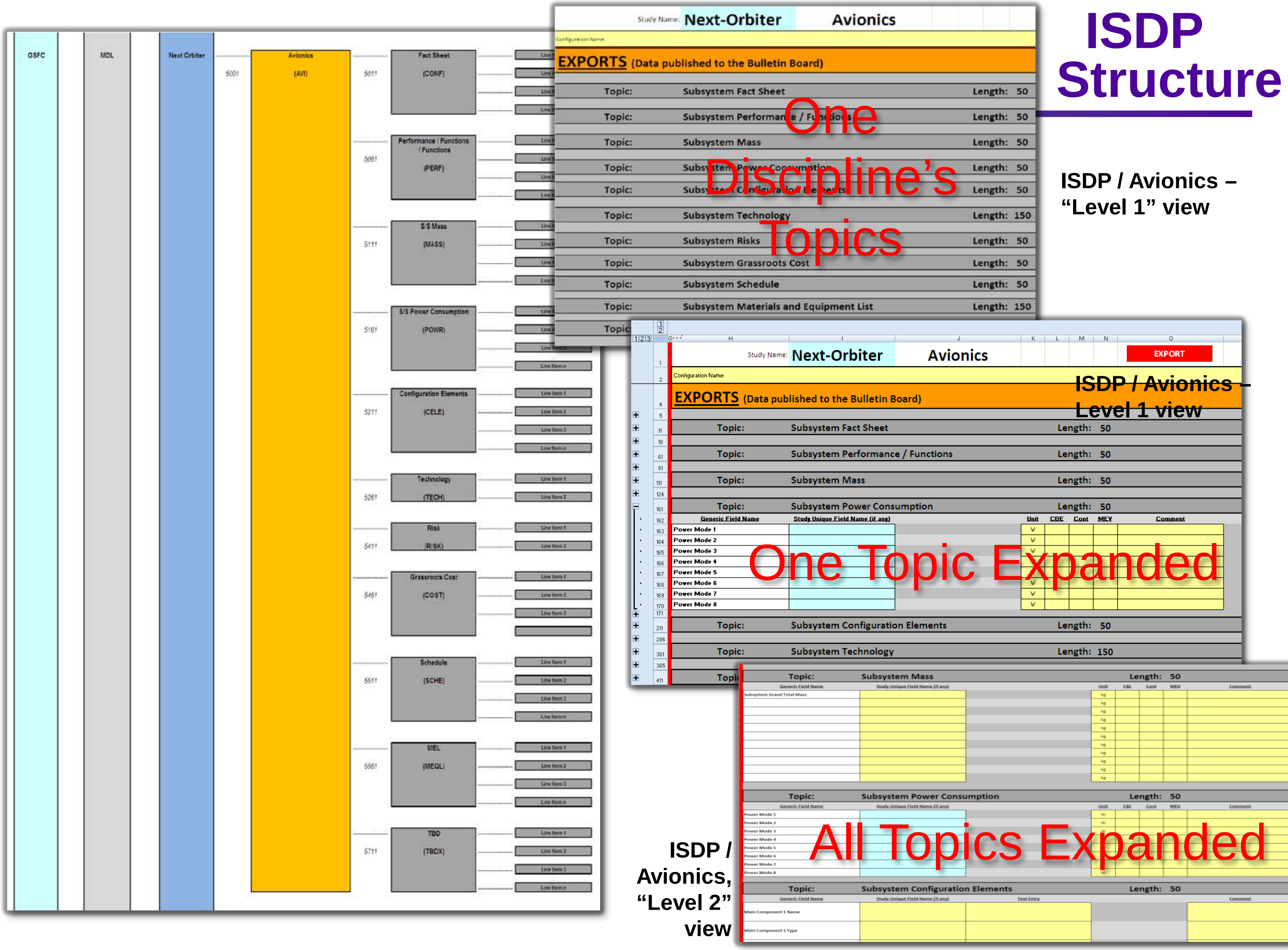
ISDP Data Structure

The hub of INDEX is essentially a Bulletin Board where all Disciplines reposit all their data

The totality of study information contained in INDEX is referred to as

INDEX Study Data Product (ISDP)

ISDP Structure



INDEX Moves Areas, Not Values

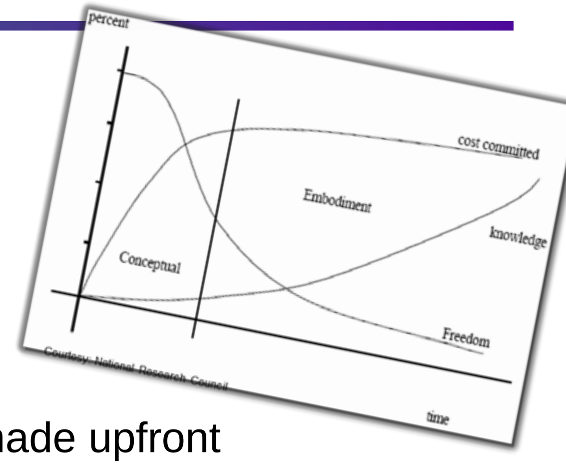
- **INDEX has no links between Disciplines**
- **INDEX copies entire areas (ranges), not individual values one by one**
  - Move data as a table of individual values (not as an image)
  - Greatly reduces complex web on links
  - Preserves the value inherent in Structures
  - Ready for "human consumption" without reformatting

Item	Unit	Value
Comm Relay S/C Bus		
Mechanical CBE	kg	40.7
Mechanical MGA	%	30.0
Mechanical MEV	kg	52.8
Propulsion Dry CBE	kg	54.9
Propulsion Dry MGA	%	15.0
Propulsion Dry MEV	kg	63.1
GN&C CBE	kg	19.8
GN&C MGA	%	15%
GN&C MEV	kg	19.8
Thermal SCM	kg	15%

Item	CBE [kg]	MGA [%]	MEV [kg]
Comm Relay S/C Bus	212.7		252.2
Mechanical	40.7	30%	52.8
Propulsion Dry	54.9	15%	63.1
GN&C	19.8	15%	22.8
Thermal SCM	10.9	15%	12.5
Power	42.0	15%	48.3
Harness (5% of dry mass)	10.0	30%	13.0
RF Comm	26.5	15%	30.5
Avionics	8.0	15%	9.2
Comm Sat Propellant			451.9

Contingency and Margin in Concurrent Engineering

The Need for Contingencies and Margins



- Knowledge about the system designed is acquired

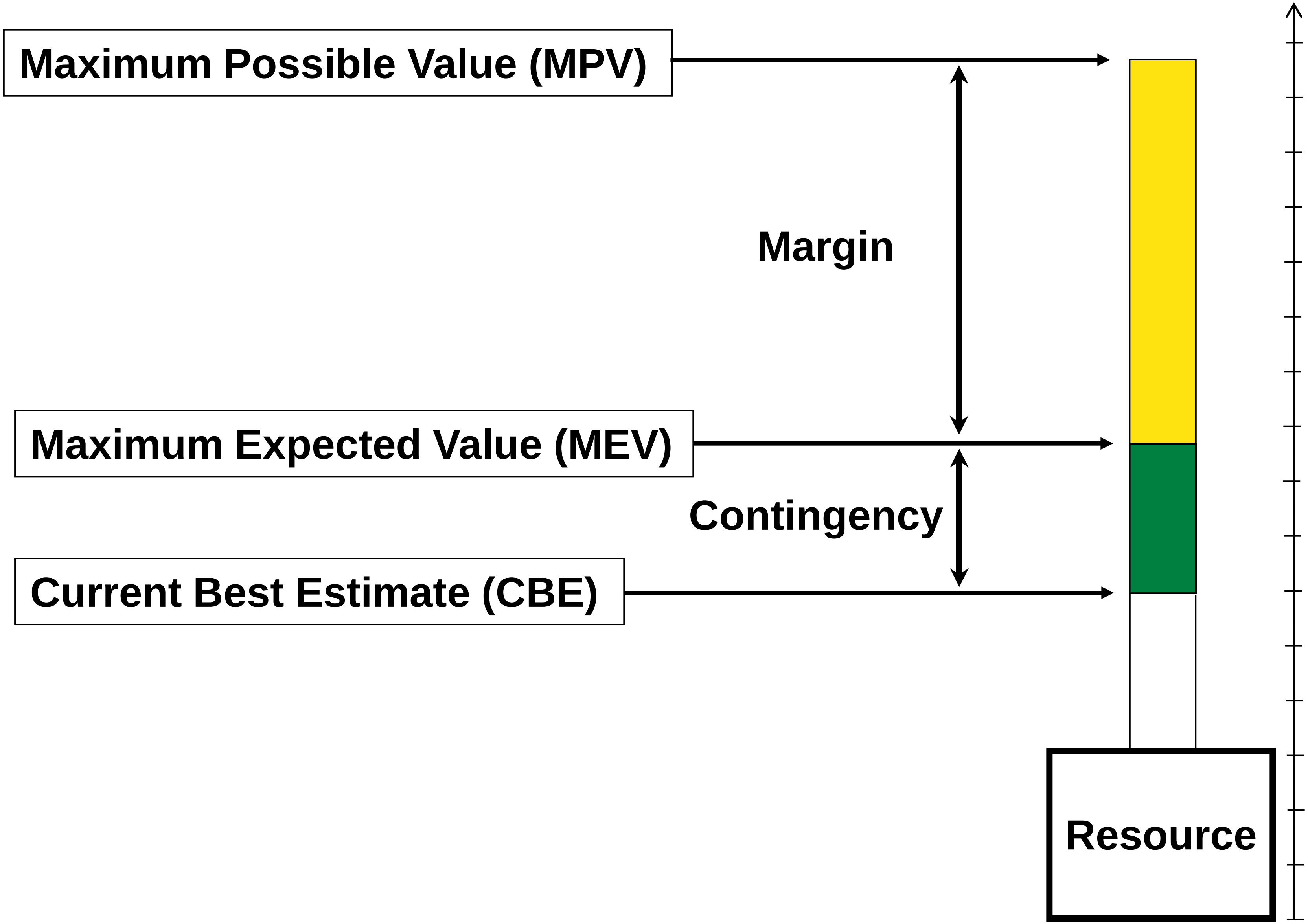
Incrementally as it's built and used, but commitments must be made upfront

(in some ways, in the unknown)

To buffer against surprises, contingencies and margins must be embedded in the design

- This issue presents itself in full force in the aerospace industry, where unprecedented systems are formulated and committed to as a matter of routine

Margin and Contingency Definitions



Mass Contingency
IDC Guideline

Guideline (in compliance with GOLD Rules, GSFC-STD-1000 Revision E):

– Apply Mass Contingency %'s as per the Table below

- *In the case of existing technology items, disregard the "TRL Range" Column. Basing row selection on the "TRL Range" column alone may be misleading!*

Table 1.06-2 Recommended Mass Contingency/Reserve by Subsystem[1]

All values are assumed to be at the end of the phase

Sub-system Design Maturity[2]	TRL Range[2]	Contingency/Reserve (in percent)[3]											
		Electrical/Electronic			*Structure*	*Brackets, Clips, Hardware*	*Battery*	*Solar Array*	*Thermal Control*	*Mechanisms*	*Propulsion[4]*	*Wire Harness*	*Science Instrument*
		0-5 kg	*5-15 kg*	*>15 kg*									
Basic principles reported thru technology concept and/or application formulated.	0 to 2	30	25	20	25	30	25	30	25	25	25	55	55
Analytical/experimental proof of concept thru breadboard validation in relevant environment	3 to 5	25	20	15	15	20	15	20	20	15	15	30	30
Sub-system/component prototype demo in an operational environment	6	20	15	10	10	15	10	10	15	10	10	25	25
Sub-system engineering unit test in an operational environment	7	10	5	5	5	6	5	5	5	5	5	10	10
Actual sub-system completed and flight qualified	8	3	3	3	3	3	3	3	3	3	3	5	5
Actual sub-system flight proven through successful mission operations	9	0	0	0	0	0	0	0	0	0	0	0	0

1. Adapted from Table 1, "Space Systems - Mass Properties Control for Space Systems",S-120-2006e, AIAA.
2. See the latest version of NPR 7120.8 Appendix J for NASA TRL definitions and classification schema.
3. Contingency % =100% x Contingency(kgs)/(Maximum Expected Value(kgs) - Contingency(kgs))
4. Propulsion sub-system dry mass only.
5. For system margins, see Table 1.06-1.
6. Subsystems not identified as new technology developments can be evaluated as if they are at TRL 6.
7. Subsystems which are fully qualified at the system level for the current mission, and have been weighed, can be evaluated as if they are at TRL 9

Mass Margin
IDC Guideline

Guideline (in compliance with GOLD Rules, GSFC-STD-1000 Revision E):

– In addition to the Mass Contingency %'s (as per the previous slide), also carry Mass Margin at the System Level as per the Table below

Table 1.06-1 Required Minimum Acceptable Technical Resource System Margin
All values are assumed to be at the end of the phase

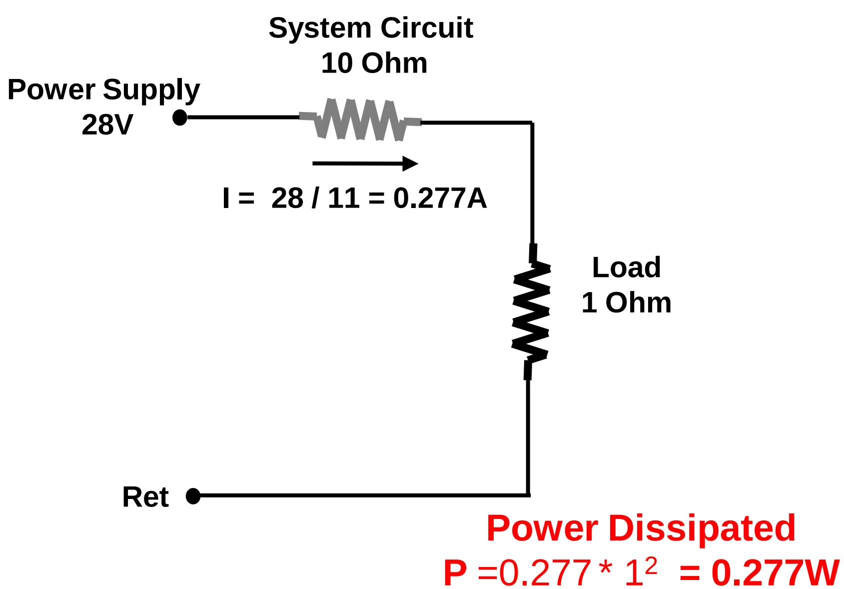
Resource	Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E
MEV for Dry Mass	30%	25%	20%	15%	0	
Power (at EOL)	30%	25%	15%	15%	10%[1]	
Propellant (Δv)[2]	3σ				3σ	
Telemetry and Command hardware channels[3]	25%	20%	15%	10%	0	
RF Link	3 db	3 db	3 db	3 db		

Maximum Possible Value = The physical limit or agreed-to limit.
Maximum Expected Value (MEV) = Current Best Estimate (CBE) + Contingency/Reserve
Margin=Maximum Possible Value-Maximum Expected Value
% Margin=100% x Margin/Maximum Expected Value

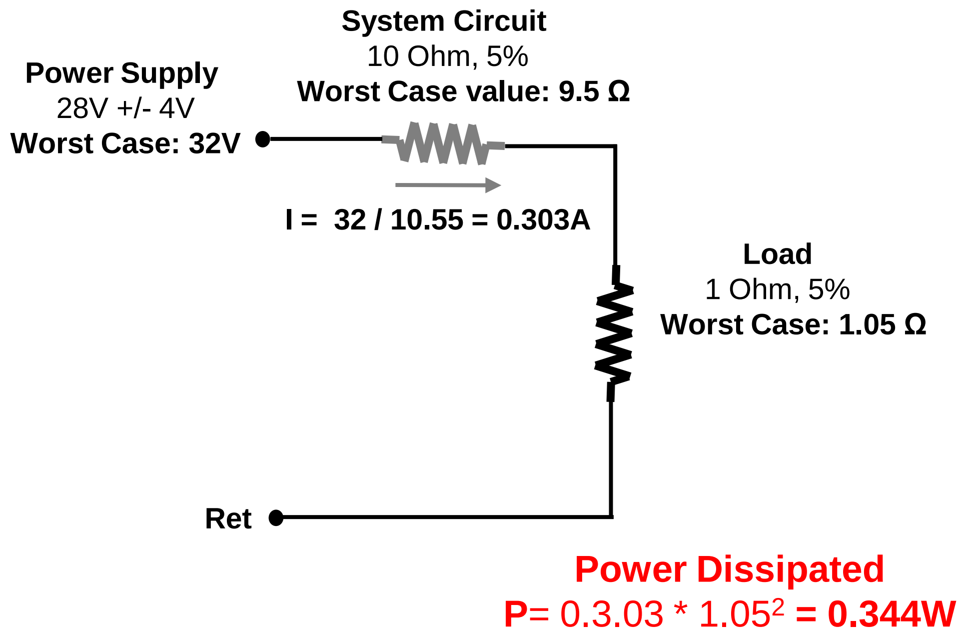
1. At launch there shall be 10% predicted power margin for mission critical, cruise, and safing modes as well as to accommodate in-flight operational uncertainties.
2. The 3σ variation is due to: 1). Worst-case spacecraft mass properties; 2). 3σ low launch vehicle performance; 3). 3σ low propulsion subsystem performance (due to thruster performance alignment, propellant residuals); 4). 3σ flight dynamics errors and constraints; 5). Thruster failure on single fault tolerant systems.
3. Telemetry and command hardware channels read data from hardware such as thermostats, heaters, switches, motors, and so on.
4. See Table 1.06-2 for recommended mass contingency.

What is CBE for, what is MEV for

CBE reflects theoretical calculations in an ideal world



MEV reflects real-life conditions, and is the number to use for real designs

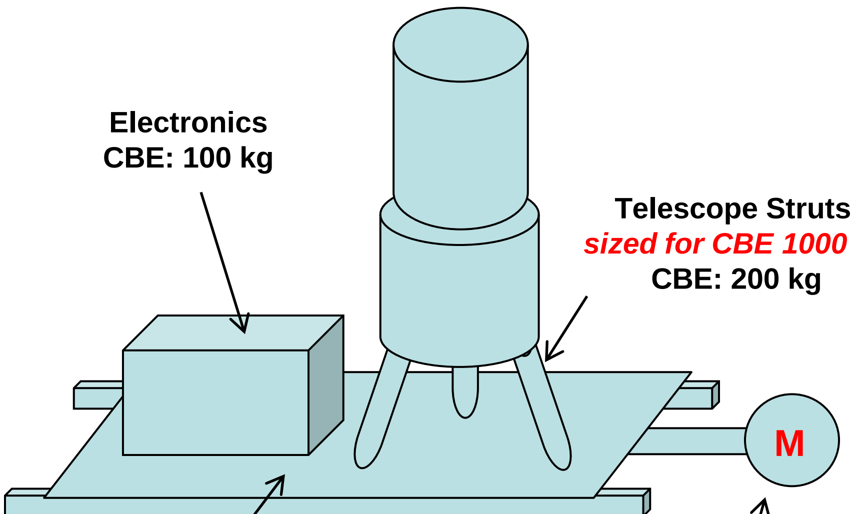


Using MEV values results in a 24% growth in dissipated power!

It's NOT the same design, when sized using MEV's instead of CBEs !

All Contingency %'s per GOLD Rules (on slide 13). Exact same sizing rationale used in both cases.

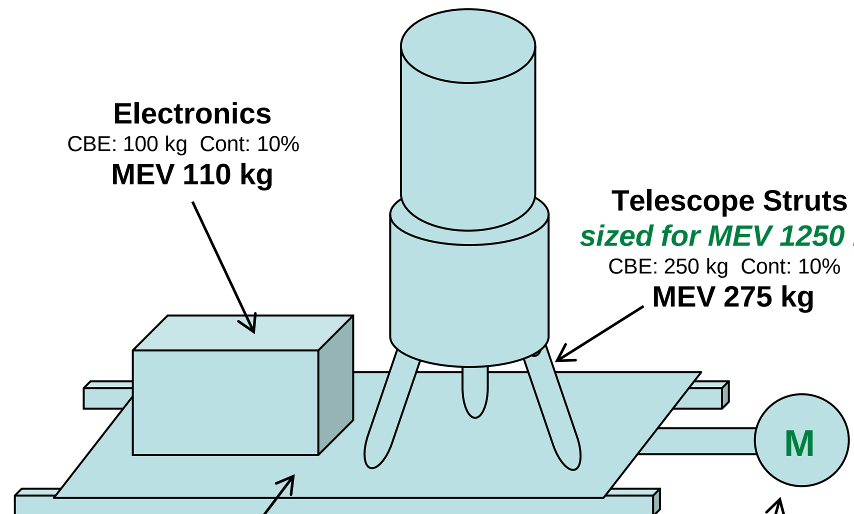
Sizing with CBEs



Total System Mass:
CBE 1960 kg

If Telescope and Electr. Box come in at MEV masses, then these Struts / Optical bench could be undersized!

Sizing with MEVs



Total System Mass:
CBE: 2189 kg Comp.Cont: 17% **MEV 2558 kg**

If Telescope and Electr. Box come in at MEV masses, then these Struts / Optical bench are sized right.

Contingency Pile-up

- **Concurrent Engineering is vulnerable to undesired excessive “Contingency Pile-ups”**

- *Excessive Contingency pile-ups can strangle a mission. Here is how it can happen:*
  1. RF Comm gets the CBE Data Rates from Science, and adds 30% Contingency.
  2. RF Comm selects a slightly oversized RF Hardware to handle the MEV (Contingent) Data Rate
  3. RF Comm sends the (higher) CBE power consumption of the oversized RF hardware to EPS
  4. EPS adds 30% Contingency to the already oversized load and sizes a Power System for that load
  5. EPS sends the MEV power dissipation of that (Contingent Size)^2 Power System to Thermal
  6. Thermal sizes a radiator panel for it with Contingency added to its area
  7. Mechanical accommodates it and adds some mass Contingency to the related structures
  8. Reaction wheels are selected to handle that MEV inertia plus Contingency
  - … and so forth…
  - *Hopefully the pile-up is convergent, and not divergent…*

- **Margin doesn’t pile up!**

It is preferable to have a lesser (but realistic) Contingency with the balance carried as Margin than to have 30% Contingency and a lesser Margin

When is Contingency Pile-up Right, when is it Wrong

- **The consecutive allotment of series of Contingencies over sequential "domains" of the design cycle** (i.e. Contingency on the Data Rate then on the Data Hardware's power consumption then on its mass, etc.) **may be right or may be wrong…**

When is Contingency pile-up right?

- **Contingency pile-up is right when the causes for the growth of a resource over different sequential "domains" in the design cycle are CORRELATED (i.e. one domain drives the other)**
  - E.g. : 15% Contingency is added to the CBE mass of a box. As the box could really grow to that MEV mass, its support structure should be sized for the MEV mass. The design of the support structure then yields a CBE mass for the structure. As the support structure itself could then experience mass growth of its own, it is proper to add a Contingency % to it's mass too, and account for that at the System level. *In this example, the supported mass obviously drives the support structure sizing, thus the two domains are correlated, and the consecutive allotment of Contingencies is right.*

When is Contingency pile-up wrong?

- **Contingency pile-up is wrong, when the causes for Resource Growth in different sequential "domains" in the design cycle are UNCORRELATED (i.e. one does not drives the other)**
  - E.g. : 15% Contingency is added to the CBE mass of an avionics box. The CBE power consumption of the CBE box was 100W. It does **not automatically** follow that Avionics should report a "growed" power consumption 15% greater (i.e. 115W total). Why? Because the power consumption of the avionics box doesn't necessarily grow when its mass grows. It could be simply that a bigger box was needed to fit in the exact same electronics, and the power consumption didn't change at all. *These two growth domains uncorrelated, therefore there is no need for consecutive allotment of Contingencies.*

The golden rule is: Too much as bad as too little!

Logical end-to-end thinking is required when applying Contingencies

System Resiliency to Resource Growth

Too much Contingency can stifle a mission, too little can break it. How much Contingency is right also depends on the resiliency of the system or phenomenon to resource growth. Exceeding the MEV could result in a soft or graceful degradation of system performance or a hard breakpoint:

- **Soft / Graceful Degradation example:**
  - Reaction Wheel sizing (in some missions) may exhibit soft degradation: if the inertia exceeds the expected value, slew times from one observation to another will increase correspondingly. Observing efficiency will suffer a small degradation.

- **Hard Breakpoint example:**
  - Mass calculations have a hard breakpoint: if the launch mass exceeds the launch vehicle's throw mass then the desired orbit won't be reached. The mission may be over!

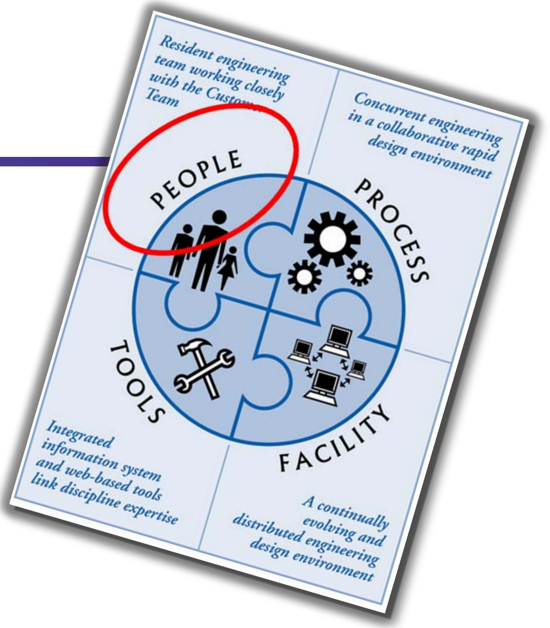
Less Contingency is needed for phenomena exhibiting soft degradation, more Contingency is needed for phenomena facing a hard breakpoint

- **Risk Posture:**
  - Contingency should also reflect the project's risk posture: more required for a Class A mission then for a Class C

Agile Margins for Agile Concurrent Engineering

- ACE tailors a lab’s concurrent design process to varying customer needs
- ACE study product quality and accuracy vary
- Varying study accuracy leave more uncertainty bands around key parameters. That calls for well adapted **variable margins and contingencies.**
  - The contingency and margin policies applied during those studies must be adjusted, to provide adequate cushioning for the variable uncertainties.

People



Teamwork in High Performance Concurrent Engineering Teams

"People are our most important resource"

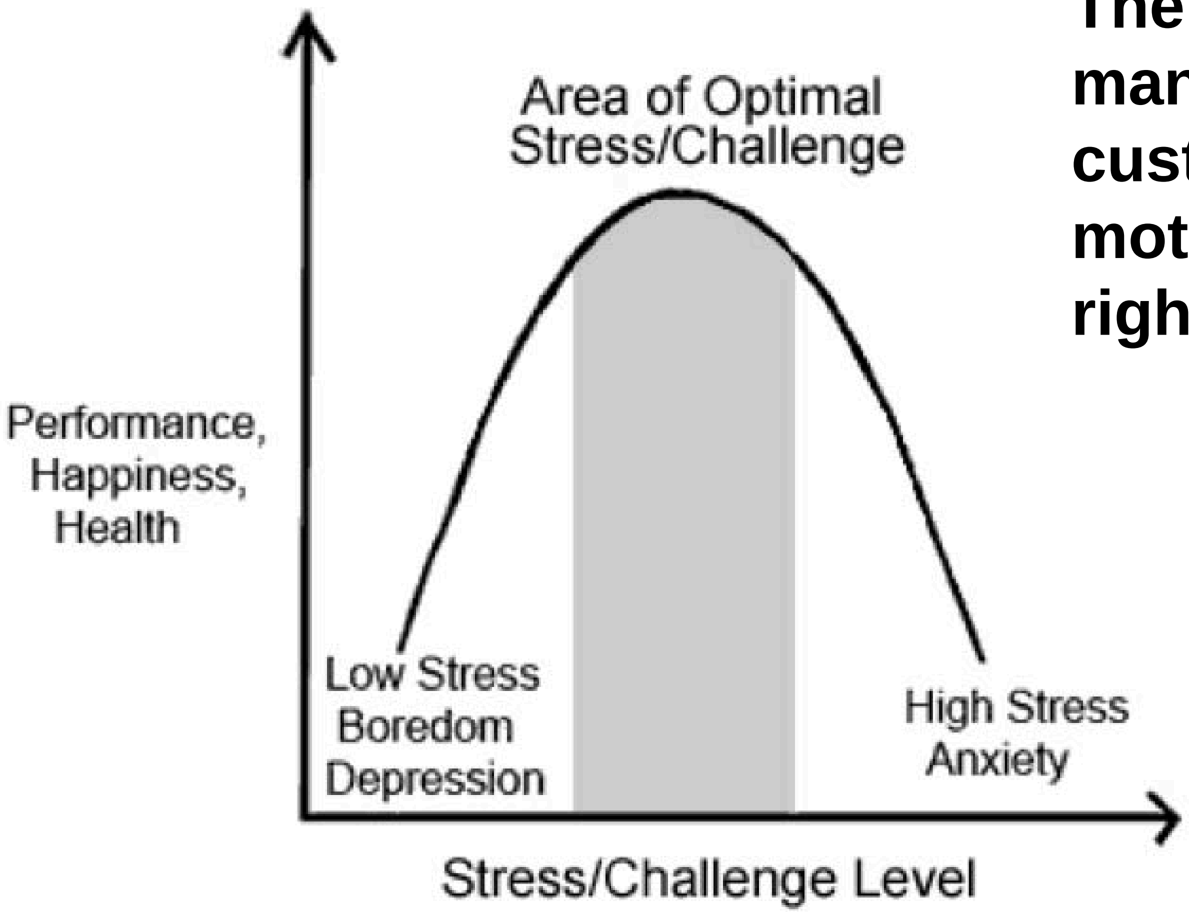
High Performing CE Teams

- **Human performance model**
- **Survey of team leads**
- **Future possibilities**

Aspects of Design

- **Team – a group of people working together toward a goal (implies leadership)**
- **Engineering – (SE Seminar audience)**
- **Concurrent – see Gabe's portion**
- **High Performance – team fires on all cylinders**
  - **Synergy, speed, success, Flow State**
- **Human Aspect – the Peopleware**
  - **Is this now the lowest hanging fruit?**

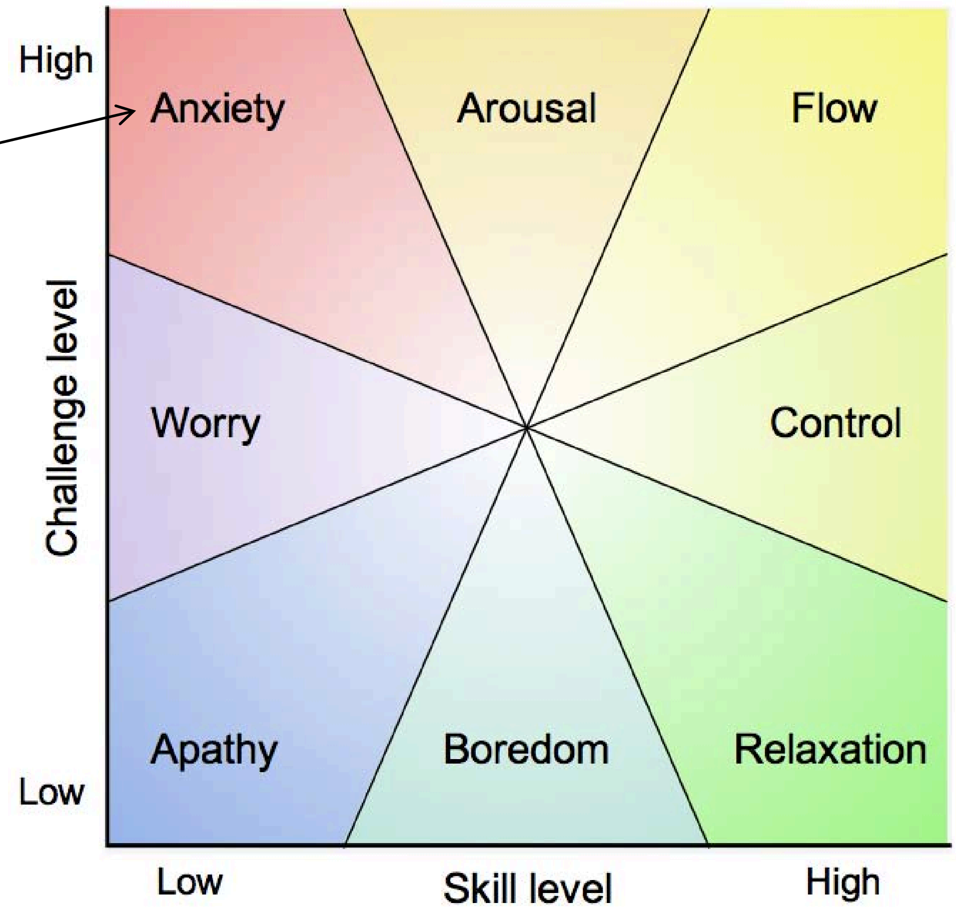
Human Performance Model: Productivity vs. Stress



The CE environment, management, and customers provide motivation to move right or left

Human Performance Model: Challenge Level

Watch the body language



"You cannot achieve the highest creative flow state without about 10 years of technical experience in your field"
- Csikszentmihalyi TED Talk 2004

Team Lead Survey (1 of 2)

- Simple question: "What human factors contribute to the best studies you have led?"
- Interviewed 17 people at 10 organizations
  - Received detailed responses from 6 people

Acknowledgement is key:

- Communication/Collaborative ability
- Public validation of good work
- Constant maintenance, checking the mood
- Noticing everyone's contribution
- Study is a party, Team Lead is the host
- Public praise, private rebuke

Team Lead Survey (2 of 2)

- A flexible customer
- A Team Lead who can "inspire the team to be creative and feel responsible for the quality of the design"
- Early discussions with the customer
- Setting aside personal disagreements when you have to collaborate
- Comfort with lack of surety
- Balance of time allowed vs. depth of product

CE Team Leads: Insights

- **Team Leadership is more difficult in CE environments (Time pressure, new goals, new people in both local team and customer)**
- **A CE study can be similar in scope/intensity to flight project I&T (but not duration!)**
- **ESA CE presentation (lessons learned slide) at AIAA Space 2010: “Team Leader - talented system engineer with skills in HR real-time management. How to scout/train new Team Leaders?”**

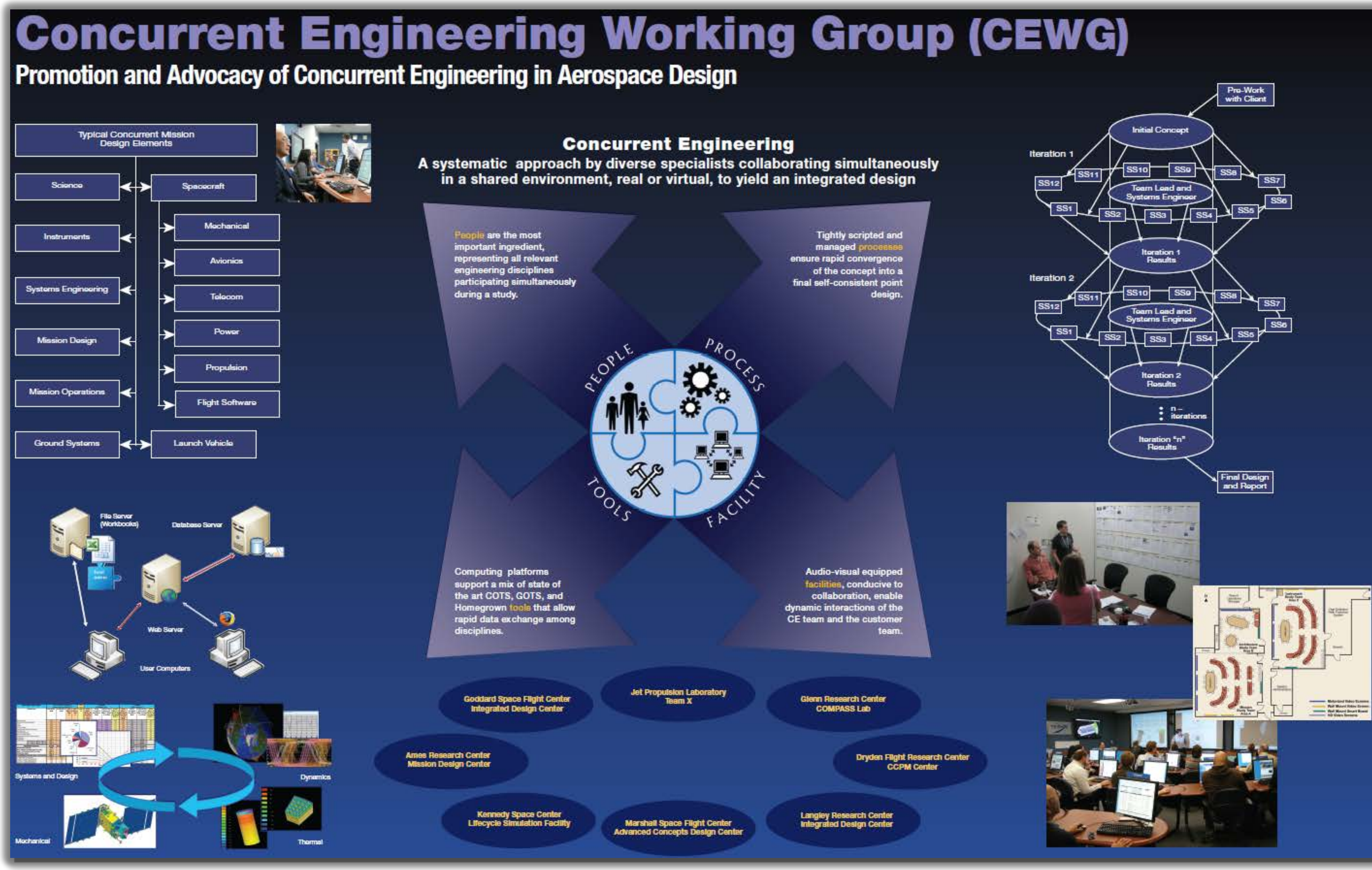
Future Possibilities (1 of 2)

- **Group Flow**
  - **Creative spatial arrangements: Pin walls, charts, no tables; work primarily standing and moving**
  - **Playground design: Charts for information inputs, flow graphs, project summary, creative craziness, safe speaking place, result wall**
  - **Parallel, organized working with targeted group focus**
  - **Participant differences are opportunity not obstacle**

Future Possibilities (2 of 2)

- **Explicit Conflict Resolution Process**
  - **Osborn: 0 of 8 CE design centers had explicit conflict resolution strategies: Why?**
  - **Maier and Sashkin: You or I win, we compromise, or "integrative alternative"**
- **Traditional team-building activities**
  - **4-D Systems, After Action Reviews, Trust Building**

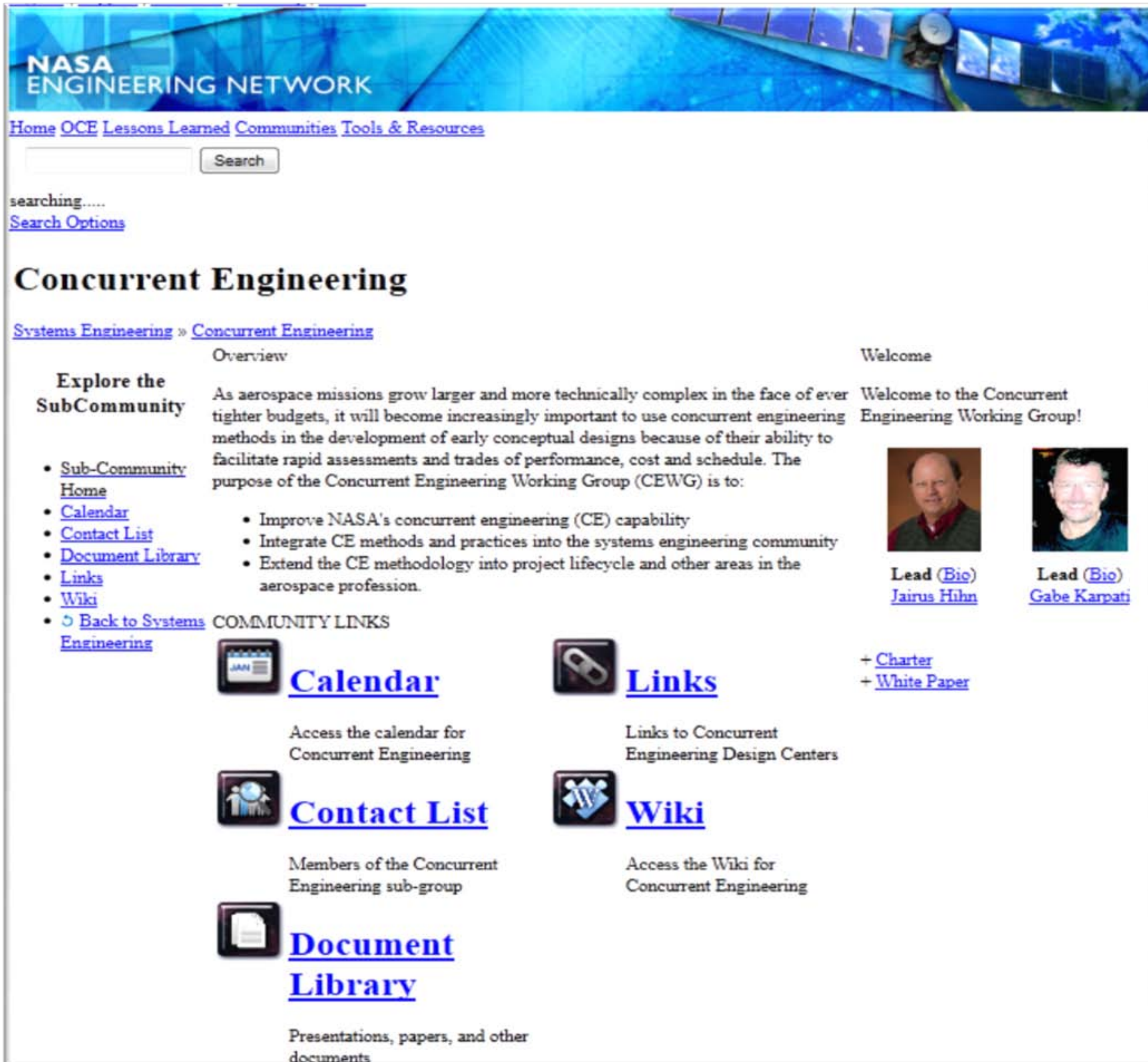
NASA's Concurrent Engineering Working Group



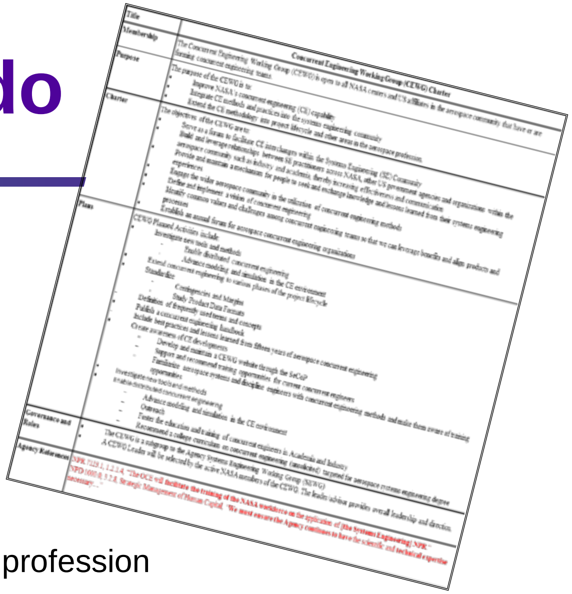
Concurrent Engineering Working Group

The Concurrent Engineering Working Group is a Sub-Group of the <u>Systems Engineering Working Group</u> within the NASA Systems Engineering Community of Practice

https://nen.nasa.gov/web/se/ce



What does the CEWG do



Title	Concurrent Engineering Working Group (CEWG) Charter
Membership	The Concurrent Engineering Working Group (CEWG) is open to all NASA centers and US affiliates in the aerospace community that have or are forming concurrent engineering teams.
Purpose	The purpose of the CEWG is to: • Improve NASA's concurrent engineering (CE) capability • Integrate CE methods and practices into the systems engineering community • Extend the CE methodology into project lifecycle and other areas in the aerospace profession.
Charter	The objectives of the CEWG are to: • Serve as a forum to facilitate CE interchanges within the Systems Engineering (SE) Community • Build and leverage relationships between SE practitioners across NASA, other US government agencies and organizations within the aerospace community such as industry and academia, thereby increasing effectiveness and communication • Provide and maintain a mechanism for people to seek and exchange knowledge and lessons learned from their systems engineering experiences • Engage the wider aerospace community in the utilization of concurrent engineering methods • Define and implement a vision of concurrent engineering • Identify common values and challenges among concurrent engineering teams so that we can leverage benefits and align products and processes • Establish an annual forum for aerospace concurrent engineering organizations
Plans	CEWG Planned Activities include: • Investigate new tools and methods – Enable distributed concurrent engineering – Advance modeling and simulation in the CE environment • Extend concurrent engineering to various phases of the project lifecycle • Standardize – Contingencies and Margins – Study Product Data Formats • Definition of frequently used terms and concepts • Publish a concurrent engineering handbook • Include best practices and lessons learned from fifteen years of aerospace concurrent engineering • Create awareness of CE developments – Develop and maintain a CEWG website through the SeCoP – Support and recommend training opportunities for current concurrent engineers – Familiarize aerospace systems and discipline engineers with concurrent engineering methods and make them aware of training opportunities • Investigate new tools and methods • Enable distributed concurrent engineering – Advance modeling and simulation in the CE environment – Outreach – Foster the education and training of concurrent engineers in Academia and Industry – Recommend a college curriculum on concurrent engineering (uncollected) targeted for aerospace systems engineering degree
Governance and Roles	• The CEWG is a subgroup to the Agency Systems Engineering Working Group (SEWG) • A CEWG Leader will be selected by the active NASA members of the CEWG. The leader/advisor provides overall leadership and direction.
Agency References	NPR 7123.1, 1.2.1.4, "The OCE will facilitate the training of the NASA workforce on the application of [the Systems Engineering] NPR." NPD 1000.0, 3.2.8, Strategic Management of Human Capital. "We must ensure the Agency continues to have the scientific and technical expertise necessary…"

<u>**As codified in the CEWG Charter:**</u>

- **Mission**
  - The promotion and advocacy of Concurrent Engineering in aerospace design
- **Purpose**
  - Improve NASA's concurrent engineering (CE) capability
  - Integrate CE methods and practices into the systems engineering community
  - Extend the CE methodology into project lifecycle and other areas in the aerospace profession
- **Objectives**
  - Serve as a **forum** to facilitate CE interchanges within the Systems Engineering (SE) Community
  - Build and leverage relationships between CE practitioners across NASA, other US government agencies and organizations within the aerospace community such as industry and academia, thereby increasing effectiveness and communication
  - Provide and maintain a mechanism for people to seek and exchange knowledge and lessons learned from their concurrent systems engineering experiences
  - Engage the wider aerospace community in the utilization of concurrent engineering methods
  - **Define** and implement **a vision of concurrent engineering**
  - Identify common values and challenges among concurrent engineering teams at various institutions, so that we can leverage benefits and **align products and processes**
  - Establish an annual forum for aerospace concurrent engineering organizations

<u>***Confidentiality Statement:***</u>

- *CEWG members acknowledge and respect the integrity and sanctity of each member organization's proprietary capabilities, practices, and competitive advantages; will protect those; and will coordinate and collaborate only in mutually beneficial open areas.*

Reaching out to Aerospace Concurrent Engineering Facilities Worldwide

CEWG Then and Now

- "Founded" in August 2010 (during the AIAA Space 2010 Conference)
  - 19 attendees from 7 organizations (9 JPL)

- In Nov 2011 CEWG mailing list has 52 members from 15 organizations
  - 3 international, 2 corporations, 1 university, 3 FFRDCs, and 6 NASA centers

- CEWG Charter officially approved by NASA
  - S. Kapurch approved CEWG to become a NASA Working Group under the Systems Engineering Community of Practice
  - Website is up and running: https://nen.nasa.gov/web/se/cewg

- Growing presence at AIAA Space Conference
  - In 2010 conducted a Panel Session on CE
  - In 2011, four dedicated "CE Papers" Session, JPL, GSFC, GRC presented; also a Poster Session on "CE at NASA MSFC"
  - For 2012 eight dedicated "CE Papers" planned

- CEWG Face-to-Face September 2011
  - 31 registered people from 11 organizations

CEWG Meetings

- **<u>First CEWG Meeting</u> held at the AIAA "Space 2010" Conference site**
  - The CEWG was founded by the following participants :
    - Massimo Bandecchi ESA/ESTEC
    - Jason Baughman Boeing
    - Chet Borden JPL
    - Bruce Campbell NASA/GSFC
    - Mike Caulfield Boeing
    - Deb Chattopadhyay JPL
    - Jay Harris SMC/XR
    - Cate Heneghan JPL
    - Jairus Hihn JPL
    - Daniel Judnick Aerospace Corporation
    - Gabe Karpati NASA/GSFC
    - Alfred Nash JPL
    - Daniel Nigg Aerospace Corporation
    - John Panek NASA/GSFC
    - Steve Prusha JPL
    - Tim Sarver-Verhey NASA/GRC
    - Keith Warfield JPL
    - Becky Wheeler JPL
    - John Ziemer JPL

- **First CEWG meeting preceded by a <u>Panel Session</u> on Concurrent Engineering at the AIAA Space 2010 Conference**
  - Joint IDC / Team-X / ESCA CDF Presentation

CEWG Meetings

2nd CEWG meeting held at GSFC on March 29, 2011

- 31 Attendees from 11 organization
- Laid Out Charter
- Laid out plans to integrate with NEN Communities of Practice
- Planned on papers for a dedicated AIAA CE session
- Planned website

- **Meeting followed by 3 days Poster Session at the Goddard Memorial Symposium**
  - Stand manned by GSFC IDC, JPL Team-X, Aerospace Corp., and Glenn COMPASS representatives

3rd CEWG meeting held at the Aerospace Corporation in El Segundo, CA on Sept 27, 2011

- 29 Attendees from 8 organization

- **Meeting followed by CE Session at at the AIAA Space 2011 Conference**
  - Dedicated "Concurrent Engineering" Session, (JPL, GSFC, GRC presented four papers on Concurrent Engineering
  - Also a Poster Session on "CE at NASA MSFC"

- **4th CEWG meeting planned at GRC in March, 2012**

CEWG Products (so far)

- **CEWG Charter**
  - “Incorporated” under NEN SEWG

- **CEWG White Paper (to NASA Chief Engineer)**
  - “Distributed Collaborative Design: The Next Step in Aerospace Concurrent Engineering”

- **CEWG Posters and Handouts**
    - Presented / distributed at 2011 Goddard Memorial Symposium and AIAA Space 2011 Conference

- **Papers for AIAA Space 2011 Conference**
  - Key CEWG member institutions authored 4 publications
  - Two paper with GSFC authors:
    - GSFC IDC Paper (Abstract accepted, approved by GSFC): “Information Exchange In A Concurrent Engineering Lab, And The Tools That Enable It, by Gabe Karpati; Bruce Campbell; John Panek (NASA GSFC); George Polacek (DoD), Mark Avnet (MIT)”
    - Joint JPL/GSFC/Glenn Paper, based on earlier broader scope version of the White Paper

CEWG Plans

CEWG Plans

- **Investigate new tools and methods for the CE environment**
  - Distributed concurrent engineering
  - Advance modeling and simulation. Conduct a simulation tools survey.
  - Extend concurrent engineering to later phases of the project lifecycle.
- **Catalog, Map, Standardize:**
  - Standard Unified Study Product Data Sheet
  - Ontology (definition of frequently used terms and concepts)
  - NASA WBS mapping
  - Design and Cost assumptions / Procedures (Contingencies and Margins)
  - Study Product Data Format (define and map a Standard Key Parameter List with definitions)
- **Publish:**
  - A Concurrent Engineering Handbook (include best practices and lessons learned from fifteen years of aerospace concurrent engineering)
  - A Team Skills, Tools, and Products Inventory

CEWG Objectives for 2012:

- Establish an annual forum for Aerospace Concurrent Engineering Organizations
- Become a working group under AIAA's Space Systems Engineering and Space Economics Track - *in essence approved by AIAA Track Leadership in Long Beach*
- Organize a session dedicated to concurrent engineering at AIAA Space 2012

CEWG Outreach

- Foster the education of future concurrent engineers in Academia and Industry
- Familiarize aerospace systems and discipline engineers with concurrent engineering methods

CEWG Benefits (so far)

Comparison, Insight

- Methods, Procedures, State of the Art
- Standards
- Tools, equipment

Concurrent Concept Validation Datapoint

- Aerospace reported the first ever end-to-end CE concept validation results over the entire lifecycle
  - GPS satellites were studied in the CDC over 10 years ago, since then have been built and flown
    - All the “as built / as flown” technical and cost parameters are known, documented
  - All CDC key parameters generated during the conceptual design 10 years earlier (designed using the same standard SMAD principles as the GSFC IDC) were within less than +/- 10% of the as built as flown actuals.

IDEA Data Exchange Platform

- Complete IDEA Program Package transferred to GSFC free of charge in June 2011
- Aerospace CDC (Dan Nigg) also “threw in” free IT expert support from their Chantilly office (come to GSFC if needed, Aerospace carries FTE)

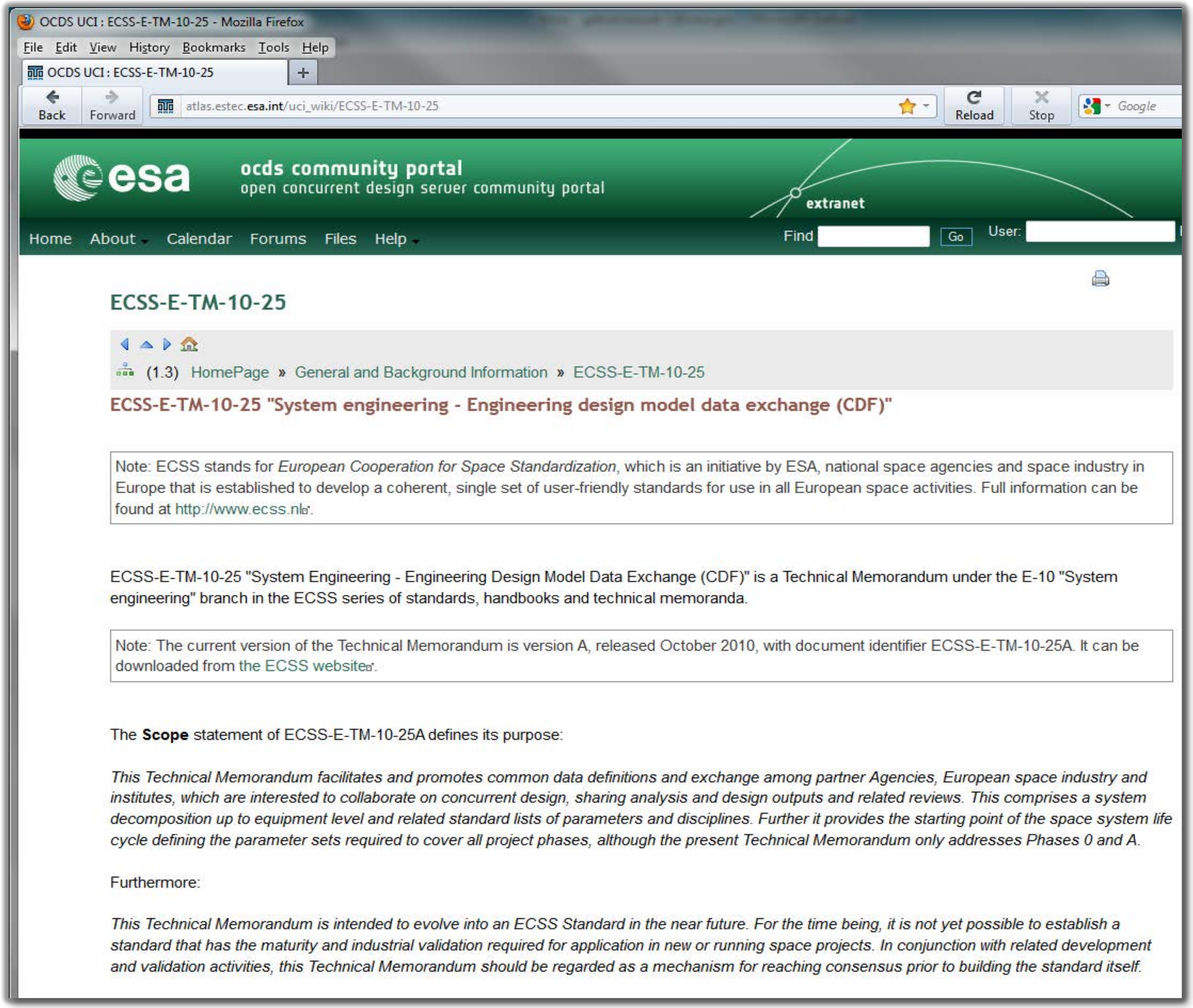
Community

- The best benefit of all is having a community of peers for informal exchanges, sharing, advice, help…

Lab Metrics Comparison

Lab	Study Duration	Discipline Hours Charged	Numer of Studies Completed
Aerospace CDF	3 x 4 hours	16 hours	300
Team-X	3 x 3 hours	20 hours	1100
IDC MDL, IDL	5 x 8 hours	56 hours	550
ESA CDF	6 x 4 hours (over 1 month)	96 hours	150

ESA Standard on Study Data Product



ECSS-E-TM-10-25

(1.3) HomePage » General and Background Information » ECSS-E-TM-10-25

ECSS-E-TM-10-25 "System engineering - Engineering design model data exchange (CDF)"

Note: ECSS stands for *European Cooperation for Space Standardization*, which is an initiative by ESA, national space agencies and space industry in Europe that is established to develop a coherent, single set of user-friendly standards for use in all European space activities. Full information can be found at http://www.ecss.nl.

ECSS-E-TM-10-25 "System Engineering - Engineering Design Model Data Exchange (CDF)" is a Technical Memorandum under the E-10 "System engineering" branch in the ECSS series of standards, handbooks and technical memoranda.

Note: The current version of the Technical Memorandum is version A, released October 2010, with document identifier ECSS-E-TM-10-25A. It can be downloaded from the ECSS website.

The **Scope** statement of ECSS-E-TM-10-25A defines its purpose:

This Technical Memorandum facilitates and promotes common data definitions and exchange among partner Agencies, European space industry and institutes, which are interested to collaborate on concurrent design, sharing analysis and design outputs and related reviews. This comprises a system decomposition up to equipment level and related standard lists of parameters and disciplines. Further it provides the starting point of the space system life cycle defining the parameter sets required to cover all project phases, although the present Technical Memorandum only addresses Phases 0 and A.

Furthermore:

This Technical Memorandum is intended to evolve into an ECSS Standard in the near future. For the time being, it is not yet possible to establish a standard that has the maturity and industrial validation required for application in new or running space projects. In conjunction with related development and validation activities, this Technical Memorandum should be regarded as a mechanism for reaching consensus prior to building the standard itself.