The Power System In a Concurrent Engineering Environment at JPL Team-X

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In recent years JPL has applied a concurrent engineering approach for the pre-phase A design of space missions. The group of people performing this task is known as Team-X. Each subsystem (Mission design, GN&C, C&DH, Mechanisms & Structures, Thermal, Power, etc.) is represented by an element lead equipped with state of the art tools, which are electronically linked. In a typical session, the team is given a set of Level-3 requirements and the team proceeds via trades and negotiation to the baseline design.

The team-X power tool is capable of providing relevant components for the three major power elements (power generation, energy storage and power electronics). A wide range of technologies and topologies are available to the analyst.

Designing the power subsystem requires a trained analyst. A working knowledge of the power subsystem design as well as the interactions with other subsystems is required. The analyst may be asked to design anything from a fleet of small inexpensive probes, up to massive futuristic spacecraft. The team also provides a grassroots costing of the project, providing an important feasibility input to proposal teams.

Conflicting constraints are resolved through rapid trade-off analysis, optimizing at a system level. Power requirements for all subsystems are automatically reported to the power analyst's tool, allowing the power subsystem design to eventually reach closure after an iterative process. The result of a study is a report that is largely written by subsystem analysts, but is collated and editing into final form.

The Team-X method of program definition has proven to be quick and cost efficient for JPL. Over 500 studies have been performed, including a number that are now under full development. The purpose of this paper is to describe this approach and present several examples.

The Power System in a Concurrent Engineering Environment at JPL: Team-X

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Outline

- Team-X Charter
- Concurrent Design Process
- Power Tool Design
- Statistics
- The Analyst's Role
- Advantages to Institution
- Disadvantages OR Pros and Cons???
- Challenges

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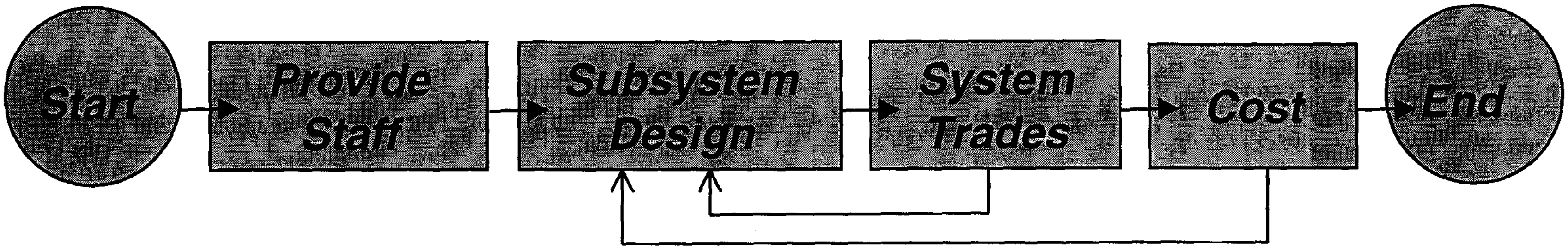
Team-X Charter

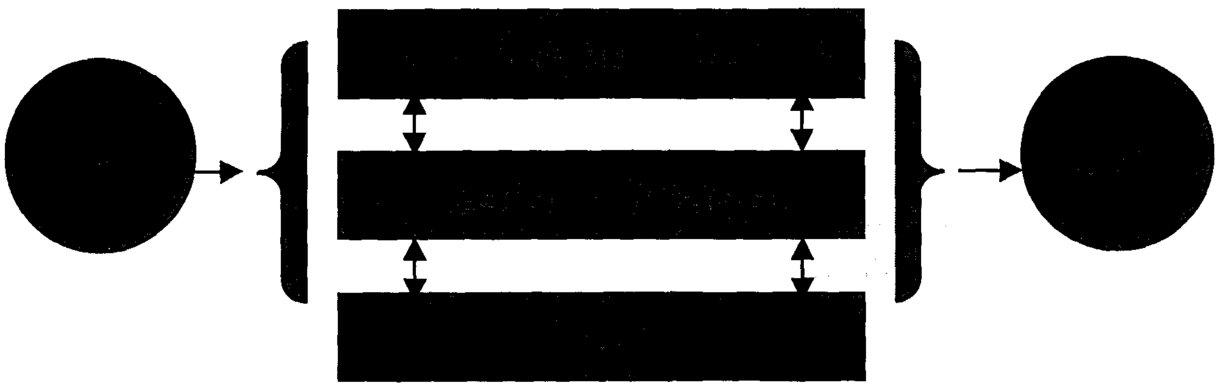
- The Advanced Projects Design Team ("Team X") was started in April of 1995. The team was chartered to:
- Quick response quality ~~Improve the speed and quality of JPL's new~~ mission concept development.
- Create a reusable study process with dedicated facilities, equipment, procedures, and tools.
- Develop a database of initial mission requirements that can be easily updated and electronically transferred for use in subsequent project phases.
- Develop mission generalists from a pool of experienced engineers.
- Train .....

Concurrent Design Process

Old Process – Sequential



New Process – Concurrent



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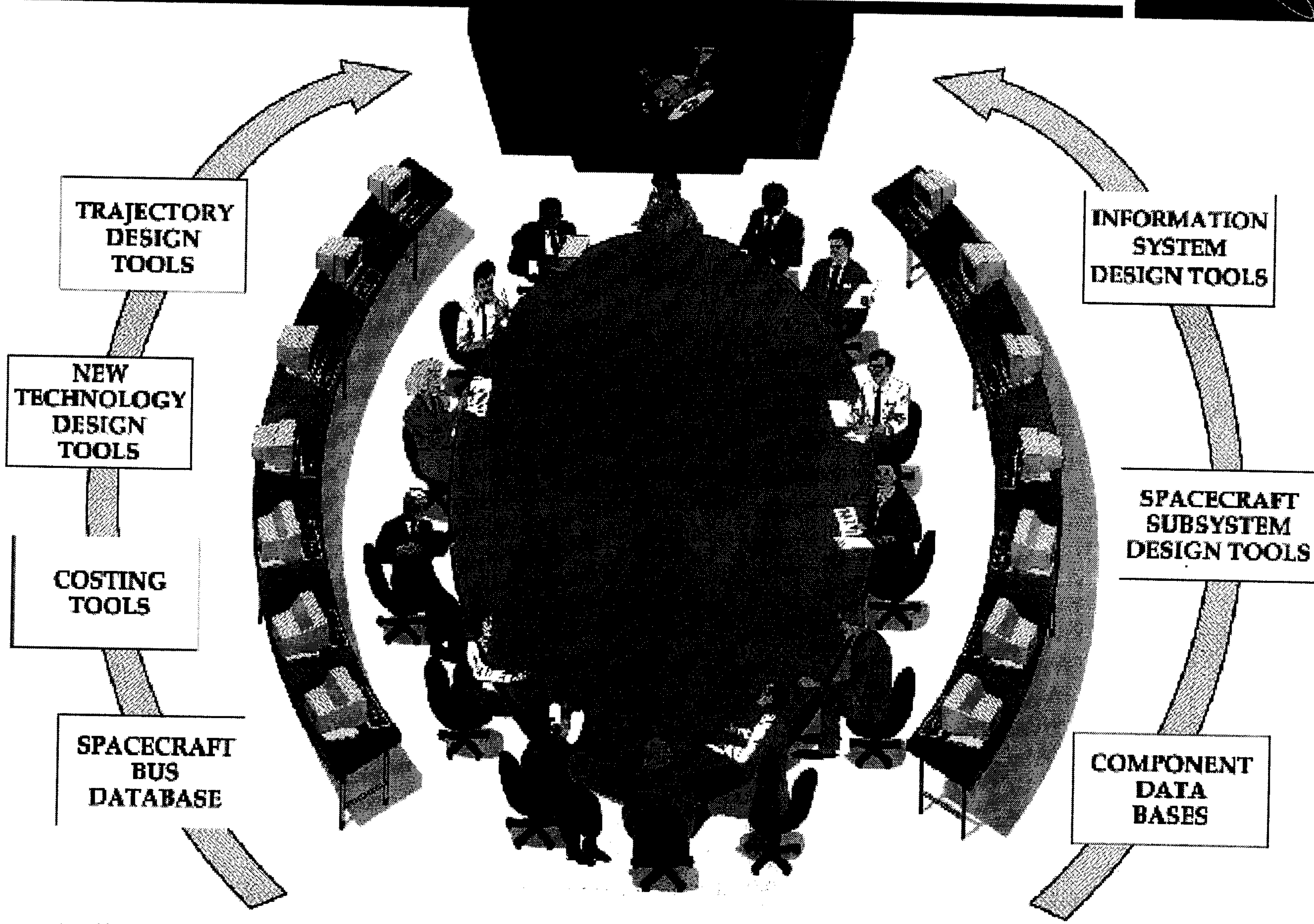
Design Team Tools



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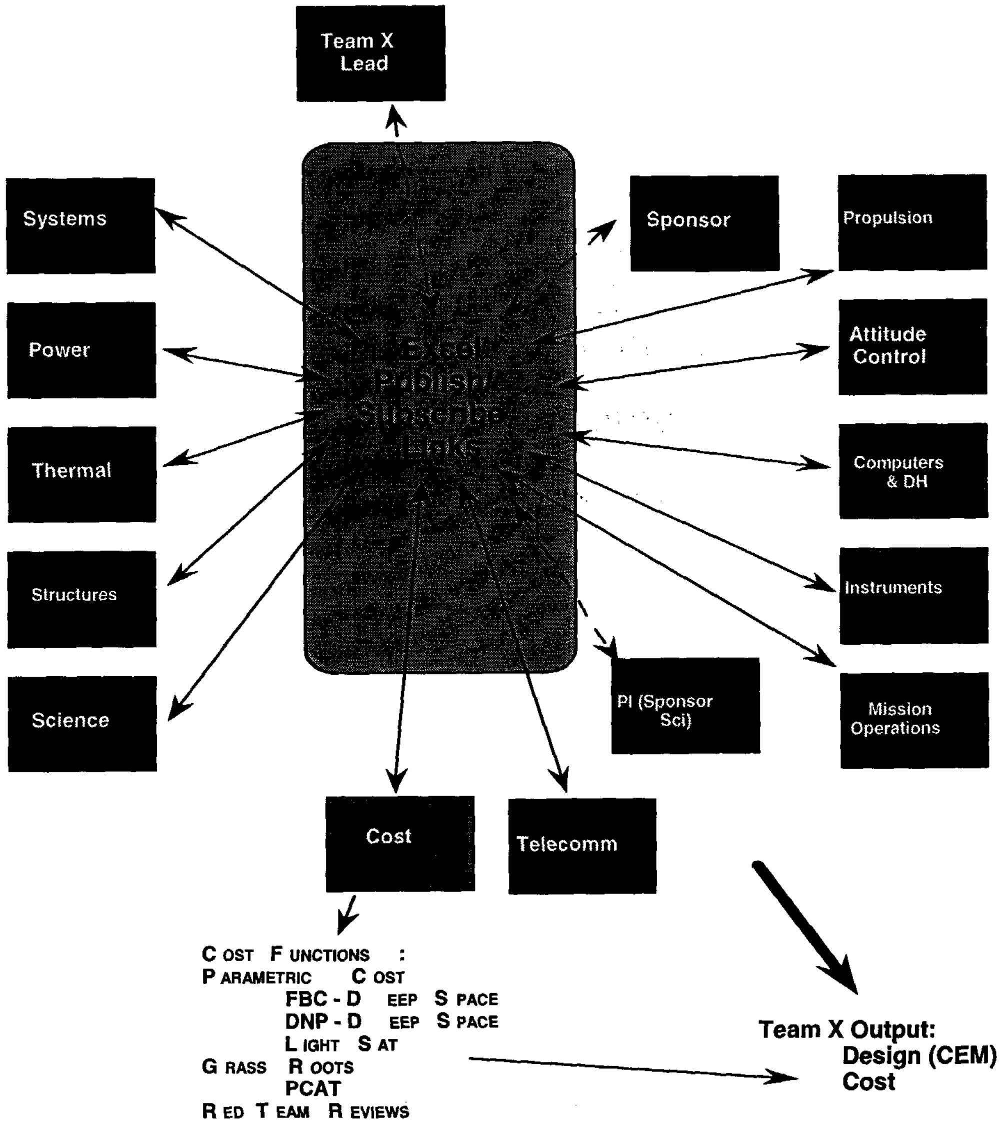
Team-X Process

- Pre-meeting preparation
  - Mission/science objective is defined
  - Measurement objectives and instrument requirements are defined
  - Mission design and instrument specification
- Concurrent engineering design sessions
  - Customer presents mission/science objectives
  - Team reviews mission requirements
  - Team identifies requirements and trades
  - Mission and system design is developed
  - Option trade studies
  - Mission cost development

Team-X Process



Types of Tools

- Catalog driven tools – select from known assemblies
  - Examples include flight computers and propulsion tanks
  - Used when new designs are rare and difficult to modify
- Parametric tools – calculated based on sizing algorithms
  - Examples include flight software and spacecraft structure
  - Often used when redesign is the norm
- Database driven Tools
  - Used when a range of technologies may be selected
  - Database of ~~provide~~ key parameters for all technologies
  - Sizing algorithms use parameters to size components
  - Calibration of tools is done by adjusting database and algorithms
  - Databases exist as viewable products, facilitating knowledge capture

Power Tool Design

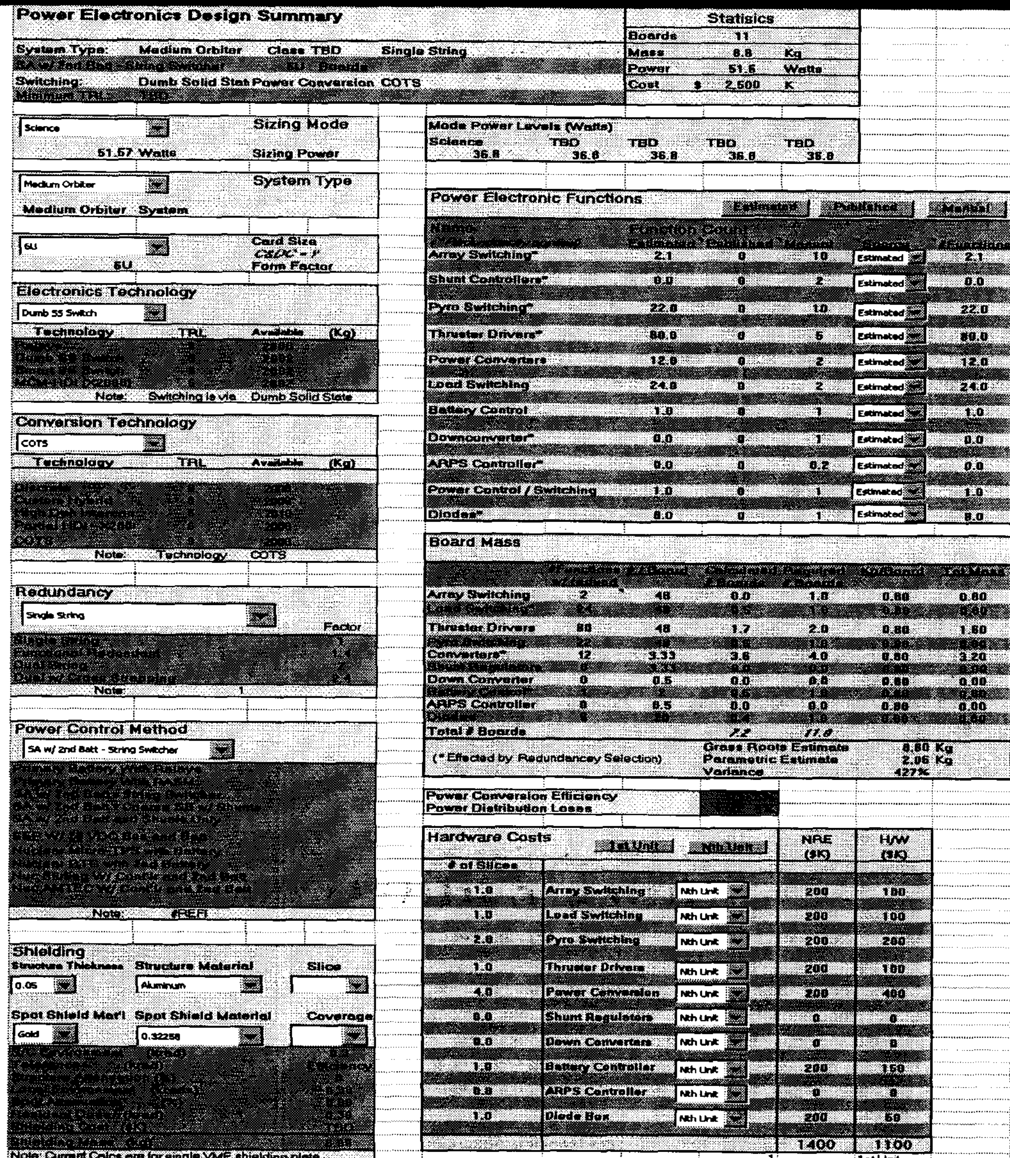
This and next chart is a mixed bag of good info. I see where you are going-try to compartmentalize or group logically

- Parametric tool originally designed by Aerospace Corp.
- Conceived of as earth orbiting spacecraft design tool
- First use at JPL is 3/11/1996
- Extensive revision and expansion recently completed
- Emphasis on database driven design used throughout
- All databases populated with new technologies
- Algorithms expanded for design of space probes, landers, rovers, etc.
- Solar Arrays include rigid and flexible substrates, thin film, concentrators
- Nuclear power source sizing tool added
- Improved labor costing models developed
- Labor cost estimates broken out by WBS element and mission phase
- Labor grade and inflation tables added
- Probabilistic cost distribution capability added

Power Electronics Tool Inputs

- Novel power electronics sizing method developed
- Initial estimates are achieved through six menu selections
- Selections are made for following areas
  - System Type (Large Orbiter, Small Rover, Complex Probe, etc)
  - Subsystem Topology (Solar, Nuclear, Primary Battery, etc)
  - Switching Technology (Smart Solid State, Dumb Solid State, etc)
  - Conversion Technology (Discrete, COTS, Custom Hybrid, etc)
  - Redundancy Level (Single String, Functional, Dual String, etc)
  - Board Size (3U, 6U, 9U, other)
- Estimates of functional requirements are quantified and translated to designs
- Manipulation of design to optimize and combine are typically done
- Variation in the amount of NRE is adjusted to suit specific designs
- Cost, mass and equipment lists are published to other subsystems

Power Electronics Tool Screenshot



This and next two – very busy and difficult to hold audience attention

Solar Array Tool Screenshot

TEAM
Jet Propulsion Laboratory

Mission:	Study Name		3/26/2003 14:58

Orbit Parameters

Orbit Period	132	*minutes*
Max Eclipse	30	*minutes*
Sunlit Duration	102	*minutes*
Orbits per year	3985	
Array voltage nom	[illegible]	*Volts*

Solar Array Design Summary

Mass	0.00	*kg*
Area	0.00	*m^2*
# Panels	0	
Design	GaAs adv TJ Ultra-flex	
Diameter	0.00	
Cost	$0	*K*

Main Selection Panel

Articulation	One Axis w/ Yaw Steer
Configuration	None
Technology	GaAs adv TJ Ultra-flex
	3

Cosine Loses (degrees)		
	[illegible]	Fixed Array
	[illegible]	Single Axis
	[illegible]	Single Axis w/ Yaw Steering
	[illegible]	Dual Axis
	[illegible]	Spinner

Electrical Energy Requirements

Operating Mode	Published Power	Estimated Power	Duration [mins] Eclipse	Duration [mins] Sunlight	Energy [Wh] Eclipse	Energy [Wh] Sunlight
Science	36.8	[illegible]	[illegible]	[illegible]	30.7	307.2
Telecom	36.8	[illegible]	[illegible]	[illegible]	84.8	8.5
TCM	36.8	[illegible]	[illegible]	[illegible]	0.0	0.0
Cruise	36.8	[illegible]	[illegible]	[illegible]	0.0	0.0
Launch	36.8	[illegible]	[illegible]	[illegible]	0.0	0.0
Totals			30.0	102.0	115.5	315.6

Estimated

Notes: *Nuclear Power added to ron* 219.4 Watts

Negative Value Indicates excess RTG Power

Subsystem Topology: SA w/ 2nd Batt - String Switcher

Degradation and Build-Up Loses

Distance from sun	[illegible]	AU
Mismatch & fabrication	[illegible]	
Wiring & diode loss	[illegible]	
Cell temperature	[illegible]	·C
Shadowing losses	[illegible]	
Sun offset angle	0	deg
Ultraviolet degradation	[illegible]	
Radiation degradation	[illegible]	
Fatigue (thermal cycling)	[illegible]	
Micrometeoroid loss	[illegible]	

Figure of Merit

BOL 1 AU FOM	100.4	W/Kg
EOL X AU FOM	100.4	W/Kg

Array Power Output

292	W @ EOL 1 AU, 28 oC
292	W @ BOL 1 AU, 28 oC
292	W @ BOL 1 AU, 28 °C

Hardware Cost Estimator

Hardware Cost	Subtotals ($K)
Flight Panel	0
Spare Panel	[illegible]
Test Panel	[illegible]
Cost Summary ($K)	0.0

Rigid Substrate *(not used for thin film or ultra-flex)*

Honeycomb Core Thickness (cm)	3.00
Facesheet Thickness (Mils)	14
Honeycomb Core Material	AlHC
Facesheet Material	Al

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Power Cost Screenshot

Power System Totals	RE	1,150 K	NRE	$	700
Study Name	Total	1,850 K	Development	$	400

		Units	Mass kg	Cost K$
Radio		Fuel Cost (DOE)		0
isotope		Hardware (NRE	0.00	0
Power		Engineering		0
		Development		0
		Other Mass	0.00	
		Totals:	0.00	0
Notes	To Remove: Set Tech = None & Fuel = 0			
Solar		Fab./assembly	0.00	0
Array		Mgmt. & eng. design		0
		electrical testing		0
		environmental testing		0
		Array totals:	0.00	0
Notes			0.00 KW	
2ndary	0	Flight Unit(s)	0.00	0
Battery	0	Test Unit(s)		0
	0	Spare Unit(s)		0
	0	Additional Cells		0
		Test Labor		0
		Engineering		0
		Battery totals:	0.00	0
Notes		Chemistry:	Ni-H2 (CPV)	
		Capacity	11.00 AH	

2 Cell/ Vessel, Use < 50 AH, > 10 AH, Large Self Discharge at > 20 deg C,

		Units	Mass kg	Cost K$
Power		Hardware	7.20	850
Electronics		Chassis		0
		Spares		
		Labor		1,000
		Totals:	7.20	1,850
Notes	*SA w/ 2nd Batt - String Switcher*			
Switching, Dumb Solid State	Conven. COTS			
Primary	0	Flight Unit(s)	0.00	0
Battery	0	Test Unit(s)		0
	0	Spare Unit(s)		0
		Add'l Cells		0
		(for labor add in to total at right)		
		Hardware totals:	0.00	0
Notes				
Thermal	0	Flight Unit(s)	0.00	0
Battery	0	Test Unit(s)		0
	0	Spare Unit(s)		0
		(for labor add in to total at right)		
		Hardware totals:	0.00	0
Notes				

WBS Item	Workforce Levels A	B	C/D	E	Labor Cost	Hard ware	Labor Grade
Subsystem Mgmt	0.0	0.0	0.0	0.0	0		Princip Eng
Engineering Analysis	0.0	0.0	0.0	0.0	0		Senior Eng
Conversion and Reg Design					200		
Solar Array						0	
Engineering	0.0	0.0	0.0		0		Staff Eng
Testing					0		
Nuclear Engineering	[illegible]	[illegible]	[illegible]		0	0	Senior Eng
Battery (2nd, Prim, & Thermal)						0	
Engineering	0.0	0.0	0.0		0		Senior Eng
Testing			0.0	0.0	0		Staff Eng
Power Control Engineering					400		
Pyro and Prop Driver Eng					400		
Packaging Fab & Assbly						850	
BCE/AHSE/GSE							
Labor			0.0		0		Staff Eng
GSE H/W						[illegible]	
Subsystem I&T			0.0	0.0	0		Staff Eng
	0.0	0.0	0.0	0.0			

Cost Reviewed	2/24/2003	Cost Comments	[illegible]
Time of Last Review		Cost Assumptions	[illegible]

FY Dollars: 2003

Phase	A	B	C/D	E
Duration (Months)	3	9	36	12

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Tool Development Goals

- Provide rapid method for estimation
- Include range of technologies
- Include high and low TRL items
- Make basis for estimates simple to review
- Maintain calibration by review of content experts
- Create reusable data products for reporting
- Create cost numbers with good visibility
- Follow institutional standards for cost and design

Various Statistics

- Over 2200 parameters available to Team-X tool
- Power Systems tool uses 157 Inputs nine sources
- Power Systems tool outputs 107 output ?? to server
- 16 different power items output to equipment list
- Up to three different types of batteries per design element
- Sometimes up to seven design elements used in conjunction
- Over 500 Studies performed to date
- Current rate of production is about 2 / week
- Typical tenure on team is 2 years
- Eight power analysts trained since 1996

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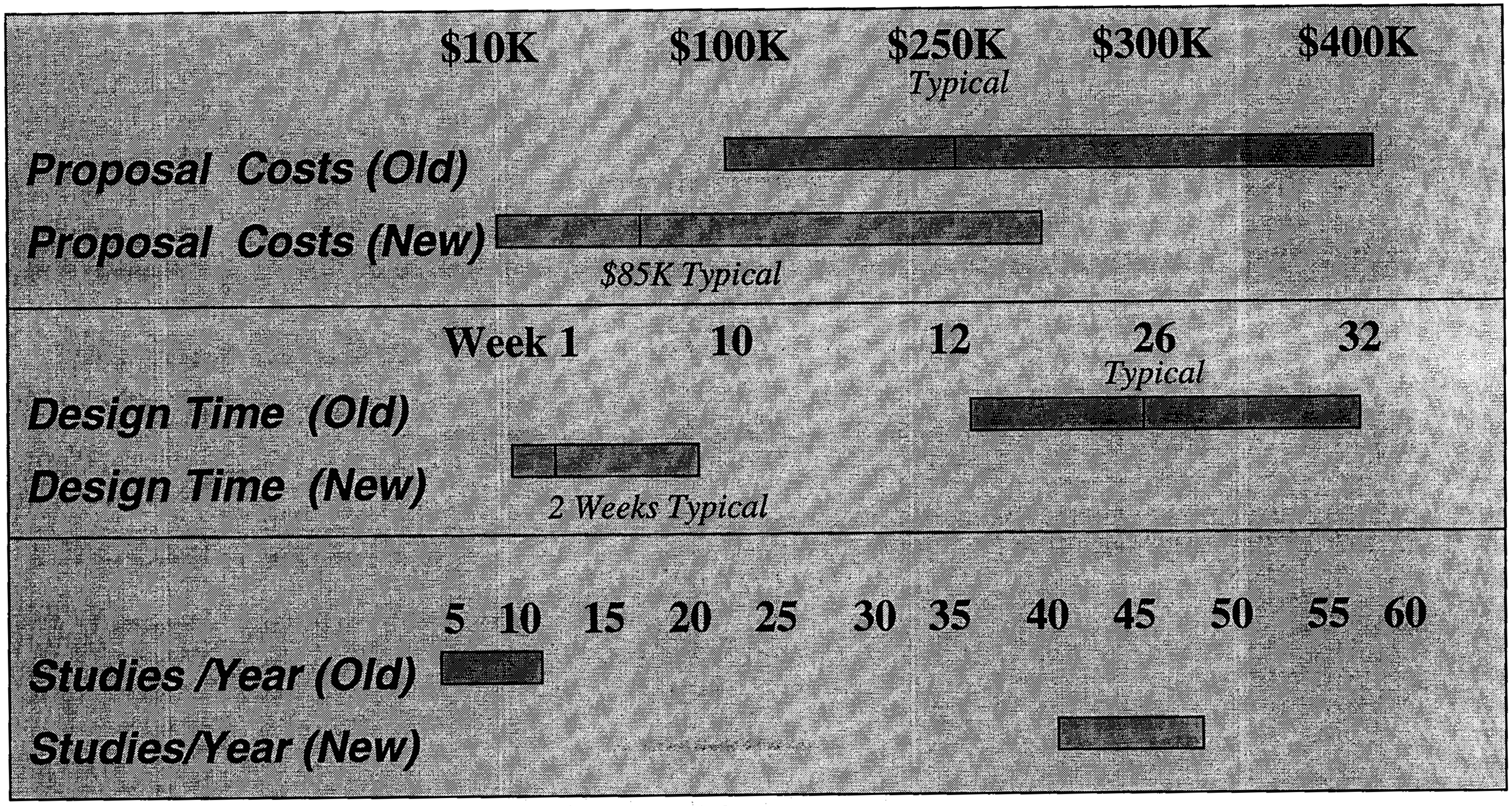
Analyst Roles and Responsibilities

- Must be trained how to operate the tool
- Must be familiar with technologies
- Must be able to identify sizing conditions
- Must be familiar with mission design impacts on power
- Must be able to use external contacts to resolve issues
- Must work within team to identify and complete trades
- Must work in real-time with team to converge upon solutions
- Must be able to provide cost estimates appropriate to mission
- Must be familiar with institutional standard practices
- Must follow internal team design rules
- Must be able to documents work to help prepare reports

Savings of Team-X Process

*Mission Studies**



*** *Phase-A Quality Conceptual Mission/Spacecraft Designs***

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Advantages of Team-X Process

- Enables real-time concept design and evaluation
- Rapid resolution of trades by team members.
- Allows team members to utilize tools while interacting with others
- Allows visibility across subsystem interfaces.
- Enables early agreement on decisions by all disciplines.
- Improve quality of JPL proposals and pre-projects
  - **Facilitates assessment of cost, risk and performance**
  - **Facilitates assessment of tradeoff and descope options**
  - **Facilitates "sanity check"**
- Improves pre-proposal designs while saving money and time
- Helps provide accurate cost estimates

Conclusions

- A concurrent engineering approach to spacecraft design has been used to improve the mission formulation and proposal process at JPL.
- A systematic power system design discipline has been applied to a wide range of space systems.
- Team-X power tool has been expanded to incorporate knowledge of the elements modern space system design.
- Team members are able to rapidly provide accurate power system cost and mass estimates.