GSFC Systems Engineering Seminar

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

Gabe Karpati and John Panek
GSFC, Code 592

January 10, 2012
• Introduction to the GSFC Integrated Design Center 15 min

• Introduction to Concurrent Engineering 60 min
  • Processes 15 min
    • Task Ordering
    • “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)
  • Facilities and Tools 15 min
    • Micro-Comm Platform (The Room) (2 min)
    • Macro-Comm Platform (Data Exchange Platforms, ISDP) (5 min)
    • Contingencies and Margins (5 min)
  • People 30 min
    • Teamwork in High Performance Concurrent Engineering Teams

• Overview of the CEWG 15 min
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
• 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

- **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
  - CEWG, Reviews, Techn. Authority, Talks, Outreach, etc.

Over 500 Studies conducted since 1998
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
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
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IDC Facility

Resident engineering team working closely with the Customer Team

Concurrent engineering in a collaborative rapid design environment

Integrated information system and web-based tools link discipline expertise

A continually evolving and distributed engineering design environment
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
Customer Participation During An Actual Design Session
IDC Recent Expansion

New MDL
Support Staff
New IDL

Multi-purpose Lab
IDC People

Resident engineering team working closely with the Customer Team

Concurrent engineering in a collaborative rapid design environment

Integrated information system and web-based tools link discipline expertise

A continually evolving and distributed engineering design environment
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
- Structural Analysis
  - TBD
- Mechanical Systems Engineer
  - TBD
- Electro-Mechanical Systems
  - TBD
- Thermal Engineer
  - Kim Brown 545
  - George Daelemans 545
  - Eric Grob 545
- Contamination
  - Philip Chen 546
- Mechanical Designer
  - David Peters 543
- Avionics/Electrical Systems
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- Power Systems
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- RF Communications
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  - Brian Gosselin 567
- Integration and Test
  - Harvey Safren 568
- Ground Systems
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  - Stephanie Nickens 581
  - Cindy Adams 584
- Flight Software
  - Keguan Luu 582
  - David Hardison 588
  - Carver Audain 582
- Missions Operations
  - Stephanie Nickens 581
  - Steve Tompkins 581
  - Cindy Adams 584
- GN&C/ACS
  - Doug Freesland 596/ACSE
  - Dave Olney 595
  - Scott Miller 424/OSC
- Lab Lead
  - Mark Steiner 592
- Mission Systems Engineer
  - Frank Kirchman 592
- Deputy Lab Lead/MSE
  - TBD 592
- Launch Vehicle
  - Larry Phillips 592
- Mission Costing
  - Larry Phillips 592
  - Sharon Seipel 605
- Orbital Debris
  - Ivonne Rodriguez 592
- Flight Dynamics
  - Michael Mesarch 595
  - Frank Vaughn 595
  - Greg Marr 595
- Propulsion
  - Rick Caverly 454/OSC

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

Resident engineering team working closely with the Customer Team

Concurrent engineering in a collaborative rapid design environment

Integrated information system and web-based tools link discipline expertise

A continually evolving and distributed engineering design environment
Concurrent Engineering Tools
http://idc.nasa.gov
• **Applications**: 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

• **Internal Databases**:  
  – Pre-Work Databases  
  – Instrument and Mission Design Archives  
  – Discipline Component Catalogs  
  – Spacecraft Bus Catalog  
  – Launch Vehicles Catalogs, etc.
Use of Modeling in Concurrent Engineering

- Engineering Models
- Integrated Models
- System Models
IDC Study Process

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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)
Study Execution

- Study begins with a “Prework Meeting” 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

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

Each discipline prepares material that addresses
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.
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’. Concurrent engineering significantly modifies this outdated method and instead opts to use what has been termed an iterative or integrated development method.[1]
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

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.

Courtesy: National Research Council
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 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
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 “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
Optimizing the DSM by Partitioning

• A concurrent design session has numerous complex precedence relationship 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.
Information Content “Applied Research”:

The Gezintos-Gezoutos Project

(by George Polacek, DoD)
Inputs the Mission Operations Discipline Needs

- From the customer before the study
  - Data latency requirements
  - From Altitude Control
    - Number of spacecraft
    - Number of instruments for each spacecraft
  - Data rates for science and housekeeping data
  - Mission Life (required and extended)
  - Launch target date
  - Preferences/prearrangements for locations of customers

Inputs the Mission Operations Discipline Needs

- From other disciplines during the study
  - Communications
    - Downlink rates
    - Number of contacts required per day
  - Flight Dynamics
    - Number of trajectory orbit maneuvers
    - Number of attitude control maneuvers
  - Systems
    - Power: Initial sizing input and power profile
    - Propulsion: Thruster torque requirements
    - Reliability: Components used (preference from prime)
    - Systems: Flight software list (make, model, mass, power, cost)
    - Systems: GSE equipment list (items and cost)
    - Systems: Subsystem component item, qty, mass, power per module, TRL and cost into PRIME
    - Systems: Subsystem cost updates in PRIME
    - Systems: Avionics system (are) options (note: word spacing issues)
    - Systems: Mechanical components and labor costs
    - Systems: Mechanical component part list
    - Systems: Mechanical: All components number, mass, size, placement
    - Systems: Mission Ops: Number of attitude control maneuvers per month
  -Avionics
    - All: Any unusual I&I problems that can be foreseen
    - All: Power load information in terms of watts
    - All: Power load information in terms of volts
    - All: Power load information in terms of operating times
    - All: Power load information in terms of operating modes
    - All: Mission Ops: Cost updates in PRIME
  - Instruments
    - All: Final updates into PRIME (including any changes as a result of questions raised during the TD-1)
    - All: Systems: Final grassroot cost updates in PRIME
    - All: Systems: Questions, comments and concerns about the mission and its requirements
    - All: Systems: Avionics system (are) options (note: word spacing issues)
  - Testbeds
    - All: Any unusual I&I problems that can be foreseen
    - All: Power load information in terms of watts
    - All: Power load information in terms of volts
    - All: Power load information in terms of operating times
    - All: Power load information in terms of operating modes
    - All: Mission Ops: Cost updates in PRIME
    - All: Systems: Final grassroot cost updates in PRIME
    - All: Systems: Questions, comments and concerns about the mission and its requirements

Mission Operations staffing phases superimposed (available early day 4)

- Mission Operations Costs [available early day 4]
- Mission Operations Concept (available early day 4)
- Mission Operations Timeline (launch to normal ops)
- Nominal Operations Timeline
- Mission Operations Costs Summary (available end day 4)
- Basis of Estimate for Mission Ops costs (estimate available end day 4)
- Mission Ops costs broken out by WBS number (available end day 4)
- Mission Ops costs broken out by staffing phase (FTE,5) (available end day 4)
- Identify any issues for later study
- Make recommendations to customer
- Presentation to customer [day 5]

Technical Input Required for Structural Analysis

From the Customer Team:

- Minimum Information Required
  - Generally, structural analysis works from the mechanical model and masses generated by the other disciplines.
  - Desired Information
    - If the following data exists...
      - Launch vehicle
      - Quasi-static loads (including temperature extremes)
      - Frequency requirements
      - Distortion requirements

Products that are Possible in a 2-week Study

- Design optimization
- Performance analysis
- Thermal distortion, jitter, etc.
- Analysis of secondary structural design margins

Technologies Synthesis & Analysis Laboratory

- Systems Synthesis & Analysis Laboratory
- Mission Design Laboratory
- Mission Analysis Laboratory
- Instrumentation Synthesis & Analysis Laboratory
- Spacecraft Synthesis & Analysis Laboratory
- Structural Analysis Synthesis & Analysis Laboratory
- Ground System Analysis Laboratory
- Instrumentation Synthesis & Analysis Laboratory
## Information Exchange Matrix

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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.

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:


- Closely related additional publications:


Agile Concurrent Engineering
Raising the Bar: the Need for Agility

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

• The problem is: not all customers need the exact same well-rehearsed process
  – 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 **Agile Concurrent Engineering (ACE)**

• **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 planning** 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 knowledgeable leadership** 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 <1 week 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.
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

### Baseline Subsystem Configuration Summaries

<table>
<thead>
<tr>
<th>Mech</th>
<th>Structures, Matl, Payload Accommodations, Mechanisms, Volume and OB</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS</td>
<td>Driving Requirements, ACS type, Sensors, Actuators</td>
</tr>
<tr>
<td>Therm.</td>
<td>Requirements, Technologies, Radiators, Heaters, Htr Par.</td>
</tr>
<tr>
<td>Prop.</td>
<td>Prop. types, Thrusters, Delta</td>
</tr>
<tr>
<td>Power</td>
<td>Max. eng. load, Bus Voltage, Arrays, Cells, S/A Dev.</td>
</tr>
<tr>
<td>C/OM</td>
<td>Configuration / Functionality, Processor, Mass Data</td>
</tr>
</tbody>
</table>

### Propellant Calculator

- **Impulse burn thrust:**
  - Required delta-v [m/s]: 113
  - Isp [sec]: 127

- **Dry mass [kg]:** 7.026

- **Propellant [kg]:** 442.2

- **Total propellant mass [kg]:** 445.199

### Total Mass

<table>
<thead>
<tr>
<th>[kg]</th>
<th>CBE</th>
<th>Allocation</th>
<th>Margin %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propellant + Pressurants Total</td>
<td>0.0</td>
<td>0.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

### Science Payload [kg]

<table>
<thead>
<tr>
<th>Payload Total Mass</th>
<th>CBE</th>
<th>Allocation</th>
<th>Margin %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

### Bus Subsystems & Structure [kg]

<table>
<thead>
<tr>
<th>Bus Subsystems &amp; Structure [kg]</th>
<th>CBE</th>
<th>Allocation</th>
<th>Margin %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>ACS</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Thermal</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Propulsion</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Power</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Harness</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>CAD</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
<tr>
<td>OP Comm</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

### Total Mass

<table>
<thead>
<tr>
<th>[kg]</th>
<th>CBE</th>
<th>Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAYLOAD TOTAL</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>BUS SUBSYSTEMS &amp; C/OM TOTAL</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Observing Dry Mass</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>PROPellant</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SATELLITE WET MASS</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Baseline - Power Loads, CBE [W]

<table>
<thead>
<tr>
<th>Day</th>
<th>Night</th>
<th>Load</th>
<th>Max.</th>
<th>Safe Mode</th>
<th>Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Option 1 - Power Loads

<table>
<thead>
<tr>
<th>Day</th>
<th>Night</th>
<th>Load</th>
<th>Max.</th>
<th>Safe Mode</th>
<th>Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The tables and graphs show various configurations and calculations related to spacecraft design and mission planning.
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.

MCP Discipline Attending Admin

Mission Head Parameters Edit

MCP Administration
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 / Avionics – “Level 1” view

<table>
<thead>
<tr>
<th>Topic</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsystem Fact Sheet</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Performance / Functions</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Mass</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Risks</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Grassroots Cost</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Schedule</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Technology</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Materials and Equipment List</td>
<td>150</td>
</tr>
<tr>
<td>Subsystem Power Consumption</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Configuration Elements</td>
<td>50</td>
</tr>
</tbody>
</table>

### ISDP / Avionics – “Level 2” view

<table>
<thead>
<tr>
<th>Topic</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsystem Fact Sheet</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Performance / Functions</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Mass</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Risks</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Grassroots Cost</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Schedule</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Technology</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Materials and Equipment List</td>
<td>150</td>
</tr>
<tr>
<td>Subsystem Power Consumption</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Configuration Elements</td>
<td>50</td>
</tr>
</tbody>
</table>

### ISDP / Avionics – All Topics Expanded

<table>
<thead>
<tr>
<th>Topic</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsystem Fact Sheet</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Performance / Functions</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Mass</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Risks</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Grassroots Cost</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Schedule</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Technology</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Materials and Equipment List</td>
<td>150</td>
</tr>
<tr>
<td>Subsystem Power Consumption</td>
<td>50</td>
</tr>
<tr>
<td>Subsystem Configuration Elements</td>
<td>50</td>
</tr>
</tbody>
</table>
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
Contingencies and Margins

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

- Maximum Possible Value (MPV)
- Maximum Expected Value (MEV)
- Current Best Estimate (CBE)

Margin

Contingency

Resource
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>
<thead>
<tr>
<th>Sub-system Design Maturity</th>
<th>TRL Range</th>
<th>Electrical/Electronic Contingency/Reserve (in percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 2</td>
<td>Basic principles reported thru technology concept and/or application formulated.</td>
</tr>
<tr>
<td></td>
<td>3 to 5</td>
<td>Analytical/experimental proof of concept thru breadboard validation in relevant environment.</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Sub-system/component prototype demo in an operational environment.</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Sub-system engineering unit test in an operational environment.</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Actual sub-system completed and flight qualified.</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Actual sub-system flight proven through successful mission operations.</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Resource</th>
<th>Pre-Phase A</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
<th>Phase D</th>
<th>Phase E</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEV for Dry Mass</td>
<td>30%</td>
<td>25%</td>
<td>20%</td>
<td>15%</td>
<td>10%</td>
<td>0</td>
</tr>
<tr>
<td>Power (at EOL)</td>
<td>30%</td>
<td>25%</td>
<td>15%</td>
<td>15%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Propellant ($\Delta v)^2$</td>
<td>3\sigma</td>
<td>3\sigma</td>
<td>3\sigma</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telemetry and Command hardware channels$^3$</td>
<td>25%</td>
<td>20%</td>
<td>15%</td>
<td>10%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>RF Link</td>
<td>3 db</td>
<td>3 db</td>
<td>3 db</td>
<td>3 db</td>
<td>3 db</td>
<td></td>
</tr>
</tbody>
</table>

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 3\sigma variation is due to: 1) Worst-case spacecraft mass properties; 2) 3\sigma low launch vehicle performance; 3) 3\sigma low propulsion subsystem performance (due to thruster performance alignment, propellant residuals); 4) 3\sigma 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**

- **Telescope**: CBE: 1000 kg
- **Electronics**: CBE: 100 kg
- **Optical Bench**: sized for a load of 1300 kg, CBE: 260 kg
- **Motor/Actuator/Rails**: sized for CBE of 1560 kg, CBE: 400 kg

**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**

- **Telescope**: CBE: 1000 kg, MEV 1250 kg
- **Electronics**: CBE: 100 kg, MEV 110 kg
- **Telescope Struts**: sized for MEV 1250 kg, CBE: 200 kg, MEV 275 kg
- **Optical Bench**: sized for a load of 1635 kg, CBE: 327 kg, MEV 360 kg
- **Motor/Actuator/Rails**: sized for MEV of 1995 kg, CBE: 512 kg, MEV 563 kg

**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
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
• 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.
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.
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
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
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 (CEWG)

Promotion and Advocacy of Concurrent Engineering in Aerospace Design

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

People
- People are the most important ingredient, representing all relevant engineering disciplines participating simultaneously during a study.

Process
- Tightly scripted and managed processes ensure rapid convergence of the concept into a final self-consistent design.

Tools
- Tools include databases, spreadsheets, common software tools, and hardware platforms.

Facility
- Audio-visual equipped facilities facilitate collaboration, enable dynamic interactions of the CE team and the customer team.

NASA’s Concurrent Engineering Working Group (CEWG)

Promotion and Advocacy of Concurrent Engineering in Aerospace Design

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

People
- People are the most important ingredient, representing all relevant engineering disciplines participating simultaneously during a study.

Process
- Tightly scripted and managed processes ensure rapid convergence of the concept into a final self-consistent design.

Tools
- Tools include databases, spreadsheets, common software tools, and hardware platforms.

Facility
- Audio-visual equipped facilities facilitate collaboration, enable dynamic interactions of the CE team and the customer team.

NASA’s Concurrent Engineering Working Group (CEWG)

Promotion and Advocacy of Concurrent Engineering in Aerospace Design

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

https://nen.nasa.gov/web/se/ce
What does the CEWG do

As codified in the CEWG Charter:

• **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

**Confidentiality Statement:**

– 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
First CEWG Meeting 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 Panel Session on Concurrent Engineering at the AIAA Space 2010 Conference

- Joint IDC / Team-X / ESCA CDF Presentation
CEWG Meetings

2\textsuperscript{nd} 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 \textbf{Poster Session} at the Goddard Memorial Symposium
  - Stand manned by GSFC IDC, JPL Team-X, Aerospace Corp., and Glenn COMPASS representatives

3\textsuperscript{rd} CEWG meeting held at the Aerospace Corporation in El Segundo, CA on Sept 27, 2011
- 29 Attendees from 8 organization

• Meeting followed by \textbf{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”

• 4\textsuperscript{th} 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

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

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