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Integrating Product Design and Analysis Models

An Overview of ProAM:
Product Data-Driven Analysis in a Missile Supply Chain

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Extended Abstract

The U. S. Department of Defense Joint Electronic Commerce Program Office (JECPO) has sponsored the ProAM effort with the Army Aviation and Missile Command (AMCOM) as primary stakeholder. Under subcontract to Concurrent Technologies Corp. through the Atlanta Electronic Commerce Resource Center (AECRC), ProAM has focused on improving missile electronics through advanced engineering analysis integration and delivery. This Georgia Tech-led effort has addressed barriers to small & medium-sized enterprise (SME) analysis of product physical behavior with the involvement of Circuit Express Inc. and System Studies and Simulation Inc., two SMEs in the AMCOM supply chain.

This presentation overviews the ProAM project and resulting tools and technologies:

• **U-Engineer.com, a self/full-serve Internet-based engineering service bureau (ESB)** with highly automated analysis modules for printed wiring board (PWB) fabricators and designers. Some modules, including PWB impedance models and the IPC-D-279 plated-through hole fatigue model, are available for usage via web-based thin clients. Accessing U-Engineer.com-based solvers as a thick client, *XaiTools PWA-B* provides other tools for PWB layup design and warpage analysis.

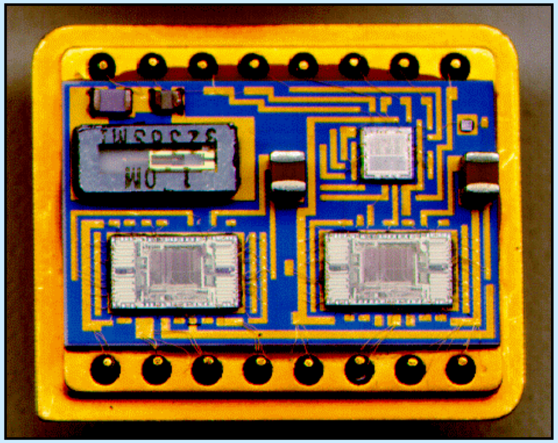
• **General ESB and analysis integration techniques** underlying U-Engineer.com, including:
    • A prototype template to aid establishing other Internet-based ESBs via technologies such as thick and thin client tools, CORBA-wrapped analysis solvers, and Internet security.
    • Product data-driven analysis techniques to enable highly automated plug-and-play usage via emerging product standards like ISO STEP AP210 and IPC GenCAM/GenX. *XaiTools*, the general-purpose analysis integration toolkit underlying *XaiTools PWA-B*, is highlighted with its integration to commercial CAD/CAE tools and applications to other product domains.

U-Engineer.com utilization by SMEs and Primes is highlighted, including evaluating design/process alternatives, and increasing awareness of potential issues. Experience has shown that ProAM technology excels at delivering automated product-specific analysis to places it has never gone before.

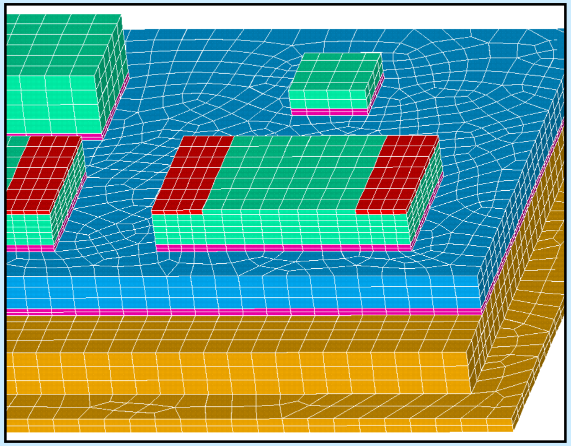
While ProAM has focused on tools for the AMCOM PWB supply chain, these same tools and techniques can benefit other industries. Envisioned applications include development of analysis module catalogs for other domains and establishment of company-specific Internet/Intranet-based engineering service bureaus.

Motivation for Physical Behavior Analysis

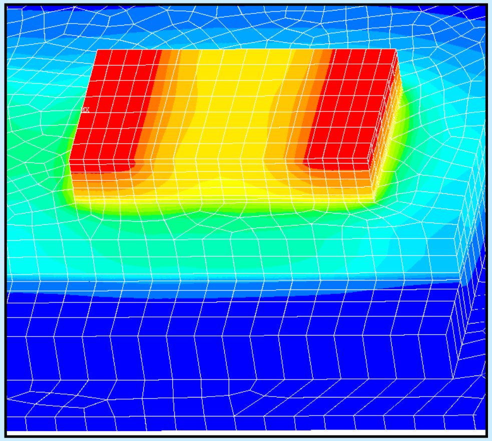
Need for Predictive Analysis



Missile MCM
with Overheating Problems

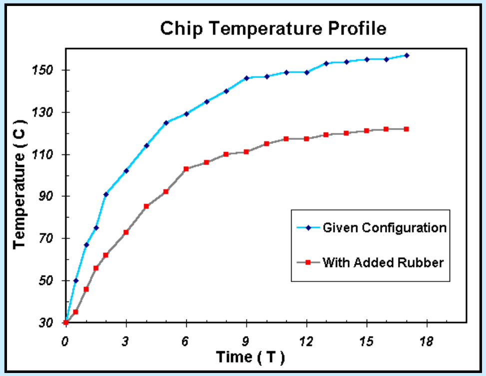


Finite Element Analysis



- Costly delays
- Serious consequences
- High improvement potential

Improved vs.
Existing Design

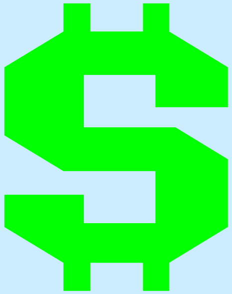


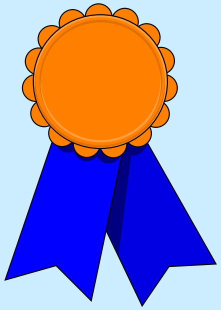
Representative Product Domain: Electronics

- $300B+ industry; widespread technology

Analysis Motivation for Small-Medium Enterprises (SMEs)

- Typically niche-experts
  - Precise mfg. process knowledge
  - Specialized product <u>design</u> knowledge (ex. PWB laminates)
- SME analysis needs
  - Product improvements (DFM)
  - Mfg. process troubleshooting
  - Mfg. process optimization





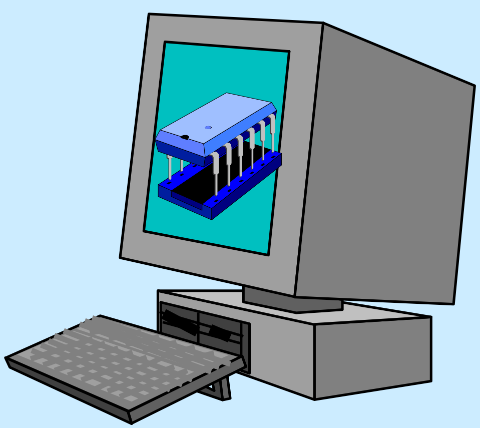
- More accurate data → Better analysis
- Bottom line drivers:

Higher Yields, Lower Cost,
Better Quality, Fewer Delays

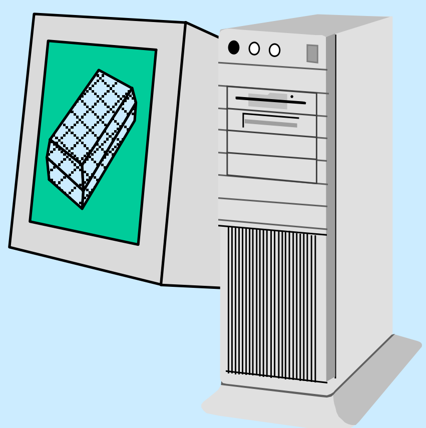
Barriers to SME Analysis

- Lack of awareness
- High costs of traditional analysis capability
  - Secondary: Specialized Software, Training, Hardware
  - Primary: Model Access/Development, Validation, Usage
- Lack of domain-specific integrated tools

Product Model



Analysis Models



Skilled Personnel

ProAM Deliverable Highlights

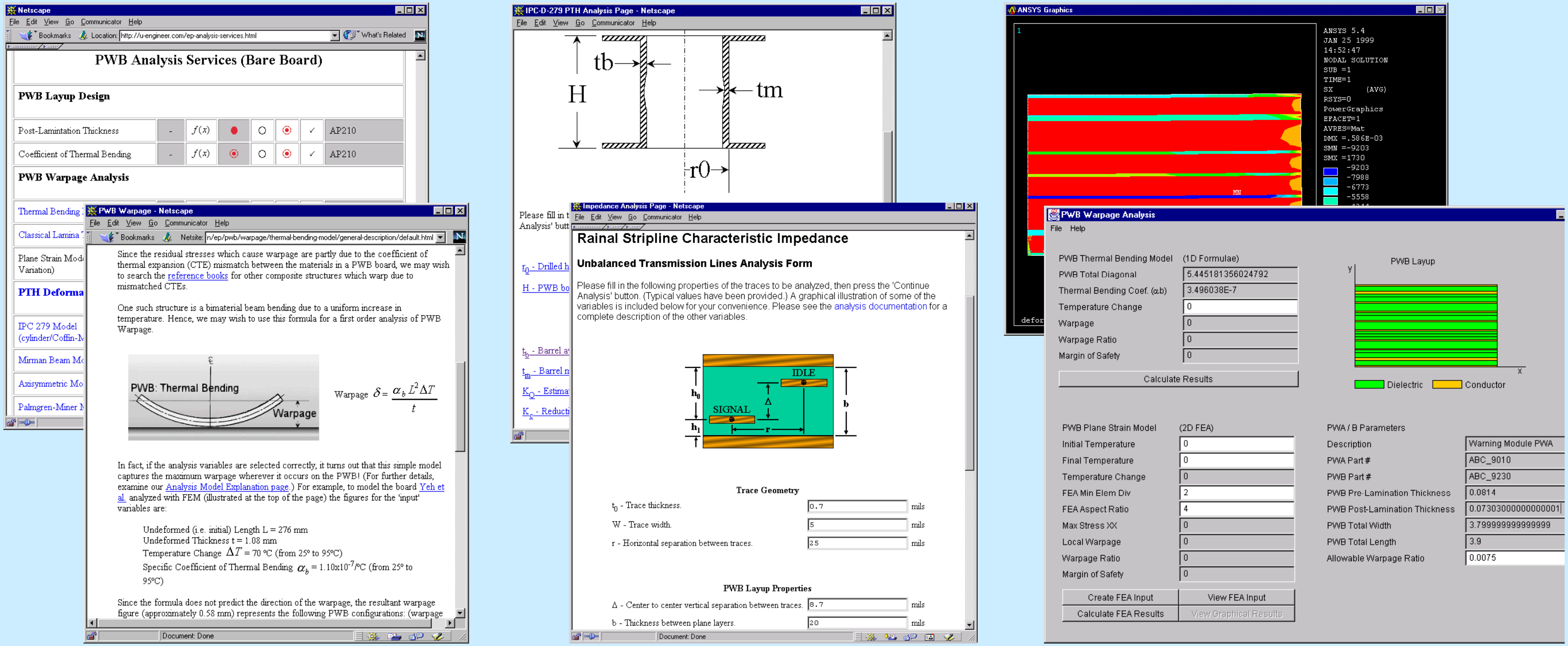
Applications in U. S. Army AMCOM context

- *U-Engineer.com* pilot commercial ESB
  - Internet-based PWA-B analysis modules & toolkit
- Usage in AMCOM supply chain

General techniques

- Internet-based engineering service bureau (ESB)
- X-analysis integration (XAI)
  - Product data-driven plug-and-play analysis modules
  - General purpose XAI toolkit, *XaiTools*

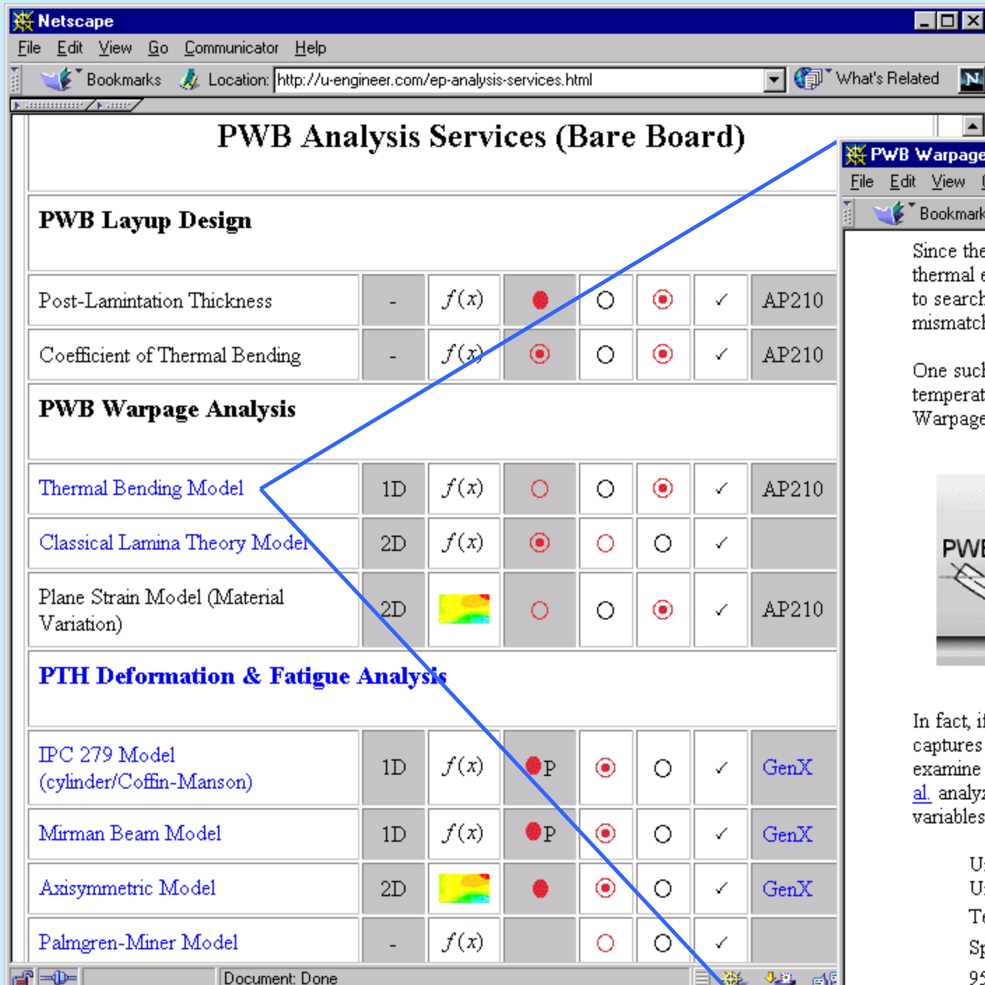
U-Engineer.com
Engineering Service Bureau (ESB)



Analysis Documentation Ready-to-Use Analysis Modules

Lower cost, better quality, fewer delays in supply chain

ESB Analysis Module
Catalogs & Documentation



Netscape
File Edit View Go Communicator Help
Bookmarks Location: http://u-engineer.com/ep-analysis-services.html What's Related

PWB Analysis Services (Bare Board)

PWB Layup Design							
Post-Lamintation Thickness	-	$f(x)$	●	○	◉	✓	AP210
Coefficient of Thermal Bending	-	$f(x)$	◉	○	◉	✓	AP210
PWB Warpage Analysis							
Thermal Bending Model	1D	$f(x)$	○	○	◉	✓	AP210
Classical Lamina Theory Model	2D	$f(x)$	◉	○	○	✓	
Plane Strain Model (Material Variation)	2D		○	○	◉	✓	AP210
PTH Deformation & Fatigue Analysis							
IPC 279 Model (cylinder/Coffin-Manson)	1D	$f(x)$	●P	◉	○	✓	GenX
Mirman Beam Model	1D	$f(x)$	●P	◉	○	✓	GenX
Axisymmetric Model	2D		●	◉	○	✓	GenX
Palmgren-Miner Model	-	$f(x)$		○	○	✓	

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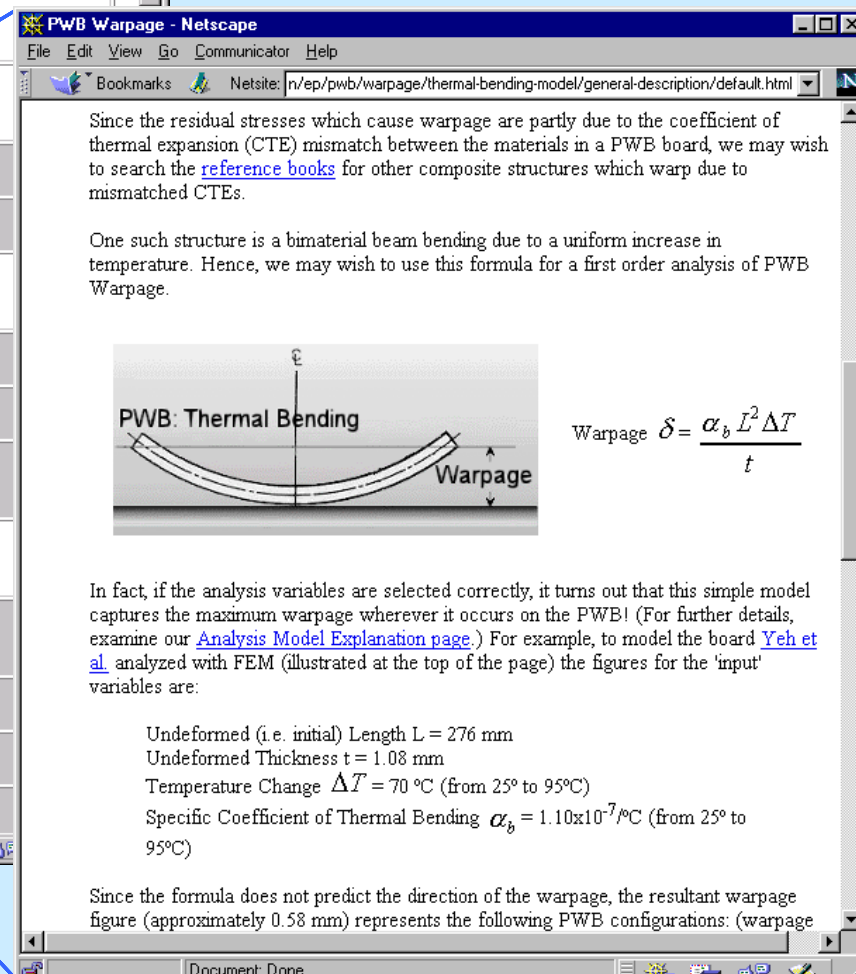

PWB Warpage - Netscape
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Bookmarks Netsite: n/ep/pwb/warpage/thermal-bending-model/general-description/default.html

Since the residual stresses which cause warpage are partly due to the coefficient of thermal expansion (CTE) mismatch between the materials in a PWB board, we may wish to search the reference books for other composite structures which warp due to mismatched CTEs.

One such structure is a bimaterial beam bending due to a uniform increase in temperature. Hence, we may wish to use this formula for a first order analysis of PWB Warpage.

Warpage $\delta = \dfrac{\alpha_b L^2 \Delta T}{t}$

In fact, if the analysis variables are selected correctly, it turns out that this simple model captures the maximum warpage wherever it occurs on the PWB! (For further details, examine our Analysis Model Explanation page.) For example, to model the board Yeh et al. analyzed with FEM (illustrated at the top of the page) the figures for the 'input' variables are:

Undeformed (i.e. initial) Length L = 276 mm
Undeformed Thickness t = 1.08 mm
Temperature Change ΔT = 70 °C (from 25° to 95°C)
Specific Coefficient of Thermal Bending α_b = 1.10x10^{-7}/°C (from 25° to 95°C)

Since the formula does not predict the direction of the warpage, the resultant warpage figure (approximately 0.58 mm) represents the following PWB configurations: (warpage

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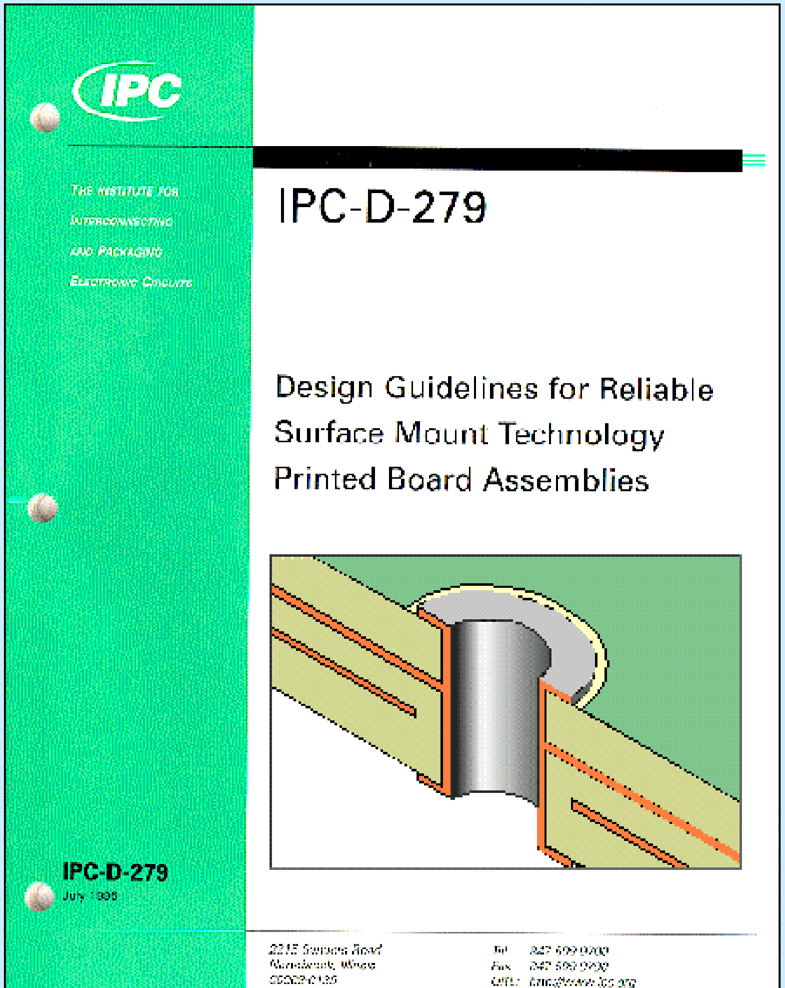
Paper-based IPC-D-279 Plated Through Hole Fatigue Analysis

Tedious to Use



PTH/PTV Fatigue Life Estimation

$$\sigma_{avg} = \frac{\left[(\alpha_E - \alpha_{Cu})\Delta T + S_y \cdot \frac{E_{Cu} - E_{Cu}'}{E_{Cu} \cdot E_{Cu}'}\right] A_E \cdot E_E \cdot E_{Cu}'}{A_E \cdot E_E + A_{Cu} \cdot E_{Cu}'}$$

$$\Delta \varepsilon_{avg} = \frac{(\alpha_E - \alpha_{Cu})\Delta T \cdot A_E \cdot E_E - S_y \cdot A_{Cu} \cdot \frac{E_{Cu} - E_{Cu}'}{E_{Cu}}}{A_E \cdot E_E + A_{Cu} \cdot E_{Cu}'}$$

$$N_f^{-0.6} D_f^{0.75} + 0.9 \frac{S_u}{E} \left[\frac{e^{D_f}}{0.36}\right]^{0.1785 \log \frac{10^5}{N_f}} - \Delta \varepsilon = 0$$

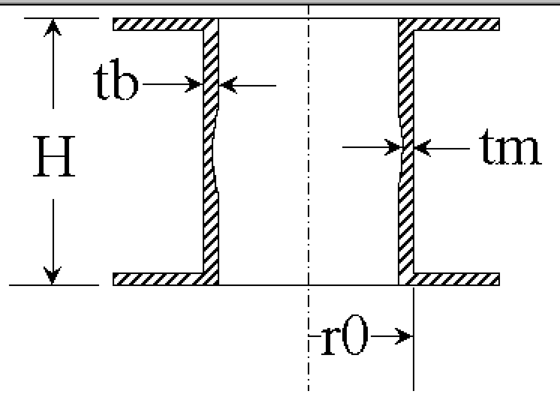
$$N_f(x\%) = N_f(50\%) \left[\frac{\ln(1 - 0.01x)}{\ln(0.5)}\right]^{\frac{1}{\beta}}$$

Web-based IPC-D-279 PTH Analysis Module

Easy to Use

IPC-D-279 PTH Analysis Page - Netscape

File Edit View Go Communicator Help



Please fill in the following properties of the PTH to be analyzed, then press the 'Continue Analysis' button. (Typical values have been provided.)

PTH Geometry

r_0 - Drilled hole radius.	0.0125	inches
H - PWB board thickness.	0.0625	inches

PTH 'As Manufactured' Properties

t_b - Barrel average plated thickness.	1.2	mils
t_m - Barrel minimum plated thickness.	1.0	mils
K_Q - Estimate of plating quality.	6	
K_c - Reduction in cross section due to local defects.	10% Reduction	

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Netscape

File Edit View Go Communicator Help

PTH Analysis Results

Input Variables

Drilled hole diameter, d: 0.025 inches
PWB Board thickness, H: 0.0625 inches

Barrel average plated thickness, t_b: 0.0012 inches
Barrel minimum plated thickness, t_m: 0.001 inches
Estimate of Plating Quality, K_Q: 6
Reduction in local cross sectional area due to plating or drilling defects, K_c: 10 %

Change in temperature, ΔT: 200°C
Reference temperature (ambient), T_{ref}: 25°C

Compression modulus of resin, E_f: 500000 psi
Coefficient of Thermal Expansion of resin, α_f below T_g: 0.000067 /°C
Coefficient of Thermal Expansion of resin, α_f above T_g: 0.000315 /°C
Glass Transition Temperature, T_g: 137 °C

Tensile modulus of barrel material, E_b: 3000000 psi
Plastic modulus of barrel material, E_b': 100000 psi
Yield Strength of barrel material, S_y: 25000 psi
Ultimate Strength of barrel material, S_u: 41000 psi
Plastic strain at fracture of barrel material, D_f: 0.203
Coefficient of Thermal Expansion of barrel material, α_b: 0.000017 /°C

Analysis Model

IPC-D-279 Plated Through Hole Model

Results

Average Stress in the PTH barrel: 30.0317e3 psi
Maximum Strain in the PTH barrel: 0.121682
PTH barrel Fatigue Life: 10.61e3 cycles to 50% failure probability.

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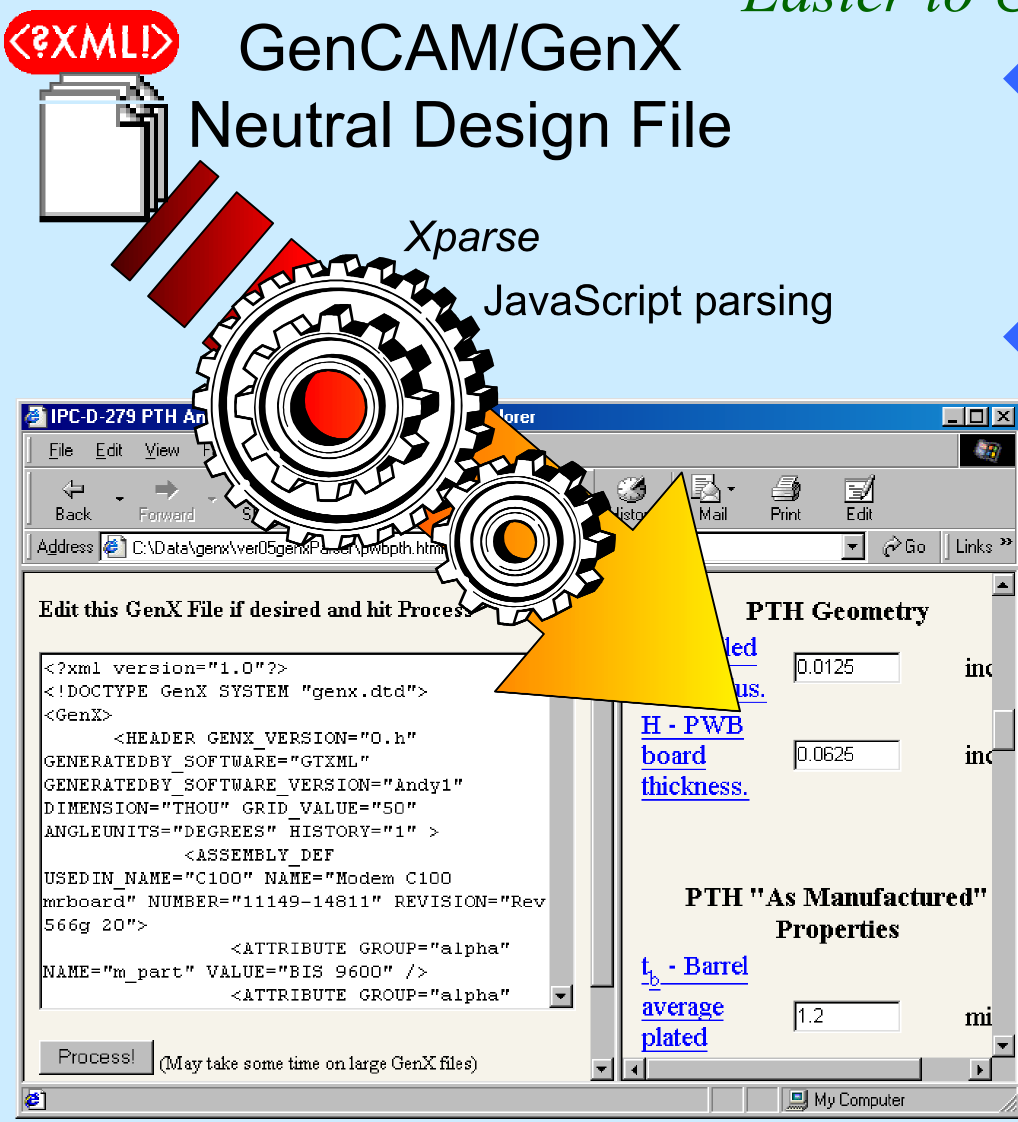
Product Data-Driven
IPC-D-279 PTH Analysis Module

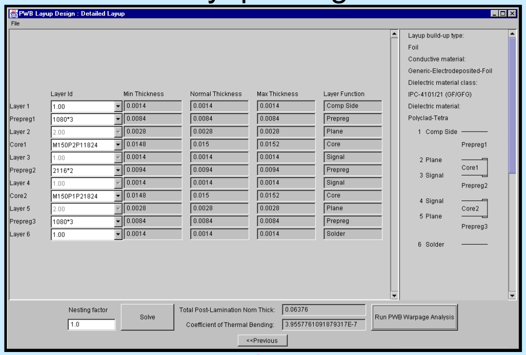
Easier to Use



- Local browser:
  - + Idealizes design data
  - + Inserts into analysis
- Benefits
  - + Fewer errors vs. manual idealization & re-entry
  - + Automated exhaustive search (100s of PTHs)
  - + Data compression (as much as 100x)
  - + Increased security

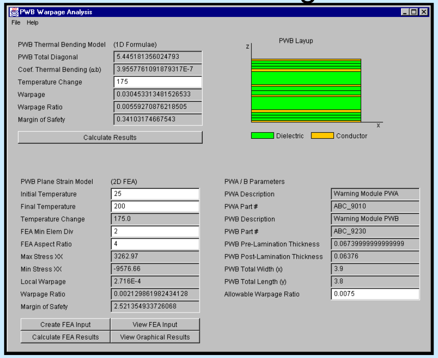
Iterative Design & Analysis

PWB Layup Design Tool



Layup Re-design

1D Thermal Bending Model



Quick Formula-based Check

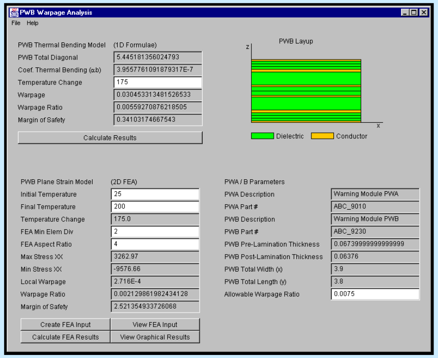
$$\delta = \frac{\alpha_b L^2 \Delta T}{t}$$

$$\alpha_b = \frac{w_i \alpha_i y_i}{t/2 \quad w_i}$$

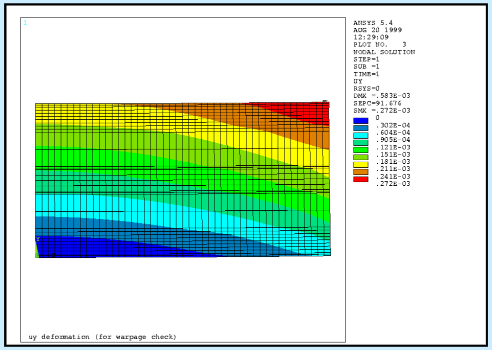
Analyzable Product Model

PWB Warpage Modules

2D Plane Strain Model



Detailed FEA Check



ProAM Deliverable Highlights

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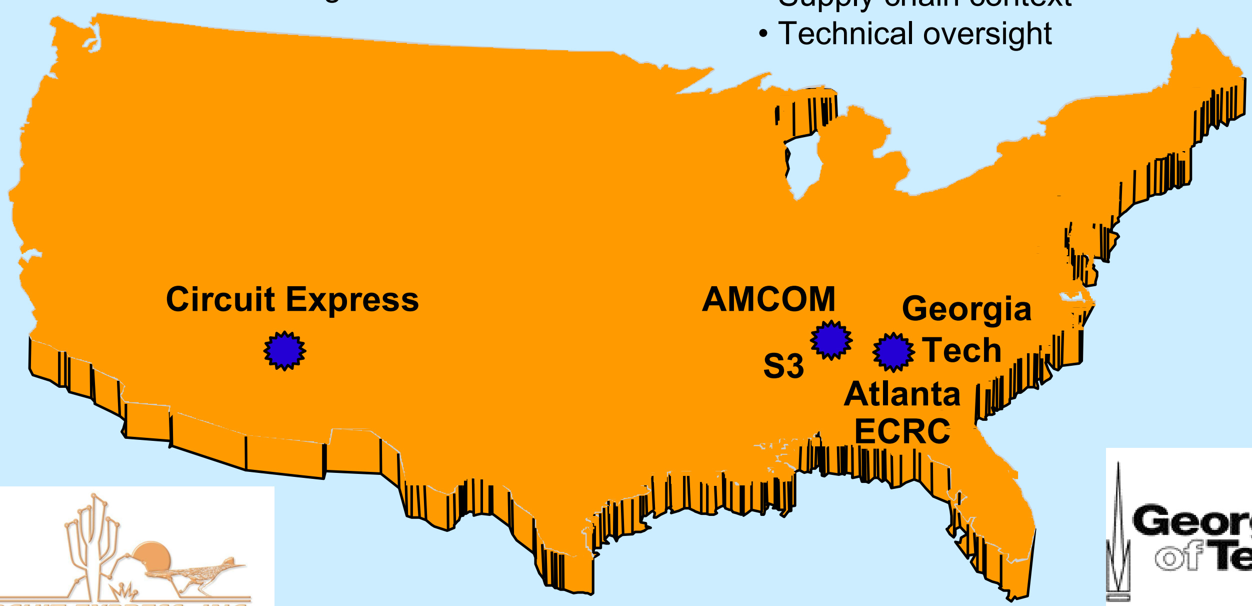
ProAM Technical Team

Missile supply chain SME
• PWB design & fabrication expertise
• Tool usage & feedback

Missile system end-user
• Supply chain context
• Technical oversight



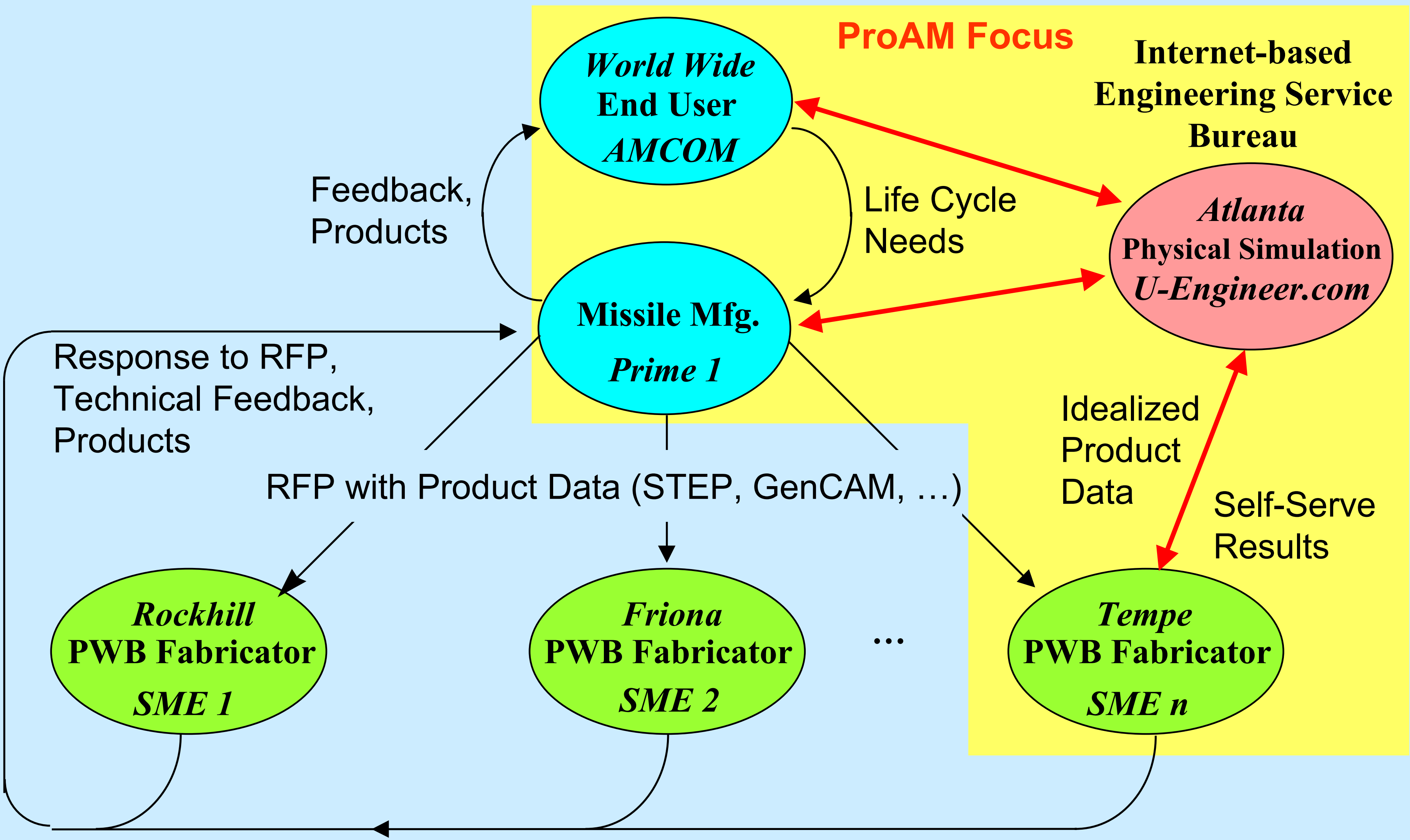
Missile supply chain SME
• PWB fabrication expertise
• Tool usage & feedback

Electronic commerce resource center
• Mgt., ESB, and computing support

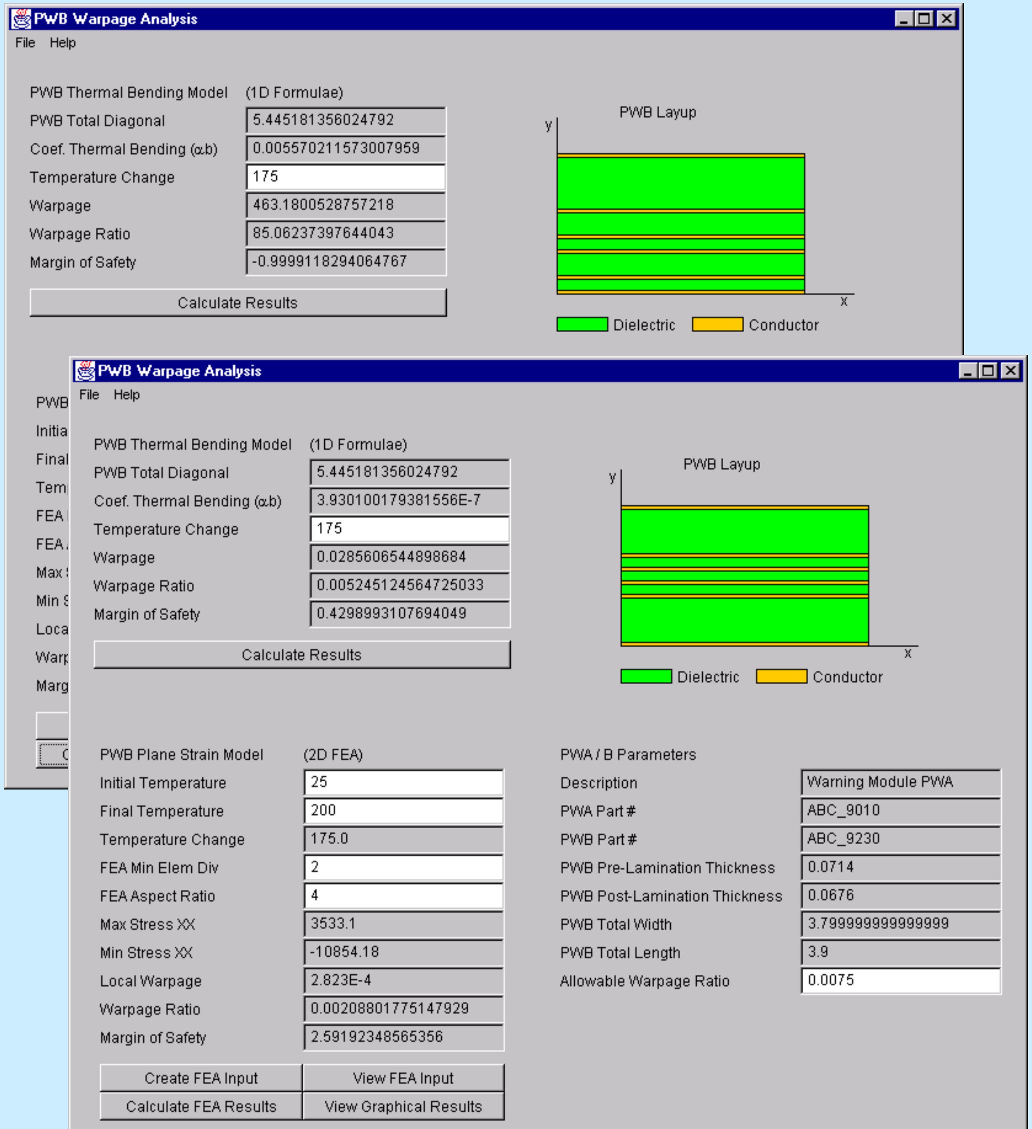
Research & development lab
• Program management
• Technical concepts
• Tool implementation

ProAM Focus

Automated Internet-based Analysis for Supply Chains



Example SME Usage



- Original design:
  - Six layer board
  - Unsymmetrical layup
  - Severe warpage
  - Analysis predicted thermal distortion
- Alternate design:
  - Modeled construction variables
  - Analysis predicted improved distortion
- New capability aided design improvement

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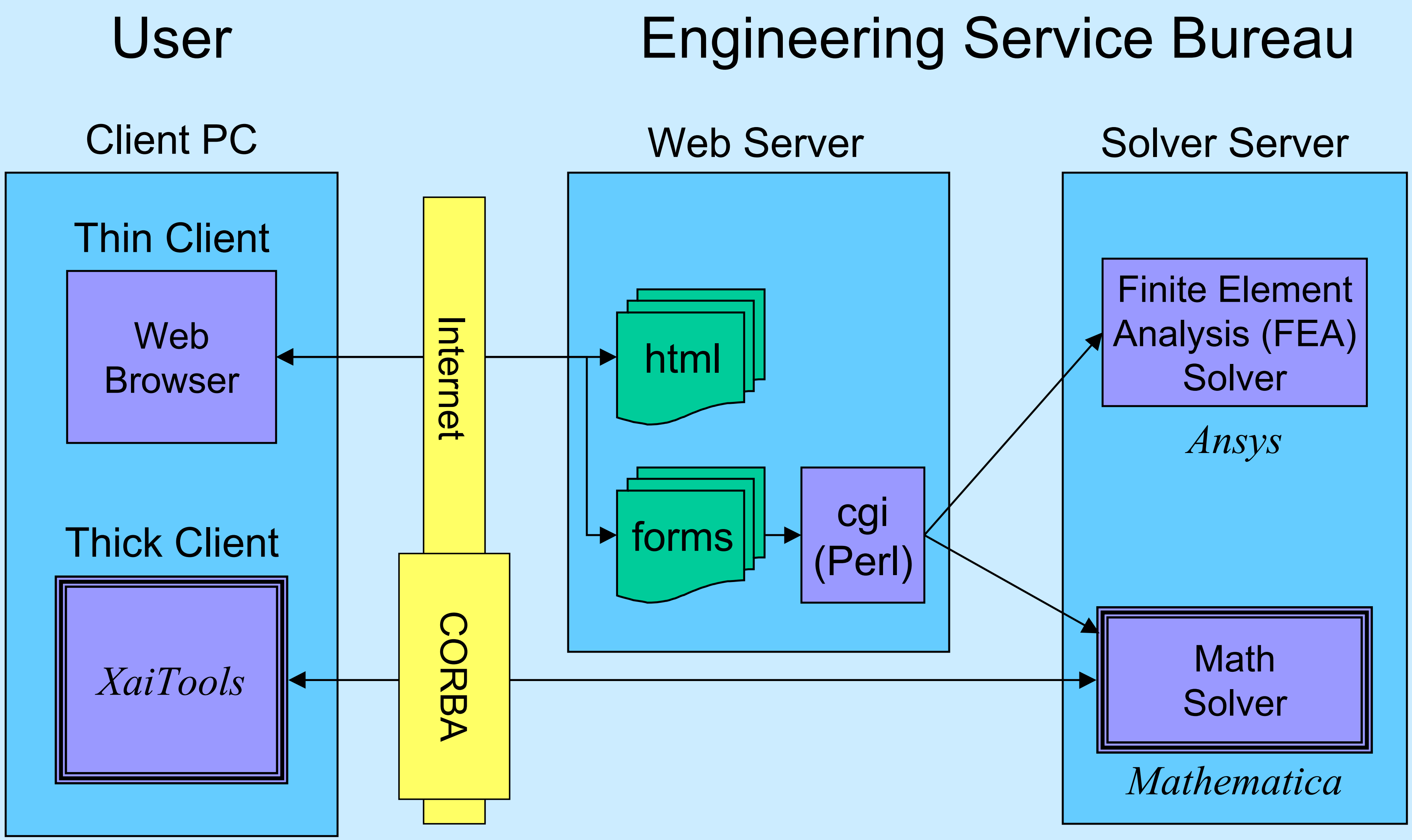
Example ESB Client-Server Architecture



Internet-based ESB Techniques

- Analysis module template & methodology
- Range of access methods:
  - Remote Tools
    - Login to remote workstation; X-Windows display
  - Thick Clients
    - Locally installed w/ Internet/LAN-based solvers via CORBA
  - Thin Clients
    - Web-based forms & solvers all located at ESB
- General web techniques
- General e-commerce: electronic payment, etc.

ProAM

ESB Characteristics

- **Self-serve analysis**
  - Pre-developed analysis modules presented in product & process contexts
  - Available via the Internet
  - Optionally standards-driven (STEP, GenCAM ...):
    - » Reduce manual data transformation & re-entry
    - » Highly automated plug-and-play usage
  - Enabled by X-analysis integration technology
- **Full-serve analysis as needed**
- **Possible business models:**
  - Pay-per-use and/or pay-per-period
  - ESB hosting
  - Costs averaged across customer base

ProAM Deliverable Highlights

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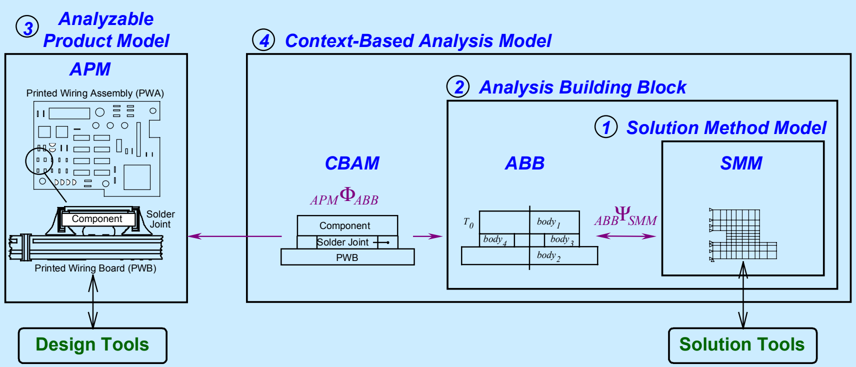
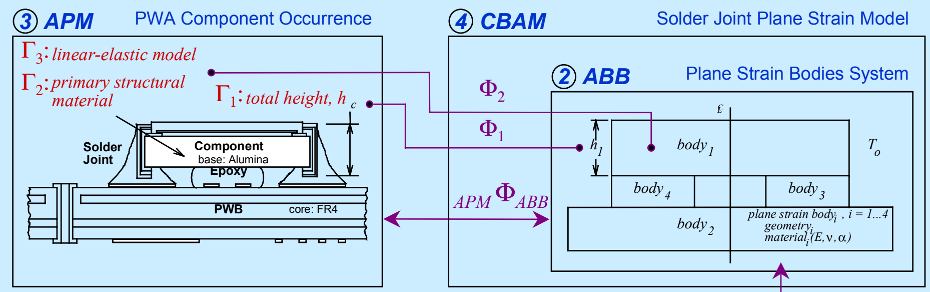
X-Analysis Integration Concepts

Multi-Representation Architecture (MRA)

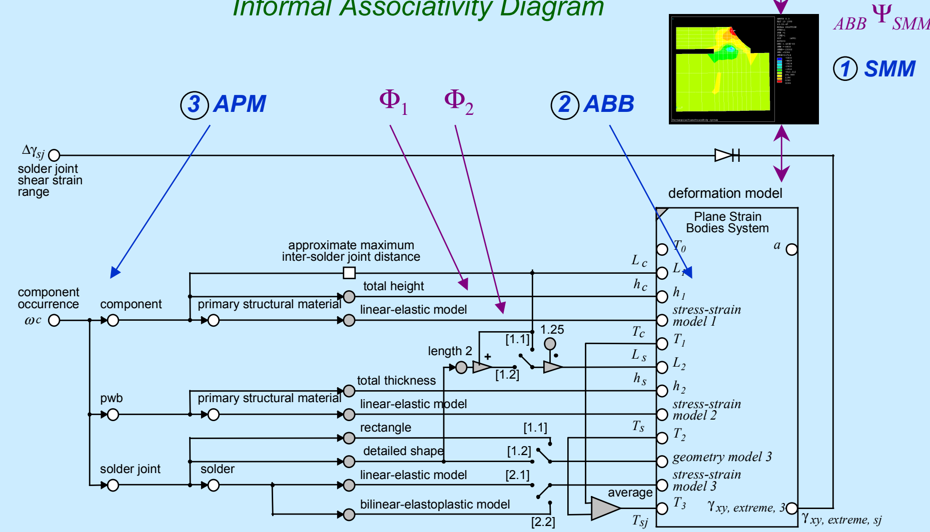


Design-Analysis Associativity

Design Model *Analysis Model*

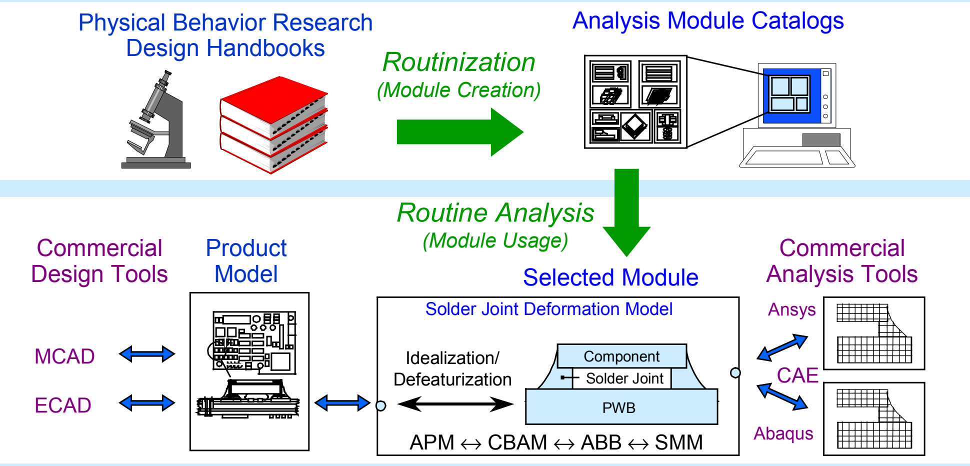


Informal Associativity Diagram



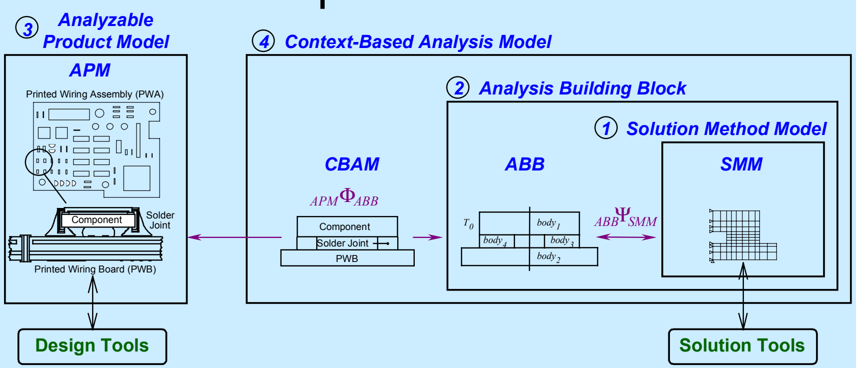
Constraint Schematic (Information Model)

Analysis Module Creation Methodology

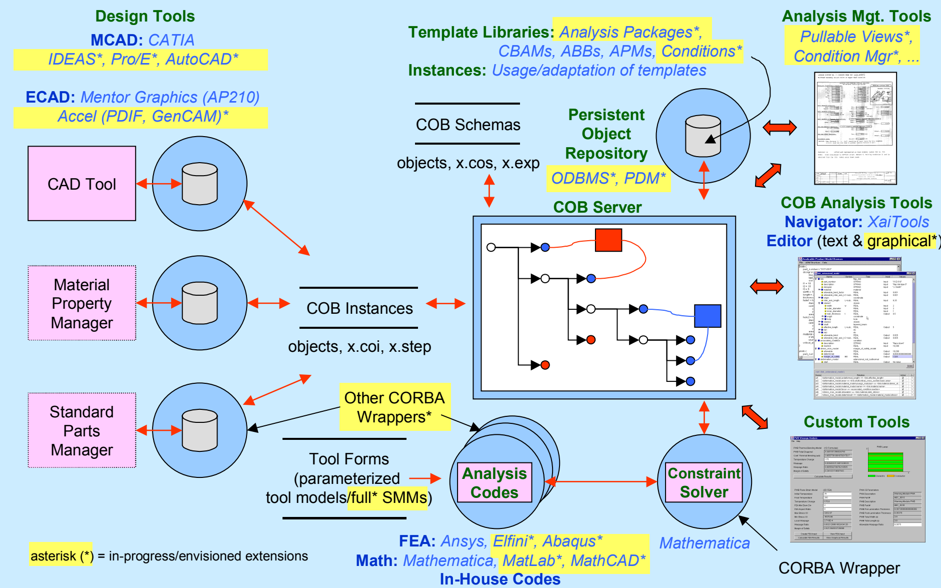


XaiTools™
X-Analysis Integration Toolkit

Multi-Representation Architecture (MRA) Implementation

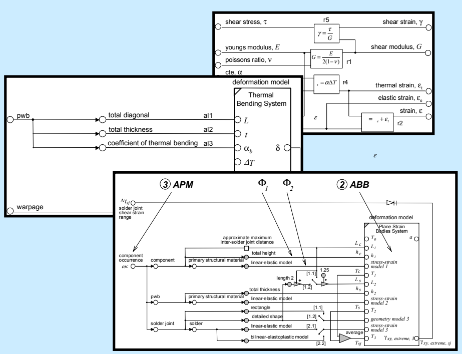


CAD/E Framework Architecture

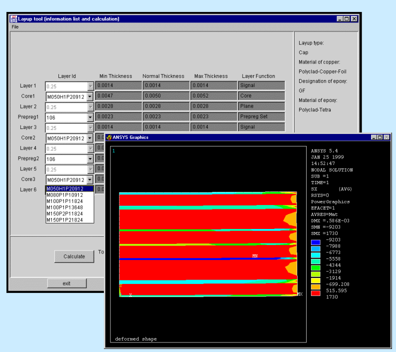


Analysis Modules & Building Blocks

Constraint Schematics



Implementations



Product-Specific Applications

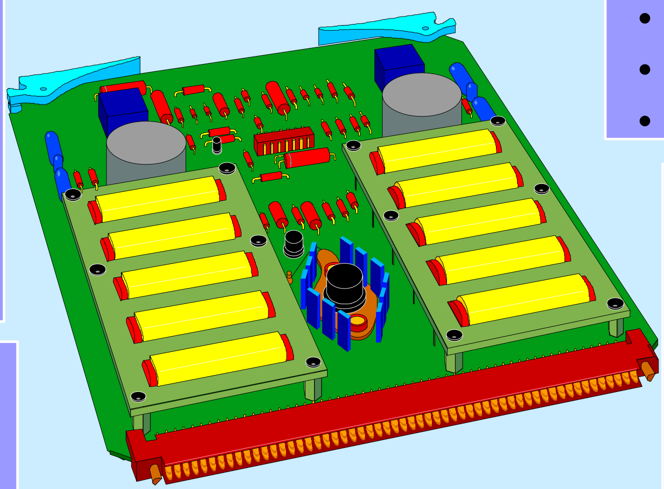
- Aerospace structural analysis
- PWA-B thermomechanical analysis & design
  - *XaiTools PWA-B*™
- Electronic package thermal analysis
  - *XaiTools ChipPackage*™

STEP AP 210
PWA/B Design Information

Product Structure/ Connectivity
- Functional
- Packaged

Part
- Functionality
- Termination
- Shape 2D, 3D
- Single Level Decomposition
- Material Product
- Characteristics

Physical
- Component Placement
- Bare Board Geometry
- Layout items
- Layers non-planar, conductive & non-conductive
- Material product



Configuration Mgmt
- Identification
- Authority
- Effectivity
- Control
- Requirement Traceability
- Analytical Model
- Document References

Geometry
- Geometrically Bounded 2-D Shape
- Wireframe with Topology
- Advanced BREP Solids
- Constructive Solid Geometry

Requirements
- Design
- Allocation
- Constraints
- Interface

Technology
- Fabrication Design Rules
- Product Design Rules

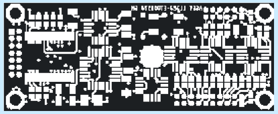
ProAM Design-Analysis Integration

Electronic Packaging Examples: PWA-B

Design Tools

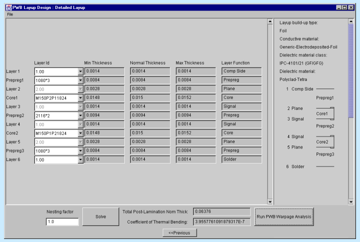
ECAD Tools

*Mentor Graphics, Accel**



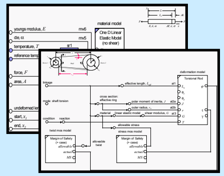
PWB Layup Tool

XaiTools PWA-B



Laminates DB

Materials DB



Modular, Reusable Template Libraries

STEP AP210, GenCAM**, PDIF*

Analyzable Product Model

XaiTools PWA-B

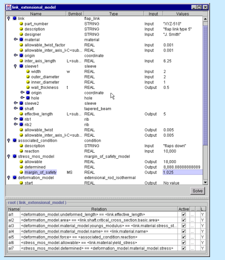
Analysis Modules (CBAMs) of Diverse Mode & Fidelity

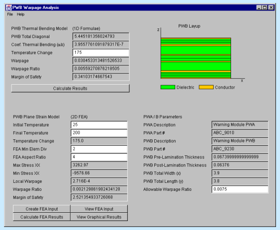
Solder Joint Deformation* — 1D, 2D, 3D

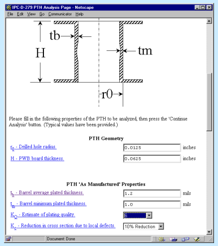
PWB Warpage — 1D, 2D

PTH Deformation & Fatigue** — 1D, 2D

XaiTools PWA-B



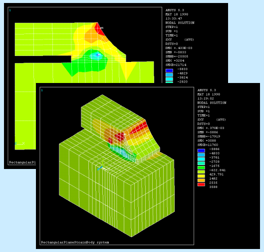


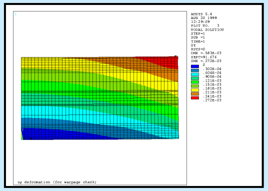


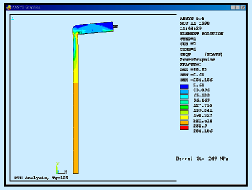
Analysis Tools

General Math *Mathematica*

FEA *Ansys*







* = Item not yet available in toolkit (all others have working examples) ** = Item available via U-Engineer.com

Summary

- Internet-based engineering service bureaus (ESBs)
  - ➡ *Key step for affordable SME analysis*
- Product data-driven analysis technology
  - Analysis integration toolkit
- AMCOM missile supply chain applications
  - ➡ *U-Engineer.com & electronic packaging analysis*
- Exemplar usage of electronic data files like STEP
- Applicability to other product industries
- Framework for automated analysis
  - ➡ *Improved product performance, reliability, and manufacturability*

For Further Information ...

- EIS Lab web site: *http://eislab.gatech.edu/*
  - See Publications, DAI/XAI, Suggested Starting Points
- ProAM home page: *http://eislab.gatech.edu/projects/proam/*
- *XaiTools* home page: *http://eislab.gatech.edu/*
- Pilot commercial ESB: *http://www.u-engineer.com/*
  - Internet-based self-serve analysis
  - Analysis module catalog for electronic packaging
  - Highly automated front-ends to general FEA & math tools

Presenter Biosketch

Russell S. Peak is a Senior Researcher in the Georgia Institute of Technology CALS Technology Center where he is the Assistant Director of the Engineering Information Systems Laboratory. He also is part of the Atlanta Electronic Commerce Resource Center Technology Development Group. Dr. Peak's specialty is engineering design-analysis integration (DAI) with applications including electronic packaging and structural analysis.