Product Data-Driven Analysis in a Missile Supply Chain (ProAM) Final Report

GIT Technical Report E-15-642-D05

GIT Project No. E-15-642
Period of Performance: 8/26/97 to 6/30/99

Stakeholder:
U. S. Department of Defense
U. S. Army Aviation & Missile Command (AMCOM)
AMSAM-RD-SE-MT
Redstone Arsenal, Alabama USA
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Sponsor:
U. S. Department of Defense
Joint Electronic Commerce Program Office (JECPO)
National Electronic Commerce Resource Center (ECRC) Program

Subcontract N00140-96-D-1818/0008
Concurrent Technologies Corporation
Johnstown, Pennsylvania

Project Directors:
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Atlanta Electronic Commerce Resource Center (AECRC)
http://www.ecrc.gatech.edu/
Engineering Information Systems Lab
http://eislab.gatech.edu/

CALS Technology Center
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Phillip J. Spann (System Studies and Simulation, Inc.)

August 23, 1999a

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 document overviews the ProAM project and resulting tools and technologies:

- **U-Engineer, 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-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, 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 utilization by SMEs and Primes is highlighted, including solving production problems, 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.

Document Reference:
R. S. Peak, A. J. Scholand, R. E. Fulton, D. Koo, D. R. Tamburini, M. W. Wilson, S. Zeng, J. H. Roberts, P. J. Spann (Aug 23, 1999) Product Data-Driven Analysis in a Missile Supply Chain (ProAM) Final Report, Georgia Tech Engineering Information Systems Lab Technical Report E-15-642-D05, Concurrent Technologies Corp Contract N00140-96-D-1818/0008 for US DoD JECPO.

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1 Overview

One key to obtaining quality parts from Small to Medium-Sized Enterprises (SMEs) is their ability to analyze the physical behavior of parts and manufacturing processes. Through techniques such as finite element analysis, SMEs can greatly impact products by optimizing their performance, judging design alternatives, and improving manufacturing yields. However, industry often does not benefit from such analysis due to the lack of easy-to-use, product-specific capabilities. This situation is exacerbated in SMEs where limited resources typically preclude having in-house analysis tools and staff. Yet SMEs need analysis capabilities as they are often the ones with the required precise product and process knowledge.

This project has addressed these issues and provided working tools for new SME capabilities that are aimed at improving product cost and performance within the missile sector. The Aviation and Missile Command's (AMCOM) Manufacturing Science and Technology (MS&T) Division is promoting improvements to the missile supply chain through initiatives like ProAM and the Affordable Multi-Missile Manufacturing (AM3) Program. Georgia Tech and the Atlanta ECRC have teamed with the MS&T Division to develop and transition these new SME tools to AMCOM missile programs. Direct applications and implementations through the AM3 program's supply chain initiatives are a related goal.

1.1 Related Documents and Resources

This report highlights items described in more detail in these documents and resources:

ProAM Home Page:

- *http://eislab.gatech.edu/projects/proam/*
  Includes June, 1999 Demonstration Handouts (also on CD-ROM)

Internet-based Engineering Service Bureau Technology

- GIT EIS Lab Technical Report EL003-1999A (Appendix B)
- Self-Serve analysis modules at U-Engineer.com: *http://www.u-engineer.com/*

Analysis Integration Technology

- Analysis integration research and applications (Appendix A)

General-Purpose Toolkit

- *XaiTools* Home Page: *http://eislab.gatech.edu/tools/xaitools/*
- *XaiTools Users Guide* (Appendix C)
- *XaiTools Installation and Configuration Guide* (Appendix C)

Product-Specific Applications:

- *XaiTools PWA-B Users Guide* (Appendix C)

All the above are available on the ProAM CD-ROM (except the full Internet web site contents), and all are available via the ProAM Internet home page. See in particular the June, 1999 Demonstration Handouts (Table 1) for items not covered in this document

Table 1 Outline of June, 1999 Demonstration Handouts
(available on ProAM web and ProAM CD-ROM)

1.	**Main Session**
	• Welcome & Background - *Bob Fulton*
	• Project Overview - *Russell Peak & Andy Scholand*
	    • ProAM Team
	    • Motivation & Objectives
	    • Tasks
	    • Deliverable Highlights
	        • General Techniques
	            • Engineering Service Bureaus (ESBs) & Analysis Integration
	        • AMCOM Supply Chain Applications
	            • U-Engineer Analysis Modules & SME Pilot Usage
	• SME ProAM Experiences
	    • PWA/B Designer & Fabricator Perspective - *Phillip Spann (S3)*
	    • PWB Fabricator Perspective - *Jake Roberts (Circuit Express)*
	• Wrap-Up - *Russell Peak*
	    • Summary of Accomplishments
	    • Post-Project Plans
	    • Technology Transfer:
	        • Eagle Engineering - *Jim Thaxton*
	        • EPS - *Dirk Zwemer*
	    • Collaboration Opportunities
	    • Summary of Benefits

2.	**U-Drive Hands-on Tool Usage** - *Donald Koo, Miyako Wilson, Sai Zeng*
3.	**Introduction to Internet/Intranet-Based Engineering Service Bureau (ESB) Technology** - *Andy Scholand*
4.	**Overview of Emerging STEP AP210 and GenCAM/GenX Standards for Electronics Product Data** - *Russell Peak & Andy Scholand*
5.	**MARC Center for Board Assembly Research (CBAR) Tour** - *Alex Goldstein*
6.	**Introduction to X-Analysis Integration (XAI) Technology**- *Russell Peak*
7.	**Rapid Prototyping and Manufacturing Institute (RPMI) Tour** - *Reggie Ponder*
8.	**Georgia Tech Packaging Research Center (PRC) Tour** - *Carl Rust*
9.	**Electronic Packaging Services, Inc. (EPS) Tour** - *Dirk Zwemer* (warpage measurement tools & services)

2 General Techniques

This section highlights the general techniques developed or extended during ProAM.

2.1 Internet-based Engineering Service Bureau Technology

Key References:

- GIT EIS Lab Technical Report EL003-1999A (Appendix B)
- June, 1999 Demonstration Handouts
- Self-Serve Analysis Modules at U-Engineer.com: *http://www.u-engineer.com/*

The technical report describes the concept of an Internet-based Engineering Service Bureau (ESB), and defines both the business need for ESBs and the benefits of ESBs to distributed organizations (Figure 1). It further details the distinctives of an Engineering Service Bureau, as opposed to generic application service providers, and outlines the technical infrastructure needed by both the clients and the service bureau itself. These concepts are illustrated with examples from U-Engineer.com, a pilot commercial service bureau established during ProAM, which currently in use by several DoD suppliers.

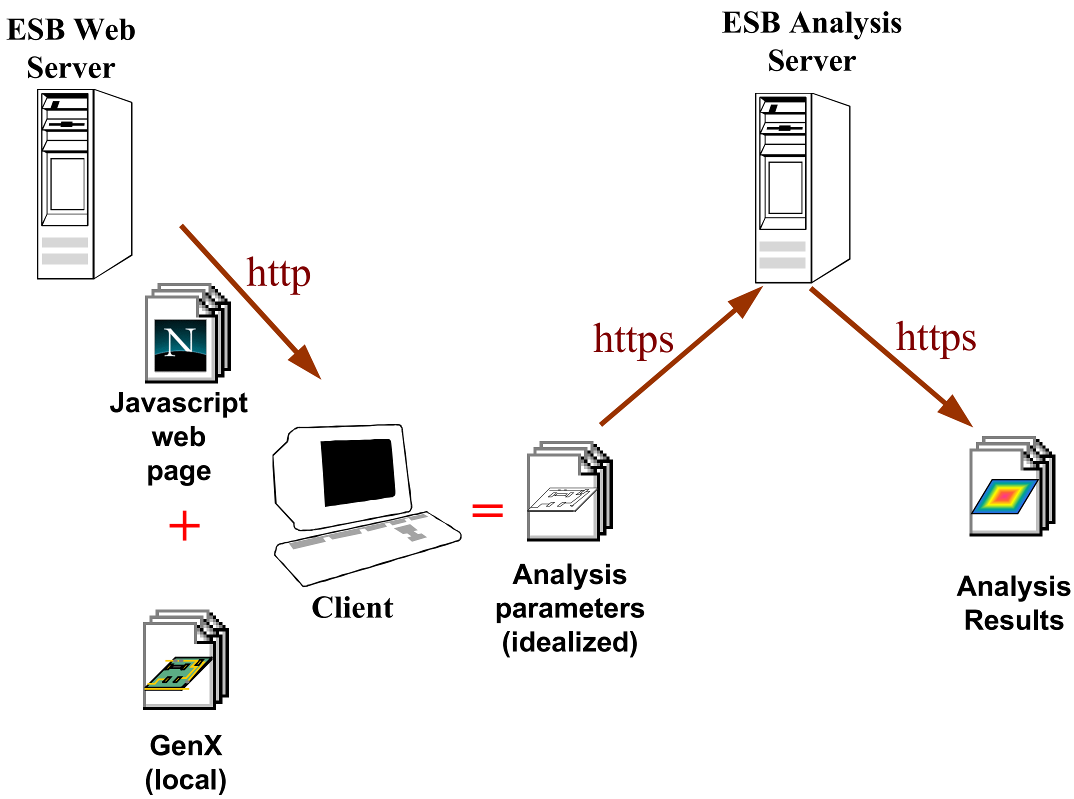


Figure 1 Web-based product data-driven analysis at an ESB

2.2 Analysis Integration Concepts and Toolkit

Key References:

- General-Purpose Toolkit:
  - *XaiTools* Home Page: *http://eislab.gatech.edu/tools/xaitools/*
  - *XaiTools Users Guide* (Appendix C)
  - *XaiTools Installation and Configuration Guide* (Appendix C)
- Product-Specific Applications:
  - *XaiTools PWA-B Users Guide* (Appendix C)
- June, 1999 Demonstration Handouts
- XAI suggested starting points (Appendix A)

This general-purpose analysis integration toolkit, *XaiTools* v0.3.2, is an implementation of advanced X-analysis integration (XAI) concepts based on objects and constraints. It provides a general architecture (Figure 2) for product-data driven analysis capabilities in domain-specific toolsets like *XaiTools PWA-B*. Appendix A gives references for the underlying analysis integration techniques, including capturing explicit design analysis associativity and a methodology for creating analysis module catalogs (Figure 3 and Figure 4).

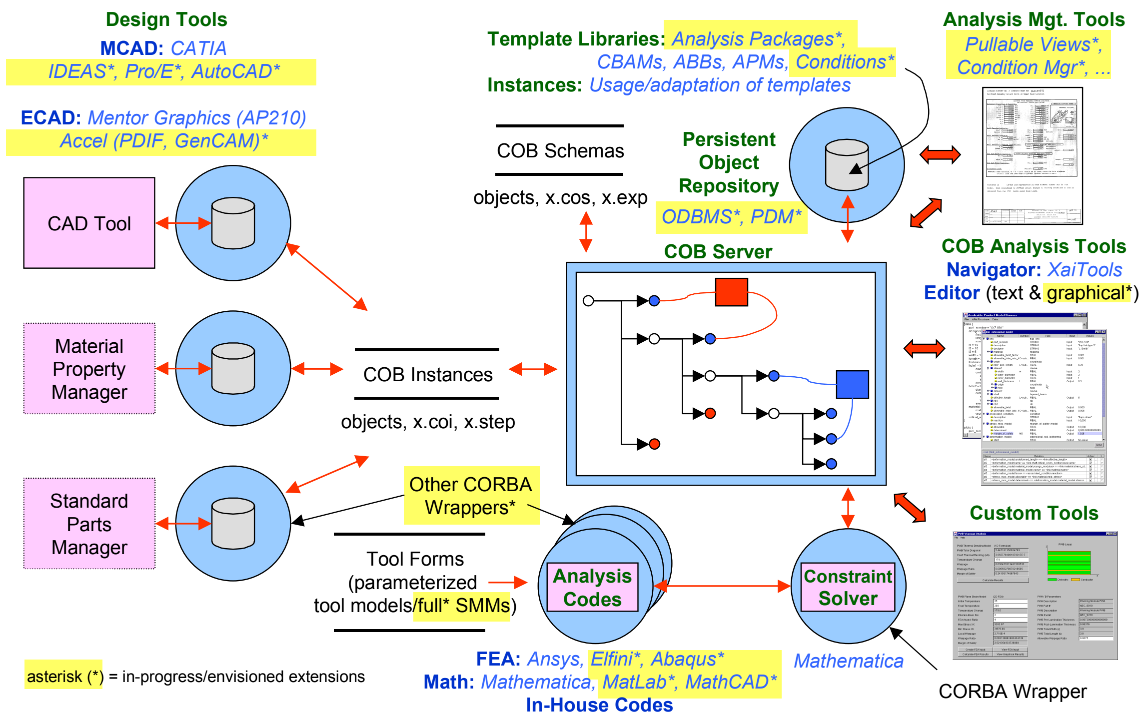


Figure 2 *XaiTools* software architecture

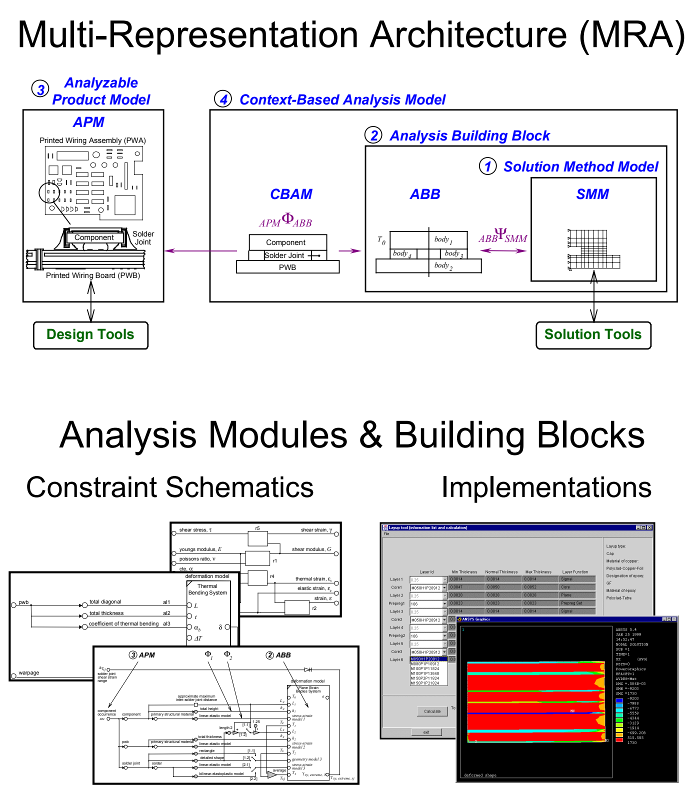


Figure 3 Object oriented constraint-based analysis integration concepts

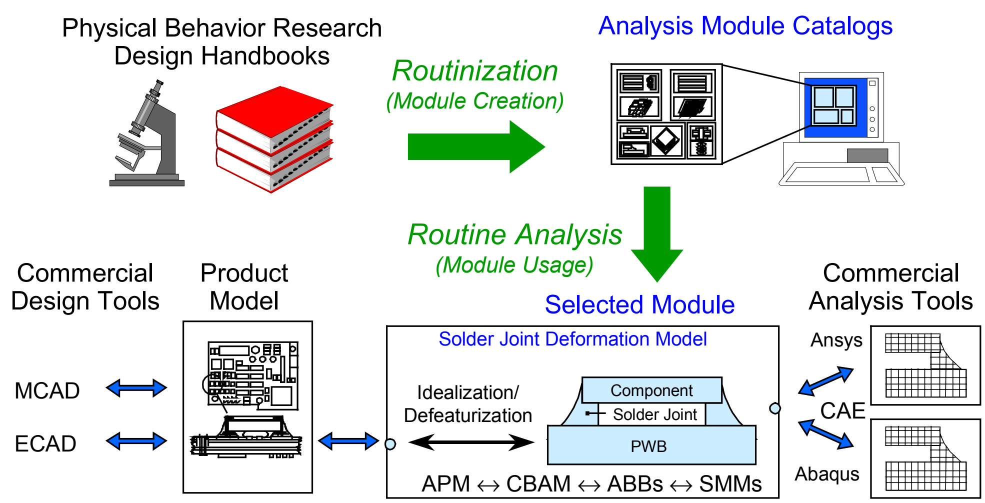


Figure 4 Plug-and-play analysis module creation methodology

3 Application Solutions

3.1 U-Engineer.com

Key References:

- June, 1999 Demonstration Handouts
- GIT EIS Lab Technical Report EL003-1999A (Appendix B)
- Self-Serve Analysis Modules at U-Engineer.com: *http://www.u-engineer.com/*

U-Engineer.com is an Internet-based engineering service bureau with self-serve analysis modules for PWA designers and PWB fabricators (Figure 5)

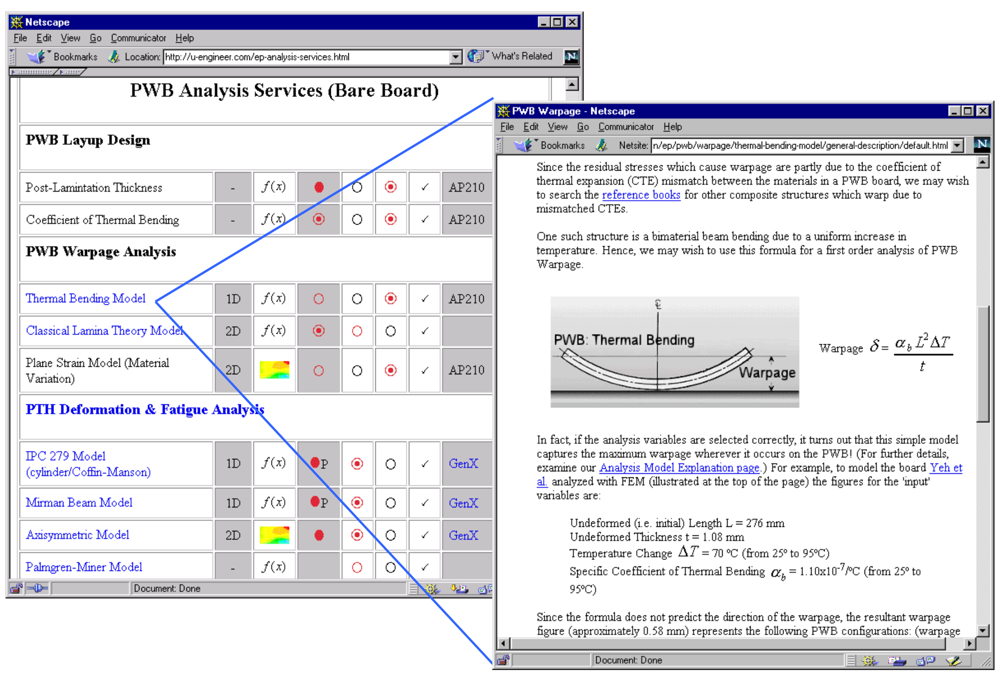


Figure 5 PWA-B analysis module catalogs at U-Engineer.com

3.2 XaiTools PWA-B

Key References:

- *XaiTools PWA-B Users Guide* (Appendix C)
- *XaiTools* Home Page: *http://eislab.gatech.edu/tools/xaitools/*
- June, 1999 Demonstration Handouts

This toolset provides product-data-driven PWB layup design tool and PWB warpage analysis modules to help designers and fabricators automate tedious tasks and compare design alternatives. (Figure 6, Figure 7, Figure 8)

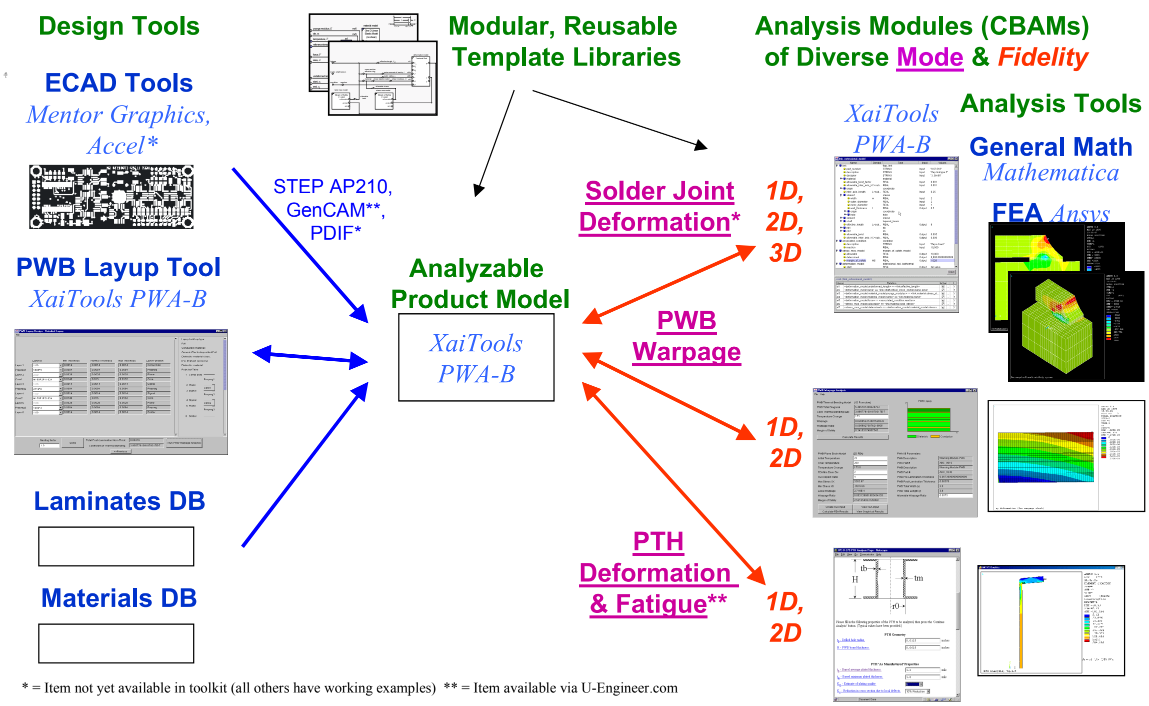


Figure 6 Multi-fidelity multi-disciplinary PWB-A analysis

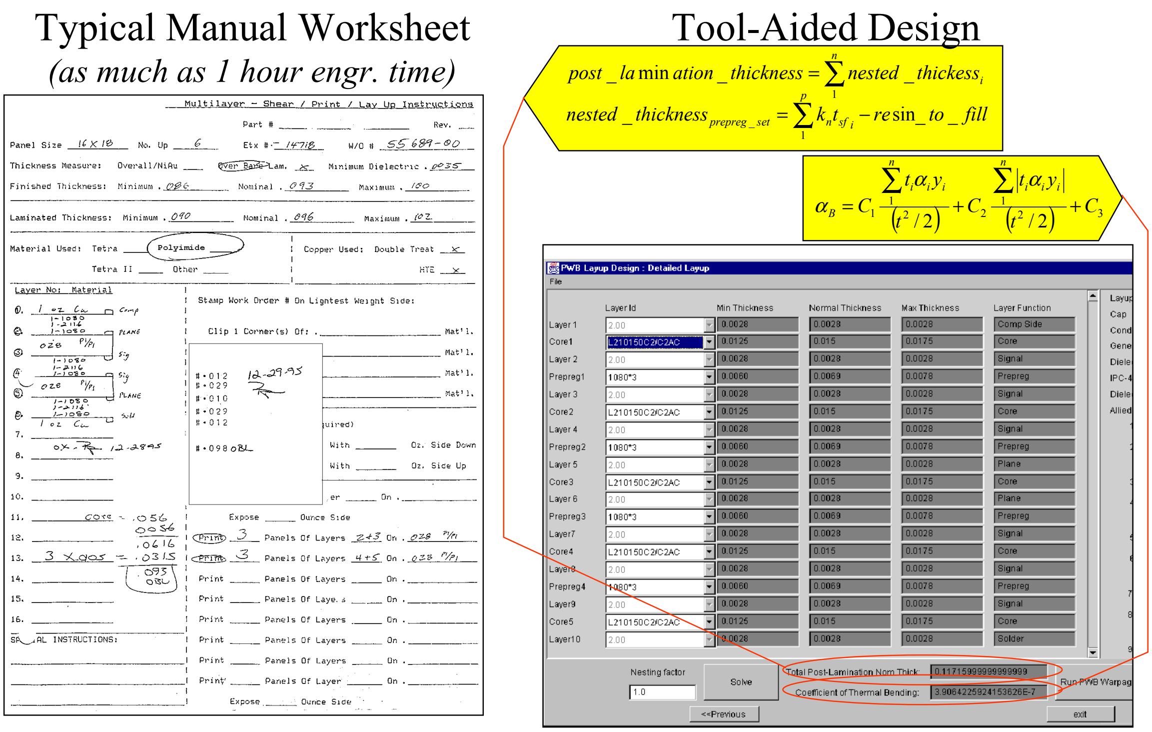


Figure 7 Improving the PWB layup design process with computer-aided tools

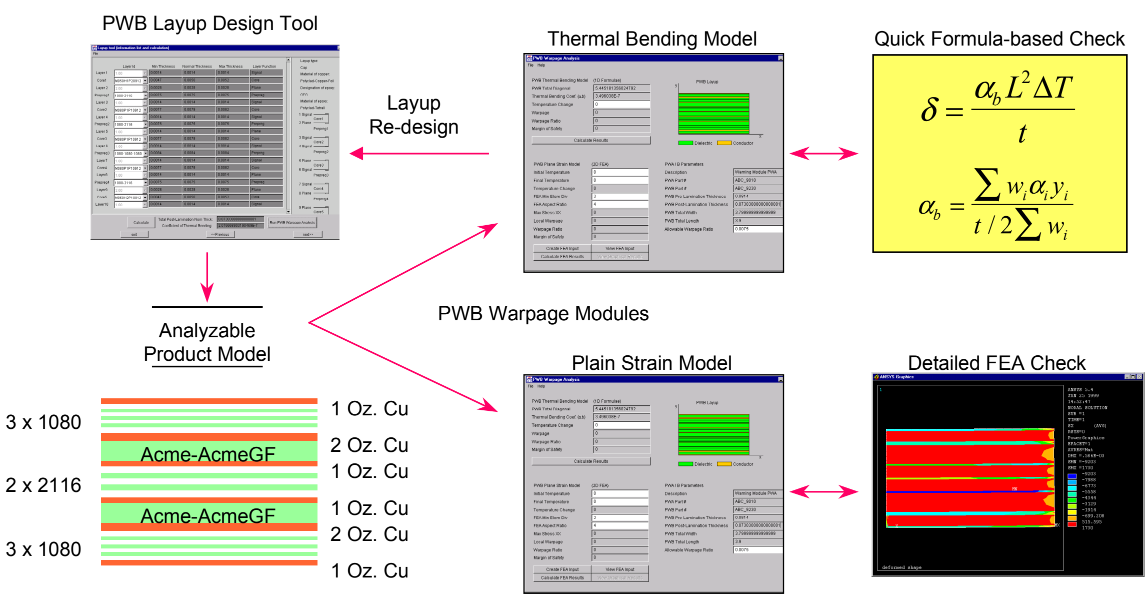


Figure 8 Iterative PWB layup design and analysis

4 Pilot Usage in the AMCOM Supply Chain

Key References:

- June, 1999 Demonstration Handouts
- GIT EIS Lab Technical Report EL003-1999A (Appendix B)

4.1 Supply Chain Context

This section overviews the usage of ProAM technology within the AMCOM supply chain. While the project has focused on tool usage by SMEs, Figure 9 shows how other levels of the supply chain can benefit as well. A key point is that each supply chain member typically has analyses that are best carried out at their level, as those analyses require information and impact the product in areas primarily within their responsibility. PWB layup exemplifies this point in that the SME fabricator designs layup details (within overall specs provided by the PWA-B designer) and needs tools to help judge design alternatives (Figure 7, Figure 8, Figure 11, and Figure 12). At the Prime level (where most analysis is done today), analysis needs typically focus on performance and reliability at the part (PWA-B) and parent subsystem level. At the end-user level (e.g., AMCOM), analysis needs range from independent checks on Prime designs, to system-level analysis, to maintenance and re-engineering checks. Each of these levels looks at the product in different degrees of fidelity and with different abilities to impact overall cost, performance, and reliability. Thus, we hold that ProAM-like analysis techniques which support these diverse needs are important for this supply chain spectrum.

Other distinctives in Figure 9 are driving analysis directly with product design data and the use of an Internet-based engineering service bureau. Both of these aspects are discussed in the Appendix B technical report.

The remainder of this section highlights specific supply chain applications within the ProAM project.

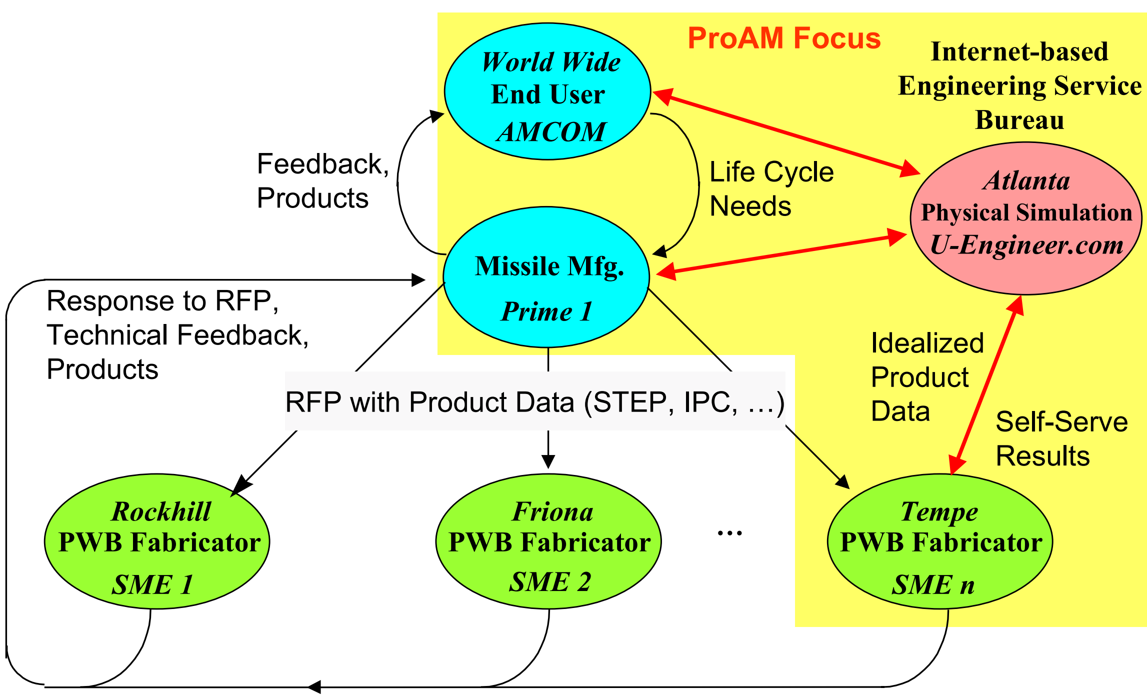


Figure 9 Internet-based product data-driven analysis in the AMCOM supply chain

4.2 Usage by ProAM Team SMEs

4.2.1 SME Selection and Setup

SMEs in the AMCOM supply chain were funded in ProAM to:

- Identify and clarify SME analysis needs
- Provide representative product and process data for test cases
- Utilize ProAM tools during development and provide feedback
- Utilize new ProAM tools on a pilot production basis

Two SMEs were selected after evaluating nine candidates:

- *Circuit Express, Inc.* (Tempe AZ) - a PWB fabricator in the missile supply chain
- *System Studies & Simulations, Inc.* (S^3) (Huntsville AL) - a contractor who provides PWA/B design and fabrication services to AMCOM

After subcontracts were established with these SMEs, they setup to utilize first-generation X-Windows-based analysis capabilities at the ProAM engineering service bureau, U-Engineer.com. This preparation included:

- Acquiring and configuring necessary PC hardware, software, and Internet access
- Attending the ProAM SME Involvement Kick-off and Training in Atlanta
- Completing tutorial exercises from their home sites
- Completing and analysis needs survey and company profile

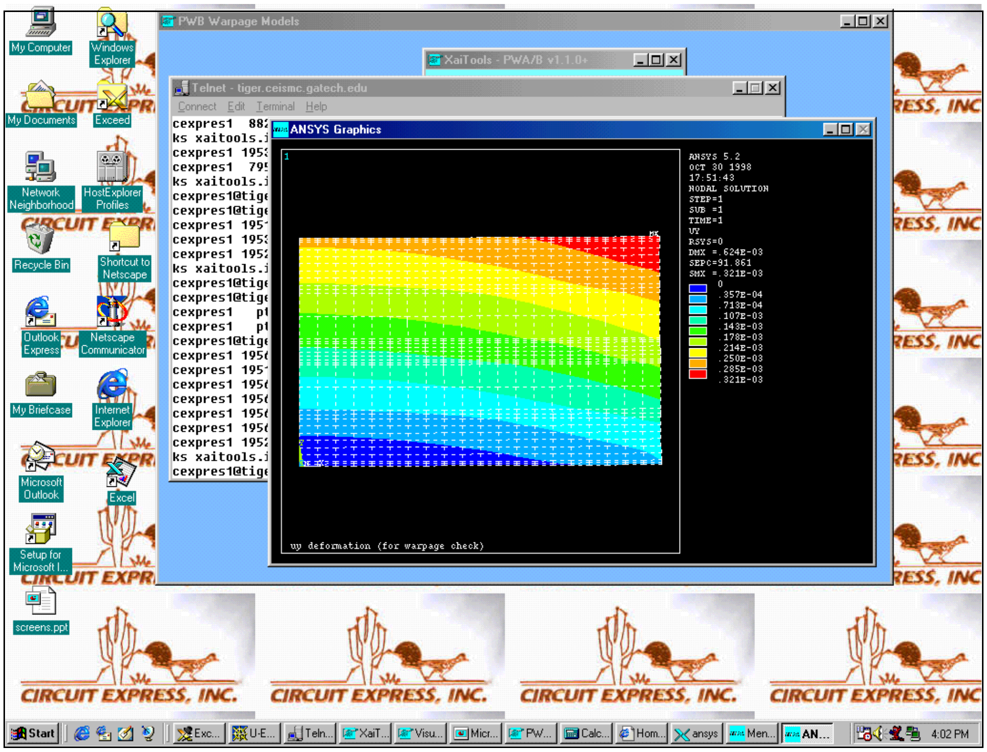
The GIT team delivered the second-generation Java-based tools (*XaiTools PWA-B*) to these SMEs later in the project and made iterative improvements based on their feedback. The U-Engineer.com web site was also updated for their use with improved navigation, additional modules, and clearer usage guidelines. With these improvements, the SMEs were able to take better advantage of U-Engineer.com as described next.

4.2.2 Overview of SME Tool Usage

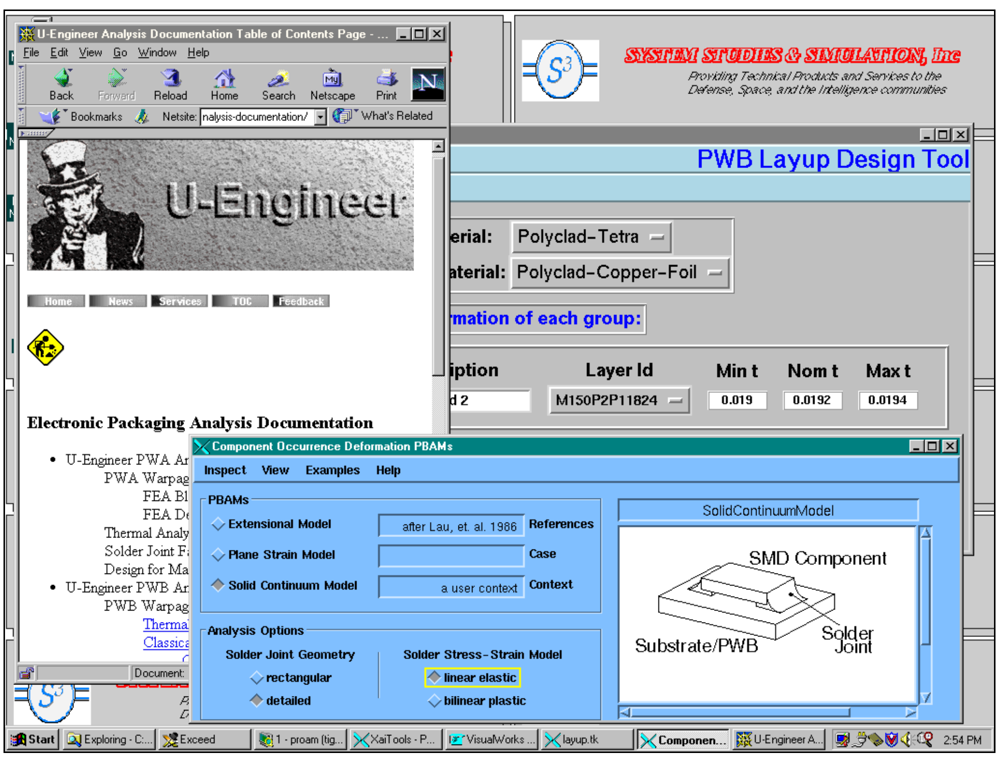
Figure 10 shows SME tool usage from their home sites. SME purposes of analysis tool usage have included:

- *Awareness* - Becoming aware of what analysis models are available for PWA/Bs and what types of physical behavior can potentially cause problems.
- *Trends* - Studying the relative effects of various factors on a behavior of interest (e.g., how board warpage tends to increase with decreasing board thickness).
- *Design Alternative Comparisons* - Comparing design alternatives to see which one will have better behavior (e.g., comparing two layup designs to see which one is likely to produce less warpage).
- *Design Checks* - Checking if a design meets specified criteria (e.g., checking if a plated through hole design will have the required fatigue life).
- *Design Problem Identification & Resolution* - Determining what is causing a problem in an existing design, and what to do to fix it.
- *Marketing* - Making their customers aware that the above capabilities are available if needed.

As the second-generation tools were not available until later in the project, the SMEs had limited experience with them prior to the June, 1999 project demo. Still, Figure 11 and Figure 12 give a flavor of their experiences up until then. See the Demo Handouts for other SME examples. The next sections, reported by the SME team members, describe these and later experiences first-hand.



a) Circuit Express - Tempe, Arizona

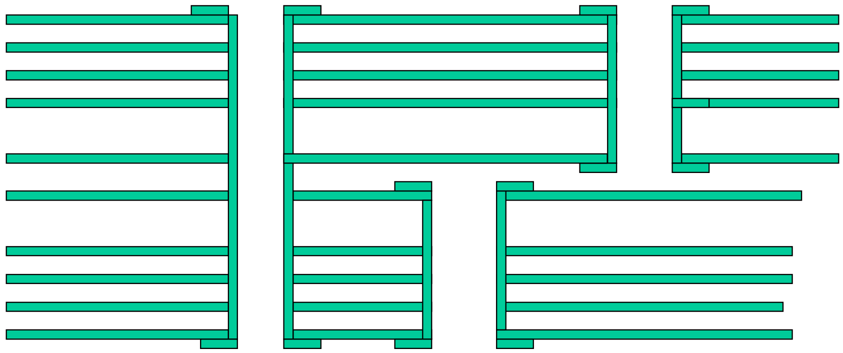


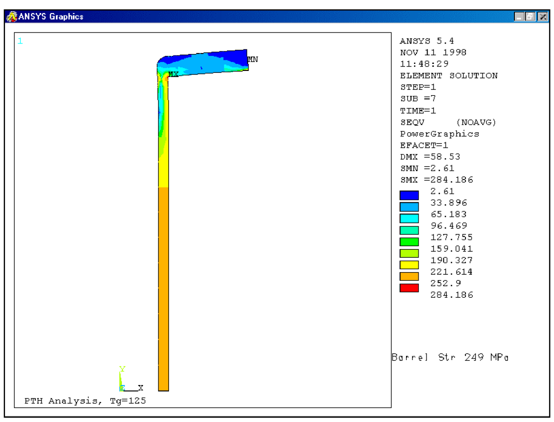
b) S^3 - Huntsville, Alabama

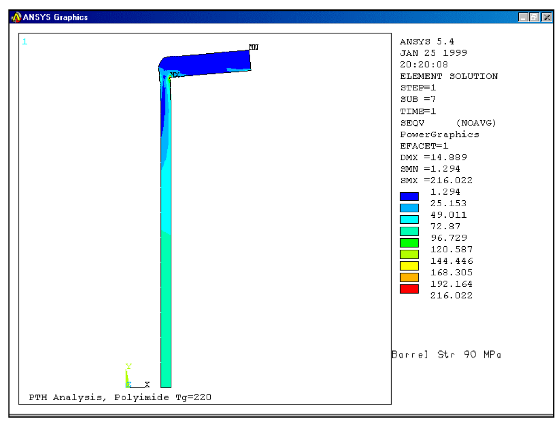
Figure 10 Usage of ProAM Tools from SME Home Sites

CASE 2 LAY- UP

LAYERS 1-5 & 6-10 ARE BLIND







Standard FR4
σ_{barrel} = 249 MPa

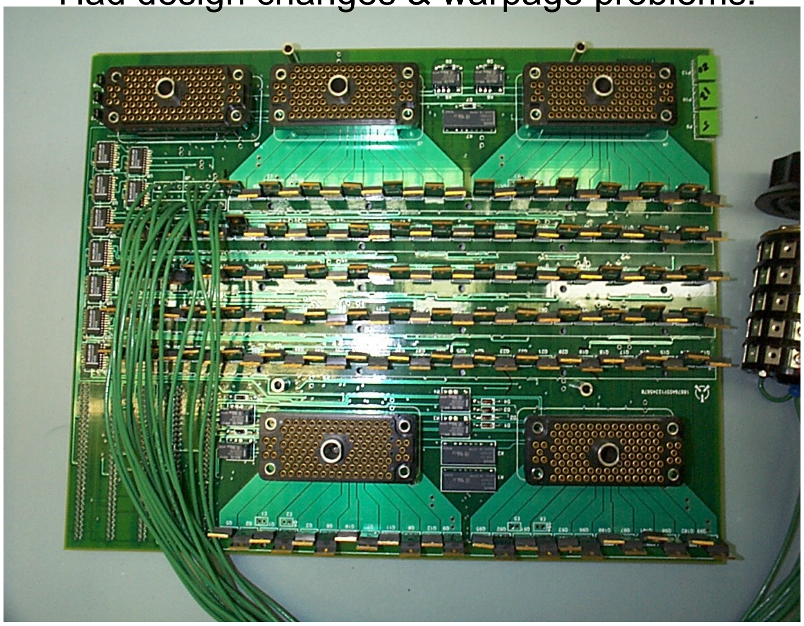
T_g = 220 ºC Polyimide
σ_{barrel} = 90 MPa

Conclusion: Polyimide design needed to reduce stress and increase reliability

Figure 11 CEI experience with ProAM tools (board from DoD prime)

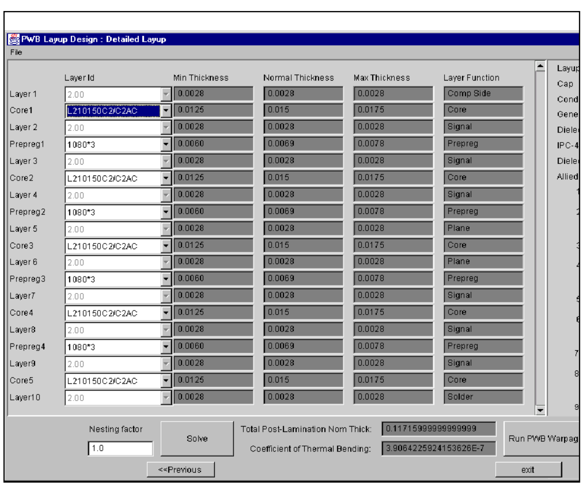
Current Situation **(before analysis tools):**

- Built prototype 3 times.
- Had design changes & warpage problems.

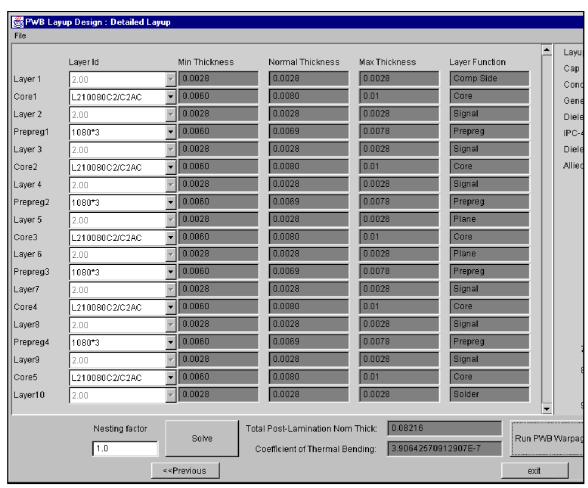


Next time: **Use of engineering analysis tools**

Initial Design



Re-Design (thinner)



Layup Design Alternatives

Figure 12 S3 experience with ProAM tools (missile power board)

4.2.3 ProAM Experiences by Circuit Express Inc. (CEI)

CIRCUIT EXPRESS, INC. (480) 966-5894
229 S. Clark Drive, Tempe, AZ 85281 (480) 966-5896 FAX

June 30, 1999

Mr. Russell S. Peak, Ph.D.
Assistant Director
Engineering Information Systems Lab
Cals Technology Center
Georgia Institute of Technology
813 Ferst Drive, MARC 452
Atlanta, Georgia 30332-0560

Re: Summary Report of ProAM project

OVERVIEW

Circuit Express, Inc. is a small business located in Tempe, Arizona. We are a manufacturer of printed circuit boards and have served the electronics industry since 1987.

As a small manufacturer, we are often challenged with solving manufacturing and design problems without the benefit of sophisticated tools. We have limited engineering resources and must rely upon the expertise of our suppliers and our customers. However, our experience has provided us with the basic understanding that many of the problems that we face are repetitive and their solutions are often not permanent. The problem will sometimes correct itself over time so it will also re appear at random. These issues have resulted in the recognition that our company needs to increase our ability to permanently solve the complex problems or at least understand the causes.

AWARENESS AND PROBLEM RESOLUTION

During a recent growth period for our company, we were manufacturing a complex multi layered circuit board containing state of the art design technology. Our customer was using the parts in a sophisticated communication system.

The manufactured parts were experiencing fatigue failure due to latent undetected defects. After several weeks of experimentation and through trial and error on the process, we had concluded that we did not have the knowledge to solve the problem. Accordingly, we began to search for expertise.

We discovered Georgia Tech's web page dealing with the issues of plated through hole fatigue and warpage in printed circuit boards. Both of these issues were involved in our failures so we contacted Andrew Scholand to enlist his support and assistance in helping to solve these problems.

These failures had the potential to impact our business monetarily in the short term; and could also cause us to lose a good customer, which would hurt our business in the long term. Mr. Scholand guided us through the collection of the facts related to the failures and gathered construction details on the current design.

June 30, 1999
Mr. Russell S. Peak, Ph.D.
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After a great deal of analysis and guidance from the Student Assistants, we were able to draw some conclusions that were governed by manufacturing variables. Andy Scholand recommended a very subtle design change and also specified the sensitivity of the manufacturing parameters on the results. We implemented his suggestions and were able to affect a solution to the problem.

Our interaction with Mr. Scholand and the Georgia Tech Engineering Lab resulted in the solution of an immediate problem but also had a long-term affect of increasing our ability to solve our own problems through the use of computer aided analytical tools.

Based upon the original exposure to the "Web based tools," Circuit Express, Inc. became a participant in the ProAm project, which has provided us with an additional capability that we have never had in the past. These tools have assisted us in the analysis of designs and have permitted us to determine the impact of processes on the manufacturing results.

CASE STUDIES AND USE OF TOOLS

During the past year, Circuit Express, Inc. had the occasion to use the analytical tools with real live cases. There were three separate projects that required the use of analytical tools. Each one was designed with blind via holes and required sequential lamination cycles. The major issues were warped boards due to unbalanced construction and non-uniform lay-up.

We were able to use the lay-up tools and the thermal bending model to suggest design changes to the customer. The changes were implemented resulting in an improvement in the design.

EXPERIENCE WITH THE TOOLS

Circuit Express, Inc. has benefited from our participation in the project.

As a result of the project participation, we have been able to enhance our own capability. This enhancement has permitted us to offer design assistance to our customers and has allowed us to analyze our own process.

The lay-up tools were developed near the end of the project cycle and accordingly need to have a few enhancements to permit them to be fully effective. We have found them to be somewhat time consuming to run and still limited in the amount of material choices. We are aware that work is continuing and will result in an improvement in the capability. Accordingly, we will continue to evaluate the effectiveness and will feedback information as they are used.

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In connection with the Plated through hole model, we have found that to be very helpful in the situations where the design is very unusual. In addition, the sensitivity evaluation has been helpful to determine the effect of low or poor plating.

We just used the thermal bending model to help a customer decide on a particular lay-up of a ten-layer board. They were thinking of using very thin core construction and we showed them the relative effect on warp by simply increasing the core thickness slightly.

SUMMARY

Circuit Express, Inc. has gained a great deal from the participation in the ProAm project. Besides the obvious benefit of learning about the use of analytical tools on the internet, we have gained new friends and contacts at Georgia Tech. Our company has benefited from their academic expertise and we believe that we have contributed to their overall knowledge by providing a practical real life application of the analytical tools. We at Circuit Express, Inc. appreciate being part of the ProAm project and intend to continue our participation with the Georgia Institute of Technology in other projects of a similar nature.

Respectfully submitted:

Jackson H. Roberts
President

4.2.4 ProAM Experiences by System Studies & Simulations Inc. (S3)

System Studies and Simulation, Inc.
Involvement in the PROAM project
June 28, 1999

System Studies and Simulation (S3) is a small business with 75+ employees that provide technical and program management services to DoD, NASA, and the intelligence community. As part of the technical service side of S3, we support the US Army Aviation and Missile Command (AMCOM) at Redstone Arsenal near Huntsville, AL with electronic design and verification. We design, re-design, and reverse engineer electronic assemblies and sub-assemblies which require high reliability and ease of production.
Through these requirements, we have been pleased to be a part of the PROAM team. We believe the services and tools developed and used in the PROAM project will be of value to S3.

The Electronic Manufacturing Lab of AMCOM, which S3 supports, has a PC board manufacturing and assembly service. Many of our prototype circuit boards are manufactured at this facility. The S3 design engineers, circuit and mechanical layout personnel work together to develop concepts for multiple circuit board systems. At times we are faced with the challenges of high current and extreme temperature requirements for our designs. Circuit board layout and manufacture plays a critical role in meeting these requirements. We have routinely used the IPC-279 plated-thru. hole fatigue and impedance calculators located on the Proam's U-engineer internet web site. The PCB Layup tool has become one of the most valuable web based tools for the AMCOM lab.

The Layup tool helps S3's engineering team to select materials to properly build the bare circuit board with minimal warpage and cost by allowing us to try out different laminates and prepregs on a software simulation program instead of building the actual board. This program lets the user select from a variety of commonly used circuit board materials and specify the lay up for a particular design. Data that can be input includes material selection using manufacturers part numbers and/or the new IPC4101 designations, the location or layer in the stackup, and the percentage of etched copper on a layer. With a click of a tab the Layup tool calculates the pre and post lamination thickness. The user can then click another tab and run a warpage analysis on his lay up by defining a set of temperatures. This helps our team get better results on the first prototype circuit board saving both time and money.

During the Proam project S3 was in the process of laying out a missile power board which had a current requirement of 25 amps. This kind of layout required very large circuit board traces which populated almost half of the power board on 5 of its 10 layers. The nature of the layout caused the board not to be balanced in construction, which caused a concern for post lamination warpage. By using the U-engineer Layup tool, we were able to shift around layers and alternate prepreg to achieve the most warpage resistant construction.

S3's participation has made our company aware of the benefit of internet based services, such as the U-engineer web site. These tools and services are now available to small and medium sized businesses without having to hire expert personnel or purchase expensive software tools. This helps us to compete with the larger companies that may have these capabilities in house. We are looking forward to new ideas along the same lines as the Proam project provides.

Phillip J. Spann
CAD/CAM Dept.
System Studies and Simulation
3315 Bob Wallace Ave., Ste. 207
Huntsville, AL 35805

4.3 Other DoD Supply Chain Usage

Since the June, 1999 project demo, numerous DoD supply chain organizations have continued to contact us for support in applying ProAM technology to their needs (Table 2).

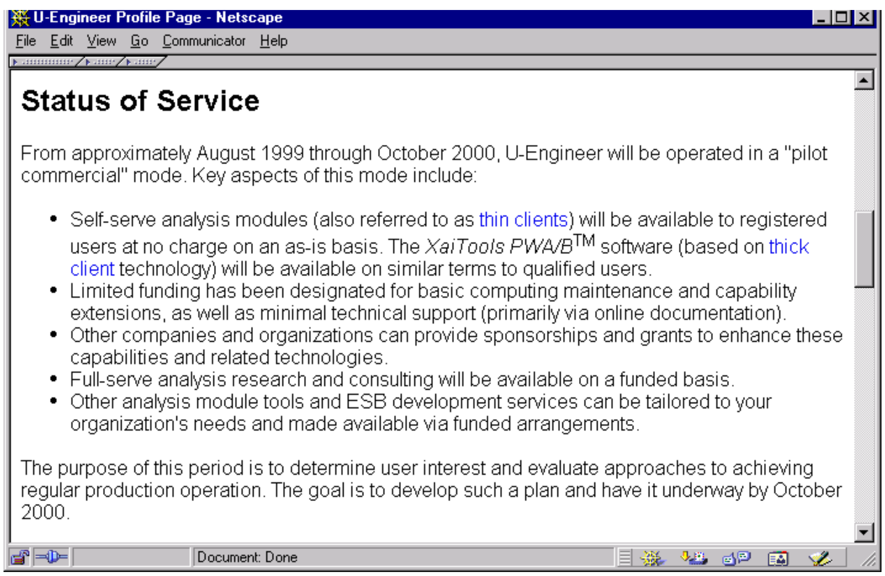
Table 2 Technical support to DoD supply chain - June 21-August 6, 1999

Organization Type	Basic Technical Support	Extensive Technical Support
DoD Facility	4	1
DoD Prime	5	3
DoD SME	26	3
Other ECRC	2	1
Other US Govt.	1	-
Totals	38	8

Extensive technical support has ranged from 8 to 40 hrs of work per item and has included manufacturing improvements, onsite visits, and demonstrations. As the above response has been from the limited June demo audience and direct inquiries, it appears project results are addressing an important need in the DoD supply chain.

5 Post-Project Plans and Technology Transfer

The following summarizes post-project plans for U-Engineer.com and a tentative schedule. As evidenced by the need per Table 2, the Atlanta ECRC will support U-Engineer.com at a basic level as a service to its DoD and SME clientele.



Through 8/99: Limited audience alpha pilot usage
Through 10/99: Broader audience beta pilot usage
Through 10/00: General audience pilot usage

The following summarizes a key achievement of ProAM: commitment by Electronic Packaging Services, Ltd. Co., http://www.warpfinder.com/, to sponsor research in web-based warpage analysis as a prelude to potential commercialization of a full-scale ESB.

ELECTRONIC PACKAGING SERVICES, LTD. CO.

EPS ESB Objectives

- Predictive Warpage Models Deliver Experimental Results in the Most Useful Form
- ***First Step -*** EPS Sponsors Engineering Service Bureau (ESB) Web Page on Georgia Tech EIS Lab Server
- ***Further Steps -*** EPS works with EIS Lab and Others to Validate Models and Create Materials Properties Databases
- ***Future -*** EPS becomes an ESB for Mechanical Performance and Reliability of Electronic Packages

Other technology transfer activities and proposals are highlighted in the June Demo handouts, including collaborative opportunities like the following:

- Company-tailored supply chain pilots
- Other applications:
  - Company-specific analysis modules
  - Intranet/Extranet-based engineering service bureaus
- Further extensions:
  - Catalogs with multi-fidelity “drive-before-buy” simulations
  - Other domains: control systems, propulsion, etc.
- U-Engineer sponsorship
- Commercialization of U-Engineer-like ESBs

6 Summary

6.1 ProAM Accomplishments

Mature Prototype State

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

Early Pilot State

- **Applications in specific AMCOM context:**
  - U-Engineer.com pilot commercial ESB with Internet-based PWA/B-specific analysis modules & toolkit
  - Usage by SMEs in AMCOM supply chain:
    - Full-serve and self-serve missile examples

6.2 ProAM Benefits

- Internet-based engineering service bureaus (ESBs)
  - ➡ *A key step towards affordable SME analysis*
- Product data-driven analysis technology
- Analysis integration toolkit
- AMCOM missile supply chain application
  - ➡ *U-Engineer & 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*

Appendix A - Analysis Integration Research and Applications

The following papers overview Georgia Tech EIS Lab X-analysis integration (XAI) research, with applications including electronic packaging thermomechanical analysis and aerospace structural analysis. Most publications are accessible on the web at http://eislab.gatech.edu/ along with project information.

Other publications are planned describing newer developments (e.g., CBAMs) and applications (e.g., thermal resistance analysis for chip packages). Advances beyond the main MRA paper [Peak *et al.* 1998] and TIGER-era capabilities [Peak *et al.* 1997, 1999] include:

- *APMs* – Combine & filter design information from multiple sources and add idealizations that are reusable in potentially many analyses (typically in CBAMs). Recognizes that the full design-oriented PM is not typically required for analysis, thus simplifying APM management.
- *CBAMs (context-based analysis models)* – Generalizes PBAMs by adding associativity with the context of why an analysis is being done, including objectives (e.g., determining margin of safety). PBAMs focused on associativity between design objects (APM entities) and product-independent analysis objects (ABBs). Other context elements under development include the behavior modes being analyzed and boundary condition objects (loads, conditions, and links to next-higher analyses).
- *Lexical COBs* – Generalizes the 'ABB structure' as the primary computable lexical representation for constraint graphs underlying APMs, ABBs, and CBAMs.
- *Mechanical/aerospace part applications* – Demonstrates MRA product domain independence through examples beyond earlier electronic packaging applications. Utilizes techniques for integrating APMs with general geometric CAD models such as CATIA models [Chandrasekhar, 1999].
- *XaiTools* – next-generation Java-based MRA toolkit (beyond Smalltalk-based *DaiTools*). Includes:
  - *Mathematica-based constraint solver* – Manages basic associativity relations (typically equalities) as well as complex idealization and analysis relations. Viewed as a key step towards a subsolver architecture in which solution tools like *Mathematica* would be SMM-based subsolvers.
  - *CORBA-based wrappers* - Next-generation means for multi-platform distributed computing (e.g., it is now used to wrap *Mathematica* as the main shared constraint solver; other anticipated applications include SMMs, design tools, and persistent data storage).

The Multi-Representation Architecture (MRA) Technique

Peak, R. S.; Scholand, A. J.; Tamburini D. R.; Fulton, R. E. (1999) Towards the Routinization of Engineering Analysis to Support Product Design. Invited Paper for Special Issue: Advanced Product Data Management Supporting Product Life-Cycle Activities, *Intl. J. Computer Applications in Technology*, Vol. 12, No. 1, 1-15.

> Overviews the routinization methodology for creating highly automated product data-driven analysis modules that can be implemented in the MRA (c. 1997).

Peak, R. S.; Fulton, R. E.; Nishigaki, I.; Okamoto, N. (1998) Integrating Engineering Design and Analysis Using a Multi- Representation Approach. *Engineering with Computers*, Vol. 14 No. 2, 93-114.

> Introduces the multi-representation architecture (MRA) which places product models (PMs), PBAMs, ABBs, and solution method models (SMMs) in a broader, interdependent context. Presents the explicit representation of design-analysis associativity, and proposes a routine analysis automation methodology (c. 1995). APMs, CBAMs, and lexical COBs are newer MRA concepts described elsewhere.

Peak, R. S. (1993) Product Model-Based Analytical Models (PBAMs): A New Representation of Engineering Analysis Models. Doctoral Thesis, Georgia Institute of Technology, Atlanta.

> Focuses on the PBAM representation (including the ABB representation and constraint schematics) and automation of routine analysis. Includes example applications to solder joint analysis, and defines objectives for analysis model representations. Contains a starter set of ABBs. Discusses PMs and a precursor to SMMs, but does not explicitly define the MRA itself.

Constrained Objects (COBs)

Wilson, M. W. (expected 1999), The Constrained Object (COB) Representation for Engineering Analysis Integration , Masters Thesis, Georgia Institute of Technology, Atlanta.

Defines the primary computable lexical representation for the constraint graph-based objects underlying APMs, ABBs, and CBAMs.

Analyzable Product Models (APMs)

Tamburini, D. R (1999), The Analyzable Product Model Representation to Support Design-Analysis Integration, Doctoral Thesis, Georgia Institute of Technology, Atlanta.

Introduces the analyzable product model (APM) as a product model representation specifically for engineering analysis. APMs coordinate design data from multiple sources (including STEP models) and add multi-fidelity idealizations to support diverse analysis models.

Tamburini, D. R., Peak, R. S., Fulton R. E. (1997) Driving PWA Thermomechanical Analysis from STEP AP210 Product Models, *CAE/CAD and Thermal Management Issues in Electronic Systems*, EEP-Vol. 23/HTD-Vol. 356, Agonafer, D., et al., eds., ASME Intl. Mech. Engr. Congress & Expo., Dallas, 33-45.

Includes slides overviewing how APM technique was used with STEP AP210 in TIGER.

Tamburini, D. R.; Peak, R. S.; Fulton, R. E. (1996) Populating Product Data for Engineering Analysis with Applications to Printed Wiring Assemblies. Application of CAE/CAD to Electronic Systems, EEP-Vol.18, Agonafer, D., et al., eds., 1996 ASME Intl. Mech. Engr. Congress & Expo., Atlanta, 33-46.

Describes how to populate APMs from design tool data via STEP. This technique was later used in TIGER [Peak et al. 1997] to drive analyses from STEP AP210 PWA product models.

Chandrasekhar, A. (expected 1999), Interfacing Geometric Design Models to Analyzable Product Models with Multifidelity Mismatched Analysis Geometry, Masters Thesis, Georgia Institute of Technology, Atlanta.

Solution Method Models (SMMs)

Koo, D.; Peak, R. S.; Fulton, R. E. (1999) An Object-Oriented Parser-based Finite Element Analysis Tool Interface, SPIE Intl. Symposium on Intelligent Systems and Advanced Mfg., Photonics East '99, Boston.

Parametric Modular Finite Element Modeling

Zhou, W. X. (1997), Modularized & Parametric Modeling Methodology for Concurrent Mechanical Design of Electronic Packaging, Doctoral Thesis, Georgia Institute of Technology, Atlanta.

Defines technique for taking advantage of product-specific knowledge to create complex finite element models that are not practical with typical automeshing methods.

Zhou, W. X.; Hsiung, C. H.; Fulton, R. E.; Yin, X. F.; Yeh, C. P.; Wyatt, K. (1997) CAD-Based Analysis Tools for Electronic Packaging Design (A New Modeling Methodology for a Virtual Development Environment). InterPACK'97, Kohala Coast, Hawaii.

Overview of [Zhou, 1997] as well as interactive finite element models.

Internet-based Engineering Service Bureau Concepts

A. J. Scholand and R. S. Peak (Aug 20, 1999) Internet-based Engineering Service Bureau (ESB) Technology, Georgia Tech Engineering Information Systems Lab Technical Report EL003-1999A.

Overviews the extended Internet-based engineering service bureau (ESB) concepts based on DoD supply chain experiences in ProAM

Scholand, A.J.; Peak, R. S.; Fulton, R. E. (1999) Enabling Distributed Data Processing for Internet Analysis with GenX, ASME Design Engineering Technical Conference (DETC99), Las Vegas.

Scholand, A. J.; Peak, R. S.; Fulton, R. E. (1997) The Engineering Service Bureau - Empowering SMEs to Improve Collaboratively Developed Products. CALS Expo USA, Orlando, Track 2, Session 4.

Overviews the Internet-based engineering service bureau (ESB) paradigm initiated in the DARPA-sponsored TIGER Program. Describes services ranging from self-serve to full-serve, with a focus on highly automated product data driven analysis. Includes ESB setup and user guidelines.

Applications

R. S. Peak, R. E. Fulton, A. Chandrasekhar, S. Cimtalay, M. A. Hale, D. Koo, L. Ma, A. J. Scholand, D. R. Tamburini, M. W. Wilson (Feb. 2, 1999) Design-Analysis Associativity Technology for PSI, Phase I Report: Pilot Demonstration of STEP-based Stress Templates Georgia Tech Project E15-647, The Boeing Company Contract W309702.

Overviews MRA applications relevant to integration of aerospace structural analysis. Includes CBAM concepts, APM links to CATIA CAD models, and *XaiTools* usage of Mathematica as a COB-based constraint solver.

Peak, R. S.; Fulton, R. E.; Sitaraman, S. K. (1997) Thermomechanical CAD/CAE Integration in the TIGER PWA Toolset. InterPACK'97, Kohala Coast, Hawaii.

Shows how MRA techniques were applied in the DARPA-sponsored TIGER Program. Includes PWA and PWB thermomechanical analyses driven by STEP AP210 product models that originated in the Mentor Graphics BoardStation layout tool.

Peak, R. S.; Fulton, R. E. (1993b) Automating Routine Analysis in Electronic Packaging Using Product Model-Based Analytical Models (PBAMs), Part II: Solder Joint Fatigue Case Studies. Paper 93-WA/EEP-24, ASME Winter Annual Meeting, New Orleans.

Condensed version of solder joint analysis case studies in [Peak, 1993]. Illustrates automated routine analysis, mixed formula-based and FEA-based analysis models, multidirectional analysis, and capabilities of constraint schematic notation.

Tools

XaiTools Users Guide

XaiTools Installation and Configuration Guide

XaiTools™ is Java-based toolkit for X-analysis integration based on the MRA. This document gives basic usage instructions. Other documents describing the general architecture, examples, tutorials, COB creation guidelines, and developer guidelines are planned. See the *XaiTools* home page at *http://eislab.gatech.edu/tools/xaitools/*

XaiTools PWA-B Users Guide

This application provides a PWB layup design tool and PWB warpage analysis modules to help designers and fabricators automate tedious tasks and compare design alternatives. Built upon the general-purpose *XaiTools* foundation, it can be configured as a thick client to take advantage of Internet-based analysis solvers.

U-Engineer.com

An exemplar Internet-based engineering service bureau with self-serve analysis modules for PWA designers and PWB fabricators.

Appendix B - Technical Report: Internet-based Engineering Service Bureau Technology

GIT EIS Lab Technical Report EL003-1999A
http://eislab.gatech.edu/pubs/reports/EL003/

If you are accessing this document via CD-ROM, the above document is available from the main index.

Appendix C - XaiTools Documentation

- Product-specific Applications:
    - *XaiTools PWA-B Users Guide*
- General-Purpose Toolkit
    - *XaiTools Users Guide*
    - *XaiTools Installation and Configuration Guide*

http://eislab.gatech.edu/tools/xaitools/

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