Improved CAD-CAE Integration with ISO STEP and XML Standards at Electric Boat

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Principal Engineers
General Dynamics / Electric Boat Corporation
Outline

EB’s VPD Climate and Characteristics
- **From**: CAD-Centric Process, PDM for CAD only
- **To**: Balanced VPD Environment, Enterprise-Level PLM
- Hurdles Encountered: Historical, Cultural, Organizational, Technical
- Some Approaches to Improve Electronic Access and Utilization

ISO STEP Standards
- Why AP209?
- Examples and Uses

Web and XML Implementation
- XML Interfaces to Enterprise PLM
- XSLT Mediation for Flexibility and Agility
- ISO STEP Application Protocols for Information Model Content
Electric Boat’s Climate and Characteristics

• We are currently at low ship production levels (1 sub/year).
• There are few new ship designs on the horizon.
• There is much more collaboration in both construction and design.
• We need to become more nimble, agile in all facets of VPD.
Electric Boat’s Climate and Characteristics (cont’d.)

• Unlike other industries, shipbuilding does not generally involve construction and testing of full-scale prototypes or models.
• The first hull in a class is delivered to the customer!
• Lean and six-sigma methods are being used across many current process improvement activities.
• STEP and XML enabling technologies are being employed to move VPD from a “Design Checking” status to a “Design-Driven” paradigm. (Less CAD-Centric and more CAE-Centric.)
Virtual Product Development (VPD)

CAD-CAE Integration includes **both** CAD-Centric and CAE-Centric Processes.

- EB has historically been a CAD-Centric organization.
- New sub designs are often controlled by space utilization, ship arrangements, and prior class designs.

- Current process improvement efforts focus on balancing CAD and CAE.
- The earlier the employment of simulation in VPD, the more CAE-Centric the process will become.
- STEP and XML are “enabling” technologies.
VPD Process Balance at EB

Utilize Just the Right Amount of Engineering

Integration Requires Process Balance

Simple

Complex

Spectrum of Analysis Options

Mid-Range

Enablers:
- Rules-Based Methods
- Electronic Data Exchange
- Automated Model Building
- Enterprise-Wide PDM
Full Ship Simulation

The Design of Naval Vessels Involves Both High-End Computational Mechanics Simulation and Testing

Simulation models at this scale are not automatically created or readily meshed from CAD geometry.

Nonlinear transient analysis with fluid-structure interaction.
ISO STEP AP209
File Exchanges

PLM
- BOD / BOA
- Nominal CAD Geometry
- FE Models
- FE Analysis Results

STEP File (AP209)

CATIA V4
Theorem CADverter

MSC.Patran

EB / ADAPT

GPD

FEA + Geom.

FEA + Geom.

Geom.

FEA

AP209

EB / COMMANDS

SFG - 8
A Rules-Based System Developed for Weld Stud Foundations (Pre-Engineered Design)
EB Process Improvement

Current VPD CAD-CAE Integration Objectives:

• Extend and increase the direct electronic use of product models by engineering personnel.

• Exploit earlier use of engineering analysis and optimization in the design of ship structural and mechanical concepts, concurrent with formal enterprise CAD capture.

• Implement enabling tools and technologies to make Concurrent Engineering Analysis a reality!

• Move engineering into our emerging Enterprise-Level PLM system
The Vision

Enable Improved CAD-CAE Integration & Electronic Utilization of Product Model

Yesterday

Today

Tomorrow
Roadblocks to Total Enterprise Integration

- CSC/IT
- CAD Organization / Culture
- CSC Open Shop Environment
- Process, Standards, Work Methods
- People
- Software
- Hardware
- CAE Organization / Culture

Differences

Barriers

CSC Open Shop Environment

Process, Standards, Work Methods
Hardware
Software
People
CAE Organization / Culture
Removing Former Constraints

Hindrances to VPD and Concurrent Engineering:

- **Culture Based on Drawing Exchange** - Internal data exchange for CAD to CAE still largely based on drawings and sketches
- **Limited Electronic Accessibility to Product Models** - CAD-Side Closed-Shop Environment (vs. Open-Shop CAEN)
- **Light-Weight 3D Product Model** - S&P rules result in less-usable and non-portable 3D product models, which employ light-weight and application-specific CATIA entities

Our Approach:

- **Implement New Enabling Tools** - Several new CAD and CAE tools are now in place for electronic CAD-CAE exchange
- **Require Little or No Change in Designer Process** - Adopt concurrent engineering analysis approach from the CAE Network (CAEN) side
Enterprise-Wide, Life-Cycle PLM

Phase II

Need Pilots, Metrics

Phase I

Improved CAD-CAE Process 1

Improved CAD-CAE Process 2

Improved CAD-Side Access, DE Browser, Common File System

CAT2SOL  CADverter

GPS/GPD

CATSTP  STPCAT

CATIA MEC  CATIA AEC

Infraestructure

CAD "Side"  CAEN "Side"

New Processes

Enabling Tools

Existing Capabilities

CATIA AEC

COMMANDS  PATRAN

FESOL  FEMAP

VIBES  ABAQUS  CAE

Infraestructure

Need Pilots, Metrics

Improved CAD-CAE Process 2

Improved CAD-CAE Process 1

Phase I

CAD "Side"  CAEN "Side"
CAD-CAE Integration - Observations

• CAD-CAD Exchange Implies Replicating the Exact Same Item
• Whereas, CAD to CAE Integration:
  • Can Involve Different Types (Genders) of Geometry
  • Will Usually Employ Differing Amounts of Detail
  • Is Not Dependent Only Upon the Existence of Electronic CAD Geometry, but ...
  • Will be a Function of the Scale, Scope, and Purpose of the CAE Analysis
  • Most Often Requires an Engineer’s Judgement and Idealization
CAD-CAE Integration

Whether CAD-CAE applications can be closely-integrated and automated depends upon:

- The scale, scope, and purpose of the CAE analysis.
- The nature and type (order, or “gender”) of the captured CAD geometry.
- The amount of detail required for the CAE application.

We find that today’s bottleneck in CAD-CAE integration is not automated mesh (grid) generation, it lies with efficient creation of appropriate “simulation-specific” geometry.
Branch Point

More Detailed Background Slides

Additional CAD-CAE Integration Topics:

• CAE-Centric vs. CAD-Centric Integration
• Need for Geometry “Gender Changing”
• Mid-Surfacing Solids for Thin-Walled Structure
• De-Featuring Geometry (or the Reverse)
• Process Needs - Electronic Feed-Back to CAD

Overview Continuation
Status of Process Improvement

• Provided Electronic Access to Separate CAD System
  • NT CAES to AIX RS6000 CAD
  • Design-Engineer (DE) Browser
  • CATIA Portal Implementation
• Automated Updating of Lightweight CAD Entities
  • Background CATIA Process
• Created Engineer’s Interface for CAD-CAE
  • ADAPT Code
  • Various Selection and De-Featuring Capabilities
  • Implemented Automated and Interactive Multi-Part Mid-Surfacing
• Implemented ISO STEP AP203 and AP209 Interfaces
  • Employing AP209 with MSC.Patran, CATIA, COMMANDS
  • Employing AP203 with Nearly All CAD & CAE Tools
• Initiated a Pilot Project Integration of Engineering (FEA) with PLM
  • Open, Published PLM XML Schema
  • Employing AP209 Information Model
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Why ISO STEP AP209?

The ISO STEP 10303-209 (AP209) standard reached International Standard (IS) status in 2001. It is more than a simple exchange mechanism for CAD or CAE digital data.

The AP209 Application Protocol contains a complete and extensive information model for the representation of related, yet separately versioned, design and engineering analysis information in a PDM/PLM framework.

- We use AP209 today for simple file-based transfers.
- We plan to exploit the AP209 information model further as we move toward enterprise level PLM.
AP209 is not just about simple data exchange!

AP209 captures and integrates design, analysis, and PLM information.

Growing Repository File “Built” by Multiple Codes
What is the Content of ISO STEP 10303 AP209?

AP209 is an ISO 10303 STEP International Standard which includes FEA (and Much More!)
One can use AP209 with any one or more of these pieces, but the real power lies with the assemblage of all these parts.

AP209 = CAD + CCS + CAE + FEM + FEA + PDM
ISO STEP AP203 & AP209 Standards
Support Multiple Geometry Types

Nearly all vendors support CC’s 2, 4, & 6

**AP203/AP209 Conformance Classes (CC)**

1. Configuration Management
2. Surface and Wireframe (Non-Topological Surface and Wireframe)
3. Wireframe with Topology
4. Manifold Surfaces with Topology
5. Facetted Boundary Representation
6. Advanced Boundary Representation

Solids, Lines, Curves, Surfaces
Recent AP209 Demos at Several PDES and ISO STEP Venues

Demo Scenario

Company A
- GPS/GPD
- DS / CATIA V4
- Theorem CADverter
- IBM AIX
- RS6000

Company B
- EB / COMMANDS
- NT PC
- FESOL

Company C
- MSC.Nastran
- SGI UNIX
- MSC.Patran
- 3 Different Software Codes, Computer Hardware, and Companies

STEP Files (AP209)
Crankshaft Demo with ISO STEP AP209 File Exchanges

- CATIA V4
- Theorem CADverter
- STEP File (AP209)
- MSC.Patran
- FEA + Geom.
- EB / COMMANDS
- AP209
- FEA
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Next-Generation IPDE Environment using Open PLM Systems

Pilot Implementation of CAE in PLM
FEA & Next Generation PLM

Native File Interfaces
- CATIA V4
- CATSOL
- AutoCAD

Native File Interfaces
- ADAPT
- FEMAP
- PATRAN
- COMMANDS
- ABAQUS

Architecture includes both Native and Standards-Based Interfaces Across Hardware Platforms

Next Generation PLM Services

PLM DB
- BOD / BOA
- Nominal CAD Geometry
- Idealized CAE Geometry
- FE Models
- FE Analysis Results

Archive Vault

All Queries and Status via PLM

FEA Analysis is 3D CAD Geometry Based

FEA
We are assessing the viability of integrating FEA with PLM using both XML and ISO STEP AP209.

3D CAD Geometry Based FE Analysis
CAD Codes

Shipbuilders and their suppliers not only use general-purpose CAD tools:
- CATIA
- AutoCAD
- Pro/Engineer
- ComputerVision

But also use shipbuilding-specific CAD tools:
- AVEVA / TRIBON
- Sener / FORAN
- Intergraph / ISDP
- Intergraph / GSCAD

In this arena, one current approach for data exchange involves ISO STEP Shipbuilding Application Protocols: AP215 - Ship Arrangements, AP216 - Moulded Forms, AP218 - Ship Structure, AP227 - Piping & HVAC.
NSRP Model for Information Interoperability

Transactions of Data Packaged in Standards

XML = Industry Standard Container for Data
STEP = ISO Standard Language for Data
Data

Company or Dept. A → Standards → Company or Dept. B
Web Services: Request + Data In SOAP
XML Mediation Addresses CAD-CAE Interoperability with Ship APs

A Mediation Example from 2003 NSRP Demos

STP (Express) Files

Ship CAD Tools

CAE Analysis Tools

XML Files

Interoperability
Summary

Electric Boat is:

• Extending our VPD Environment
• Removing Former Hindrances to Interoperability
• Implementing Electronic CAD-CAE Integration Tools
• Employing Open, Standards-Based Methods
• Using ISO STEP and XML as Enabling Technologies
• Piloting Next-Generation PLM Strategies
• Making ‘Concurrent Engineering’ a Reality
First Generation Integrated Product Development Environment (IPDE)

Electronic DRAWING
- Computer-Aided Drafting

3D Design
- 3D Wireframe/Solids
- Rudimentary Data Mgmt

Digital MOCKUP
- Data Config. Mgmt.
- 3D Visualization (Polygonal)
- Interactive Walkthrough
- Anthropomorphic Modeling

Virtual Product & Process
- Desktop Visualization
- Business Process Modeling
- Integrated Design/Build Process
- Sophisticated Engineering Analysis
- Simulation Based Design

Digital Ship Design Process Evolution

ELECTRIC BOAT is here!

Next Generation IPDE

Collaborative Design-Build
- Enhanced Product Model
- Lean Design
- Rules Based Design
- Internet Technologies
- Remote Collaboration
- Intensive Simulations
- High-end Integrated Analysis
Questions?
More Detailed Background Slides

Additional CAD-CAE Integration Topics:

• CAE-Centric vs. CAD-Centric Integration
• Need for Geometry “Gender Changing”
• Mid-Surfacing Solids for Thin-Walled Structure
• De-Featuring Geometry (or the Reverse)
• Process Needs - Electronic Feed-Back to CAD
CAD and CAE Integration

When the scale, scope and purpose of an engineering analysis are not consistent with the type and detail of the existing CAD product model geometry, a computer-assisted “man-in-the-loop” or semi-automated process may be more feasible and appropriate than a fully-automated process. (Still a place for engineering judgement!)

Like many of you, we have found that the time and cost to change, re-work, and de-feature CAD geometry can sometimes be greater than that for creating analysis models from readily-generated “idealized” geometry. (Not a popular view in today’s world!)

The more abstract, idealized (or de-featured) geometry used for analysis is also referred to as “Simulation-Specific” or “FEA-Specific Geometry”.
Integrating CAD-CAE Processes

The value of engineering analysis and optimization early (‘up front’) in the design process is readily accepted and is generally unassailable.

Unfortunately, there is often the perception (sometimes from MCAD vendor hype) that engineering analysis is a totally seamless process within CAD.

This view can be a disservice to many sectors of business (including shipbuilding), where solid product models have become the CAD approach of choice, but the wrong geometry for much of our analysis.

Articles in the literature have recently begun to reflect some of these different views on delivering analysis in VPD.
Articles Show Some Differing VPD Views

“Three-Dimensional CAD Design and Analyzing with Shell Elements - A Soluble Contradiction?”, by M. W. Zehn, H. M. Baumgarten, & P. Wehner, NAFEMS 7th Int’l. Conf., Newport, RI, April 1999

“Don’t Change the Model Till the Simulation Finishes”, by Paul Kurowski, Machine Design, August 19, 1999

“Rookie Mistakes - Over Reliance on CAD Geometry”, by Vince Adams, NAFEMS Benchmark, October 1999

“Common Misconceptions About FEA”, by Vince Adams, ANSYS Solutions, Fall 2000

“Eight Tips for Improving Integration Between CAD and CFD”, by Scott Gilmore, Desktop Engineering, May 2000
"Don’t Change the Model Till the Simulation Finishes"
by Paul Kurowski
Machine Design
August 19, 1999

When analysis geometry is not the same as design geometry!

“Simulation-specific geometry” or “FEA-specific geometry”

(A twist on the SDM inner and outer loop approach.)
Other Industries with Similar Experience

“Harmonization at Bombardier Transportation Brings Design and Analysis Together”
by Charles Clarke, alpha.mscsoftware.com, Volume 1, Winter 2003

“Solid geometry is fairly straightforward - the CATIA model can be imported directly and meshed with standard meshing tools.”

“When a mid-surface model is required, then either the analyst produces it or Bombardier has another process at some sites where the designer makes a copy of the CAD model and transforms it into a mid-surface model for the analyst. This ensures congruent surfaces for the analysis. It also allows small details that would upset the meshing algorithms, such as holes and small radii, to be removed without compromising the master CAD model.”
The First “Problem” - Geometry Type

In general, the most automated CAD-to-CAE processes are for MCAE “same gender” geometry classes, eg. widgets and gadgets, or 3D volumes filled with 3D elasticity tet or hex solid elements; or piping analysis employing 1D geometry.

In the structures discipline, our ship product lines most often involve very large scale, simplified geometry and analysis models, e.g. large assemblages of stiffened 2D plate/shell surfaces and framework structures.

However, our current enterprise CAD product model geometry capture is fundamentally light-weight (“Mock-Up”) 3D solid models supplemented with “application-specific” entities.

Thin-walled structure is still more accurately and efficiently analyzed as plates and shells.
Analysis Model Creation (e.g. FEA)

Geometry is not always the same!

Captured CAD Geometry → Idealized Geometry → Engr. Anal. Model (FEM)

Change Type or “Gender”
Simplify Idealize De-Feature
Pave Mesh Discretize

CAD-Centric → CAE-Centric

A mechanical engineer, a structural engineer, and a piping engineer may each require different forms of geometry capture.
Geometry Representations

Same Object ...

Multiple/Different Forms of Geometry Capture

1D Line (Curve)

2D Surface (Shell)

3D Solid (Volume)
Exploded View - Same Geometry, Different Data Capture

- 3D Solid (Volume)
- 2D Surface (Shell)
- 1D Line (Curve)

“Gender Changing”
**Same “Gender” Geometry**

CAE-Centric Creation of Engineering Analysis Models

<table>
<thead>
<tr>
<th>Geometry Type</th>
<th>Analysis Model Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-D Points</td>
<td>Lumped Masses, etc.</td>
</tr>
<tr>
<td>1-D Lines, Curves</td>
<td>Beams, Trusses</td>
</tr>
<tr>
<td></td>
<td><em>Axisymmetric Shells</em></td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>2-D Surfaces</td>
<td>Plates &amp; Shells</td>
</tr>
<tr>
<td>2-D Planar Surfaces (or Sections)</td>
<td>Plane Stress / Strain Elasticity</td>
</tr>
<tr>
<td></td>
<td><em>Axisymmetric Solids</em> (“Quasi-3D”)</td>
</tr>
<tr>
<td>3-D Volumes</td>
<td>3D Solid Elasticity</td>
</tr>
</tbody>
</table>
## Our Expectation When Interfacing with CAD

<table>
<thead>
<tr>
<th>CAD Product Model Geometry</th>
<th>Idealized (Simulation) Geometry</th>
<th>Analysis Model Type (e.g. FEM)</th>
</tr>
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<tr>
<td>0-D Points</td>
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<td>Beams, Trusses, Axisymmetric Shells</td>
</tr>
<tr>
<td>2-D Surfaces (in 3-D Space)</td>
<td>Stiffened Plates &amp; Shells</td>
<td></td>
</tr>
<tr>
<td>2-D Sections (or Sections)</td>
<td>Plates &amp; Shells</td>
<td></td>
</tr>
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<td>3-D Solids</td>
<td>3-D Volumes</td>
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</tbody>
</table>

1-D Lines, Curves: Beams, Trusses, Axisymmetric Shells
2-D Surfaces: Plates & Shells
3-D Volumes: 3D Solid Elasticity
In Reality, We Find This!

**CAD Product Model Geometry**

**Idealized (Simulation) Geometry**

**Analysis Model Type (e.g. FEM)**

- 0-D Points → Lumped Masses
- 1-D Lines, Curves → Beams, Trusses, Axisymmetric Shells, Axisymmetric Solids ("Quasi-3D")
- 2-D Surfaces (in 3-D Space) → Stiffened Plates & Shells, Plates & Shells, Plane Stress / Strain Elasticity
- 2-D Planar Surfaces (or Sections) → Plane Stress / Strain Elasticity, Axisymmetric Solids
- 3-D Volumes → 3D Solid Elasticity

EB CATIA V4
Process: Mock-Up (Light-Weight) Solids and (Application-Specific) *STR Entities
The Second “Problem” - Model Content and Amount of Detail

In general, the captured CAD geometry contains a great deal of detail, necessary for creating drawings and for manufacturing support, but too much detail for most idealized FEA models.

Therefore, the idealization portion of FEA requires simplifying the geometry, removing unwanted details which are not commensurate with the scale of the idealized FEA model. Examples include removing small holes, adding or removing fillets, even eliminating whole portions which may be idealized as a rigid mass, or may not be in the analysis at all!

This process of simplification is sometimes referred to as “suppressing the details” or “de-featuring” the geometry.

For welded structure adding features (weld fillets) to the CAD product model may be required for detailed stress analysis.
Welded Thin-Walled Structure with a 3D Solid Product Model

Weld material is only annotated (e.g. weld symbols), but not explicitly captured as fillets in the product model (as it would be for a machined part).

Typical ‘de-featuring’ might include eliminating the small holes but keeping the larger ones.

Whereas, a ‘featuring’ change could be adding weld fillets to avoid calculating stress concentrations or singularities at sharp corners.
COTS capabilities now exist in CAE software for automated creation of mid-surface geometry and shell FEA mesh.
EB Example - Automated Mid-Surfacing with Multiple Solids
(Solids-to-Shells)

Welded Plate Tank Structure - Multiple Brep Manifold Solids
Automated Mid-Surfacing
(Solids-to-Shells)
Process Improvement

Need Automated Electronic Feed-Back (From CAE to CAD)

Examples:

<table>
<thead>
<tr>
<th>COTS CAE Codes - ISO STEP Geometry Import and Export</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendor</td>
</tr>
<tr>
<td>------------</td>
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<tr>
<td>MSC</td>
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<td>EDS</td>
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<td>ABAQUS</td>
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<tr>
<td>Altair</td>
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<tr>
<td>PTC</td>
</tr>
</tbody>
</table>

Yes = Robust Capability Exists
Yes* = Basic Capability, Some Nuances
No = No Capability
P = Partial Capability (e.g. Geometry Imported from AP209 File)

Return to Overview
Electric Boat is committed to Open Systems and Standards Use

• STEP is essential for our production data transfers
  - Multiple CAD platforms and transfer tools are used between EB and both internal and external customers
  - A dedicated group exists to support data transfers and research new methods of production data transfers
• STEP standards are the tools of choice
  - AP203 used for the exchange of CAD data for hundreds of solid models each year
  - AP227 is starting to be used between EB and NNS for PIPESTRESS analysis and piping transfers
  - AP209 and AP203 are being introduced for CAD-CAE integration and for structural and mechanical process improvement
• Web and XML Implementation is Key
  - NSRP ISE Project is using XML and STEP for the Web to demonstrate data transfer using shipbuilding APs - AP216, AP218, and AP227 Ed.2
  - XML interfaces are being employed for new PLM system implementation
An XML Integration Approach

Step 1
- AP209 Express Schema
- GEN-X
- Config. File

Step 2
- AP209 XML Schema
- XSL Transform Map (Style Sheet)
- PDM XML Schema

Step 3
- AP209 Formatted Part28 XML File
- XSLT Engine (Transform)
- Formatted PLM XML File
- PLM

3D CAD Geometry Based FE Analysis

- BOD / BOA
- Nominal CAD Geometry
- Idealized CAE Geometry
- FE Models
- FE Analysis Results

PLM XML Interface

PRODUCT DEVELOPMENT CONFERENCE

MSC Software

2004 v[pd] • Huntington Beach, California
Improved CAD-CAE Integration with ISO STEP and XML Standards at Electric Boat

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