CAD/FEA INTEGRATION WITH STEP AP209 TECHNOLOGY AND IMPLEMENTATION

Keith A. Hunten, P.E.
IPT Lead - Analysis Tools and Integration
Virtual Product Development Initiative
Lockheed Martin Tactical Aircraft Systems

ABSTRACT

The requirements to share geometric shape and analysis information in a large-scale system, especially composite structures, are essential. An emerging standard, the ISO10300 STEP AP209, has been developed to address the data exchange to the design/analysis/manufacturing process. This paper describes the scope, progress and implementation of this effective standards-based solution.

Trademarks are capitalized and listed at the end of this paper

Introduction

The Design/Structural Analysis integration problem is typified by the requirement to share geometric shape and analysis information in an iterative environment. The integration is made more difficult when composite structures become a part of the problem. Figure 1 illustrates the interconnectivity that this paper addresses. Most production systems currently employ specific point-to-point translators to enable this process, and very few analysis systems are able to seamlessly return geometric shape information to the design shape modeler. With composite structures there are the additional problems of calculating true fiber directions and ply flat patterns that are shared with the manufacturing process. All of this information needs to be shared with commercial or in-house detailed analysis codes such as those for fastened joints and panel buckling.

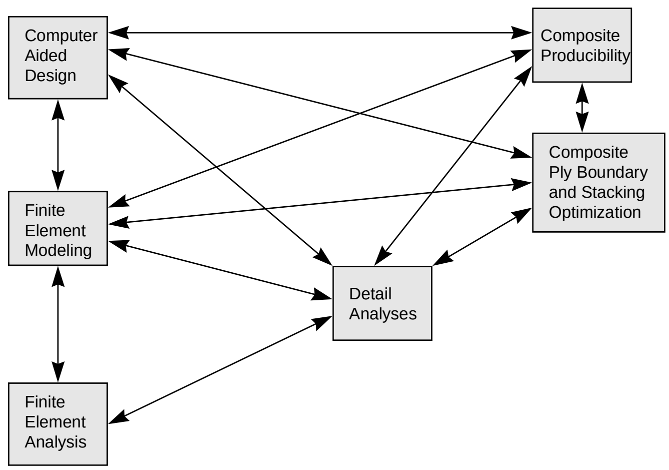

Figure 1. Engineering design, analysis, and manufacturing information interconnectivity.

In large scale industrial settings a standards-based solution to the iterative design/analysis /manufacturing process is becoming an imperative. Figure 2 illustrates the ‘four-or-more’ problem that is the major drawback to the point translator approach. If a standard data model (as in the right hand portion of figure 2) is used to provide information integration there is a significant reduction in the number of translators and in maintenance. In a large-scale system such as that represented in figure 6 there may well be dozens of applications that are required to share information. The ISO 10303-209 STEP Application Protocol (AP) Composite and Metallic Structural Analysis and Related Design has been developed to address this approach to the Design/Structural Analysis problem.

Trademarks are capitalized and listed at the end of this paper

Figure 2. The ‘four-or-more’ problem.

Trademarks are capitalized and listed at the end of this paper

STEP Overview

ISO 10303 STEP (STandard for the Exchange of Product Model Data) is the standard that provides a complete, unambiguous, computer-interpretable definition of the physical and functional characteristics of a product throughout its life cycle. The standard has been created by a team of international experts from disciplines such as aerospace, automotive, shipping, process plants, CAD/CAE/CAM, academia, and government.

Figure 3 illustrates the various aspects of the STEP standard. The core of the standard is a series of integrated data models that provide resources for information such as product design, geometric and topologic representation, and some specialized representations. These data models are all written in EXPRESS, an implementation-independent computer-sensible language that is also an ISO standard. There are then Application Protocols (APs) that define application specific views of the integrated resources in a clearly defined context. Some examples of APs include AP202 Associative Draughting, AP203 Configuration Controlled Design, and the subject of this paper, AP209 Composite and Metallic Structural Analysis and Related Design. There are two implementation methods defined within STEP, the first is a flat ASCII file (Physical File), and the second a standardized application programming database interface (STEP Data Access Interface (SDAI)). Finally, each AP has an associated set of Conformance Testing documents to provide a method to test and certify translators and interfaces.

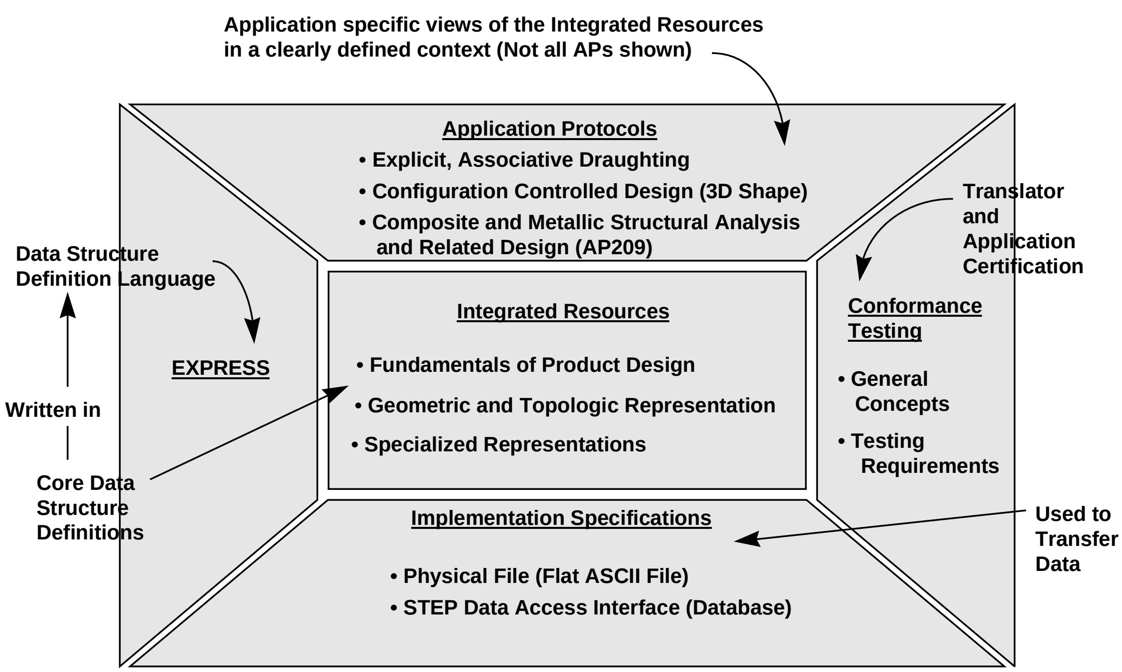

Figure 3. The structure of the STEP standard.

The internal structure of an AP is illustrated in figure 4. The first section of an AP describes what is in and out of scope for data exchange. There is then an Application

Activity Model (AAM) of the process that the AP enables that is written in the IDEF0 modeling language. The AAM is primarily used to set the context for the data exchange and to provide a basis for data exchange requirements. The Application Reference Model (ARM) is an information (data) model of all of the information requirements of the AP defined in language that an application expert would be familiar. The ARM is the part of an AP that a reviewer or user would find most useful. Finally there is the Application Interpreted Model (AIM) that is the result of the mapping of the ARM requirements information model to the STEP integrated resources information models. The AIM is written in EXPRESS and is useful only for implementers. There are also definitions of conformance classes for applications implementing the AP, and there are associated documents that delineate the test cases/suites for certifying implementations.

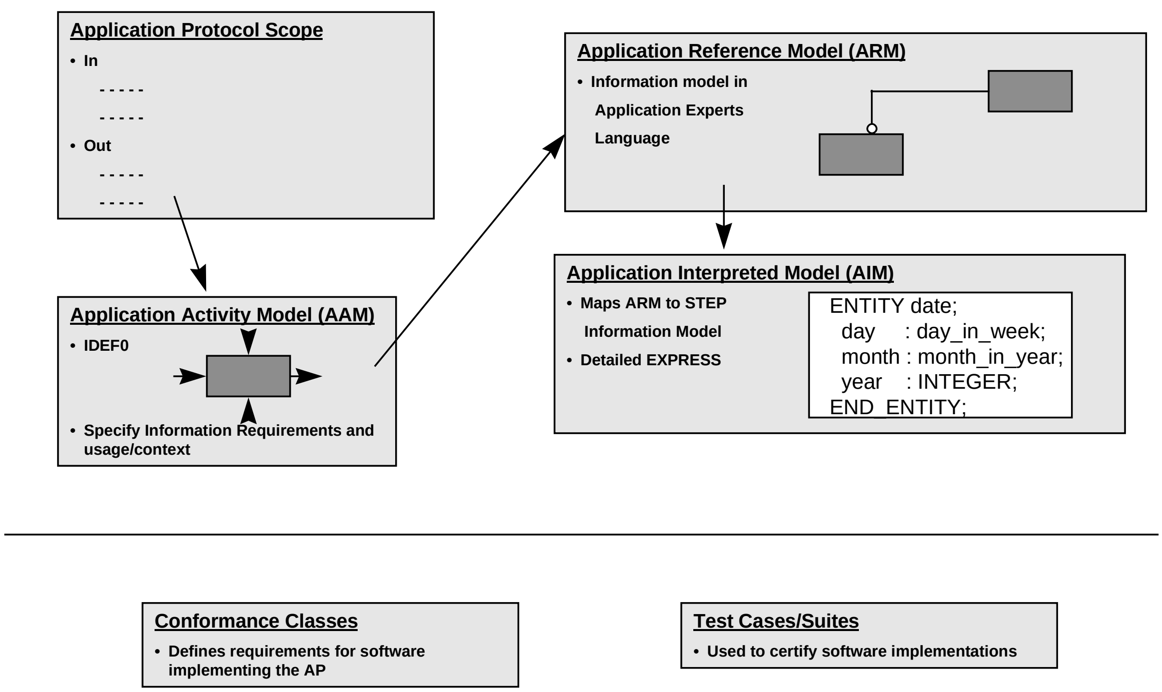

Figure 4. The internal structure of an Application Protocol

AP209 Scope

The scope of AP209 is illustrated in figure 5. A central theme to the partitioning of information within AP209 is that there are separate product definitions for the analysis and design disciplines. This division is primarily a constraint from the Aerospace industry, however similar requirements were noted from shipping, offshore, and automotive. Both product definitions may be independently configuration controlled, and many aspects of each are subject to approvals. Another crucial concept is that the shape and analysis information is meant to be implemented to enable bi-directional transfer to enable the feedback of information in the iterative design/analysis environment.

The analysis discipline product definitions primarily concern finite element models, analysis controls, and analysis outputs. Loads and boundary conditions may be applied to either mesh or geometry. Linear statics, modes, and frequency analysis types are supported. The scope of the analysis options was decided upon merits of trading addressing all analysis needs versus resources available to develop the standard. Surveys showed that the scope selected typically will address 60 to 90 percent of the analysis needs of an enterprise. It should be noted that AP209 was designed to be easily enhanced to support nonlinear analyses with little or no disturbance to the existing data model. In fact roughly 90 percent of the nonlinear problem is addressed at the present time. The analysis report serves several purposes: first is to document design and analysis decisions such as geometric and material idealizations, and second to reference documents containing text and/or graphical documentation of the model, analysis controls, and results.

The design discipline product definition is primarily concerned with shape representation and assemblies thereof. The geometric shape representations within AP209 are entirely interoperable with those in AP203 that are currently being implemented by most CAD and CAE vendors. There is one additional shape representation unique to AP209 that is utilized to represent the shape of composite constituents such as plies and sandwich cores.

The composite constituents contain geometric information, a variety of laminate stacking tables definitions, and either an as-laid or as-draped fiber orientation definition. Both part and zone ply table capabilities are supported. Another important benefit of AP209 is the standardization of a taxonomy of composite constituents. Definitions and illustrations are given each of the constituents such as ply, core, and filament laminate.

Material specifications and properties are represented both for composite and homogeneous (metallic) materials. The specifications and properties may be expressed either at the design level, or more specialized analysis specifications and properties may be represented.

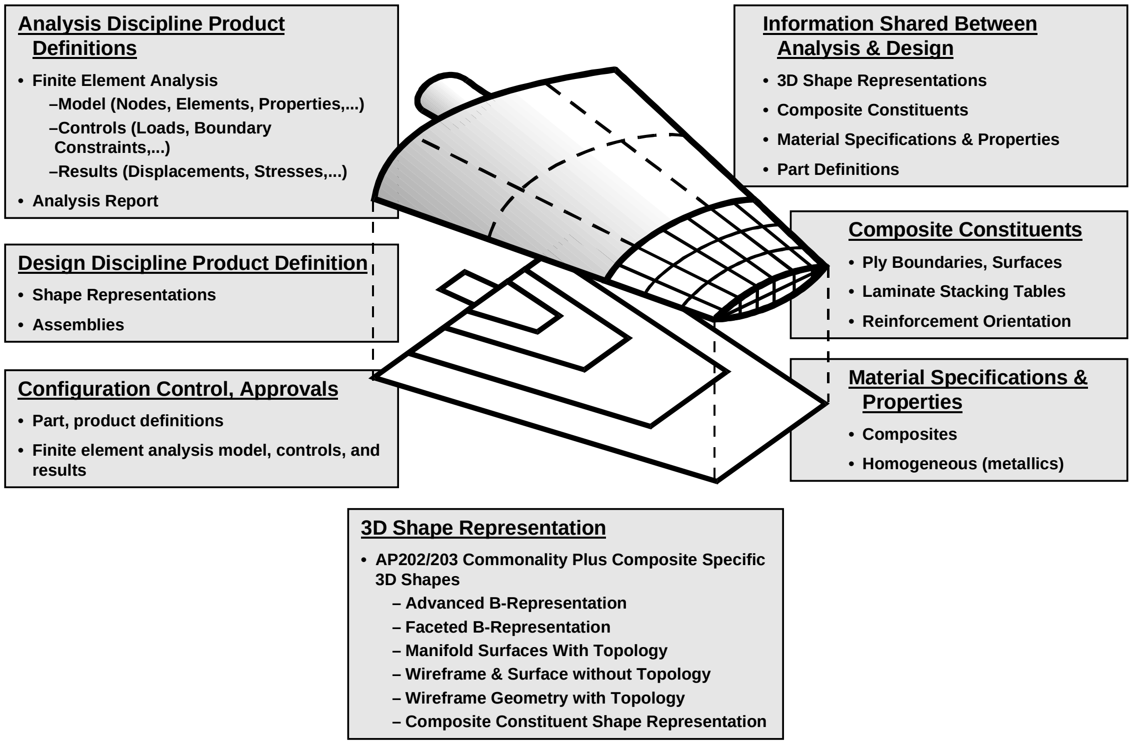

Figure 5. AP209 scope.

An important feature of AP209 is the sharing of information between the design and analysis product definitions. The shape information is shared at the lowest level allowing locations for nodes to be the same as points defining curves, surfaces, and solids. Additional associativities between nodes and elements may be forged to geometric aspects such as curves and surfaces to facilitate processes such as mesh generation. Both disciplines may also share composite constituents, material properties, and material specifications. A final crucial concept is that both disciplines share the same product structure definition capability.

ISO Status of AP209

The AP209 standard passed the ISO Committee Draft (CD) international ballot in October 1996 with thirteen of eighteen P-members voting. Eleven countries agreed, and two disagreed. AP209 has also been part of a focused effort to ensure the maximum degree of interoperability (data sharing) between STEP APs. Issues regarding AP interoperability were submitted as CD ballot comments. No substantial technical issues were raised against the CD document, and resolution of all ballot comments is complete. The AP209 document is currently being prepared for distribution as a Draft International Standard (DIS), with a target release date for international DIS balloting beginning in June 1997.

Information Integration with AP209

The integration of tools (applications) in a large-scale system is illustrated in figure 6. There are five major groups of applications represented: CAD-based shape design, composite producibility and optimization, analysis model creation and post-processing, a configuration control and archival management system to enable the use of many different Finite Element Analysis (FEA) tools, and detail analysis tools such as the panel analysis applications illustrated. AP209 technology is utilized throughout to provide bi-directional sharing of information.

The CAD-based shape design tools today often have at least some level of functionality of Finite Element Model (FEM) generation capability. The use of AP209 provides a standardized format so that the mesh information and any related geometric associativities created in the CAD tool may be shared with each of the other processes in figure 6. The composite shape and structure information may also be associated and shared. This combination of associated shape, mesh, and composites information enables applications such as automated composite analysis material property generation for finite elements, that is a task previously impossible without the information integration offered by AP209. A typical automated property routine would loop though all composite plies associated with an element and use the ply thickness, orientation, and material property information to calculate elastic response matrices.

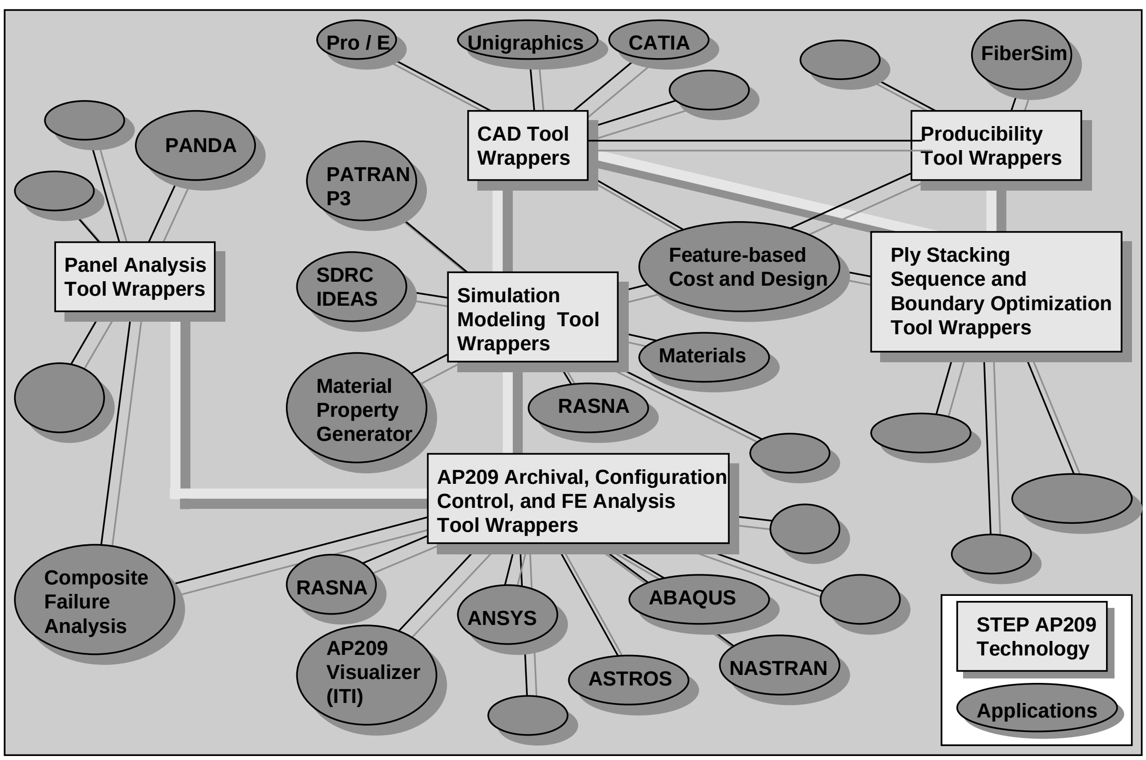

Figure 6. Large scale system integration with AP209.

Composites producability and optimization tools stand to benefit most from AP209 technology as the ability for the tools to share ply shape and structure table information in a standardized format has not been available before. There are two paradigms for composite structure and shape representation within AP209: ply by ply stacking to define the entire part, and zones of constant laminates (either at a point or over an area on a surface). A part may be described by both methods to maximize flexibility in the composite product development process. An example of the need for dual representation is designing and analyzing a part by area zones, and then deriving the ply boundaries for manufacturing, and then the flat patterns for a fabric cutting machine.

An area of information management that has long been neglected is the configuration control and management of FEA. The combination of product structure, work authorization, and configuration management data structures in AP209 offer the capability to manage a wide variety of CAD/CAE information. An application to manage and archive AP209 information provides the engineer with more options than may be available with current generation point-tot-point translators. An example of this utility would be SPAM (Stiffened Panel Analysis Modeler), that was originally written to output ABAQUS information. Engineers at a different corporate site wanted to use SPAM, but only had ANSYS available. Conversion of SPAM to AP209 in combination with the management and translation application would allow the use of the tool with a wider variety of solvers without further modification of the detail analysis tool providing a significant resource and maintenance cost savings.

Having a standardized shape, analysis, and composites database enables other processes than those that have been classically involved in the Design/Analysis process. An example of this is composite failure analyses that require analysis, shape, and detail analysis input to perform the task.

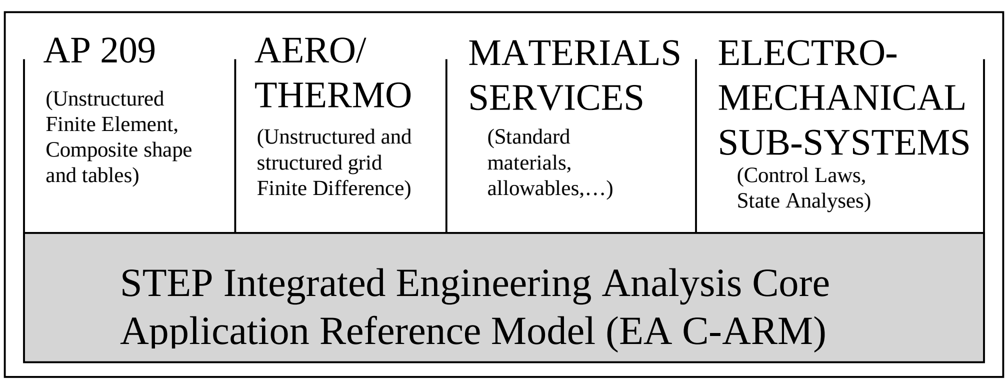

Figure 7. Engineering Analysis Core ARM architecture.

Future Engineering Analysis Development

There is currently a new work item (NWI) being initiated in the ISO Engineering Analysis (EA) committee to build upon AP209 to create a suite of EA APs. An EA Core ARM is being developed that will unify various analysis disciplines (figure 7). The requirements model in the EA C-ARM will be completely mappable to that in AP209 assuring interoperability with other disciplines. To date three other APs have been scoped for implementation within the EA Suite. The first will be a material services AP that will provide a standard to represent properties and allowables for materials, adhesives, and standard fasteners. A second AP will be created to represent structured and unstructured finite difference aerodynamic and thermodynamic information. The last AP will be created to represent information to perform the electro-mechanical sub-systems integration and analysis tasks such as control laws and state space analyses. The intent is to provide an interoperating suite of EA APs that will share information in a multi-disciplinary environment.

AP209 Implementations

To date there have been three successful pilot implementations of AP209, and two more are underway. The pilots completed to date were performed by three teams of companies: one under the auspices of the PDES, Inc. consortium, another under a contract from the US Airforce Manufacturing Technologies Directoriate's PDES Application Protocol Suite for Composites (PAS-C) program, and the third under contract from the US Army Tank Command (TACOM). Subsequently two more efforts are underway: a Phase two pilot under PDES, Inc., and the Defense Advance Research Program Administration (DARPA) MADE (Manufacturing Development) Integrated Product Data Environment (IPDE) program being worked at Boeing. The successes of these pilots have proven the effectiveness and accuracy of the AP209 data exchange standard.

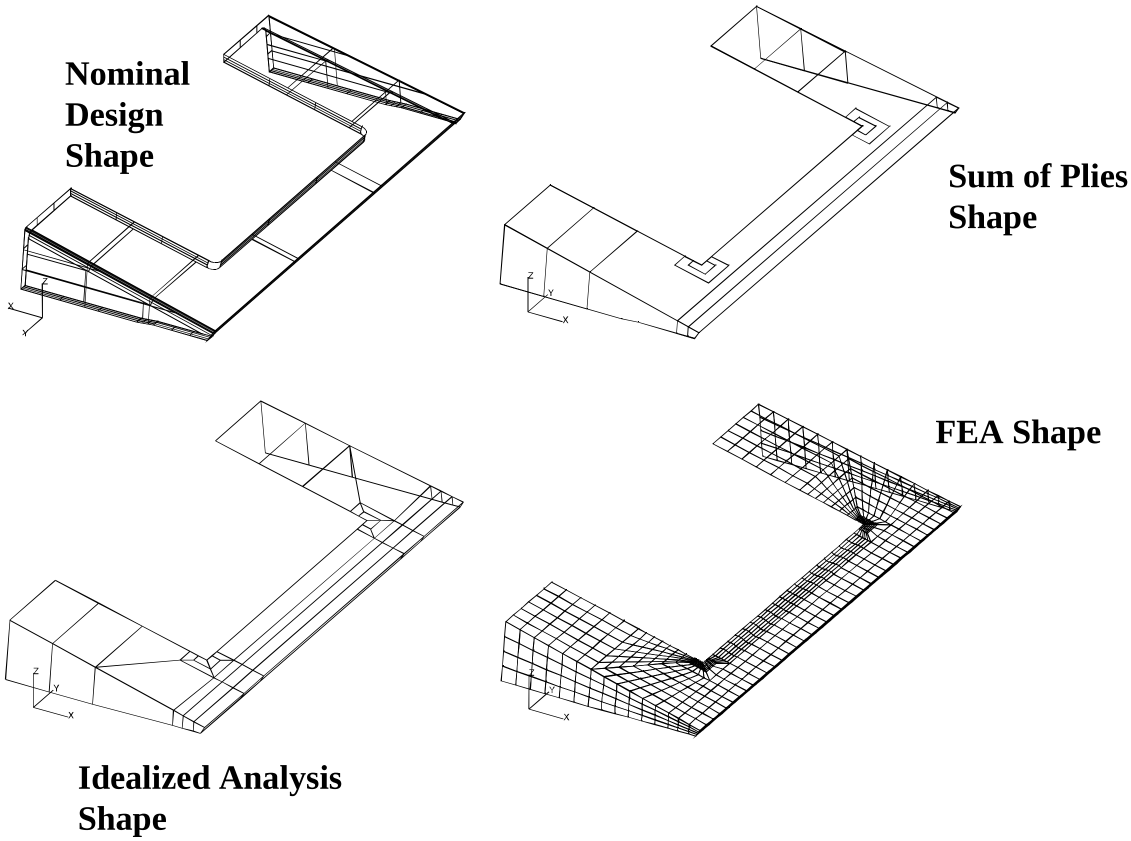

Figure 8. Shape representations from the TACOM AP209 pilot.

The initial PDES, Inc. FEA pilot team included participants from Boeing, Ford, General Motors International Technegroup Incorporated (ITI-OH), Lockheed Martin, The MacNeal-Schwendler Corporation, and Northrop Grumman. The exchanges centered upon the analysis of a metallic automotive engine crankshaft. A solid model of the crankshaft was transferred from ComputerVision (CV) to MSC/PATRAN where an idealized analysis shape and the derived analysis model were created. The model was subsequently analyzed in MSC/NASTRAN, and also written out in AP209 format and read into CV Stresslab where an identical analysis was performed. During each step in the demonstration information was appended to an AP209 Physical File repository and displayed in an AP209 Visualizer application created by ITI-OH. Note that the AP209 visualizer had support from the TACOM and PAS-C pilots as well. Thus at the end of the cycle there were analysis results available in CV Stresslab, MSC/PATRAN, and in the AP209 visualizer demonstrating the sharing of analysis information. A video documenting this project is available from PDES, Inc.

The TACOM pilot concentrated on the design and analysis of a composite upper hull of an armored vehicle. The participants included South Carolina Research Authority (SCRA), Lockheed Martin, and The MacNeal-Schwendler Corporation. Figure 8 illustrates the various shape representations of the nose of the composite armored vehicle (CAV) that were represented in a single AP209 repository throughout the life cycle of the pilot. The solid model of the nose CAV was transferred out of Intergraph and into

MSC/PATRAN, as were the surface/wireframe representations of the ply boundaries. The ply boundaries were also put through a ply merger and appended to an AP209 repository of the solid model shape. A finite element model of the nose was then made in MSC/PATRAN, and output to AP209 format and appended to the AP209 repository. An application developed under the pilot was then run to automatically generate the material response matrices from the plies and elements that were then passed back to MSC/PATRAN. The analysis was then performed in ABAQUS, translated back into MSC/PATRAN, and then into AP209 format and appended to the repository. The completed repository was then read back into Intergraph. In the end there were three applications able to visualize the analysis output: PATAN, Intergraph, and the AP209 visualizer.

The PAS-C program AP209 pilot was performed with AP232 (Technical Data Packaging Core Information and Exchange) to show how the two APs cooperated in performing a configuration controlled design and analysis modification to a horizontal stabilizer skin of an airlifter. Both AP209 and AP232 were primarily developed under the PAS-C program. The PAS-C pilot began with a metallic horizontal stabilizer skin native CAD (Unigraphics) and AP209 files with related configuration control information being transmitted to a subcontractor via AP232. The subcontractor then took the AP209 shape of the metallic skin and used it as a basis to create a hat-stiffened composite replacement skin design. The composite design was first created using a zone composite description, and then converted to a ply description. The shape information was shared with MSC/PATRAN to create a finite element model, and the zone descriptions paired with the finite element model used to automatically create the skin elastic response matrices. The analyses of the metallic skin (again in AP209 format) was used as a basis for loads and boundary conditions to analyze the replacements composite skin. The composite shape, FEM, composite plies and zones, and analysis information was aggregated in an AP209 repository in a similar fashion to the last two pilots. Analysis results were viewed both in MSC/PATRAN and the AP209 visualizer. Finally the revised versions of the shape and analysis models were packaged in AP232 format and returned to the prime contractor. A video documenting this pilot is currently in production.

The Phase two PDES, Inc. EA pilot has been underway since October 1997. The scope of the pilot is to expand the richness of AP209 implementations completed in the Phase one FEA pilot, and to extend the implementations to include panel and finite difference aerodynamic information. The aero data will then be coupled with structural data to enable a loosely coupled un-trimmed aeroelastic analysis. The participants include Boeing (including the MADE IPDE work related in the next paragraph), Lockheed Martin, MacNeal Schwendler, and NASA Lewis.

The DARPA/Boeing MADE IPDE contract is to provide an AP209 based coupling between structural and aerodynamic analysis. The team includes Boeing, Arizona State University, and MacNeal Schwendler Corporation. The structural tools involved include MSC/PATRAN and MSC/NASTRAN, and the aerodynamic tool is the Boeing A502 panel aerodynamic application. The project includes both Physical File and SDAI data sharing implementations, and includes an innovative approach to integrating applications with multiple APs. A typical analysis iteration involves reading in the AP209 file of A502 panels and pressures into MSC/PATRAN, reading in the AP209 file of FEM and analysis results into MSC/PATRAN, mapping the pressures from the A502 model onto the structural model, analyzing the FEM with MSC/NASTRAN, mapping the deflections back onto the A502 mesh in MSC/PATRAN, and writing out the A502 panel model in an AP209 file for another aerodynamic analysis with A502. To date the AP209 Physical File based implementation has successfully demonstrated five iterations to a converged aeroelastic analysis of a composite VTOL aricraft wing.

Conclusions

The ISO 10303 STEP AP209 emerging standard has received widespread review during the last six years since the inception of the project. Many pilot implementations have proven that AP209 capabilities are mature enough for large-scale commercial implementations. Current efforts underway will ensure that AP209 will function interoperably within a suite of EA APs that address the multi-disciplinary analysis problems that are increasingly facing engineers. Work with AP232 and other AP interoperability projects have ensured data sharing with many other STEP APs. Finally, it is clear that the scope of AP209 provides an effective standards-based solution to the majority of the iterative structural Design/Analysis integration problems.

Trademark Acknowledgments

NASTRAN is a registered trademark of NASA. MSC/NASTRAN is an enhanced, proprietary version developed and maintained by MacNeal Schwendler Corporation.
MSC/PATRAN is a registered trademark of the MacNeal Schwendler Corporation.
Unigraphics is a registered trademark of the Electronic Data Corporation.
Computervision is a registered trademark of the Computervision Corporation.
Stresslab is a registered trademark of the Computervision Corporation.
Intergraph is a registered trademark of the Intergraph Corporation.

Abbreviations List

STEP, Standard for the Exchange of Product Model Data
AP, Application Protocol
ARM, Application Reference Model
AIM, Application Interface Model
FEA, Finite Element Analysis
SPAM, Stiffened Panel Analysis Modeler