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ANALYTICAL DESIGN PACKAGE - ADP2 A COMPUTER AIDED ENGINEERING TOOL FOR AIRCRAFT TRANSPARENCY DESIGN

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ABSTRACT

The Analytical Design Package (ADP2) is being developed as a part of the Air Force Frameless Transparency Program (FTP). ADP2 is an integrated design tool consisting of existing analysis codes and Computer Aided Engineering (CAE) software. The objective of the ADP2 is to develop and confirm an integrated design methodology for frameless transparencies, related aircraft interfaces, and their corresponding tooling. The application of this methodology will generate high confidence for achieving a qualified part prior to mold fabrication.

ADP2 is a customized integration of analysis codes, CAE software and material databases. The primary CAE integration tool for the ADP2 is P3/PATRAN, a commercial-off-the-shelf (COTS) software tool. The open architecture of P3/PATRAN allows customized installations with different application modules for specific site requirements. Integration of material databases allows the engineer to select a material and those material properties are automatically called into the relevant analysis code. The ADP2 materials database will be composed of four independent schemas: CAE Design, Processing, Testing and Logistics Support.

The design of ADP2 places major emphasis on the seamless integration of CAE and analysis modules with a single intuitive graphical interface. This tool is being designed to serve and be used by an entire project team, i.e., analysts, designers, materials experts and managers. The final version of the software will be delivered to the Air Force in January, 1994. The Analytical Design Package (ADP2) will then be ready for transfer to industry. The package will be capable of a wide range of design and manufacturing applications.

1 INTRODUCTION

ADP2 is an integrated design tool consisting of existing analysis codes and Computer Aided Engineering (CAE) software. The objective of the ADP2 effort is to develop and confirm an integrated design methodology for frameless aircraft transparencies. ADP2 analysis capabilities include: aerodynamic heating, transient thermal response, static and dynamic structure response, optical ray trace, injection molding process simulation, and an aircraft transparency related material properties modeling and databank system. The design process is to be iterative and capable of producing frameless transparency designs, information needed for the design of integral aircraft interfaces, and information needed to support the design of injection molding tooling and the specification of molding process parameters for specific materials.

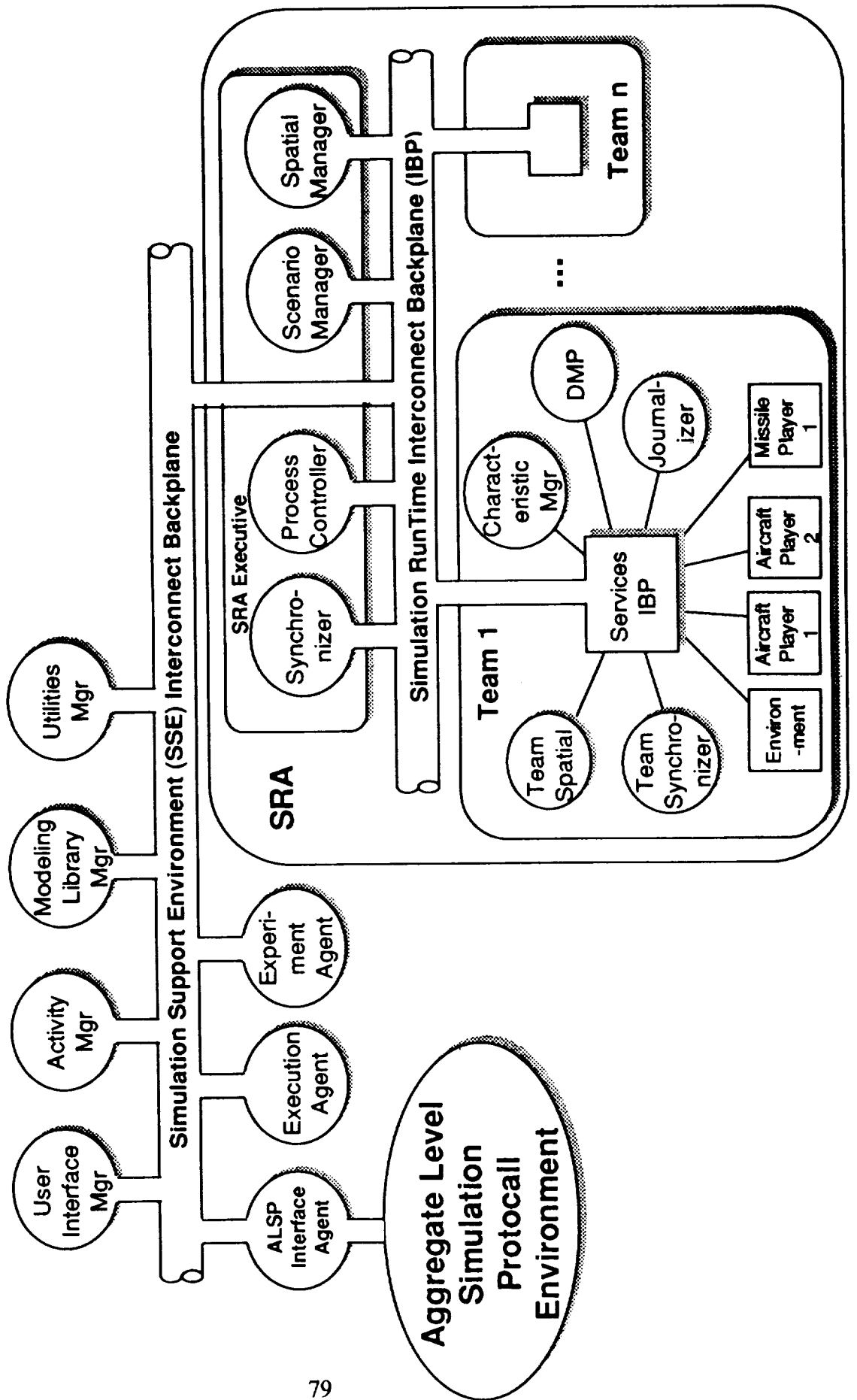
ADP2 is a second generation analysis system. The initial ADP development was initiated in 1989, References 1, 2 and 3. Since the inception of the original ADP, significant developments in both CAE and design support software relevant to aircraft transparency design have evolved. In addition, certain current design requirements, e.g., optics analysis and material properties modeling, were not addressed in the original ADP. Finally, significant advances in computing hardware have occurred making it possible to perform the required computations on workstation systems as opposed to mainframe platforms.

Recent developments in CAE design tools have introduced the ability to integrate special purpose and commercial-off-the-shelf (COTS) software in a user friendly (intuitive/interactive) environment. That is, to have a single user interface serve the primary analysis functions, specifically:

1. Modeling

- Geometric Modeling (construction and modification)
- CAD and IGES File Import
- Graphics Manipulation

J-MASS Architecture Extensible to Wargaming



- Meshing
 - Loads and Boundary Conditions Specification
2. Materials Data Management
 - Analysis Code Properties Input
 - Test Data Processing and Reduction
 3. Analysis Module and Module Parameter Specification
 4. Results Evaluation

The design of ADP2 places major emphasis on the seamless integration of CAE and analysis modules with a single intuitive graphical user interface.

2 ADP2 SCOPE

The principal objective of the ADP2 end product is to provide an integrated CAE tool to support the design of frameless (injection molded) aircraft transparencies. This tool is being designed to serve and be used by the entire project team, i.e., analysts, designers, materials experts, and managers. Emphasis is being placed on ease of use with the need for the user to learn only one common graphical user interface.

The ADP2 design places emphasis on the use of standardized methods for electronic communication of data to support the CAE process. Specific examples include: (1) the ability to import CAD and/or IGES files to simplify geometry model development, (2) the ability to store, process and import materials property data to support the design process, and (3) to allow users (including users at different sites) to share analysis results.

Finally, the ADP2 design addresses the issue of cost effectiveness. Where possible, commercial off-the-shelf (COTS) software is specified. This approach alleviates the need for the software owner to support and upgrade the software system as relevant new developments and improvements emerge. In addition, COTS software portability is generally maintained for common engineering work station platforms. Cost effectiveness is also addressed through ease of use and enhanced design team communication. For example, the design team will have the ability to review analysis results from the perspective of their individual needs. Ease of use will allow all members of the design team to communicate through direct use of the ADP2 to support their individual roles.

The specified analysis module requirements for the ADP2 are listed in Table 1, (note the ADP2 column). A comparison of the original ADP and ADP2 analysis module set is shown. It can be seen that the specified upgrades are extensive. In fact, none of the original ADP modules are planned for the ADP2 end product. This is the result of several major developments since the original ADP was defined some four years ago. It is planned that ADP2 will be configured so as to eventually allow the evolution of an ADP based on commercial-off-the-shelf (COTS) software. This potential evolution is indicated as ADP/COTS in Table 1. Although ADP/COTS is not a development target for the present program, it is, however, an important planning issue for ADP supportability and has a direct impact on the ADP2 architecture.

Table 1 ADP Development Phases

MODULE FUNCTION	ADP	ADP2	ADP/COTS
Design Process Manager, Graphical User Interface, and Project Manager	IRIS 4-SIGHT	P3/PATRAN	P3/PATRAN
Modeling/Post-Processing	PATRAN 2.4	P3/PATRAN	P3/PATRAN
CAD Interface	IGES File	P3/UNIGRAPHICS P3/IGES	P3/UNIGRAPHICS P3/IGES
Aeroheating Environment	STAHET	STAHET II	P3/CFD
Thermal Response	TAP	TAP II	P3/THERMAL
Structural Analysis	MAGNA	P3/FEA	P3/FEA

Birdstrike Analysis	MAGNA	X3D	ABAQUS EXPLICIT
Optical Raytrace	NONE	OPTRAN	CODE V
Injection Molding	C-MOLD 1.5	C-MOLD 3.2	C-MOLD 3.2
Materials Properties and Process Data Management Sys.	FTPMAT	M/VISION P3/MATL. SELECTOR	M/VISION P3/MATL. SELECTOR
Results Animation	NONE	P3/ANIMATION	P3/ANIMATION

The primary CAE integration tool for ADP2 and ADP/COTS is P3/PATRAN. The open architecture of P3/PATRAN provides the option to use several solver modules other than the baseline modules indicated in Table 1. A listing of alternative solvers which are commercially integrated with P3/PATRAN are listed in Table 2. This flexibility of P3/PATRAN will expand the opportunity for ADP2 and or ADP/COTS users to use their favorite solvers.

Table 2 Application Modules Commercially Integrated With P3/PATRAN

MODULE FUNCTION	MODULE TRADE NAME
CAD INTERFACE	UNIGRAPHICS CADD5 CATIA Pro/ENGINEER EUCLID-IS IGES PDES/STEP
THERMAL RESPONSE	P3/THERMAL SINDA P3/ADVANCED FEA ABAQUS
STRUCTURAL ANALYSIS	ABAQUS ANSYS MARC MSC/NASTRAN P3/FEA P3/ADVANCED FEA

ADP2 is initially being developed for the Silicon Graphics (SGI) Iris workstation which has a UNIX (IRIX 4.0.5) operating system. A development goal is to have the end product portable to common UNIX based engineering workstations. The specific development workstation is an SGI IRIS CRIMSON / ELAN with 64 megabyte main memory, a 50 megahertz (MIPS R4000) processor, and a 3.8 gigabyte capacity system disk.

The overall architecture of the planned ADP2 end product is shown in Figure 1. The primary CAE integration element of ADP2, P3/PATRAN, provides the basic framework for the executive control to implement application module integration, preprocessing (modeling) capability and post-processing (results display) capability. The basic capability of P3/PATRAN is extended by the ADP2 customization, indicated by the shaded area in Figure 1.

3 ADP2 INTEGRATION

What does the ADP2 Customization consist of? This is a question that many ADP2 users have asked. Comments have been made to the effect that one is not able to determine where P3/PATRAN ends and ADP2 begins. The reason for this is actually one of the advantages of using the customization features of the all new P3/PATRAN as the core of ADP2. Enhancements made to P3/PATRAN via the use of the COTS supported PATRAN Command Language (PCL) tool kit makes all added functionality seamless. In other words, the enhancements actually appear to be a part of P3/PATRAN.

3.1 ADP2 System

The ADP2 system includes several specified commercial and non-commercial software application modules which support the design and manufacturing process. These software products are then integrated with custom software to simplify the work of the engineering analyst.

Specifically, the software modules specified for ADP2 were listed in Table 1. ADP2 System functionally consists of two major parts: the Project Manager and the Application Interfaces. The Project Manager manages all data which the engineer creates and accesses. It also manages the process flow between P3/PATRAN and the various simulation tools. The Application Interfaces integrate the specific simulation tools with P3/PATRAN. The overall architecture of the system was shown in Figure 1.

3.2 Project Manager

The Project Manager is responsible for all items that relate to Project Management and Process Flow. Under most instances, the user will no longer need to keep track of his files. All data within ADP2 is referenced with respect to a specific project or task. The user simply selects the task or project that he is interested in and begins modeling or analyzing. ADP2 will even keep track of where the user was during his last visit to ADP2 and place him at the same task the next time he visits ADP2.

The Project Manager also ensures that the analysis tool requested by the user will be used on the model associated with the specified task. The Project Manager actually informs P3/PATRAN of which analysis tool is to be used with a specific model. So, when the engineer specifies that he would like to perform an analysis, P3/PATRAN will know exactly which analysis to perform.

Another feature of ADP2 is the ability for engineers to share data. An engineer can easily copy data from one project to another. He can also copy data from the outside world (data existing outside of the ADP2 system) into the ADP2 Project Management System.

3.3 Application Interface

The Application Interface consists of all analysis tools as well as their forward and reverse translators to P3/PATRAN. It also consists of the graphical forms interface with which the user interacts with to specify what it is that he would like to do with a specific analysis tool.

For instance, take the case of the application interface for the birdstrike analysis module, X3D. Once the Project Manager has handed the model to P3/PATRAN, the user can use P3/PATRAN to improve upon the model. When the user is ready for analysis, he selects "Analysis" on the menu bar and the X3D graphical forms are displayed to assist the user in specifying the parameters for the type of simulation he would like X3D to perform. These forms are part of the custom code developed for the Application Interface of ADP2. When the user is satisfied with the model and parameters that he has specified, he will "Apply" these parameters and begin the simulation task. In the case of X3D, The model and parameters are automatically input into the forward translator. This translator converts the data into the format required by X3D. This translator is also a part of the custom code developed for the Application Interface of ADP2. After the model and parameters have been translated, X3D is automatically submitted as a background job. Once the X3D job has completed, the results can be imported back into the PATRAN 3 model by use of the reverse translator, another piece of the custom code developed for the Application Interface of ADP2.

4 ADP2 APPLICATION MODULES

There are a total of nine primary modules integrated into the ADP2 analysis tool. An overview of the functionality embedded in each of these modules follows.

4.1 P3/PATRAN

P3/PATRAN is an advanced computer aided engineering (CAE) integration tool introduced by PDA Engineering, Costa Mesa, CA, in June of 1992, Reference 4. P3/PATRAN tool has an open architecture which provides several important capabilities. These include:

1. direct software links to leading CAD systems,
2. direct software links to analysis software programs, both leading commercial and user developed programs,
3. pre- and post-processing capabilities to allow geometry and FEM development, as well as analysis results display,
4. an integrated subset of the materials selection capability from PDA's M/VISION family of products,
5. a fully integrated set of P3/PATRAN analysis modules for performing structural, thermal, computational fluid dynamic, fatigue, and other types of mechanical analyses.

P3/PATRAN has a user friendly "mouse activated" window environment graphical user interface (GUI) which provides execution of the analysis system without the need to remember a particular command syntax. The open system architecture and GUI provide the basic capability to build a user friendly executive control capability for ADP2.

P3/PATRAN has been specified for ADP2 primarily for its capability as a CAE system integration tool. However, there are several analysis modules that are fully developed and completely integrated with P3/PATRAN. These analysis modules include:

1. P3/FEA for comprehensive finite element analysis,
2. P3/ADVANCED FEA which is a non-linear module developed jointly with HKS based on ABAQUS analysis technology,
3. P3/FATIGUE for durability analysis,
4. P3/CFD is a state-of-the-art computation fluid dynamics module for workstations,
5. P3/THERMAL is a state-of-the-art finite element based thermal analysis, and
6. P3/ANIMATION is an advanced, state-of-the-art animation capability co-developed with Intelligent Light.

All of the above modules have specific relevance to the requirements of the ADP. However, the initial development plan includes only two modules. These are P3/FEA which is reviewed in Section 4.5 and P3/ANIMATION which is reviewed in Section 4.7.

4.2 M/VISION

M/VISION is a PDA Engineering materials software system which provides for data visualization, selection and integration, Reference 5. M/VISION uses centralized relational databases organized to reflect the classes of materials information needed in the design-to-manufacturing process:

1. **Material:** Material source and designations, as well as extension to account for the multiple sources associated with composite materials.

2. **Specimen:** Detailed information about the specimens including composition and processing specifics.
3. **Environment:** Specific information about the experimental conditions including temperature and humidity as well as statistics and quality.
4. **Properties:** Mechanical, physical, thermal, and electrical properties of materials including extensions to account for anisotropy. Curves and rasterized images are represented as well.

Data stored in M/VISION may be directly accessed by P3/PATRAN via the P3/MATERIALS SELECTOR.

M/VISION provides a very significant upgrade for ADP2's materials database management functionality, compared to that in the original ADP. Details of the role of M/VISION in the ADP2 design methodology are presented in Reference 6. The following partial list summarizes several pertinent features provided by the M/VISION COTS product:

1. Complete graphical user interface (GUI) that provides visualization of all materials database functions.
2. Customization of database schema; i.e., attribute list, relationships, etc. Easy to expand database to include more properties and more property types.
3. Units easily changed to SI or any user defined system.
4. Metadata and footnotes provided with data values that enable inclusion of material source, specimen conditions, test environment, test anomalies, etc.
5. Data can be stored and manipulated using an extensive spreadsheet functionality.
6. Database queries using engineering terminology to define search conditions.
7. Full-featured manipulation and storage of tables, graphics, and CAT scan images.
8. Strict adherence to government and industry standards.
9. Provides data importing and exporting features using the following exchange protocols:
 - IGES
 - PDES/STEP
 - PATRAN Neutral File
 - ASCII Text Spreadsheet Files
10. M/VISION databases can be accessed directly or queried using the new P3 "materials selector" functionality (via GUI form driven features).

As a powerful stand-alone product, M/VISION can be utilized in a variety of ways, within the design-to-manufacturing process. Generally, throughout the design process, engineers do not have a central on-line source and electronic access to high quality materials information required for analytical design assessment simulations. Often the materials information that is available is missing critical property values requiring further testing or analytical material synthesis. Therefore, M/VISION's role could be two-fold. As a central source for database management, M/VISION could serve to create, update, and store all the available materials information pertinent to the transparency design community. In this role, M/VISION would be executed and maintained by a Materials and Processes group(s) for the overall design-to-manufacturing process. Materials data, needed by design simulation modules, would be accessed using one of the various transfer protocols listed above.

4.3 STAHET II

STAHET II performs the computations which predict the aerodynamic heating history to the transparency system for a specific aircraft configuration and mission profile. The results of these computations are then used as input boundary conditions to the transient heating analysis (TAP II) for the detailed transparency model, as discussed in Section 4.4.

The STAHET II and TAP II codes are embedded in the STAPAT II (Specific Thermal Analyzer Code for Aircraft Transparencies) development. STAPAT II, rather than a single computer program, is actually an analysis methodology incorporating a set of computer codes. There are 5 major elements of this methodology, specifically:

1. develop the forebody model,
2. compute the aeroheating over the transparency surface using the STAHET computer code and these models (STAHET),
3. develop the transparency finite element model (STABLD),
4. compute the transient, three dimensional transparency system temperatures using the TAP computer code and the finite element model (TAP), and
5. display the models and results using the STAPLT computer code (STAPLT).

Details of the above methodology are reported in References 7, 8, and 9.

The above methodology has several inconsistencies with the ADP2 architecture, specifically with respect to Item 1, forebody model; Item 2, transparency finite element model; and Item 5, display models and results. In ADP2, all of these tasks are handled by P3/PATRAN. In addition STAPAT II was specifically developed for the DEC VAX/VMS computer systems. For ADP2, both STAHET II and TAP II have been ported to UNIX based platforms.

STAHET II represents a significant upgrade to the STAHET code which is embedded in the first generation of ADP (Reference 3). The ground rules for developing the code were that STAHET II must: (1) be user friendly and non-proprietary, (2) provide accurate transparency temperatures without excessive computing resources; (3) use existing methodologies to predict heating rates and temperatures; and (4) retain or improve all original STAHET capabilities, Reference 7.

The general capabilities of the STAHET II code are summarized in Table 3. Details of the indicated capabilities, their assumptions and limitations, and their implementation are presented in References 8 and 9.

Table 3 General Capabilities of STAHET and STAHET II

STAHET	STAHET II IMPROVEMENTS
<ul style="list-style-type: none"> • Two Streamline Tracing Methods • Modified Newtonian Pressure Calculation • Laminar and Turbulent Heating Correlations • Boundary Layer Transition Options • Wall Temperature Effect Modeling • Mission Profile (Mach and Altitude) Input for 3-D Geometries • 2-D Wind Tunnel Modeling • Standard Day, Hot Day, Cold Day Atmospheres • Ideal Gas Air Model 	<ul style="list-style-type: none"> • Simplified Streamline Tracing Techniques Selected as Default • User Input of Streamline Starting Angles Added • Four Shadow Region Pressure Prediction Techniques Added • Wall Temperature Effect Modeling Improved • 3-D Wind Tunnel Model Capability Added • Extension to Hypersonic Flow

The integration of STAHET II into the ADP2 product is limited to those capabilities relevant to current tactical and strategic aircraft. Capabilities relevant to hypersonic vehicle applications, i.e., Mach Number greater than about 4 and altitude greater than 100,000 feet, exist in the basic STAHET II code. The implementation of this

capability would require an extension of the ADP2/STAHET II application interface.

An important feature of the STAHET II integration into ADP2 is the inclusion of (and ready availability of) aircraft forebody geometries. The complete file of 16 STAHET II geometries has been included. Geometries relevant to conventional military aircraft include F-16, F-15, F-4, F-18, and B-1B. Low RCS aircraft, missile, and several hypersonic forebodies also exist in the library. The example of the F-16 forebody configuration is shown in Figure 2.

An example of an ADP2/STAHET II result is provided in Figure 3. Shown is a fringe plot of aerodynamic heating rate over the portion of the forebody relevant to the transparency. The relevant aerodynamic heating parameters are then transferred to TAP II where the predictions of the transient thermal response for the transparency are conducted.

4.4 TAP II

The TAP (Transparency Thermal Analysis) application module performs the transient thermal response analysis for the transparency structure. The primary end result of the analysis is the temperature field as a function of time for the detailed 3-dimensional finite element model. These data may then be queried to examine for critical temperatures and/or be directly handed off to the thermal stress finite element model via the P3/PATRAN FEM Field Interpolator.

The general capabilities of the TAP application module are summarized in Table 4. Details of the above capabilities and their implementation are discussed in References 8 and 9.

An example geometry used to build the TAP finite element model (FEM) is shown in Figure 4. The specific geometry is for the designated "Confirmation Frameless Transparency" (CFT7A) as specified by Wright Laboratories. Example TAP II results are shown in Figure 5. Shown is the temperature field, at a specific mission time point, displayed in the TAP II FEM via the P3/PATRAN post-processing capability.

Table 4 General Capabilities of TAP and TAP II

TAP	TAP II IMPROVEMENTS
<ul style="list-style-type: none"> • 3-D Finite Element Solution • Material Property Data Base • Aeroheating Imposed on External Surface • Thermal Boundary Conditions <ul style="list-style-type: none"> - Generalized Convection - Defog - Anti-Ice (Hot Air Blast) - Electrical Anti-Ice - Generalized Heat Flux - Radiation-to-Sky - Element-to-Element Radiation • Standard Day, Hot Day, Cold Day Atmospheres • Mission Profile (Mach, Altitude and Time) Input 	<ul style="list-style-type: none"> • Defog Modeling Improved • Cabin Cooling Air Velocity Default Added • Fluid Gap Modeling Improved • External Anti-Icing Improved • Line Source Capability for Convection Added • Earth Radiation Sink Temperature Added Expanded Material Property Data Base <ul style="list-style-type: none"> • Viscosity and Molecular Weight Added to Material Property Data Base • Gap Fluids Added to Material Property Data Base • Extension to Hypersonic Flow

4.5 P3/FEA

P3/FEA is a finite element based structural analysis solver that is fully integrated with the P3/PATRAN family of COTS products. P3/FEA has a wide variety of analysis capabilities, solution sequences, element types, and material models, including temperature dependent laminated composite and nonlinear material properties, Reference 10. P3/FEA makes full use of the graphical user interface (GUI) forms system provided by P3/PATRAN. P3/FEA analysis jobs are assembled, submitted, queried, or aborted from within the P3/PATRAN environment. Results evaluations are completely menu driven and fully integrated with the P3/FEA results database.

P3/FEA solves a wide variety of structural problems. An extensive finite element library and set of solution procedures, which can handle very large matrix equations are available in P3/FEA. No translators are needed

to transfer model data from P3/PATRAN to P3/FEA or to transfer results back to P3/PATRAN for post-processing. The close coupling of P3/PATRAN and P3/FEA provides the user with all the efficiencies related to integrated software.

P3/FEA can handle extremely large problems. Models of over one-hundred thousand degrees-of-freedom have been analyzed. A restart capability is provided for large problems that require efficient re-analyses as new cases are defined for existing models.

P3/FEA will provide two basic analytical simulations needed to support the ADP2 transparency design assessments. These are:

1. static analysis (linear and nonlinear) and
2. dynamic normal modes.

The static analysis will include mechanical load environments (pressures) and/or thermal load environments (in-depth thermal gradients). The load/temperature values defined for these analyses are provided by the TAP II aerothermal simulation module solution results. Automated procedures to interpolate the TAP II results onto and into the P3/FEA model are included in the P3/PATRAN FEM field interpolation function. The transparency FEM can include "contact only" nonlinear elements in the regions of attachment to simulate joint details. The nonlinear iterative procedures to establish the discontinuous contact elements' unique combination of contact and gapping is provided as one of the P3/FEA solution procedures. The transparency material properties used in these static analysis simulations can be temperature dependent and/or nonlinear in their defined constitutive relationships. P3/FEA provides the static solution procedures to accommodate temperature dependent element material property evaluations.

The dynamic environments to be simulated by P3/FEA for the transparency design assessments will include normal modes evaluations and possibly subsequent frequency response and random vibration solutions. P3/FEA provides enhanced dynamics analysis capability sufficient to simulate any foreseen transparency dynamic load environment or modal content survey. P3/FEA can solve these problems in either a time or frequency domain.

An example P3/FEA result is shown in Figure 6. Shown is a fringe plot of Von Mises stress on the transparency surface displayed on the P3/FEA finite element model. The illustrated stress is the result of the combined effects of pressure and thermal loading.

4.6 X3D

X3D is an explicit FEA code, used to simulate soft body impact problems, including the birdstrike of aircraft transparencies. It provides substantial improvements over the MAGNA analytical functionality of the original ADP.

The analytical simulation of transparency non-linear transient dynamic response to birdstrike represents a distinctive class of impact structural behavior. The University of Dayton Research Institute (UDRI) has developed and is continuing to enhance a new explicit non-linear dynamic response FEA code, X3D (References 11, 12 and 13). X3D utilizes an explicit solution approach similar to other well-known FEA codes; e.g., DYNA3D, WHAMS, and ABAQUS Explicit. These solution methods and codes have been widely used for the numerical simulation of a variety of shock and wave propagation problems. Impact problems in general can be dominated by complicated contact surface conditions which can require very small numerical integration time steps which in turn remove the solution advantages of an implicit solution approach.

X3D provides functionality to idealize both the bird (impactor) and the transparency (target) and to allow them to come into transient contact with the physics of momentum transfer defined by the non-linear explicit solution algorithm solution results. That is, no analysis assumptions regarding contact pressure time histories or spatial distributions are required.

X3D has been evaluated through executions and correlations with benchmark test cases; i.e., impacting Taylor cylinder, exploding cylindrical shell, and F-16 centerline transparency impact. Although documented validation problems are limited, those completed to-date show promising correlations and demonstrate the improved simulations possible with the use of X3D code.

The X3D impact dynamics code provides a significant numerical tool kit to simulate the complex soft body impact environment of transparency birdstrike:

1. FEA Elements

- Both 3D solid (HEX and TET) and 2D layered shell elements are provided. The 2D layered shell element accommodates soft interlayers (plane selections do not remain plane over the overall layered shell thickness)

2. Material Models (2D)

- Elastic-Plastic, Rate Sensitive, Isotropic
- Linear Elastic, Orthotropic, Brittle Failure
- Viscoelastic with failure

3. Material Models (3D)

- Elastic-Plastic, Rate Sensitive, Isotropic
- Same as above with Discontinuous P-V
- Newtonian Viscous Fluid

4. Automated Contact Surface Evaluation Procedures

- Slave and Master node sets that are nonlinearly evaluated for contact

5. Simple "Rigid Wall" designation procedures

6. Linked element lists for failure assessments

7. Element and integration stabilization features

An example X3D result is shown in Figure 7. The deformed transparency and bird finite element models are displayed, for the specified time point. A fringe plot of Von Mises stress is displayed on the model.

4.7 OPTRAN

OPTRAN is a raytrace code which evaluates the optical quality of aircraft transparencies subjected to operational load conditions. The code was developed by the University of Dayton Research Institute, References 14 and 15.

The raytrace optical code is interfaced to finite element thermal and stress analysis codes to permit the effects of operational loads to be modeled. Thermal, displacement, and stress field definition data computed by the finite element codes are input to the optics module. This information is required to compute the orthotropic indices of refraction throughout the material volume of the aircraft transparency. This computation is performed at each step along the propagation path of each ray.

The optics code tracks rays of various wavelengths through the transparency. The deformed geometry generated by the stress analysis is used to determine angles of reflection and refraction at transparency layer boundaries. Birefringent indices of refraction are computed as a function of material, temperature and stress state at the refracting surfaces and within the transparency material.

Key results include angular deviation, transmittance, and polarization effects over specified regions of the transparency. Displacement vectors and deformed grids can also be generated.

4.8 C-MOLD

The C-MOLD product is a family of computer codes designed to support the design of tooling and specification of process parameters for fabrication by injection molding, Reference 16. The modular product supports both the processing of thermoplastic and reactive materials. C-MOLD is a commercial-off-the-shelf (COTS) product developed and marketed by AC Technology, Ithaca, NY. AC Technology also provides materials characterization services and maintains a materials database relevant to the injection molding of plastics.

The frameless transparency development is concerned with the use of thermoplastic materials. Therefore, there are three primary processes requiring simulation. These are:

1. the process of the initial filling of the mold (C-FLOW),
2. the post-filling process where shrinkage occurs (C-PACK), and
3. the transient cooling of the part prior to mold separation (C-COOL).

The product modules which address these processes are defined in parentheses above.

The C-FLOW analysis models the mold filling process as a generalized Hele-Shaw (very slow motion) flow (Reference 16). The flow conditions are for an incompressible viscous polymeric melt under non-isothermal conditions and symmetric thermal boundary conditions. The numerical solution is based on a hybrid finite-element/finite-difference method to solve pressure and temperature fields, and a control-volume method to track moving melt fronts. Details of the analysis methodology are presented in References 17 and 18.

The C-PACK analysis module extends the above analyses module to include the effects of asymmetric thermal boundary conditions. A set of unified governing equations for the flowfield is used throughout the filling and post-filling stages. The analyses can model a three-dimensional, thin cavity with a melt-delivery system that may contain cold or hot, circular or non-circular runners. The influence of shrinkage is also included. Details relevant to the C-PACK analysis are presented in References 19, 20, and 21.

C-COOL is a three-dimensional mold cooling simulation to assist in designing the cooling channel system for plastics injection molding processes. The capability exists to model a homogeneous, three-dimensional mold with a thin cavity and with a cooling system that contains circular or non-circular channels, baffles and bubblebers. A channel network analysis within the program within C-COOL predicts flow rates in different cooling lines.

The C-COOL module uses a strategy which minimizes input data requirements, user time and computer memory requirements. Heat transfer within the polymer melt is treated as transient, local, one-dimensional heat conduction with static solidification. Heat transfer within the mold is treated as transient, three-dimensional conduction. Heat exchange between the channel surfaces and the cooling fluid is treated as steady and is accounted for using correlations for the convective heat transfer coefficient. To solve the relevant governing equations simultaneously, C-COOL uses a hybrid scheme consisting of a modified, three-dimensional boundary element for the mold region and a finite difference method with a variable mesh for the melt region. These two analyses are coupled iteratively to match the temperature and heat flux at the mold/melt interface. A special algorithm has been developed which reduces the computational memory requirements by a factor of 100, compared to the requirements for a traditional approach.

An example C-MOLD result is shown in Figure 8. Shown is a result from the C-FLOW module, which shows the melt front as a function of time during the mold filling process. The example modeled the Configuration Frameless Transparency, using a representative polycarbonate resin.

4.9 P3/ANIMATION

P3/ANIMATION is a powerful tool that offers interactive visualization, animation, photo-realistic rendering and video tape output of geometry and results data, Reference 22. It is designed to assist engineers in the investigation and presentation of data which are normally very difficult to visualize. With P3/ANIMATION, information can be displayed in a number of different ways including: Wireframe, Hidden Line, Solid Shaded and Fringed models. Display can be further enhanced with the use of motion to view the data from a variety of angles and a host of other variables such as transparency, surface coloring and shading characteristics.

P3/ANIMATION uses on-screen animation to show geometry and results as dynamic moving pictures. After completing an analysis in P3/PATRAN, static, modal and transient data sets are read directly into

P3/ANIMATION. The user then has complete control over visualization in both space and time. Models may be positioned or rotated to gain a better view and any single time step or range of time may be examined. Fringe plots and arrow fields are used to display scalar and vector data, respectively, and model deformations may also be displayed. Sophisticated timing controls can be used to zoom in on portions of the analysis that are particularly interesting, while skipping over portions of less interest.

The Animator Tool can be used to create simple or key frame animations. In simple animations, models cycle through the results data while rotating about a single axis. In key frame animations, different groups can be posed with various rotations, scales and rendering transforms applied. Posing allows for much more creative and illustrative animations, in which many attributes and transforms can be set or varied over time.

Once an animation is defined, the Flipbook Tool can be used to compute sequences of frames or flipbooks for subsequent playback on any X Windows device in the network. Flipbook images are created and displayed using available graphics hardware to increase performance.

5 CONCLUDING REMARKS

ADP2 has been designed specifically to support the Air Force Frameless Transparency Program. But the package will be capable of a wide range of design and manufacturing applications. The completion of the planned work will provide an important suite of tools to aid in the design and performance evaluation of injection molded transparency systems. The validation of these tools will be a critical aspect of the ADP2 development process.

ADP2 provides a fully integrated methodology relevant to the general problem of aircraft transparency design. A key aspect of ADP2 is the seamless integration of the analysis modules with P3/PATRAN, an advanced commercially supported CAE integration tool. This integration provides a single form driven user interface which serves to manage the analysis process and the analysis module input and output (results) data. The user remains in an intuitive environment and is freed of the complexities and/or peculiarities of the computer operating system throughout the entire design process. The support provided by the employment of a commercial CAE integration tool and the selection of state-of-the-art application modules will provide Air Force and its contractors with a cost effective tool with a significant life potential.

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