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Scenario-Based Affordability Assessment Tool

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Introduction:

Conceptual design in a technology-driven environment happens when reliable and rapid analysis procedures respond to creative design ideas. The value of a design depends on a number of factors. These factors include accurate weight and cost estimates. The Scenario-Based Affordability Assessment Tool (SBAAT) concept addresses these factors with a new approach toward product development and technology investment planning. The resulting design environment (code named MISTC) is currently in the earliest stages of commercial development.

Product development derives benefit from high fidelity data early in the design process. Design intelligence is developed and decisions become responsive to high-level changes. The output of this high fidelity design process allows a system definition with a lower development risk. The authors believe these assumptions are commonly held among the majority of designers.

The improved design activity described in this paper has been called "concept refinement" (CR). CR is appropriate after mission requirements and configuration concepts have been established. These starting concept designs are based on historical regressions and intuition for weight and cost. The CR phase adds significant knowledge where the concept design deviates from historical precedent. The proposed CR process involves the integration of geometric design tools (for vehicle level innovation), knowledge based modeling tools (for rapid product description and modeling), high fidelity modeling tools (for physics-based data generation including manufacturing cost) and operations modeling tools (for system effectiveness studies such as engagement modeling done for the military). Through a philosophy of smart product modeling, the CR process is facilitated. To prove the utility of these assumptions, the Scenario-Based Affordability Assessment Tool (SBAAT) is a design-modeling product, which draws from several commercial sources including MSC.Software and TechnoSoft Inc.

The Air Force Research Laboratory (AFRL) and Lockheed Martin Aeronautics Company (LM Aero) have joined in the cost-shared development of a dual-use product-modeling environment for guiding a concept refinement process in terms of affordability. The target customers will include vehicle manufacturing industries (aerospace and automotive) where early decisions in product development have large consequences in subsequent production. AFRL interests lie in the development of a modeling environment for technology assessment, which anticipates (by necessity) military system product development. The target military application is the Simulation-Based Research and Development (SBR&D) initiative at AFRL Air Vehicles Directorate. At the heart of SBAAT is AFRL's role in identifying technology needs and prioritizing technology solutions with unprecedented attention to affordability issues.

Paper presented at the RTO AVT Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation", held in Paris, France, 22-25 April 2002, and published in RTO-MP-089.

The objective of this paper is to describe and document the practicality, usefulness and payoff in the proposed CR process for meeting affordability interests related to new product design and vehicle technology development.

Simulation-Based Research and Development:

SBR&D provides a common, affordable and flexible environment to improve all phases of a technology's or weapon system's life cycle. In Figure 1, the components of SBR&D are depticted. These are (1) the design analysis process (2) the weapon system analysis and (3) the cost analysis. These three components are all required to generate a meaningful Distributed Product Description. A number of new software developments are required before this process will respond at the envisioned high rate and with the required fidelity. The SBAAT initiative described in this paper will support the rapid Design Analysis component.

The rapid response of the CR models is dictated by the needs of the SBR&D process. SBR&D operates at the engagement level with different mixes of mission objectives, blue and red team assets, and proposed technologies (either individually or integrated as a package). CR models must be rapidly synthesized to set up the SBR&D experiment and capable of overnight reconfiguration with new datasets reflecting new concept capabilities afforded by technology variants.

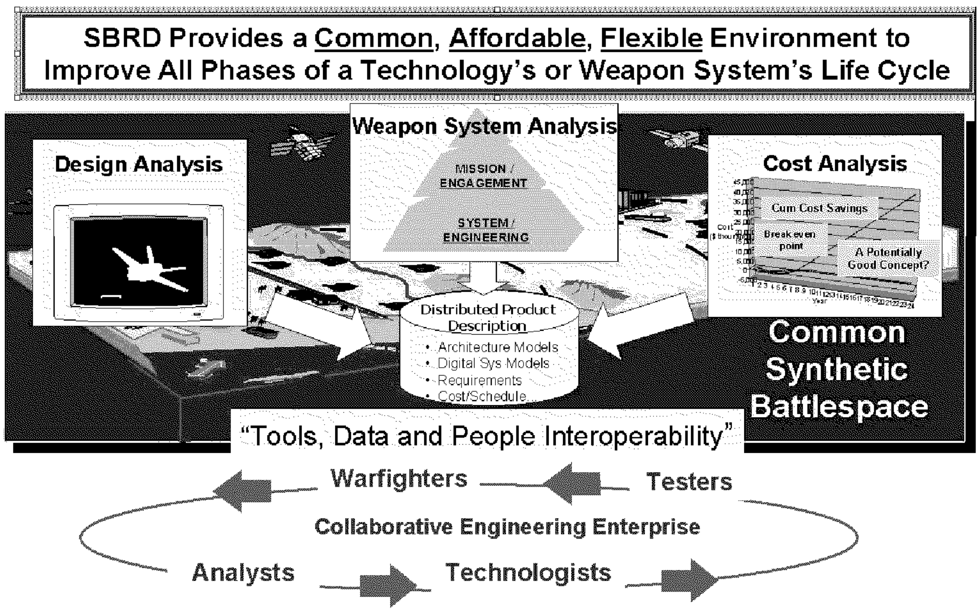


Figure 1: Elements of Simulation-Based Research and Development Initiative

Candidate SBR&D scenario scripts:

The recent proliferation of UAV concepts requires the military to take a fresh look at technology investment. For instance, with the pilot safely out of the cockpit, the relationship of vulnerability and cost can be revisited. For instance, SBAAT will help technology planners identify the best investments for maneuverability and stealth technologies.

The military focus on hypersonic systems also requires a fresh look at technology investment. The cost of sustained hypersonic system operations is heavily influenced by maintenance costs associated with thermal systems. SBAAT will help technology planners identify the best technology investments for affordable operations. For instance, research and development for reducing the cost of hot structures products may be given higher priority over extending hot structures performance.

Background:

Adaptive Modeling Language (a product of TechnoSoft Inc known as AML) has evolved from an in-house (Materials Directorate of AFRL) feature-based design project to a commercial product in use by a number of industries. AML is an object-oriented environment with built-in dependency-tracking and demand-driven calculations that facilitate the integration and control of all aspects of the design process. With dependency tracking, AML facilitates the control of a large number of design alternatives with a single set of driving requirements. Dependency tracking can also be used to facilitate design parameterization and rapid product description through associative properties. With demand-driven calculations, the designer can readily control when and how design information flows.

A significant number of design process innovations have arisen from the AML and it's Web-enabled Design Environment initiative (ref 9 - 11). They cover a number of topics including concept modeling, manufacturing, cost and optimization. Boeing Co developed the PACKS code (ref 5) for composite laminate process modeling. Currently, PACKS is under commercial development. LM Aero internally developed CAD-C in the AML environment for vehicle assembly planning. AFRL entered into a contract with LMAC, which led to the development of Scenario Based Synthesis (SBS), a pilot code for SBAAT development (ref 3). Foster-Miller was funded by AFRL to explore the potential for AML to model their processes with a view toward Web-enabled Design Environment. This proprietary work is documented in reference 12. SBAAT team member, MSC.Software, has developed MSC.FLD (Flight Loads and Dynamics) environment (ref. 13) to work seamlessly with their flagship products, MSC.Nastran and MSC.Patran. In addition, AFRL has invested in a number of other structures modeling innovations such as Interface Elements with Applied Research Associates (ref 6) and MSC.ASTROS for preliminary level multidisciplinary structural optimization (ref 7).

Past and ongoing in-house research in the application of AML in AFRL is documented in references 1, 2, 4 and 8. An early vision for the current development arose from references 1 and 2. An in-house cost-modeling endeavor was covered in reference 4. An example of ongoing in-house effort with joined-wing modeling is addressed in reference 8.

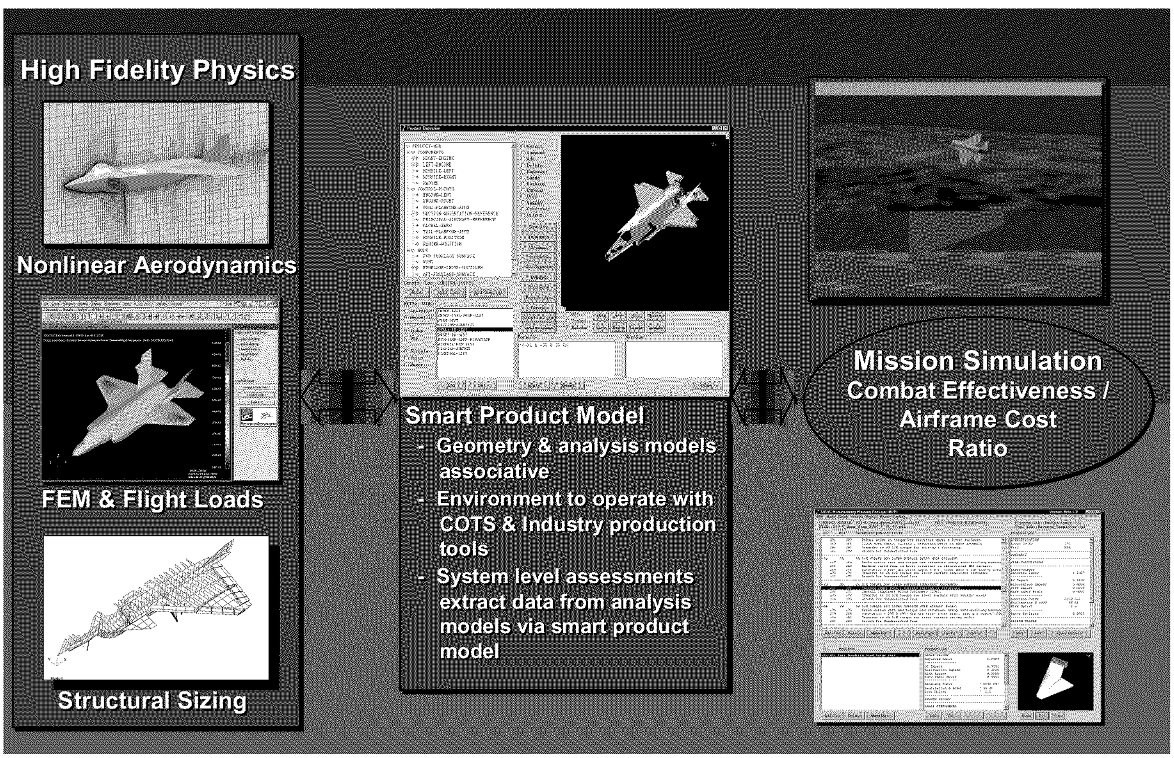


Figure 2: SBAAT Technical Vision is to Implement Smart Product Modeling for Rapid Assessment of Structural Integrity and Costs

Technical Goals:

The technical goals for this program range from successfully implementing the SBAAT conceptual approach to validating concept payoffs. Specifically, the SBAAT program will

- Create a streamlined software environment for integrating high-fidelity physics-based simulation tools with mission simulation tools
- Reduce cycle time for mechanical-structures concept definition, integrity analysis, and manufacturing cost assessment by 75%
- Integrate a process-based affordability assessment into technology development
- Demonstrate our proposed system in a USAF technology planning exercise and a commercial technology planning exercise.

These goals will be accomplished with available commercially based software products that are currently being used to model many products. The SBAAT team will provide integration of structural analysis tools such as MSC.Nastran, MSC.Patran, and MSC.FLDS (Flight Loads and Dynamics System). Through TechnoSoft's AML smart product model concepts will be implemented. Smart product modeling is modeling that builds automatic associativity between product description and product behavior. Smart product model requirements establish context of product development that facilitate layout, sizing, and producibility assessments of structure. Aircraft and automotive applications will be developed.

The technical vision for the SBAAT program is depicted in Figure 2. In the middle of the figure and the process is the development of product data and an associative smart product model. At the left side of the figure are the models that are required to evaluate the structural integrity of a product. At the right hand side of the figure are the system level metrics of the product. The desire is to expedite product behavior analysis such that the product user may understand the benefits of the product concepts and technologies in terms of system performance and cost.

Functional Description:

A primary objective in the SBAAT program is to define and develop smart product modeling relationships in a modeling and simulation environment that facilitates the types of studies performed in the concept development and technology assessment phase of product development. These studies are performed on configuration variants and historically, are known as trade studies. The process of evaluation includes definition of variants to be studied, development of product geometry and associated product data, assessment of product behavior and cost, and finally, a roll-up of behavior and cost into a system level scenario. The variants are evaluated across the range through established performance metrics. Metrics such as weight and cost roll-up into scenario based assessments such as life cycle costs and mission performance. The SBAAT program is focused on the structural integrity and costs aspects of the overall system.

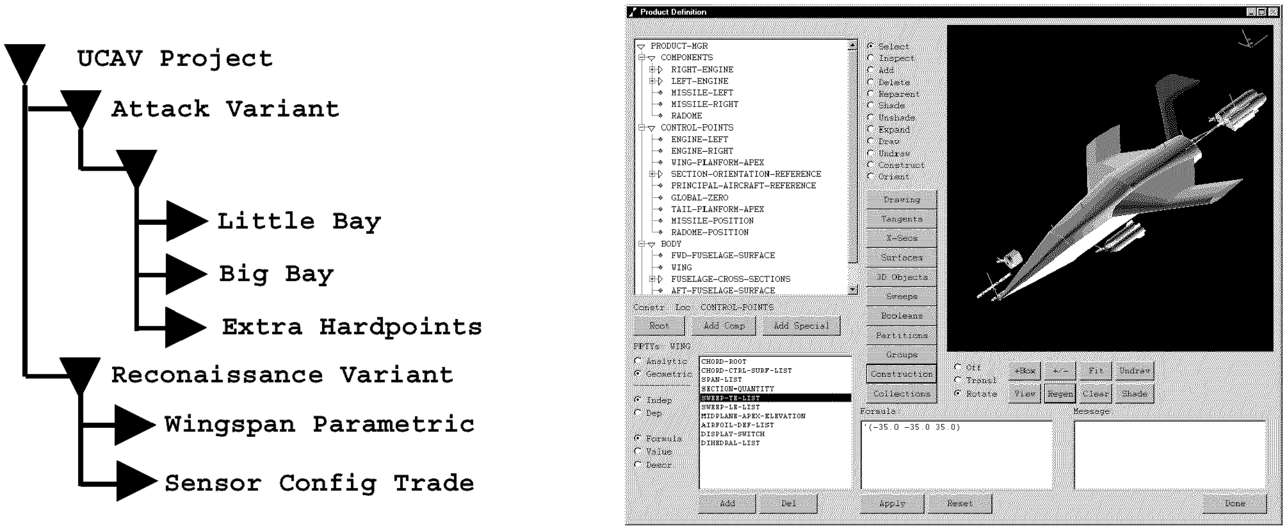


Figure 3: Conceptual Workbench for Product Definition

Configuration Trade Studies: The SBAAT environment will allow a geographically distributed team of engineers to create, maintain, store and retrieve configuration variants in the most efficient approach. While AML does provide a powerful demand-driven environment with run-time object creation, the volumes of data which result from such data operations (finite-element models, aerodynamic models, costing etc) demand the use of efficient database operations for configuration studies and reviews. With SBAAT, configuration changes can branch off at any level of the product description. Objects are not copied. Instead the use of AML's dependency tracking allows rapid propagation through all dependent configuration variants. Data dependencies then are tracked through the user workbench as illustrated in Figure 3.

From the workbench depicted in Figure 3, the user may define multiple weapons carriage concepts that are tracked as configuration trade variants. Another example (not shown) would depict a family of spar spacing concepts that are stored as well, as configuration variants, while maintaining dependency on wing geometry. Of course, changes in geometry may result in large number of calculations for each analysis model in the configuration study. With the demand-driven feature of AML, calculations are performed only when the user demands the output. New configurations are developed by editing the current model and saving the results along with the other configuration variants. Configuration options are callable from an automatically generated tree structure using the efficient filtering operations made possible through the AML environment. Time intensive calculations may be saved for batch processes that are scheduled at convenience.

Geometric Modeling: AML has been successfully deployed with a number of geometry engines. While supporting standard interface for geometry, initial SBAAT development emphasizes ParaSolids with its open environment and existing links to MSC.Software products. Using AML to drive ParaSolids, a number of geometric modeling innovations are being considered for rapid generation of conceptual design studies. One such innovation, Morphing-object, was developed under an SBIR contract with TechnoSoft. This is a procedure for developing a refined geometry transition between controlling sections along a prescribed trajectory. Polygon sections can be morphed into curved sections. Another geometric modeling innovation is the seamless link between AML geometry models and Patran meshes. With this capability, mesh refinement can be controlled at the object level with user-specified dependency on a number of geometric parameters. Control at the object level is key to the smart product modeling concepts because it propagates associativity. Resulting meshes will be used as input to MSC.Software products such as MSC.FLD and MSC.Nastran.

Analysis Tools: Within the SBAAT approach, a product concept is defined, modeled, analyzed and iterated. In defining the product the user emphasis is in describing; geometry, material properties, wing attachment concepts, control surface hinge and actuation concepts, manufacturing processes. The product description acquires modeling information for associated analysis. Regions of the structure are tagged for meshing by the user within the AML workbench. This is done through the use of rules applicable based on historical needs and then is meshed within MSC.Patran. Rules for mesh density are provided in the interface for the user to select as the model is developed. Within a menu driven system, the user may define product functionality, and the analysis models will derive associated attributes.

A variety of emerging technologies are being considered within the SBAAT environment. One such technology is interface element technology in which parts may be meshed independent of assembly. Geometric compatibility may be provided through the AML environment. The interface element then provides the integration of subassemblies.

MSC.Software products will allow structural integrity assessment within the SBAAT environment. MSC.Nastran provides industry with the standard finite element analysis capabilities merged with a multidisciplinary suite of tools for aeroelasticity and structural optimization. This tool suite is well advertised http://www.mscsoftware.com/. Functional analyses such as static, modal, and aeroelastic analyses are performed within MSC.Nastran. An example of such associative modeling and analysis is provided at the end of the paper.

Cost Synthesis: From a design perspective cost at the early stages of technology development is relative as well as absolute. Compared costs and cost consequences are used in trade studies to prioritize technology implementation and thus, technology maturation. There are many ways to account for cost at the conceptual level. There are simplified weight-based parametric cost models based on historical regression. These are useful for projecting cost with old technology - but potentially misleading where new technology is considered. For instance, technology development in composite materials and manufacturing is focused on reduced labor and processing time. Weight based approaches have no parameter to capture such attributes. Integration issues in technology or concept development are evaluated with respect to cost consequences, and cost is one of those areas where "the devil is in the details."

An alternative to weight-based parametrics is process-based cost models. These models are readily developed with currently available software tools as will be shown in this paper. We expect they can be usefully formulated in terms of confidence intervals for identifying cost risk. Process based models decompose the cost down to whatever level of detail is required to make a judgement. However, decomposing the cost in terms of materials, labor, assembly, outsourcing, capital investment and any other overhead is not the whole story. This capability has to be put into the hands of the lead designer who is making rapid decisions, which have a strong influence on the cost. This capability is addressed in reference 4.

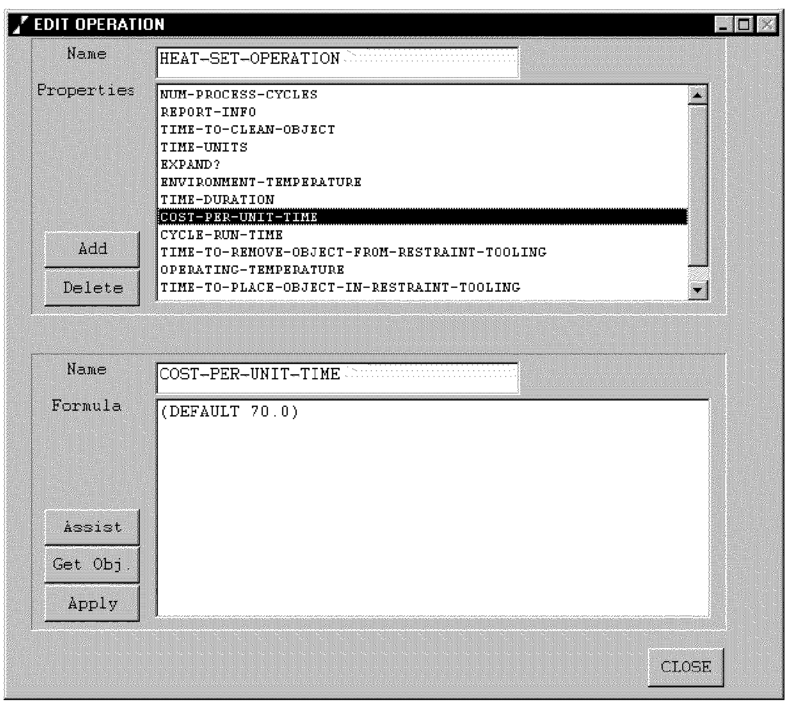


Figure 4: Proposed Edit Manufacturing Operation Form

Manufacturing operations are gathered from various sources for the purpose of synthesizing a cost strategy and identify opportunities for affordability. With SBAAT, the concept designer will have easy access to the operation's time estimates through a graphical user interface. Likewise, other properties and relationships, such as labor rate ($/hr – which is unique within each company), will be customized by the user within an Edit Operation form as depicted in Figure 4.

In general terms, the manufacture of a component occurs by a single operation or by an ordered sequence of operations. The user can browse through the Operation Catalog by utilizing the quick view capability. This allows the user to get a top-level view of any selected operation's properties and children (operation sequences). In order to assign an operation or predefined operation sequence, the user must select it from the Operation Catalog, and then transfer it to the Operation Sequence list. This notifies CAPTURE (ref 4) that the selected process is required to define the component's fabrication. For a multi-step manufacturing procedure the user continues to select and transfer operations to the Operation Sequence list in a user-prescribed order. The form that drives a carbon-carbon woven beam is depicted in Figure 5.

Once the components have been created, the user begins the second task of creating subassemblies. Two-part in nature, this task requires the user to group any number of components and/or subassemblies together, and apply manufacturing assembly techniques to join the components into a unified assemblage.

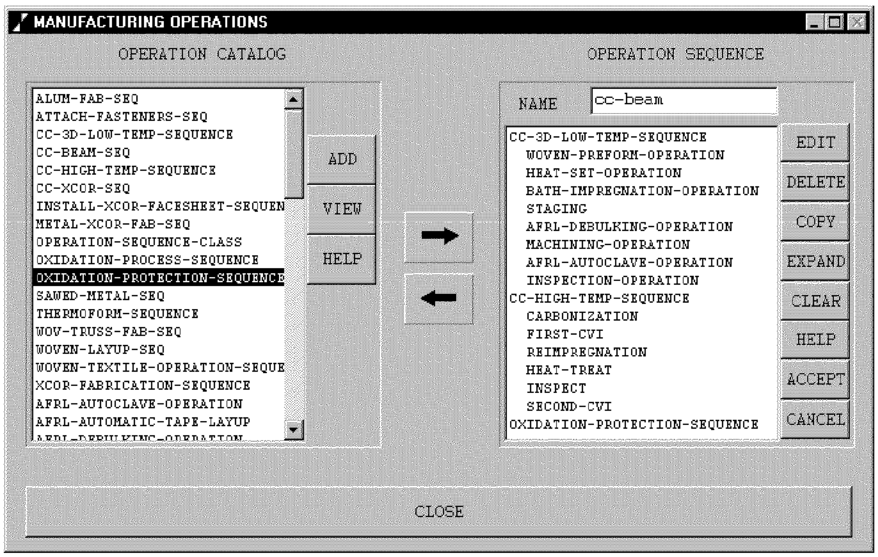


Figure 5: Proposed Manufacturing Operation Catalog

The CR process needs to be responsive to SBR&D data needs at the engagement level. The SBAAT cost models must anticipate the SBR&D needs with prior synthesis, which can be rapidly recalled during the exercise. While the exact cost will never be achieved, specific affordability issues can be addressed. For instance, the projected consequence with respect to a limited set of technologies will be anticipated in SBAAT models.

Smart Product Modeling:

The most time consuming paths in CR is the creation of product analysis models from product description and the update of product description from design changes based on product analyses. Our philosophy of smart product modeling (SPM) is to facilitate the modeling functions needed as depicted in the illustration shown in Figure 6. SPM enables user-defined automated operations that tightly integrate geometric and nongeometric product description data with product behavior data.

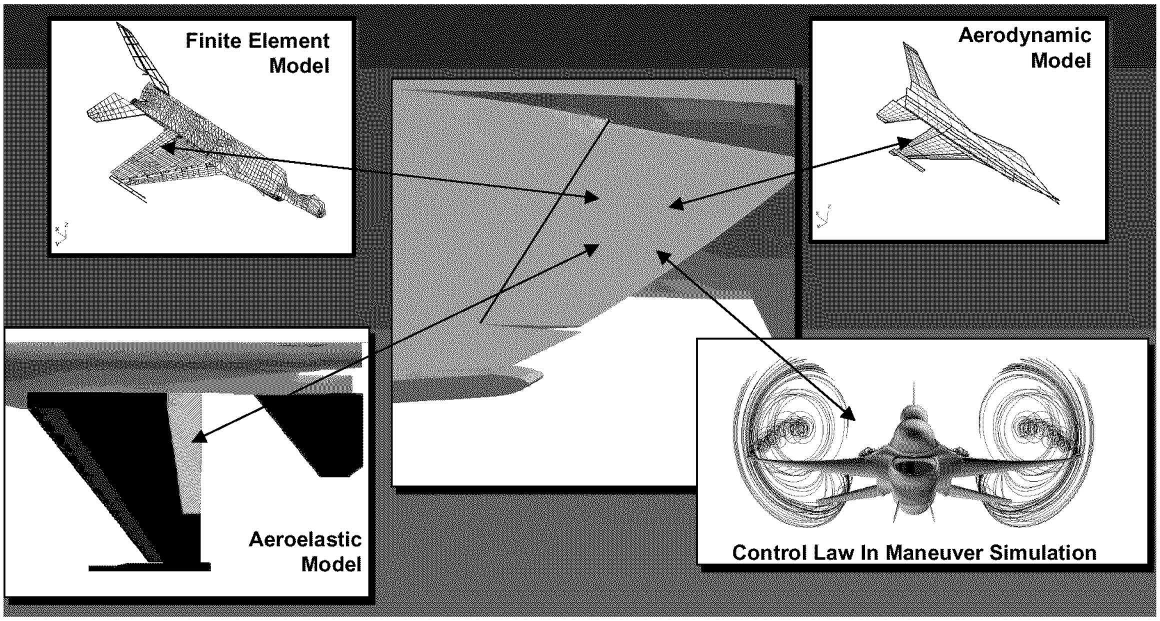


Figure 6: Smart Product Model Role in SBAAT

For example, an aircraft control surface is defined through geometric representation, and it behaves by rotating about a hingeline. The intelligence related to rotation about a hingeline delineates an aircraft maneuver and control mechanism. These attributes are required in the development and use of aerodynamic, structural, and loads models for structural integrity and weight analyses. In another example, an automobile door panel may be defined with a resin-transfer mold process that thus, determines design allowables for structural sizing. Applying smart product modeling provides building blocks for automated modeling and thus, rapid modeling for rapid development of product behavior data. This philosophy will decrease modeling time and enhance trade study capacity in lieu of time and manpower constraints.

The SPM operations encapsulate engineering analysis processes including data flow and translation and thus, enhance multidisciplinary design. Extensive detail of engineering processes are mapped through an object-oriented approach from the creation of a product data description through the development of analytic models and the ensuing high fidelity computational analysis. SPM then provides traceability from the derived design back to the product description. Thus, in the end of trade studies, design decisions are traceable directly to design requirements.

Technology trades and configuration trades will be worked together. With rapid-response product behavior data, scenario based mission performance and cost may be evaluated rapidly as well.

The evaluation process may provide either (1) a sound suite of technologies optimal for a given scenario or (2) to assess technology maturation requirements for a given scenario. The parametric based smart product model lends to design of experiments, probabilistic design, and genetic based algorithms.

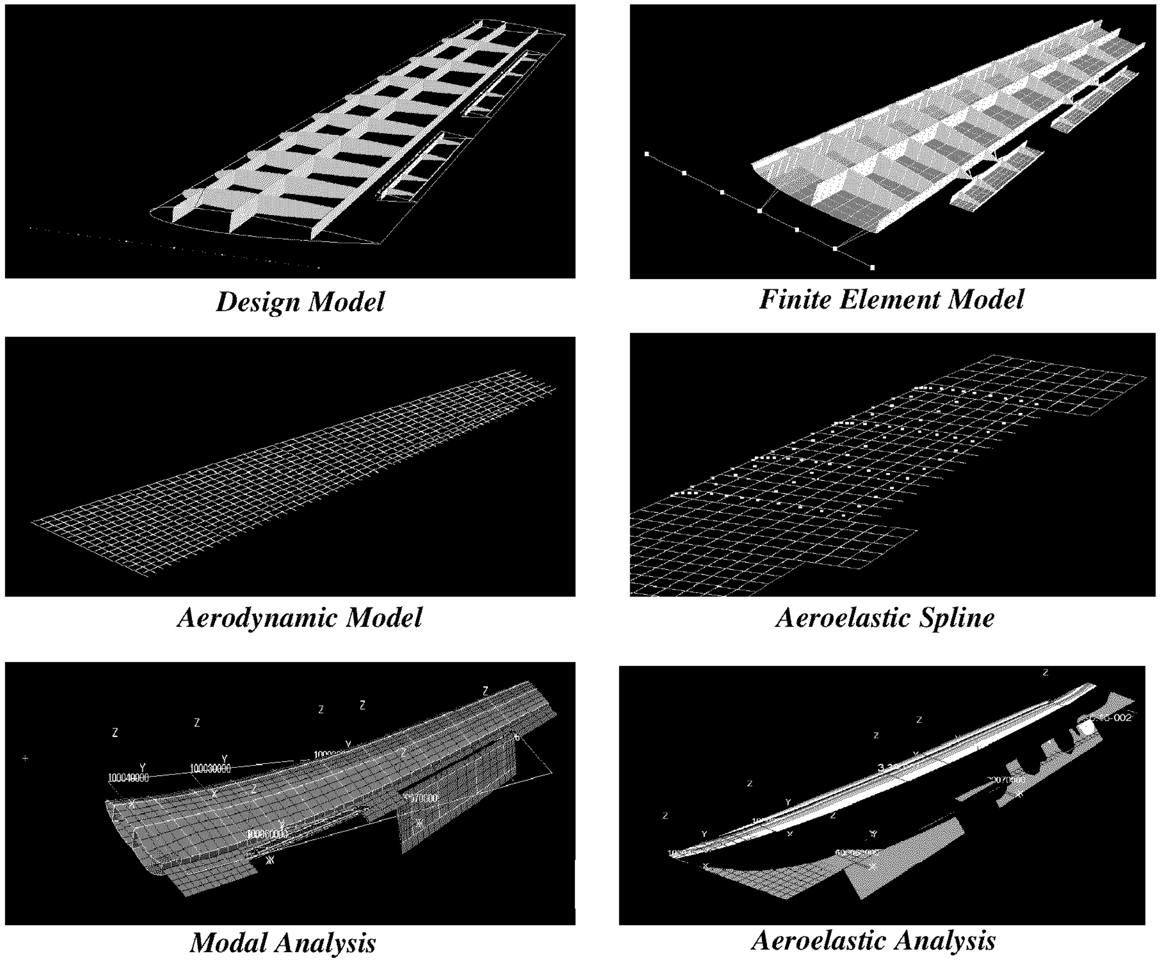


Figure 7: Stages of Product Description and Evaluation

Concept Pilot - Wing Design Example:

A concept pilot environment was developed to initiate the integration of AML, MSC.Nastran, MSC.Patran, and MSC.FLDS and demonstrate key features of smart product modeling. A wing design concept was defined and analyzed. Within the environment, structural arrangement variations are analyzed rapidly including modal and static aeroelastic disciplines. Weight approximation, flight control flex-to-rigid ratios and structural load paths will be available for future refinements in the context of smart product modeling. Figure 7 illustrates various stages of product definition and assessment.

The wing aspect ratio, span, taper, leading edge sweep and airfoil definition are specified. The trailing edge control surfaces and hinge lines are specified. The front spar of the control surfaces and the rear spar of the wing box are set by spacing criteria from the hingeline. Since there is no leading edge flap, the front spar is set by spacing criteria from the leading edge. The wing box spars and rib locations are specified in case parametrically, but may be quite arbitrary.

From the product definition, the structural finite element model is developed automatically. For a wing of this description, the solution is easy within a tightly integrated computer aided design system. The point of this demonstration however is in the concurrent tasking in server/client relationship; in this case, AML and MSC.Patran. In addition to the discrete components that are modeled (i.e., wing box and control surfaces) is the automated linkage through hinges and actuators. The user specifies hinge and actuator locations and types in AML, and the system creates the attachments.

The second row of pictures in Figure 7 illustrates the concurrent tasking between AML and MSC.FLDS (Flight Loads). A doublet lattice aerodynamic model is created through a user defined model that extracts key features from the product description (e.g., planform, control surface definition). Then from user parameters that drive the mesh density, MSC.FLDS automatically creates the aerodynamic model. To link this model to the structural FEM, a spline definition must be created. Historically, a user must perform the tedious task of creating spline boundaries and selecting structural grid points suitable for the spline. This is performed automatically with the aid of predetermined standards in the structural finite element and aerodynamic panel models as well as the selection of grid points only along defined structure (as depicted in Figure 7 for the Aeroelastic Spline).

The third row of pictures in this figure depicts results from a modal analysis and a static aeroelastic analysis. A key feature also explored in the pilot concept is the spline verify feature in MSC.FLDS. This feature uses the mode shapes to graphically verify the spline. The deformation shape for each structural mode is superimposed on the aerodynamic model through the spline. The Modal Analysis picture is captured from this analysis with the structural finite element model and the aerodynamic model shown together. Once assured a valid spline, the user may confidently proceed with the aeroelastic analysis.

The second point of the pilot was to initiate definition of the smart product modeling scheme for SBAAT. In so doing the utility of the pilot should demonstrate rapid response in the definition of a configuration variant. In Figure 7, the concept has four spars and nine ribs. Note that there is no root rib. In the Modal Analysis, the root is cambering as the wing deflects. A second concept and associated results are shown in Figure 8. This concept includes five spars and eleven ribs. A root rib has been defined in this concept. Note the modal results. There is no cambering in this concept. The point, here, is not that cambering is a feature of interest, but rather the behavior of the structure may be rapidly assessed for configuration variants.

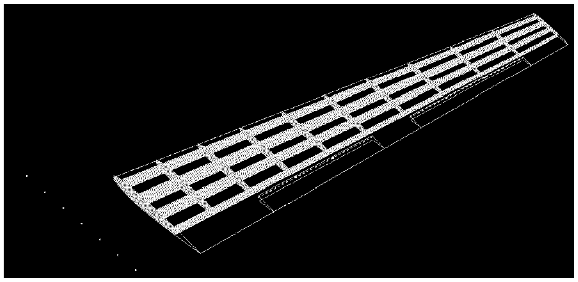
Figure 8 repeats the sequence of operations depicted in Figure 7 for a four-spar configuration. While one might not expect a large weight difference and subsequence performance improvement, questions still remain as to the most effective structural layout in terms of weight and cost. This simple design trade example is appropriate for the SBAAT team to get started. More complicated design trades will be encountered during the course of the program.

Summary and Conclusions:

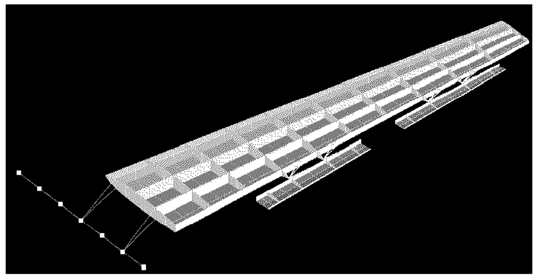
It goes without question; vehicle systems in the next generation will grow more complex. Complexity tends to favor conservative design evolution. Design revolution requires a design modeling environment that can reduce design complexity into metrics that a single designer can understand. For instance, multifunctional structures promise drastic performance improvements and reduced maintenance cost. However, the vehicle designer still needs to capture the fundamental metrics of weight, drag and cost before technology benefits can be understood rationally. Instead of prescribing miracles based on historical guesswork, MISTC software enables a designer to clearly demonstrate how and why new ideas will work and where to place one's developmental focus.

There is little doubt the ongoing developments are setting the stage for designing innovative vehicle systems for the next generation. SBAAT software developments will decrease the time for a team to synthesize a technology-laden design. Subsequently, a single lead concept designer will further explore design space with rapid reacting physics-based models. The customer will communicate needs more clearly with technology development placed in a vehicle and mission context, the raison d'etre for Simulation-Based R&D. Ultimately, this environment will replace risk aversion with excitement for sound technology development.

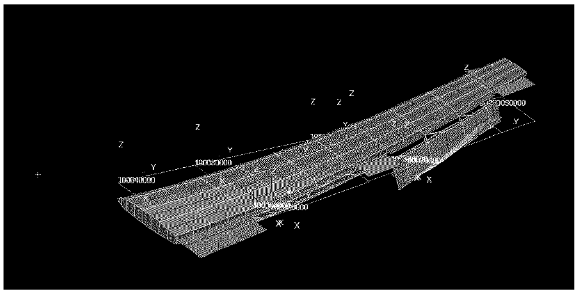
SBAAT represents a bold step by MSC.Software with aggressive software innovation made possible in this collaboration with TechnoSoft. There is every reason to believe this approach will grow and succeed for future generations with their commercially supported open software approach.



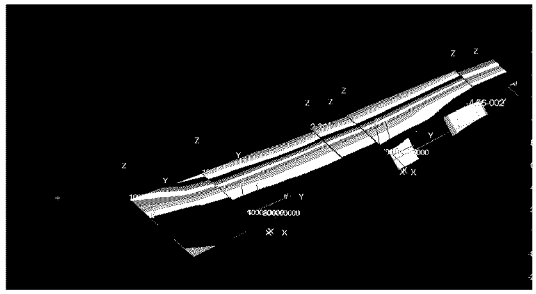
Design Model



Finite Element Model



Modal Analysis



Aeroelastic Analysis

Figure 8: Configuration Variant Rapidly Defined and Reanalyzed

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