WL-TM-97-3070

Conceptual and Preliminary Level Modeling of Wings Using the Adaptive Modeling Language

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June 1997
Final Report for Period September 1996 to June 1997

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1997

3. REPORT TYPE AND DATES COVERED
Final Report, September 1996 - June 1997

4. TITLE AND SUBTITLE
Conceptual and Preliminary Level Modeling of Wings Using the Adaptive Modeling Language

5. FUNDING NUMBERS
PE: 62201F
PR: 2401
TA: LA
WU: BR

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Structures Division
Flight Dynamics Directorate
Wright Laboratory
Air Force Material Command
Wright-Patterson AFB, OH 45433-7542

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Flight Dynamics Directorate
Wright Laboratory
Air Force Material Command
Wright-Patterson AFB, OH 45433-7542
POC: Dr. Maxwell Blair, WL/FIBD, WPAFB, OH 45433-7542; Ph: (937)255-6434

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
WL-TM-97-3070

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; Distribution is Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This memorandum demonstrates a methodology for an automated design process. The design process was developed in the Adaptive Modeling Language (AML). This effort concentrates on developing a system for linking conceptual level wing geometric parameters to a preliminary level finite element model. This environment allows for rapid changes in the geometric parameters of the wing planform (e.g., wing sweep, span, chord length, etc.) as well as the capability for updating internal substructure (i.e., number and placement of ribs, spars and stiffeners) in an integrated environment. In this effort, a fully associative geometric design model (developed in AML) is coupled with an aerospace structural optimization code, ASTROS.

14. SUBJECT TERMS
Object-oriented, design process, composites, fully associative, finite elements, design architecture

15. NUMBER OF PAGES
25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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Preface

This technical memorandum was prepared by Ms. Geetha Bharatram, Wright State University under contract F33615-94-C-3211 titled "Object-Oriented Multidisciplinary Design of Aerospace Structures", and Dr. Jeffrey V. Zweber, Design & Analysis Branch, Structures Division of the Flight Dynamics Directorate. This effort is in support of the Multidisciplinary Design IPT, performed by the Flight Dynamics Directorate of the Wright Laboratory. This report documents the development and integration of conceptual and preliminary level design objects for structural analysis in the Adaptive Modeling Language.

This technical memorandum covers work accomplished from September 1996 to June 1997.

This memorandum has been reviewed and approved.

1. Introduction

Composite designers are quick to point out that if only the conceptual designer understood the nature of composites, they would lay out geometry which is compatible with the material limitations and manufacturing processes for affordable structures. There would be no sharp corners, no bolted joints, fewer parts and so on. If the conceptual designer worked with high fidelity design processes and criteria, he could find a way to realistically apply composites to primary structures.

Feedforward and feedback in the design process is extremely valuable in the composite design process. Consider a simple isolated example: the outer moldline of a wing. Traditionally, when a conceptual airframe design is completed, the outer moldline is generally assumed to be frozen. This freezing is a result of a compartmentalized design process. The output from a conceptual design is really a set of loose design requirements (e.g., fuel weight, specific fuel consumption, aspect ratio, etc.). The goal of the conceptual designer should not be to freeze the outer moldline.

With design feedforward and feedback, the conceptual designer can be part of the process for identifying the best outer moldline. It may be that if the conceptual designer had more accurate information, a different design concept would come to the forefront. Without feedback, the conceptual designer of combat aircraft is depending on historical data. This is an interesting paradox because there has never been an all-composite military aircraft.

The designer of aerospace vehicles has the option to choose from a large suite of viable materials and processing concepts. The set of composite design guidelines for each process is too expensive and complex to capture at the conceptual vehicle level. There is a need for a composite aerospace structures design process which is tightly integrated with bidirectional dependency between conceptual and preliminary levels. Bidirectional dependency fully integrates composite design details such as stress, weight and cost with important vehicle performance metrics such as range and maneuverability.

This research effort concentrates on developing a system for linking conceptual level wing geometric parameters to a preliminary level finite element model. This environment allows for rapid changes in the geometric parameters of the wing planform (e.g., wing sweep, span, chord lengths, etc.) as well as the capability for updating internal substructure (i.e., number and placement of ribs, spars, and stiffeners) in an integrated design environment.

In this effort, a fully associative geometric design model is coupled with an aerospace structural optimization code, ASTROS. The intention behind this development is to rapidly regenerate a finite element model from geometric surface features, perform a MultiDisciplinary Optimization (MDO) to resize the thickness of the structural elements, and then feedback preliminary level weight information to the conceptual level. The designer may be interested in a trade-off between structural weight and aerodynamic drag as the wing geometry is varied. For such a design study, the structural weights data generated by ASTROS is important.

The point here is to extend full associativity from just conceptual level geometric parameters to the preliminary level finite element models. With this system, the designer can proceed with the process in a minimal time, depending only on computer speed.

2. Integrated Tools

2.1 The Adaptive Modeling Language

There is a growing movement toward the use of commercially available design architecture software [1]. Some of the features of these software architectures, which help the designer to develop a design process, are:

1. Knowledge-based capability [automated rules and tools]
2. Data process control [spawning, linking, parallel processes]
3. High-level, object-oriented language
4. Extensive library of design objects [manufacturing processes, geometric modeling, FEM, mesh generation, graphical user interface elements].

To address the issues surrounding the integrated composite wing design environment described in section 1, reference will be made to the Adaptive Modeling Language^{TM} (AML) architecture. AML has evolved from an in-house feature-based design project to a commercial product in use by industries ranging from automotive (e.g., Ford and Volvo), to aerospace (e.g., Lockheed-Martin and McDonnell-Douglas), and power generation (e.g., Balke-Durr and Siemens). AML already has built-in objects to address complex meshing and manufacturing issues. This architecture enables the user to interactively propagate constraints across several modeling systems.

AML [2] is a comprehensive, feature-based modeling environment for the integration of design specifications, geometry, manufacturing, inspection, and analysis processes into a unified part model. AML provides a Knowledge Based Engineering (KBE) framework that captures the engineer's design process and results in models that contain the design intent.

Various aspects of a design can be detailed through a single unified model in AML. For example, in the case of wing structural design, first a geometric concept is created. This concept may have many parameters of interest (e.g., span, chord, sweep, airfoil data, etc.). Based on these parameters and the conceptual geometry, the knowledge for generating a finite element model and performing an analysis/optimization can be added/captured. AML allows all this information to be stored within a single model. Furthermore, knowledge for manufacturing, inspection, tooling and cost can be incorporated in the same model.

Feedback could be provided at various stages to different entities in the model. A Graphic User Interface (GUI) for the given design problem/process can be created. The GUI can be associated with the same part model that encompasses the various aspects of the application.

AML inherently supports **demand driven calculations** and **dependency tracking.** Until a value is demanded, an internal flag refers to the property value as being *unbounded.* Hence several properties that effect a certain property can be modified, but the effected property does not need to be recalculated every time, only when it is finally requested. Dependency tracking is the mechanism that actually propagates design changes throughout the part model. When a property is modified, all the properties in its effect list are smashed (unbounded). With dependency tracking, AML facilitates the control of a large number of design alternatives with a single set of driving requirements (feedforward). Dependency tracking can also be used to facilitate design parameterization (feedback).

For example, dependency tracking and demand driven calculations can be used with a wing structural model. The mid spar location effects the overall structural box geometry, the finite element model and the results of the finite element analysis. After changing the mid spar location in AML, the architecture notifies all of the effected models that they are no longer current (they are unbounded). Demand driven calculations allow the engineer to view the structural box geometry for numerous mid spar locations without being required to wait for the finite element model to be recalculated. Additionally, dependency tracking will ensure that when the FEM is requested, all of the objects that are required to make the FEM are current and will be recalculated if needed.

AML provides a feature based design environment. Geometric as well as non-geometric features can be modeled. Attribute tagging and propagation are being utilized for associating non-geometric information with the geometric entities of a model. This information is typically data that needs to be conveyed to downstream processes such as manufacturing, inspection, meshing or analysis. As a result, when a model is reconfigured (i.e., upstream design entities are modified), the attribute propagation mechanism ensures that supplementary information is passed downstream automatically.

Attribute tagging was used in this project to associate mesh parameters with the components of the wing box. The mesh generation system in AML allows selective mesh refinement around vertices and edges, or on surfaces of the geometry to be meshed.

AML offers a flexible modeling environment that can be utilized for a wide range of engineering problems. The interpretive environment is suited to simulating "what-if" scenarios and iterative modeling environments. AML's capabilities, along with feature based geometry in a single open-access object-oriented architecture, make it very attractive as a means of addressing and demonstrating the practicality of bidirectional dependency in the design of aerospace vehicles with composite processes.

2.2 ASTROS

ASTROS [3] integrates a number of potentially conflicting design constraints (e.g., material stresses, static aeroelasticity and flutter) and converges on the optimal set of structural design variables to meet a user blended objective function (e.g. minimum composite material weight). ASTROS is unique with its ability to achieve a single optimal structural design for a number of flight conditions involving various maneuvers at various speeds and altitudes. ASTROS uses a suite of one and two dimensional structural finite elements (e.g. beams, membranes and shells) which are tailored to the needs of aerospace designers at the preliminary design level. The aerodynamic analyses in ASTROS include linear steady and unsteady aerodynamics at subsonic and supersonic conditions.

3. Unified Model

The unified model for this design process was built using the AML design architecture. A wing configuration, which was based on a generic Uninhabited Air Vehicle (UAV), was developed for the demonstration [4]. The configuration used in this report is shown in Figure 1.

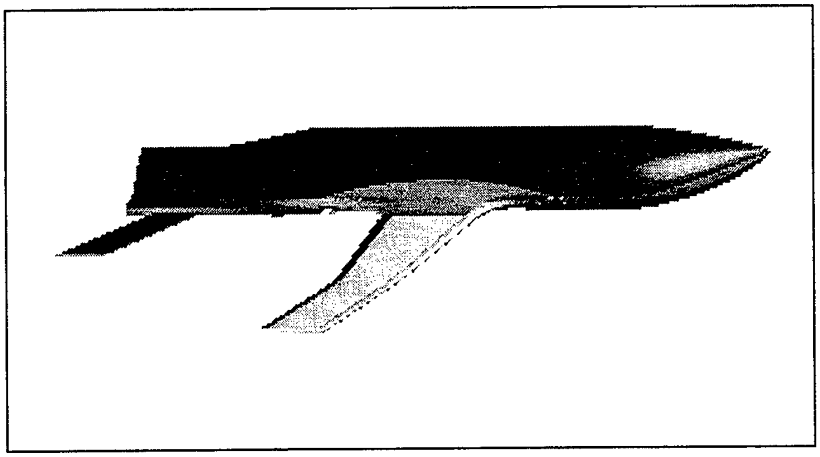

Figure 1. UAV model

In this memorandum, a composite wing-box concept will be designed for preliminary level aeroelastic requirements using the AML architecture. The designer will be allowed to change planform parameters, substructure layout, and laminate families, while determining the weight of each concept by performing a preliminary level analysis. The integrated design process that was implemented for this project is shown in Figure 2. This process demonstrates feedforward and feedback between conceptual and preliminary levels.

The wing outer moldline is developed from planform and airfoil parameters such as span lengths, chord lengths, sweep angles, etc. The substructure layout is represented on the planform, where the designer can interactively control the placement of spars, ribs, stiffeners, and the structural box boundary via the AML interface. This 2D layout will be transformed into ribs, spars and stiffeners in the wing surface model.

This wing surface model is meshed using AML's native capabilities. An ASTROS finite element model of the structural box is created from the mesh and then optimized for minimum weight, subject to stress constraints and the aerodynamic load associated with a steady 5-g pull-up maneuver. ASTROS will resize the thickness and cross-sectional areas of user specified structural elements. The following sections discuss the individual modules that were developed to demonstrate the bidirectional flow of data from conceptual to preliminary design phases.

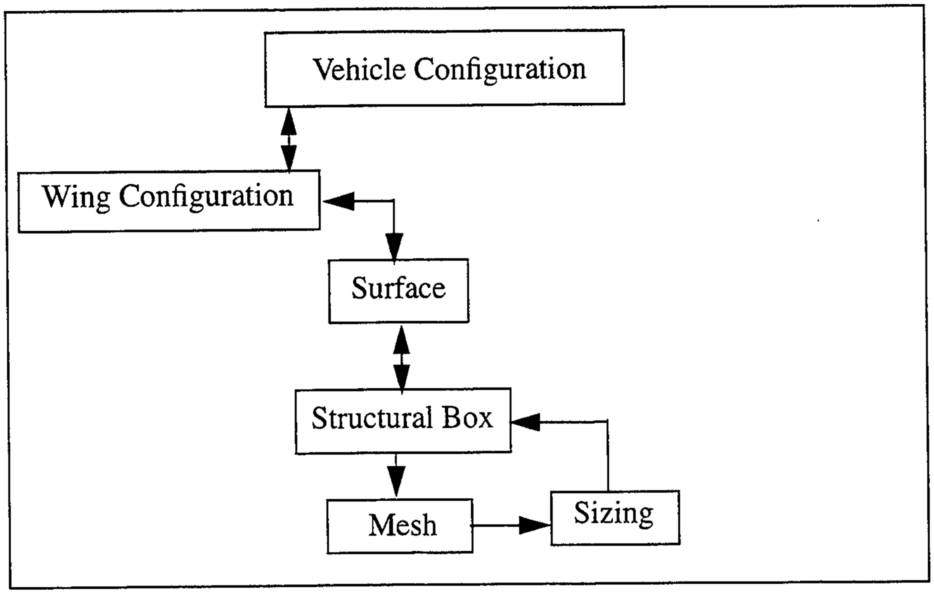

Figure 2. An integrated design process

3.1 Airfoil section

Figure 3 shows the airfoil cross-section for the NACA four digit airfoil [5] object, as modeled in AML. This object was created using AML's native *interpolated-curve-object.* The *interpolated-curve-object* creates a single curve from a set of points with derivatives and parameters. In the airfoil curve object, the curve starts at the leading edge, goes along the upper surface, continues

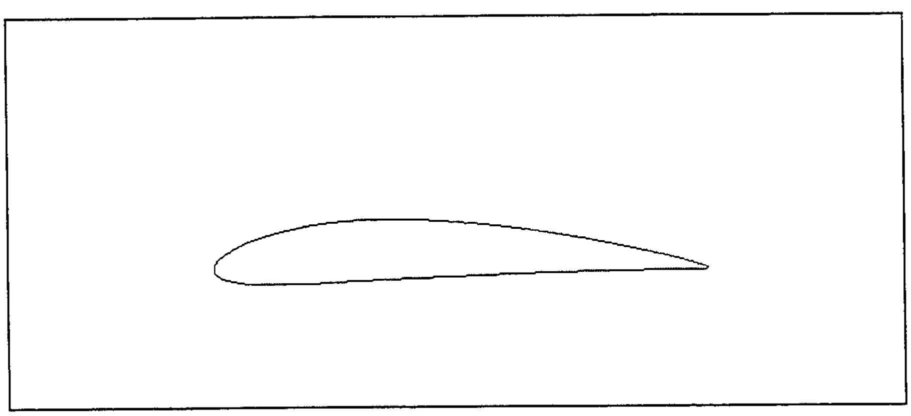
Figure 3. NACA four digit airfoil

around the blunt trailing edge and closes back at the leading edge. The parameters that control the shape and size of the airfoil are shown in Table 1

Table 1: Geometric parameters of the NACA 4 digit airfoil object

Parameter	Value	Comment
Camber	0.04	Percent chord - For 4412
Camber at chord position	0.40	Percent chord- For 4412
Thickness to chord ratio	0.12	Percent chord- For 4412
Trailing edge thickness	0.1	For creating a blunt trailing edge for manufacturing.
Radius	0.02	For rounding corners between the trailing edge and adjacent surfaces
Chord length	50.0	

3.2 Wing surface

The conceptual level wing planform parameters were computed by a synthesis program that used mission requirements to size the vehicle [6]. This set of parameters is the baseline for the whole demonstration. They have been calculated for a two panel wing. Using the parameters (span, sweep angles, chords etc.) shown in Table 2, a wing planform object was created. The planform object was created with some AML basic objects (i.e., *point-object*, *line-object, polygon-object,* etc.). AML's built-in functions (math computations) were utilized for computing the planform points from the given sweep angles, chords, spans, dihedrals and twists. Figure 4 shows the planform of the starboard wing for the two panels. This planform representation contains both twist and dihedral.

Because this project is using a two panel wing with different dihedral angles for each panel, the airfoil sections at the tip of the inboard panel and at the root of the outboard panel could intersect. To alleviate this problem, an "offset break" parameter is used between the panels. This parameter specifies the distance between the adjacent airfoil sections at the interface between the panels. In addition to the airfoil sections placed on each of the panels at the "panel breaks", airfoil curves were placed at the root and tip of the wing and as needed on each panel to obtain the desired resolution. Figure 5 shows the placement of the airfoils at the various spanwise locations

Table 2: Geometric parameters of wing

Geometric Parameter	Value	Comment
Number of panels	2	
Sweep apex coordinates	(145.0 40.0 0.0)	
Chords	Root - 50.0 Break - 35.0 Tip - 35.0	
Sweep axis location	Root - 0.2 Break - 0.2 Tip - 0.2	Percent chord
Sweep angles	Inboard - 40.0 Outboard - 40.0	Two Panel - Degrees
Dihedral angles	Inboard - 0.0 Outboard - 5.0	Degrees
Semi-spans	Inboard - 64.0 Outboard - 40.0	
Twist angles	Root - 2.0 Break - 2.0 Tip - 5.0	Degrees
Twist axis location	Root - 0.5 Break - 0.5 Tip - 0.5	For twist axis computation - percent chord
Airfoil designation	Root - 4412 Break - 4412 Tip - 4412	NACA four digit series
Additional airfoil locations	Inboard - (0.3 0.6) Outboard - (0.2 0.8)	For surface smoothness in individual panels - percentage of panel span
Offset breaks	Inboard - 0.05 Outboard - 0.05	Transition between the inboard and outboard panel -%panel span

of the wing. It should be noted that these airfoils are placed on the planform after the twist distribution and dihedral have been calculated. AML's native *surface-skin-object* was used to generate the surface. This object creates a skinned surface from a list of curves (airfoil curves in this case). Figure 6 shows the wing surface for the geometric configuration listed in Table 2.

The airfoil curves used for this project were the NACA four digit airfoil objects described in Section 3.1. Because a 12% thick airfoil was computed by the synthesis program, Reference [6], the 4412 series airfoil was used for this report.

Because of AML's dependency tracking capability, the wing surface is fully associative. Any changes to a parameter in Table 2 will be automatically carried forward to the wing surface model.

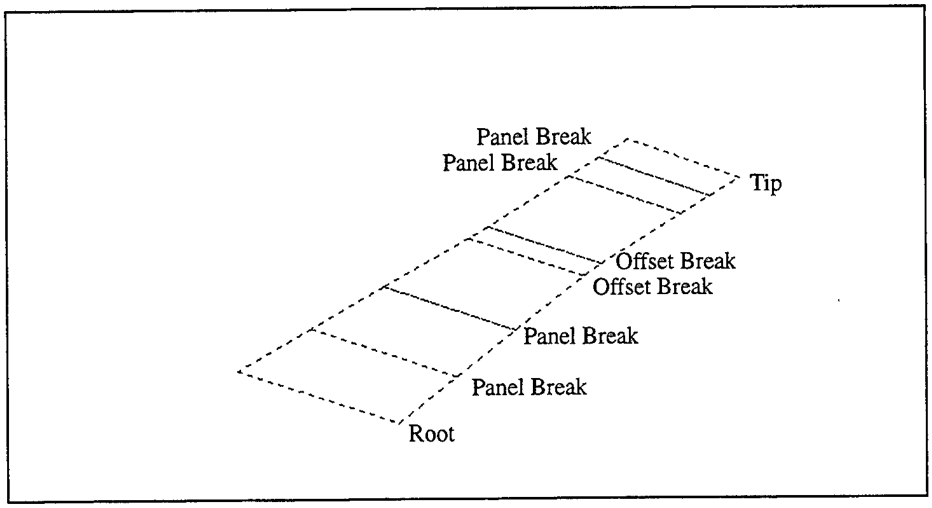

Figure 4. Planform for two panel wing

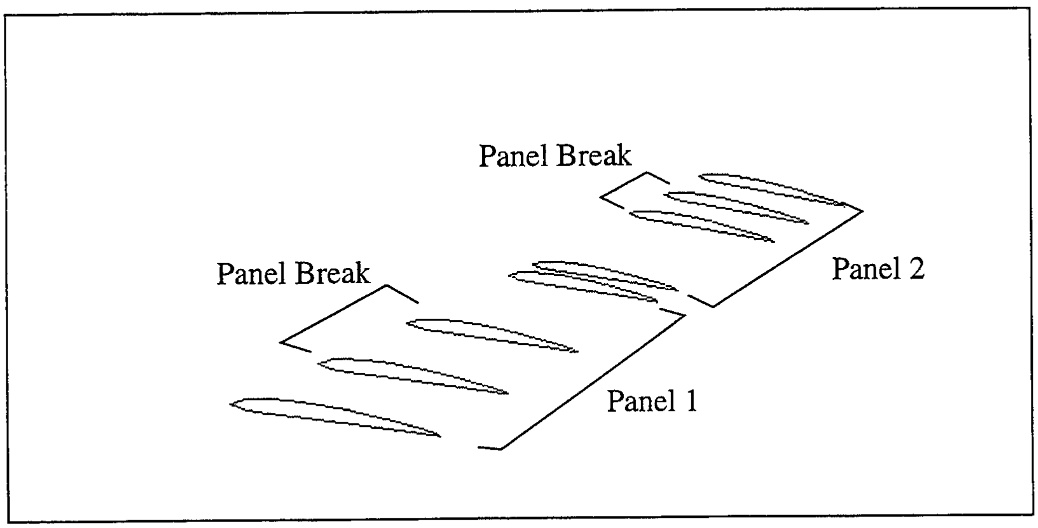

Figure 5. Airfoil placement at the various span-wise locations

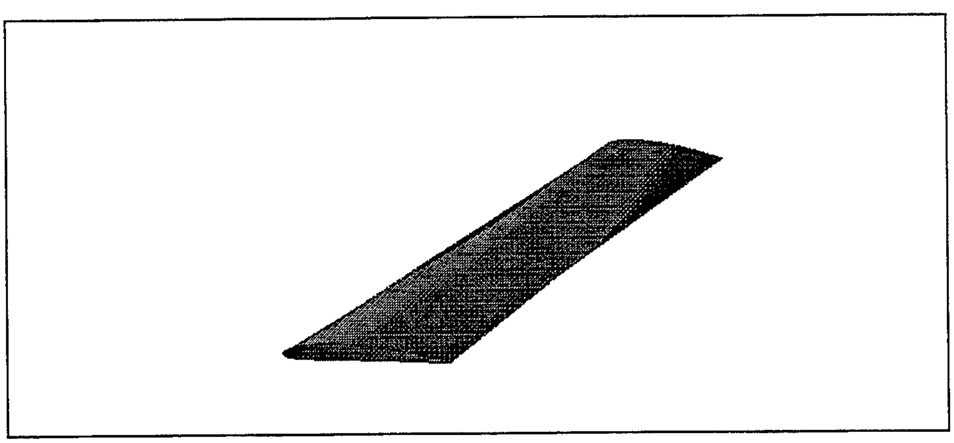

Figure 6. Wing surface

To summarize, the following order of dependency was used to create the wing surface model. This is for each panel.

1. Compute the wing root leading edge and trailing edge coordinates based on the sweep apex and root chord.
2. Compute the wing tip leading edge and trailing edge coordinates based on the wing root coordinates, sweep angles, tip chord and span.
3. Compute the wing planform with dihedral data.
4. Compute the wing planform with twist and dihedral (include the offset amount at the panel interface).
5. Compute airfoil section data (e.g., chord, camber, local angle of attack) based on the wing planform with twist and dihedral and the user specified intermediate airfoil locations.
6. Place the airfoils at the computed wing points.
7. Create the wing surface by skinning the airfoil curves for all the panels.

3.3 Wing structural box

The next step is to describe the substructure layout for the wing. The location of leading and trailing edge of the wing-box is specified, followed by the locations of the spars, ribs and stiffeners. For this project, the locations are specified on a flat surface and later projected on the twisted planform. The data is listed in Table 3 and shown graphically in Figure 7.

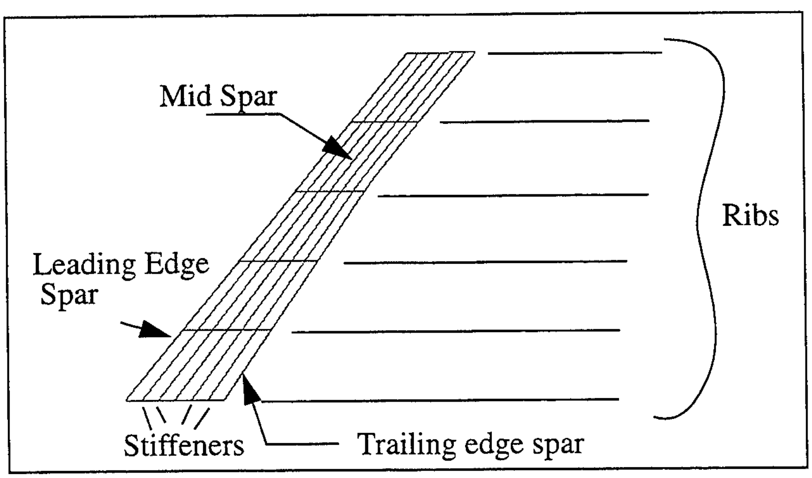

Figure 7. Substructure layout in planform

Table 3: Geometric parameters of the structural box

Parameter	Value	Comment
Structural box outline	Root - (0.2 0.8) Break - (0.2 0.8) Tip - (0.2 0.8)	Leading and trailing edge spar locations - percent chord.
Mid spar locations	Root - 0.5 Break - 0.5 Tip - 0.5	Mid spar locations as a percentage of chord at root, break and tip. - Number of mid spars 1
Rib locations	Root rib - (0.0 0.0) Rib 2 - (0.2 0.2) Rib 3 - (0.4 0.4) Rib 4 - (0.6 0.6) Rib 5 - (0.8 0.8) Tip rib - (1.0 1.0)	Rib locations at leading and trailing edge spar - percent of total span. - Number of ribs 6
Stiffener locations (top)	Stiffener 1 - (0.3 0.3 0.3) Stiffener 2 - (0.4 0.4 0.4) Stiffener 3 - (0.6 0.6 0.6) Stiffener 4 - (0.7 0.7 0.7)	Stiffener locations as a percentage of chord at root, break and tip. - Number of stiffeners 4
Stiffener locations (bot)	Stiffener 1 - (0.3 0.3 0.3) Stiffener 2 - (0.4 0.4 0.4) Stiffener 3 - (0.6 0.6 0.6) Stiffener 4 - (0.7 0.7 0.7)	Stiffener as a percentage of chord at root, break and tip. - Number of stiffeners 4

After the designer lays out the structural components on the planform (Section 3.2), a surface model of each part (i.e., wing skins, spars, ribs, spar caps, rib caps and stiffeners) is created. A series of boolean operations are performed to generate the surfaces (skins, spars and ribs) and curves on the surfaces (spar and rib caps, stiffeners). These structural components/parts will be modeled as shell structures - two dimensional surfaces with thickness properties. The wing structural box surface model is shown in Figure 8.

The boolean operations performed to create the wing structural box surface model are described below. All of these operations are performed using AML's native geometric modeling capability.

1. The wing surface is bounded at the two ends to create a closed *bounded-surface-object.*
2. This bounded surface is then converted to a solid object with the *make-halfspace-object.*
3. The planform spar lines are projected in the top and bottom directions (z in an aircraft coordinate system) until they are outside the wing surface.

4. The projected curves are skinned with the *surface-skin-object* to create an extended spar surface.
5. This spar surface is intersected with the solid wing to create the individual surface spar. The *intersection-object* creates a geometry consisting of only the common regions between the wing solid and the extended spar surface.
6. The rib surfaces are created in a manner similar to the spar surfaces, steps 3 through 5.
7. The stiffeners are created by intersecting the surface created by extending the stiffener curves (step 4) with the wing surface. This operation creates curves on the top and bottom skin surfaces.
8. The spar and rib caps curves are obtained by extracting the edges from the spar and rib surfaces created in steps 5 and 6.
9. The original wing surface is trimmed at the leading edge by the leading edge spar and at the trailing edge by the trailing edge spar to obtain the top and bottom wing box skin surfaces.

This set of two dimensional geometries is fed into the mesh module for tagging and meshing. The tagging and meshing operations are described in Section 3.4.

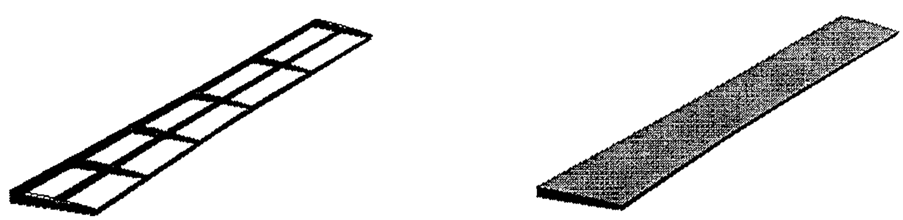

Figure 8. Surface geometry of the structural box

3.4 Mesh generation for structural optimization

After the generation of the wing structural box surface model, the finite element model can be created. In this project, flags are provided for turning on or off the generation of finite elements for the spar caps and rib caps as well as the stiffeners. The following steps were performed to create a finite element model of the structural box. Again, all of these operations were performed using AML's native capabilities.

1. **Tagging:** All the geometric entities of the wing box (surfaces - top skin, bottom skin, spars and ribs; curves - spar caps, rib caps and stiffeners) were tagged with the *tagging-object.* The tagging object allows mesh calculation parameters to be tied to the geometric entities. What this means is that as the geometry changes (e.g., spar locations change), the mesh parameters are automatically associated with the updated geometry. The meshing attributes associated with the *tagging-object* are maximum edge size, minimum edge size, curvature refinement value, curvature approximation error, segment value, segment size and entity tolerance. These attributes are required for the meshing of the object. The other important property in the *tagging-object* is the tag-dimensions. This determines which dimensions (i.e., vertices, edges, surfaces or solids) of the geometry are to be tagged. In this project, the surface geometry (i.e., spars, ribs and skins) is tagged for all points, edges and surfaces associated with the geometry and the curve geometry (i.e., spar caps, rib caps and stiffeners) is tagged for all points and edges associated with the geometry.
2. **Union:** The tagged geometries that were to be meshed were joined together with the *union-object.* The union-object creates a single geometric instance by adding n number of geometric instances together. The mesh utility in AML requires a single geometry for meshing.
3. **Meshing:** The unioned geometry is then meshed with the *mesh-object.*

The automatic mesh generation module in AML creates unstructured triangular mesh elements. Therefore the skins, spars and ribs were modeled as triangular plate elements. Typically, structural finite element models use quadrilateral elements. The automatic structured mesh generation modules needed for creating quadrilateral elements have not been implemented in AML. The spar and rib caps were modeled as rod elements and the stiffeners as bar elements. Figure 9 shows the finite element mesh for the wing structural box.

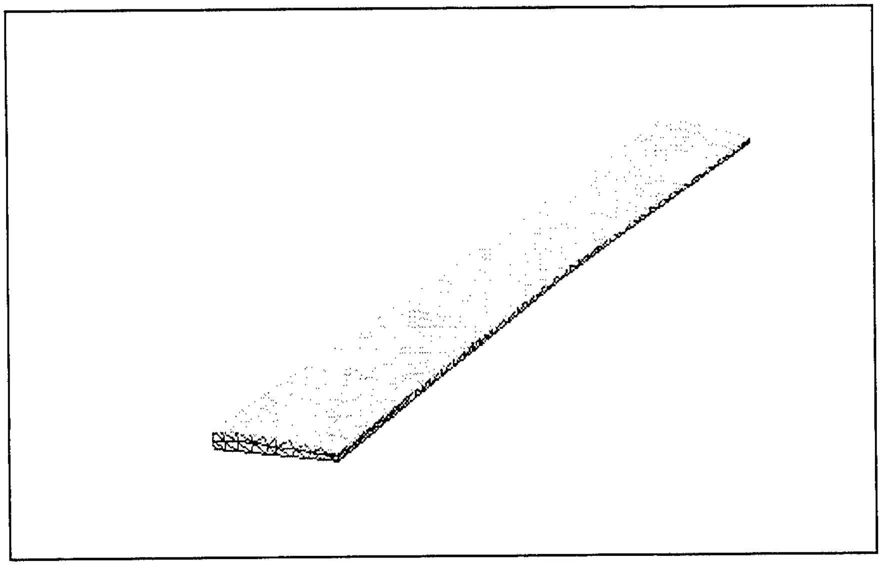

Figure 9. Finite element model

3.5 Optimized structural box (sizing)

After the mesh is generated, AML's mesh query objects were used to retrieve nodes, line elements and plane elements based on the geometry and tag-dimensions specified in the *tagged-object*. The *0D-mesh-entities-query-object* retrieves nodes, the *1D-mesh-entities-query-object* retrieves mesh lines and the *2D-mesh-entities-query-object* retrieves plate elements from the objects specified in the tagged-object-list property. Additional properties such as material-id, property-id, and cross-section (for 1D) and thickness (for 2D) were added to the *1D-mesh-entities-query-object* and *2D-mesh-entities-query-object.* These properties were required to write the finite element input file. An ASTROS interface was written to create the input deck for the optimization of the structural elements of the wing-box.

ASTROS is used in this project to resize the aeroelastic structure for minimum weight and simultaneously withstand the stress induced by a 5-g pull up. Von-Mises stress constraints and ply minimum gage constraints were applied in this optimization problem. The ASTROS program specializes in aerospace elements. These elements (e.g. beams and shells) model a structure with one and two dimensional geometry. Parametric properties (e.g. shell thickness) formed in AML were passed on to ASTROS. The optimized thicknesses from ASTROS were retrieved by AML from the ASTROS database.

There is a strong motivation to reduce the number of design variables and active constraints in structural optimization. Laminated composite material design requires a significantly larger number of design variables than (single layer) isotropic material design. Each layer of composite material adds an additional set of design variables.

ASTROS has a design variable linking capability. To simplify the optimization process in ASTROS, only the top and bottom wing surface were considered as layered composites. A four layer composite layup, as shown in Table 4, was considered for the top and bottom wing skins. The +45 and -45 layers were linked during the optimization. All the elements on the top and bottom skin were physically linked to one design variable (for the individual composite layers). Therefore, the top or bottom skin is designed with three design variables (+45/-45 (linked), 90.0, 0.0). Spars and ribs were considered as "black metal". They were considered a single layer composite material. The rib and spar caps were also considered as black metal. Table 5 shows the material properties for all the structural components of the model.

Table 4: Top and bottom skin laminate layup

Layer	Orientation	Linking
1	[+45]	Linked
2	[-45]	
3	[90]	Individual
4	[0]	Individual

Table 5: Material properties for the structural box

Component	Material Properties
Top Skin	E_{11} - 18.5e6, E_{22} - 1.60e6, G_{12} - 0.65e6, ν - 0.25, ρ - 1.42e-4
Bottom Skin	E_{11} - 18.5e6, E_{22} - 1.60e6, G_{12} - 0.65e6, ν - 0.25, ρ - 1.42e-4
Spars	E - 18.5e6, ν- 0.3, ρ - 1.42e-4
Ribs	E - 18.5e6, ν- 0.3, ρ - 1.42e-4
Stiffeners	E - 18.5e6, ν- 0.3, ρ - 1.42e-4
Spar Caps	E - 18.5e6, ν- 0.3, ρ - 1.42e-4
Rib Caps	E - 18.5e6, ν- 0.3, ρ - 1.42e-4

The top skin, bottom skin, spars and ribs were modeled as triangular plate elements. Neither the spar and rib caps or the stiffeners were modeled in the optimization problem. The properties were smeared into the top skin, bottom skin, ribs and spars. This technique is used in many preliminary level structural design models. Using these modeling practices, the number of design variables was reduced to 15.

The linear aerodynamic model implemented in ASTROS is Woodward's USSAERO code. The flat two panel wing planform is outlined in with a light line (Figure 10). The wing structural box is shown as the heavy line. Aerodynamic loads from the wing were transmitted to the points on the entire upper surface.

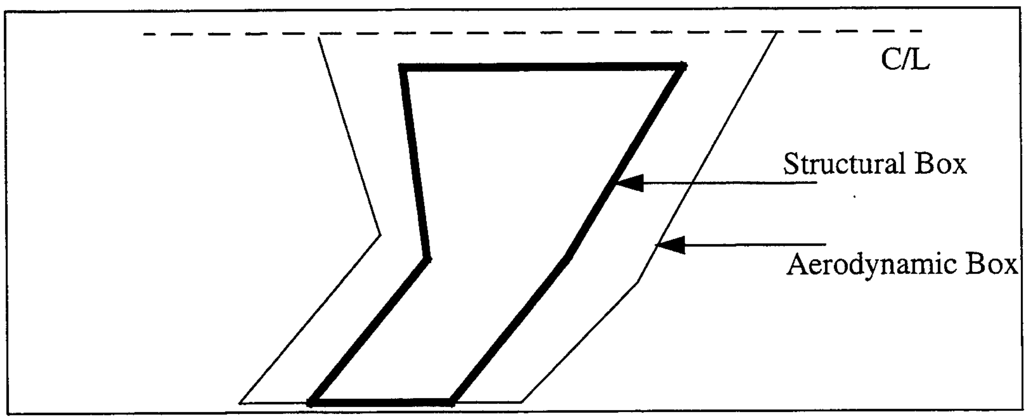

Figure 10. Aerodynamic/structure modeling

The optimization run was performed on an SGI Indigo R4400 machine. The optimized thicknesses and cross-sectional areas were extracted from the ASTROS database.

Figure 11 shows the Von Mises stress contours of the optimized model. As expected, most of the stress concentration is in the wing root region and the bulk of the loading on the skins is carried by the $+45^{o}$ and -45^{o} fiber direction layers. Also as expected, there are no significant stress levels on the ribs. However, when compared with contemporary wing designs, there is an unusual stress concentration in the spars. Typically, this load is carried in the wing skins. This design was most likely caused by modeling the spars and ribs as plate elements. The stress distributions and modeling practices are further discussed in Section 4.

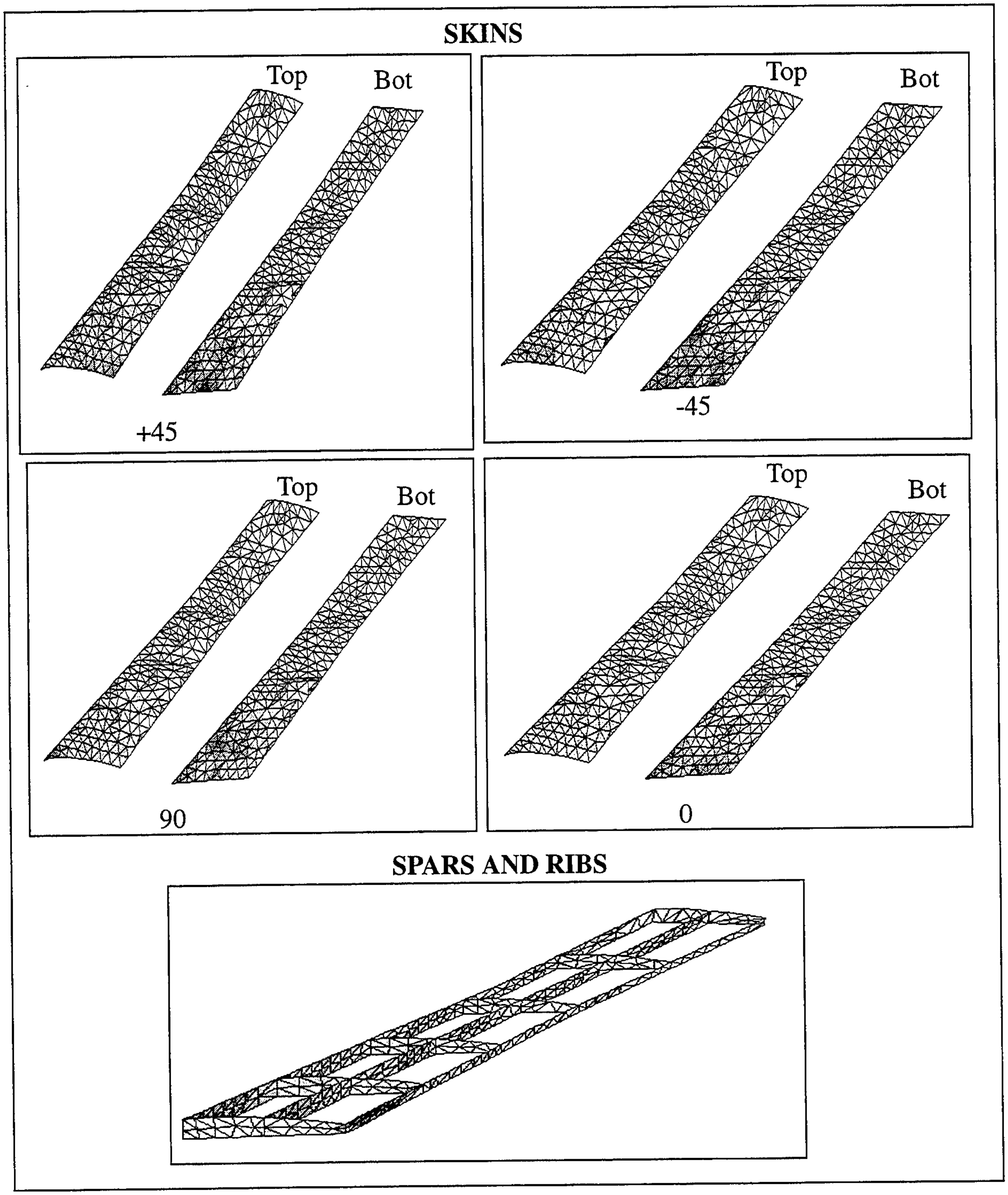

Figure 11. Stress contours for Design 1

4. Demonstration of Rapid Model Regeneration and Data Feedback

Once the design process is captured in AML, it can be used to rapidly perform trade studies. In this project, the process captured was one of laying out the wing substructure and performing a preliminary level finite element analysis and optimization for a given outer moldline. Using conventional practices, the generation of a new finite element model for even a small change in the substructure or outer moldline is very time consuming.

To demonstrate this project's ability to perform a trade study involving planform parameters, a second finite element model was generated. For the second design, the root chord length was changed from 50.0 inches to 90.0 inches. All other planform and substructure parameters were the same as in the original design. The effect of this one change is automatically propagated through all of the design models. The new wing outer moldline surface is shown in Figure 12. This new surface is then used to generate the new structural box surfaces shown in Figure 13, which are subsequently used to create the new finite element mesh shown in Figure 14.

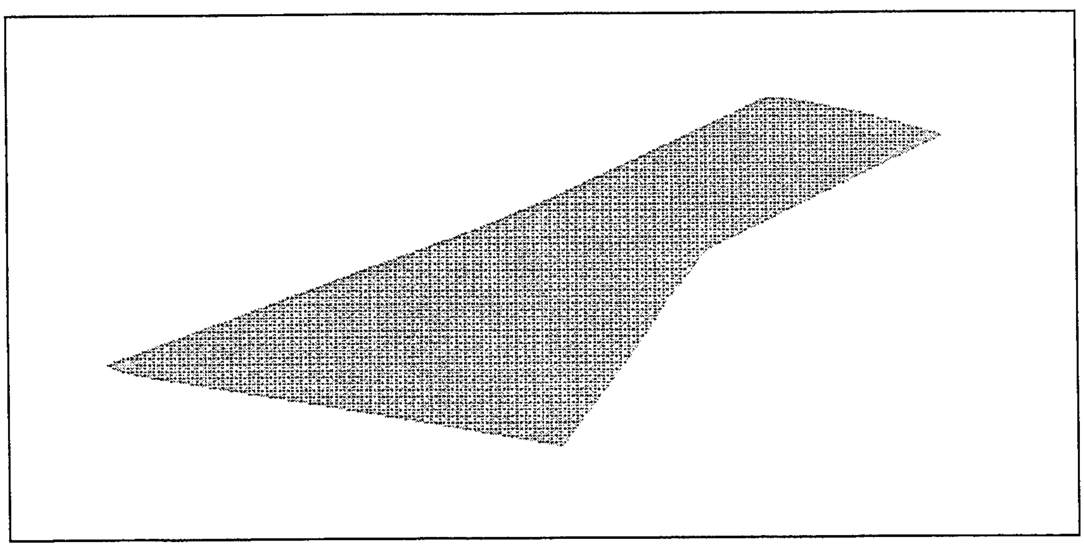

Figure 12. Second wing surface model

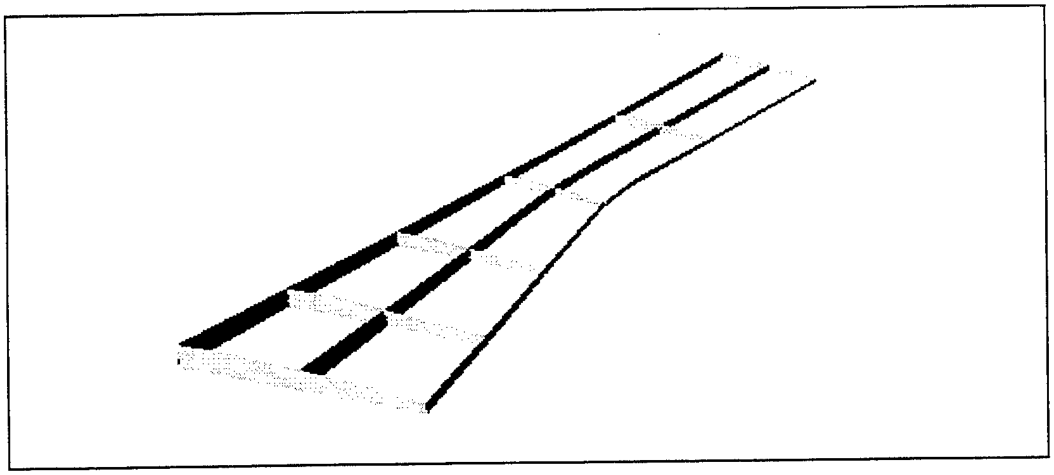

Figure 13. Second wing structural wing box model

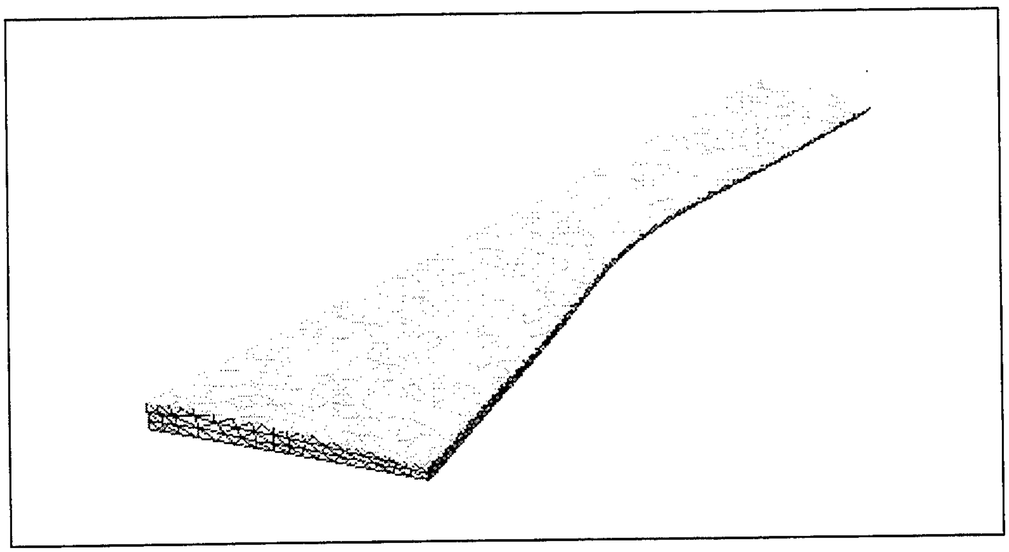

Figure 14. Second mesh

The new model was subjected to the same optimization scenario as the original model. The resulting designs are compared in Table 6. Figure 15 shows the stress contours for the model with the longer root chord after optimization. In both designs, the leading and trailing edge spars were quite thick. Compared with current wing designs, this is not a typical wing-box. The differences are most likely due to the modeling practices that were used in this project.

The design problem used here was simplified; internal pressure loads and skin buckling constraints were not used. These constraints generally cause the wing-box to have thick skins and

Table 6: Design Summary

	Design 1	Design 2
Root Chord	50.0	90.0
Weight -lbs	7.8380	7.9674
Trimmed angle of attack	20.723	16.2200
Optimized Thickness:		
Skin - Top	Layer 1 (+45) 0.01665 Layer 1 (-45) 0.01665 Layer 1 (90) 0.08112 Layer 1 (0) 0.034812	Layer 1 (+45) 0.1241 Layer 1 (-45) 0.1241 Layer 1 (90) 0.0309 Layer 1 (0) 0.0572
Skin - Bottom	Layer 1 (+45) 0.00609 Layer 1 (-45) 0.00609 Layer 1 (90) 0.00548 Layer 1 (0) 0.008160	Layer 1 (+45) 0.0052 Layer 1 (-45) 0.0052 Layer 1 (90) 0.0052 Layer 1 (0) 0.0052
Spars	1 - 0.123397 2 - 0.053569 3 - 0.165135	1 - 0.2384 2 - 0.05 3 - 0.2774
Ribs	1 - 0.05 2 - 0.05 3 - 0.05 4 - 0.05 5 - 0.05 6 - 0.05	1 - 0.05 2 - 0.05 3 - 0.05 4 - 0.05 5 - 0.05 6 - 0.05

thin spars. Because most wing designers omit buckling constraints at the preliminary level, the state of the art is to model the spars and ribs as shear elements. Designers know that because shear elements do not carry any in-plane or bending loads, optimization programs will not increase their size to carry the load. The current finite element codes only support quadrilateral shear elements; however, due to the AML mesh restrictions, only triangular elements could be generated for this project. This limitation meant that the spars and ribs had to be modeled as plate elements. Because plate elements and the simplified set of constraints were used, the optimization program designed the structure using the spars to carry a significant part of the load.

The results of this demonstration may not be significant from a structural perspective, but creating a final wing-box design was not the objective of this project. Its purpose was to demonstrate a tool that can be used to improve the design process. As additional disciplines are incorporated into the AML environment, rapid higher-fidelity analysis of competing designs will give the designer access to the information he needs when it can easily effect his decisions.

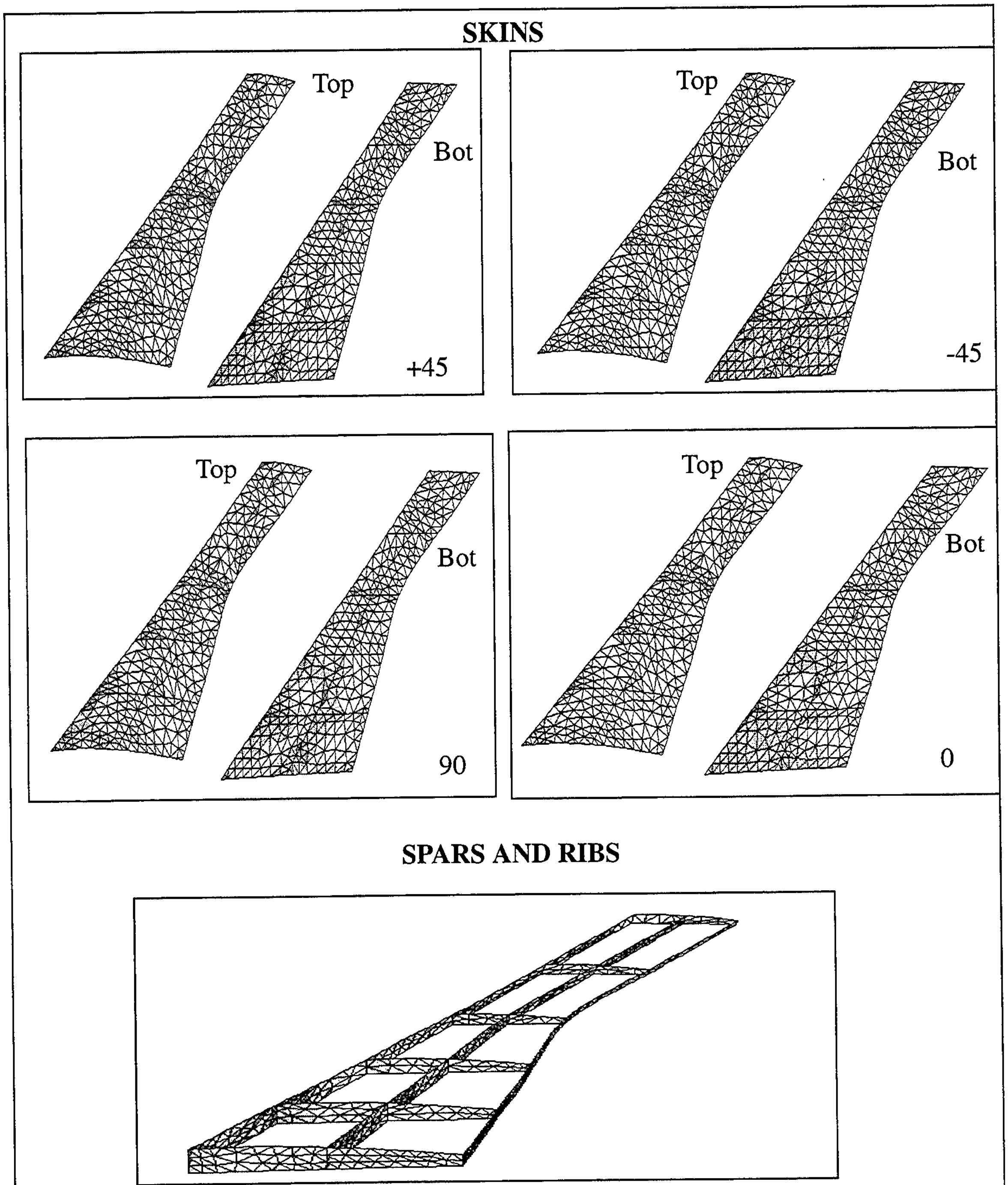

Figure 15. Stress Contours for Design 2

5. Summary and Conclusions

This memorandum proposes a far-reaching motivational vision to automate paths of design feedforward and feedback. To some, this vision may seem well-intentioned but overly idealistic, encompassing ideas of full design automation. Of course, the redesign process can never be totally automated, some insight from the engineer is always needed. However, we need to investigate the ways it makes sense to replace slow and expensive human activity. This vision may provide a focus for future research on how to improve the design process by making full use of our computer resources, design architectures and object-oriented programming.

In this memorandum, some groundwork has been laid for the demonstration of an automated redesign process. A fully associative link between wing geometric parameters (conceptual level), wing surface geometry (outer moldline) and preliminary aerospace structural optimization software (finite element based) has been developed. The development of a more comprehensive demonstration of concurrent engineering between conceptual level, preliminary level, and detailed level design is now ready to begin.

The fact that the second design model did not significantly improve the design does not detract from the significance of the unified design model. Once the elements of cost, manufacturability, survivability, etc. are incorporated, the payoffs for feedforward and feedback should be seen. Ultimately, this will lead to the capability to rapidly perform high fidelity cost - performance trades at the conceptual level.

The unified model described in Section 3, can be used as a central module for feedforward and feedback of data. For example, the outer moldline wing surface can be directly passed to an aerodynamic analysis code such as QUADPAN. These codes can perform detailed analysis of the airloads for specified maneuvers (mandated by the conceptual designer). AML can generate a QUADPAN specific mesh and create the input deck for the required analysis. The airloads computed by the code can be fedback to the unified design model, where they can be accessed by structural analysis and optimization codes such as ASTROS. Also the lift, drag and other information provided by QUADPAN would provide high fidelity information for the conceptual designer to perform "trade-off" studies at an earlier stage in the design process.

The optimized design for the structural components from ASTROS can be used for detailed design, cost and manufacturing computations through a solid model module developed in AML.

The ASTROS thicknesses and cross-sectional areas provide the geometric data for generating the solid geometry. This solid geometry module can be used for detailed level structural analysis, cost and manufacturing analysis etc.

The proposed virtual design process expands a traditional design process with electronic media which closely simulates all aspects of design, including performance, manufacturing and production. In a virtual design process, numerical design algorithms are merged with virtual prototyping and all information is processed and transmitted very rapidly. The motivation for virtual design is to reduce the need for building expensive prototypes and to create better and perhaps unrealized products.

In this memorandum, a small step in the direction of developing design module interfaces was taken. This step was taken in order to understand the driving design integration issues. A piece of the design process is presented here in order to demonstrate the practicality of composite design within the envisioned architecture. This composite design example suggests a way for generating practical composite structures design data at the conceptual level.

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