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Structural Design Optimization with Survivability Dependent Constraints Application: Primary Wing Box of a Multi-role Fighter †

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Douglas J. Dolvin

Flight Dynamics Directorate
Wright Laboratory, Wright Patterson Air Force Base, Ohio

INTRODUCTION

The superior survivability of a multi-role fighter is dependent upon balanced integration of technologies for reduced vulnerability and susceptability. Current methods for preliminary design of these vehicles do not employ analytical methods nor empirical procedures for simultaneous assessment of structural survivability as a function of structural effeciency. The Air Force, NASA, and many airframe contractors have invested significant resources in the development of multidisciplinary optimization methods which integrate aeroelastic tailoring into the conventional strength dependent design (references 1-5). These computationally intensive procedures form the foundation of preliminary design, yet they do not have the capability to assess effects of survivability dependent constraints on structural weight. A comprehensive survey of current capabilities and future requirements for automated methods of multidisciplinary design is presented in reference 6.

The dependent relationship between survivability and structural weight will dominate preliminary design trade studies for future Air Force aircraft (reference 7). Therefore, significant benefits exist for expanding current design codes to include a structural design methodology for optimization with survivability dependent constaints. The multidisciplinary optimization program ASTROS (Automated STRuctural Optimization System) is ideally structured to enable users to add analysis for other disciplines and therefore this code will function as the basis for methodology development of this project (reference 8). The proposed enhancement will support development of a preliminary design of greater balance through parallel optimization for requirements of survivability and maneuverability, rather than performing separate analysis for each discipline. Further, this effort will provide methodology for comprehensive studies of survivability performance on derivative configurations of a conceptual aircraft, thus identifying design deficiencies early in development when corrections can have the greatest impact on vehicle performance and life cycle cost.

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† this work was performed by the Air Force Project Engineer with Air Force Facilities

OBJECTIVE

The objective of this project is to develop a methodology for structural design optimization with survivability dependent constraints. The principal design criteria for optimization will be survivability in a tactical laser environment. The author will investigate the following analyses to establish a dependent design relationship between structural weight and survivability:

1) develop a physically linked global design model of survivability variables
2) apply conventional constraints to quantify survivability dependent design

BENEFITS

This research will provide design methodology for structural optimization with non-optimal design constraints and will advance the in-house capabilities for preliminary design by integrating requirements for laser survivable structures into multidisciplinary methods for design optimization. The Air Force Flight Dynamics Directorate has identified this technology area as providing high payoff for future aircraft including a multi-role fighter (reference 9). Further, strategic plans of the HQ-AFSC have determined that technology for increasing aircraft survivability 'have vital importance to future Air Force capability needs' (reference 10).

APPROACH

The context of this paper will present a summary of in-house work being performed under Task 1 of a cooperative program between Air Force and Georgia Tech Research Institute (GTRI) entitled: Design Development for Survivability.

Under Task 1, the project engineer will develop design methodology and perform survivability analysis of a primary wing box for multi-role fighter which employs technology for increased survivability including structural arrangement, substructure configurations, cocured lower wing skins, composite fastened upper wing skins, and damage tolerant composite face sheets with syntactic foam cores. The principal design criterion will be vulnerability against High Energy Laser (HEL) threat. The multidisciplinary optimization code ASTROS will be employed in development of a design methodology for optimization with survivability dependent constaints. ASTROS is derived from NASTRAN finite element procedures and performs analysis of structural, static aeroelastic, unsteady flutter, dynamic and blast conditions. In addition, this code incorporates significant algorithms of aeroelastic tailoring and mathematical programming from two procedures developed under Air Force contract (references 2 and 3). Current preliminary design methods require successive evaluation of the Finite Element Model (FEM) under flight loads followed by the Survivability Model (SUM) under threat loads. During this process, the designer would iteratively modify the models until all performance criteria are satisfied within a defined tolerance. A preferred approach would be to develop an overall design model which includes both structural and survivability dependent elements and to optimize the design model for survivablity in the same manner as would be pursued for conventional constraints of strength or strain. To establish a dependent design relationship between structural weight and laser survivability, trade studies will be conducted on a design model with new constraint types which are survivability specific and existing constraint types in a manner which is survivability dependent. The laser vulnerability code VAASEL (Vulnerability Analysis of Aircraft Structures Exposed to Lasers) will be used to assess the survivability improvement attained from integration of advanced technologies versus associated weight penalty (reference 11).

Under Task 2 of this program, researchers of the Signature Technology Laboratory at GTRI will perform the optical design and survivability analysis of a leading edge for multi-role fighter which employs advanced technology for decreased susceptibility including; geometric shaping, low reflectivity coatings, holographic filters, submicron periodic arrays, and inorganic absorbers (reference 12). The principal design criteria will be multispectral surface reflectivity at wavelengths corresponding to airborne targeting and LIDAR threats. The infrared/visual analysis code GTSIG (Geoorgia Tech SIGnatures) will be used to analyze laser signature of the baseline edge design and to conduct trade studies on advanced configurations.

Under Task 3, the project engineer will fabricate two full scale components and perform tests against high energy laser and low energy LIDAR threats. The components will be fabricated at the Composites R & D Facility of the Flight Dynamics Directorate; the baseline structural concepts have been selected and survivability evaluation of representative test panels is scheduled for March 1992 (see figure 1). Upon completion of the susceptability testing, the undamaged component will be attached to a full scale composite wing box to be developed under an in-house effort intitled Bolted Advanced Survivable Structures (reference 13). The component will be designed to provide redundant paths for load redistribution after ballistic impact. The box is constructed of three bays; a load introduction cell, a load reaction cell, and a multi-spar / multi-rib airfoil section which employs many structural concepts and damage resistant materials incorporated in this design study including the structural arrangement, substructure configurations, and laminate constructions. Current plans include laser vulnerability testing at the WL/ML LHMEL facility, susceptability testing at the GTRI Signature facility, and ballistic survivability testing at the WL/FIV range.

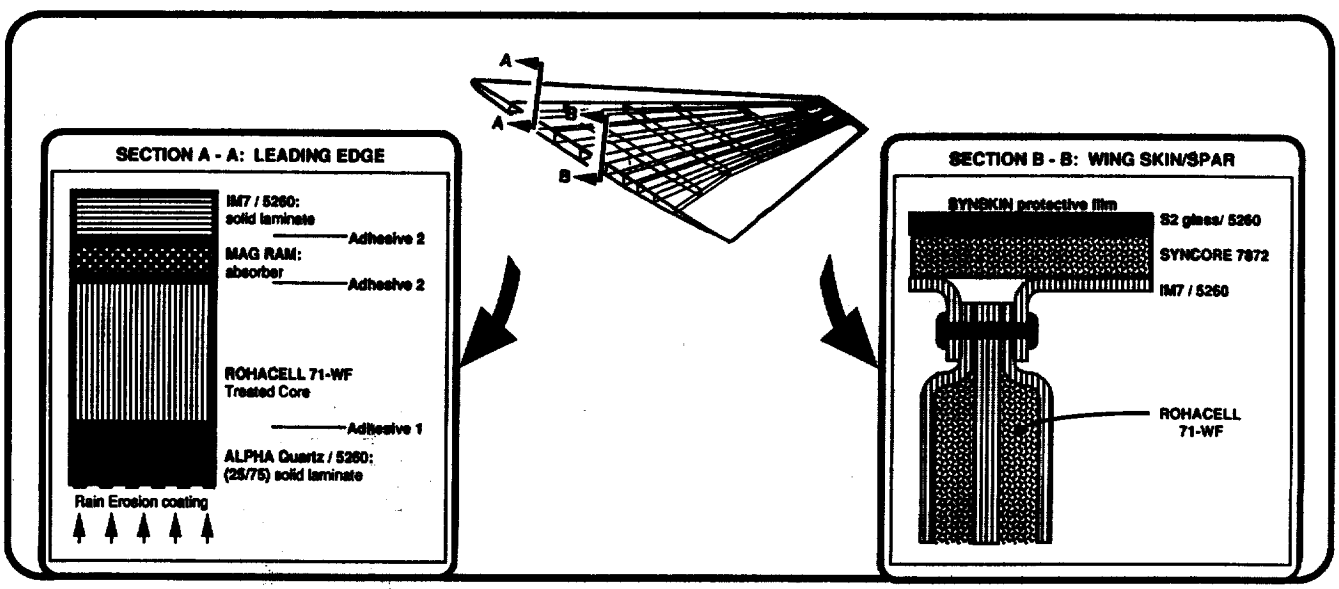

FIGURE 1 - structural concepts for the design baseline

DESIGN CRITERIA

The aircraft performance criteria were adopted from Air Force conceptual design studies on Tail-less Fighter performed by WL/TXA and from the best available performance data on Multi-Role Fighter developed under ASD/XR Multi-Role Fighter Concept Assessment Studies. The mission and general aircraft performance criteria are presented in figure 2 (reference 14). The critical maneuver point selected for this design study is as follows: symmetric pull-up under instantaneous load of 9 g, at a speed of MACH 0.78, applying maximum A/B power, and flying at an altidude of 10,000 feet. The wing loading applied during this maneuver shall include pressure of steady aerodynamics, structural weight, 50 % fuel weight of 2900 lbs/wing, and two AIM-9L missiles. Aircraft pitch stability is attained from integrated control of two aerodynamic surfaces per wing, two canted tails, and 2-D thrust vectoring nozzles.

Mission Definition

1. Takeoff Fuel Allowance
   a. 20 Minute Warm-Up, Minimum Dry Power
2. Takeoff Roll/Accel to Mach 0.64/SL, Maximum A/B Power
3. Cruise to FEBA at Mach 0.64/SL for 150 NM
   (TFLF/ P_s = 500 ft/sec Reserve)
4. Constant Altitude Accel to Dash Speed at Mach 0.82/SL
   (Maximum A/B Power)
5. Dash 100 NM at Mach 0.82/SL
   (TFLF/ P_s = 500 ft/sec Reserve)
6. Combat
   a. 3 – 360° Turns, 0.80 Mach, Mil Power
   b. Expend Air-to-Ground Weapons (2 TMSD's)
7. Dash 100 NM at Mach 0.82/SL
   (TFLF/ P_s = 500 ft/sec Reserve)
8. Constant Altitude Decel to Cruise Speed at
   Mach 0.64/SL 0.64
9. Cruise at Mach 0.64/SL for 150 NM
   (TFLF/ P_s = 500 ft/sec Reserve)
10. Constant Altitude Decel to Mach 0.2/SL
11. Loiter: Fuel for 10 NM at SL, Mach Number
    for Best Endurance

Performance Requirements

Requirements	Specification
Takeoff and Landing Ground Roll	1,500 ft., Standard Day
Mission Radius	250 NM
Maximum Mach Number	1.8
Cruise Altitude	Sea Level
Sustained Load Factor, n_z 50% Internal Fuel + 25 mm Gun + 250 Rounds	5.0g at Mach 0.6/30,000 ft Maximum A/B Power 3.0g at Mach 0.7/30,000 ft Maximum A/B Power 4.5g at Mach 0.9/30,000 ft Maximum A/B Power
Specific Excess Power, P_s 50% Internal Fuel + 25 mm Gun + 250 Rounds	400 fps at Mach 0.9/30,000 ft Maximum A/B Power 500 fps at Mach 1.4/30,000 ft Maximum A/B Power 1,000 fps at Mach 0.9/SL Maximum A/B Power

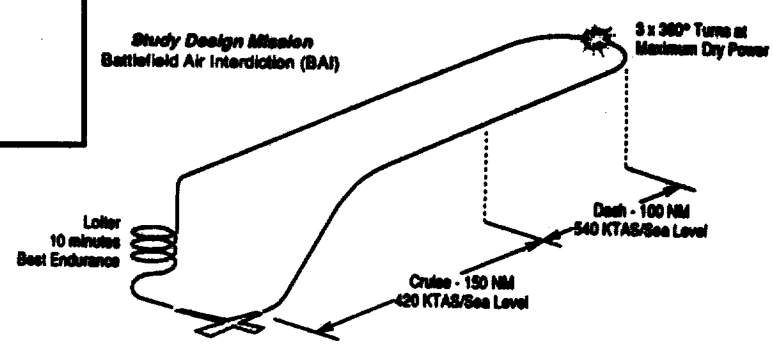

FIGURE 2 - general aircraft performance criteria

The following structural design criteria were developed from consolidation of requirements for current aircraft including F-16 and Air Force sponsored studies on future aircraft including multi-role Fighter and a non-conventional ASTOVL fighter.

Strength Requirements (application limited to design of the wing):
- limit load for rolling pull out to include abrupt displacements of control surfaces
- quasi-static loads for nose and main landing gear (sink rate of 10 feet/second)
- primary structure reacts aerodynamic loads and maneuver loads with inertia relief
- secondary structure reacts local air loads and distributes loads to primary structure
- no buckling of skins at 2G and/or 115% limit load
- no buckling of ribs and spars at ultimate load
- no buckling of substructure at 115% limit load if it restricts mechanical operability
- structural deformation shall not affect aerodynamics or survivability
- waviness and smoothness tolerances of OML determined by structural assembly

Operational Requirements:
- peacetime service life of 6K hours and total operational life of 24K hours
- equivalent design temperature of 180°F, stagnation 248°F, and adiabatic wall 217°F
- maximum acoustic pressure of 165db occurs on deck of fuselage aft body

Durability Requirements:
- composite parts apply reduced strength allowables where applicable
- metallic parts apply reduced allowables in design of joints and lugs

Damage Tolerance Requirements (based on AFGS MIL-STD-87221A):
- no visible dent resulting from low velocity impact of 100 ft/lb on upper skin, 25 ft/lb on lower skin, and 6 ft/lb leading edges
- composite parts have visible damage detection limit of 0.1 inch
- zones of high probability for damage designed with reduced allowables
- skin panels of minimum gage designed with reduced allowables

Material Strength Requirements:
- composite structure: MIL-HANDBOOK 17; when data of this confidence level is not available,use material properties generated under DoD sponsored research programs
- metal structure: MIL-HANDBOOK 5
- structural sandwich core: MIL-HANDBOOK 23

Survivability Requirements: The principal design criterion is survivability in a tactical laser environment. Therefore, the analysis will focus on thermal loads resulting from laser threats. Upon laser engagement, the primary load carrying wing box structure must retain sufficient strength to enable the aircraft to return to safe basing operating with only moderate limitations to the maneuver envelope. A representative mission has been adopted from work performed under the Air Force sponsored Structural Assessment and Vulnerability Evaluation (SAVE) program (reference 15). The mission depicts a multi-role fighter which is configured as a Wild Weasel for suppression of enemy air defenses. The aircraft encounters ground based High Energy Laser (HEL) systems during an attack on surface to air missile batteries.

DESIGN BASELINE

The design baseline, designated 287-1006, is a single seat, single engine, multi-role fighter developed under a cooperative Air Force / McDonnell Douglas program entitled Propulsion Integration for Aerodynamic Control Nozzles (reference 14). This aircraft was selected for in-house studies because the design is non-proprietary, thus sufficient data were available to develop a detailed structural model. The deltoid wing configuration was preferred because the planform allows for significant variation of internal structural arrangements and the thin airfoil section provides a basis for selection of an efficient skin stiffening concept. Confidence in the design has been substantiated by significant trade studies performed on a similar configuration, the Northrop / McDonnell Douglas YYF-23, for survivability versus supportability. Further, the multi-role fighter was selected because operational requirements include high survivability and the methodology for multidisciplinary optimization with ASTROS will provide valuable design data. The design continues to evolve under conceptual design studies for the multi-role fighter entitled Aero Configuration and Weapons Fighter Technology (reference 16). Aircraft lay-out with 3-D views and physical parameters of the wing design are presented in figure 3 (reference 14).

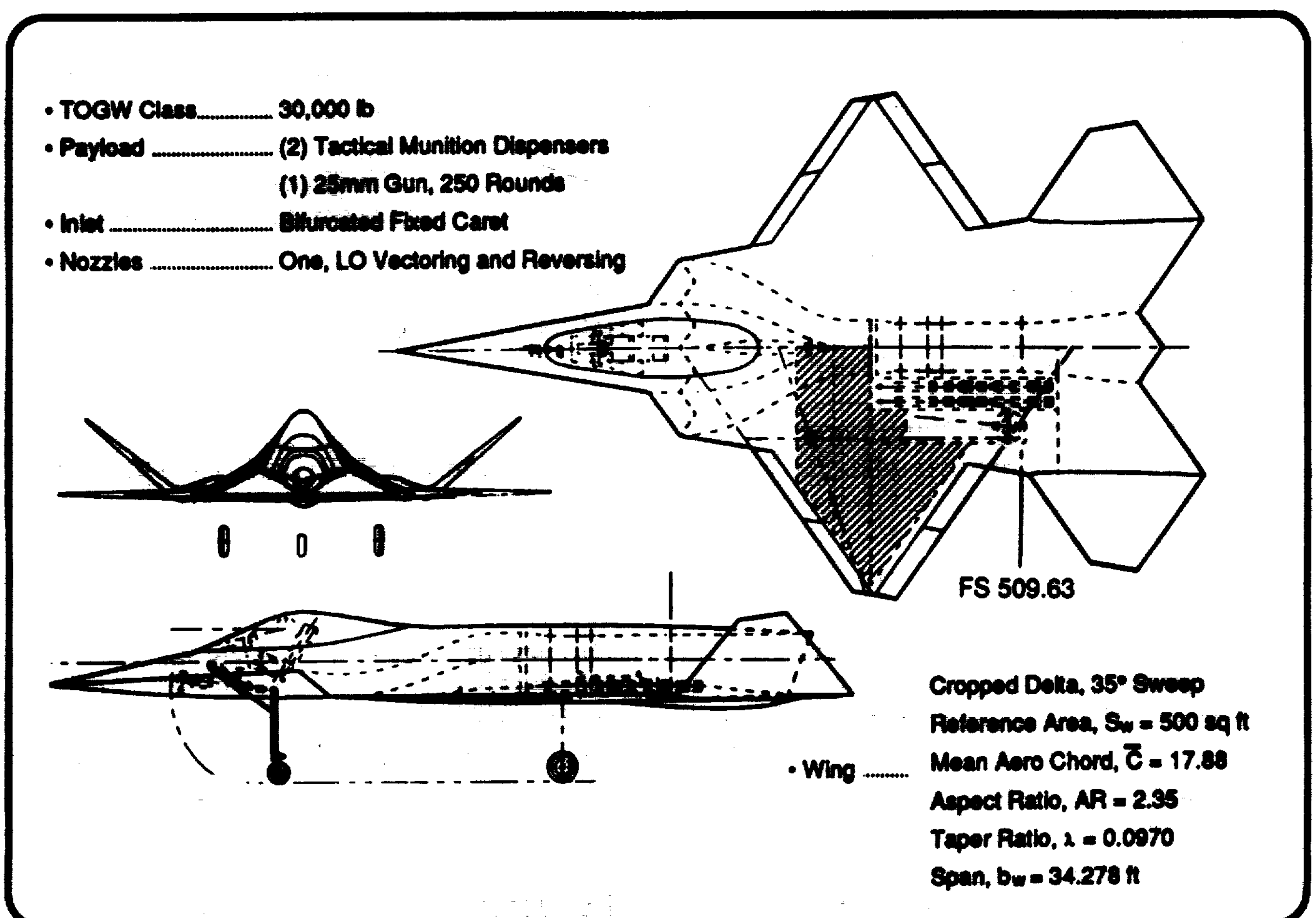

FIGURE 3 - Air Force / McDonnell Douglas 287-1006

DESIGN TRADE STUDIES

Analyses were performed on a finite element model of the baseline wing to establish reference levels of structural weight and survivability performance. Detail models were developed for two advanced configurations which incorporated structural concepts and composite materials for increased survivability. Optimization studies were performed on the three models to assess functional dependence between structural weight and survivability performance. Design differences are as follows.

Structural Configurations: The baseline wing, designated WING.BL, has four spars, seven ribs, and integrally stiffened skins. The wing attaches to the fuselage carry-through bulkheads with clevis lugs and bolts. The spars are oriented perpendicular to the fuselage, which provides efficient load transfer and eliminates the structural weight penalties resulting from kick loads. The forward most spar attachment reacts only the vertical shear loads while the remaining spar attachments react the wing bending moments as well as vertical shear. The ribs provide buckling stability and react loads from wing torque, fuel pressure, and air pressure. The torque box employs solid laminate skins with hat-section stringers of non-linear distribution in the spanwise direction. This design provides a smaller effective panel width and minimizes weight in a postbuckled structure. The advanced wing designs have seven spars, twenty-seven ribs, and sandwich stiffened skins. The first configuration, designated WING.11, has spars which are oriented perpendicular to the fuselage carry through structure; and the second advanced configuration, designated WING.21, has spars which are oriented along constant percent chord sections of the wing .

Structural Concepts: The baseline wing is designed with conventional solid laminate skins of current composite materials and mechanically fastened metallic substructure. The advanced configurations employ the following high survivability concepts :

- multi-spar/multi-rib wing box with redundant load paths
- sandwich composite skins with syntactic foam near inner surface
- damage arresting strips at cut-outs and through thickness stitching of spar caps
- spar caps use two rows of fasteners at boundaries of the fuel tank
- spar flanges are oriented towards outside of fuel tank to minimize leak paths
- outer plies ±45° of principal load axis for improved compression after impact
- outer surface of skin treated for laser attenuation
- inner surface of skin treated with elastomer for fuel containment after impact
- comingled outer surface ply of nickel-coated Gr/BMI for lightning strike protection and fiberglass/BMI inner-most ply for corrosion protection

In addition, the following structural concepts were identified for improved supportability and were applied to the advanced configurations in locations where supportability features would not compromise survivability (reference 17).

- sandwich composite skins of toughened thermoset composites
- mechanically fastened upper skins and cocured lower skins
- minimum laminate thickness of 0.033 and compression strain allowable of 3500 μ in/in for increased damage tolerance and durability
- close out assemblies over wrapped with fiberglass/BMI for damage resistance

Structural Materials: The baseline wing is designed with AS4/3501-6 composite skins, 7075-T6 Aluminum spars, 7075-T6 Aluminum ribs, and 2024-0 close out edges. The advanced configurations employ the following materials for increased survivability:

- IM7/5260 BMI outer skins * having laminate construction: [0/±45n/90]s
- syntactic foam core of 0.1875 thickness
- IM7/5260 BMI inner skins having laminate construction: [±45]n
- S2glass/BMI inner-most ply having laminate construction: [0]
- IM7/8551-7A spars and ribs having laminate construction: [±45]n
- 7075-T6 Aluminum connecting rods
- S2 glass/8551-7A close out edges

* the susceptability analysis will be performed on a modified configuration having S2 glass/5260 or HVR Nicalon/5260 BMI outer skins of laminate design [0/±45n/90]s.

FINITE ELEMENT MODEL (FEM)

Model Construction: The basic finite element model represents a preliminary level design of typical monocoque construction with 392 nodes and 1573 structural elements having 2358 Degrees of Freedom. The model was constructed with the aid of a pre-processor developed at the University of Notre Dame entitled XPUT (reference 18). XPUT is capable of generating the nodal coordinates and element assignments but it is limited in that spars must be located at constant percent of chord and ribs must be parallel to the global X-Y plane. The wing must have a constant airfoil section with no twist. The resultant FEM employs conventional NASTRAN elements with associated constraints, physical properties and material cards (reference 19). Access doors and antenna panels which do not carry load are modelled as normal membranes of negligible stiffness. Notched allowable material properties at 180°F were used for composite skins. In addition, the material densities were multiplied by a factor to account for ply build-ups at joints and hard points. The finite element model of shells is presented in figure 4 and the rod model is presented figure 5.

Composite wing skins are modelled with 324 QUAD4 elements which react inplane tension/compression. The membrane option was selected because ASTROS does not support optimization of bending stiffness for shell elements and the superior shear modelling of the QUAD4 element is not required for loads typical of deltoid wings.

Composite spar/rib webs are modelled with 351 SHEAR elements which react inplane shear. The shear flow distribution is constrained to satisfy equilibrium conditions and stress constraints are calculated from average shear stresses at the nodes.

Isotropic spar/rib caps are modelled with 702 ROD elements which react uniaxial tension/compression. The ROD element was selected because ASTROS can efficiently optimize for uniaxial loads and the out of plane bending capability of BAR elements was not required because this function is performed by connecting rods.

The upper and lower wing skins are connected by 196 ROD elements which react uniaxial tension/compression. The connecting posts are required to transmit wing bending moments around shear panels used to model spar and rib webs.

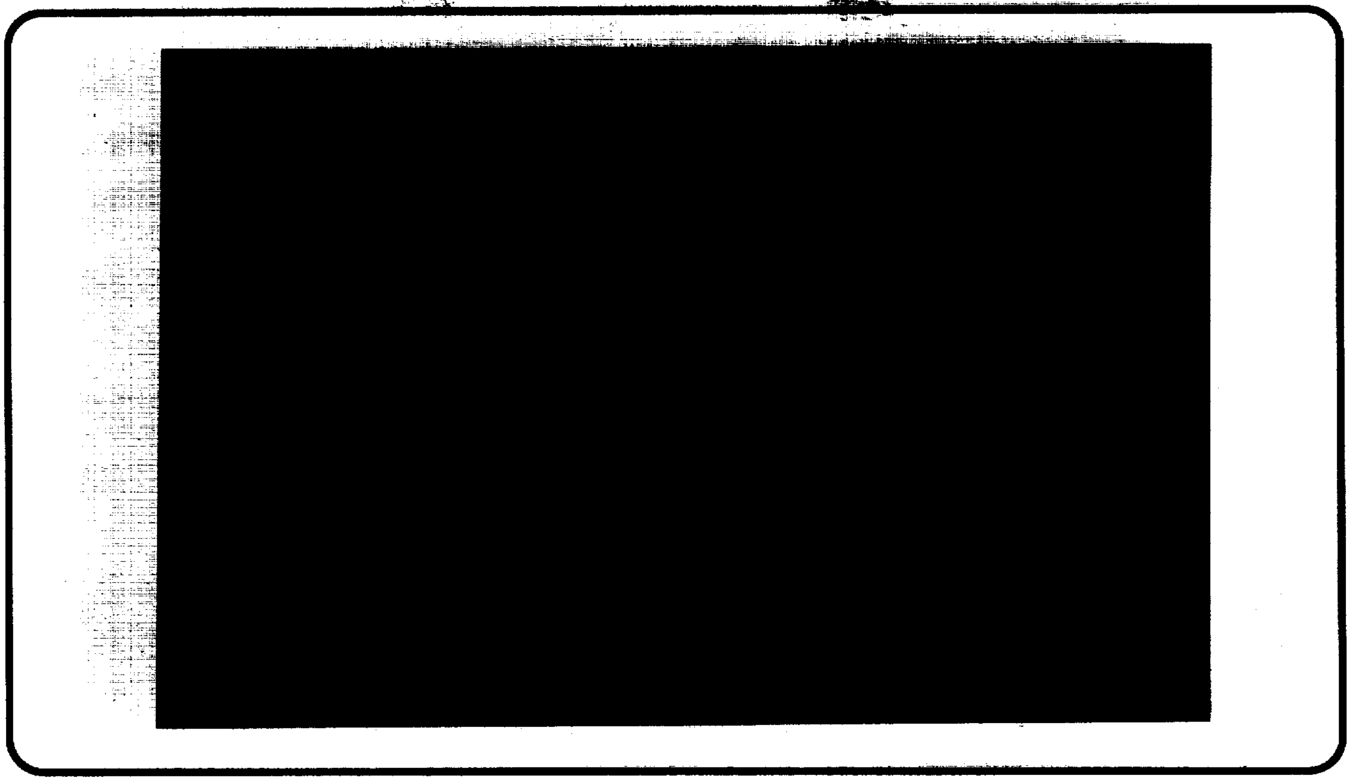

FIGURE 4a - Finite Element Model of shells for configuration MRFWING.11

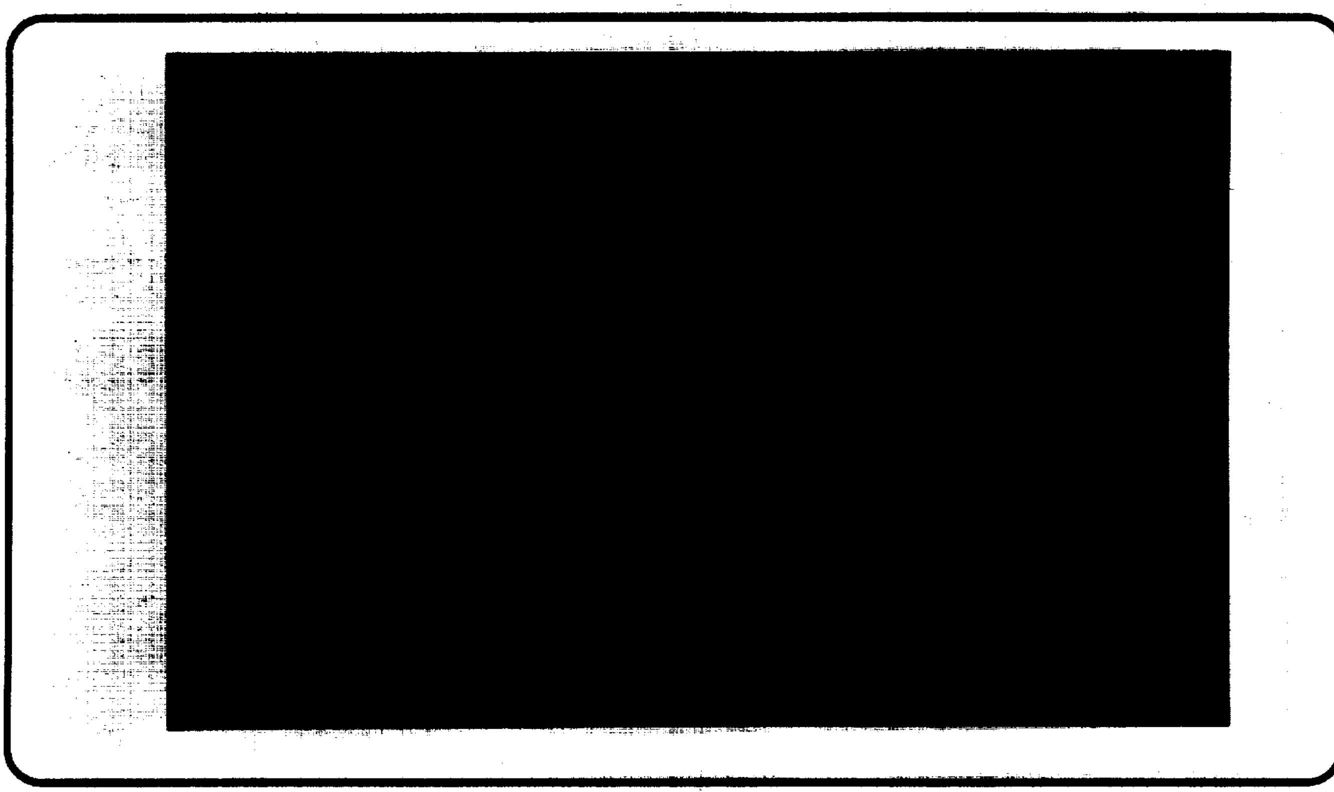

FIGURE 4b - Finite Element Model of shells for configuration MRFWING.21

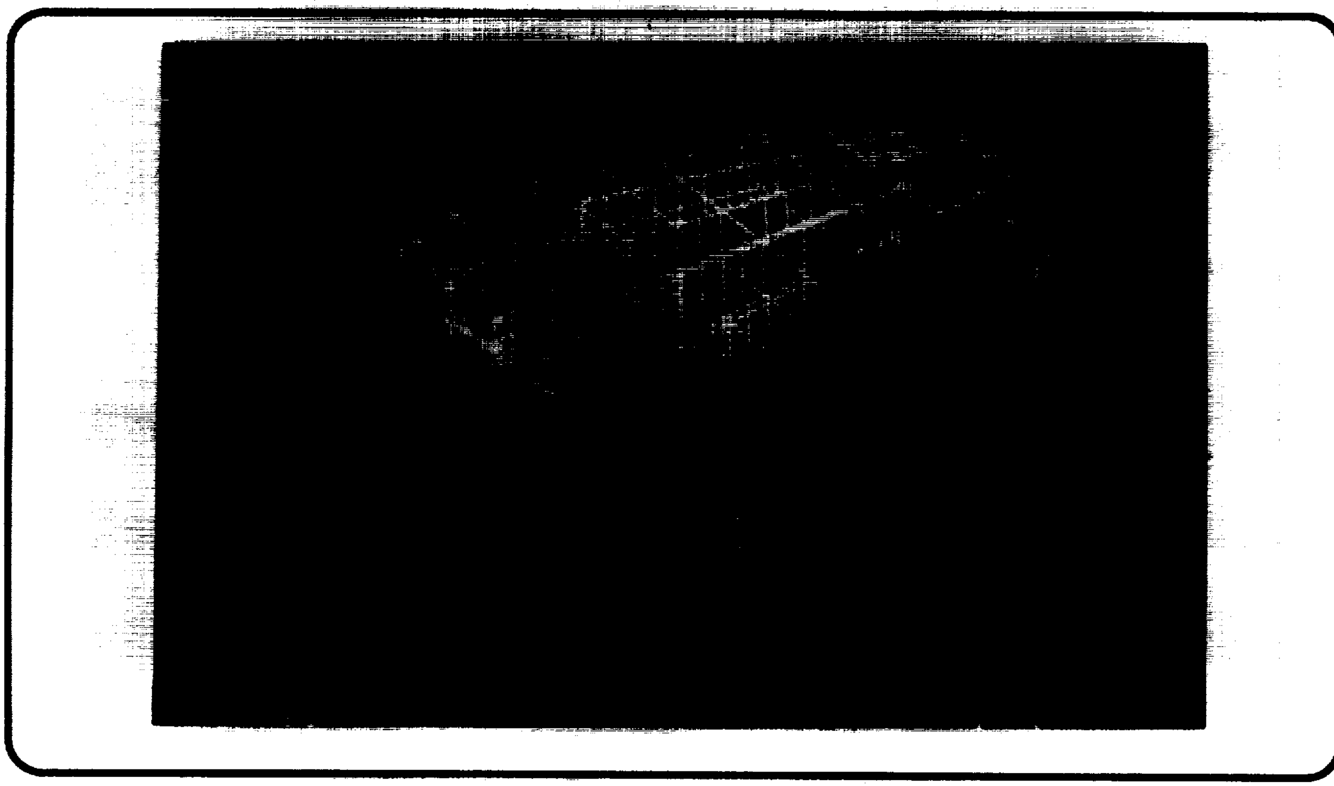

FIGURE 5a - Finite Element Model of rods for configuration MRFWING.11

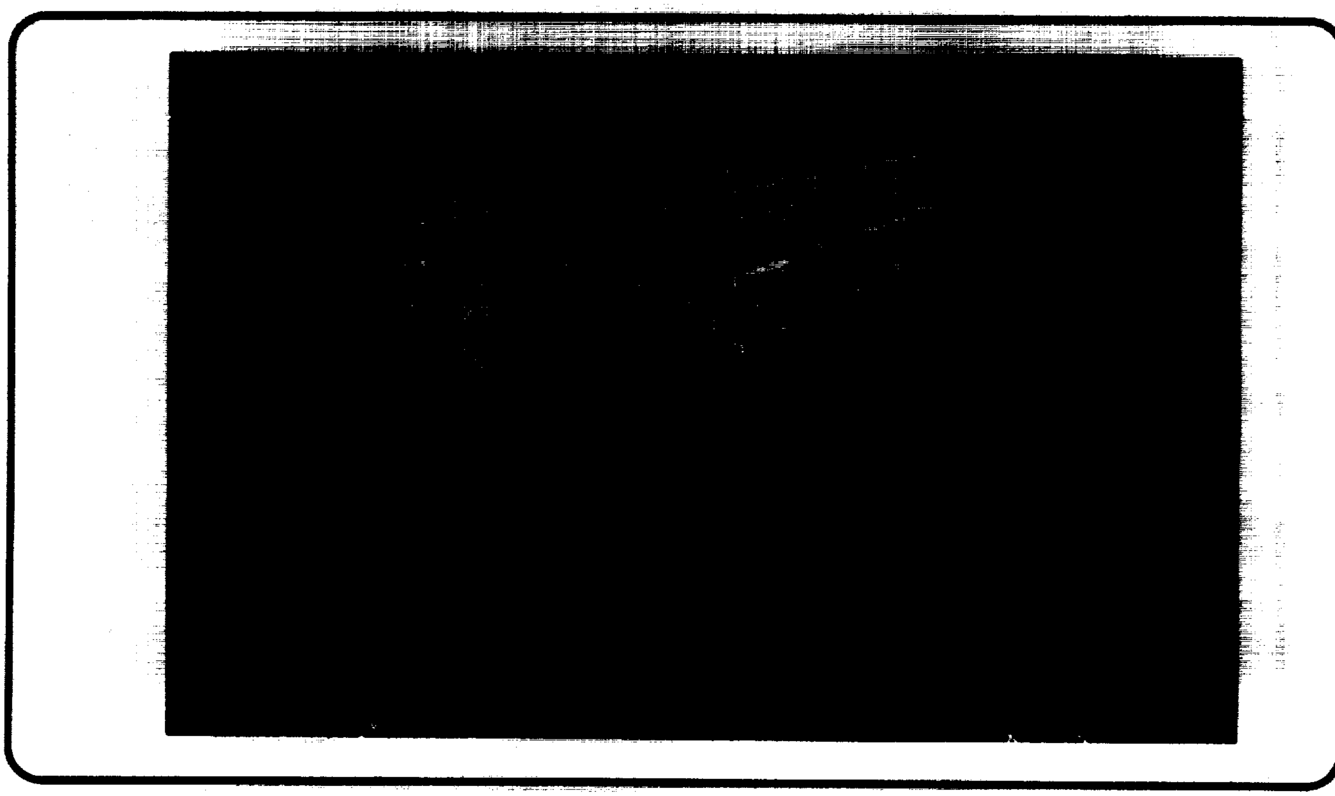

FIGURE 5b - Finite Element Model of rods for configuration MRFWING.21

AERODYNAMIC MODEL

The air loads for steady aerodynamic analysis were calculated with the Unified Subsonic and Supersonic AEROdynamics (USSAERO) which is a numerical procedure embedded in ASTROS (reference 20). USSAERO computes steady pressure loading on a wing-body-tail configuration during a trimmed maneuver. The structural model and aero model are coupled through splining matrices; the aerodynamic loads are splined to stuctural nodes on the upper surface of the wing.

Wing Geometry: A single aerodynamic panel model was used for all three wing configurations because the planform dimensions remained constant. USSAERO differentiates between the structural configuration and the panels used to discretize the aerodynamic surfaces. This capability allows for detail description of the wing in terms of planform geometry, airfoil thickness and camber. The model is constructed of seven cordwise divisions and nineteen spanwise divisions for a total of 133 panels. The aero model employs a thin supersonic airfoil (NACA 64-206) with a sharp leading edge which is representative of current high survivability fighters like the Northrop proposed configuration for ATF YF-23. Basic guidelines for construction of the USSAERO panel model were obtained from reference 21.

Trim Condition: The wing is trimmed for lift during a symmetric pull-up where load factor nz = 9.0, MACH = 0.78, altitude = 10k ft, and angle of attack is the free variable.

DESIGN MODEL (DEM)

The design model refers to the collection of information found in bulk data which defines the design task in a format compatible with ASTROS operations. The design model defines the form of the objective function and the assignment of design variables which represent global properties of the finite element model. In most cases, the design model is optimized for structural weight, thus the objective function is weight. The design model also includes physical constraints and element lists which define the functional relationship between elements connected by a single design variable. The variables must satisfy the following mathematical equation;

$$\{t\} = [P]\{v\}$$

where $\{t\}$ is a vector of local variables and $\{v\}$ is a vector of global relationships. The mathematical procedure operates directly on the $\{v\}$ vector; where the vector $\{t\}$ is determined indirectly and the $[P]$ matrix is invariant. The designer must generate the operational relationships of the $[P]$ matrix and the initial values of the $\{v\}$ vector. An inherent understanding of this equation is required to manage interaction between variables and ensure the best possible design is developed. The final objective function may vary considerably depending on sophistication of the initial design model and accuracy of the applied loads.

The comprehensive assignment of design constraints is critical for rapid convergence of the optimization process. The design constraints must satisfy one of the following mathematical equations:

$$g_j\{v\} \leq 0 \text{ where } j=1, ncon$$

$$h_k\{v\} = 0 \text{ where } k=1, ne$$

$$v_i(lower) < v_i < v_i(upper)$$
where i=1 thru number of design variables

where g specifies the function of inequality constraints and h specifies the function of equality constraints. The equation for v specifies side constraints on global design variables (reference 10). The design model for advanced configurations of the multi-role fighter wing employs the following constraints:

- side constraints: establish minimum gage for survivability and damage tolerance
- principal strain constraints: compression after impact for composite skins
- Tsai-Wu stress constraints: notched hole allowables at 180°F for composite skins
- Von Mises stress constraints: B allowables for isotropic materials of rods and shears
- survivability constraints: the development of special constraints for panel buckling and signature effectiveness is ongoing at WL/FIB

DESIGN OPTIMIZATION

The design optimization is performed by mathematical algorithms which resize the design and force the objective function towards the minimum value which satisfies all performance criteria. The local design variables are linked together and operated on as a tractable number of global variables. The assignment of global design variables and design constraints governs the path the optimizer follows to develop the final design, thus the design model must be constructed efficiently to guide the optimization process towards the best solution.

Boundary Conditions; assigned in solution control

- MPC: 42 dependent multi-point constraints at wing root (1,2&3 degrees of freedom)
- SPC: 1181 independent single point constriants on rotational degrees of freedom
- SUPPORT: 1 reference node at aircraft cg to support the z direction for inertia relief

Optimization parameters; assigned in the engineering module ACTCON

- NRFAC set to 0.5 to limit retained constraints to below 200
- EPS set to -0.100 to limit cutoff constraint value
- DELOBJ set at 2.0 to limit relative change in objective function between successive iterations. This parameter was increased during intitial runs to accelerate verification of design methodology; yet generate sufficient information to evaluate dependency of the constraints.

MAXITIR set at 3 to accelerate verification of design methodology

The mathematical optimization process establishes a practical limit on the number of discrete design variables (approximately 200), thus variables should be limited to the minimum required to evaluate a desired relationship in the design model. The design variables are separated into two types by optimization function. This acts to minimize the total number of variables operated on during a single mathematical procedure and ensure most efficient optimization.

Local Design Variables: The local design variables {t} are those used to represent physical properties of the individual finite elements including thickness, cross sectional area, and laminate construction, mass, and stiffness. The mass and stiffness matrices of physical properties are a linear function of the design variable value. At the completion of each design iteration, the total weight of designed elements is determined by summation of the variables multiplied by element size and material densities. Note that this calculation will not include the weight of non-optimal structure, non-structural hardware, fuel, or subsystems. The design model for the multi-role fighter wing is comprised of 5461 local design variables which are allocated as follows; 4212 variables for thicknesses of each lamina of the composite membranes, 351 variables for thicknesses of the composite webs, and 898 variables for cross sectional areas of the isotropic rods.

Global Design Variables: The global design variables {v } are those used to control relationships between elements of a set. Actual element thicknesses are obtained by multiplying global design variables and the thicknesses defined on the property cards. The design model developed in this project for a multi-role fighter wing is comprised of 202 global design variables. To maximize the benefits of aeroeleastic tailoring, more than fifty percent of these variables are used to describe design relationships between elements of the composite wing skins (reference 22).

Physical Linking of Design Variables: Physical linking requires that one global design variable uniquely define a collection of local design variables. This option provides for simultaneous variation of all elements forming a structural region, which implies that there is no preconceived reason why each element must be designed independently. Further, physical linking requires that a single column of the [P] matrix be derived from thicknesses specified on the element property entries; all other columns specify rows controlled by the element lists (PLIST) which are zero. The design model for the multi-role fighter wing employs 118 groups which are physically linked according to substructure type (example: inboard wing skins on the upper side and all webs for a specific spar). This assignment was selected because it resulted in a signifiant variation in structural weight and this translates into the largest variation in structural resilience to laser damage.

DESIGN CONSTRAINTS

The strength of finite elements are bound by physical constriants on material properties which represent allowables established by mechanical loading and environmental exposure. The size of finite elements are bound by side constraints on global design variables which represent limits established by survivability, damage tolerance, and manufacturing.

SURVIVABILITY MODEL (SUM)

The structure of the multi-role fighter wing box will be designed against catastrophic failure such that the aircraft can continue flying without severe limitations to the maneuver envelope. The finite element based code Vulnerability Analysis of Aircraft Structures Exposed to Lasers (VAASEL) will be used to model structural response during the laser encounter (reference 11). VAASEL is capable of modelling ablation, systematic failure and load redistribution as the laser beam slews across composite materials. The development of a 3D thermal model for vulnerability evaluation of the advanced configuration is under current study. Detailed characteristics of the proposed threat are classified SECRET, therefore, a generic ground based laser threat was selected from reference 11 to verify the modelling approach. The normal incident laser intensity is 6.1 kW/cm2 during a laser encounter of 5 seconds. The wing is exposed to the laser beam for 1.5 seconds as it slews over the upper skin. The pursuit of this task has been significantly hindered by difficulty in collection of the thermal data required to model particular structural concepts and composite materials employed in the advanced configurations. Due to a high level of confidence in data for the baseline material (AS4/3501-6), the design of the wing skins may be modified for all VAASEL analysis to use a solid laminate of this material and eliminate sandwich construction.

DESIGN RESULTS

Of foremost interest is whether or not the work performed under this study will produce significant improvements in laser survivability. At this time, the only definitive result is that the application of physical variable linking has affected distribution of structural weight and this usually translates into variation in structural resilience to laser damage. The total structural weight of the advanced configurations varied by approximately 30 percent. Note these values include only the weight of optimized elements and do not account for joints, subsystems, fuel, and other nonstructural elements. The design weight of the advanced configuration with spars at constant cord is approximately 20 percent lighter than the baseline design. The weight penalty is attributed to the high kick loads which are found in the region of transition from perpendicular inboard spars to constant cord outboard spars. Another significant result is that the advanced designs with far more spanwise stiffeners resulted in a lighter weight design, thus an optimal stiffener spacing versus sectional area could be determined. An analysis segment was performed after the design optimization task to obtain print of final strain distributions and to evaluate the final model under additional boundary conditions. The results of this analysis are presented in figures 6 thru 8. The stress-strain distributions correlate very closely with the displacement plots. Further, note the effect of the AIM-9 missile at span Y=34 inches. Figure 9 presents a convergence summary of the optimization parameters and figure 10 presents a summary of the design constraints applied in the optimization. The evaluation of HEL vulnerability is under current study and mechanical influence testing of composite panels will be conducted in September 92.

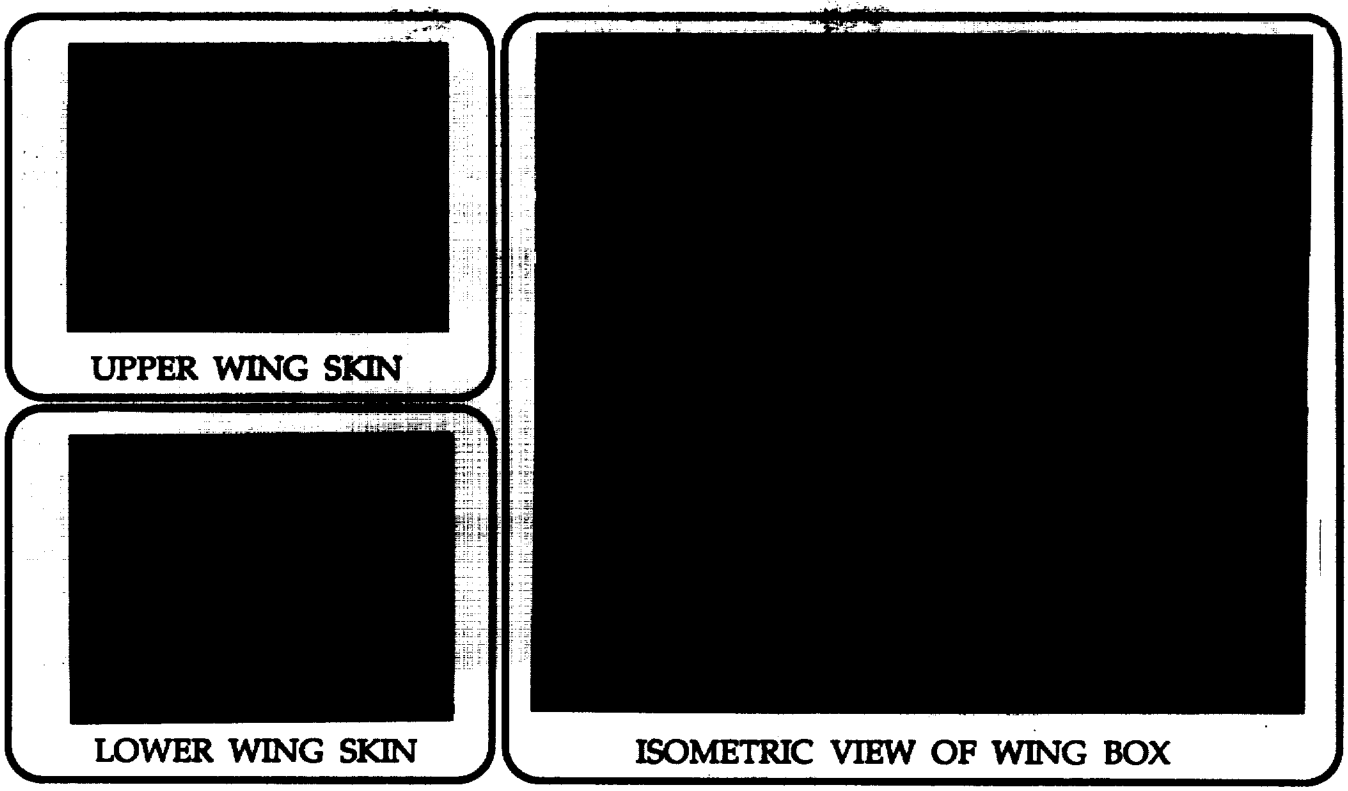

FIGURE 6a - Spanwise Maximum Stress Distribution for configuration MRFWING.11

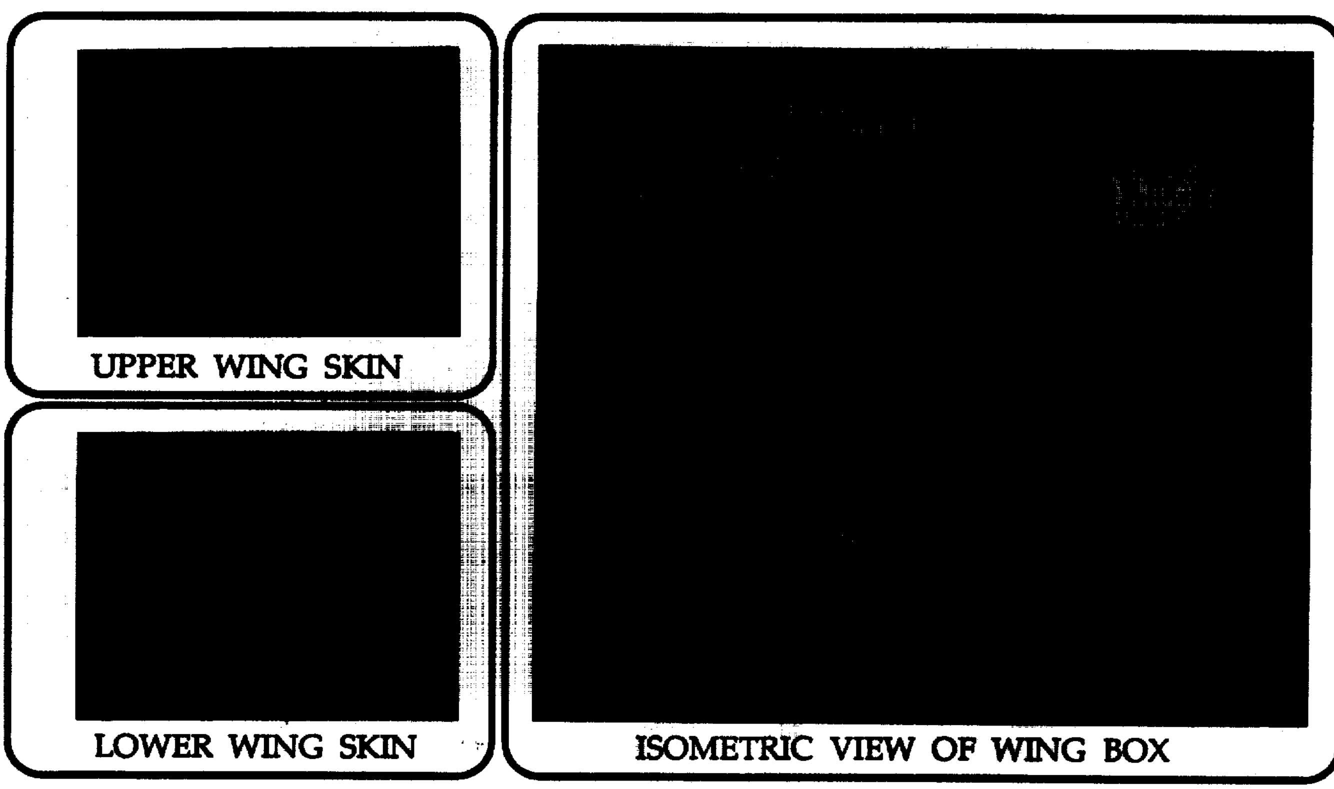

FIGURE 6b - Spanwise Maximum Stress Distribution for configuration MRFWING.21

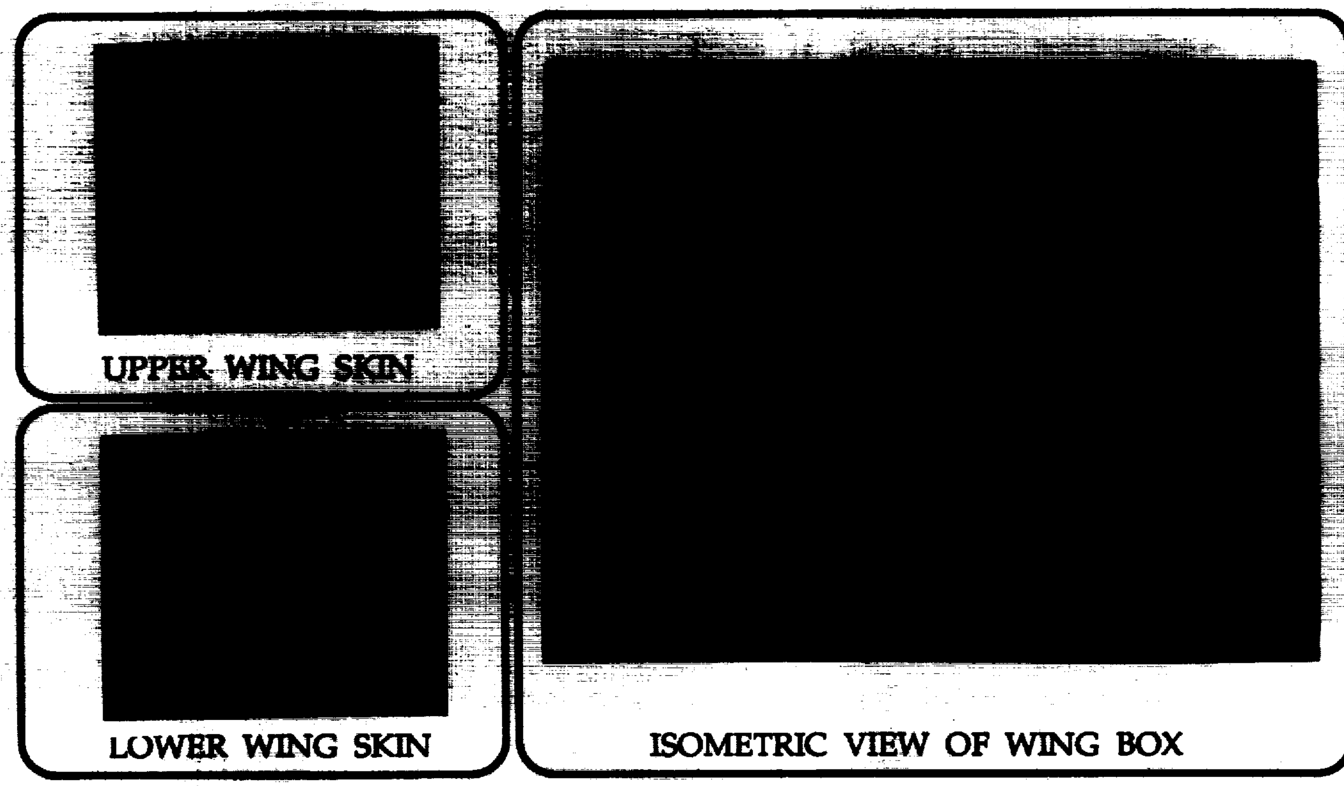

FIGURE 7a - Spanwise Strain Distribution for configuration MRFWING.11

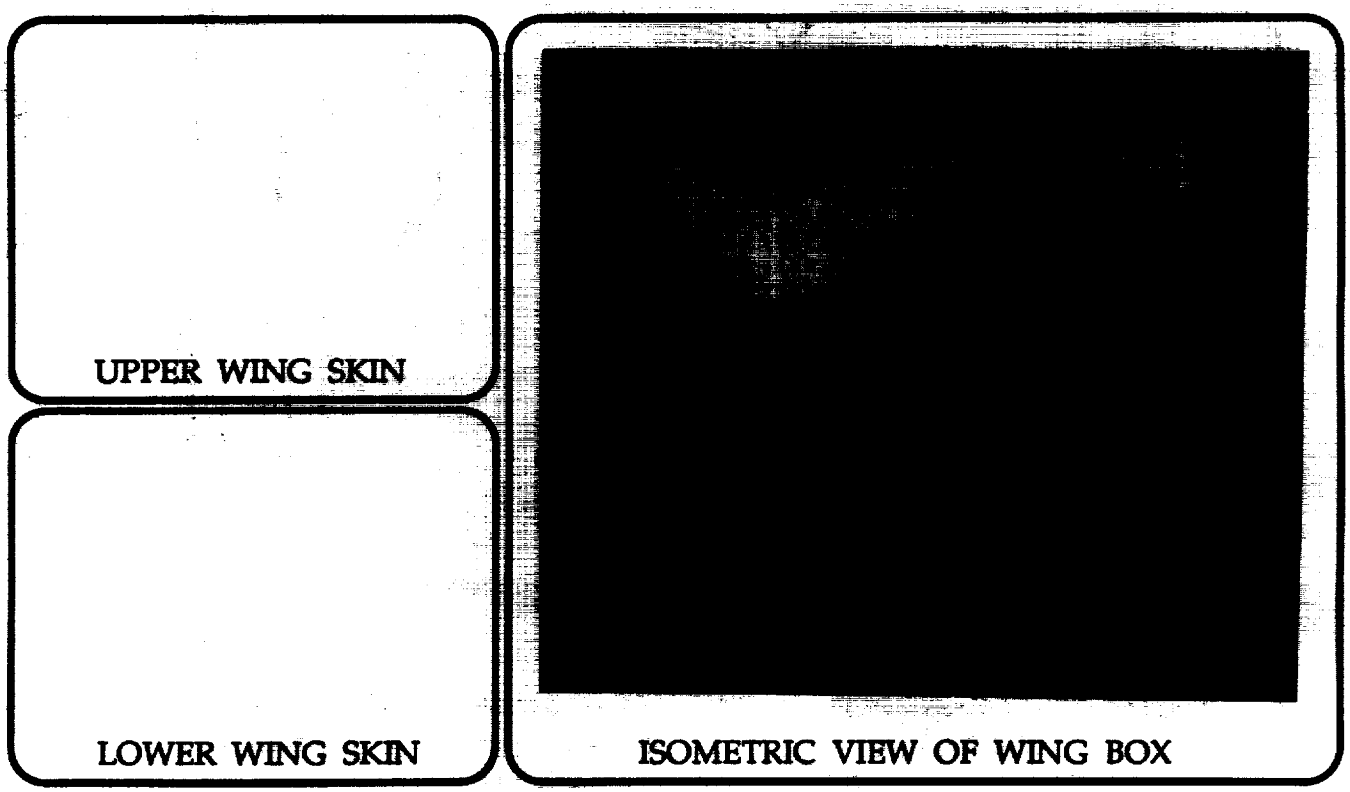

FIGURE 7b - Spanwise Strain Distribution for configuration MRFWING.21

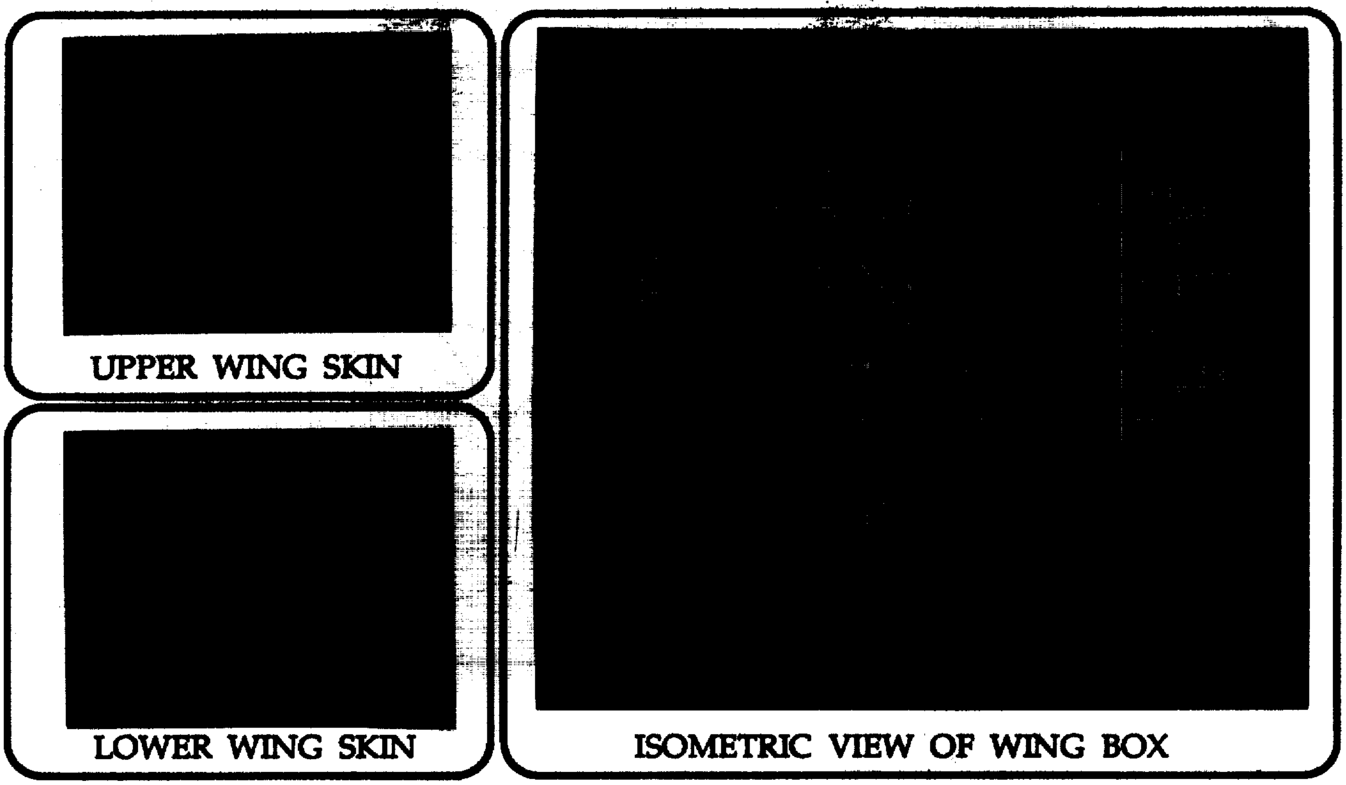

FIGURE 8a - Element Thickness Distribution of configuration MRFWING.11

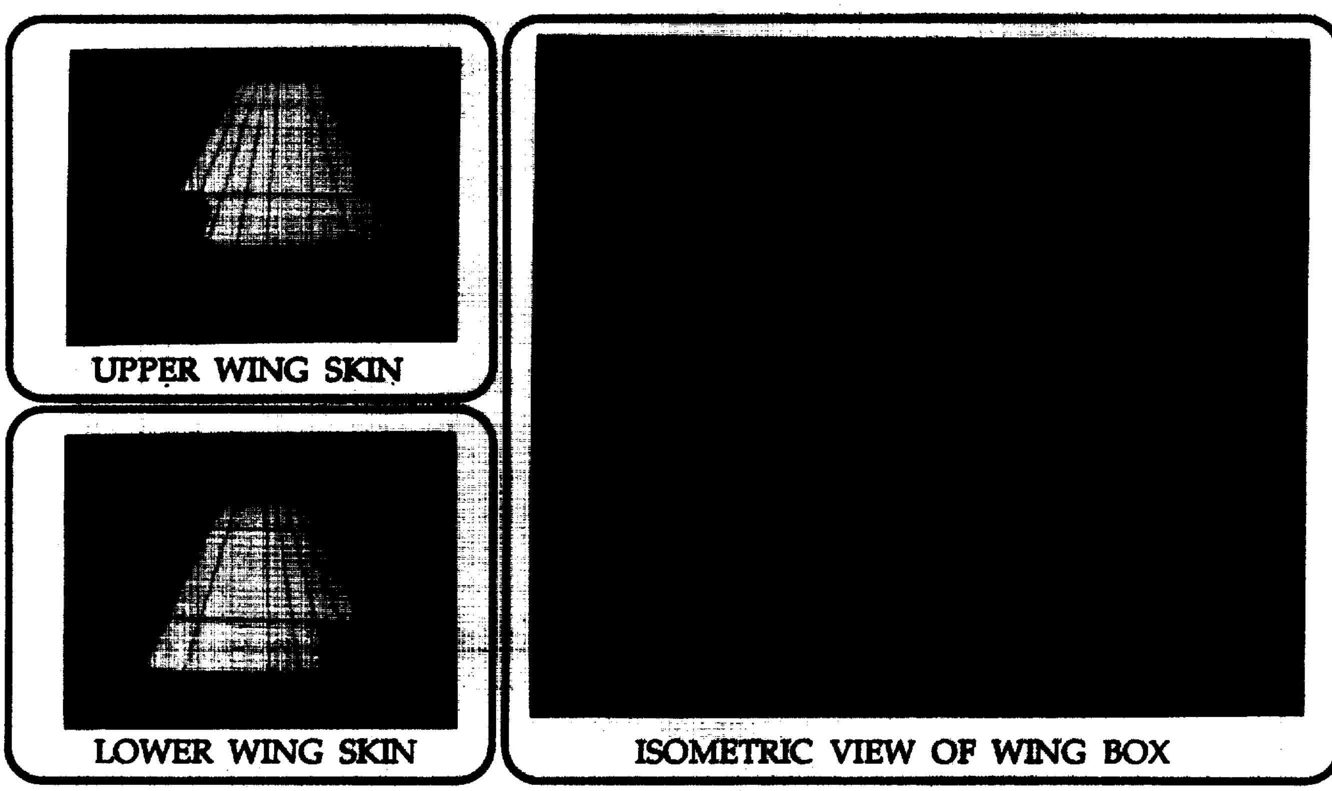

FIGURE 8b - Element Thickness Distribution of configuration MRFWING.21

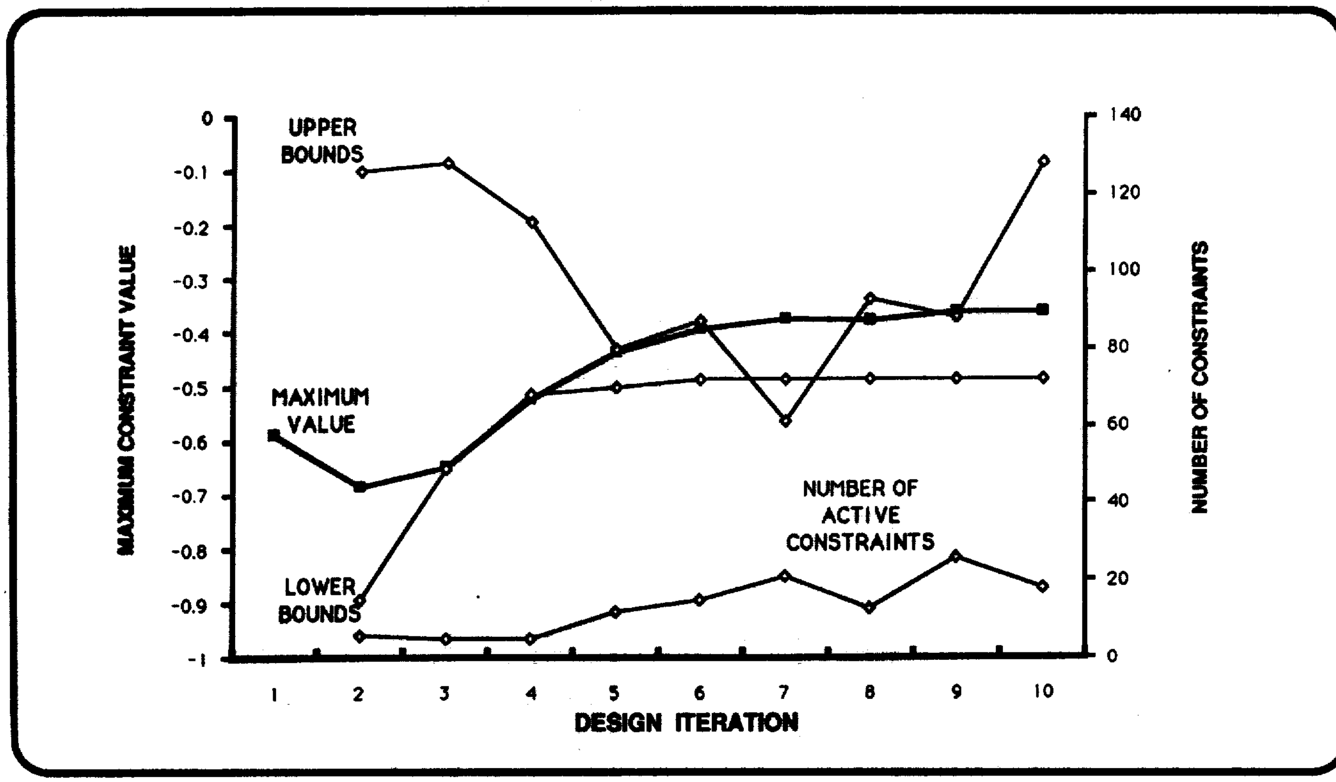

FIGURE 9a - Design convergence summary for configuration MRFWING.11

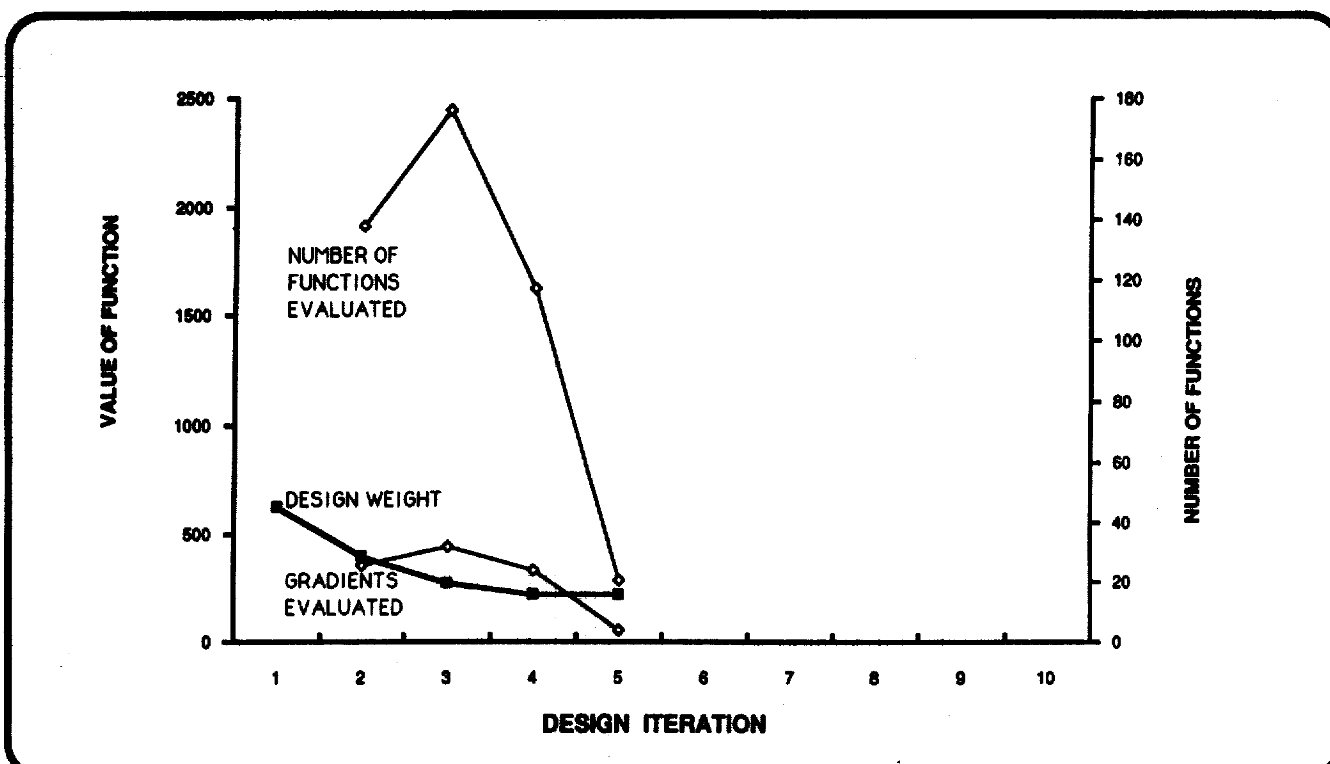

FIGURE 9b - Design convergence summary for configuration MRFWING.21

C-6.

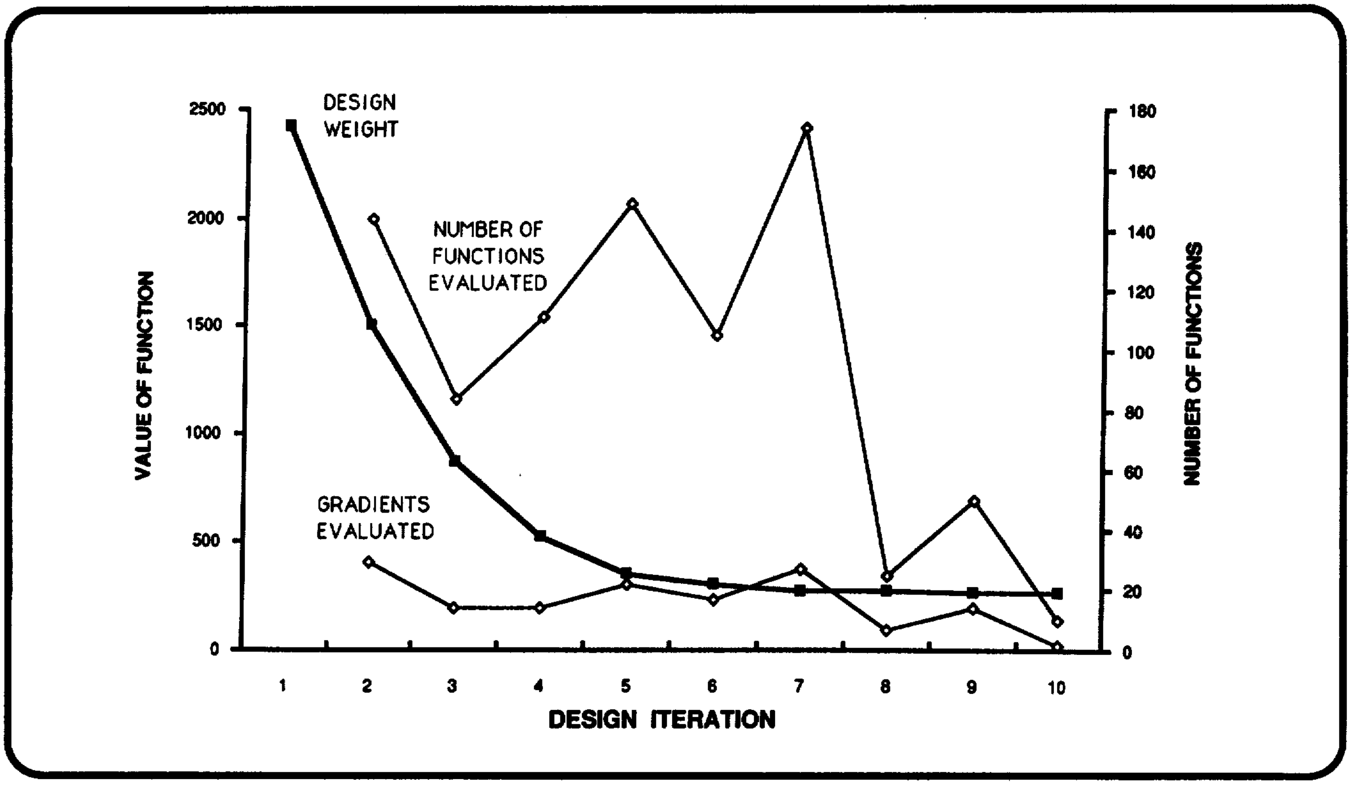

FIGURE 10a - summary of optimization constraints for configuration MRFWING.11

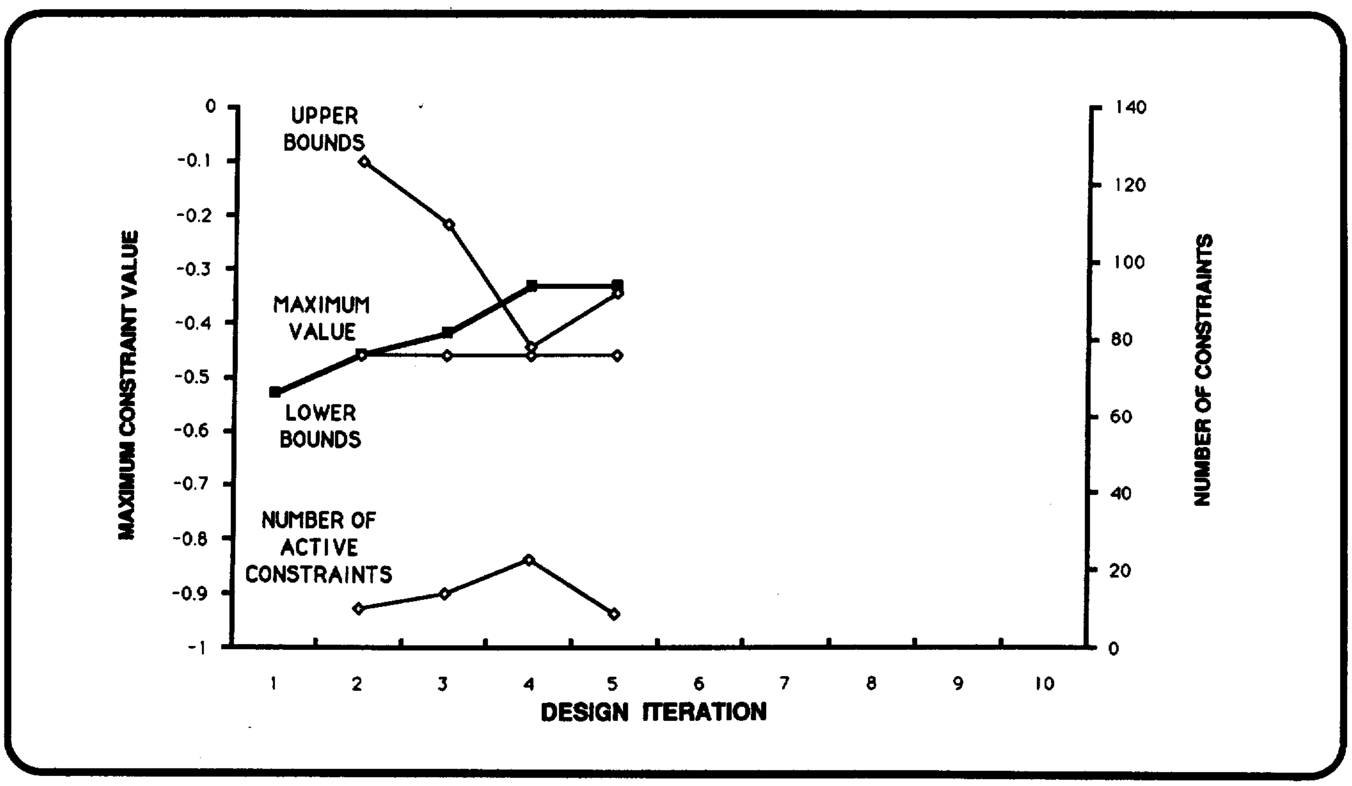

FIGURE 10b - summary of optimization constraints for configuration MRFWING.21

CONCLUSIONS

Under the scope of this effort, it was not possible to develop an exact approach which would include all aspects of survivability dependent design, therefore the author offers analysis guidelines for solving similar problems. The following recommendations are presented for researchers who wish to pursue development of a specialized constraint type or the non-conventional application of constraints.

Methodology: When developing new methodology for non-conventional constraints, it is critical that the researcher select a baseline finite element model which has been well characterized. The preferred approach would be to use an established benchmark model which has a very robust dependence on conventional variables and is not optimized within a tight bandwidth. The model should possess all of the characteristrics required to assess the relationship between cause and effect, but should not be so complex that the effect of the new methodology is normalized by interaction between many dependent variables. In the case of this research, the author unwisely elected to develop new models for three configurations of the wing box for a conceptual aircraft having insufficient maturity. This resulted in excessive time being spent on evaluating the correctness of the model, thus limiting the resources available for verification of results attained from new methodology.

Optimization: The selection of design variables and linking type is critical to success of the optimization process. It is important to isolate a relationship between design variables early in methodology development and then focus on only those variables which are dependent on this relationship. The linking type applied in this research was physical linking of element thicknesses because this assumes no predefined dependency between elements and applies fewer inherent constraints in optimization. Further, physical linking offers flexibility to modify linked sets of elements without changing coefficients of the design model. The negative attribute of physical linking is the lack of the capability to apply multiple links per element; thus the model requires an excessive number of design variables. An alternative approach is to apply shape funtion linking or a combination of the two. In general, the designer should select an approach to optimization which provides the greatest control of specific elements under study without effecting optimization of the rest of the model.

Visual Data Analysis (VDA): The visualization of design models and analysis results with graphical processing software will greatly enhance the researcher's ability to identify functional dependencies and dedicate resources to the development of methodology. These codes prove invaluable for interactive evaluation of large multidimensional datasets, thus preventing the expenditure of considerable time in pursuit of an incorrect relationship. In the case of this research, the author used the commercially available code PATRAN coupled with an FEM pre-processor code developed at the University of Notre Dame (reference 18). An Air Force developed translator was used for conversion from ASTROS output to PATRAN neutral format.

Structural Test: A structural test is worth a million bits of data. The significance of analytical studies must be verified through hardware demonstration. Under Task 3 of this program, the WL/FIBC Composites Facility will fabricate and test two full scale components against both high energy laser and low energy LIDAR threats.

In addition, the leading edge component will be attached to a full scale composite wing box which will be developed under the in-house effort intitled Bolted Advanced Survivable Structures (reference 13). Thus, the fabrication and test of a representative structural component will substantiate the analytically predicted improvement in survivability. We are currently developing a subscale leading edge having similar structural design and materials. This effort is being pursued to develop expertice in fabrication of thermoset composite tooling and to gain experience in processing parts of the unique core materials (see figure 11).

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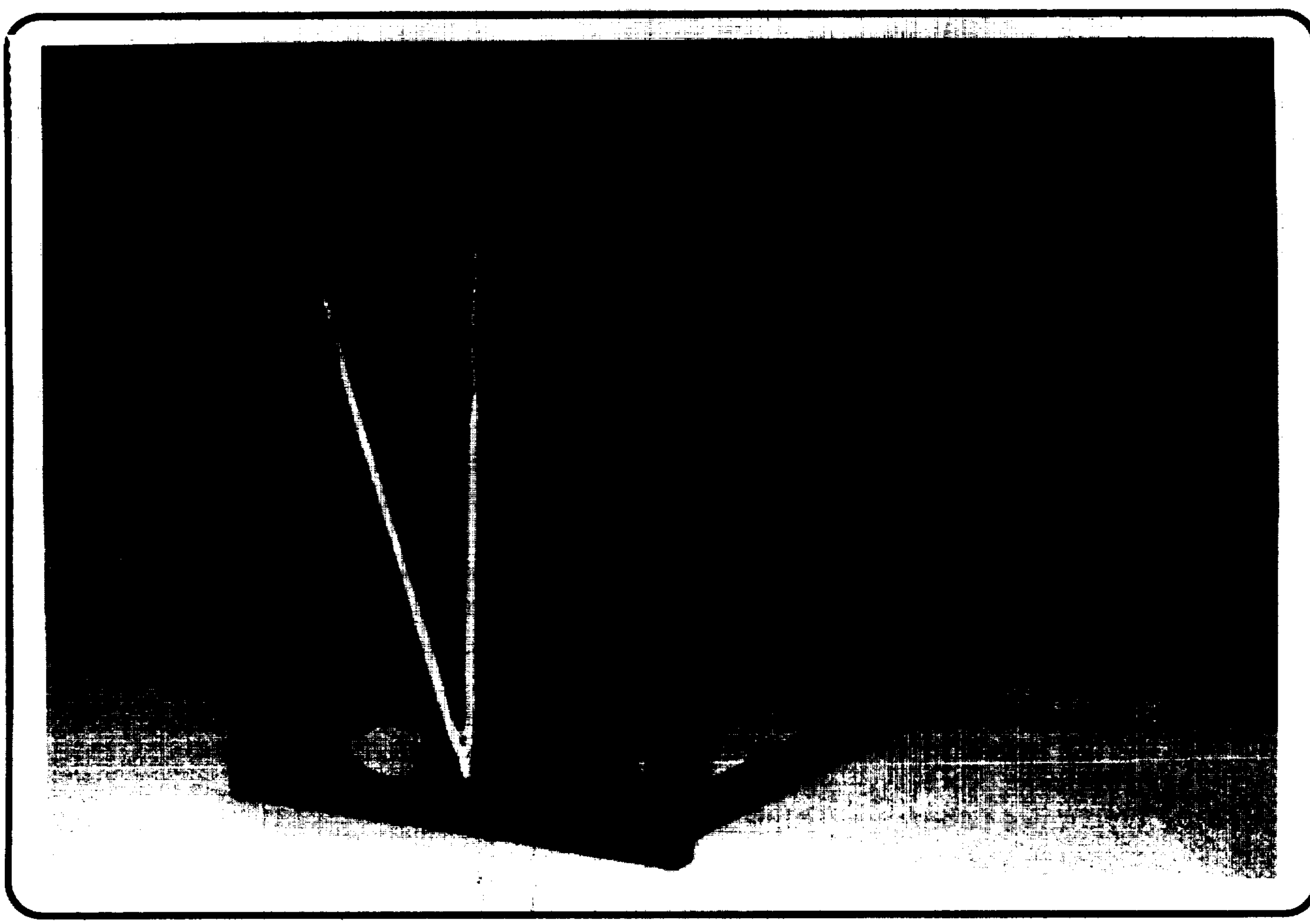

FIGURE 11 - leading edge composite tooling for producibility assessment

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