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Adaptive Modeling, Engineering Analysis and Design of Advanced Aerospace Vehicles

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Abstract

This paper describes initial progress towards the development and enhancement of a set of software tools for rapid adaptive modeling, and conceptual design of advanced aerospace vehicle concepts. With demanding structural and aerodynamic performance requirements, these high fidelity geometry based modeling tools are essential for rapid and accurate engineering analysis at the early concept development stage. This adaptive modeling tool was used for generating vehicle parametric geometry, outer mold line and detailed internal structural layout of wing, fuselage, skin, spars, ribs, control surfaces, frames, bulkheads, floors, etc., that facilitated rapid finite element analysis, sizing study and weight optimization. The high quality outer mold line enabled rapid aerodynamic analysis in order to provide reliable design data at critical flight conditions. Example application for structural design of a conventional aircraft and a high altitude long endurance vehicle configuration are presented. This work was performed under the Conceptual Design Shop sub-project within the Efficient Aerodynamic Shape and Integration project, under the former Vehicle Systems Program. The project objective was to design and assess unconventional atmospheric vehicle concepts efficiently and confidently. The implementation may also dramatically facilitate physics-based systems analysis for the NASA Fundamental Aeronautics Mission. In addition to providing technology for design and development of unconventional aircraft, the techniques for generation of accurate geometry and internal sub-structure and the automated interface with the high fidelity analysis codes could also be applied towards the design of vehicles for the NASA Exploration and Space Science Mission projects.

I. Introduction

The Conceptual Design Shop (CDS) sub-project within the Efficient Aerodynamic Shape and Integration (EASI) project, within the former Vehicle Systems Program was initiated with the major objective of "Efficiently and confidently designing and assessing unconventional atmospheric vehicle concepts and advanced technologies to meet NASA's aeronautics goals." Although numerous software tools and methods exist for conceptual design and sizing of conventional aerospace vehicles, geometry based adaptive modeling and engineering analysis tools are essential for detailed design, verification and validation of unconventional concepts. Figure 1 shows a schematic diagram of a proposed framework for integrating various discipline analysis toolsets. The CDS toolset and the integration framework were envisioned to be of variable fidelity in its scope. The emphasis was on easy usability as a geometry centric interactive tool. The eventual task was to assemble and seamlessly integrate a complete set of software for structural, aerodynamics, controls, propulsion, noise, and aeroelastic analysis. The purpose was to generate engineering design data for a viable vehicle at the conceptual design stage rapidly and transfer knowledge for detailed design and development. The CDS sub-project tasks were carried out by several teams. During the first phase, the Variable Fidelity Framework team developed one framework for conceptual design by integrating existing low-fidelity methods (Ref. 1-5). This framework also included a new web-based collaboration and distributed computing capability (Ref. 6). The Control team provided the capability to analyze the stability and control characteristics of a subsonic air vehicle including static stability, dynamic stability, maneuvering and simulation. They also developed a Confidence Module designed to assist an analyst to quantify handling characteristics due to parametric uncertainty. The noise and emissions team developed and integrated higher order, physics-based modeling and noise footprint prediction tools.

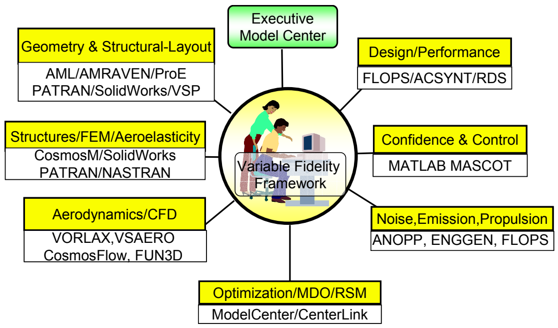

Figure 1. A framework for integrating high fidelity analysis and design toolsets, with application to advanced aerospace vehicles.

The Geometry, Structural Layout and Packaging (GSLP) team identified and integrated higher fidelity preliminary design tools for parametric geometry and outer mold line development, including internal layout for structural analysis. This paper presents the work done by the GSLP team with focus on adaptive modeling and engineering analysis. The parametric geometry data and outer mold line of aerospace vehicle concepts were generated using innovative software which provided an adaptive modeling environment and interfaced with high fidelity structural and aerodynamic analysis tools. The software environment and its usage are described in Sections II and III. In Sections IV through VII, several analyses are described using the geometry models generated by the software.

II. Adaptive Modeling Environment

The geometry-based software tool which provided the adaptive modeling environment, was developed by TechnoSoft using Adaptive Modeling Language (AML) and was specialized for rapid aerospace vehicle engineering (Refs. 7, 8). This Adaptive Modeling and Rapid Aerospace Vehicle Engineering tool (AMRAVEN) was partially funded and used extensively by the Air Force Research Laboratory for Uninhabited Combat Air Vehicle (UCAV) preliminary design, often leading to a prototype design and production (Ref. 9). After a conceptual vehicle overall geometry description is developed, a mathematical definition of the vehicle outer mold line (OML) and visualization of the internal structural layout (ISL) is necessary for detailed analysis. This OML and ISL creation utility provided by AMRAVEN is parametric with respect to the key vehicle geometry design drivers, in order to investigate the whole range of design space. For example, in wing design, if the wing airfoil shape, projected area and aspect ratio are changed, the entire geometry, outer mold line and internal structural layout configuration are automatically regenerated.

This parametric geometry-based tool was adopted and was enhanced to meet special design requirements, such as high fidelity rapid Finite Element model (FEM) analysis and Computational Fluid Dynamics (CFD) analysis for a wide variety of design options. AML-based coding was used to enhance the capability of AMRAVEN, including object-oriented interface with PATRAN-based meshing and NASTRAN-based FEM analysis (Ref. 10). The Parasolid formatted geometry and .data exchange files are also generated by the AMRAVEN utility. These files were also imported to the computer aided design (CAD) codes such as SolidWorks and the FEM analysis codes such as CosmosWorks (Ref. 11) for additional supporting analysis, sizing and redesign

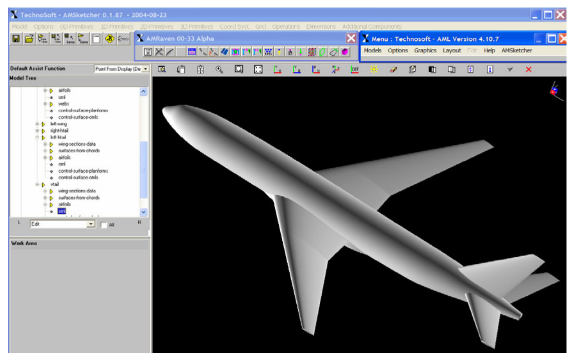

Figure 2. Boeing 777-ER outer mold line and analysis object tree development using AMRAVEN.

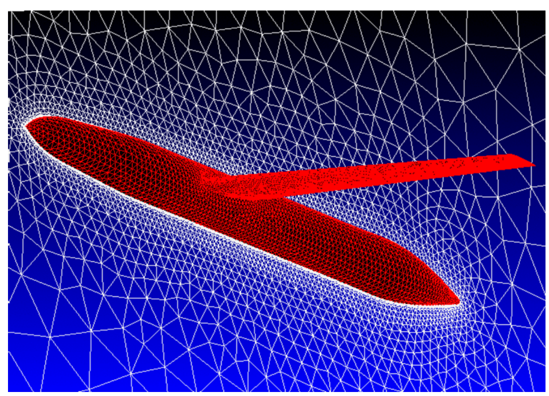

Figure 3. Boeing 777-ER: Surface mesh and volume grid generation from outer mold line using GridEx (Ref. 14).

Examples are presented for a conventional commercial transport aircraft and a long endurance high altitude remotely piloted aircraft. This design tool may fill a major gap in the existing design framework for advanced aerospace vehicles. The implementation may also dramatically facilitate physics-based systems analysis for the NASA Fundamental Aeronautics Mission. In addition to providing technology for design and development of unconventional aircraft such as Blended Wing Body (Ref. 12), the techniques for generation of accurate geometry and internal sub-structure could also be applied towards the design of space vehicles (Ref. 13) for the NASA Exploration and Space Science Mission projects.

<u>Commercial Transport Aircraft</u>: A complete outer mold line (OML) of the Boeing 777-ER vehicle with known geometry, shown in Figure 2, was developed using this tool for validation purposes. The watertight OML was created in AMRAVEN as a ParaSolid file and translated into Initial Graphic Exchange Specification (IGES) and Standard for Exchange of Produce (STEP) format files. Then, surface and volume grids are generated using the adaptive meshing software GridEx (Ref. 14). An example of the surface mesh is shown in Figure 3. The meshed OML is used for subsequent aerodynamic analysis.

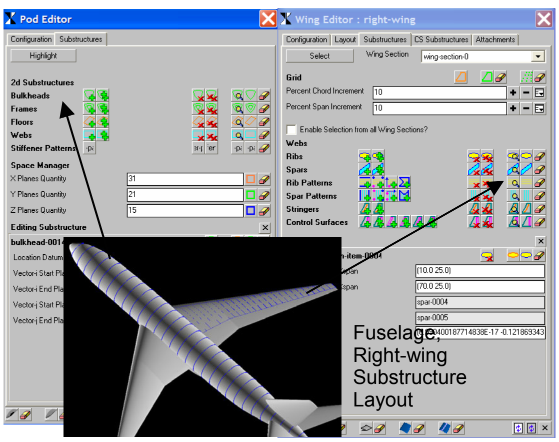

Figure 4. Internal sub-structural layout for the wing and fuselage, using interactive graphical editors (AMRAVEN).

The geometric data and visualization for the internal sub-structural layout (ISL) of spars, ribs, stringers, frames and bulkheads for the wing and fuselage are added for detailed finite element analysis and sizing. The wing-editors and pod-editors, described in Section III, are used for developing the parametric ISL and structural design. Composite snapshots of the computer screen for the ISL development are shown in Figure 4.

<u>Advanced Concept</u>: For an advanced concept such as a high altitude long endurance aircraft shown in Figure 5, for which previous database may not exist, AMRAVEN is used for rapid development of vehicle configuration, visualization, and to facilitate aerodynamic and structural analysis. Special purpose interactive editors for the development of parametric geometry, structural layout of the wing, fuselage, horizontal and vertical tail, are explained in the next section.

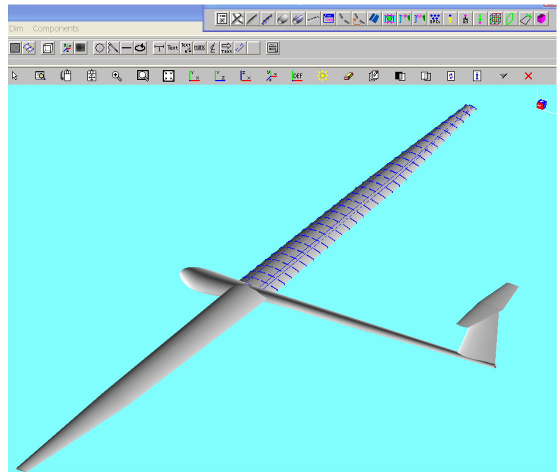

Figure 5. AMRAVEN generated geometry of a high altitude long endurance remotely operated vehicle (HALE-ROA).

III. Parametric Geometry and Structure Layout

The adaptive modeling environment of AMRAVEN is based on an object-oriented, multidisciplinary, parameter knowledge driven approach. The independent design parameters such as wing cross section, wing area, span, and sweep can be changed by the designer. The corresponding change in dependent variables such as outer mold line, internal structural layout, etc. are built-in as knowledge using an Adaptive Modeling Language (AML). The changes propagate through the object-tree and object instance property on demand. The design object, analysis object, optimization objects and post processing objects are added as necessary. These features would enable rapid design, analysis and parametric optimization of a number of flight vehicle configurations, without having to leave the AMRAVEN design engineering (Windows XP) environment. Some of the high computationally intensive analysis may reside on a different computational platform (Sun, UNIX). For special CFD and FEM analysis, additional grid generation and grid refinement techniques, special cross platform data transfer techniques may be required.

With emerging design requirements, new parametric geometry templates such as pod design, wing carry-through structure design have been added. The general purpose Wing editor for generating and designing the right and left wing, left and right tail, vertical tail, or any general lifting surface, and the internal structural layout such as ribs, spars, spar caps and stringers are described next. The Pod-Editor for generation and designing the fuselage, pod or other non-lifting surfaces and the internal structural layout such as bulkheads, frames, floors, stingers and webs are described afterwards.

Wing Editor: Configuration

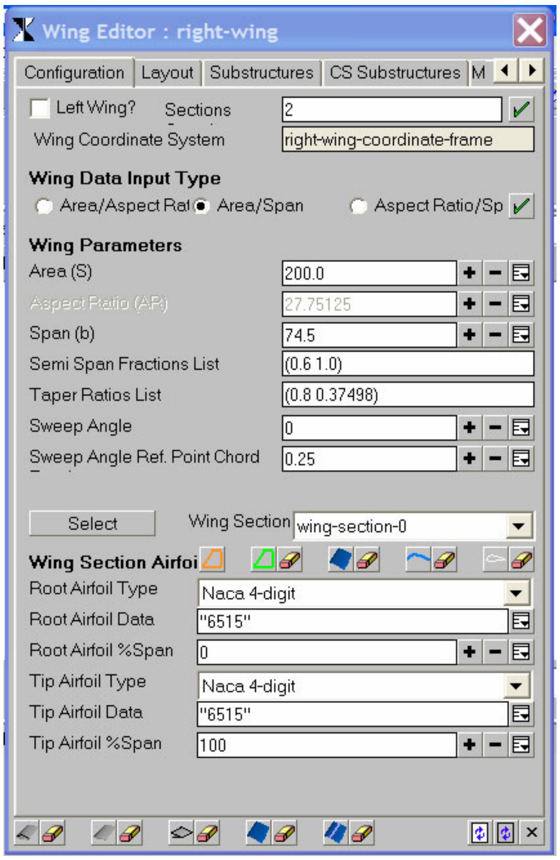

Figure 6. AMRAVEN Wing editor utility for configuration, layout and substructure generation.

Figure 6 shows the Wing-Editor utility with 5 tabs shown at the top for overall wing configuration development, wing section and subsection layout, wing substructure generation, control surface with substructure generation, and material properties definition. The wing coordinate frame is first selected from previously generated coordinate object. The number of wing plan-form subsections is generated in the configuration tab. The driving wing plan-form data input type such as area and span are chosen next. The computed wing parameter, in this case, Aspect ratio is grayed out. Alternate options of Area and Aspect ratio or Aspect ratio and span are also shown. Based on the number of wing-section, the semi-span fraction list and taper ratio list are selected next. The sweep angle and reference point chord are selected next. The corresponding wing can be visualized on the screen interactively. The wing section airfoil type at the root and tip can be selected as any 4 digit NACA airfoil or can be read from a predefined wing section point file. The data are fitted smoothly by a spline, and a high quality surface is created by lofting the subsection root and tip airfoil. An editable smooth transition section is created at the subsection junction. The icons at the bottom of the Wing Editor are used for shaded drawing and un-drawing of the trimmed wing outer mold line, untrimmed wing outer mold line, control surface outer mold line, wing camber surface and edges of the wing camber surface, respectively.

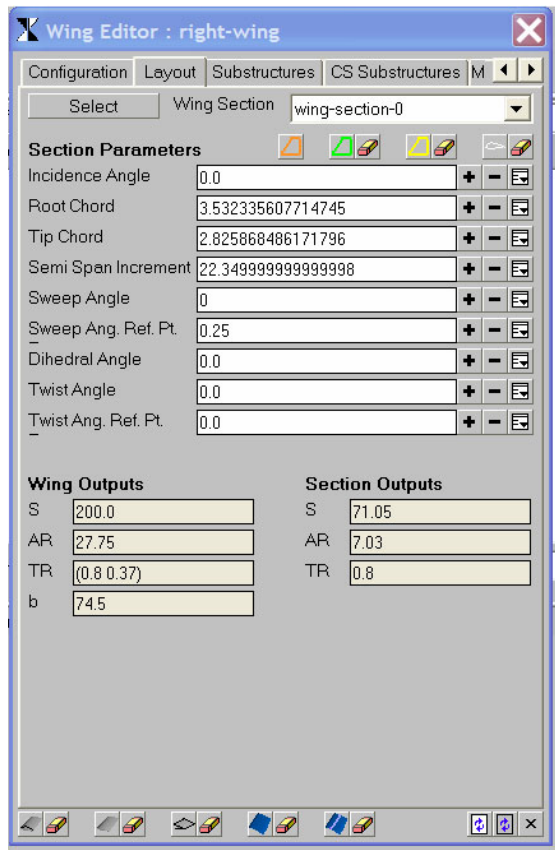

Figure 7. AMRAVEN Wing Editor Tab for the wing-subsection layout.

Wing-Editor: Layout The wing layout tab of the wing editor is shown in Figure 7. Each wing-section layout primary parameters are incidence angle, root-chord, tip-chord (based on the Semi-span fraction list and taper ratio list), semi-span increment, sweep angle and its reference point, dihedral angle, twist angle and its reference point. The corresponding values of these parameters for the wing-section number being edited are shown in the value box. The overall wing area (S), aspect ration (AR), taper ration (TR) and span (b) are computed and shown under Wing outputs. These values for the corresponding wing-section are also shown under Section outputs.

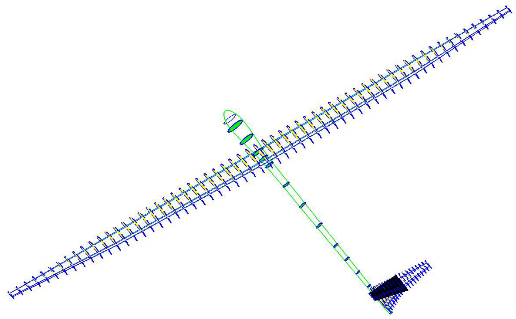

Figure 8 HALE-ROA Vehicle wing, fuselage, and tail substructure layout.

Figures 5 and 8 show samples of visualization of the sub-structure layout inside the vehicle wing, fuselage, horizontal and vertical tail. These internal spars, ribs frames, bulkheads were created using the fuselage-editor and wing-editor templates. The wing-editor tab for generating the wing substructure layout and the Pod-editor for generating the fuselage OML and the fuselage substructure are described next.

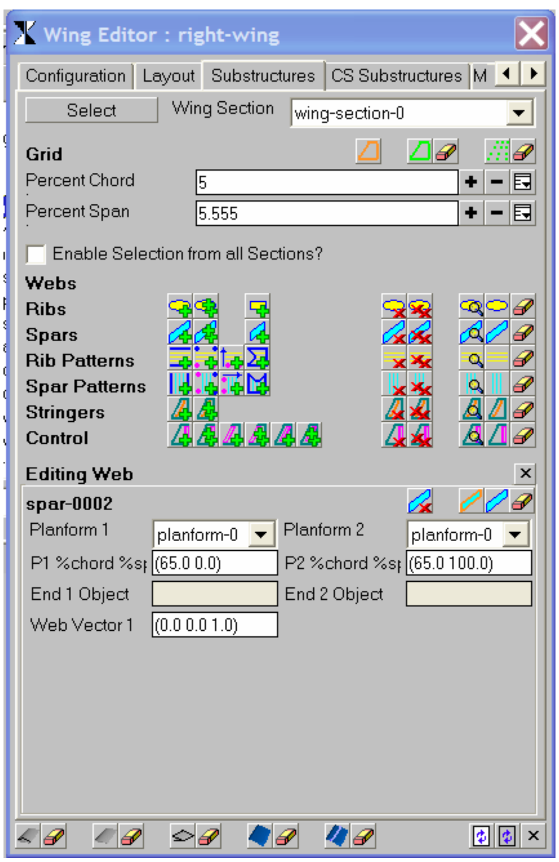

Figure 9. Wing-Editor tab for Substructures development.

Wing-Editor: Substructure: The wing substructure editor tab shown in Figure 9 is used to create compatible trimmed line and surface geometry objects to represent multiple ribs and spars, rib-pattern, spar-pattern, stringers and control surfaces. The edit utility is used to verify and change the end control points, orientation and connectivity. The end control points are chosen from a point grid as percentage of wing chord and span location.

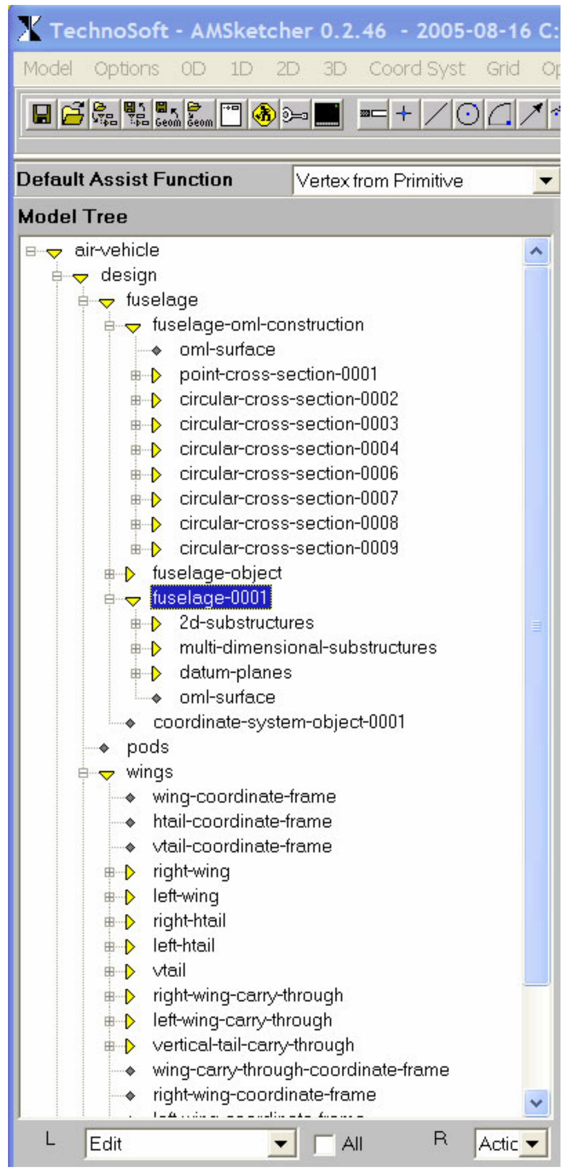

Figure 10. Air-vehicle object tree for HALE-ROA vehicle design.

Fuselage OML construction: AMRAVEN version 57-alpha was created by Dahl specially to meet the practical need for defining a better structure at the wing-fuselage junction and the fuselage-tail junction structure and bulkheads. This process is explained using the special air-vehicle object model tree for HALE-ROA vehicle shown in Figure 10. The fuselage-oml-construction object consists of a set of consecutive datum planes and corresponding cross-section geometry. These geometry objects are then lofted to create the fuselage-oml-surface. The fuselage-object invokes the Pod Editor for editing fuselage configuration and substructure generation. Figure 10 also shows the object tree for wing object and sub-objects, right-wing, left-wing, right-htail, left-htail, vtail for invoking corresponding Wing-Editor instances.

Figure 11 shows the Pod (Fuselage) Editor template for configuration control and generating fuselage internal substructure. Once the internal structure is generated, major component such as wing, fuselage, tail etc. can be reconfigured, redesigned, and resized for rapid analysis, individually or as attached structure.

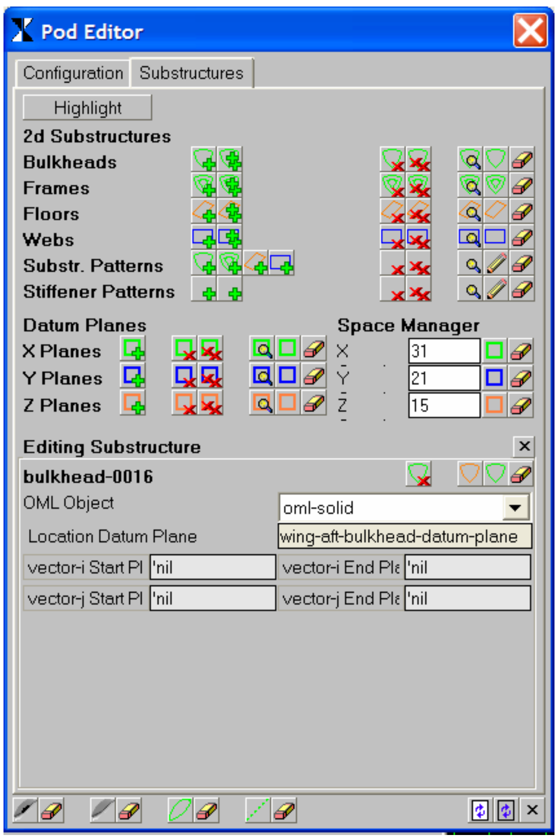

Figure 11. AMRAVEN Pod (fuselage) Editor to generate fuselage internal substructure, bulkhead, frames, floors, webs along with substructure and stiffener pattern.

Pod (Fuselage) Editor: In order to construct a realistic wing-fuselage junction for engineering analysis, the fuselage-0001 object was developed by Dahl for creating a continuous carry-through substructure between left and right wing. The details of the carry-through webs are modeled as the fuselage bulkhead as shown in Figure 12. The vehicle outer mold line generated by the AMRAVEN is a watertight surface definition in the parametric ParaSolid format file. This file or the translated IGES format file can be read by a Grid generation and refinement tool such as GridEx (Ref. 14) for CFD analysis (Ref. 15).

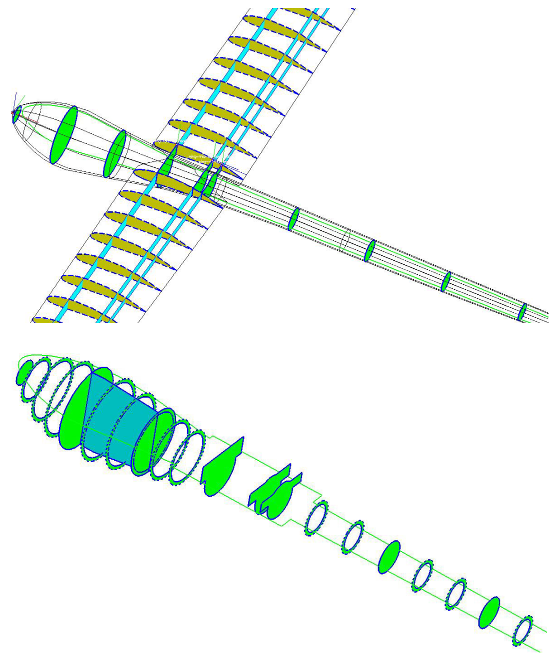

Figure 12. Details of HALE-ROA wing-fuselage junction and fuselage carry-through internal structure, fuselage frame, web, floor and bulkhead.

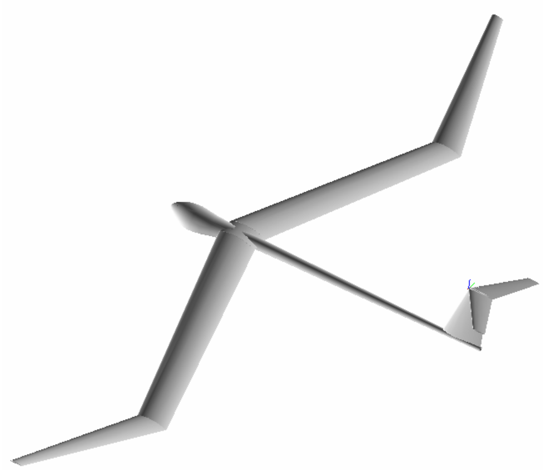

Figure 13. Derived configuration with inboard and outboard wing sweep and dihedral, tail sweep and dihedral as design driver parameters.

Parametric Vehicle Model Generation: Since the entire vehicle OML and internal structural layout are parametrically related to the major design variables, one can rapidly generate many derived vehicle configurations and conduct structural and aerodynamic analysis. For example, Figure 13 shows the HALE-ROA vehicle with an Albatross wing configuration with 15 degree sweep back inboard wing with 6 degrees negative dihedral, 15 degrees sweep forward outboard wing with 10 degrees positive dihedral, and 33deg swept back tail. This derivative vehicle is generated by simply changing these design drivers in the Wing-Editor and on-demand regeneration of the OML. The compatible internal structural layout details are automatically regenerated and can be redrawn. The rest of the aerodynamic and structural analysis follows. This is the unique capability of the adaptive rapid modeling and engineering analysis.

IV. Engineering Analysis

The AMRAVEN module has an interface with PATRAN for surface and substructure mesh generation and for generating a corresponding NASTRAN bulk data input file. The editable NASTRAN-analysis object inside AMRAVEN allows the user to choose the type of structural analysis, populate or edit the material selection and element properties from the default value, and run the NASTRAN executables. If the NASTRAN run is successful, AMRAVEN post-processing object will parse the NASTRAN output files and plot the stress and displacement distribution based on applied loads, shown in Figure 14.

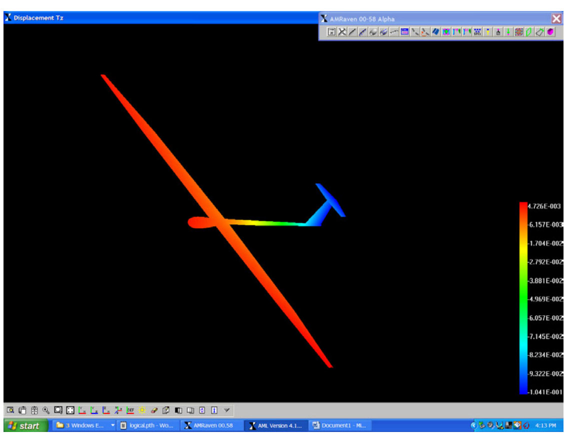

Figure 14. Graphical plot of a NASTRAN static analysis using AMRAVEN-PATRAN-NASTRAN Interface and default data.

If the static aeroelastic analysis option of the NASTRAN solution is executed properly, vortex lattice aerodynamic loads (Ref. 18) are generated within NASTRAN using the mean camber surface mesh generated within AMRAVEN. Alternatively, the generated NASTRAN block data file can be read directly by PATRAN for grouping, editing and detailed parametric analysis and sizing.

AMRAVEN has the option to translate the geometric data into an IGES file, STEP file or a Parasolid formatted file for the vehicle or its components including the substructure and import the file as an input to a FEM analysis code. For HALE-ROA wing design, the Cosmos Design software was used for an independent finite element analysis and parametric study for wing structural mass estimation. The wing and internal structure layout was also generated independently within SolidWorks, but the process is not always as rapid and adaptive as in AMRAVEN. But for a given geometry and internal layout, a large number of design oriented stress, buckling and modal analysis can be done quite rapidly with graphical visualization of results. For this analysis, primary design variables are material properties and shell element thicknesses. Figure 15 shows result of a FEM analysis for the right wing, depicting wing deflections at 2.5 g pull up at the maximum take-off gross weight (MTOGW) of 2828 kg.

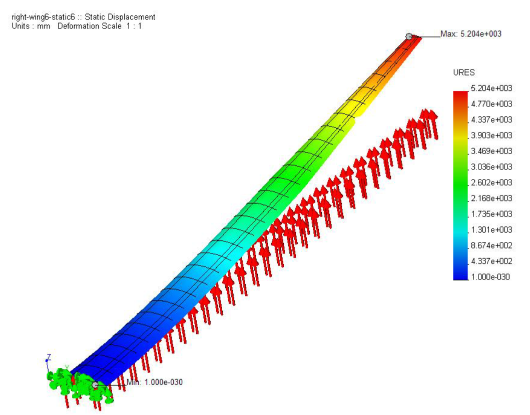

Figure 15. HALE-ROA wing deformation for a 2.5g pull up at the maximum take off gross weight.

The discretized elliptic load distribution values over 15 span-wise stations for the 38.1 meter semi-span wing with elliptic wing loading at maximum take-off gross weight of 2828 kg (HALE-ROA 7 day demonstrator MTOGW) at a 2.5g pull up and a factor of safety of 1.5, are shown in Table 1. The comparison of several design studies using aluminum and composite material properties and thickness values are shown in Table 2. The sizing study used three thickness variables, and three materials (AL6061, AL7075 and Advanced Composite). The factor of safety is based on the material maximum yield stress. Optimum right wing weight with the AL7075 is 1233 kg and with the advanced composite material is 657 kg.

V. Wing Modeling and Weight Optimization using PATRAN/NASTRAN.

In this section, a method for FEM sizing and optimization is presented as an alternative to using AML. This method involves a graphical user interface (GUI) and associated functions developed in PATRAN Command Language (PCL) as well as some custom software to generate the design optimization cards in NASTRAN. In the following paragraphs, the PATRAN/NASTRAN optimization method is described, results are presented, and the efficiency of this method is discussed.

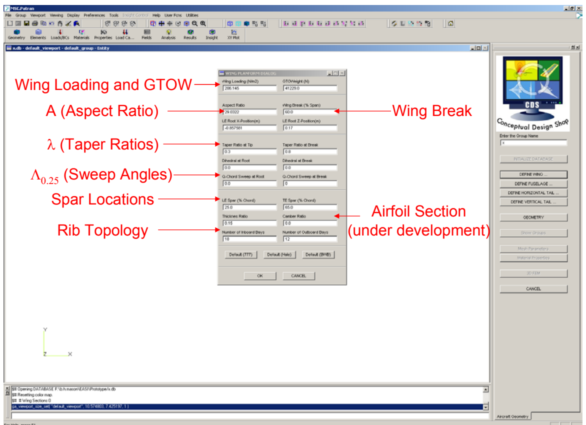

Figure 16. Graphical user interface for a generic wing structural layout generation using PATRAN Command Language (PCL).

A simple, easy-to-use GUI for wing editing was developed using PCL as shown in Figure 16. The GUI dialog box is limited to using only a few parameters, which it passes to a wing generator PCL function. The wing generator PCL function provides more options than the GUI allows, and this function can be executed from the PATRAN command line or in a session file; therefore, this function can be easily executed in batch mode. The geometry generated by the GUI is shown in Figure 17 along with a finite element mesh control GUI. Another GUI is used to define the shell and beam properties as shown in Figure 18. These functions also define an elliptic load distribution on the wing and boundary conditions on the wing root to complete the data required to perform a NASTRAN analysis. PCL functions have also been used to generate the fuselage, tail, and carry-through structure, but they are not presented in this paper.

Figure 19 shows an example of batch execution of the wing generator PCL functions. In Figure 19, special purpose PATRAN and NASTRAN wrappers were written for use with the ModelCenter design integration software (Ref. 16). In this example, a simple optimization was set-up in ModelCenter to minimize weight subject to a displacement constraint and using two design variables. One design variable controlled the thickness of the upper wing cover, and the second variable controlled the thickness of the lower wing cover. While this procedure was simple to set up in ModelCenter, it is not very efficient because it uses PATRAN to re-generate the entire model during each iteration.

If the design process does not change the shape of the model (e.g. finite element node locations), it is usually more efficient to change the element property cards outside of PATRAN, because the design variables are tied to only one property data entry in the NASTRAN deck. Additionally, the linear static NASTRAN deck can be modified to perform a NASTRAN optimization study, as described in the next paragraph.

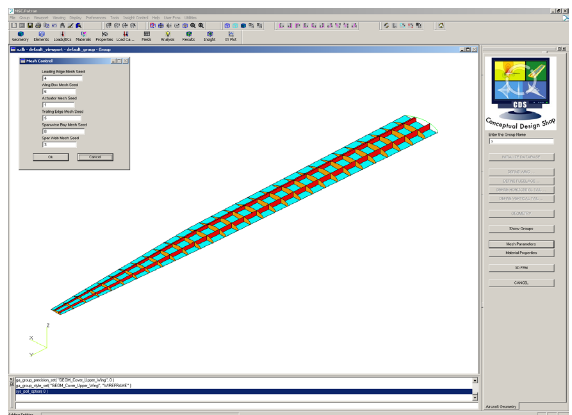

Figure 17. Mesh control editor and generated geometry.

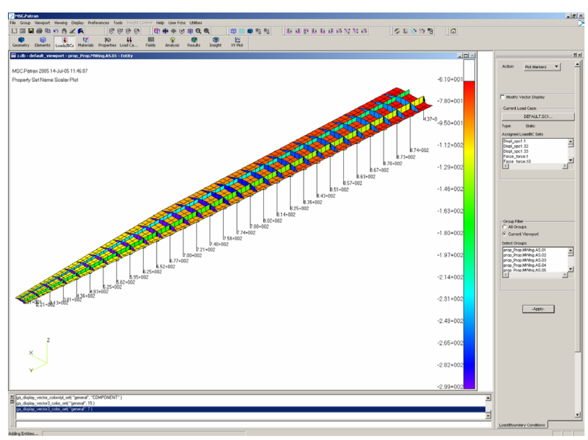

Figure 18. Finite Element Mesh with defined section properties and elliptic load distribution.

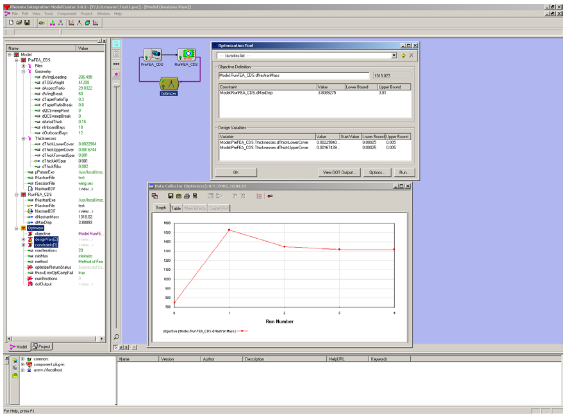

Figure 19. Execution of model generation using a NASTRAN analysis wrapper in the ModelCenter.

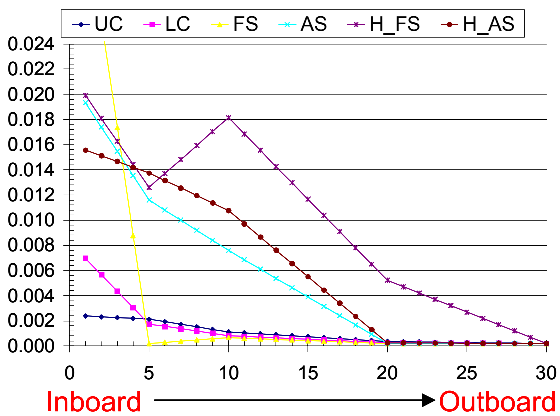

Figure 20. Wing skin and spar thickness distribution for weight optimization with 30 design variables.

A NASTRAN optimization study was set up to minimize the weight of the wing subject to a +2.5 gust load with a 1.5 factor of safety. The constraint for the problem was that the stress was less than the maximum yield stress of the aluminum alloy AL7075. Design variables were established in the following sections of the wing as shown in Figure 20: upper cover thickness (UC), lower cover thickness (LC), forward spar thickness (FS), aft spar thickness (AS), forward spar cap height (H_FS), and aft spar cap height (H_AS). The element thicknesses and beam heights in the designed sections were piece-wise linear functions of the five design variables in the span-wise direction (from inboard to outboard) in each section, as shown in Figure 20. The five variables in each of the six wing sections results in a total of thirty design variables. The values of the design variables shown in Figure 20 are the values of the optimum design. Note that the thicknesses vary from 20.0 mm at the wing root to 0.25 mm (minimum gage) at the wing tip. The optimum weight for this study was 1310 kg. Unfortunately, the 2005 version of PATRAN is not capable of associating element property cards with more than one variable (*e.g.*, a piecewise linear function), so the previously generated NASTRAN deck linear static analysis had to be modified manually in this study to perform the optimization.

The following observations were made during this PATRAN/NASTRAN modeling and optimization study. First, PATRAN PCL can be used to efficiently generate the aircraft geometry and FEM. As with AML, expert training with PCL is required to make significant modifications to the model generation functions. PCL is a functional language rather than an object-oriented language, and it can be easily executed from a command line or from a script outside of the PATRAN GUI. Unlike AMRAVEN, PATRAN does not permit true editing of the geometry (only creation and deletion), so a preview of the geometry cannot be generated in PATRAN. AMRAVEN requires either PATRAN's meshing routines or needs to export the geometry in order to generate a FEM. Because the geometry and the meshing routines are both native to PATRAN, there is no loss of information with the creation of the FEM by PCL functions and the user only has to know how to use one modeler, PATRAN. Unfortunately, neither AMRAVEN nor PATRAN currently have the capability to completely define the optimization problem studied in this section without manual modification of the NASTRAN deck.

VI. Full Vehicle FEM Analysis and Weight Optimization using PATRAN/NASTRAN

A structural analysis and weight optimization of the full HALE-ROA vehicle was performed using MSC/NASTRAN. The internal structural layout of the HALE-ROA vehicle was based on the design rules for small commercial airplanes given in Ref. 19. The initial weight breakdown of the vehicle was estimated using the HALE aircraft conceptual design code described in Ref. 17. The MSC/PATRAN model was developed by reading in the AMRAVEN generated NASTRAN bulk data file. The material properties of all components of the HALE-ROA vehicle were chosen to be that of aluminum alloy AL7075. The fuel tank, power plant, motors, pods, props, avionics, battery, servos, wires, fuel, landing gear, mounts, and payload masses were modeled as point masses in order to add the inertia effects of the fixed component masses. Figures 21 and 22 show detailed internal structural layout of the full HALE-ROA vehicle. Figure 21 shows the complexity of the structural component layout and connectivity at the wing fuselage junction, and the carry-through structure. The congruent meshing details of the fuselage skin, frames, bulkhead and keel beam to support the landing gear are also shown. Figure 22 shows the internal structural layout of the horizontal T tail, tail-fuselage junction, tail internal spars, ribs, along with the FEM component meshing details.

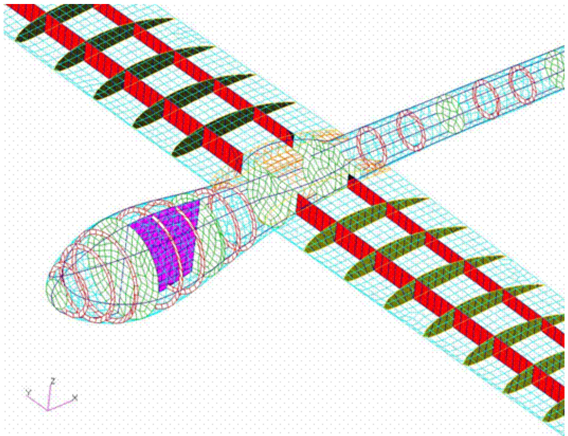

Figure 21. Structural layout and mesh details of the fuselage, wing and the wing-fuselage junction.

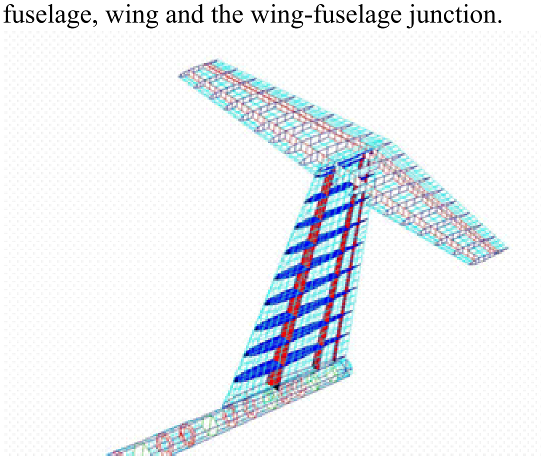

Figure 22. Internal structural layout and mesh details of the vertical and horizontal T tail.

A NASTRAN structural optimization analysis was set up in PATRAN. The optimization analysis included 52 design variables for skin thickness, and beam cross-section heights and widths to minimize the vehicle weight. The optimization constraints were for maximum stress based on the yield stress of aluminum. The applied loadings on the HALE vehicle included 2.5 g elliptical loading on wings at MTOGW with a 1.5x factor of safety. Uniform loading was applied on the horizontal tail with a 1.5 factor of safety, and gravity loading. The analysis and optimization was performed in free-free a flying condition using the inertia relief feature in NASTRAN. Figure 23 shows the result of the full HALE-ROA vehicle mass optimization using NASTRAN. The vehicle mass was reduced from an initial 4370 kg to 3452 kg over 19 design cycles, a reduction of over 900 kg of structural weight for a full stress design. Figure 24 shows the deflection of the HALE-ROA vehicle at a 2.5 g pull-up flight load at the optimized takeoff gross weight.

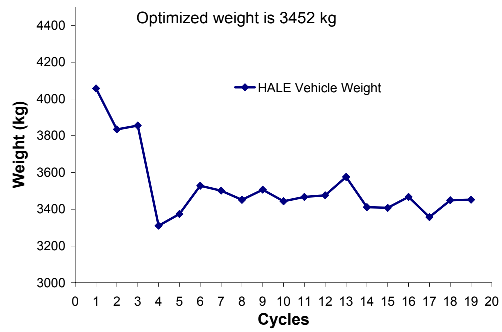

Figure 23. Full vehicle weight optimization trend over 20 design cycles.

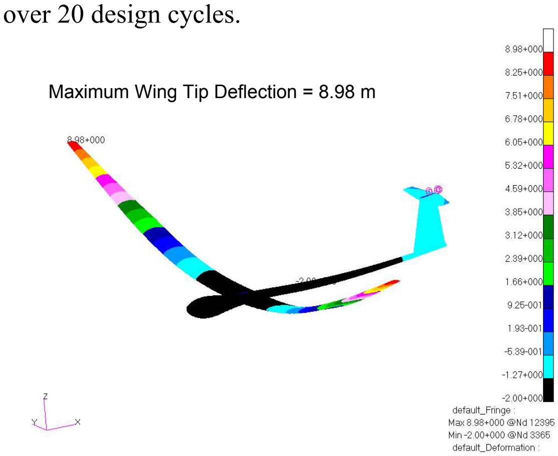

Figure 24. HALE-ROA vehicle structural analysis showing deflections for a 2.5g pull up flight load at the maximum takeoff gross weight.

VII. Aerodynamic Analysis

The aerodynamic analysis of the vehicle was performed in several fidelity levels. The HALE-ROA vehicle outer mold line was originally defined using the Vehicle Sketch Pad (VSP) software developed by Gludemann under a NASA contract (Ref. 4). A typical interactive window of the VSP is shown in Figure 25. Although this OML cannot be used for input into GridEx for suitable CFD mesh generation, since it consists of flat triangles, utilities are available for quick low fidelity aerodynamic analysis. The latest version of this software contains a vortex lattice method for computing the lift and induced drag (Ref. 4, 18).

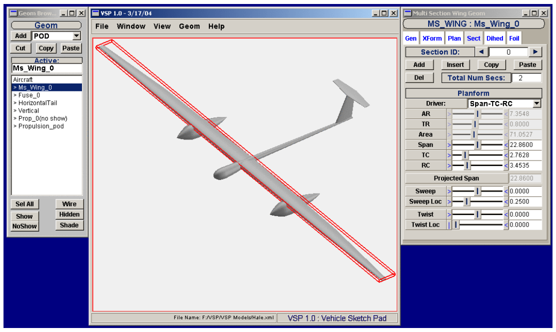

Figure 25. HALE-ROA geometry sketch using Vehicle Sketch Pad (VSP) for simple aerodynamic analysis with the vortex lattice method (Ref. 4, 18).

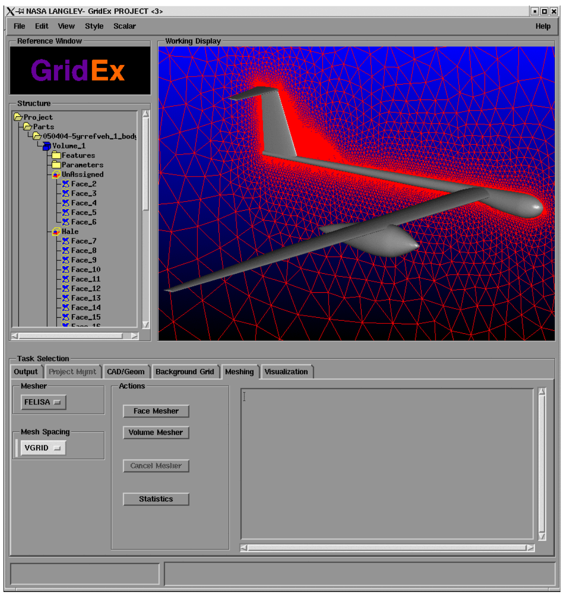

Figure 26. An adaptive surface and volume grid generation example for the HALE vehicle using GridEx (Ref. 14).

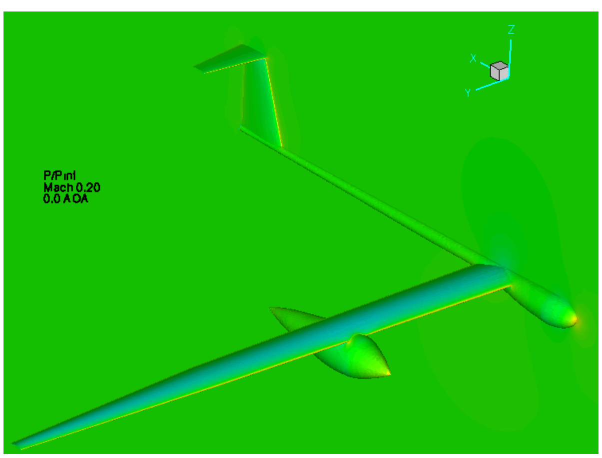

Figure 27. HALE-ROA with wing pod: Inviscid flow pressure distribution at Mach 0.2 at 0 angle of attack using FUN3D CDF analyses.

The AMRAVEN Wing-Editor also creates a wing mean camber surface and rectangular aerodynamic mesh on this mean camber surface which is used by NASTRAN to compute a pressure distribution using the vortex-lattice method. For CFD grid generation, the vehicle OML developed using AMRAVEN is imported to GridEx (Ref. 14) an unstructured adaptive grid generator software. This surface and/or volume grid can be used by CFD analysis codes such as FUN3D or CFL3D. A typical interactive screen from GridEx is shown in Figure 26. Figure 27 shows the pressure distribution using an unstructured surface mesh non-viscous Euler solution from the computational fluid dynamics software FUN3D (Ref. 15). There are several schemes of linking and executing FEM and CFD analysis procedures which were discussed in Ref 13. These procedures and techniques will be implemented in the future, subject to available funding.

Conclusions

A set of software tools for rapid adaptive modeling, and engineering analysis of advanced aerospace vehicle concepts are described. The adaptive modeling tool was used for generating vehicle parametric geometry, outer mold line and detailed internal structural layout of wing, fuselage, skin, spars, ribs, control surfaces, frames, bulkheads, floors, etc., that facilitated rapid finite element analysis, sizing study and weight optimization. The high quality outer mold line enabled rapid aerodynamic analysis in order to provide reliable aerodynamic shape and performance design data at critical flight conditions. The parametric modeling feature allowed for rapid what-if analysis by changing important design parameters and vehicle geometry. Example applications for structural design of a conventional aircraft and a high altitude long endurance vehicle configuration are presented. Detailed finite element models were developed for the wing and the full vehicle, and the structural weights were optimized. For the full vehicle structural optimization, a 21% reduction in structural weight was achieved. Implementation of these high fidelity model development and analysis techniques may facilitate physics-based systems analysis for the NASA Fundamental Aeronautics Mission. In addition to providing technology for design and development of unconventional aircraft, the techniques for generation of accurate geometry and internal sub-structure and the automated interface with the high fidelity analysis codes could also be applied towards the design of vehicles for the NASA Exploration and Space Science Mission projects.

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Table 1. Discretized elliptic load distribution at 15 span-wise stations for a 38.1 meter semi-span wing at the maximum take-off gross weight of 2828 kg, during a 2.5g pull up, including a factor of safety of 1.5.

	xloc	yloc	zloc	lift load	shear	bending mc	qt crd torsion mom				
root	0	0		208.8	5302.5			N/Sqm	kgf/Sqm	psi	psf
1	0	0		208.8	416.6	93948.5	0.0	343.10	34.97	0.0497	7.16
2	2.54	0		207.8	412.9	79134.5	0.0	341.57	34.82	0.0495	7.13
3	5.08	0		205.0	405.5	65501.2	0.0	337.00	34.35	0.0489	7.04
4	7.62	0		200.4	394.3	53142.8	0.0	329.37	33.58	0.0478	6.88
5	10.16	0		193.9	379.5	42125.4	0.0	318.70	32.49	0.0462	6.65
6	12.7	0		185.6	360.9	32486.7	0.0	304.97	31.09	0.0442	6.37
7	15.24	0		175.4	338.7	24236.0	0.0	288.20	29.38	0.0418	6.02
8	17.78	0		163.3	312.7	17354.5	0.0	268.38	27.36	0.0389	5.60
9	20.32	0		149.4	283.0	11795.1	0.0	245.50	25.03	0.0356	5.13
10	22.86	0		133.6	249.6	7482.4	0.0	219.58	22.38	0.0318	4.58
11	25.4	0		116.0	212.5	4312.7	0.0	190.61	19.43	0.0276	3.98
12	27.94	0		96.5	171.6	2154.0	0.0	158.59	16.17	0.0230	3.31
13	30.48	0		75.2	127.1	846.0	0.0	123.51	12.59	0.0179	2.58
14	33.02	0		52.0	78.9	200.3	0.0	85.39	8.70	0.0124	1.78
15	35.56	0		26.9	26.9	0.0	0.0	44.22	4.51	0.0064	0.92

Table 2. Summary of results of some initial wing sizing analysis and parametric trade studies.

Material	Study name study	Sheet-1 main wing Shell thickness:	Sheet-2 traling edge	Sheet 3-188 rest	Total wt:	max tip defl	MaxVonMises top	Min FOS	Max FOS
AL-6061	Shell 1	3 mm	3 mm	3 mm	2700 kg	1.853 meter	1.125E+8N/m	1.103	100
AL-6061	Shell 2	3 mm	2 mm	2 mm	1821 kg	2.153 meters	1.249E+8 N/n	0.9198	100
AL-7075	Shell 3	2.5 mm	1.5mm/6061	1.5 mm	1473 kg	2.153 meters	1.349E+8 N/n	0.99	100
AL-7075	Shell 3a/4	1 mm	1 mm	1 mm	805 kg	3.951 meters	4.348E+8 N/n	0.291	100
AL-7075	Shell 3b/5	2 mm	1 mm	1 mm	1233 kg	2.343 meters	1.377E+8 N/n	0.901	100
ACT RFI	Shell 6	1 mm	1 mm	1mm	407 kg	9.852 meters	6.856E+8 N.n	0.5	100
ACT RFI	Shel 6a	2 mm	1 mm	1 mm	657 kg	5.204 meters	2.195E+8 N/n	1.571	100