An Overview of NASA's Integrated Design and Engineering Analysis (IDEA) Environment

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Historically, the design of subsonic and supersonic aircraft has been divided into separate technical disciplines (such as propulsion, aerodynamics and structures), each of which performs design and analysis in relative isolation from others. This is possible, in most cases, either because the amount of interdisciplinary coupling is minimal, or because the interactions can be treated as linear. The design of hypersonic airbreathing vehicles, like NASA's X-43, is quite the opposite. Such systems are dominated by strong non-linear interactions between disciplines. The design of these systems demands that a multi-disciplinary approach be taken. Furthermore, increased analytical fidelity at the conceptual design phase is highly desirable, as many of the non-linearities are not captured by lower fidelity tools. Only when these systems are designed from a true multi-disciplinary perspective, can the real performance benefits be achieved and complete vehicle systems be fielded.

Toward this end, the Vehicle Analysis Branch at NASA Langley Research Center has been developing the Integrated Design & Engineering Analysis (IDEA) Environment. IDEA is a collaborative environment for parametrically modeling conceptual and preliminary designs for launch vehicle and high speed atmospheric flight configurations using the Adaptive Modeling Language (AML) as the underlying framework. The environment integrates geometry, packaging, propulsion, trajectory, aerodynamics, aerothermodynamics, engine and airframe subsystem design, thermal and structural analysis, and vehicle closure into a generative, parametric, unified computational model where data is shared seamlessly between the different disciplines. Plans are also in place to incorporate life cycle analysis tools into the environment which will estimate vehicle operability, reliability and cost.

IDEA is currently being funded by NASA's Hypersonics Project, a part of the Fundamental Aeronautics Program within the Aeronautics Research Mission Directorate. The environment is currently focused around a two-stage-to-orbit configuration with a turbine-based combined cycle (TBCC) first stage and a reusable rocket second stage. IDEA will be rolled out in generations, with each successive generation providing a significant increase in capability, either through increased analytic fidelity, expansion of vehicle classes considered, or by the inclusion of advanced modeling techniques. This paper provides the motivation behind the current effort, an overview of the development of the IDEA environment (including the contents and capabilities to be included in Generation 1 and Generation 2), and a description of the current status and detail of future plans.

I. Introduction

IN the world of conventional aircraft design, technical disciplines can operate in relative isolation from each other because cross-discipline interactions are often either minimal or at least can be treated as linear. On the contrary, the design of hypersonic airbreathing vehicles, like NASA's X-43 vehicle shown in Figure 1, is dominated by strong non-linear interactions. For instance, the forebody and aftbody surfaces on the underside of vehicle provide the majority of the vehicle's total aerodynamic lift, but also act as the inlet and nozzle for the scramjet engine. As such, both the aerodynamic and propulsion disciplines are greatly affected by their design, which is often determined through a multi-disciplinary optimization performed at the vehicle level. Such trade-offs and multi-disciplinary analyses are common for this class of vehicle and, in fact, are required for the design to achieve its full performance potential[1].

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In the United States, the hypersonics community (government, industry and academia) strongly agrees that the key to unlocking the potential in hypersonic aircraft lies in multi-disciplinary analysis at the vehicle level and that improvements in this capability are critical to future success. In 2005, at the request of the United States Congress, the National Institute of Aerospace (NIA) developed and released *"Responding to the Call: Aviation Plan for American Leadership"*[2], a 1000+ page document which detailed the deterioration of America's dominance in aviation and aeronautics

Figure 1. Artist's concept of X-43 showing airflow along vehicle forebody and aftbody.

research. It provided, as a start towards recovery, a detailed plan in each of seven aeronautics sectors, among which was hypersonics. In the hypersonics plan, the first critical area identified was Multidisciplinary Design, Analysis and Optimization (MDAO), stating, *"The highly integrated nature of hypersonic vehicles, combined with their high levels of technological and economic uncertainty, render conventional design practices inadequate for synthesizing systems to meet all performance, effectiveness, and economic requirements. Improved methods of system design that account for and even take advantage of the highly integrated nature of hypersonic vehicles are therefore crucial to their successful development."* The plan went on to describe the components and attributes of an integrated design and optimization environment, saying that *"Successful hypersonic vehicle design is not possible without such improved, integrated and automated methods."* The need identified here by the NIA has also been detailed by the U.S. Air Force[3], Boeing[4] and NASA[5].
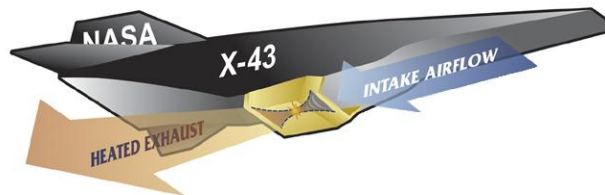
II. Background

Figure 2 shows the combination of analytical disciplines typically involved in the design, analysis and optimization of hypersonic airbreathing vehicles. Among these ten, "Life Cycle Analysis" encompasses an additional set of disciplines that help to provide estimates of system cost, reliability and operability. Classic MDAO methods (response surface fitting techniques, multi-objective / multi-attribute optimization, numerical smoothing, uncertainty quantification / uncertainty propagation, etc.) are captured under "Optimization & Advanced MDAO Techniques". The remaining eight discipline areas are those that are traditionally included in determining the overall performance of the system.
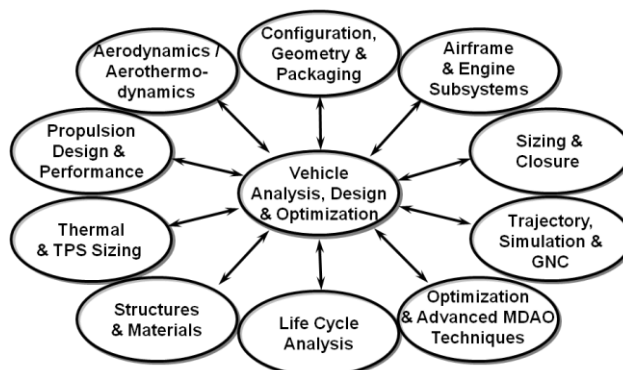
Numerous attempts have been made in the past by NASA and others to integrate these disciplines

Figure 2. Graphic showing analytical disciplines involved in hypersonic systems analysis and design.

into a unified environment. Different frameworks with varying levels of integration have been fielded, yielding mixed results. One of the more notable efforts in recent years was the Advanced Engineering Environment (AEE)[6], funded by NASA's Space Launch Initiative. AEE was built utilizing Phoenix Integration's ModelCenter© framework. While AEE worked well for expendable and reusable rocket-based launch vehicles, it lacked the detailed geometry capability that is crucial to accurately model and analyze hypersonic airbreathing vehicles. The hypersonics group within Boeing recognized this need and endeavored to develop their own internal parametric geometry modeling capability that ultimately would become the heart of their environment, BIVIDS[4]. Researchers at the Air Force Research Laboratory (AFRL) also saw this need and found their answer[3] with the Adaptive Modeling Language (AML)[7], a product of Technosoft, Inc. While it can communicate natively with other commercial computer aided design (CAD) packages (Pro-E, Catia, etc.), AML and its environment, like the Boeing system, have at its core a parametric geometry modeling capability. This feature is critical, as it allows each discipline to natively share, understand and interpret the knowledge of the same geometry. Often, in the more typical design cycle where the disciplines are not well-integrated, it is common for each discipline to generate its own representation of the actual geometry, leading to potential inconsistencies and complicating configuration control. With AML controlling and distributing information about the geometry in the form required by each discipline, this issue is avoided. In addition to parametric geometry generation, other requirements for the environment include

streamlined data transfer between analysis tools; automated coupling and execution of computational analyses; multi-disciplinary design optimization methods; and probabilistic methods and processes that enable system level risk assessment/mitigation and robust vehicle configuration optimization. The environment must also support and integrate multiple levels of analytical fidelity.

AFRL researchers introduced AML to the hypersonics group in the Vehicle Analysis Branch (VAB) at NASA Langley in 1998. Since then, VAB has been partnering with Technosoft through a multi-phase Small Business Innovative Research (SBIR) award to develop interfaces in the AML environment for some of VAB's legacy codes[8]. Initially focused on providing engineers with enhancements to their individual discipline tools, the focus has shifted over the last several years towards integrating these tools into a unified, multi-disciplinary analysis and design capability. Known formerly as CoHAVE and AdVISE[9], the system is now referred to as the Integrated Design and Engineering Analysis (IDEA) Environment. The current effort is being supported by the MDAO Discipline within the Fundamental Aeronautics Program's Hypersonics Project.

III. Discipline Fidelity Levels

During NASA's Next Generation Launch Technology (NGLT) program, the Systems Analysis Project (SAP) conducted and coordinated multiple sets of system analyses across various missions and with varying levels of technology assumptions[10]. In order to get a better understanding of the differences between analyses and the level of uncertainty (generally) contained in each, the SAP endeavored to standardize definitions for the various levels of fidelity within each of the disciplines. The MDAO Discipline within the Hypersonics Project has updated and adopted this matrix to help guide it with tool development and as a basis for comparing analytical results on system studies. The matrix includes five distinct levels of fidelity for the eight performance-related disciplines mentioned previously, as well as five levels of fidelity for the disciplines that make up life cycle analysis. This matrix has also been adopted and employed in the NASA-USAF Joint System Study, an effort established by the Air Force Chief Scientist and NASA Associate Administrator for Aeronautics Research that endeavors to studied the application of hypersonic airbreathing propulsion for access-to-space missions. Use of the fidelity matrix in the Joint System Study greatly enhanced the ability of the two agencies to communicate and compare analyses of hypersonic vehicle designs. In order to provide additional clarity, fidelity definitions shown in this paper include several updates to those used in the Joint Sysetm Study.

The updated matrix for the performance-related disciplines is included in tables in each respective section below. As seen in the tables, at the lowest level of fidelity (level 0), the disciplines typically employ historical or scaled empirical data in order to estimate vehicle performance. In general, uncertainty is expected to be the highest at this level, although computational speed and flexibility in the design space are the greatest. One can also relate the programmatic development cycle[11] and the typical system breakdown structure (SBS) or system hierarchy (architecture > major system > element > subsystem > component > subassembly > part)[12] to the various levels of fidelity. At the beginning of any program (pre-Phase A), trade studies and systems analyses are conducted at the highest SBS level, the architecture level. Here, the entire mission and its global requirements need to be considered in order to determine the performance required out of each of the major systems. This program phase and SBS level generally will incorporate analyses conducted at fidelity levels 0-1. As a program progresses into Phase A, the level of detail in the design increases from the architecture and major system level, down to the element level. This progression would correspond roughly with discipline analyses at fidelity level 2 and bring a design close to the System Requirement Review (SRR) level of maturity. As the level of fidelity and the amount of detail increase, the level of uncertainty in the design should correspondingly decrease, although computational speed continues to slow, and design flexibility continues to become more limited. As detail increases to the subsystem and component levels, discipline fidelity increases to levels 3 and 4, and the program pushes towards Preliminary Design Review (PDR). At this point in the design, the majority of the design choices will have been made and standard engineering development takes over to complete detailed subassembly and part specifications.

Within the MDAO Discipline of the Hypersonics Project, architecture level trade studies and systems analyses are performed using the EXAMINE tool[13]. EXAMINE, developed over the last five years at NASA Langley, is a collection of Microsoft Excel© workbooks that contain empirical data and mass estimating relationships (MERs), i.e. data at fidelity level 0, for numerous vehicle classes and related subsystems. EXAMINE offers the ability to rapidly perform trade studies at the architecture level to help guide major system and element requirements. The long-term plan for IDEA is to be centered about the Level 2 fidelity capability, with the ability to run at Level 1 (and mixed Level 1 to 2) as well as directly support analysis at Level 3 and higher. Ultimately, analyses performed at higher levels of fidelity will be used to update or even create new models at lower levels of fidelity that are computationally more efficient and support the cycle times needed to perform optimization at the vehicle level.

American Institute of Aeronautics and Astronautics

The current fidelity level definitions for the life cycle analysis-related disciplines (i.e. cost, reliability, and operations) is included in that discipline's section in Table 9. Currently, few tools exist in these areas and most are Level 1 at best. As such, the Hypersonics Project is endeavoring to fill some of these gaps, largely through the use of NASA Research Announcements (NRAs). One such NRA was just completed with Spaceworks, Inc., who developed a discrete event simulation of operations for hypersonic vehicles[14]. Built using Arena[©], the "Descartes" tool provides estimates of the operational characteristics of the vehicle such as turn around time and operations cost. Ideally, the MDAO Discipline would like to issue a similar award through the NRA process for development of an improved safety and reliability tool for hypersonic systems.

Care is being taken to ensure that IDEA can readily support analyses at higher fidelity levels. One such effort currently underway is aimed at automated generation of structured CFD grids, guided by geometry and grid topology, to be used with the Vulcan CFD code[15]. Vulcan is a structured code that solves the full Navier-Stokes equations for turbulent, non-equilibrium, chemically reacting flows[16]. During the X-43 program, Vulcan was used to compute full vehicle, powered solutions that were found to compare extremely well with flight data[17]. Vulcan analyses have also shown excellent agreement with powered and unpowered tests in Langley's 8-ft. High Temperature Tunnel, as well as other scramjet and high-speed test facilities. In 2003, Vulcan was used to compare to a simulated powered test of a rocket-based combined cycle (RBCC) vehicle in Langley's 16-ft transonic facility, again with excellent agreement[18]. As such, Vulcan has become the benchmark CFD tool at Langley for hypersonic vehicles, and being able to support it directly with automated grid generation from IDEA is essential.

IV.   IDEA Contents and Capabilities

The MDAO Discipline plans to develop and roll out the IDEA environment over several generations, ultimately being centered around the discipline tools that meet fidelity Level 2 requirements. While multiple vehicle classes will ultimately be defined within IDEA (e.g. waveriders, "beta" boosters, vehicles with 3-D inlets, etc.), the current environment is built around a fully-reusable, two-stage-to-orbit (TSTO) system that employs a turbine-based combined cycle (TBCC) lifting-body first stage and a rocket-based winged-body second stage, as shown in Figure 3. This vehicle served as the NASA reference concept developed under the Joint System Study, mentioned previously. Results from that study will be used for verification as IDEA is developed and fielded.

Figure 3.   Two-stage-to-orbit launch vehicle concept with a turbine-based combined cycle first stage and a reusable, rocket-powered second stage.

A.   Configuration, Packaging and Geometry

The fidelity matrix for the Configuration, Packaging and Geometry discipline is shown in Table 1. For creation of the vehicle outer mold line (OML), the geometry engine in AML will provide a fully parametric modeling capability. Figure 4 shows the range of vehicle shapes that can be generated for the second stage with the current class definition. The body shape is specified through an overall length, width and height at the fuselage base, and by placing some control points along the length of the body. In general, the body has an elliptic cross-section; however,

Table 1. Fidelity level definitions for the Configuration, Packaging, and Geometry discipline.

| Level 0	Level 1	Level 2	Level 3	Level 4
Parametric, empirical or analytical geometry model	External & major internal components such as propellant tanks payload bay, propulsion, etc. modeled for volume, area, and key linear dimensions	Majority of components modeled, packaged, and analyzed for geometric properties including center of gravity. OML includes bluntness, surface deflection details, etc.	All components modeled, packaged, and analyzed for geometric properties including center of gravity and inertia characteristics. OML detail includes steps and gaps, etc.	Internal components modeled after actual hardware elements and real geometry. OML detail includes all external protuberances.
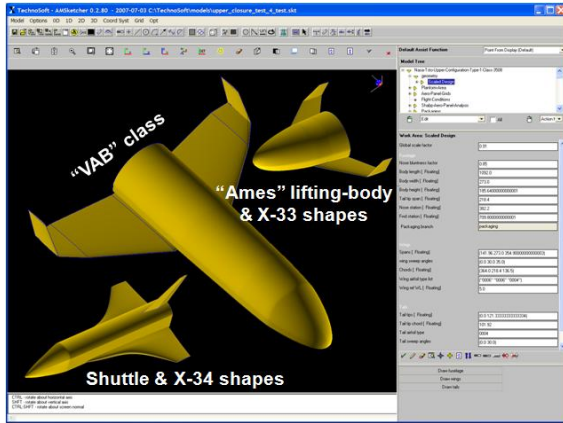
Figure 4. Second stage design interface showing the variety of vehicle shapes that can currently be modeled.

options are available to flatten the sides, as seen in the X-34 design, or the vehicle bottom (making the traditional "D" shape). Control is provided over nose bluntness and droop angle. Wings are specified by standard parameters such as span, leading edge sweep, chord length, etc., as well as the overall vertical and axial wing location. The user can specify the airfoil type, either NACA series or diamond, and can add multiple sections over the span of the wing, controlling the features of each section independently. The wing leading and trailing edges can have distinct breaks at the sections, or a smoothing feature is available that results in a wing like that in the lower left corner of Figure 4. Tails can be added and controlled in a similar manner.

For the booster, vehicle lofting begins with a lateral extrusion of the high-speed keel line (development of the keel line is discussed below in the Propulsion section). User inputs control the maximum width of the vehicle at various axial locations as well as the desired "2-dimensional" flowpath width. The effects of these controls are shown on the three vehicles, as viewed from the bottom, in Figure 5. Wings and tails can be added to the booster in a similar manner as the orbiter, and the user has control over the height and axial location of maximum height of the booster upper surface. In addition, the user has full control over the placement of the orbiter relative to the booster. This allows control over the mated center of gravity location and the degree to which the upper stage is embedded into the first stage. Bluntness effects are also included on all leading edges and can be controlled by the user. In general, such geometry modeling capability can support fidelity levels 1-4. At lower levels of fidelity, where more detailed geometry information is not needed, "feature suppression" is used to mask unwanted detail.

A packaging system has also been created in IDEA that allows the user to select from a wide range of predefined packaging items, each of which can have an associated geometry. This geometry can be imported from another CAD system, or can be generated from scratch using an internal library of basic shapes. The packaging system has knowledge of the vehicle OML geometry and thus can automatically shape packaging elements to be conformal with the vehicle OML. This feature is quite useful when modeling conformal fuel tanks, payload bays with doors that conform to the OML, or when laying out structural elements (bulkheads, longitudinal beams, etc.) that conform to the vehicle's
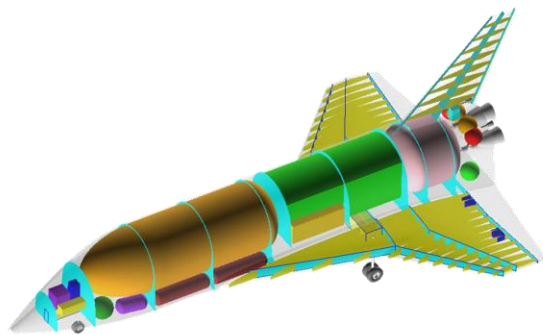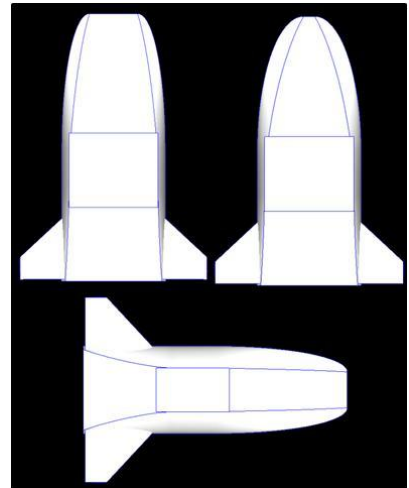

Figure 5. Various booster shapes generated by IDEA showing effects of vehicle and flowpath width controls.

OML. The packaging system is also generic; the OML being packaged can either be generated internally by IDEA or imported from another CAD system, such as through IGES or STEP translation. This still allows for vehicle designs created outside of the IDEA environment to be analyzed with IDEA. There is one drawback, however, in that an imported geometry would not be parametric, making modification of the design very difficult. A sample packaging of a second stage concept is shown in Figure 6. Here, the orbiter geometry (OML) was imported from CAD, and the packaging system within IDEA was used to place all of the elements shown.

For each packaging item, mass properties can be assigned (either through a lumped amount or through an alternate estimating method, i.e. an MER) or calculated based on the packaging element geometry and proper

Figure 6. Sample internal packaging and structural arrangement for a second stage concept.

assignment of materials. The mass properties management system within IDEA can then easily generate integrated mass properties for the entire vehicle. The packaging system fully supports fidelity Levels 1-4, according to Table 1, as the primary difference between the levels is the number of packaging items that are contained within the model (from only tanks and payload at Level 1 to the inclusion of all subsystems at Level 3 and higher). Several enhanced features are also under development, including time dependent and trajectory dependent mass properties. Here, the goal is to feed back time histories from the trajectory simulation of vehicle attitude, acceleration and propellant usage to the mass properties module, in order to generate trajectory specific and time dependent propellant loading states and corresponding mass properties.

A packaging strategy has been implemented for Generation 1. This strategy provides guidance to IDEA on the preferred user arrangement of the main packaging elements, namely the two propellant tanks, the payload bay, and the cockpit (if one exists). The strategy would identify the preferred order of the primary elements. The payload and cockpit are typically defined with fixed dimensional values and are held constant with closure. Tanks are defined such that their heights and widths are specified as percentages of the vehicle OML, allowing their lengths to vary as dictated by propellant choices and the vehicle closure process. A typical strategy, as shown in Figure 6, is to locate the LOX tank aft, the fuel tank forward, and place the payload bay between them. Such a strategy and parametric definition of propellant tanks allows the total amount of propellant, as well as the ratio of propellants, to vary as engine operational parameters are altered, vehicle performance changed, and the vehicle repackaged as closure progresses and the vehicle is scaled.

B. Structures and Materials

Table 2 shows the analytical fidelity definitions for the Structures and Materials discipline. Separate efforts are being undertaken to support Level 1 and Level 2 modeling. To support both efforts, a load case generation module has been developed. This module allows the user to parametrically identify critical load cases experienced by the vehicle for a given trajectory. Typical load cases include maximum and minimum (or maximum negative) normal acceleration and maximum axial acceleration. The user can set the module up to automatically identify these cases and to extract necessary information required for structural analysis such as: vehicle and propellant mass, accelerations, and applied forces. Flight condition information will also be extracted and supplied to an aerodynamic analysis code so that distributed aerodynamic forces or pressures can be obtained. All of this information will then be compiled and used to develop load cases for structural analysis. Additionally, the user can specify non-trajectory-based load cases, often used for modeling a runway bump or landing load. Here, the user is allowed to supply a flight condition for aerodynamic analysis, if desired, as well as accelerations to be applied.

For Level 1 analysis, 1-D beam and shell theory will be used to estimate structural component masses. Here, 3-D aerodynamic forces will be mapped to a 1-D line model, thrust and point loads applied, and a 1-D mass distribution developed. Once section loads have been generated, a structural concept and a material system need to be defined in order to estimate structure weights. For example, a stiffened-skin wing structure consists of skins, ribs, and spars. A stiffened-skin fuselage would have skin, stringer, frame, and bulkhead structural elements. Section properties are used to distribute section loads to cross-section structural elements. For instance, the longitudinal stringers at a fuselage cross-section would be sized to resist axial force and bending moment. The skin would carry shear and would transmit pressure loads to the stringers and frames. Many of the methods for distributing section

Table 2. Fidelity level definitions for the Structures and Materials discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Parametric or historical equations adjusted to level 1 or higher for similar technology and vehicle configuration	1D bending loads analysis based on structural theory of beams, shell, etc… with non-optimums based on level 2 or higher results	Limited 3D FEA (<20,000 nodes) for all major load cases, structure sized to allowables, non-optimums determined empirically or analytically	3D FEA (>20,000 nodes) for all major load cases, structure sized to allowables, non-optimums determined empirically or analytically. Thermal effects included. Dynamic frequencies estimated.	3D FEA (>100,000 nodes) for all load cases, structure sized to allowables, non-optimums determined empirically or analytically. Thermal effects included. Dynamic frequencies estimated.

loads to cross-section structural elements are documented in Reference 19. From this point, shear and moment diagrams can be created, and mass estimates for each section generated.

For Level 2 structural analysis, structural elements such as ribs, spars, bulkheads, floors, and stringers can be created as part of the packaging system. This allows these elements to be conformal with the vehicle IML. Knowledge of the other packaging elements also allows automated cutouts in the shape of each element to be made in the structure to accommodate them. Once the structure has been laid out, the individual elements are sewn together and passed to Patran[©] or a similar code to be meshed. A sample mesh of a second stage is shown in Figure 7. Once the mesh is ready, it is combined with load case information generated from the trajectory and passed to Nastran[©] to generate structural deflections. Nastran output will

Figure 7. **Snapshot of a sample structural mesh generated for a second stage.**

then be passed to Hypersizer[©], a commercial structural sizing program from Collier Research Corporation, in order to generate masses for each of the structural components. Several iterations of this loop will be required to generate a final set of structural element masses, which guarantees that all bending and deformation constraints have been satisfied. A more detailed description of the structures module has been documented separately[20]. Once this sizing system is in place, it can easily be extended to allow structural dynamics analyses, as well as analyses of hot structures. These capabilities will likely be incorporated in Generation 3.
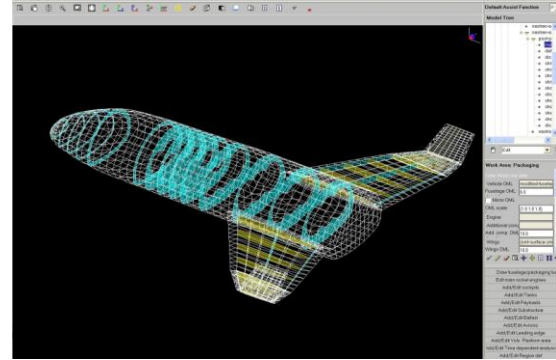
C. Trajectory, GNC and Simulation

For the Trajectory, Guidance, Navigation & Control (GNC) and Simulation discipline, Table 3 shows the current fidelity definitions. The IDEA environment will employ the POST2 code[21] for trajectory analysis and vehicle simulation. POST2 is an industry standard point mass trajectory tool for simulating the motion of powered or unpowered vehicles near an arbitrary, rotating, oblate, attracting body. POST2 can be run in various modes encompassing levels of fidelity one through four, depending on options selected and data inputs. For IDEA, a generalized user interface has been developed that offers full access to all inputs available in POST2. At many points in the input setup, depending on the selection of various methods and operational flags, many of the input variables available in POST2 become invalid. Intelligence has been added to the interface to only display those variables and options that are valid, making the interface more user-friendly. In addition, cryptic POST2 variable names are hidden from the user (there is a flag for experienced users that will display the variable names), and the interface uses descriptive phrases to explain available options. All POST2 event types (primary, secondary, roving, repeating) are accessible through the interface, providing a completely generic capability. Options to perform automated trade studies and Monte Carlo analysis have also been incorporated. Within IDEA, the POST2 interface has been integrated with other discipline tools to allow automated population of vehicle data into the input deck. Output from POST2 is also used by several disciplines. Trajectory information is used to generate loads analysis cases for structural sizing and will be used for sizing the thermal protection system (TPS) and various airframe and engine subsystems. Propellant usage is used by the Sizing and Closure discipline to size the vehicle to a given mission, as described below, as well as by the packaging system to generate time dependent mass properties information.

Table 3. Fidelity level definitions for the Trajectory, GNC, and Simulation discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Rocket equation or energy methods (path following simulation)	Optimized ascent, flyback & re-entry 3-DOF point mass simulation (un-trimmed)	Optimized ascent, flyback & re-entry 3-DOF (pitch trim) point mass simulation; longitudinal stability & control evaluation	Optimized ascent, flyback & re-entry 6-DOF simulation; longitudinal, lateral & yaw stability & control evaluation; perfect GN&C	Optimized ascent, flyback & re-entry 6-DOF simulation; longitudinal, lateral & yaw stability & control evaluation; real GN&C with gain scheduling (or similar) lags, noise, etc.

Some advanced features have been recently added to the trajectory interface, including the ability to dynamically link one trajectory module to another, allowing trajectory branching. This feature is extremely useful in modeling the TSTO problem. A deck modeling the orbiter ascent from stage separation to orbit can be dynamically connected to the mated ascent simulation. Here, the orbiter simulation will take as its initial state the exact separation conditions achieved by the mated system. With this dynamic link, changes to the mated trajectory phase will automatically be propagated to other flight phases, and vice versa. This capability will ultimately allow trade studies and optimization to be performed on the entire TSTO concept, with impacts from all disciplines and flight phases included, in a more automated fashion. Trade study and optimization results should also be more accurate when performed with this capability as a complete and exact set of state information will be transferred from flight phase to flight phase. With so much information being passed and multiple models to update, it's quite easy for errors to creep into the process when these types of analyses are performed manually.

An automated "crash" recovery feature has been added that allows the user to guide POST2, during automated execution, regarding what changes to make to the model to recover from an initial nonfeasible starting solution. This type of situation occurs often when a large perturbation is applied to the vehicle (e.g. significant increase in mass), and trajectory optimization is attempted with a starting solution based on the previous, non-perturbed vehicle. For example, the orbiter ascent trajectory is typically guided by a table of pitch angle versus velocity. If vehicle mass is increased substantially, this profile will not provide sufficient lift and upward thrust vector to allow the vehicle to achieve orbit. It will typically crash back to Earth, and the run will terminate. The recovery feature allows the user to link a trajectory constraint to a trajectory input parameter. For the orbiter example, the user could create a constraint that the flight path angle at engine cutoff has to be positive. When the vehicle crashes, that constraint will not be met. The recovery feature would allow the user to connect that constraint with the pitch angle profile. When the case crashes, IDEA would identify that the linked constraint was not satisfied and increment the pitch profile by a user-specified amount. This adjustment will eventually raise the flight profile enough that orbit can be attained, yielding an initial feasible solution for optimization to begin. Additionally, an advanced run feature has been added that will execute POST2 in targeting mode. This mode will allow the user to find a trajectory solution that satisfies all of the constraints prior to turning on optimization. This method has been found to aid optimization in achieving a solution more quickly.

Methods will also be incorporated at appropriate levels of fidelity that evaluate vehicle stability and control at various points along the flight profile. Using a similar method to the structural load case generator, points along the trajectory will be examined for longitudinal and lateral-directional static margin, control effectiveness and dynamic stability. Issues arising from these evaluations will likely result in alternate control surface placement, size, or configuration or result in changes to the vehicle center of gravity.

D. Sizing and Closure

Table 4 shows the fidelity definitions for the Sizing and Closure discipline. The closure methodology in IDEA utilizes an "as drawn" and a scaled or "as closed" version of the vehicle geometry. Initially, the vehicle geometry is defined at the "as drawn" level. For instance, as described previously, the second stage OML is defined by roughly 30 or so parameters, mostly physical dimensions of each of the main parts of the vehicle. Each of these parameters contains a property that can be set by the user which determines whether that parameter is allowed to vary or not as the vehicle is scaled. It also allows the user to specify the minimum and maximum allowable value for that parameter. As closure begins, vehicle scaling is photographic (i.e. the scale factor in each primary axis is the same), unless a scaling constraint is reached. For example, if a payload of fixed length, width and height is packaged, at some point when photo-scaling down, continued scaling of the OML would result in the payload no longer fitting within the vehicle, likely either in height or width. Here, scaling in that direction (height, width or both) would cease, and scaling would continue in the unconstrained directions.

When the closure process begins, the "as drawn" and "as closed" vehicle scales are identical. In the simplest form, closure is achieved by first computing the propellant fraction available (PFA) for the "as closed" vehicle. Vehicle data (aerodynamic & propulsion databases, mass properties, etc.) are sent to the POST2 trajectory module which flies the vehicle, optimizes on the given mission, and returns a propellant fraction required (PFR). The "as closed" version of the geometry is then scaled up or down appropriately until PFA of the "as closed" equals PFR from the POST2 run. When scaling reaches the point where PFA equals PFR, new vehicle data is generated for the "as closed" version of the vehicle and passed to trajectory again for analysis. This cycle continues until convergence is achieved, i.e. the PFA going into the trajectory analysis is the same (within some numerical tolerance) as the PFR coming out. A similar closure process is currently being implemented for the first stage. For complete Level 1 and Level 2 closure, the closure iterations would also include TPS and structural sizing based on the "as closed"

trajectory. Information from those sizing efforts will be included in the vehicle mass and volume updates on every closure iteration.

Table 4. Fidelity level definitions for the Sizing and Closure discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Weight, volume and dimensional closure w/ consistent bookkeeping of all propellants, fluids and other subsystems needs, based on commensurate fidelity level inputs from other disciplines; All outside analyses input parameters should be within +/- 30% of their final closure values. "As Closed" vehicle photographic scale factor < +/- 15% from "As Drawn"	Weight, volume and dimensional closure w/ consistent bookkeeping of all propellants, fluids and other subsystems needs, based on commensurate fidelity level inputs from other disciplines; All outside analyses input parameters should be within +/- 20% of their final closure values. "As Closed" vehicle photographic scale factor < +/- 10% from "As Drawn"	Weight, volume and dimensional closure w/ consistent bookkeeping of all propellants, fluids and other subsystems needs, based on commensurate fidelity level inputs from other disciplines; All outside analyses input parameters should be within +/- 10% of their final closure values. "As Closed" vehicle photographic scale factor < +/- 5% from "As Drawn"	Weight, volume and dimensional closure w/ consistent bookkeeping of all propellants, fluids and other subsystems needs, based on commensurate fidelity level inputs from other disciplines; All outside analyses input parameters should be within +/- 5% of their final closure values. "As Closed" vehicle photographic scale factor < +/- 3% from "As Drawn"	Weight, volume and dimensional closure w/ consistent bookkeeping of all propellants, fluids and other subsystems needs, based on commensurate fidelity level inputs from other disciplines; All outside analyses input parameters should be within +/- 2% of their final closure values. "As Closed" vehicle photographic scale factor < +/- 1% from "As Drawn"

E. Propulsion Design and Performance

For the Propulsion Design and Performance discipline, Table 5 shows the current analytical fidelity definitions. Three main elements make up the tool suite for the area. For liquid rockets engines, IDEA utilizes a rocket performance and sizing module built in AML by the U.S. Air Force and Technosoft that the Air Force uses in its Reusable Military Launch System (RMLS) and Integrated Propulsion Analysis Tool (IPAT) environments[3]. This module provides the user with the ability to select an existing engine from a database of over 40 predefined engines or to create a new engine. This is accomplished by specifying some general sizing and performance information about the engine or engines and selecting propellants from a list of nearly 40 fuels and seven oxidizers. The module comes with mass estimating relationships based on physical dimensions and operating characteristics of the engine.

For scramjet engines, IDEA utilizes the SRGULL code[22], a tip-to-tail hypersonic cycle analysis tool developed and used extensively at NASA Langley. SRGULL uses a two-dimensional Euler method for the forebody, inlet and nozzle and a one-dimensional incremental combustor with an integral boundary layer method for all components. A snapshot of the interface for the keel line design that has been developed in IDEA is shown in Figure 8. As mentioned in the configuration section, the development of the booster for the current TSTO vehicle begins with the definition of the keel line. This interface allows the user to assemble the entire high-speed keel line from scratch, using a building block approach. Each of the flowpath components (forebody, inlet, isolator, combustor, nozzle) are assembled from simple pieces of geometry (e.g. lines, conics, circular arcs, etc.). Design rules are incorporated that specify the relation between flowpath components. Once the user is satisfied with the design, IDEA will generate the necessary input data for SRGULL analyses and run the desired cases. For optimization purposes, a design of experiments capability has also been incorporated into the keel line design module.

For turbine analysis, plans are in place to integrate IDEA with the Numerical Propulsion System Simulation (NPSS) tool from NASA Glenn[23]. NPSS has become an industry standard cycle
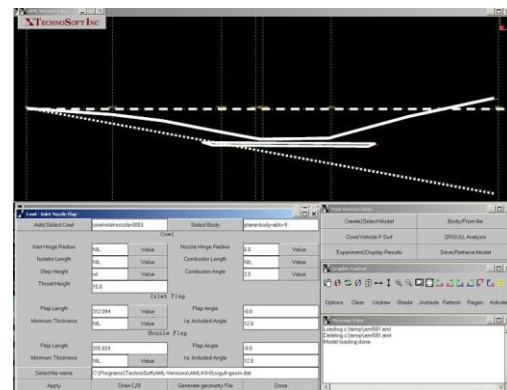

Figure 8. Snapshot of SRGULL / keel line design interface in IDEA.

analysis tool in the turbomachinery world and is currently in use by all of the major aircraft engine manufacturers. Efforts are also underway to develop a generic, high Mach number turbojet model in NPSS that will be driven by IDEA.

Table 5. Fidelity level definitions for the Propulsion Design & Performance discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Scaled empirical estimates of engine Isp and thrust-to-weight ratio fixed based on comparable engine size, propellant choices, and cycle type. Engine vacuum thrust scaled up or down rubberised) to meet requirements by up to 50% while holding selected Isp and T/W approximately constant	1D cycle analysis adjusted to level 2 or higher results (MIL standard or other installation effects included) Simple steady-state compustion chemistry analysis based on actual propellants, mixture ratio, and chamber pressure. Determine vacuum Isp based on actual expansion ratio with empirical corrections from ideal expansion solutions. Engine thrust-to-weight ratio to reflect actual nozzle expansion ratio, chamber pressure, and chosen powerhead cycle. Match "as-analyzed" engine vacuum thrust to required thrust value within 5% prior to estimating vacuum Isp and T/W.	2D/3D finite difference inviscid (Euler) flowfield analysis w/ heat conduction / transfer & integral boundary layer analysis. Propulsive moments, installation effects & thermal balance computed. Full power balance for steady state operation that accurately represents the selected power cycle (matching pump and turbine power). Steady state combustion chemistry and nozzle flow to predict Isp. Proper accounting for gas generator or precombustor performance, as applicable. Empirical estimates of nozzle and chamber heat transfer. Weight modeling at the component level (e.g. individual pumps, valves, lines, main chamber, nozzle, etc.) using individual physics-based estimating equations. Engine not scaled more than 1% from "as-analyzed" engine vacuum thrust before analysis of Isp and T/W must be re-assessed.	2D/3D parabolized Navier-Stokes finite difference / volume flowfield analysis w/ heat conduction / transfer & integral boundary layer analysis. Propulsive moments, installation effects & thermal balance computed. Full mechanical design. Full power balance for both steady state and transient operation (including performance during start-up and throttling events). Combustion chemistry at the level of 3-D Navier-Stokes CFD to account for combustor and injector performance, nozzle flow (including flow separation at low altitude), and heat transfer. Complete modeling of powerhead components. Detailed structural modeling to predict engine weight including FEA to estimate weights of major structural components (chamber, nozzle, lines, turbomachinery, etc.). Engine not scaled more than 1% from "as-analyzed" engine vacuum thrust before analysis of Isp and T/W must be re-assessed.	3D full or thin-layer Navier-Stokes (FNS or TLNS) flowfield analysis including pressure feedback, shear stress & heat transfer effects computed directly. Propulsive moments, installation effects & thermal balance computed. Full mechanical design. Full power balance for both steady state and transient operation (including start-up and throttling events). Combustion chemistry at the level of 3-D Navier-Stokes CFD to directly account for combustor and injector performance, nozzle flow (including flow separation at low altitude), and heat transfer. Incorporate component-level hardware test data on major elements such as injectors and pumps. Detailed structural modeling to predict engine weight including FEA to estimate weights of major structural components (chamber, nozzle, lines, turbomachinery, etc.) under static as well as dynamic loads. Incorporate hardware test data for predicting engine component weights. Engine not scaled more than 0.5% from "as-analyzed" engine vacuum thrust before analysis of Isp and T/W must be re-assessed.

F. Aerodynamics and Aerothermodynamics

Table 6 shows the fidelity definitions for the Aerodynamics and Aerothermodynamics discipline. Tools employed within this discipline vary based on the flight condition being analyzed and the level of fidelity of interest. At Level 1 for high-speed calculations (Mach > 3), the IDEA environment will rely on SHABP[24] and CBAero[25], both of which have been integrated into IDEA, in order to generate aerodynamic and heat transfer information. These codes allow the user to choose from a variety of Newtonian impact methods in order to estimate the lift, drag and moment of the vehicle. A snapshot of an SHABP run at hypersonic speeds on a representative first stage is shown in Figure 9. For aerodynamic heating, both codes calculate the location of streamlines along the vehicle surface and estimate running lengths. Then, both estimate a skin friction coefficient based on laminar or turbulent flow. Finally, they calculate a convective heat transfer rate based on wall

Figure 9. Snapshot of pressure coefficient distribution for a hypersonic flight condition generated by SHABP on the first stage.

temperature. SHABP allows a user-defined temperature profile (which is useful in analyzing hot structures) or will calculate the profile based on a radiation equilibrium assumption. CBAero implements the radiation equilibrium assumption. For low-speed aerodynamics, IDEA will employ the UDP slender body theory contained within APAS[26]. Similar theory is also available in CBAero and may be used as well.
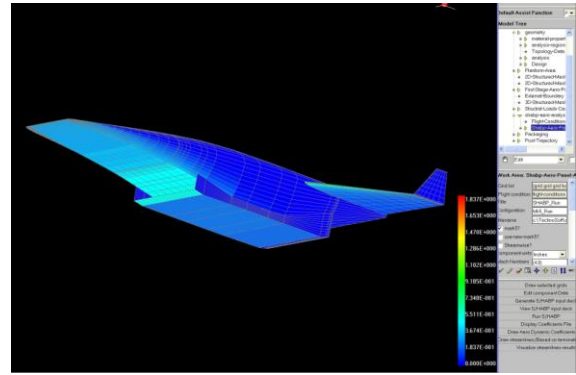
Table 6. Fidelity level definitions for the Aerodynamics and Aerothermodynamics discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Scaled empirical	Linear/impact methods with all drag increments (empirical)/Heating (engineering-based) adjusted to level 2 or higher; vehicle satisfies all takeoff/landing speeds, glide path, and runway length requirements (Including abort), no control surface deflections	3D CFD inviscid (Euler) w/ integral boundary layer or potential w/ semi-emperical drag increments or thin layer Navier Stokes w/ semi-emperical non-viscous drag increments, or CFD anchored Level 1; vehicle satifies all takeoff/landing speeds, glide path, runway length, and longitudinal stability requirements (including abort)	3D CFD parabolized Navier-Stokes (PNS) finite difference / volume flowfield analsis w/ heat conduction / transfer & integral boundary layer analysis; vehicle satifies all takeoff/landing speeds, glide path, runway length, and longitudinal, lateral & yaw stability requirements (Including abort)	3D CFD full or thin layer Navier-Stokes (FNS or TLNS) flowfield analsis including pressure feedback, shear stress & heat transfer efects computed directly; vehicle satifies all takeoff/landing speeds, glide path, runway length, and longitudinal, lateral & yaw stability requirements (including abort)

Solutions from all of these codes will continuously be checked and updated with higher fidelity information from a variety of CFD codes. For Level 2 aerodynamics, several options are currently under evaluation to support the environment. The most likely candidate at this point is to use CART3D[27], an Euler code from NASA Ames, although this option would require the addition of an integral boundary layer method to estimate viscous effects, in accordance with the Level 2 fidelity definition. A design of experiments may also be employed in conjunction with CART3D to reduce the required number of cases.

G. Thermal Management and TPS Sizing

The Level 0-4 analytic fidelity definitions for the Thermal Management and Thermal Protection System (TPS) Sizing discipline are shown in Table 7. In the this discipline, plans are in place to incorporate the EXITS routine from Miniver[28]. EXITS is a finite element-based heat transfer code used for approximating transient temperature distributions in one-dimensional (plug) models of TPS. Basic element groups, which model heat transfer based on conductivity and capacitance of solids, radiation, convection within gases, and lumped mass thermal capacitance, are utilized as building blocks for model construction and the assembly of any TPS concept. Pressure and

aerothermal heating, radiation to space, and convection to an ambient temperature are used to define boundary conditions. A capability has been added to IDEA to allow the user to break the vehicle OML into regions for TPS sizing. A example of the region definition capability is shown in Figure 10. Outputs of the TPS sizing module include material thickness distributions across the vehicle, as well as mass estimates.
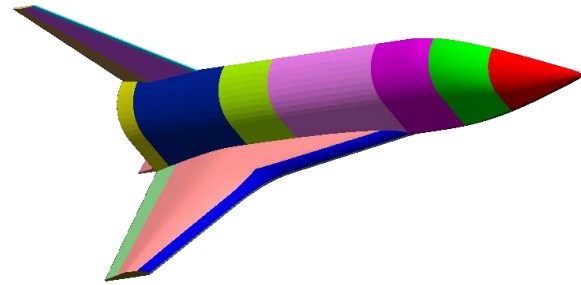
The TPS sizing capability will take advantage of the structural load case generation capability mentioned previously. Here, a set of sizing cases will be identified along the trajectory profile that, when linearly interpolated, will provide a basic reproduction of the flight profile without having to analyze every trajectory time step. In addition, future plans for the structural sizing module currently under development in IDEA include an extension towards analysis of hot structures. A capability to analyze and appropriately size leading edges will also be included.

Figure 10. Example of TPS region definition capability in IDEA that allows individual elements to be grouped and sized together.

Table 7. Fidelity level definitions for the Thermal Management and TPS Sizing discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Parametric or Historical	1D thru the thickness TPS sizing for acreage; leading edges evaluated with assumed bluntness effects to determine active / passive requirement	Quasi-2D TPS sizing for acreage; blunt leading edges analyzed; active cooling rates quantified	Quasi-2D TPS sizing for acreage; blunt leading edges analyzed; leading edge cooling channels sized; complete vehicle thermal balance for flight	3D TPS sizing for acreage; complete vehicle thermal balance including ground and flight ops

H. Airframe and Engine Subsystems

Table 8 shows the fidelity level definitions for the Airframe and Engine Subsystems discipline. In this area, the plan for Level 1 is to implement existing MERs for all major engine and airframe subsystems. Currently, EXAMINE has several sets of MERs that the user can choose, which include varying technology assumptions. At present, many of these subsystem MERs have been incorporated into IDEA, although a comprehensive set is not yet complete. In the long term, as dictated by the fidelity matrix in Table 7 for Level 2 analysis, more rigorous, physics-based models of subsystems will be built that consider loading and environment information from the trajectory simulation, plus thermal and power balance analyses. All of these influence the mass and volume of the individual subsystem. Ideally, even more metadata will be tied or estimated for each system based on its characteristics, such as technology level, failure rate, failure mode, maintenance requirements, etc. that can be used to feed life cycle analyses estimates for the entire vehicle.

Table 8. Fidelity level definitions for the Airframe and Engine Subsystems discipline.

Level 0	Level 1	Level 2	Level 3	Level 4
Parametric or Historical	Functional definition & evaluation and/or 1D or generic modeling of subsystem	Quantitative thermal & fluid analysis of subsystem; Component masses estimated with empirical and/or historical data	Quantitative thermal, fluid & power analysis of subsystem; Component masses estimated with analytical data/analysis	Subsytem masses and functional properties based on actual hardware specifications.

I. Life Cycle Analysis

For the Life Cycle Analysis disciplines, Table 9 shows the current fidelity definitions for reliability, operations and cost. Several tools are under development or planned through NASA's NRA process. Spaceworks Engineering has just completed the development of a discrete event simulation (DES) of vehicle operations that estimates vehicle characteristics such as turnaround time, maintenance requirements and operations cost. For development costs, IDEA will utilize the NASA-Air Force Cost Model (NAFCOM) with updates to some of the cost estimating

relationships (CERs) to better account for some of the airbreathing-specific elements of the vehicles of interest. Both of these codes will be incorporated in Generation 2 of IDEA. As mentioned previously, the MDAO Discipline

Table 9. Fidelity level definitions for the Life Cycle Analysis disciplines.

	Level 0	Level 1	Level 2	Level 3	Level 4
Safety and Reliability	Comparison to historical systems or quantification by limited expert opinion	Reliability and Fault Tree Analysis to the subsystem level with historical failure rate data; Preliminary documentation of critical failure modes; Deterministic or Probabilistic analysis	Reliability and Fault Tree Analysis to the subsystem or component level with historical or manufacturer failure rate data as available; Limited accounting for multiple failure modes (e.g. startup, dormant, continuous operation) and common cause failures; Probabilistic analysis according to MIL-STD-1629A or equivalent; Probabilistic analysis	Formal (e.g. MIL-STD-217F or equivalent) component level bottoms-up reliability & safety assessment, FMECA, etc.; Failure rate data from multiple sources including existing databases, and manufacturers; Full accounting for multiple failure modes and common cause failures; Probabilistic analysis; Quantitative FMECA according to MIL STD-1629A or equivalent; Probabilistic analysis	Component level bottoms-up reliability & safety assessment with experimental reliability test data; Consideration of formal program safety plans, Hazard Analysis
Flight Ops	Comparison to historical systems or quantification by limited expert opinion	Propulsion, TPS and other subsystems estimated from aircraft & space vehicle historical data & adjusted for advanced technology increments	Component-level maintainability estimated from aircraft & space vehicle historical data & adjusted for advanced technology increments	Formal (e.g. MIL-STD-472 or similar) maintainability assessment at the component level; Maintenance data from multiple sources including databases and manufacturers	Component level bottoms-up O&M assessment with experimental maintenance test data
Ground Operations	Comparison to historical systems or quantification by limited expert opinion	All ground processing flow defined to the facility level; Propulsion, TPS and other major subsystems estimated from aircraft & space vehicle historical databases & adjusted for advanced technology increments; Deterministic analysis with consideration of multiple scenarios	Discrete Event Simulation (DES) with events at the subsystem-level (propulsion, TPS, structures); Analysis of a single vehicle design with some design trades; Probabilistic simulation; All ground processing flow defined to the subsystem level. Subsystem estimates based on historical databases and adjusted for technology increments. Support and processing time requirements are based on analysis of a single point design with some trades using probabilistic simulation.	DES at the component-level; Broad design trade set exploration; Specific accounting for resources (e.g. individual facilities, technicians, etc.); Ground processing flow defined to the component level. Specific accounting for lowest level categories of resources. Probabilistic simulation and optimization	Support for Processing time requirements are based on component failure rates and requirements for both nominal and off-nominal processing. Complete resource and task-level scheduling
Cost	Weight based CER's derived from aircraft or space vehicle historical data with adjustments for technology complexity; Deterministic analysis at the system or subsystem level	Weight and programmatic factor based CER's derived from aircraft or space vehicle historical data with adjustments for technology complexity; Probabilistic analysis at the subsystem level and some component-level analysis	Component level parametric CER's; probabilistic analysis with statistical accounting for additional internal and external program risks/threats	Component or parts level bottoms-up cost estimate with primary research of cost for individual parts	Formal RFI and/or actual contractor bids
Economics	Basic financial {break-even and net present value (NPV)} assessment based on supporting cost estimate and assumed mission model; market (demand) from from subset of existing data; Generally a single point estimate	Basic financial (break-even and NPV) assessment based on supporting cost estimate and various mission models; market (demand) from by research of existing market studies and projections; Multiple scenarios considered	Financial estimate to include aspects of capital structure such as debt, equity, depreciation, etc.; Research of existing market studies and projections; Market possibly characterized by small customer survey or expert group; Development of pro-forma financial statements (income, balance sheet, cash flow); Probabilistic analysis	Use of advanced financial analysis methods such as agent-based simulation, options analysis, and game theory; Development of formal business plan and/or marketing plan for commercial entities	Primary research, consultation, and quotes from financial institutions, regulatory bodies, and investors / stakeholders; Market characterized by focus groups, large survey samples

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would like to issue a topic area in an upcoming NRA call for improved safety and reliability models for hypersonic vehicles. The call would contain elements for both models at the subsystem level, which could be integrated into subsystem models under development in IDEA, as well as vehicle level methods for reliability estimation.

V.   Schedule and Roadmap

The IDEA environment is being rolled out over several major milestones. Each generation of IDEA will build upon the previous release. An overall schedule for the rollout is shown in Figure 11. Generation 0, which was completed in FY09, provided the basic building blocks for performing vehicle closure. The POST2 trajectory interface was combined with the sizing and closure algorithms and with the automated parametric packaging capability so that a user could automatically resize and close the second stage for a given mission. Significant effort was spent making the closure process robust, ensuring that from a wide range of initial inputs (vehicle dimensions, propellant choices, mission parameters, etc.) the closure system was stable and would converge to a solution. The final test for Generation 0 was an automated run of 117 design of experiments (DOE) cases that varied propellant choice, staging conditions, payload mass, vehicle fineness and engine design parameters for the second stage. The entire matrix was run, each starting from the same "as drawn" vehicle definition, without any failures, resulting in closed vehicles with gross weights varying from 90,000 to 800,000 lbs and lengths from 55 to 127 feet. This methodology is now being implemented on the first stage to achieve complete system closure.
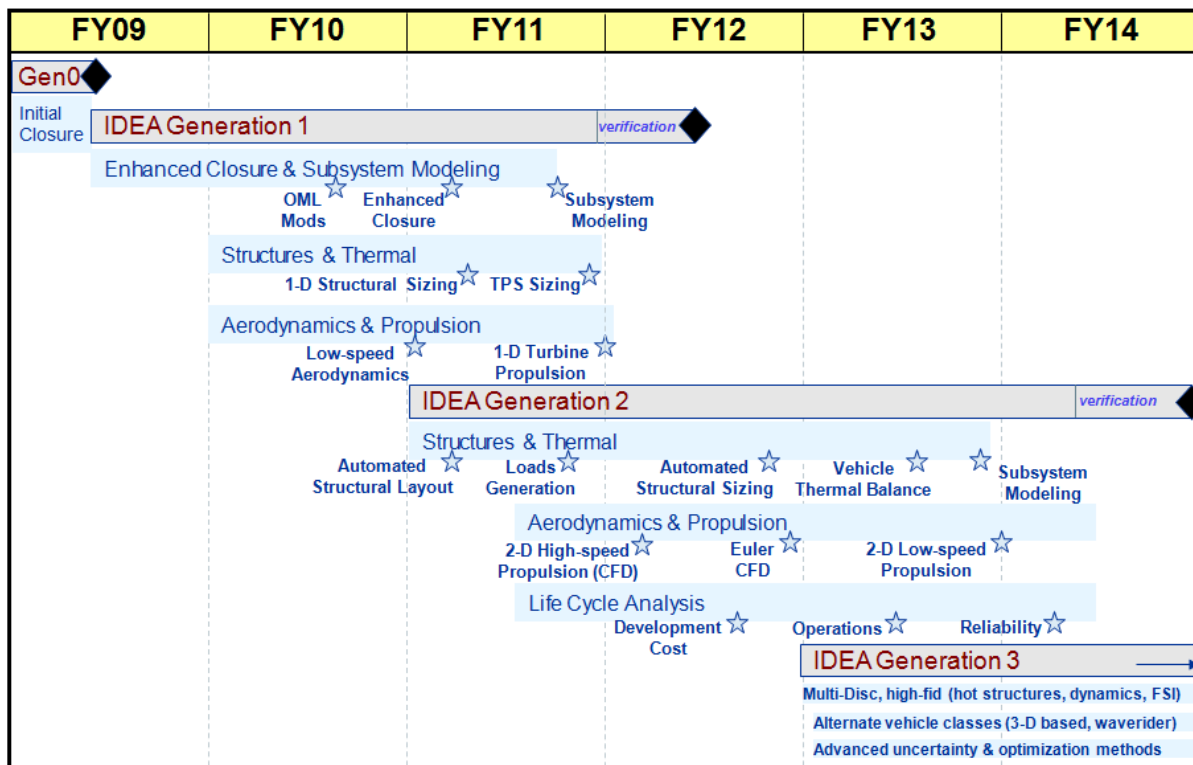

Figure 11. **Schedule and major milestones for IDEA development and rollout.**

Generation 1 will provide a complete Level 1 closure capability, incorporating all performance related disciplines. Several of the modules under development are dependent on inputs and models from other disciplines within the Hypersonics Project. The guidance, navigation and control discipline will be supplying methods for stability and control evaluation, along with advanced, physics-based actuator sizing routines. The materials and structures discipline is assisting with the TPS sizing routines, and the propulsion discipline is integrally involved in the automated CFD meshing and lowspeed propulsion integration. As seen, the current timeline shows Generation 1 delivery in FY12. The Hypersonics Project has an Annual Performance Goal (APG), a Congressionally reported milestone, related to the delivery of Generation 1 in FY12. According to the APG, to be completely successful, Generation 1 will have to provide a complete re-closure of the TSTO concept in less than two days. As demonstrated in the Joint System Study, the current timeframe for this capability is on the order of several months.

While Generation 1 will complete the integration of the performance-related disciplines into IDEA, Generation 2 will increase the level of fidelity of these disciplines to Level 2. Generation 2 will also begin to integrate the life cycle tools into the environment. As shown and previously discussed, several of these models are currently under development through the NRA process, and several more are tentatively planned. Generation 2 will also begin to expand on the vehicle classes that are included in IDEA. Higher fidelity analysis capabilities, such as analysis of hot structures or structural dynamics models, will be included in Generation 3, as well as advanced optimization and uncertainty methods.

VI.   Summary and Conclusions

Hypersonic airbreathing systems, with their high level of integration and non-linear cross-discipline coupling, demand that a multi-disciplinary approach be taken for their design, analysis and optimization. To solve this problem, NASA's Hypersonics Project is currently developing the Integrated Design and Engineering Analysis (IDEA) environment. IDEA is a collaborative environment for parametrically modeling conceptual and preliminary launch vehicle configurations using the Adaptive Modeling Language (AML) as the underlying framework. The environment integrates geometry, packaging, subsystems, propulsion, aerodynamics, aerothermodynamics, trajectory, closure, and structural analysis into a generative, parametric, unified computational model where data is shared seamlessly between the different disciplines. A matrix of various fidelity levels for each of these disciplines has been introduced. IDEA environment development is currently being focused on mid-level fidelity analyses, i.e. those that should be sufficient to bring a concept to a System Requirements Review phase of a project. Substantial progress has been made in the development. The first version of the environment, Generation 0, has already been completed, and work is well underway on Generation 1, due to be delivered in FY12.

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