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THE DESIGN OF FUTURE AIRBREATHING ENGINE SYSTEMS WITHIN AN INTELLIGENT SYNTHESIS ENVIRONMENT

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Abstract

This paper describes a new Initiative proposed by the National Aeronautics and Space Administration (NASA). The purpose of this Initiative is to develop a future design environment for engineering and science mission synthesis for use by NASA scientists and engineers. This new Initiative is called the Intelligent Synthesis Environment (ISE). The paper describes the mission of NASA, future aerospace system characteristics, the current engineering design process, the ISE concept, and concludes with a description of possible ISE applications for the design of air-breathing propulsion systems.

Introduction

As a major research and development agency, NASA, has a unique, multifaceted mission:

- To advance and communicate scientific knowledge and understanding of the earth, the environment of space, the solar system and the universe;
- To explore, use and enable the development of space for human enterprise;
- To research, develop, verify and transfer advanced aeronautics, space and related technologies to industry.

This mission, serves both the needs of the nation and mankind in general, and inspires human creativity and innovation.

The NASA mission objectives are divided into four major strategic areas, or Enterprises. The four areas are the Aero-Space Technology Enterprise, the Earth Science Enterprise, the Space Science Enterprise, and the Human Exploration and Development of Space (HEDS) Enterprise. Each of these Enterprises has distinct challenges or goals. The goal of NASA's Aero-Space Technology Enterprise is to pioneer the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics and space transportation technologies. The challenge of the Earth Science Enterprise is to develop understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. The Space Science Enterprise seeks to solve mysteries of the universe, explore the solar system, discover planets around other stars, search for life beyond Earth, chart the evolution of the universe, and understand its galaxies, stars, planets, and life. Finally, the goal of the HEDS Enterprise is to open the Space frontier by exploring, using and enabling the development of Space and to expand the human experience into the far reaches of Space.

Missions in each of these Enterprises must continue to provide significant returns on investment in both science and engineering, as they have in the past. In the current budget environment, cost estimates used to plan NASA missions must be as accurate as possible, and the risk associated with each mission must be predicted accurately, so that project managers can make appropriate decisions. In the future, system development costs must be cut by an order of magnitude, development cycle times reduced by a factor of five, and the reliability of system hardware and software improved by three orders of magnitude. These are challenging, stretch goals, but the success of future NASA missions depends largely on making significant progress towards achieving them.

The challenges faced by other government agencies are in some respects similar in magnitude. For example, nuclear test-ban treaties drive nations to certify nuclear weapons by analysis instead of testing. Also, industry is being challenged to utilize rapidly changing technology in order to compete in a global market place with affordable products that deliver lasting value at competitive cost, and are maintainable and environmentally safe. This competitive pressure leads towards requirements to drastically reduce product design cycle time. What is true about products in general is also true about space science and human exploratory Missions. Both products and missions require that complete and comprehensive life-cycle studies be performed early in product or mission planning so that costly redesigns and fixes can be avoided. A brief examination of the characteristics of future aero-space systems of interest to NASA will illustrate the complexity and challenges awaiting engineers of these systems.

Future Aerospace System Characteristics

NASA missions of the future will likely require aero-space systems which possess a number of unique and complex features. Among these characteristics are machine intelligence, modular construction and component miniaturization.

Deep space missions, such as flights to the outer planets of the solar system, or excursions to the nearest star, will require significant changes in the design of spacecraft. Because of the immense distances, and hence, large communication times involved, spacecraft cannot be controlled in the normal way by earth-based ground observers. If trouble occurs enroute to the spacecraft's destination, ground controllers will have no opportunity to transmit corrective messages to the spacecraft. Instead, "thinking" spacecraft must be developed which possess some measure of intelligence. Intelligent features, such as self-diagnostics, real-time damage assessment, decision making, unstructured storage and retrieval of data, execution of high level instructions, learning, adaptation and some measure of self-repair, will be designed into the spacecraft. Within limits, distributions of sensors will be able to react to anomalous conditions, the resulting data will be processed onboard the vehicle, and actuators will reconfigure the vehicle to respond to the perceived problem. To achieve this autonomous capability, traditional computational methods will be augmented by "soft" computing techniques, such as neutral networks, genetic algorithms, and fuzzy logic.

Another concept that will appear in future aircraft and spacecraft is that of modular construction. Spacecraft with widely varying missions, such as solar-system exploration and interstellar probes, will be assembled with properly designed, similar component modules. Standard interfaces between components will allow for attachment of those unique components required for different missions. Modular construction will ultimately reduce product development time and overall production costs. In a similar manner, some aircraft for the future may be fabricated using interchangeable components. Miniaturization of spacecraft components will be a necessary step towards dramatically reducing the cost of launching new space missions in the future. Over the past decade, significant progress has been made in this area. For example, the Viking mission to Mars, while very successful from a scientific perspective, cost over $3 billion in today's dollars, took a decade to develop, and was the size of an automobile. The recent Mars Pathfinder mission took 75 percent less time to develop, cost less than 10 percent of the Viking mission, was a fraction of Viking's size and weight, and returned comparable science information.[1] On an average, the weight of today's spacecraft can be reduced an order of magnitude from 1000 kg down to about 100 kg. However, future missions may require reductions in weight another two orders of magnitude. These "nano-spacecraft" are envisioned to weigh less than one kilogram, but possess the same capabilities in terms of data acquisition and processing as today's spacecraft.

In addition to the above described characteristics, future systems must also have the ability to withstand harsh environments, and NASA must be able to operate these mission vehicles safely from remote distances with greatly reduced operational personnel and facilities. As successful as engineering design processes have been in the past, it is unlikely that, unchanged, these same processes will be able to meet the breakthrough system characteristics required for NASA's future missions at affordable costs.

The Current Engineering Design Process

Traditional design processes for aircraft and spacecraft vehicles typically follow the five distinct phases listed below:

1. Concept Development
2. Configuration Refinement
3. Detailed Design Validation and Release
4. Fabrication and Assembly
5. Operations and Support

This traditional process is sequential in nature, usually requires long development times, and does not easily integrate customers and suppliers into the design process. Furthermore, following traditional design practices, ~90 percent of the total cost of an aerospace vehicle is built into the design in the first 10 percent of the development cycle. Unfortunately, the total cumulative knowledge of the design is still very low at this point, about 15 to 20 percent of the knowledge available at the end of the development cycle.

The current design process has evolved from past approaches, which used paper-and-pencil, slide-rule calculations, and carpet-plot data presentation, to one that approaches a paperless process, using computer calculations and CRT-display of data as a standard presentation mode. The computation methods used throughout the design process are based on traditional, physics-based equations and models. While these computational methods are vastly improved over earlier prediction capabilities, a critical need still exists to greatly decrease the amount of effort required to produce new models and the "wall clock-time" required to compute results from these models on today's supercomputers and workstations. For example, it still may take months of effort to develop a Computational Fluid Dynamics (CFD) grid for a complete aircraft configuration, while computational "clock" times can still be measured in hours rather than in minutes. Future product development processes must not only allow for, but also encourage, insertion of new cost-reducing and performance-enhancing technologies. The risks associated with new technology insertion must be well understood before commitment, the costs of insertion affordable and the payoff considerable. Furthermore, the ways in which aerospace systems are to be produced, operated, maintained and removed from service, must become factors considered in the original design process. In turn, this philosophy entails dramatic changes in the scientific and engineering culture, education, and training.

In response, many industries have adopted new views of design such as Integrated Product and Process Design (IPPD), whereas others are adopting simulation-based design methods.

This attests to the belief that the design process must encompass more than what has been traditional design; it must encompass risk assessment, manufacturing, maintenance and repair, disposal and life cycle costs. These revolutionary changes in the design process require a revolutionary environment for product and mission development. NASA must be a primary partner in defining, creating and utilizing this environment.

There are a number of programs and activities in other government agencies, industry, and universities, which are producing key ingredients for such a revolutionary product and mission development environment. NASA must work closely with these centers of activity in defining and developing this new environment. However, because of its bold endeavors, NASA faces some unique challenges for this environment.

The ISE Concept

To meet NASA's unique needs the future product and mission development environment must accommodate different groups of people, such as engineers, designers, scientists and technology developers. These groups must be able to work together collaboratively, and must also be able to integrate both customers' and suppliers' requirements into the process.[2-4] These diverse teams will collaborate in utilizing new computational resources in innovative and meaningful ways. Teams will not be in one location, so the design environment must support collaboration of geographically distributed teams. Computational tools that are utilized within this environment must be easy and intuitive to use, and make use of a balanced mix of multi-sensory technologies. The design environment must allow scientists to interact with simulated vehicles and missions so as to study science payload, mission performance and interaction of science requirements with vehicle and mission engineering. Ultimately, this environment should be usable by engineers, scientists, operators, program sponsors, and stakeholders.

Therefore, the vision of this new design and mission synthesis environment is:

To effect a cultural change that integrates into practice widely distributed science, technology and engineering teams to rapidly create innovative, affordable products. This is accomplished by using a combination of technologies to build/assemble an integrated Intelligent Synthesis Environment (ISE) for creative engineering and science.

ISE: A New NASA Initiative

In order for NASA to meet its unique mission needs in space science, human exploration, earth science and aeronautics, NASA proposes a new Initiative to develop an Intelligent Synthesis Environment (ISE). ISE will utilize computational intelligence to synthesize existing, newly developing and future relevant technologies to provide the future product and mission development environment. In the ISE, synthesis takes place in three ways:

- Collaborative synthesis of scientists, engineers, technology developers, operational personnel and training personnel all working in geographically, as well as temporally, distributed locations;
- Synthesis of cutting-edge technologies and diverse, life cycle design tools seamlessly integrated together both horizontally and vertically at all levels of fidelity;
- Synthesis of humans, computers, intelligent hardware (e.g., robotics) and the synthetic (virtual reality) simulated designs and design languages.

The intelligent nature of ISE is derived from its concentrated use of non-traditional, intelligent computational systems such as intelligent product objects, intelligent agents and intelligent computational methods. The computational intelligence, which will be built into the design environment, will guide the utilization of the vast resources of knowledge and predictive capability that the environment will have access to.

Very importantly, the ISE program will make meaningful use of related developments sponsored by other government agencies and industry. This will be accomplished through the use of R&D ISE laboratories in which technologies from government, industry and universities will be synthesized, assessed, validated and demonstrated. To this end, NASA will form partnerships and coalitions with other government agencies, the software vendor industry, aerospace and non-aerospace industries and universities. In addition, ISE Large-Scale testbeds will be created to apply new ISE products to engineering projects and science missions of importance to NASA. These testbeds will be distributed geographically and will be reconfigurable to meet new requirements as these are identified. They will provide a showcase for demonstrating how state-of-the-art computational and communication facilities and tools can be synthesized with engineering, science, manufacturing, operations and training teams to dramatically improve productivity, enhance creativity and foster innovation at all levels of product and mission development.

The Major Elements of the ISE Initiative

The ISE Initiative contains five major elements:

1. Rapid Synthesis and Simulation Tools
2. Cost and Risk Management Technology
3. Life-cycle Integration and Validation
4. Collaborative Engineering Environment
5. Revolutionize Cultural Change, Training and Education

Element 1, Rapid Synthesis and Simulation Tools (RSST), has as its objective the development of synthesis and simulation capabilities necessary to predict a product's life-cycle or system's responses, and performance. Intelligent, ultra-fast and accurate, physics-based computational methods, both deterministic and non-deterministic, will be developed using soft computing methods. These are non-traditional design tools which incorporate artificial intelligence methodologies, such as neural networks, genetic algorithms, and fuzzy logic. These capabilities support the collaborative design environment for the synthesis of science, engineering and technology development.

Element 2, Cost and Risk Management Technology (CRMT), provides new and more accurate methods for cost and risk quantification and management. These methods will be developed in a unified framework applicable to the design development processes. Operations and knowledge databases across all missions and enterprises and will be compatible with the RSST life-cycle simulations. As the simulation capabilities developed within the RSST element evolve, the cost prediction methodology will change from techniques based on historical databases, to methods which mine the new design simulations with the help of intelligent software agents.

Element 3, Life-cycle Integration and Validation (LCIV), has as its objective the assembly of R&D laboratories, the development of integration/synthesis tools used within the laboratories, and the performance of research application studies and demonstrations carried out within the laboratories. This element integrates the developments of the first two ISE elements with new capabilities such as virtual reality and 3D data immersion hardware and software. In addition, the LCIV element will utilize certain research products produced by other NASA activities or other Government agencies. Two specific areas of importance to the LCIV element of the ISE Initiative will be Human-Centered Computing and Infrastructures for Distributed Collaboration.

Human-Centered Computing addresses the user's interaction and synthesis with the ISE. It is envisioned that the ISE will utilize virtual reality and near instantaneous system simulations as well as a host of other computational tools. It is imperative that the interaction of the environment with the user, whether it is the engineer, scientist or technology developer, is a productive and meaningful design related experience. To that end, communication between the user and the ISE will involve multi-sensory technologies so as to produce an intuitive communication process. Infrastructures for Distributed Collaboration focuses on making location completely transparent to the collaborating geographically distributed teams. Design tools, computing resources and knowledge databases located anywhere in the world will be available to any team member, as though they resided locally.

Element 4, Collaborative Engineering Environment (CEE), will identify, document, and model existing engineering processes used across NASA. Large-Scale ISE Applications will be developed to infuse current capabilities into the NASA engineering practice. Collaborative Engineering Centers (CEC's) will be designed as a vehicle for NASA, other government agencies and the U.S. Industry, to enable the transition to collaborative product and mission development. The CECs will be developed so that they can be easily configured and re-configured in response to changing product and mission needs. As new capabilities are developed under the RSST, CRMT and LCIV elements, they will be incorporated into appropriate CEE large-scale applications.

Element 5, Revolutionize Cultural Change, Training and Education, fosters a cultural change in the way product and mission development is performed. Its appearance at the element level recognizes the importance and fundamental requirement for achieving this change. The CEC's will play a major role in demonstrating, educating and training participants to operate in a new design and mission synthesis culture. As the benefits of ISE are experienced, engineering and science teams will change the way they organize, operate and conduct business. In addition, the tools used can drive applied engineering concepts back into the academic environment. The purpose of this element is to invigorate this process so that the necessary cultural changes occur more rapidly and rigorously than would otherwise be the case. This element includes Training, Education, Management Practices, Collaborative Team Environments, and Organizational Learning.

The ISE in Practice

The ISE Initiative will develop, validate, assess and demonstrate, through ISE LargeScale Applications, a revolutionary product and mission development environment which synthesizes existing, newly developing and future relevant technologies to provide the future environment for collaborative science, engineering, designing, manufacturing, certifying, operating and training. Such an environment will revolutionize design so that the conceptual, preliminary and detailed design phases merge, therefore dramatically shrinking the design cycle. Products and missions will be rapidly configured and assessed for scientific payoff or product performance leading to innovative and creative design solutions. Production, operations and training issues will be addressed early, and costs and risks accurately predicted and dramatically reduced. Redesign and manufacturing rework costs will be virtually eliminated. Certification testing requirements and costs will be dramatically reduced. In total, ISE will result in significant increases in productivity, affordability and performance.

The ISE is a comprehensive, completely integrated environment. It provides a holistic view of the product development process. It addresses the entire mission and life cycle of the aerospace system. It makes effective use of intelligent agents to increase the creativity bandwidth of the science and engineering teams. CEC's will be assembled/built to demonstrate the ISE concept, and to help in identifying technology developments needed for realizing its full potential in large-scale science and engineering applications. The testbeds will be reconfigurable, and will rapidly accommodate new synthesis paradigms as new technologies develop.

Potential ISE Applications in Air Breathing Propulsion

The NASA Strategic Plan in Aero-Space Technology is focused on very specific goals in support of the aerospace transportation to reduce noise and emissions, increase safety, reduce travel time, and reduce development time and cost. These goals are articulated in the NASA Three Pillar Goals for Civil Aviation, Revolutionary Technology Leaps, and Access to Space. As discussed above, a major objective of the NASA ISE Initiative is the development of revolutionary design methodology to reduce aerospace product development time and cost. The specific goal for aerospace development time reduction is 75 percent.

The cost of implementing new technology in aerospace propulsion systems is becoming prohibitively expensive. New commercial engines developed in the early 1990s took 5 years and $1 billion. New military engines, due to the high content of advanced technology, took up to 10 years and several hundred million dollars to deploy into the field. Much of this time and cost is associated with the substantial amount of hardware builds and tests during development. Currently, numerous rig tests of components and subsystems such as, fans, combustors, compressors and turbines are required to demonstrate new technology or to extend the operating envelope of existing technology. Demonstrating acceptable technology readiness levels appropriate to the specific program now requires multiple tests of each component. Full system tests are also required for certification or qualification of the engine. For a commercial engine, there may be as many as eight full engine builds. For a military engine this could grow to as many as fourteen engines because of the greater risk in highly advanced technologies. Building and testing hardware is obviously costly and time consuming and must be substantially reduced if the aggressive NASA goal to reduce aircraft development time is to be achieved.

Over the past decade, significant progress has been made in reducing development time and cost. However, with increasing competition and declining research and development budgets, the need to further dramatically reduce development time and cost is great. At the same time, competition and environmental concerns are driving the need for higher technology. Without a significant change in the way products are developed, advanced technology will not "buy" its way onto new products. In other words, customers will have to pay a premium for advanced technology, which may be prohibitive in a highly competitive environment.

This highly competitive environment requires comprehensive consideration of the entire life cycle cost. The full life cycle costs include product manufacturing, maintenance, repair, operations and disposal. Airline executives are now requiring guarantees that engines will fly without interruption for nearly their entire design lives. This requirement makes it critical that any new technology development program include elements that constrain the impact of that technology on product life cycle cost.

One of the keys to reducing air breathing engine life cycle cost is to increase confidence early in the design process. Design confidence reduces the need for costly hardware builds and tests and the number of field fixes after the product is delivered. Improving simulation capability through advanced concepts like ISE can substantially increase design confidence.

To gain the required confidence in a simulation that leads to reduced testing, propulsion simulations must be high fidelity and physics-based to enable accurate simulation of advanced concepts that have little or no empirical database. In addition, the transition must be made from component level of design and single discipline analysis to full system design and multi-disciplinary analysis. The critical knowledge is not how a subsystem or component performs aerodynamically in isolation, but how the full system performance changes based on local design changes. To accomplish this, a variety of ISE capabilities are required. Those of particular importance are ultra-fast and accurate, physics-based computational models, full life cycle modeling capability, and a collaborative engineering environment that enables seamless integration of the models and the people that influence product design.

Ultra-Fast, Physics-Based Models

The advance in computational methods has enabled substantial progress in the modeling of complex physical processes. The state-of-the-art has progressed from single turbo-machinery blade modeling in the 1980s to multi-blade row modeling in the early 1990s to multi-stage modeling at the present. Gains have been made primarily through improvement in the modeling of steady state, 3-D viscous flows. Engineering modeling approaches, such as using source terms in the conservation equations to handle the unsteady interaction between the rotating blade rows, known as the average passage model, has been successfully developed and implemented.[5] Recent application of this method produced a coupled cooled high pressure/low pressure turbine simulation in a modern turbofan engine as illustrated in Fig. 1. The success of this simulation will change the way turbines are designed in the future: as a large subsystem rather than individual components.[6] Similar gains have been achieved in the area of simulating 3-D, chemically reacting flow in gas turbine combustors. Improvements in modeling to reduce the number of species equations and minimizing the communications overhead have resulted in over a 200-fold reduction in turnaround time as illustrated in Fig. 2. This has enabled 3-D combustion simulations from the compressor exit to the turbine inlet to become an integral part of the combustor design process.[7]

As physical models have become more complex, greater computational horsepower will be required to shorten the turnaround time. Advancements in system software have enabled large numbers of powerful desktop workstations to be linked together to provide computing power that far exceeds that of mainframe super computers.[8] This concept will be extended in the future to link computers across the country and eventually around the world to solve even larger and more complex design problems, such as complete engines and full aircraft, as illustrated in Fig. 3. The current vision is that of an Information Power Grid that provides the user with vast computing resources at his/her desktop similar to the availability of electric power to his/her wall outlet. The power is available to the user without regard to where or how it is being generated.

This capability must be accompanied, however, by the development of nontraditional, intelligent computational systems that execute efficiently over massively parallel processors and automate the assembly, execution and assimilation of the results of the simulation. To fully exploit massively parallel systems, conventional mathematical models such as the Navier-Stokes equations may have to be replaced by other mathematical models, such as ones based upon the Boltzmann equation to minimize the amount of inter-processor communication. A naturally parallel numerical algorithm is found in the lattice-Boltzmann method. First introduced in Europe about ten years ago as an extension of the lattice-gas method,[9] the lattice-Boltzmann method has undergone a series of refinements. These refinements have taken it to the point where it can successfully compete with state-of-the-art computational fluid dynamics for a wide variety of nontrivial flows, ranging from multiphase flows in complex geometries to fully developed turbulence. The floating-point operations in a solution algorithm of the lattice-Boltzmann method are very local, which makes the algorithm suitable for efficient implementations on massively parallel machines. Fundamental research will be required to find new algorithms that take advantage of parallel computing platforms.

Full System, Life Cycle Simulation

As mentioned above, a goal of the ISE Initiative is to use advanced computational simulations to model the entire system in detail through its life cycle early in the design process before any hardware is built and tested. To achieve this goal requires not only ultra-fast, high fidelity, physics-based models of the system operation, but also simulations of the processes that impact the product throughout its life. There are three primary aspects to the simulation capability: (1) The integration of all relevant components and subsystems, (2) The integration of all the relevant disciplines, and (3) The ability to vary level of detail of analysis as required. These features, for engine development, are represented in Fig. 4 by the “Rubik’s Cube” or the “Simulation Cube”.

As to the first simulation aspect, the integration of all of the relevant components of the system is required for an accurate model of the system. This is especially important in a propulsion system because of the high level of interaction amongst the components. For instance, the life of the turbine is highly dependent upon the gas temperature coming out of the combustor, which is generally non-uniform. The fan and compressor performance are affected by distorted air flow coming through the inlet. The latter requires that the view of the propulsion system be extended to include the airframe so installation effects can be accurately represented.

The second simulation aspect, the integration of the relevant disciplines, is required to provide an accurate and realistic model of the system throughout its life cycle. As a result of the severe operating environment internal to a propulsion system, many disciplines are highly coupled. Consequently, the simulation models must represent all critical multidisciplinary interactions that take place within a propulsion system. These include heat transfer, aerodynamic loads, structural deformation, and material transformation. In addition, other life cycle elements must be included such as cost, manufacturing processes, assembly, maintenance, and health monitoring.

The ability to simulate the product through its entire life cycle will enable products to be accurately designed to the planned cost and will eliminate surprises that occur during manufacturing, assembly and in field operation. The elimination of changes in the design of the system will save time and cost not only during development but also after the product is released to the customer. Field fixes can cost millions of dollars and can also damage customer confidence. System simulation will also enable better understanding of the engine health and remaining life of the components of the system as the products are subjected to differing operating conditions. These differences range from various take-off and landing scenarios to different atmospheric conditions. An important aspect to this determination is the understanding of uncertainty and the probability of failure of a component. The use of non-deterministic modeling methods and probabilistic analysis is critical to developing this understanding.

The third simulation aspect is the ability to vary the level of detail of the simulation as required throughout the virtual representation of the life cycle. This is required to minimize the time needed to perform the simulation. Many complex models will be used to simulate physical phenomenon that span a wide range of spatial and temporal scales. In order to minimize the time required to setup, execute and analyze the results from the simulations, the designer or analyst must have the ability to vary level of detail of the analysis throughout the system and the life cycle. For example, to understand the tolerance or robustness of the system performance to distorted flows entering a turbofan engine, the low pressure subsystem (i.e. inlet, fan, bypass duct, nozzle, core inlet) should be modeled at the highest level of detail. However, the high-pressure core of the engine could be modeled at a much lower level of fidelity since much of the distortion will be mixed out by the time the air reaches the core compressor. This represents a significant savings in simulation effort since the core is a very complex part of the engine. The core compressor by itself can contain over 20 blade rows, each row with from 20 to 50 blades. An example of a hybrid fidelity analysis of a modern turbofan engine is illustrated in Fig. 5 where the low pressure subsystem is modeled at 3-D level of detail and the high pressure core is modeled at the 0-D or parametric level of detail. Despite the differing levels of detail, the two subsystems are integrated both aerodynamically and mechanically.

Collaborative Engineering

The ability of large teams to work closely together through all phases of the product life cycle is key to ensuring that the final product meets the customers requirements, which includes, of course, not only performance but also acquisition and operating costs. This is possibly the most challenging aspect since the teams will be extremely diverse and geographically distributed. The team membership will include engineers and others with experience in all phases of the product life cycle. Representatives with experience in maintenance, repair and operations will be included. In addition, representatives from the customers will be added to the team to insure adequate consideration of customer requirements. Virtual team meetings will be required that link people from around the world together to discuss the product. The team members will have to access the advanced simulation tools discussed above so "what if scenarios" can be processed in real time. For example, "What if the aircraft noise must be reduced by 3 dB during takeoff?" The team could do several trade studies during the meeting to look at the impact of changing bypass ratio, fan and nozzle design, or wing design on specific objective functions, such as, overall aircraft life cycle cost. The design of the components is distributed to specialists around the world. During the design process they are linked through a common view of the full engine or aircraft simulation as illustrated in Fig. 6. As a result, each component designer can understand how his/her changes impact the other components and the key system objective functions. At the conclusion of the meeting, action items would be assigned to team members. Because the team members reside in different time zones around the world, the design changes will be worked continuously around the clock and productivity will increase dramatically. However, additional factors must now be considered in the simulation such as the interoperability of analysis tools and a common definition of the product geometry that all team members access.

The interoperability of tools must be addressed through the development and adoption of standards and through the use of new programming models such as the object-oriented paradigm. The development of standards requires that the "team" members work together to agree on the standards. Government agencies can facilitate this process, but all involved must contribute to and accept the agreed upon standards. An example in the propulsion community is the development of a common engine thermodynamic cycle analysis tool that both engine and aircraft manufacturing companies use to model the engine performance throughout the aircraft life cycle.

NASA, the engine industry and the aircraft industry have been collaborating on the development of a new engine simulation tool called the Numerical Propulsion System Simulation (NPSS). Version 1 of NPSS is the 0-D cycle model. Future versions will have the ability to bring in higher fidelity analyses. Version 1 is written in C++ with an object-oriented software design and Common Object Request Broker Architecture (CORBA) compliant interfaces. The software engineering facilitates the implementation of public domain and proprietary software, is easily extensible for future improvements, and can be distributed across geographically dispersed computing platforms to accommodate remote team members as described in the "what if" scenario. Version 1 is currently going through testing at the participating companies as part of their implementation plans. The projected cost savings through improved productivity across the industry are estimated to be approximately $50M/year.

The next major improvement will be the integration of CAD geometry with the analysis tools to enable the common geometry representation across the team. A near term goal is to enable the generation of an axisymmetric CAD representation of a turbofan engine immediately from the requirements definition. The geometry definition is made up from data from a variety of sources including a library of parts and components, a knowledge-based system containing design rules, and a suite of physics-based analysis tools. From this initial CAD definition, a detailed, multidisciplinary design will proceed that is tightly integrated with the common CAD model. The CAD definition of a full engine will be the master model of the simulation enabling the distributed product team to work from a common geometry definition from concept through in-service operations. The development of this capability is being conducted in close coordination with international standards such as STEP and the Object Management Group to ensure consistency and compatibility with current and emerging standards.

Summary

In summary, the success of future NASA missions will depend, in part, on the development of a new way of performing engineering design and science return synthesis. NASA's answer to this challenge is the Intelligent Synthesis Environment. In a similar manner, the future design efforts for air-breathing propulsion systems will also greatly benefit from the use of an Intelligent Synthesis Environment. The ability to design a new propulsion system in a manner which permits the simulation of the complete product life cycle will ultimately result in significant reductions in development time and development costs, as well as provide improvements in risk assessment associated with incorporating new technology in future propulsion system designs. In addition, robust, virtual reality total life-cycle simulations will provide "real-time" feedback to design and systems engineers for obtaining optimum overall system level benefits.

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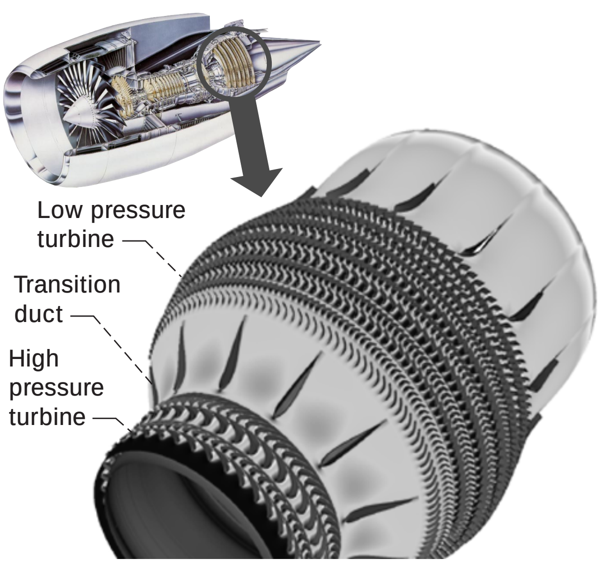

Figure 1.—Physics-based modeling enables complex coupled component simulations in large turbofan engines.

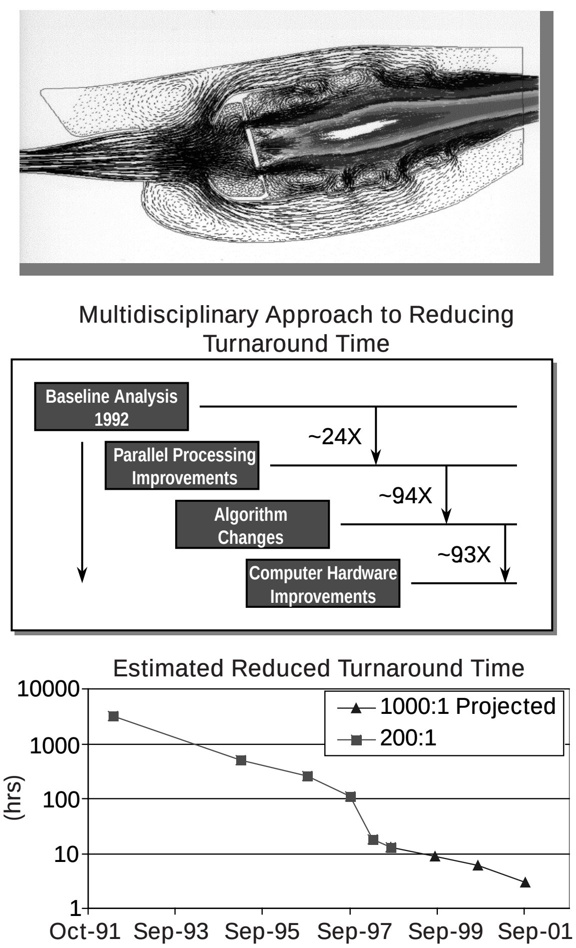

Figure 2.—High performance computing and advanced combustion modeling combine to demonstrate 200:1 reduction in combustor simulation time.

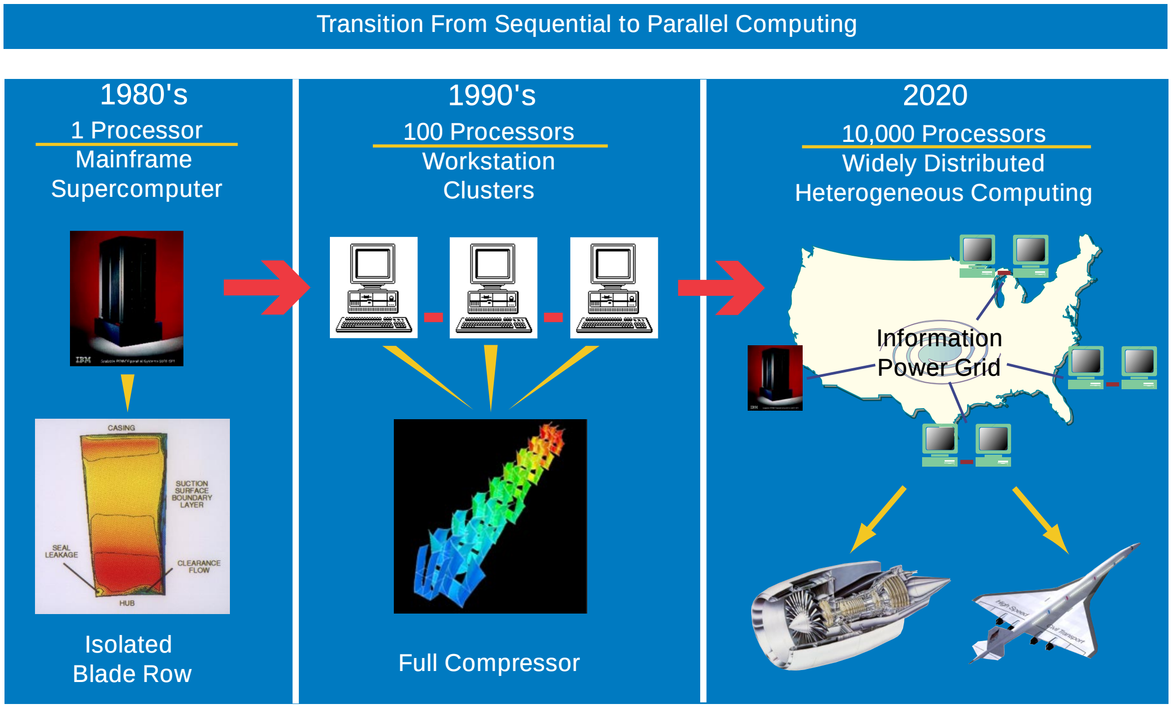

Figure 3.—The ability to effectively utilize massively parallel computing will be required to simulate large-scale engineering problems.

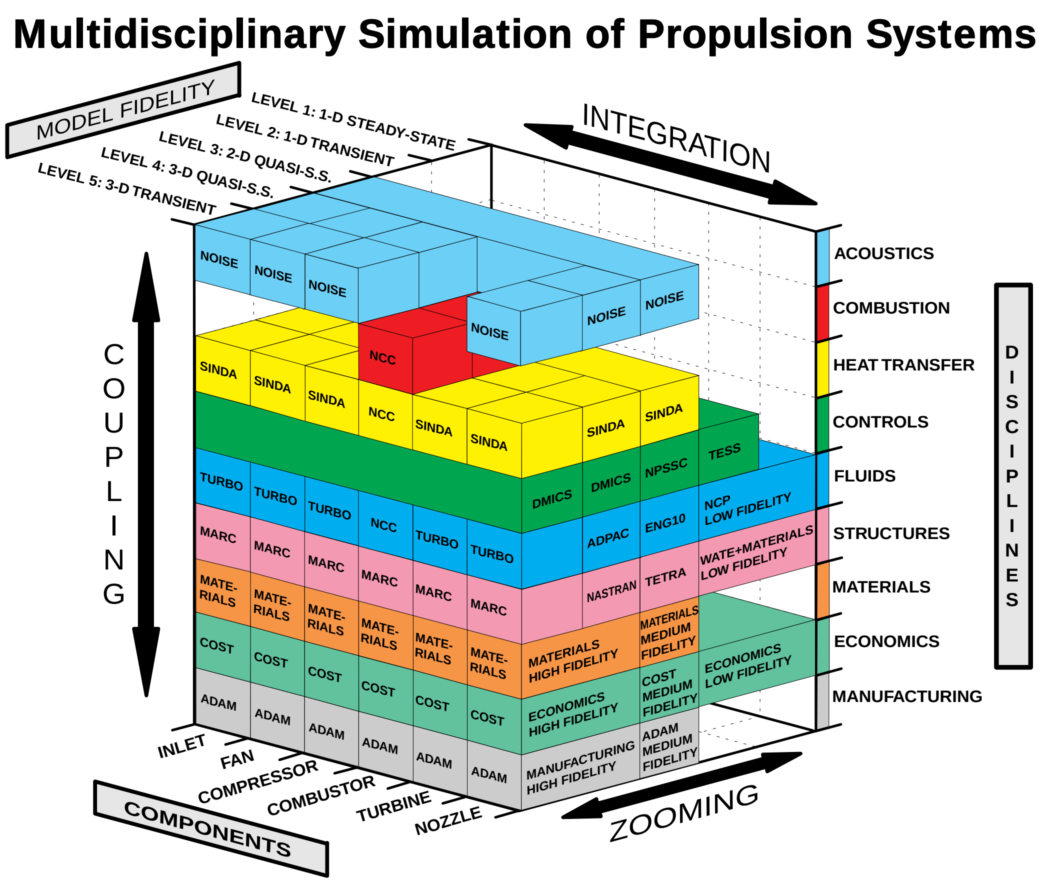

Figure 4.—Simulation of complex systems requires the integration of disciplines, components, and varying levels of model fidelity.

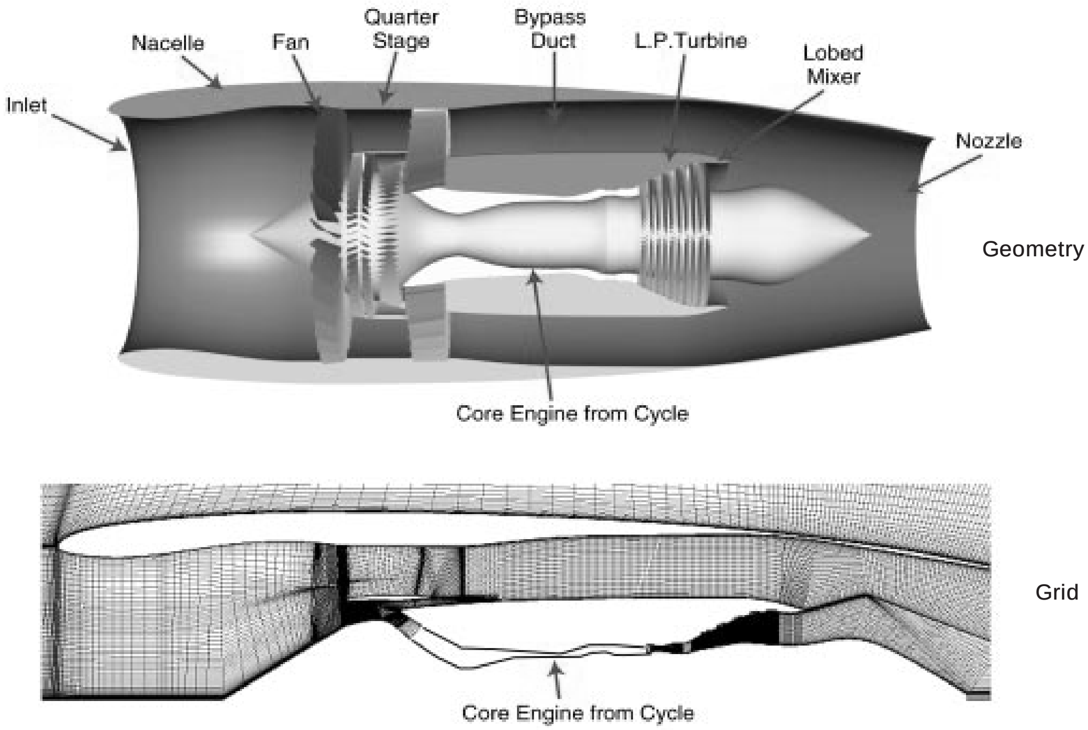

Figure 5.—Hybrid model of a high bypass ratio turbofan engine: 3-dimensional low pressure subsystem and 0-dimensional high pressure core subsystem.

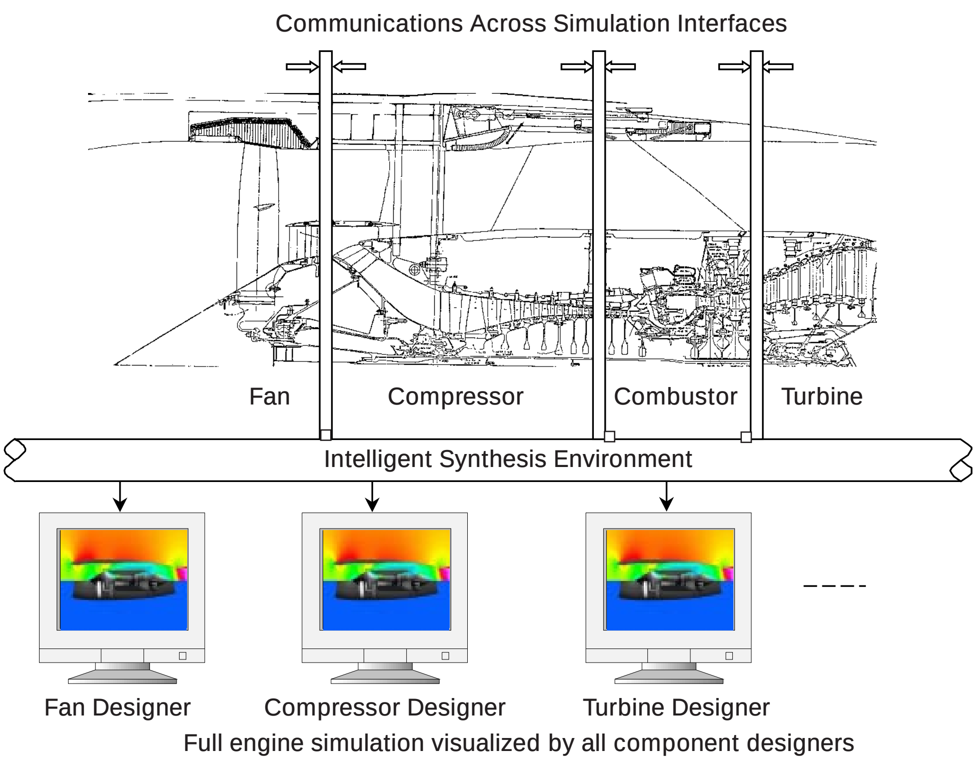

Figure 6.—Distributed engine simulation for collaborative engineering.

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13. ABSTRACT *(Maximum 200 words)*

This paper describes a new Initiative proposed by the National Aeronautics and Space Administration (NASA). The purpose of this Initiative is to develop a future design environment for engineering and science mission synthesis for use by NASA scientists and engineers. This new Initiative is called the Intelligent Synthesis Environment (ISE). The paper describes the mission of NASA, future aerospace system characteristics, the current engineering design process, the ISE concept, and concludes with a description of possible ISE applications for the design of air-breathing propulsion systems.

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