IN-20
33625
p14

NASA Technical Memorandum 105181
AIAA-91-3554

Numerical Propulsion System Simulation: An Interdisciplinary Approach

Lester D. Nichols and Christos C. Chamis
Lewis Research Center
Cleveland, Ohio

Prepared for the
Conference on Advanced Space Exploration Initiative Technologies
cosponsored by the AIAA, NASA, and OAI
Cleveland, Ohio, September 4-6, 1991

NASA

NUMERICAL PROPULSION SYSTEM SIMULATION:

AN INTERDISCIPLINARY APPROACH

Lester D. Nichols and Christos C. Chamis
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-6359

Abstract

The cost of implementing new technology in aerospace propulsion systems is becoming prohibitively expensive. Large scale system tests are required to capture the complex interactions among the multiple disciplines and the multiple components inherent in modern propulsion systems. The tremendous progress being made in computational engineering and the rapid growth in computing power that is resulting from parallel processing now make it feasible to consider the use of computer simulations to gain insights into these complex interactions and to evaluate new concepts early in the design phase before a commitment to hardware is made. This paper describes a NASA initiative to develop a Numerical Propulsion System Simulation (NPSS) capability.

Introduction

Digital simulation of aerospace propulsion system behavior has been in existence for many years. The earliest simulations were developed in the seventies. The performance and reliability of engine systems depend on the dynamic interaction of their subsystems which, in turn, depend on the dynamic interaction of their respective components. Interaction phenomena of importance include flutter, rotor instability, fatigue, flow separation, nonuniform combustion, blade containment, and noise suppression. The determination of aerothermodynamic system performance has traditionally relied on prototype tests while structural reliability has been calculated from field data. This experience has been used to develop simulation techniques that employ varying degrees of approximation to model and compute the aerothermodynamic performance and structural reliability of new designs. In general, these simulations can be divided into two classes, depending upon their time dependance.

Steady state simulations are normally used by design engineers in order to assess design tradeoffs. Here the emphasis is on ease-of-use by the designer and, in particular, allowing the designer to include "company lore" or company expertise in the design. Depending upon the use of the design system (i.e., whether it is for conceptual design, preliminary design, detailed design, or final design) there will be more or less fidelity included in the simulation. Steady-state simulations are used for design point analyses, with allowances for off-design performance. In the latter design stages, steady-state simulations can be used to develop control system schedules and to provide estimates of engine system life.

Dynamic simulations are used after the engine is designed in order to develop control laws/logic and to determine the limits of stable engine operation. Obviously, if the simulation calculations can be speeded up, more detail (i.e., spatial and temporal resolution) can be included in the simulation model. During control system hardware and software implementation, there is a need for a real-time engine simulation that can be operated with the control system in a "closed-loop" fashion.

Dynamic simulations are also used to study cases when the engine behaves differently in the field from what was envisioned in the design phase, or as uncovered in the testing of the engine before it was installed into service. These simulations can be particularly valuable when ground-based experimental facilities are not available to simulate the in-flight conditions under which the unusual behavior was observed. Obviously the more accurate the simulations, the more their value.

The analysis of propulsion phenomena involves a combination of disciplines including fluid mechanics, thermal sciences, structural mechanics, material sciences, combustion theory and controls theory. The degree of resolution within an analysis is determined by the magnitude of local effects, the extent of their region of influence, and the dynamic time scales of the appropriate physics relative to the dynamic scale of the system phenomenon being analyzed. Often the limiting factor will be the available computer power (speed and memory capacity). The analyst must determine which terms in the governing equations to retain and which to ignore so as to achieve the maximum level of fidelity within the computational constraints.

Propulsion phenomena are inherently multidisciplinary (i.e., the true system response is the coupled effect of all the participating disciplines and the aggregate of the system components' responses and interactions). Present analyses (and experiments) tend to focus on single-discipline aspects of the phenomena within a local region (e.g., a single component). Using suitable approximations, these analyses are sometimes extended to a propulsion subsystem or, in rare cases, the complete propulsion system.

Recent advances in computational fluid mechanics, computational structural mechanics, computational materials science, computational controls, and computer science and technology make it feasible to consider the development of a "computational test-cell" for propulsion that would allow for comprehensive simulation and analysis of entire propulsion concepts and designs before committing to hardware. The "computational test-cell" concept is illustrated in Fig. 1.

The "computational test-cell" will enable the incorporation of new methodologies, such as concurrent engineering and probabilistic methods, into the propulsion design process. This will provide the capability to conduct credible, interdisciplinary analyses of new propulsion concepts and designs.

Concurrent engineering is a top-down systems approach which provides a framework and information for explicit decision-making throughout the entire engineering process. Essential in this approach is the formation of multidiscipline teams to carry out integrated design, design optimization, and computer-aided engineering, design, and manufacturing. By bringing concurrence into the "computational test-cell" and into the early phases of the design system, it will be possible to reduce design time and cost as a result of reducing iterations.

Probabilistic methods can be used as the basis for reliability-based design. Recently methods have been devised that provide the capability of simulating the performance of propulsion systems at several levels of resolution. These methods make it possible to quantify uncertainty and to establish confidence bounds for the calculated values.

The introduction of reliability-based design methodology along with probabilistic analyses will provide a tool to reduce the design space for new systems and to reduce our dependence on hardware testing for proof-of-concept and system integration demonstrations. The resulting simulations will reduce the need for testing and identify potential operational problems early in the design process.

This capability will make it possible to compute the expected performance, stability, reliability, and life of propulsion components, subsystems, and systems at design and off-design conditions, to bring life cycle cost tradeoffs early into the design process and to determine optimum designs to satisfy specified mission requirements.

Approach

To make the vision of the "computational test-cell" a reality will require a coordinated research and technology program. The NASA Lewis Research Center's Numerical Propulsion Simulation System (NPSS) project is aimed at the development and demonstration of the key enabling technologies for integrated multidisciplinary simulation, analysis, and optimization of aerospace propulsion systems. A user will be able to select the resolution (both in space and frequency) of the multidisciplinary analyses. A high performance computational testbed for demonstration of the capability will be provided. The NPSS development will use a "building block" approach to gradually accomplish the integration of the disciplines, components, and computing hardware.

The NPSS approach is to introduce concurrence as early as possible into the design process via verified computation. In order to achieve concurrence, it will be necessary to focus ongoing, single discipline, single component, engine system oriented, fundamental research and technology into interdisciplinary projects. In addition, it will be necessary to acquire and utilize the best available computational capability and to anticipate the evolution of computer technology. NPSS will gain user confidence by continually applying the resulting capabilities to industry needs.

The NPSS project is a cooperative effort involving NASA, industry, and universities. To the maximum extent possible, NPSS project activities are being coordinated with other research and technology programs.

NPSS Strategy

Software Integration

The NPSS must provide the user with a convenient integration of software for engine system modeling analysis and computer operation. Since the simulations will be for total engine systems, the degree of fidelity for any single component, or discipline, or computing facet will be determined by the particular engine attribute to be simulated. Once this attribute is specified, the required fidelity of the individual simulating features will be known. If the required fidelity is available, the attribute will be simulated and appropriate conclusions drawn. If not available, then suitable development (or research) must be undertaken. Verification of simulations will be accomplished by comparison with experimental data.

The capability for users to simulate, analyze, and optimize propulsion systems will require high performance, massively parallel computers. This necessitates development of a user interface to NPSS that will shield the user from the details of the computing system while providing sufficient guidance and assistance to build and operate the simulation at hand. The vision is that of a totally "seamless" environment. The environment will integrate physical sciences, computer sciences, computer systems software, and computer systems hardware under the control of a global simulation executive.

The computational simulation of multidiscipline, multicomponent problems entails a large number of variables that must be computed at multiple scales over multiple regions with results stored on local/global database environments. These types of problems can only be effectively solved using massively parallel processor computers and networks in conjunction with parallel programming concepts. Logic and software will be developed to map computations efficiently on to processors/computers for single disciplines and for interdisciplinary analyses at both the local and global levels.

Construction of simulations can be aided by a visual simulation editor coupled to an expert system "trained" in the use of the simulation codes. Artificial intelligence approaches, including expert systems and neural nets, will be investigated for assisting the user in making appropriate decisions in constructing a simulation. Advanced computer graphics, visualization and animation complete this environment.

Computing Platform Flexibility

It is the intention of the NPSS to take advantage of existing codes to the extent possible, while at the same time maintaining the flexibility to utilize emerging massively parallel computing hardware platforms. The NPSS software architecture is shown in Fig. 3. The architecture envisioned utilizes a shared memory programming paradigm and standard software tools and programming language extensions. The programming will be independent of hardware architecture.

Within the computing system, the nature of the coupling between the computing system components (processor, memory, communication) will depend upon the engine system component codes and single discipline codes required to compute the desired engine attributes. Therefore, the selection/development of appropriate processor I/O software, compilers, networking protocols will be accomplished in conjunction with the development of engine system and discipline (i.e., application) codes.

It is expected that advances in parallel computing will make the integrated, interdisciplinary analysis of complex propulsion systems practical for design and analysis. At the same time, it is expected that approaches to problem formulation and algorithm design will have to change to be able to exploit the new parallel architectures. Therefore, NPSS will establish a testbed environment so that application and computer scientists can gain experience with state-of-the-art hardware and software tools to develop algorithms and to identify the appropriate computing architectures for the propulsion system applications.

Hierarchical Modeling

The coupling of the disciplines and component codes involves the subdivision of a complete system, e.g., an aircraft engine, into a series of subsystems, e.g., inlet, compressor, combustor, turbine, and nozzle. It is convenient to define a hierarchy of multidisciplinary simulation modules for each subsystem ranking from relatively simple time and space "averaged" analysis methods (Level I) to complex three-dimensional, time-accurate analysis methods (Level V). The relationship of these modules and their function is shown in Fig. 4. They are defined as:

Level I: Engine system performance model. This model is basically a thermodynamic model which calculates the system efficiency based upon engine configuration and component efficiencies. It allows rapid evaluation of various engine concepts.

Level II: Engine system dynamics and controls model. This model is basically a one dimensional flow path model, with simplified structural elements, controls, and other disciplines. It uses component performance information, design geometry information, and dynamic information in order to calculate engine thrust and weight as well as system transient response in order to analyze operability problems and devise control strategies to handle them.

Level III: Space and/or time-averaged engine system model. This model is basically a two-dimensional (i.e., axisymmetric) fluid model. It utilizes axisymmetric, coupled discipline models in an engine system environment in order to relate component boundary conditions (primarily input/output conditions) to overall system boundary conditions in order to simulate component interactions. This is also the basic level about which the "zooming" process is constructed. It will be a transient model and address all problems from Level II but, in addition, provide more detailed geometry information.

Level IV: Space and/or time averaged subsystem (or component) models. These models are basically three dimensional. They are multidiscipline models which are coupled in ways which are compatible with the physics of the component model, but are still averaged over smaller time and space scales. These models must also be post-processed in order to connect with the Level III engine system model in the "zooming" process.

Level V: Three-dimensional, time-accurate component models. This level of simulation basically consists of a fully three-dimensional, time-accurate simulation of all physical processes on a component-by-component basis. This is the most complete level of physical approximation.

The component coupling is determined by the propulsion system geometry and operating conditions and can be accomplished by linking discipline codes within a component code, and then linking component codes within an engine system or subsystem (Fig. 4, Levels I to III). When the coupling is determined by the physics of the simulation, then the coupling will be local and may have to take place within a component at the equation level (Fig. 4, Levels IV to V).

"Zooming"

Attempting to resolve all of the length and time scales that are present in the fluids and structures of the engine is impractical, even on high performance computers. Therefore, a rational approach for identifying and resolving the critical scales is needed. Approaches that have been shown to be effective for single component analyses will be extended to the simulation of coupled components and entire engine systems. Approaches will be developed to allow selected components to be resolved to a greater level of detail than others. Utilization of the zooming approach will allow the interconnection of a series of multidiscipline simulations in which a single or small number of modules are simulated with very accurate methods, perhaps Level IV or V, while the remainder of the subsystems are implemented with simple methods, perhaps Level II or III. This focusing or "zooming" in on a particular component will allow for a more thorough analysis of that subsystem in a complete multidiscipline system format without having to completely simulate the entire system at the same detailed level.

For example, studies of compression system stability will require a detailed treatment of the compression system to be coupled to lower-resolution treatments of the fan, combustor, turbine, and nozzle with the appropriate boundary conditions to represent the intercomponent interactions (Fig. 5). This "zooming" capability will permit the analyst to capture relevant physical processes throughout the engine in a computationally-tractable manner and will allow the analysis to be used on a routine basis for design assessment and optimization. Thus, this approach will be much more cost effective and should provide an attractive approach for overall system performance optimization. The actual interface algorithms used in this "zooming" approach will range from the direct coupling approach described above to one involving the interface of time- and space-averaged parameters. With this approach, special emphasis can be placed on the effects of interface sensitivities between two subsystems in an entire system.

Discipline Coupling

For computational simulation to be credible, it must include efficient multidisciplinary coupling. In the case of multidisciplinary simulation of dynamic phenomena, the time scales associated with various aspects of the phenomena have to be considered. In an engine interacting phenomena, such as surge, stall, flutter, component and system dynamics, low and high cycle fatigue, and takeoff and landing operations occur within widely varying time intervals. The computational procedures and the "clock cycle" of a multidisciplinary simulation have to accommodate these vast differences in time scales. The simulation clock cycle has to be consistent with the available computational power and, in the case of animated graphic representation, the perception rate of the human visual capability.

Implementing coupling in the required numerical simulation, analysis, and optimization is a tremendous challenge because of the potentially very large number of interrelated variables and the very large number of iterations that can result from general-purpose algorithms. A hierarchical approach that can reduce the dimensionality of the system description while still retaining the essential system behavior is needed. There are a variety of techniques that can be used for coupling discipline variables for propulsion components, subsystems, and systems. These include sequential iteration between disciplines, specially-derived system matrices, and coupling at the fundamental equation level. In

NPSS, all three methods will be applied to the filtered Navier-Stokes equations and the progressively substructured structural mechanics formulations. Relationships (i.e., sensitivities) will be derived for use in optimization algorithms that are streamlined for the multidisciplinary, multicomponent application.

The coupling across disciplines in a concurrent multidisciplinary formulation can be represented by coupling relations. The coefficients (elements) in these relations define the coupling of a specific variable from one discipline with respective variables from interacting disciplines (Fig. 6). Perturbation of the variables in the coupling relations provides a measure of the sensitivity of the interacting disciplines to this perturbation. A priori description of this sensitivity relationship enhances the computational simulation in several respects: (1) scoping the degree of coupling, (2) identifying the interacting disciplines, (3) resolving time/space scales, (4) selecting time/space scale for loosely coupled interacting discipline intervention during the solution processes, (5) deciding on a solution strategy, and (6) imposing convergence criteria.

Three different methods will be developed for defining and deriving sensitivity relations. These are:

(1) heuristic - based on available traditional single discipline approaches and expert opinion,

(2) progressive estimation - filling in and refining the sensitivity matrices by using optimization techniques and the strengths (weights) of developing connections in neural nets concepts, and

(3) coupled formulation - those derived in the fundamental formulation for multidisciplinary coupling.

The requisite technology base required for the development and definition of sensitivity (relations) includes: advanced methods of matrix operations for integration, differentiation, inversion and eigenvalue extraction, adaptive matrix partitioning, transfer matrices, specialty matrix manipulators/solvers, various expansion techniques and symbolic operators.

The salient coupling terms will be identified and their space/time scale resolution, integration, and contribution to the dynamic interaction computed. This approach differs from the classical analytical approach which minimizes the number of variables retained in the governing equations by using formal applied mathematical techniques. The proposed approach retains all the primitive variables in the primitive equations. This results in relatively large systems of equations that must be solved simultaneously.

Alternative methods for coupling disciplines, that have the potential for reducing the computational requirements/computing times, will also be investigated and assessed. These include multidisciplinary finite and boundary elements, adaptive superelements, hybrid finite-difference/finite-element formulations, hybrid finite-element/boundary elements, modeling, slave finite-elements, coupling matrix generators, hybrid analyzers for the above formulations, data storage and retrieval systems, telescoping scale integrators and progressive substructuring for local/global (global/local) zooming (transcending spatial/temporal scales) as well as probability and statistics for quantification of reliability and risk.

Optimization

Complex propulsion systems are currently designed sequentially at two fundamental levels: (1) single component and (2) single disciplines. Each discipline contributes its part to each component's design. Several interdisciplinary iterations usually take place which result in trade-offs between the disciplines and their competing objectives for each component. The components are assembled into a subsystem and generally require intercomponent/interdiscipline iterations to reach an acceptable (compromised) design. Part of the design iterations can be formally represented using optimization methods. These methods have been very successful for single component/single discipline optimization. Some limited multidisciplinary optimization capabilities have been developed for a single component (blade) of propulsion systems but under the restrictions imposed by current general purpose optimization algorithms.[3] Similar optimization techniques can be applied to minimize the number of iterations during the solution process. Different techniques are required for different situations.

Five different types of optimization algorithms will be investigated and assessed for application to multidisciplinary and multicomponent propulsion systems: (1) hierarchical, (2) multiscale, (3) multiregion, (4) multiobjective, (5) adaptive.

Hierarchical algorithms provide the capability to select dominant variables/disciplines/components during the optimization process. These variables/disciplines/components will continually change as the optimization progresses.

Multiscale algorithms provide the formalism for optimizing at different scales (expanding/contracting) as the optimization progresses. This algorithm will allow us to conduct local optimization simultaneously with global but at different rates and with different accuracy. It will also allow us to optimize spatially and temporally at different rates and with different convergence criteria.

Multiregion algorithms are similar to multiscale algorithms but are structured for regions and components. That is, different regions/components can be optimized at different rates while the rates can change as the system optimum becomes more sensitive to critical regions/components.

Multiobjective algorithms can handle the simultaneous optimization of multidisciplinary, multicomponent problems. Formalism will be included for coupled objectives and/or weighted objectives as well as discriminatory selection for a critical discipline/component.

Adaptive algorithms have the potential for progressively monitoring dominant conditions and providing the hierarchical algorithm with the appropriate choices.

The technology base to support development of these optimization algorithms include mathematical optimization techniques: linear, nonlinear, continuous, discrete, constrained, unconstrained, substructuring, variable linking as well as a variety of direct nonlinear mathematical and optimality criteria search methods that have evolved over the years.

Propulsion System Simulation

The development of an engine simulation capability will begin with existing Level II dynamic engine system models of aerothermal (DIGTEM)[4] and structural (TETRA)[5] behavior (Fig. 7). Level IV aerothermal and structural simulations will be used to generate the required component parameters and maps for the Level II engine models. Then, methods for improving the parametric representation of the components will be investigated so that the significant phenomenon observed from detailed analyses can be represented in the engine model.

The initial simulations involving Level II aero and structures codes will investigate the thermal lag between changes in the engine operating conditions and the heat transfer effects on the structure. Thermal strains resulting from the changes in the temperature of the structure affect the secondary cooling flow passages and tip clearance flow in the components. These effects must be accounted for in the aero codes and will result in a change in the computed engine operating conditions.

The Level IV aerodynamic simulation model that will serve as the basis for the integrated propulsion system model will be the Adamczyk average-passage formulation which consists of the filtered forms of the Navier-Stokes and energy equations.[6,7] This model was designed to resolve only those temporal and spatial scales that have a direct impact on the relevant physical processes. The effects of the unresolved scales, which appear as body forces and energy sources in the equations, are estimated through semi-empirical relations, based on experiments or high-resolution numerical simulations. The results from the lower-resolution analysis appear as boundary conditions for the high-resolution model. Initially, this model will be applied to the study of a compression system and its performance, stability, blade vibration, and noise generation. Since the methodology applies to the fundamental fluid flow equations, it will then be extended to the other propulsion components.

The structures modeling will be aimed at developing a comparable computational capability that will provide a means to traverse multiple scales of spatial resolution with a minimum number of variables at each level. In this way, an analysis can proceed from a blade to a rotor sector to a rotor to an engine core to the complete engine. The resulting system model will have a minimum number of degrees of freedom consistent with the objectives of the analysis which will minimize the computational requirements. This methodology will be applicable to the solution of linear and incremental nonlinear analysis problems. This capability will be achieved through the formulation and implementation of a progressive substructuring ("telescoping super-elements") technique within the mixed-iterative finite element method framework and associated MINUTES[8] computer code and within the boundary element framework and associated BEST3D[9] computer code.

The coupling of the Level IV aerodynamic and structures codes for the fan will permit the direct simulation of the effect of changes in fan geometry upon the operating conditions of the engine. Of particular interest is the effect on the fan/core split (aero only) and upon the effect of blade loading upon the fan clearance and the ultimate effect on the fan performance map (aerodynamic and structures).

Simulation verification requires experimental data (or some other tie to reality) to provide a validation and/or calibration of the numerical models and methods used in the solution procedure. Due to the multidisciplinary nature of a complete engine simulation, NPSS will require an extensive validation process. The baseline engine to be used in this process is the Energy Efficient Engine (EEE).[10] This advanced core engine was recently developed under government sponsorship, and has an extensive series of component and complete engine data. This data will provide an initial calibration of the NPSS methodology.

NPSS Project Management

Partnership

Because of the scope of the NPSS activities and the synergistic benefits of NPSS to the aeropropulsion community, the NPSS project team includes a number of partners and organizations. All partners are involved either as contributors or as users. Emphasis is being placed on establishing communication paths and standards to accommodate both institutionally and organizationally, on a long term basis, the inevitable personnel changes that will occur over the life of the project.

Interfaces

NASA Headquarters is the interface for program definition and funding. NPSS represents a formal mechanism to focus propulsion-related research within the aeronautics program, and a quantitative method by which mission benefits for various program tradeoffs can be made. It can represent a computational contact point for programs at other NASA centers, (e.g., in airframe/engine integration studies).

Industry interaction with NPSS will occur for both engine manufacturers and computer manufacturers. Engine companies can use NPSS as a testbed to try new analysis systems which are potential candidates for their internal use, and to evaluate different computer hardware platforms for their software. Computer manufacturers can consider the NPSS project as a potential testbed site for new equipment, as well as a way of gaining insight into computationally intensive applications that may influence the design of new equipment.

University interactions will provide a mechanism for evaluating computational research in the context of engine simulation and high performance computing. The Ohio Aerospace Institute will concentrate its efforts on providing on-site interaction with students, faculty, and possibly even industry researchers. These contacts will be useful identifying researchers who are well versed in engine simulation techniques. The on-site interaction with industry users will be useful in transferring technology (in both directions).

Planning Process

Industry and university representatives on NPSS planning groups were solicited by NASA. Planning discussions were held that resulted in drafting a project plan. During the development of the plan, questions arose for which answers from industry were required. The NASA team interacted in a round-robin fashion with the initial planning group to refine the project plan. The process will continue throughout the development of NPSS.

Clearly, it is important for NPSS developers to understand the scope of the present design processes in use by the engine manufacturers, the extent to which computational simulation presently is used, and how it might be used in the future. Methods by which this information can be determined and used in the planning of the NPSS activities are being considered and discussed with the appropriate partners. A first task is to identify critical simulation technologies that can have a significant impact on engine development time and cost. Computational limitations and bottlenecks will be identified. The impact of projected advances in computational technology on industry capabilities to simulate multidisciplinary phenomena and component-component interactions will be assessed. Promising areas for research and technology development will be identified. A roadmap for cooperative NASA-Industry technology developments and demonstrations via NPSS will be developed.

Organization

The NPSS project at Lewis is located in the Aeronautics Directorate. The technical direction and execution of the project will be accomplished via matrix managerial tasks which will be performed by the Lewis scientific and engineering staff and by contractors and/or grantees.

A combined industry/university steering committee interacts with a NASA Lewis steering committee to provide project oversight. The steering committees interact directly with Lewis technical personnel to review project activities. Implementation teams, involving participants from all three working organizations, as well as interdisciplinary members will define, advocate, and implement the technical problem solution. Communication is accomplished via continual informal communication among the implementation team members, formal frequent management meetings, and regular steering committee briefings.

Because the "computational test-cell" is viewed as a long-range goal, it is desirable to balance the nearer-term prototyping activities with longer-term basic research activities that could provide new ideas, concepts, and technologies for future generations of NPSS. It is important to strengthen the computer science element of these research institutes dealing with computational mechanics for propulsion. This will ensure a continuing, long-range research program and opportunities for technical innovation that can result in future enhancements for the NPSS.

Promising areas of research include:

Algorithm development for (massively) parallel computers

Scaling techniques that allow algorithms to be adjusted according to application requirements and available computational resources

Resource management strategies for (massively) parallel and distributed multiprocessors

Special-purpose architectures such as neural nets

Strategies for real-time applications

Fault-tolerant strategies for (massively) parallel and distributed multiprocessors

Concluding Remarks

The NPSS "Computational Test Cell" for propulsion is a long-range goal that is shared by NASA, universities, and industry. The evolution of NPSS will occur over many years with the contribution from many parties. Key to its success will be the establishment of communication mechanisms and procedures by which these contributions can be obtained, share, and used.

The NPSS technology project can develop and demonstrate many key, enabling technologies for aerospace propulsion systems design, analysis, and optimization. However, to be successful, several things must take place:

Effective interdisciplinary teams must be established to define, advocate, and implement technical solutions.

Coordination and a balancing of efforts among the interdisciplinary engine system activities (physics, algorithms, models, codes) and the interdisciplinary computer system activities (architectures, software tools, . . .) must be maintained so as not to push either activity ahead of the other.

This suggests a strong requirement for effective project management to ensure that the available funding and skilled staff are effectively used to address the needs.

References

1. Claus, R.W., Evans, A.L., Lytle, J.K., Nichols, L.D., "Numerical Propulsion System Simulation" to be published in Computing Systems in Engineering, 1991.

2. Nagpal, V.K., Rubinstein, R., and Chamis, C.C., "Probabilistic Structural Analysis to Quantify Uncertainties Associated with Turbopump Blades," AIAA Paper 87-0766, 1987. (Also, NASA TM-100278.)

3. Brown, K.W., "Structural Tailoring of Engine Blades (STAEBL), Theoretical Manual," NASA CR-175112 and CR-175113, Mar. 1985.

4. Daniele, C.J., Krosel, S.M., Szuch, J.R., and Westerkamp, E.J., "Digital Computer Program for Generating Dynamic Turbofan Engine Models (DIGTEM)," NASA TM-83446, 1983.

5. Stallone, M.J., Gallardo, V., Storace, A.F., Bach, L.J., Black, G., Gaffney, "Blade Loss Transient Dynamic Analysis of Turbomachinery," AIAA Journal, vol. 21, no. 8, Aug. 1983, pp. 1134-1138.

6. Adamczyk, J.J., "Model Equation for Simulating Flows in Multistage Turbomachinery," ASME Paper 85-GT-226, 1985. (Also, NASA TM-86869.)

7. Mulac, R.A., Celestina, M.S., Adamczyk, J.J., Misegades, K.P., and Dawson, J.M., "Utilization of Parallel Processing in Solving the Inviscid Form of the Average-Passage Equation System for Multistage Turbomachinery," AIAA Paper 87-1108, June 1987. (Also, NASA TM-89845.)

8. Nakazawa, S., "The MHOST Finite Element Program: 3-D Inelastic Analysis Methods for Hot Section Components, Vol. I - Theoretical Manual," NASA CR-182205, 1991.

9. Banerjee, P.K., and Ahma, S., "Advanced Three-Dimensional Dynamic Analysis by Boundary Element Methods," Advanced Topics in Boundary Element Analysis, ASME, 1985, pp. 65-81.

10. Davis, D.Y., and Stearns, E.M., "Energy Efficient Engine: Flight Propulsion System Final Design and Analysis," NASA CR-168219, 1985.

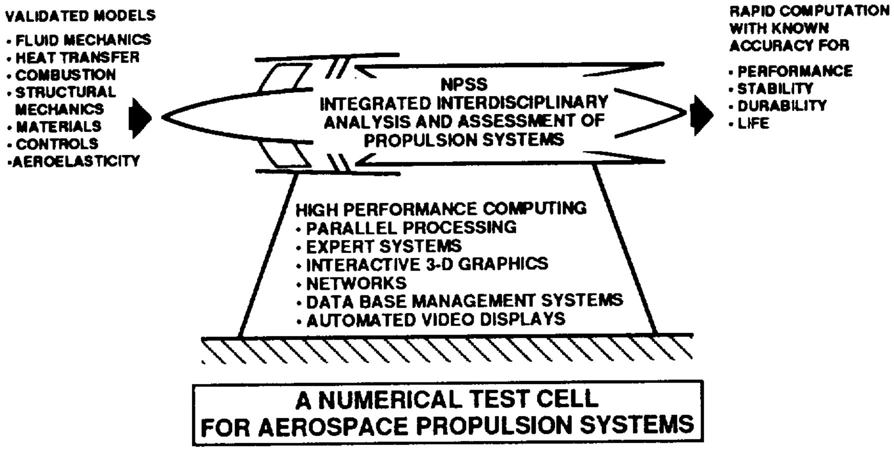

Figure 1.—Numerical propulsion simulation system (NPSS).

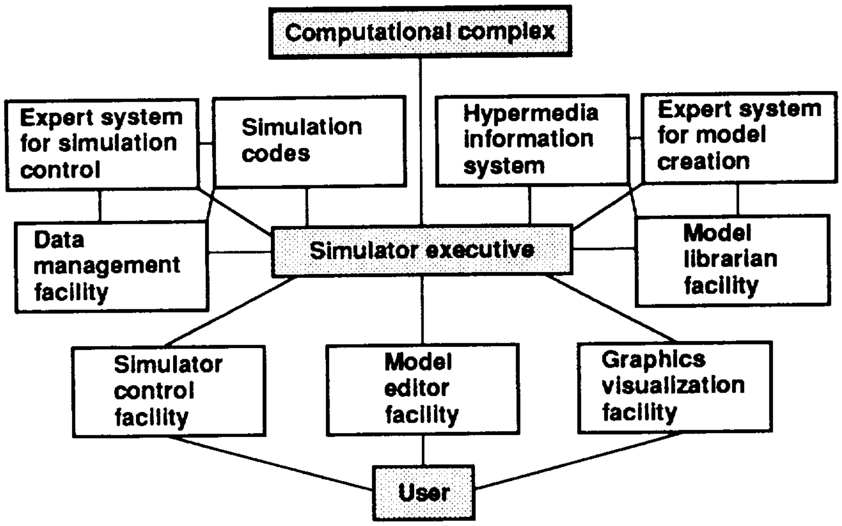

Figure 2.—Simulator architecture.

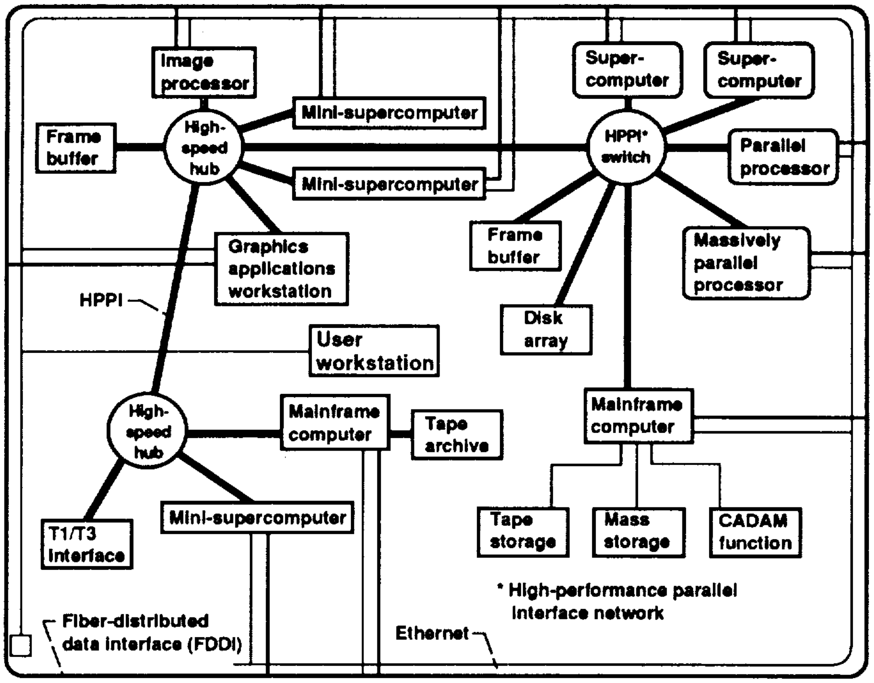

Figure 3.—NPSS architecture.

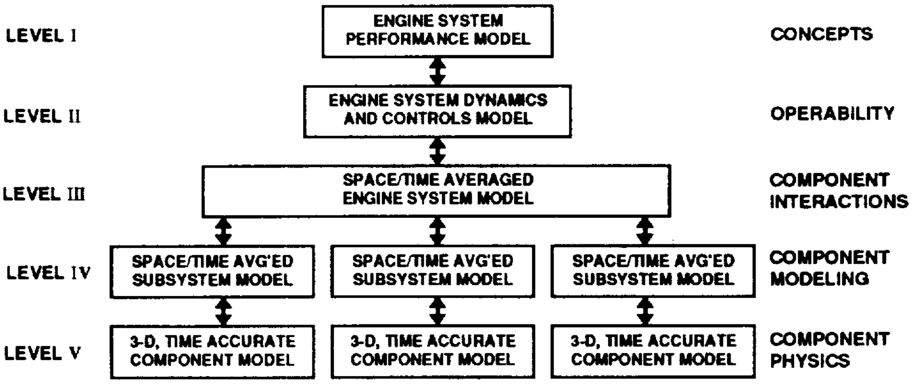

Figure 4.—Heirachy of NPSS simulation models.

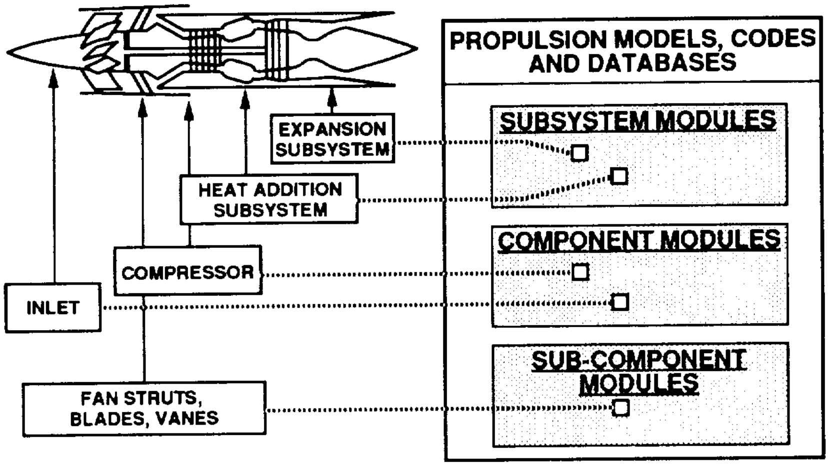

Figure 5.—Numerical propulsion system simulation. "Zooming in" on fan effects.

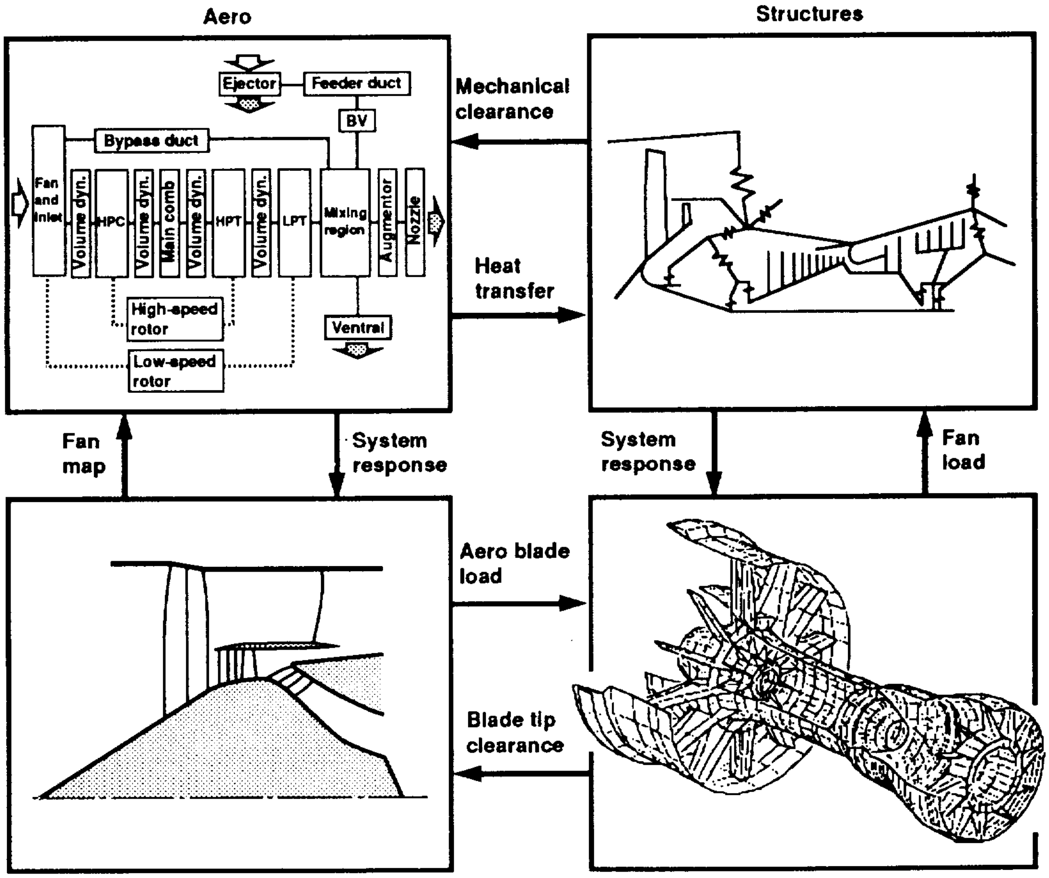

Figure 6.—NPSS models.

$$\underbrace{\begin{Bmatrix}\{A\}\\ \{T\}\\ \{S\}\\ \{M\}\\ \{F\}\\ \{P\}\\ \{C\}\end{Bmatrix}}_{\begin{array}{l}\textbf{System}\\ \textbf{response}\\ \textbf{variables}\end{array}} = \underbrace{\begin{bmatrix}[A^A_A] & [T^T_A] & [S^S_A] & [M^M_A] & [F^F_A] & [P^P_A] & [C^C_A]\\ [A^A_T] & [T^T_T] & [S^S_T] & [M^M_T] & [F^F_T] & [P^P_T] & [C^C_T]\\ [A^A_S] & [T^T_S] & [S^S_S] & [M^M_S] & [F^F_S] & [P^P_S] & [C^C_S]\\ [A^A_M] & [T^T_M] & [S^S_M] & [M^M_M] & [F^F_M] & [P^P_M] & [C^C_M]\\ [A^A_F] & [T^T_F] & [S^S_F] & [M^M_F] & [F^F_F] & [P^P_F] & [C^C_F]\\ [A^A_P] & [T^T_P] & [S^S_P] & [M^M_P] & [F^F_P] & [P^P_P] & [C^C_P]\\ [A^A_C] & [T^T_C] & [S^S_C] & [M^M_C] & [F^F_C] & [P^P_C] & [C^C_C]\end{bmatrix}}_{\begin{array}{l}\textbf{System definition/characteristics}\\ \textbf{and coupling relationships}\end{array}} \underbrace{\begin{Bmatrix}\{A\}\\ \{T\}\\ \{S\}\\ \{M\}\\ \{F\}\\ \{P\}\\ \{C\}\end{Bmatrix}}_{\begin{array}{l}\textbf{System}\\ \textbf{development}\\ \textbf{and service}\\ \textbf{parameters}\end{array}}$$

A	**Aero**
T	**Thermal**
S	**Structural**
M	**Material**
F	**Fabrication**
P	**Performance**
C	**Cost**

Figure 7.—Coupled-multi-discipline representation for aerospace propulsion systems.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Numerical Propulsion System Simulation: An Interdisciplinary Approach

5. FUNDING NUMBERS
WU 509-10-03

6. AUTHOR(S)
Lester D. Nichols and Christos C. Chamis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-6359

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-105181

11. SUPPLEMENTARY NOTES
Prepared for the Conference on Advanced Space Exploration Initiative Technologies cosponsored by the AIAA, NASA, and OAI, Cleveland, Ohio, September 4-6, 1991. Responsible person, Lester D. Nichols, (216) 433-3213.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Categories 20 and 7

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The cost of implementing new technology in aerospace propulsion systems is becoming prohibitively expensive. Large scale system tests are required to capture the complex interactions among the multiple disciplines and the multiple components inherent in modern propulsion systems. The tremendous progress being made in computational engineering and the rapid growth in computing power that is resulting from parallel processing now make it feasible to consider the use of computer simulations to gain insights into these complex interactions and to evaluate new concepts early in the design phase before a commitment to hardware is made. This paper describes a NASA initiative to develop a Numerical Propulsion System Simulation (NPSS) capability.

14. SUBJECT TERMS
Computerized simulation; Digital simulation; Parallel processing (computers); Optimization; Dynamical systems; Computational structural analysis; Computational fluid dynamics; Numerical analysis

15. NUMBER OF PAGES

16. PRICE CODE

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

National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio 44135

FOURTH CLASS MAIL

ADDRESS CORRECTION REQUESTED

NASA