N89-24640

COMPUTERIZED STRUCTURAL MECHANICS FOR 1990'S: ADVANCED AIRCRAFT NEEDS

A. V. Viswanathan and B. F. Backman
Boeing Military Airplane Company
Seattle, Washington

Abstract

This paper describes the needs for computerized structural mechanics (CSM) as seen from the standpoint of the aircraft industry. It projects these needs into the 1990's with special focus on the new advanced materials. It identifies the major areas:

- preliminary design/analysis
- research
- detail design/analysis

and elaborates on the role of local/global analyses in these different areas.

The lessons learned in the past are used as a basis for the design of a CSM framework that could modify and consolidate existing technology and include future developments in a rational and useful way.

A philosophy is stated, and a set of analyses needs driven by the emerging advanced composites is enumerated. The roles of NASA, the universities, and the industry are identified.

Finally, a set of rational research targets is recommended based on both the new types of computers and the increased complexity the "industry" faces.

Computerized structural mechanics should be more than new methods in structural mechanics and numerical analyses. It should be a set of engineering applications software products that combines innovations in structural mechanics, numerical analysis, data processing, search and display features, and recent hardware advances and is organized in a framework that directly supports the design process.

There are two aspects to the development of engineering applications software: (1) innovations and (2) improvements in the productivity of engineers.

While this paper concentrates on the first aspect, it is still important to consider the productivity aspect in the development of new methods because the software ultimately will be part of the set of tools used in the design of aircraft structures.

Structural Analysis Needs for the Aircraft Industry

- New capabilities
  - Concepts
  - Materials
  - Details
- Improved productivity
  - Engineering workstations
  - Tutorial software
  - CAD/CAM interfaces

New non-ductile materials have entered the scene and will be part of the picture for a long time to come. These materials require more detailed analyses not only because of micro-considerations and interlaminar effects but also because of their unforgiving nature which entails a significant participation of "secondary" effects in the failure modes. The complex definition of these materials and their responses required to identify behavior has resulted in a large increase in the information volumes for processing of a typical aircraft problem in the structures field.

At the same time, we have seen tightening up of requirements not only in terms of adverse environment but also in terms of improved quality. In both cases this tightening results in a need for more sophisticated analyses.

The general areas of computing technology and information science have seen dramatic changes in both hardware and software. There have been hardware changes that could be parlayed into: (1) optimization of structures with practical constraints, (2) nonlinear analyses at reasonable cost, and (3) micro-analyses at acceptable storage requirements. Developments have occurred in the field of data processing that make data base management a natural cornerstone in the future of CSM. Finally, there have been developments in the fields of graphics and CAD/CAM which would make the establishment of standardized user interfaces extraordinarily useful both from the standpoint of technology and management.

Motivation for Increased Development

- Advanced composites
  - Higher complexity
  - More unforgiving
  - Larger information volumes
- More stringent requirements
  - Lighter weights
  - Higher temperatures
  - Longer lives
- Improved computing technology
  - Numerical methods
  - Data processing/search and display
  - CAD/CAM

The only result of significance in the aircraft industry is to produce a new "better" aircraft. Any other result is intermediate and will only be acceptable if it contributes to this improvement. The success of CSM is therefore contingent on three abilities:

- To promote and support new technology in the fields of structures, numerical methods, and data processing
- To include and improve methods in the preliminary design and analysis of new aircrafts (the need to develop and refine conceptual methods for the selection and comparisons of sophisticated candidates with no experience basis should be a strong driver in goal setting)
- To introduce new methods and integrate these methods in a framework that can produce the visibility, data reduction, and sophistications that are necessary to support a production effort in a new era

What Constitutes Success?

➡ **Better aerospace vehicles**

➡ **Therefore "CSM" must**

- **Support technology development**
- **Provide NEW preliminary design and analysis methods**
- **Automate detail design and analysis methods**

The successful development of new methods in computerized structural mechanics requires an understanding of the psychology of the situation.

1. An efficient method that supports the needs of the industry must be established.

2. A practical input and output language must be used.

3. A set of useful user interfaces must be available.

4. An appropriate amount of visibility and data reduction features should be provided.

5. A realistic marketing effort should be launched.

6. A developer and user interaction is required.

Yardstick for Success for CSM

Computerized methods development will not be successful unless the new "product" is totally acceptable to the users

The CSM framework should be designed and implemented with common design questions in mind. Of these, the question of material choice and mix is very complex. An optimum distribution of materials in the primary structure of an airplane is dependent on the critical failure modes. Is it strength (in tension), stability, fatigue, damage tolerance, or stiffness requirements that size a local detail? Again, it can be seen how a global/local/global cycle must be used to come to grips with this design problem. All the design drivers are closely related, and the question of environment involves the determination of temperature, moisture, presence of chemical, corrosion, and risks of FOD*. These effects need to be assessed at least on a parallel track. The performance requirements, such as speed, load factors, roll rates, and landing speeds, all are very basic and need to be addressed again in a local/global fashion. Finally, design criteria are "soft" early in the design process and evolve in a cyclic manner as the local/global analyses of the structure mature.

What are the Structural Design Drivers?

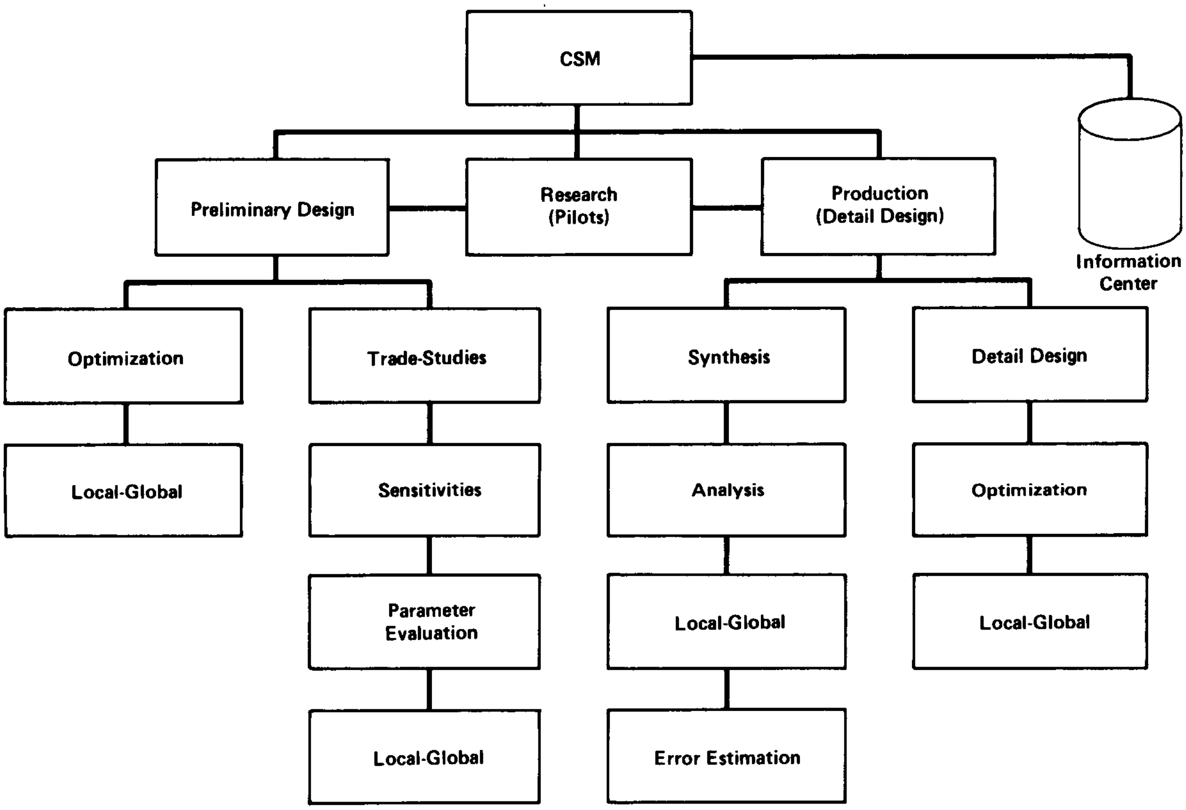
- **Material choice and mix**
  - **Strength**
  - **Stiffness**
  - **Damage tolerance**
  - **Fatigue performance**
- **Environment**
- **Performance requirements**
- **Design criteria**

*foreign object damage

There are three fields of structures that have to be included in order to give attention to all the aspects of engineering design in the aircraft industry. The first of these fields is the research activity that leads to a new technology and a better understanding of the ingredients in the design process. The second field is the preliminary design and analysis that leads to the selection of the appropriate family of vehicles or products. Both syntheses and analyses on one side and parameters and variables on the other are involved in this design and analysis.

The third field is the detail design and analysis, of which perhaps the local/global concept is more applicable than anywhere else. Here the objective is to learn as much as possible about a specific design candidate. The demands are especially stringent on CSM to include features that facilitate data reduction and display as well as sophisticated local analyses methods.

CSM, What Should be Included?



The overwhelming requirement in the preliminary design and analysis phase deals with synthesis methods that discriminate between parameters and variables in the design process and makes it possible to study alternative formulations.

Preliminary Design and Analysis

- Access to expert system data base (trade study results)
- Parametric results from local-global analyses as baseline for optimization
- Determination of sensitivities (data base)
- Algorithms for parameter determinations and variable selections
- Strategy algorithms, history function

The role of research in the CSM arena is central and its primary purpose is to promote better understanding of the materials and structures technologies required to produce better vehicles. To that end, it is essential to have significant development in (1) structural and continuum mechanics, (2) numerical methods, and (3) failure prediction and test evaluation. This must be done in a framework that allows for empiricism that is sensitive to user needs, aims at synthesis, and produces pilot capabilities with well-defined interfaces.

Research

- **Phenomena evaluation for better understanding**
- **Special purpose detail analyses**
- **New numerical methods**
- **"Pilot" development**
- **Test data evaluation methods**
- **Empirical corrections methods**

The detail design and analysis fields have always been characterized by large volumes of data. This is becoming more and more the case as the new advanced composite materials are introduced into the production environment. (Just consider the simple problem of calculating margins of safety.) This together with more complex requirements and the less forgiving nature of the materials has resulted in order-of-magnitude increases in data volumes in addition to a myriad of local analyses methods demands.

Production (Detail Design and Analysis)

- **Postprocessing, search and display (graphics)**
- **Strength checking (software for detail analyses)**
- **Management visibility and access**
- **Data base access (parametric representation...allowables)**
- **Automated resize (optimization), baseline updates**
- **Strategy for local-global analyses**
- **Error estimation**

The CSM framework has to have an information center that supports the local/global analyses and makes it possible to combine all aspects of theory, empiricism, test data, and criteria.

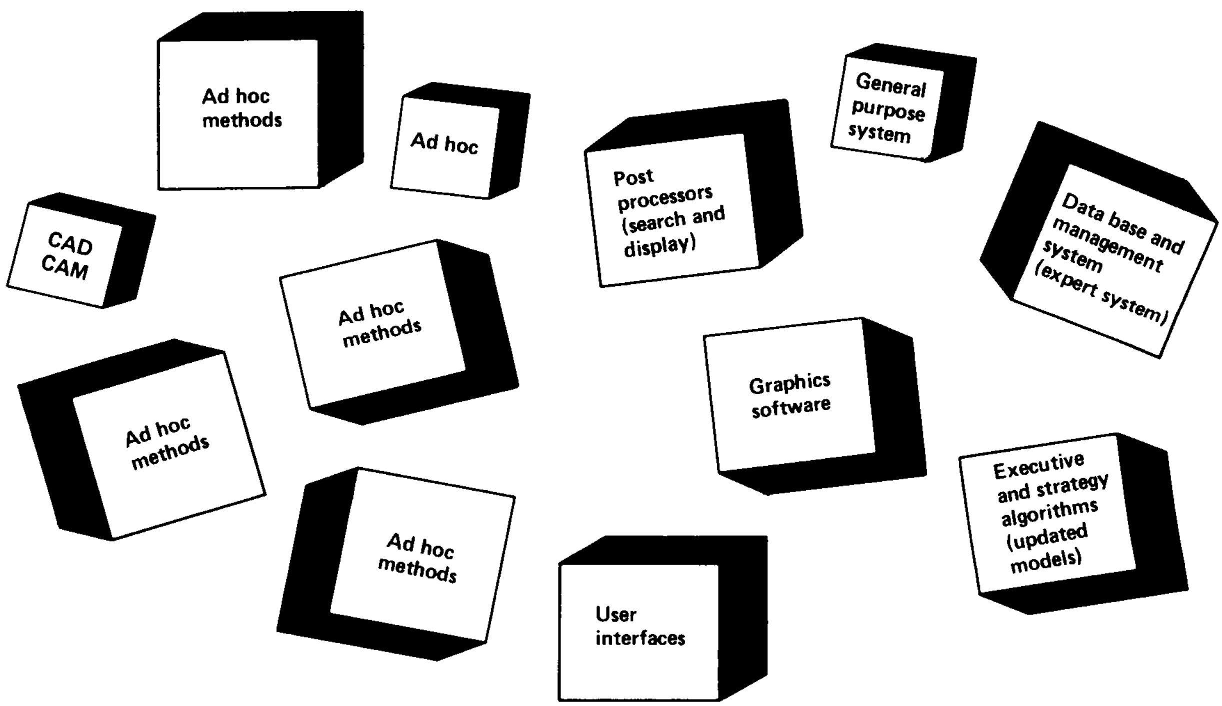
This data base should be such that it supports the preliminary design, detail design, and research.

Information Center (Data Base)

- **Self educating expert system (better modeling, improved parameter evaluation, trade projections)**
- **Test data evaluation and empirical correction**
- **Sensitivities**
- **History writing**
- **Search and display**

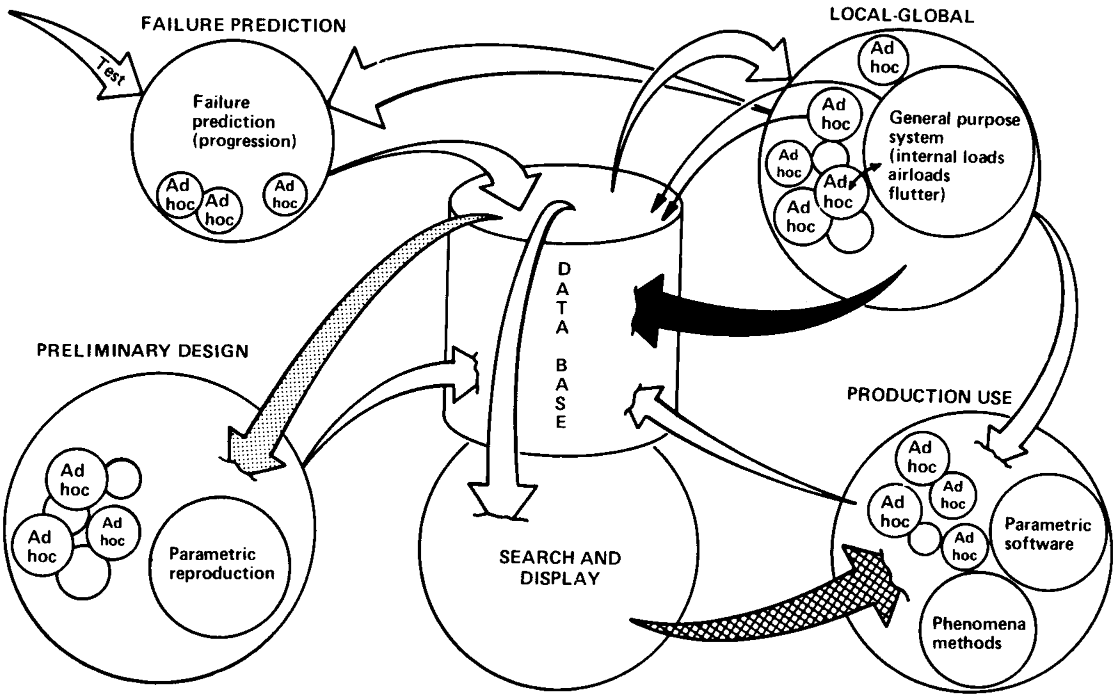
The building blocks for CSM are naturally many and of very different nature, but the central core in a local/global system will have to be a set of special purpose methods that in a very flexible way can be included, updated, and replaced.

What are the Building Blocks?



Without the proper discipline in the structuring and targeting for CSM, there is a significant risk that spur-of-the-moment CSM designs will prevail. Such designs will be avoided by a central NASA leadership.

Should the Philosophy be Uncontrolled Growth?



THE ANSWER IS NO!

From the standpoint of the aircraft industry, the last 20 years have seen an increased reliance on highly specialized experts to perform special purpose (local) analyses. This is an undesirable development, and the CSM framework should provide the requirements necessary to curtail and reverse this software engineering trend. At the same time a number of general systems have emerged, reached maturity, expanded to a high level of maintenance budget needs, and then stagnated. Finally, the framework must provide local/global communications and user interfaces.

Need from Users

- Present situation
  - Increasing dependence on highly specialized experts
  - General purpose systems in use require more user driven long term plans
    - As the present trend shows high maintenance burden and early stagnation
  - Proper framework for global to multi-local communications is missing

The strategy for the long-term CSM development could include: (1) identification of existing software that can be modified for a new environment, (2) a plan that is based on an evaluation of industry needs and experience with new operating systems, compilers, hardware, and methods, (3) the new hardware potential that must be part of the picture when targeting special fields; optimization is still a cost/hardware constrained activity, and (4) emphasis that should be based on the priorities that come out of industry needs. NASA has a key role to play in pulling all these together.

Strategy

- **Plan that modifies and uses existing software where feasible**
- **Plans driven by what the industry presently knows**
- **Plan that recognizes new hardware potentials**
- **Plan that encourages more "applied research" into fields driven by industry needs**

The requirements mentioned previously translate into a set of organizational issues that are essential to CSM development follow-through. First, the size of the software demand is such that a national commitment is necessary if the technology benefits are to be realized. Second, a number of general-purpose scientific systems and an assortment of special-purpose software have demonstrated the need for a framework designed to draw upon the benefits of both. Finally, user acceptance will depend on good visibility and easy access to solutions and results.

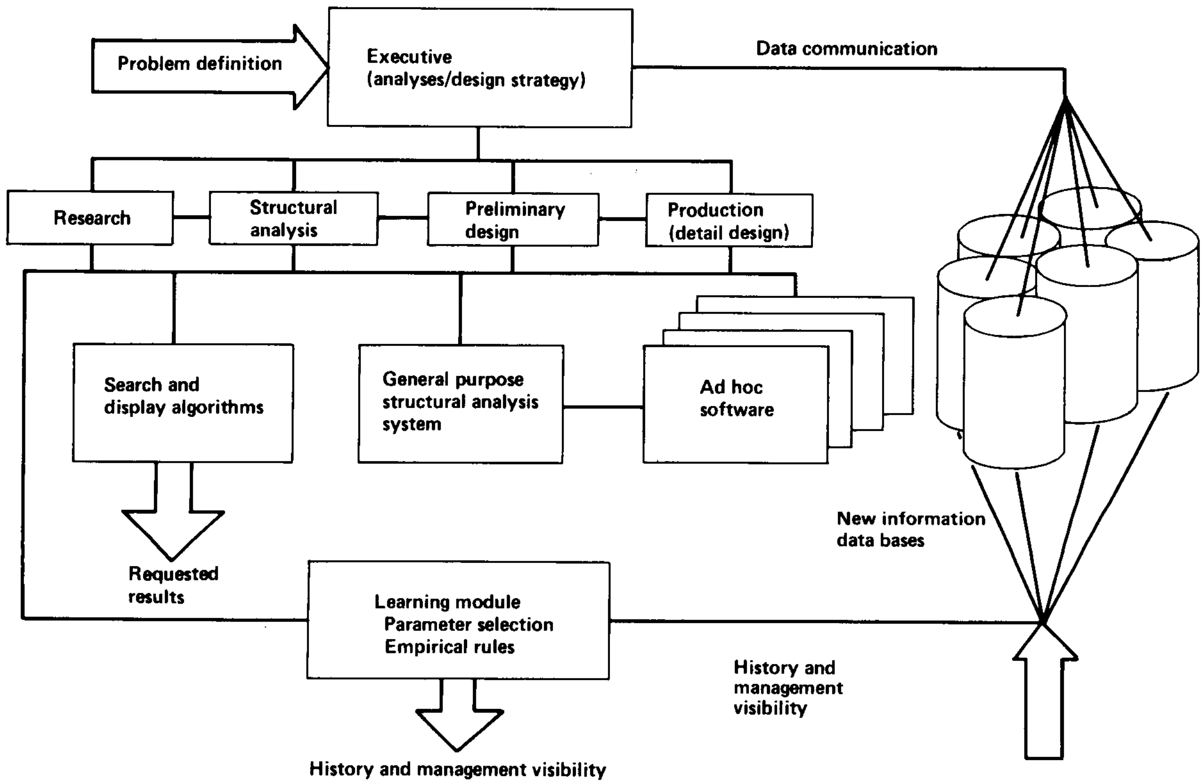
Fundamental Organizational Issues

- **The successful development of CSM requires central leadership**
- **CSM should provide the framework for unification of general/global and special/local methods**
- **Search and display algorithms and standardized user interfaces are as important as solutions**

The backbone of the CSM design approach is the data management, but the foundation for success can be found in the quality of the special-purpose methods and the associated software. Experience has shown that the success and acceptance of these methods are very dependent on availability of required data, ease of interpretation of results, and visibility of the steps leading to the final solution.

The approach should also deal with the present trends in structures, in which on one hand we are moving into fields with very limited experience bases and on the other hand we produce innovation through point design testing. We can address both situations in a framework that not only accepts new methods with ease but also uses these methods for experience development and empirical evolution.

Could This be a "Better" Approach?



The typical situation in the structures field involves a number of analyses that are directed at different levels of resolution. These levels will have to be revisited a number of times during the design process. The evolution of the design, therefore, obviously requires a number of global-to-local-to-global transitions involving huge data volumes. The efficiency of these transitions requires as much attention as the methods development.

Local-Global Analyses

- Internal loads/global, overall FE analyses, stability, aeroelastic effects, flutter, ...
- Detail stress analysis (linear/nonlinear), "local" buckling, allowables processing, postbuckling analyses, interlaminar analyses, residual strength, damage tolerance analyses, fatigue analysis
- Local optimization, multilevel optimization, automated remodeling, ...
- Error estimation
- Micro-detail-macro strategy (transitions)

An understanding of the design drivers leads to the identification of a number of fields in which work should be done in order to efficiently produce preliminary and final designs. Here the preliminary and final design processes are different in focus, but similar principles could serve both enterprises and emphasis should be given to synthesis-like features.

Development Support

- **Determination of material development targets**
- **Selection of "best" structural materials (based on most important design drivers, and determine failure progression)**
- **Establishing environmental effects**
- **Determining an optimum set of performance requirements (temperature/speed, weight, load factor,...)**
- **Exploration of sensitivities to variation in design criteria**
- **Multilevel strength, stress/stability analyses**
- **Multilevel optimization**
- **Pre- and postprocessing with search and display features**

The framework for CSM must be such that both categories of users/developers (typical engineers and experts) can be allowed their proper influence in a manner that promotes natural roles and allows for organized communications of both needs and results.

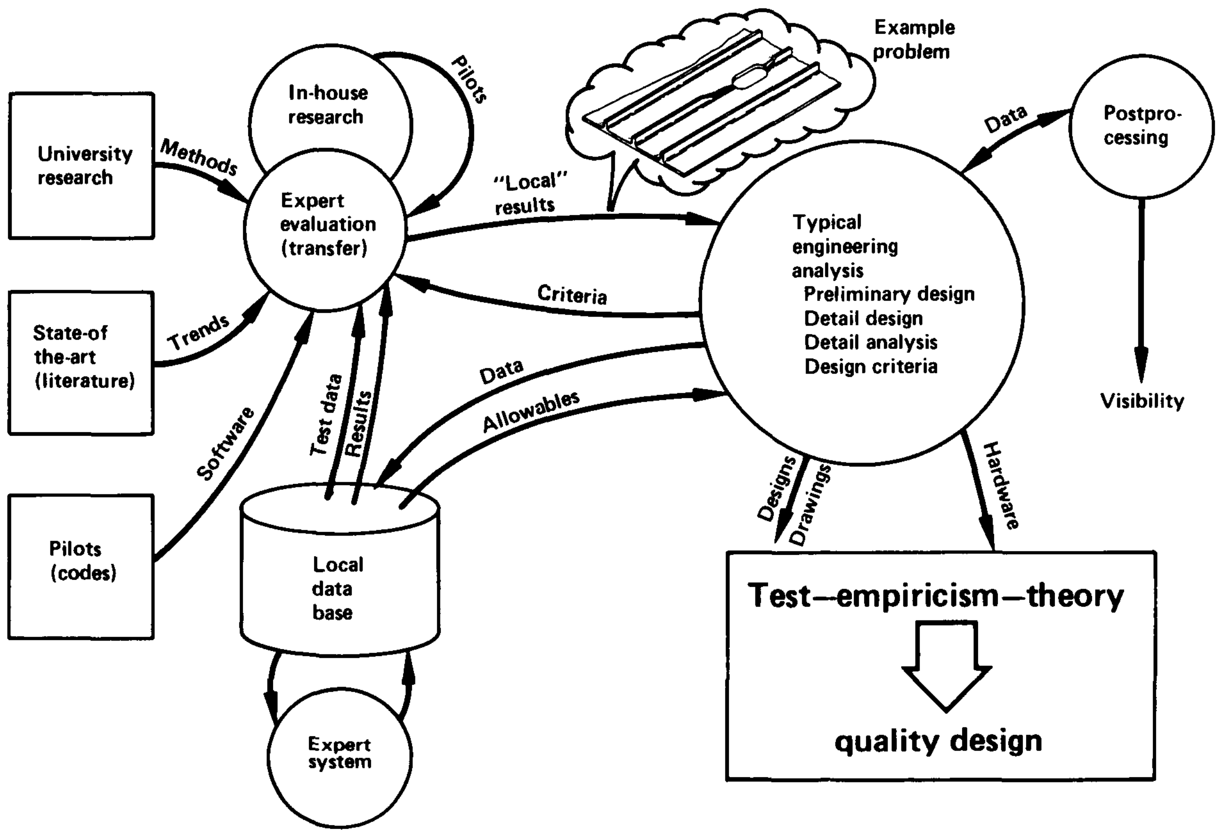
What are We Aiming For?

- A system for technology development and improved scientific understanding for experts

- A system for preliminary design, detail design and analyses for typical engineers in production environments

The local/global analysis development is seen as a three-pronged effort that includes: (1) advanced methods, (2) typical engineering analyses, and (3) data base and associated methods for experience development. The advanced methods would primarily be intended for expert evaluations, but could, if properly packaged, be included among the typical engineering analyses. The expert evaluations would produce direct input to the overall design effort, but would also feed the data base and indirectly support both parametric evaluations and preliminary design approaches. The example problem represents a number of analyses that belong on the local level and should be considered from the design standpoint.

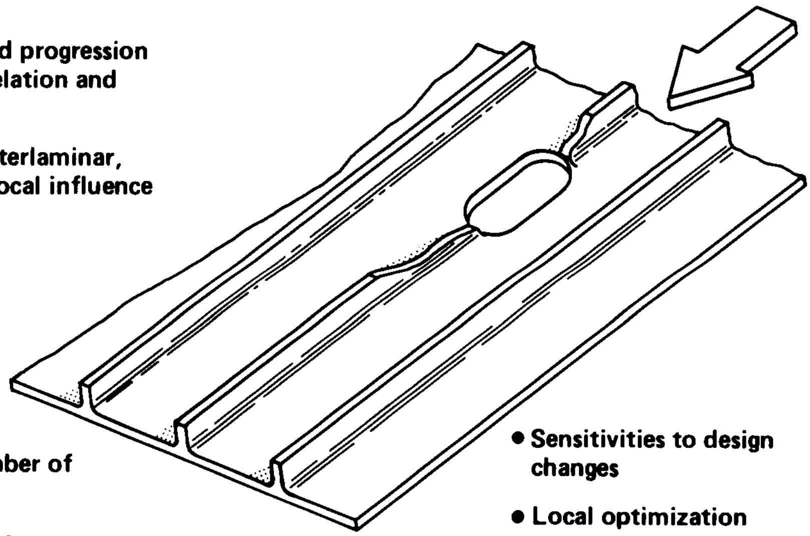
Local-Global Analysis



The example problem in the context shown in the previous figure represents a number of analyses and syntheses. All of these belong to the local or micro level when seen from the standpoint of the design process. All of these, and a number of others, are natural development (research) targets that after implementation should either directly feed results into the "typical" engineering activity or produce results to the local data base for future use or parametric access. All these developments should result in pilot capabilities or products that in an ad hoc fashion would satisfy one of the above two requirements.

What are the Analyses for the Example Problem?

- Local failure modes and progression based on test, for correlation and empirical inputs
- Multilevel analyses: interlaminar, local damage growth, local influence of postbuckling
- Stability analyses
- Postbuckling analyses
- Nonlinear material response,...
- Flaw-growth for a number of damages
- Allowables determination
- Parametric representation and empirical input to data base



- Sensitivities to design changes
- Local optimization
- Automated "remodeling" and transition regions
- Screening for criticalities, critical requirements
- "Gross" FE properties
- Residual stresses

The example problem is one of many analogous local problems that must be solved as part of the design process. Each one of these problems is solved a number of times during the evolution of the design. We are therefore forced to minimize the number of micro evaluations and expert involvement in order to produce an efficient design process. This can be done by including the results on a communal experience basis in a way that supports the practical engineering tasks. Many of the local analysis packages must be designed for minimum involvement by experts. In many types of problems, it will be necessary to identify important parameters and produce solutions in advance in a format that can be accessed in a data base management environment. Very similar considerations apply to the allowables question, whether it is processing of material structural allowables. Finally, in the failure prediction development, one can see elements of the other types and here one can hardly expect practical support of the design process without a two-level software development that ulitmately depends on empirical modifications.

The Example Problem

- **Local with "micro" requirements**

- **Local analyses with minimum expert requirements**

- **Basis for parameter selection**

- **Panel for allowables generation**

- **Candidate for failure prediction development**

In conclusion, we find that there are a number of research targets waiting for initiative from the engineering community. It has become clear, however, that the majority of these targets will be missed if not approached from the standpoint of their overall role in the design process. It is also felt that the objectives will not be met without a proper technology transfer to the users. This naturally involves both the software packaging and the promotional activity necessary for dissemination.

Conclusions

- **Research should include**
  - **Analysis methods (nonlinear, advanced materials,... structures)**
  - **Numerical methods**
  - **Artificial intelligence**
  - **Search and display/data processing**
- **Emphasis on technology transfer to industry**

NASA has a key role in the development of CSM for the 1990's and beyond. A national effort is required if new materials (composites), new computers, new methods, and new requirements are to be addressed in a manner that establishes economic advances and preserves the superior safety record established by the aircraft industry. NASA has a role not only in leadership but also as communicator assuring technology transfer and promoting user acceptance.

Recommendations