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SESSION 2 - AEROPROPULSION STRUCTURES RESEARCH

AEROPROPULSION STRUCTURES

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SUMMARY

Aeropropulsion systems present unique problems to the structural engineer. The extremes in operating temperatures, rotational effects, and behaviors of advanced material systems combine into complexities that require advances in many scientific disciplines involved in structural analysis and design procedures. This paper provides an overview of the complexities of aeropropulsion structures and the theoretical, computational, and experimental research conducted to achieve the needed advances.

STRUCTURES DIVISION

The Structures Division is engaged principally in developing validated analysis methods for predicting the performance of the structural components and systems of aerospace propulsion machinery (fig. 1). Performance here refers to a diversity of operating behavior characteristics, such as instantaneous or time-dependent stresses and deformations, structural dynamics, aeroelasticity, material behavior, and structural-life-related phenomena. Experiments are used both to validate methods and to understand complex structural and material behaviors in order to develop theoretical models that emulate them. The structures of aeronautical propulsion systems have a unique combination of complexities: they operate with long life in extremely harsh loading environments, have rotating components with complex dynamic behavior, and are constructed of lightweight advanced material systems with unique characteristics.

COMPLEX STRUCTURAL PROBLEMS OF AEROPROPULSION SYSTEMS

Propulsion systems present a number of complex structural problems from different sources (fig. 2). Because of the loading environment, materials exhibit two forms of nonlinear behavior: plasticity (considered to be instantaneous response), and creep (deformation and stress relaxation accumulating with time). Advanced material systems, because of their microstructures, represent local complexities that have to be included in global analysis methods. Single-crystal, directionally solidified, or fiber-reinforced materials result in anisotropic and nonhomogeneous local structures that must be mathematically characterized over wide ranges of nonlinear response and over the predicted structural life.

Another source of complexity is the large deflection associated with flexible structures such as fan blades and advanced turboprop blades. Large deflections introduce (a different kind of) nonlinearity into the calculations that are geometric in nature and that are usually coupled with aerodynamic and thermal effects. Furthermore, descriptions of the loading environments and the material properties may not be available except in the form of a probability distribution. Phenomena related to structural integrity and life are among the most vexing and most important considerations. All these complexities and their possible interactions have to be considered in developing credible methods for predicting the structural behavior of propulsion systems.

PARTICIPATING DISCIPLINES

Research is needed in a number of scientific disciplines to solve the complex problems facing the structural designer of aeropropulsion systems. The nonlinearities of material behavior require major advances over conventional finite element or boundary element methods. These advances also have to reflect the new opportunities offered by the upcoming multiprocessor computer revolution.

Shortcomings in characterizing the material behavior under cyclic thermomechanical mission loads are major obstacles to improved accuracy and computational efficiency. Combining the required advances in constitutive modeling with the mechanics of fiber-reinforced composites adds to the complexity (fig. 3).

Nonlinear dynamics and aeroelasticity are needed to predict the operating characteristics of rotating, flexible bladed systems so that acceptable operating envelopes can be defined (fig. 4). Methods for predicting various structural-integrity-related behaviors of advanced material systems are needed in order to realize future aeropropulsion concepts with their demands for lighter structures operating in extremely hostile environments (fig. 5).

The final intent of the structural designer is not just to analyze trial design concepts, but also to approach an optimum design. Multidisciplinary design optimization methods are needed to guide the human designer through the complex interactions of the design variables toward an optimum design (fig. 6). Experimental capabilities are needed in dynamics and in high temperatures to study new phenomena and to validate theoretical models.

STRUCTURES WORK ELEMENTS

The three fundamental structures work areas are structural mechanics, structural dynamics, and life prediction methods:

(1) Structural performance
- (a) Constitutive relationships modeling and experiments
- (b) Mechanics of composites
- (c) Vibration control
- (d) System dynamics
- (e) Aeroelasticity

(2) Structural life prediction
- (a) Interactive effects on fatigue life
- (b) Damage initiation modeling
- (c) Crack growth
- (d) Mechanics of fracture

The structural mechanics work is focused on the mechanics of materials in order to develop models for their behavior under cyclic thermomechanical mission load conditions. These models are needed in the advanced integrated structural analysis methods being developed. Under structural dynamics the aeroelasticity of flexible, rotating bladed systems is important for advanced propulsion design concepts. Developments in vibration control and systems dynamics are needed to ensure safe and efficient operation of rotating propulsion structures, particularly as they become lighter and operate at higher speeds.

The life prediction focus is on understanding, predicting, and controlling structural failures caused by fatigue and fracture. A wide range of advanced materials and material systems is being considered, many of them more brittle and therefore less forgiving.

The structural designer needs input data from all disciplines in the interdisciplinary chain of activities during product design:

(1) Integrated analysis and applications
   (a) Computational mechanics
   (b) Computational methods
   (c) Probabilistic methods
   (d) Optimization and tailoring
   (e) Nondestructive evaluation
   (f) Concept evaluation

(2) Project support and consultation

Advanced computational mechanics analysis methods are being developed for cyclic thermomechanical mission loads. Under computational methods the program architectures and algorithms are being developed that best utilize advances in computer technology. Mission load environments and also the properties of advanced material systems can often be best described in probabilistic terms. This provides designers with more information on which to base designs. Integrated analysis methods are coupled with optimization methods for integrated multidisciplinary design optimization. Experimental methods are needed for two purposes: to study and understand phenomena and formulate models, and to test models for validation. The capabilities developed are distributed to users and are also employed in providing consultation to and participation in major NASA projects.

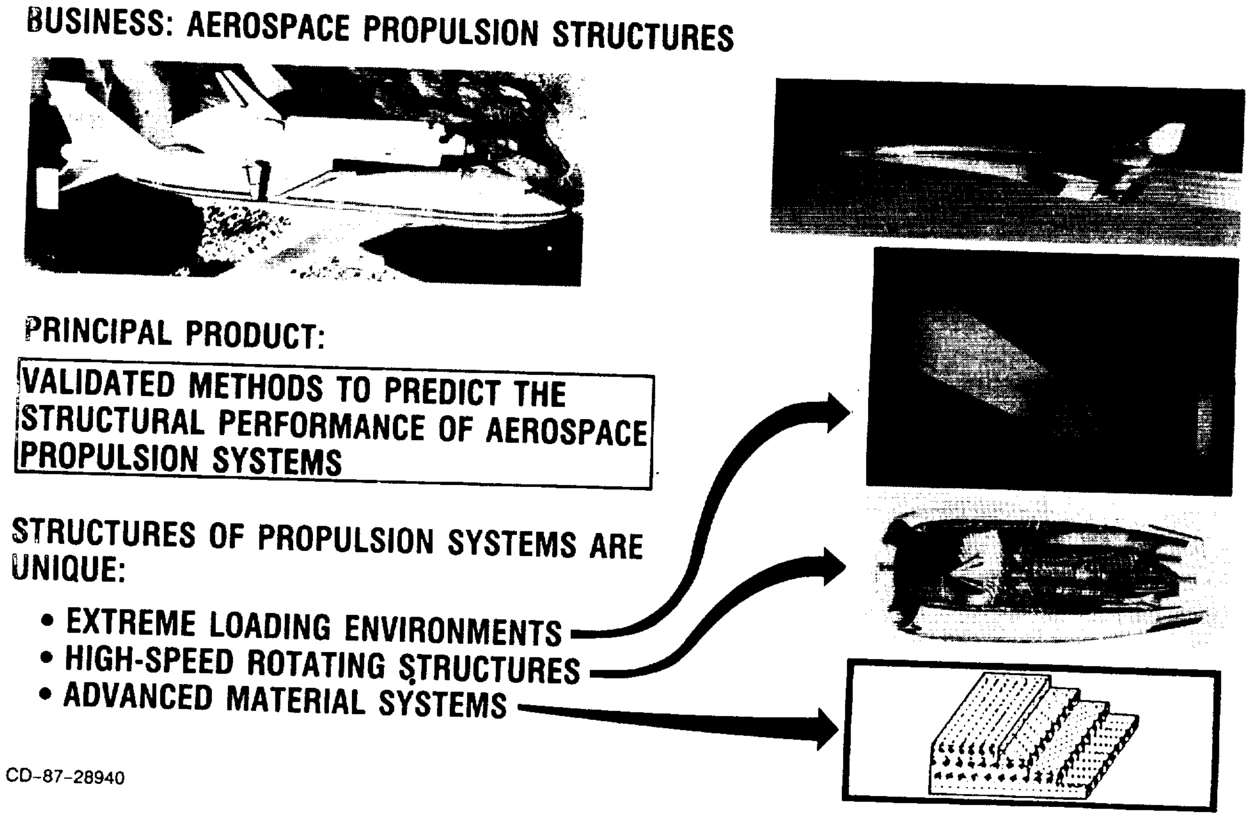
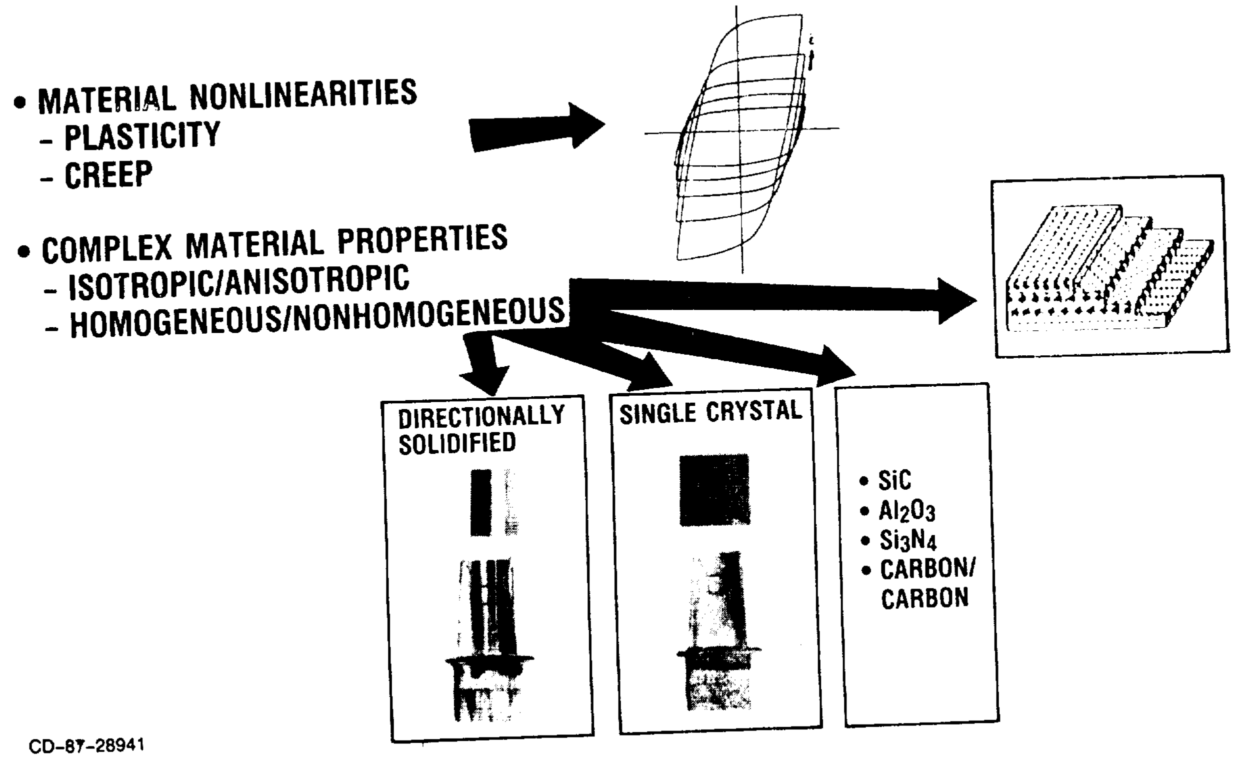


Figure 1. - Structures Division.



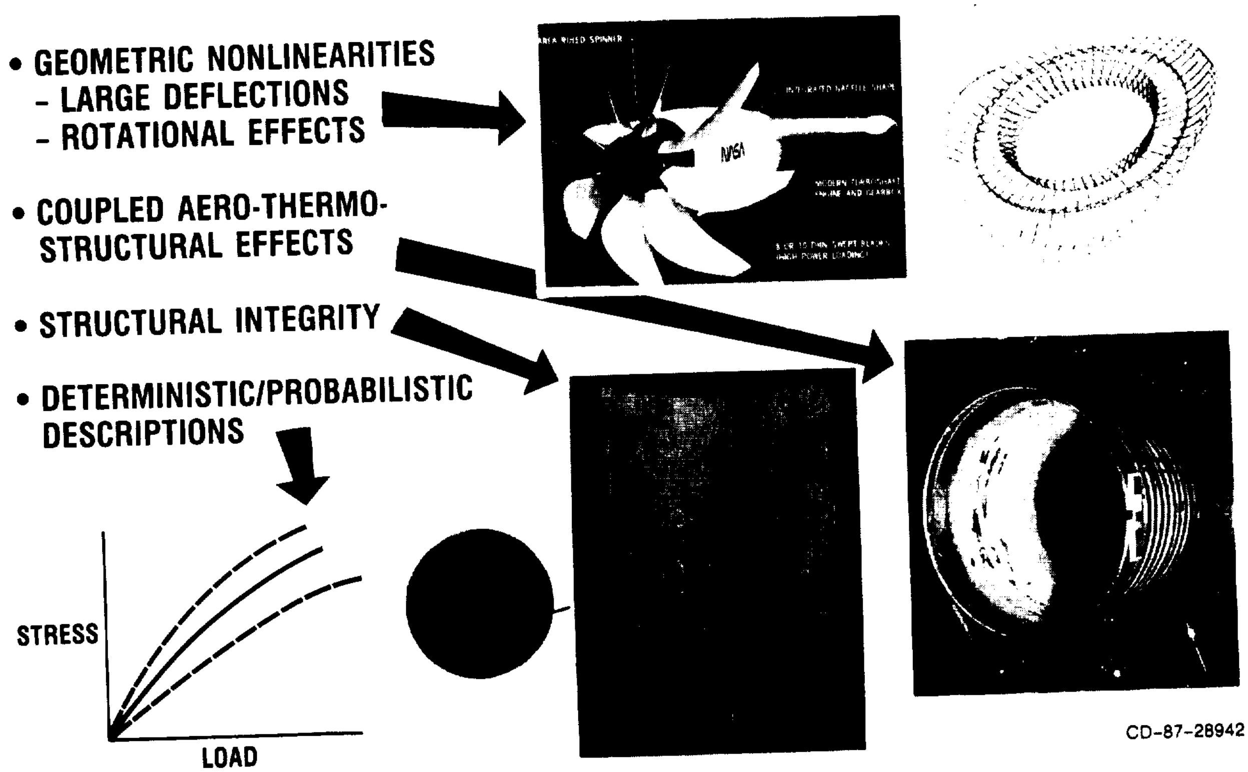


Figure 2. - Structural problem areas.

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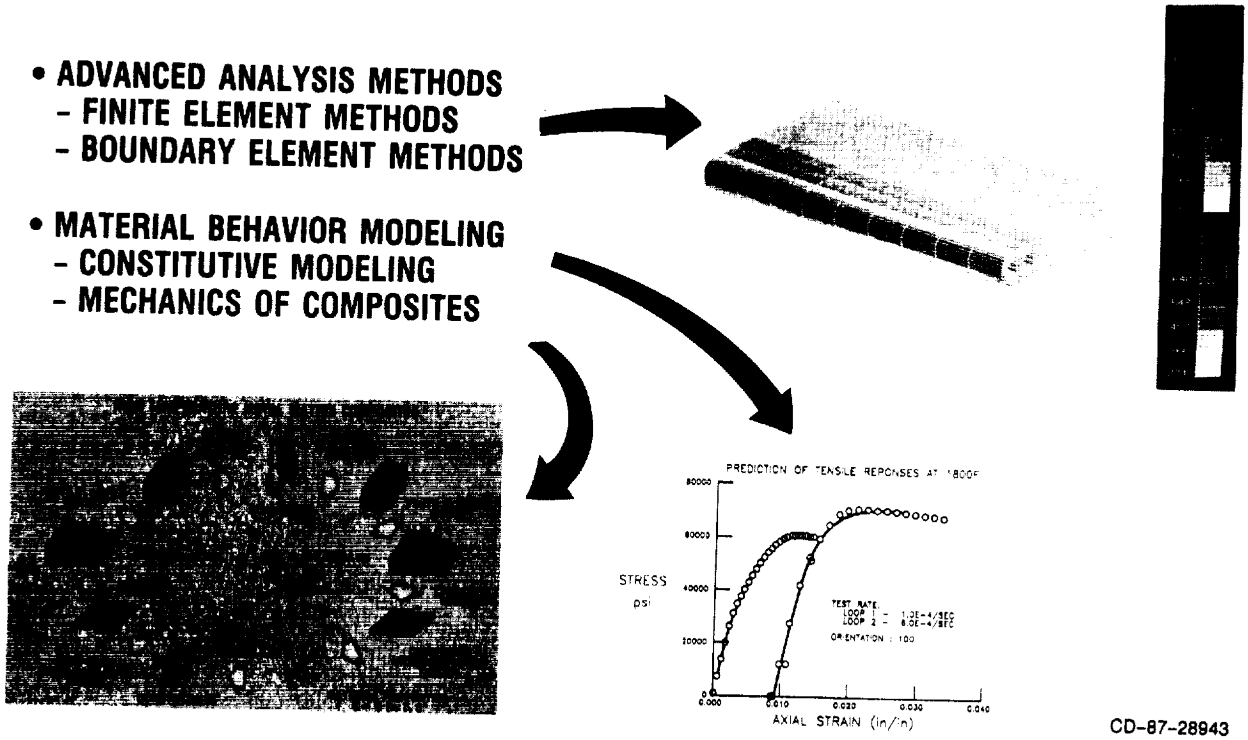

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Figure 3. - Advanced analysis methods.

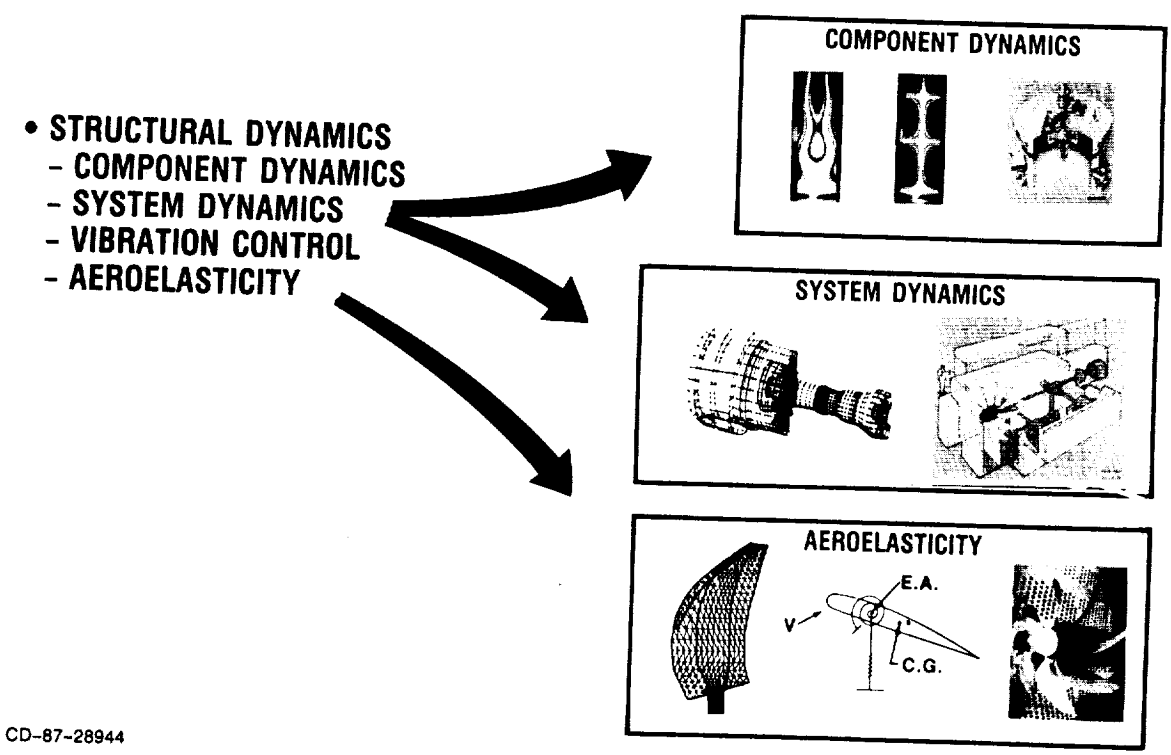

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Figure 4. - Structural dynamics.

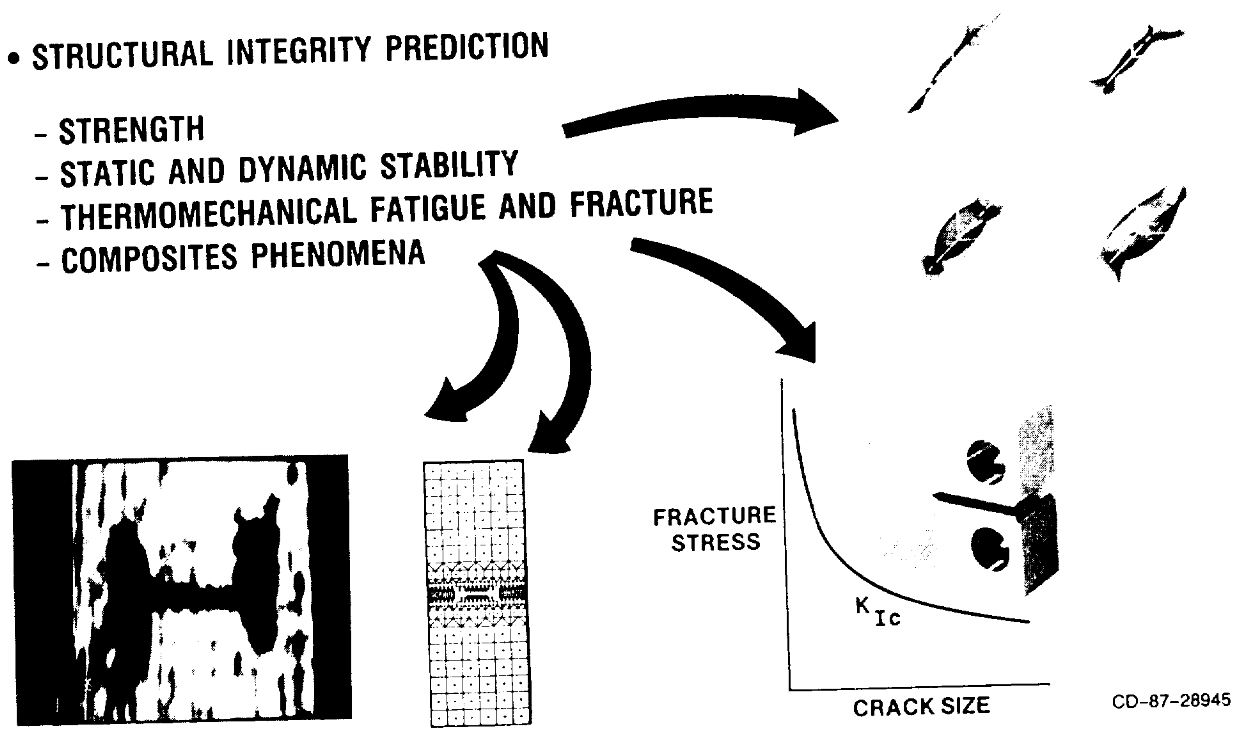

Figure 5. - Structural integrity prediction.

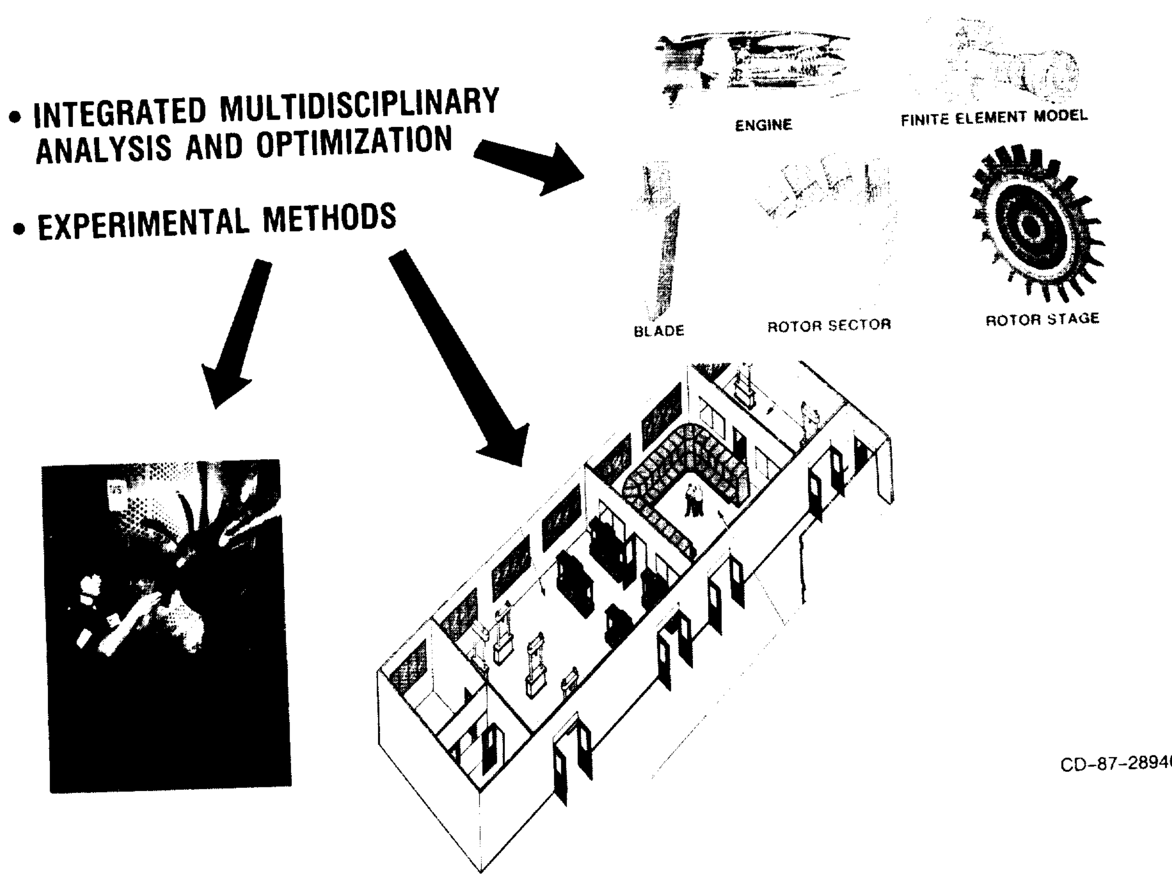

Figure 6. - Design optimization methods.