CARES/*LIFE* SOFTWARE FOR DESIGNING MORE RELIABLE CERAMIC PARTS

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Introduction

Products made from advanced ceramics show great promise for revolutionizing aerospace and terrestrial propulsion, and power generation. However, ceramic components are difficult to design because brittle materials in general have widely varying strength values. The CARES/*Life* software (refs. 1 to 5) eases this task by providing a tool to optimize the design and manufacture of brittle material components using probabilistic reliability analysis techniques.

Probabilistic component design involves predicting the probability of failure for a thermomechanically loaded component from specimen rupture data. Typically, these experiments are performed using many simple geometry flexural or tensile test specimens. A static, dynamic, or cyclic load is applied to each specimen until fracture. Statistical strength and SCG (fatigue) parameters are then determined from these data. Using these parameters and the results obtained from a finite element analysis, the time-dependent reliability for a complex component geometry and loading is then predicted. Appropriate design changes are made until an acceptable probability of failure has been reached.

CARES/*Life* is an integrated package that predicts the probability of a monolithic ceramic component's failure as a function of time in service. It couples commercial finite element programs -- which resolve a component's temperature and stress distribution -- to reliability evaluation and fracture mechanics routines for modeling strength-limiting defects. These routines are based on calculations of the probabilistic nature of the brittle material's strength. CARES/*Life* accounts for the phenomenon of subcritical crack growth (SCG) by utilizing the

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power law, Paris law, or Walker equation. The two-parameter Weibull cumulative distribution function is used to characterize the variation in component strength. The effects of multiaxial stresses are modeled using either the principal of independent action (PIA), the Weibull normal stress averaging method (NSA), or the Batdorf theory. Inert strength and fatigue parameters are estimated from rupture strength data of naturally flawed specimens loaded on static, dynamic, or cyclic fatigue.

The capability, flexibility, and uniqueness of CARES/*Life* has attracted much interest. Initially, the program was developed with an emphasis on technical features and less regard was given to ease-of-use. However, over time the program became more intricate -- requiring a higher level of expertise needed to achieve a desired result. Based on feedback from users, who typically used the program on an intermittent basis, it was found that the program's capabilities were underutilized because of it's complexity. First and foremost users wanted an easier to use program. To begin to address this criticism, CARES/*Life* has been upgraded with the following:

- Data files to create graphic templates for common business presentation software such as Lotus Freelance Graphics. This feature, known as CARES/*Graphics*, produces Weibull and fatigue plots of specimen rupture data and estimated parameters.

- An interactive input preparation program has been prepared which guides the user through various program control options and data input formats. This program, known as CARES/*Input*, is written in FORTRAN 77 and operates on PC's as well as Unix machines.

- A new interface program between the ANSYS finite element analysis program and CARES/*Life*. This program, known as ANSCARES, has a finite element model geometry surface recognition feature allowing surface flaw reliability to be performed without the previous requirement of shell elements being attached to the model's surface nodes. This program also has an expanded element library, including axisymmetric elements.

- A grinding damage model (ref. 6) has been added to account for flaws introduced from finishing (grinding) operations on components. This model is based on Batdorf methodology modified to account for non-random (anisotropic) orientation of flaws.

- Capability to use a finite element model of a specimen geometry and loading to obtain volume and area normalized Weibull and fatigue parameters.

CARES/*Life* has been in high demand world-wide, although present technology transfer efforts are primarily focused on U.S.-based organizations. Success stories can be cited in several industrial sectors including aerospace, automotive, biomedical, electronic, glass, nuclear, and conventional power generation industries. In 1997 Lewis Research Center (LeRC) in partnership with Philips Display Components Company (PDCC) and Corning Incorporated, won the American Ceramic Society Corporate Technical Achievement Award for the design and manufacture of an improved television picture tube (by PDCC) for the U.S. consumer market. Also an R&D 100 Award from R&D Magazine was recieved in 1995, the NASA Software of the Year Award, and a Federal Laboratory Consortium Technology Transfer Award were received in 1994.

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1. Nemeth, N. N., Powers, L. M., Janosik, L. A., and Gyekenyesi, J. P.: "Time-Dependent Reliability Analysis of Monolithic Ceramic Components Using the CARES/*Life* Integrated Design Program," Life Prediction Methodologies and Data for Ceramic Materials, ASTM STP 1201, C. R. Brinkman, and S. F. Duffy, Eds., American Society for Testing and Materials, Philadelphia, 1993, pp. 390-408.

2. Powers, L. M., Janosik, L. A., Nemeth, N. N., and Gyekenyesi, J. P.: "Lifetime Reliability Evaluation of Monolithic Ceramic Components Using the CARES/*Life* Integrated Design Program," Proceedings of the American Ceramic Society Meeting and Exposition, Cincinnati, Ohio, April 19-22, 1993.

3. Nemeth, N. N., Powers, L. M., Janosik, L. A., and Gyekenyesi, J. P.: "Designing Ceramic Components for Durability," American Ceramic Society Bulletin, Vol 72, no. 12, December, 1993, pp. 59-66.

4. Nemeth, N. N., Powers, L. M., Janosik, L. A., and Gyekenyesi, J. P.: "Durability Evaluation of Ceramic Components Using CARES/*Life*," ASME Transactions; Journal of Engineering For Gas Turbines and Power, Vol. 118, No. 1, January 1996, pp. 150-158.

5. Janosik, L. A., Gyekenyesi, J. P., Nemeth, N. N., and Powers, L. M.: "NASA CARES Dual-Use Ceramic Technology Spinoff Applications." Proceedings of the Thirty-Second Space Congress, Cocoa Beach, FL, April 25-28, 1995.

6. Salem, J. A., Nemeth, N.N., Choi, S. R., and Powers, L. M.: "Reliability Analysis of Uniaxially Ground Brittle Materials", ASME Transactions; Journal of Engineering For Gas Turbines and Power, Vol. 118, No. 4, October 1996, pp. 863-871.

Outline

- Probabilistic ceramic component design
- CARES/*Life* computer program
- Ease-of-use enhancements
- Technology transfer
- Conclusion

Fig. 1

Objective

Develop probabilistic based integrated design programs for the life analysis of brittle material structural components

Fig. 2

Typical Defect Populations Found in Engineering Ceramics Manufactured From Powders

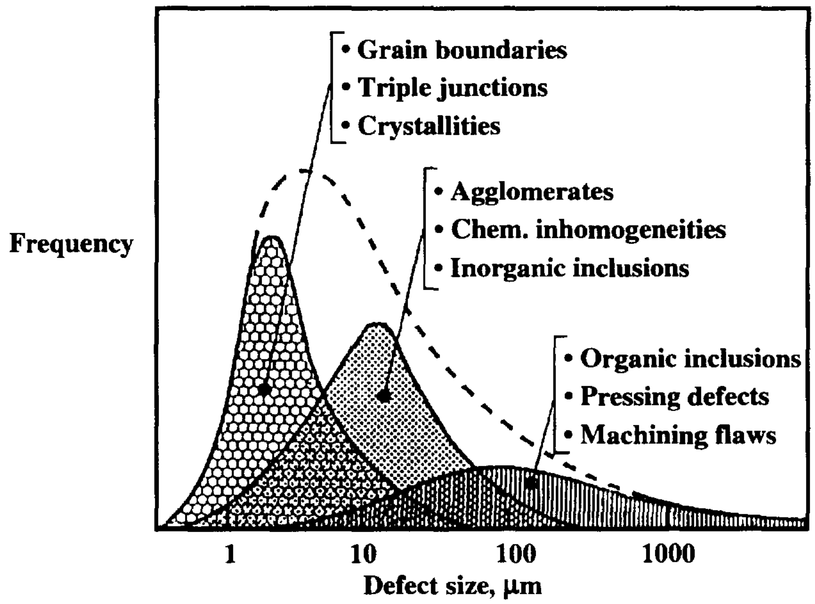


Fig. 3

Fracture Map of Hot Pressed Si_3N_4

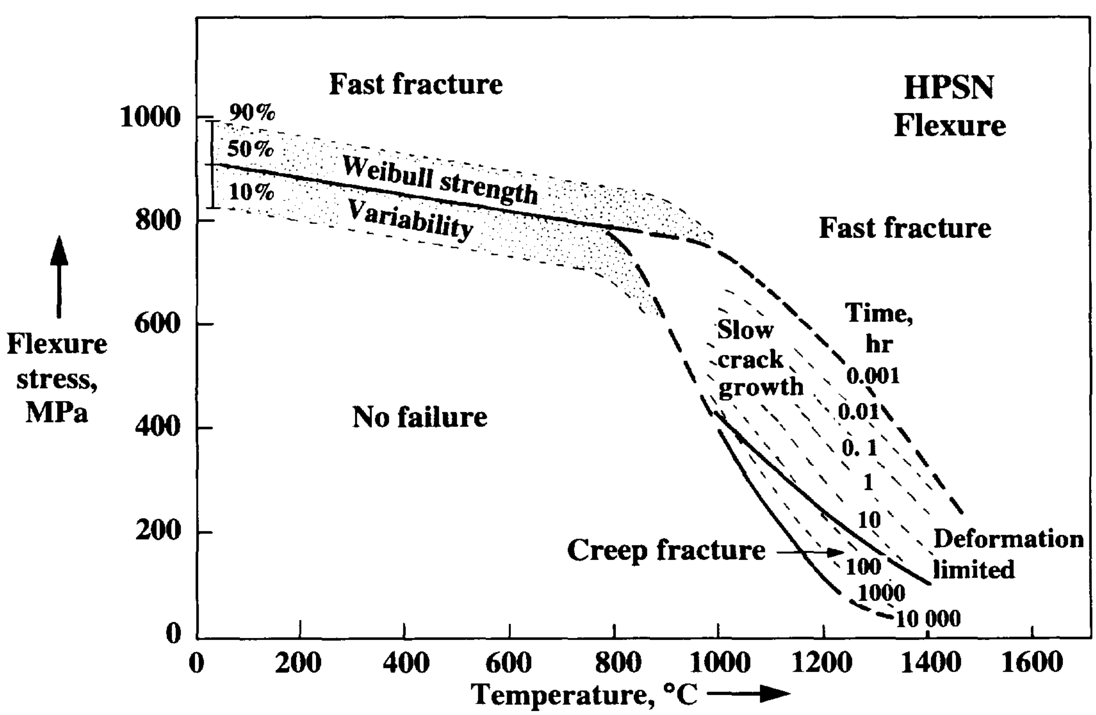


Fig. 4

Probabilistic Component Design Procedure

- **Material failure characterization**
  - Rupture tests of many simple specimens
  - Fast–fracture experiments: Estimate Weibull parameters
  - Static, dynamic, or cyclic fatigue experiments: Estimate fatigue parameters
- **Fractographic examination of ruptured specimens to determine the mode of failure**
- **Component finite-element analysis**
  - Thermal analysis
  - Stress analysis
- **Component reliability evaluation**
  - Specify probabilistic failure theory, crack type, fracture criterion, crack growth law, Weibull parameters, and fatigue parameters
- **Design optimization**
  - Risk-of-rupture intensity plot
  - Generate design diagrams: Failure probability versus time, strength–probability–time (SPT) diagrams, etc.

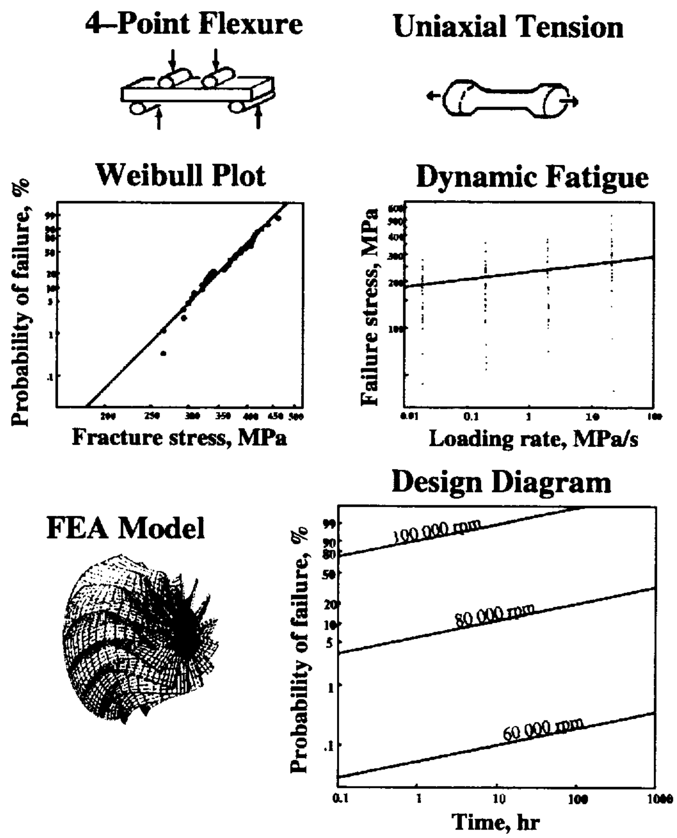


Fig. 5

CARES/*Life*

Ceramics Analysis and Reliability Evaluation of Structures
Life **Prediction Program**

- **Predicts the probability of a monolithic ceramic components failure relative to its service life**
- **Couples commercially available finite element programs to probabilistic design**

Fig. 6

NASA/CARES - Modular Format

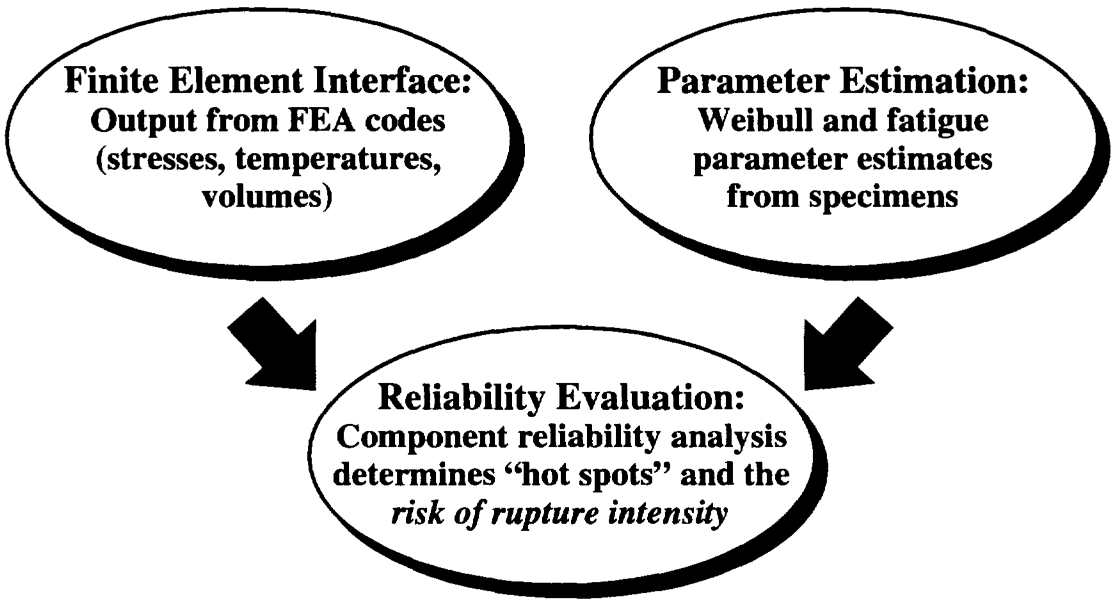


Fig. 7

CARES/*Life* Capabilities

- **Component reliability evaluation**
  - Fast-fracture
  - Time- or cycle-dependent
  - Multiaxial stress states
  - Proof test loads
  - Random or *non-random* flaw orientation *(new capability)*

- **Material characterization**
  - Any specimen geometry *(new capability)*
  - Instantaneous load
  - Static load
  - Constant stress rate load
  - Cyclic load

Fig. 8

Version 5 - New Features and Changes

Enhance Functionality and Ease-of-Use

CARES/Graphics:	**Graphical rendering of specimen rupture data; Weibull plots, static fatigue, dynamic fatigue, cyclic fatigue**
CARES/Input:	**An interactive input preparation program**
ANCARES:	**ANSYS FEA–CARES/Life interface (Most CARES/Life users have ANSYS)**
WinCARES:	**A Windows based GUI shell controlling the various FORTRAN-based numerical algorithms (Under construction)**

Fig. 9

CARES/*Graphics*

User friendly graphics templates for common business presentation software

Two Parameter Weibull Plot of Fast Fracture Data

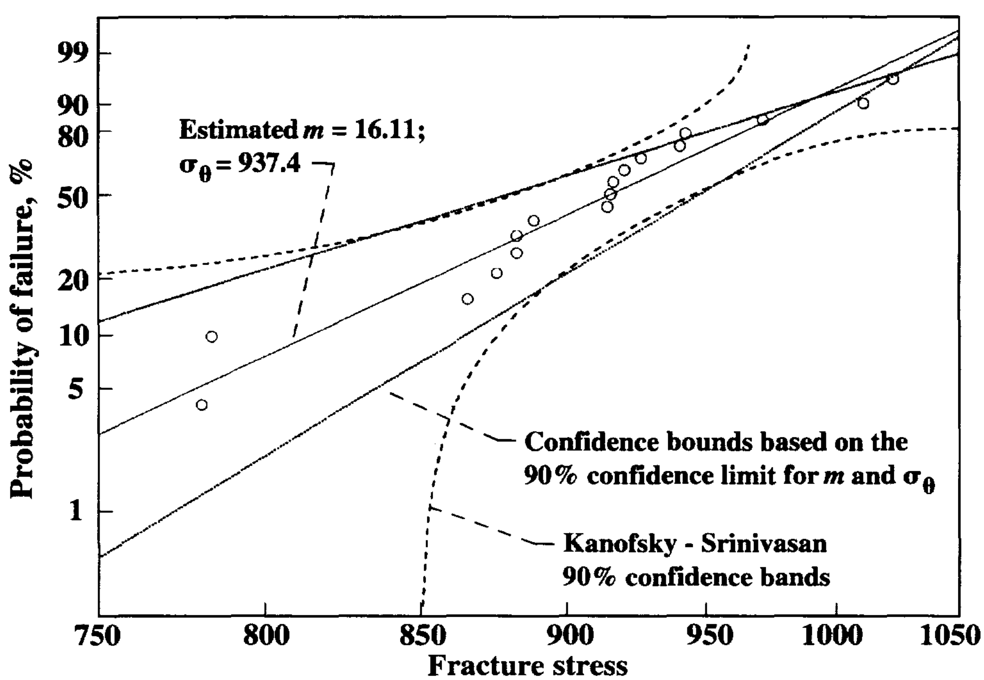


Fig. 10

CARES/*Input*

Interactive Input File Preparation for CARES/*Life*

- Simplifies the ***"bewildering array of input files and keywords"*** confronting the user
- Step-by-step walk through of input file creation
- Error checking diagnostics

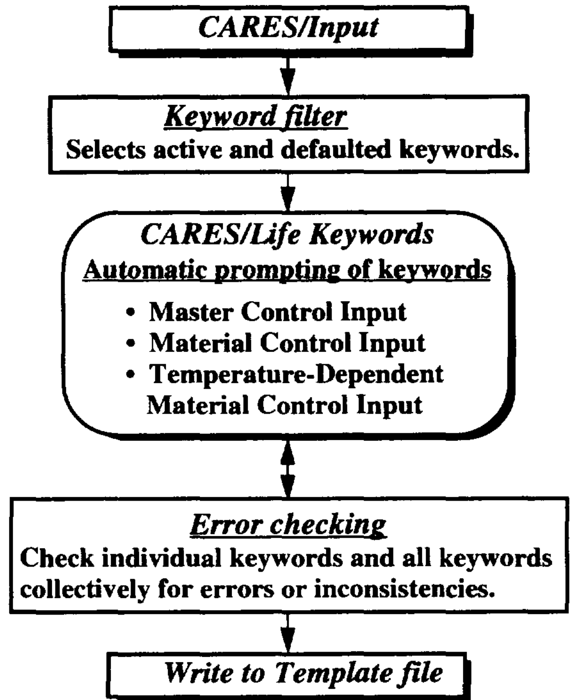


Fig. 11

ANSYS–CARES Interface

- Automatic detection and modeling of component surfaces
- Component risk of rupture rendering
- Robust element library (solid, shell, axisymemetric)

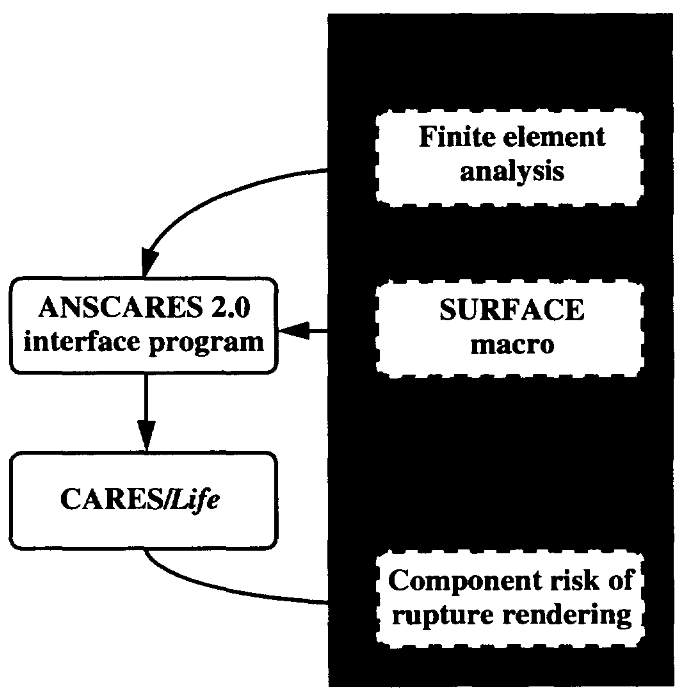


Fig. 12

WINCARES: A GUI for the CARES/*Life* algorithm

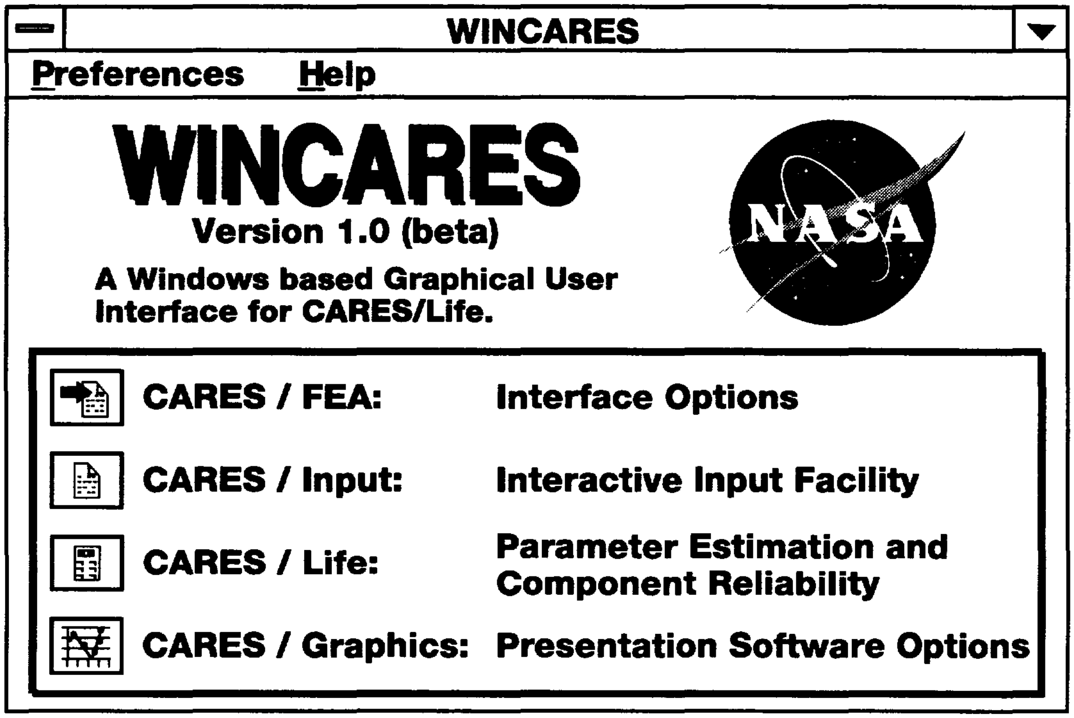


Fig. 13

Diverse Range of *CARES/Life* Applications

Aerospace/Terrestrial Power & Propulsion Applications
- Turbocharger rotors
- Rocker arm and cam followers
- Radient heater tubes
- Prototype ceramic turbines
- Poppet valves
- Combustors
- Heat exchangers

Bioengineering Applications
- Dental crowns
- Hip implants

Other Dual-Use Applications
- Infrared transmission windows
- Ceramic packaging for microprocessors
- Cathode ray tubes

Fig. 14

Successful Technology Transfer

- **Customer Focus**
- **Cooperative Efforts**
- **Dual–Use Technology**

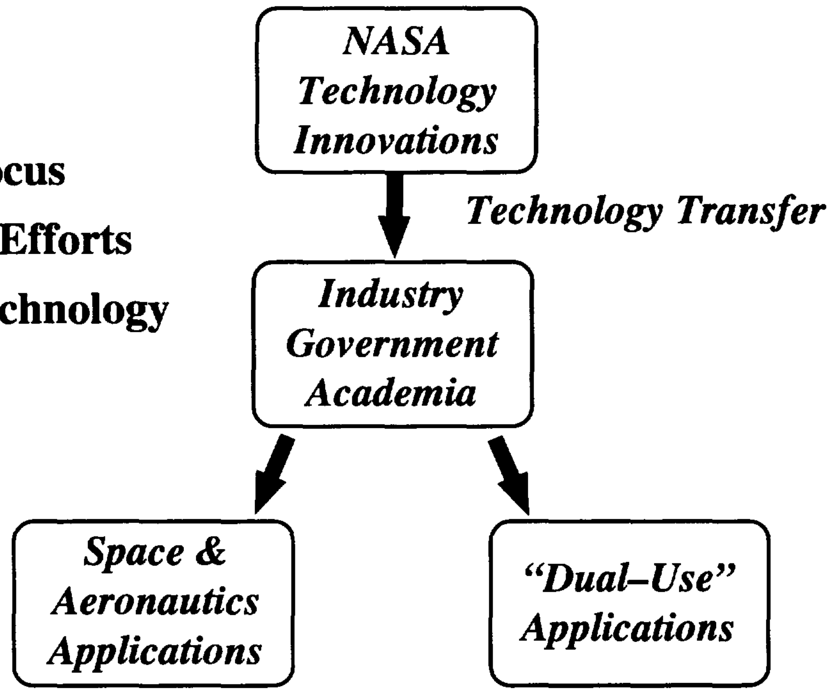


Fig. 15

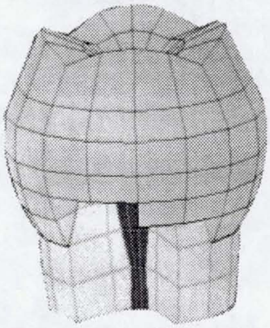
Requests for CARES/*Life* in Past Year (U.S.)

AlliedSignal	*APU Turbine Rotors*
Army	*Chip Packages and Electronic Hardware*
Battelle	*Composites Consortium*
Caterpillar	*Various Engine Parts*
Ceramatec	*Fuel Cells, Oxygen Generators, Sensors*
Cummins	*Fuel Injectors*
Los Alamos Nat. Lab.	*Alumina Windows for Particle Accelerators*
MIT/ARPA	*Micro Gas Turbines*
3M	*Various Ceramic Parts*
NASA Ames	*Reusable Spacecraft Thermal Protection*
NGK	*Various Ceramic Parts*
Novellus	*Semiconductor Wafer Manufacturing Equipment*
Snaprogetti	*Heat Exchangers, Chemical Reactors*
Teledyne TCAE	*Auto. Gas Turbines*
Thomson	*Television Picture Tubes*
U. Of Mass.	*Research, and Teaching*
U. Of Penn.	*Research*
Westinghouse	*Submarine Reactor Thrust Bearing*

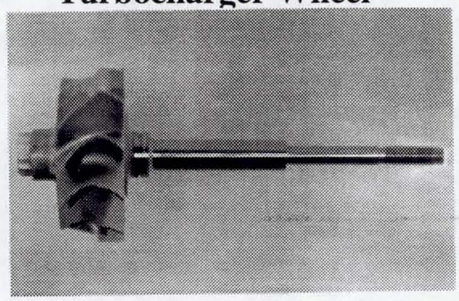
Fig. 16

NASA/CARES Dual-Use Ceramics Design Examples

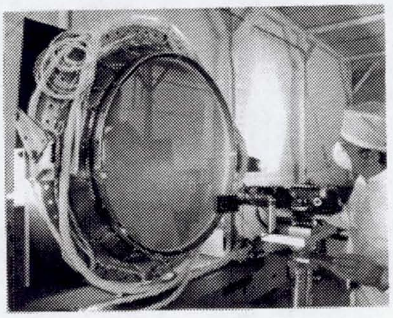
Dental Crown



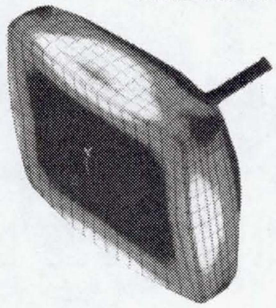
Turbocharger Wheel



ZnSe Vacuum Chamber Window



Television Picture Tube



Evacuated tube stresses

Fig. 17

NASA LeRC's innovative CARES/*Life* software design tool allowed Philips to develop superior glass television picture tubes

- **Manufactured over 1 million components**
- **Realized cost savings in excess of $1 million/year**
- **Optimized structural design for safety, reliability, performance, and efficiency**
- **Optimized component fabrication process through use of design-for-manufacturability (DFM) techniques**
- **Reduced glass consumption, tube weight, hazardous waste, and x-ray emissions**

Fig. 18

CARES Award–Winning Software

- ★ **1996 American Ceramic Society Corporate Technical Achievement Award**
- ★ **1995 R&D 100 Award**
- ★ **1994 NASA Software-of-the-Year Award**
- ★ **1994 Federal Laboratory Consortium Technology Transfer Award**

Fig. 19

Conclusions

- **Lighter weight and more durable ceramic components can be designed using *CARES/Life***
- **Program ease of use is enhanced with new graphics, input preparation, and finite element interface modules**
- **Diligent technology transfer efforts have led to successful employment of *CARES/Life* across a diverse range of industrial sectors**

Fig. 20