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OPPORTUNITIES FOR CERAMICS IN THE ERDA/NASA CONTINUOUS COMBUSTION PROPULSION SYSTEMS PROGRAM

by Charles P. Blankenship and Robert B. Schulz
Lewis Research Center
Cleveland, Ohio 44135

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OPPORTUNITIES FOR CERAMICS IN THE ERDA/NASA CONTINUOUS COMBUSTION PROPULSION SYSTEMS PROGRAM

Charles P. Blankenship, NASA-Lewis Research Center

Robert B. Schulz, ERDA-Transportation Energy Conservation Division

INTRODUCTION

The ERDA/NASA Continuous Combustion Highway Vehicles Program is directed toward reduced fuel consumption in highway vehicles. Both the gas turbine and Stirling engines are of immediate interest because of their potential improved fuel economy as compared to current automotive powerplants. Project management of this ERDA-funded program has been assigned to the NASA-Lewis Research Center. The prime objective of this program is to help industry establish the technological position necessary to have the option of gas turbine and/or Stirling powerplant production. Specific program goals are directed at improved fuel economy, low emissions, multifuel capability, and marketability. For example, a 20-30 percent gain in fuel economy is targeted for an "improved engine" option by 1982-83. For the late 1980's, a 50-60 percent gain in fuel economy is targeted for "advanced engine" systems.

High temperature ceramic materials are expected to receive major emphasis in developing both improved and advanced gas turbine and Stirling engines in this program. The use of ceramics provides the opportunity to achieve higher operating temperatures which contributes directly to improving the thermodynamic efficiency of these engines, and thus their fuel economy. Also, the use of ceramics instead of superalloys usually employed in these applications offers the potential of reduced material costs and reduced demand for critical alloy metals such as chromium, nickel, and cobalt. Potential high temperature structural ceramics such as silicon nitride and silicon carbide are derived from relatively abundant and low cost elements. In addition to higher operating temperatures, greater efficiencies are expected in engine components through improved designs and operating characteristics.

This paper presents an overview of the program scope with emphasis on the engine development projects and key opportunities for potential use of ceramics. A major ceramics materials technology effort is also described which will be conducted to meet anticipated engine system requirements. We conclude with comments relating to the unique nature of this program in terms of the automotive application, some of the more pressing technology needs, and some indications of how we plan to conduct this technology program with industry.

ENGINE DEVELOPMENT PROJECTS

Engine development projects will focus on both gas turbine and Stirling engines. Both of these engines are considered to be promising fuel-efficient engines that could be mass-produced and sold as alternatives to the conventional internal combustion engine for introduction in automobiles in the 1985-1990 time frame. The engine development projects are to be conducted by the industry through government-funded contracts.

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Emphasis in these projects will be to assist the automotive industry in achieving the technology base needed for a production option of alternative automotive propulsion systems. Efforts for both "improved engines" (for possible use in the mid-1980's) and "advanced engines" (for potential use in the 1990's) are planned as outlined in the following sections. Improved engines are classed as existing development engines that would be upgraded without significantly changing their principal design features. Advanced engines would evolve from new engine design concepts.

Improved engine development projects. This part of the program will emphasize improvements in current development engines or new engines to meet the near term, 1982-83 goal of a 20-30 percent gain in fuel economy. Existing and near-term technology would be used to achieve this and other program goals. Ceramics are expected to receive major emphasis in improving the performance of these engines, but ceramic components are likely to be used on a selective basis. One approach would be to introduce ceramics into the engine on a component-by-component basis and thereby provide for incremental improvements in engine performance.

Specific opportunities for ceramics in this type of program will be illustrated using as an example the Improved Heavy Duty Gas Turbine Engine Program. This program is being conducted by Detroit Diesel Allision (DDA) under NASA contract (NAS3-20064) and is part of the ERDA/NASA Continuous Combustion Propulsion Systems Program. The goal of the heavy duty engine program is to advance automotive gas turbine systems technology and to significantly improve the specific fuel consumption of DDA's 404/505 industrial gas turbine development engine from its current level of 0.45. This engine is contemplated for highway truck and bus applications. A step-type program is planned which consists of advancing the turbine inlet temperature from the current level of 1835°F to 1900°F, to 2070°F, to 2265°F, and possibly to 2500°F. Each step of increasing temperature involves introduction of additional ceramic components in the hot section of the engine. A ceramic regenerator disk, a ceramic gasifier nozzle, and a ceramic gasifier tip shroud would be required to achieve the 1900°F increment followed by a ceramic combustor plenum and ceramic gasifier rotor blades to achieve the 2070°F operating temperature. At the highest temperature, most components in the hot section would be ceramic. In the current study phase of this project, the potential benefits of increasing cycle temperature and adding ceramic components are being evaluated in terms of life-cycle-costs. These results will be used to help guide subsequent phases of the program which will involve ceramic component design, fabrication, and testing. Both engine and vehicle demonstrations are to be made at each major step of the improved engine development project.

Other government-supported projects are planned to develop improved gas turbine engines for automotive use. These programs will be conducted by the automotive industry through contracts with NASA. Ceramics are expected to be utilized for selected hot section components. Like the previous example given, these improved engine projects will contain significant efforts in ceramic technology development covering material improvements, characterization, component fabrication, and engine testing.

For the Stirling engine, introduction of ceramic components is planned to develop an improved engine by 1982. However, the introduction of ceramics in this engine is expected to be limited to the pre-heater to minimize the higher risk associated with this engine development program. Both rotary regenerator and fixed recuperator concepts will be considered.

Advanced engine development projects. In the advanced engine development program, emphasis is expected to be placed on both advanced engine design concepts and ceramic materials. While some preliminary conceptual engine design work will be undertaken by NASA, the major effort will be contracted to industry. This latter effort is expected to start in FY78. Several contract efforts are planned with industry to define the advanced propulsion systems and the pacing technology requirements. These initial system definition projects will be directed toward a programmatic decision point in 1983. At

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that time, the government, with input from industry, would determine merits of continuing the support of the advanced engine development program with a view toward achieving an early 1990 production possibility. Key factors in this decision would include fuel economy projections, potential marketability of the advanced engines, and projected national needs.

The "advanced engines" are expected to operate at higher temperatures and require more ceramic components than envisioned in the "improved engines." For advanced gas turbine engines, all hot section components are likely to be ceramic. A ceramic turbine rotor, essential for an all-ceramic turbine, is judged to be the most difficult technology development.

CERAMIC MATERIALS TECHNOLOGY PROJECT

The ceramics materials technology project is expected to provide technology for both the improved and advanced engine programs with emphasis on the latter. A broad-based effort is planned to include in-depth characterization of various ceramic materials, development of improved ceramic materials and processes as well as component design, fabrication, and testing. A brief outline of the planned efforts covering these three principal areas is provided in the following sections. Areas of technology emphasis are also noted. The major portion of this activity will be accomplished by industry through government-funded contract programs.

Characterization of ceramic materials. This technology area covers the in-depth characterization of mechanical and physical properties of current and advanced structural ceramics that have potential for engine applications. Maintaining a design data-base on candidate ceramic materials is viewed as a key area in this part of the program to provide input to the engine design activities. In addition, the durability of ceramics in terms of the effects of long-time engine exposure on mechanical properties and stability will be evaluated. Other efforts will include non-destructive evaluation, fracture mechanics, life-prediction methodology, and reliability analyses.

Improved ceramic materials. Efforts in this area will focus on developing improved ceramic materials to better meet future automotive requirements. For example, higher-density reaction-sintered silicon nitride is desirable for both improved strength and oxidation resistance. A project to achieve this would include optimization of the silicon powder particle size and distribution, refinement of the molding process, and improvement of the understanding and control of the nitradation step. Similar technology efforts can easily be identified for other candidate materials such as silicon carbide and the oxide ceramics. While improved material properties will be emphasized, the applicability and economic viability of the related fabrication technology for the improved ceramic material will receive appropriate attention. Fabrication processes associated with improved materials must have potential for low cost and high volume production capability.

Component design, fabrication, and testing. Technology programs in this category reflect the need to obtain a strong technology base in ceramic component performance. Efforts in this area may not be related to specific engine designs, but they will address key issues such as verification of ceramic design concepts and component reliability under operating conditions. Rig testing of components will be used as appropriate. Ceramic manufacturing technology development will also be included to better match new component designs with fabrication processes. Ceramic component manufacture at reasonable cost and high reliability will have to be demonstrated in order for the industry to have a viable engine option. The development of low-cost manufacturing technology as well as the component demonstration technology will be included in this part of the program.

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CONCLUDING REMARKS

This paper is intended to be an overview of the ERDA/NASA Program which is in the early phase of planning and implementation. Obviously, there will be changes in specific details as the program progresses and as technology needs are better defined. The strong technical reasons for using ceramics in the program are probably obvious to this audience. Also, current ceramic materials that are likely candidates for the engine components noted are well known to this group. For these reasons, we have not attempted to relate the merits of any one candidate ceramic material nor to provide a review of the status of ceramics for engine applications. (A list of references is provided for those wanting additional background).

Several technology programs have provided much of the impetus and a degree of optimism that ceramics can now be considered as viable structural materials in high performance applications such as advanced automotive engines. The most notable include the ARPA/Ford Brittle Material Design Program and the recently-initiated ARPA/AiResearch Ceramic Engine Demonstration Program. Both of these programs have well defined objectives. And they are distinctly different in scope when compared to the ERDA/NASA Program. The ARPA programs will culminate in 50 to 200 hour engine tests to demonstrate the feasibility of using ceramic components in turbine engines. However, the ERDA/NASA Program will concentrate on the technology needed to ultimately use reliable, cost-effective ceramic components in automobile engines for 3000 to 4000 hours of engine operation that includes about 20,000 engine start-ups and shut-downs. These often conflicting requirements of good endurance, high reliability, and low cost present a very formidable challenge in developing the technology for ceramic use in automotive applications.

One of the first steps in the ERDA/NASA ceramic technology program will be to evaluate the effects of long-term cyclic exposure (3000-4000 hrs.) to simulated engine environment on mechanical properties and structural stability of candidate ceramic materials. We want to identify potential problems associated with the long-life, cyclic requirements of an automobile engine early in the technology program. For example, the loss in strength (about 30 percent) of hot pressed silicon-nitride, a candidate structural ceramic, after exposure to air at 2000°F for about 400 hours was only identified recently. Identification of potential problems of this type is needed early to properly direct the activities to be undertaken in the improved ceramic materials part of the technology program.

Design methodology for structural ceramics is another key area of concern to be addressed in both the engine development and supporting technology programs. The probabilistic design approach evolved in the ARPA/Ford program provides a well-founded technical base. Our immediate need then is to assess these concepts through extended rig and engine tests of components and determine their applicability for the automotive-type application.

Reliability of ceramics and their cost-effectiveness in the automotive application will be the keys to their success. Our current state-of-technology makes it difficult to realistically assess either of these factors. Ceramic engine components, except perhaps rotary heat exchangers, have not been manufactured or tested in quantities sufficient to assess either reliability or cost. Early in the program, we expect to be in a position to focus part of the resources in initiating this assessment. This may be accomplished partly through the engine development projects and partly through the ceramics technology projects. A continual update of the reliability and cost factors will have to be maintained to help provide proper focus and program direction.

Finally, we have not attempted to make a clear distinction in the boundaries between the engine development projects and the ceramic materials technology projects. Ceramic materials evaluation will obviously be a part of both. There will be some unavoidable duplication of effort. Some will be intentional, but warranted, in order to confirm the

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performance of candidate ceramic materials. Our intent to assist the entire automotive industry further complicates this problem since there will be several companies participating in the automotive continuous combustion engine technology program. Identical ceramic materials are likely to be selected by two or more companies for the same component but with differing designs. Also, manufacturing technology efforts and design data are likely to be similar. Or, considering a different aspect, the same four candidate materials might be selected for evaluation by several companies. Obviously, the solution to minimizing duplication of effort in this type of program is certainly not straightforward. But one part of the potential duplication that can most easily be avoided is the obtaining of engineering design data. One or more independent laboratories could be funded to generate these data for the entire industry for all candidate ceramics. So we are evaluating this approach and others to provide a reasonably-balanced program with industry. Thus, a major part of our job in managing this program will be to minimize duplication while at the same time truly assisting the industry in achieving the technology required to have an option of advanced engine production to enhance our national energy posture.

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