

N89-20144

VIEWS ON THE IMPACT OF HOST

J. B. Esgar
Sverdrup Technology, Inc.
Lewis Research Center
Cleveland, Ohio

D. E. Sokolowski
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

ABSTRACT

The Hot Section Technology (HOST) Project, which was initiated by NASA Lewis Research Center in 1980 and concluded in 1987, was aimed at improving advanced aircraft engine hot section durability through better technical understanding and more accurate design analysis capability. The project was a multidisciplinary, multiorganizational, focused research effort that involved 21 organizations and 70 research and technology activities and generated approximately 250 research reports. No major hardware was developed. To evaluate whether HOST had a significant impact on the overall aircraft engine industry in the development of new engines, interviews were conducted with 41 participants in the project to obtain their views. The summarized results of these interviews are presented.

SUMMARY

The NASA-sponsored HOST Project addressed durability needs in advanced aircraft engine combustors and turbines by developing improved methods for design analysis and life prediction of critical parts. Providing technology to improve engine durability should, in turn, reduce maintenance costs and improve flight safety. Because of the nature of challenges in developing durable structures, the project was multidisciplinary and multiorganizational involving 70 research and technology activities. While most projects result in a deliverable piece of major hardware, the HOST Project instead generated approximately 250 research reports that cover results from analytical modeling, highly controlled small-scale experiments, and numerous computer codes that were developed. HOST Annual Workshops brought together representatives from all major U.S. gas turbine manufacturers and from a significant number of universities and research institutes in an effective forum to discuss and critique recent research findings. To better understand the impact of the HOST Project, its cost effectiveness, and benefits derived by organizations having association with it, numerous interviews were conducted with key program

participants, primarily from industry and academia, to determine their viewpoints. This paper summarizes results from the interviews.

INTRODUCTION

The Hot Section Technology Project, which has the acronym HOST, was initiated by NASA Lewis Research Center in the Fall of 1980 to address the need for improving durability of advanced aircraft turbine engines. Near the conclusion of the project in the Fall of 1987 a survey of knowledgeable participants was conducted to assess the impact and value of HOST to industry, to academia, and to the government. This paper summarizes the results of the survey.

The HOST Project was unique in several ways. Its focus on durability was in contrast to other recent NASA-sponsored programs that focused primarily on performance improvements. Those programs included the Energy Efficient Engine (EEE), Engine Component Improvement (ECI), and Advanced Turboprop Program (ATP) and involved only a portion of the aircraft engine industry. The HOST Project complemented such programs on performance improvement, which often tend to aggravate engine hardware durability. In addition the 70 major research and technology activities initiated under HOST drew on researchers from three work sectors--industry (including all the large U.S. engine manufacturers), academia, and government--to work jointly toward common goals.

Another unique feature of HOST was its focused and integrated research encompassing six engineering disciplines that addressed critical technology needs in the engine hot section--the combustor and turbine components. The disciplines are instrumentation, combustion, turbine heat transfer, structural analysis, fatigue and fracture, and surface protection. HOST acted as a keystone that helped bridge the gap between these sometimes diverse groups and provided mutual support in helping them work together.

While the program was justified for civil aircraft needs, military needs were equally satisfied because the same design analysis systems are used by

manufacturers in developing both civil and military engines.

Finally, no major hardware, such as an engine prototype, was developed. Instead technical understanding and design analysis capability were improved and documented in approximately 250 published research reports and in numerous computer codes that were developed. Technology was further identified and transferred in a timely manner through six major annual workshops, which had a total attendance of 1500 people. Using the research presented in the reports and at the workshops, a move was started to change development of advanced engines from the historical experimental testing approach of "build 'em and bust 'em" to a more analytical approach in which component hardware designs are analyzed with much more accurate data bases and mathematical models before testing is begun. Testing is then more for design verification than for experimental development.

A total of 40 separate activities were competitively contracted with aircraft engine manufacturers and research institutes plus 13 grants to universities. Seventeen major activities were supported at the NASA Lewis Research Center. A total of 21 organizations were represented in the effort. In addition to the above mentioned university grants, several manufacturers subcontracted parts of their work to university researchers, who may or may not also have had direct NASA HOST grants. The 40 contracts were generally multiyear and often multiphased. This approach provided a greater opportunity for interaction between various organizations represented than is normally encountered in government short-term contracted efforts.

To evaluate and report the impact of the HOST Project, 41 individuals from participating organizations were interviewed. These interviews, plus some results from a 1984 mid-project assessment that also involved industry and academia participants, are summarized in this paper to provide written testimony on the HOST Project. Further, the findings may provide guidance in planning future government-sponsored research programs.

APPROACH

The goal of this study was to determine the HOST Project's impact by obtaining views from a representative number of key participants. Efforts were made to avoid biases, if any, of the interviewer. The authors of this paper include the NASA manager of the HOST Project, who conceived and guided the study, and a support service contractor, who conducted the study and who had considerable airbreathing engine background prior to this project. The support service contractor had no prior knowledge of the HOST Project and entered the study with no biases regarding HOST. The project manager made suggestions as to appropriate HOST participating organizations and people to contact. The contractor contacted these organizations, made arrangements for visits, and conducted interviews both with people suggested by the project manager and with others suggested by some of those interviewed. Throughout the duration of the interview period some HOST participants called and volunteered unsolicited comments. By means of this approach the co-author most familiar with the project provided leads of organizations and/or personnel who had been active in the overall program, and the other author conducted the interviews and gathered data presented herein without preconceived ideas on the impact of HOST.

Approximately 90 percent of the interviews were conducted in person, with the remainder conducted by telephone. A total of 41 interviews were conducted with the following breakdown by organization: 26 from engine manufacturers, 5 from universities, 4 from research institutions, and 6 from government (NASA and U.S. Air Force). Personal interviews were conducted with key participants from the four major aircraft engine manufacturers in the program, namely Pratt and Whitney, General Electric Company, Allison Gas Turbine Division of General Motors Corporation, and Garrett Turbine Engine Company. The approach was to first call the organization and tell them the subject to be discussed. Visits then were made and those interviewed were given the opportunity to state their views on both positive and negative aspects of the project. Efforts were made to solicit individual views, either pro or con, and to avoid questions or comments seeking praise for the program. No set questions were asked in the interviews. Instead, individuals were asked a few general questions and then given the opportunity to express whatever opinions they had. Active listening was used to encourage discussion and to avoid guiding answers. If there were questions concerning the interpretation of comments given, follow-up telephone calls were made for clarification. In several cases the interviewer's written summary of comments was sent to the organizations interviewed to determine if the individuals concurred with the interviewer's interpretation. It is the belief of the interviewing author that the appraisals given were spontaneous and honest. This report does not identify individuals or organizations other than listing the four engine manufacturers and the government organizations from whom comments were solicited.

FINDINGS

There was unanimous agreement from everyone interviewed that the HOST Project was highly effective and to the mutual benefit of all participants. NASA was lauded for the conception, advocacy, and management of the program. There was agreement that without HOST many of the important research programs, which are needed to advance technology in the hot section of gas turbine engines, would have been delayed for years or never undertaken. Elements of HOST which were particularly emphasized as being beneficial by a number of those interviewed included: (1) three-dimensional inelastic structural analysis, (2) thermomechanical fatigue testing, (3) constitutive modeling, (4) combustor aerothermal modeling, (5) turbine heat transfer, and (6) protective coatings. Instrumentation research was also emphasized as being beneficial, primarily by the single organization conducting that research. Other organizations were less enthusiastic because the developed instrumentation was not commercially available to them. In a somewhat similar manner computer codes developed in the HOST Project were generally more useful to the organization developing the codes than to others, particularly for the longer, more complex codes.

Two areas, that were not research in nature, received near unanimous approval. The first was the annual workshops where current research results were presented and discussed, and the second was the improved industry-university-NASA relationships.

Discussion of comments received on the above mentioned areas plus other benefits or comments for improvement follow.

Impact on Technical Understanding and Predictive Capability

Three-dimensional inelastic structural analysis.

Inelastic or nonlinear structural analyses have limited, but very important, applications. These analyses are used primarily for short-life cyclic applications where it may be acceptable to exceed the elastic limit for a few cycles. For long-life applications, however, hardware generally should be designed for operation within the elastic range. But even for long-life applications based on elastic design, there are occasions when three-dimensional (3-D) inelastic analysis may be needed. One occasion is when a shorter than predicted life is encountered. In this case an inelastic analysis can often pinpoint the problem area. In addition a 3-D inelastic analysis can be useful for determining stress redistribution when local yielding occurs. Thus for such special cases, 3-D inelastic analysis can be a very important design tool.

True three-dimensional analytical methods have only become available to engine design analysts within the last few years--after the HOST Project was initiated. Several approaches to 3-D inelastic analysis were pursued in the project. The best approach may not be known for some time. Currently 3-D inelastic design analyses are cumbersome, complicated, and require a great deal of computer time. Consequently there is some reluctance on the part of analysts to use 3-D inelastic analysis unless absolutely necessary. With time, however, as design analysts become more comfortable with this analysis approach, it should be used more extensively. Its use is both for problems that occur early during engine development and later for pinpointing the cause and cure for field problems, when local yielding is suspected to be occurring. As a result, 3-D inelastic structural analysis has been reported by participants to be a significant advancement that resulted from HOST.

Thermomechanical fatigue testing. In the past, mechanical properties of metallic materials have been determined experimentally using simpler mechanical and thermal load variations than the complex variations experienced in many engine applications. The need to improve engine durability requires evaluation of material behavior and life under more realistic conditions. In the HOST program, contracts, grants, and NASA in-house research were conducted on evaluating material behavior, including both crack propagation and material deformation, as a function of time, under cyclic biaxial mechanical loads, and in numerous atmospheric and cyclic temperature environments. Cyclic mechanical loadings have included high frequency loads superimposed on lower frequency loads.

The key objective of this research was to gain a better understanding of how and why cracks develop in different types of materials exposed to cyclic temperature and mechanical loading conditions. These data can be the basis of engineering life predictions methods that can be applied to the severe conditions in the engine hot section. The deformation testing portion of the research supports the development of viscoplastic constitutive models for structural analysis.

These mechanical property data are obtained under more realistic conditions and with greater precision than were heretofore possible. According to some of those interviewed, the data base of thermomechanical material properties plus experimental data from other phases of HOST program may be one of the most useful aspects of the HOST Project.

Constitutive modeling. Constitutive modeling is an analytical approach for predicting stresses and strains as a function of time under complex cyclic biaxial mechanical loading and temperature variations. The modeling is based on experimental thermomechanical deformation data. Prior to the HOST Project research on constitutive modeling was done primarily at universities, and not at aircraft engine manufacturers. HOST provided a team approach of industry, universities, and NASA working together to develop a capability that did not exist previously. The aerospace industry now has the capability to use nonlinear constitutive models of both isotropic and anisotropic metallic materials in inelastic structural analysis. This research has provided a base to further extend constitutive modeling to more complex materials such as metal matrices. As a result of the HOST Project NASA Lewis Research Center has become an important center, worldwide, for constitutive modeling. HOST has not only introduced constitutive modeling to engine companies, it has resulted in a closer working relationship between them and academia.

Combustor aerothermal modeling. Research had been conducted prior to HOST on combustor modeling aimed at predicting dilution jet airflow mixing with combustion gases. Those modeling studies were based on bulk average temperature measurements from jet mixing experiments. Such research had greatly diminished by the time of HOST initiation. In the HOST Project all four engine manufacturing companies were awarded contracts to assess the state of the art in combustor aerothermal modeling. As a result of this assessment and additional research with nonreacting flows, aerothermal modeling is much better understood and is being used throughout the aerospace industry. This is not to say, however, that all problems have been solved. The accurate prediction of combustor aerothermal performance along with prediction of wall temperature levels and gradients will require further improvement in numerical schemes with input from experimental, fully-specified reacting flow data that is not yet available. HOST was terminated before reacting gas flow and fuel swirl characterization data could be obtained. However, analytical procedures have improved to the point that one organization indicated the use of three-dimensional fluid flow analysis in the design of combustors that required a minimum of testing.

There was an almost unanimous opinion of those commenting on combustor modeling that the HOST program was long overdue, and it spearheaded the move toward an analytic capability in combustor understanding and design analysis.

Turbine heat transfer. The HOST-sponsored activities in turbine heat transfer encompassed nearly all aspects of internal and external heat transfer in turbine airfoils. Some of the research contracts and grants in the overall program included external airfoil heat transfer with and without film cooling, impingement cooling, interaction of rotor and stator in a large low speed turbine, coriolis and buoyancy effects on heat transfer in coolant passages, heat transfer with flow across a moving airfoil tip, and end wall boundary layer studies. As a result of this research correlations have been developed that have resulted in significant improvement in accuracy of calculated blade metal temperatures. Also quality experimental data sets, along with good documentation, were developed that will find widespread use by heat transfer analysts in the future. It is now possible

as a result of HOST to better control local temperatures, which in turn, result in better control of blade life and surface oxidation.

Protective coatings. Protective coatings include both thermal barrier coatings, to reduce heat transfer, and oxidation resistant coatings. Progress has been made on improving coatings and a better understanding of interactions between coatings and structural base materials. In addition, thermomechanical fatigue testing has been conducted on materials having oxidation and thermal barrier coatings. Life prediction models are being developed. A side benefit of this research was development of an awareness that designers and materials research personnel must work more closely together in improving life prediction models.

Computer codes from the HOST Project. The output from HOST was technical information in the form of research reports, experimental data sets, and computer codes. A requirement in the development of computer codes was installation and operation of the codes on one or more of the following NASA Lewis Research Center computers: Cray X-MP/2-4 with COS operating system, Amdahl 5840 with VM operating system, or VAX 11-750. This requirement was aimed at making the codes more generally available and usable. In some cases the original code development was on a more advanced computer model than the one at NASA Lewis. Modification to make the code run at NASA Lewis would have the advantage of making it workable on a wider range of computers.

In practice the above described concept has not worked as well as hoped. In some cases codes developed by one organization have been readily used by other organizations. These have generally been the simpler codes. In other cases, however, the codes from HOST have been of only limited benefit to the nondeveloper of the code. For the more complicated codes, it has been the experience of NASA personnel that it takes from 3 to 12 months to debug and become familiar with codes supplied by HOST contractors for the NASA computers. A similar period of time is expected to be needed by other users of the code even though considerable debugging was accomplished at NASA. A shortcoming with these codes is that support service cannot be provided by the developer or NASA in the manner available for commercial codes.

A comment made by one of those interviewed might solve this problem of computer code support. In future programs funding should be allocated for a commercial software company to adequately debug and document the more complicated computer codes. Further, by permitting the software company to market the code they would be in a position to provide a continuing support and updating function. In this manner codes developed could be made available and usable by interested parties over an extended period of time.

Most of those interviewed stated that without code support they could make only limited use of codes from HOST that they themselves did not develop. Some organizations did state, however, that they expected to rewrite portions of some of the codes of interest. Another interviewer stated that although a code may not be directly usable as developed by another organization, it can be rewritten in about one-half the time originally required to write the code. It also is possible to capitalize on problems that may have been experienced by the original programmer so that the rewritten code will be superior to the original.

Impact on Engine Development Process

Improved engine design capability. Both computer codes and experimental data bases developed under the HOST Project have already been of value in engine design. The impact is expected to be felt for years to come. While there are certain reservations relating to the extent of code development, the overall technology generated by HOST will continue to be useful throughout the aircraft engine industry. It is clear that the value of research that has developed both computer codes and experimental data bases has been greatest to those conducting the research, but other organizations are certainly making use of the research results to varying degrees.

Design analysis capabilities have been improved in the combustor and turbine. As a result of these capabilities less experimentation is required in development of the components. It is expected that reliability will be improved because of improvements in the prediction of temperatures and stresses from heat transfer, fluid flow, and inelastic stress analyses. At this time there has not been enough history generated to determine if HOST has resulted in reduced maintenance costs, one of the goals of the project. But it is reasonable to expect that if durability and reliability are improved, maintenance costs will be reduced.

Comments received from a number of those interviewed indicated that data bases generated from experiments in fluid flow in the combustor and turbine, turbine heat transfer, and thermomechanical fatigue will be at least as important to analysts as the computer codes generated from HOST contracts. As mentioned earlier in this paper, it will probably be some time before designers are comfortable with, and will routinely use, some of the advanced computer codes that have been developed in HOST.

Reduced engine development costs. Reduction in engine development costs was not one of the original goals of the HOST Project, but it has become a possible significant side benefit. The computer codes and data bases developed in HOST have improved design capabilities to the extent that less development testing is expected for new engines. However, reduced experimental test costs are counterbalanced by increased computer costs in the design analysis process. A completely clear picture has not emerged in all cases. Part of this lack of clarity results from several factors: (1) HOST has played a significant part in improving technology in engine hot sections, but it is not a sole player. Other in-house, Independent Research and Development (IR&D), and government sponsored programs are also resulting in improved technology. It is generally difficult to quantitatively define the contributions of HOST to overall improvements in technology; (2) Each new engine development program utilizes advances in technology compared to the last engine developed, often with increased complexity and/or designs to higher limits of temperature, pressure, stress, etc. This "moving target" makes comparisons of development costs with previous engines difficult; (3) Computer capabilities are constantly improving and costs to accomplish computing tasks are decreasing.

Consideration of all these factors makes it difficult to draw definitive conclusions as to whether, or how much, HOST has actually reduced engine development costs. However, the following are informed opinions that were presented by some of those interviewed:

1. Computing methods that have been developed under HOST have resulted in annual savings of several millions of dollars in reduced computer time for the required number of computer runs in engine development programs.

2. A HOST-developed computer code that transforms temperatures from the output of coarse-grid finite element heat transfer analyses to the input of fine-grid finite element structural analyses has reduced engineering labor by 26 man-years per year for one company.

3. Increased computer costs using three-dimensional fluid flow and inelastic stress analyses that result in more refined designs are just about balanced by reduced experimental testing costs for these designs at the present time. But the analytical costs are dropping rapidly, so cost savings are expected soon.

4. It is estimated that if development of new engines had to use 1975 vintage design and testing technology, the cost of engine development would be approximately three times as high as presently experienced when using advanced technology in which HOST has been a significant contributor. The overall savings are measured in billions of dollars.

5. It is reasonable to expect that improved predictive capability in engine design can reduce testing requirements. If this improvement can eliminate just one design or test-build iteration during a development or demonstrator program, savings of \$250,000 or more can be reasonably claimed. Moreover, the cost savings by eliminating one service-revealed deficiency could be an order of magnitude greater.

From the above comments it is obvious that in some cases hard numbers can be generated for cost savings resulting from HOST. In other cases savings can be inferred but not necessarily firmly documented. However, engine manufacturing company personnel comments which relate to engine development cost reductions and savings resulting from reducing service-revealed deficiencies provide reasonable certainty that projected savings arising from HOST-generated technology will be orders of magnitude greater than the cost of the project itself.

Impact on Technology Transfer

Approximately 250 technical research reports have been written in the HOST Project and numerous computer codes have been generated. In addition six annual major workshops were held as well as a number of mini-workshops devoted to a single area of research. Because of the large attendance of 250 to 300 at each annual workshop, which had both formal presentations and informal discussions, there was a maximum opportunity for information exchange and technology transfer. Since representatives from all large U.S. engine manufacturers, as well as many from academia, research institutes, and government, attended these workshops, there was probably a better transfer of technology than from any other NASA-sponsored aircraft engine research or development project.

There was a unanimous opinion of those interviewed that the two-day workshops were highly successful. Not only were the presentations useful, but the informal discussions that occurred during breaks in the presentations and during the evening after the presentations were deemed extremely beneficial. Some comments made by those interviewed include:

1. "There hasn't been another forum in the U.S. to compare to the HOST Annual Workshops that has brought together the right mix of people to discuss research of common interest."

2. "Workshops provide an annual update in the thinking and planning by both NASA and industry. This once-a-year contact between industry and academia is of great value."

3. "The casual conversations with other participants that take place at the coffee breaks are of such significant benefit that NASA should consider increasing the number of coffee breaks and providing more informal get-togethers."

4. "HOST workshops have provided an excellent forum for probing discussions and the "give and take" necessary to generate useful knowledge and understanding for all participants of the advantages and disadvantages of various approaches. These discussions have aided companies to evaluate the directions of their own research."

5. "The workshops are useful in providing and developing relationships with peers from other organizations, including NASA."

6. "The HOST workshops are extremely effective because the technical community is better represented than at society meetings."

From the above sampling of comments it is evident that one of the big strengths of the HOST Project was not only the research and technology generated, but the timely dissemination of this information through formal presentations and informal discussions in the workshops.

Impact on Industry-University-Government Partnership

Improved relationships. There was a consensus that the HOST Project, largely through the workshops, substantially improved relationships of personnel in industry, academia, and government. The program also provided opportunities for university professors to work directly with engine manufacturers. This arrangement was a double barreled benefit; the companies were able to capitalize on present and previous university research, and the professors developed a better understanding of the environment and problems of engine manufacturers which they could pass on to their students.

One university professor stated that he, along with others, had held discussions for a number of years on how to get better interaction between industry and universities. He then said, "HOST did it!" As a result, he feels that companies and universities are now working together better.

Although most of those interviewed emphasized the improved relations between industry and universities, several also commented that the HOST program improved their relationship with NASA. In addition several were very complementary about the NASA organization and management of the HOST program. They felt that the program was well conceived, and the NASA managers were both knowledgeable and helpful in overcoming problems that developed during the course of investigations.

Enthusiasm of participants. Essentially everyone interviewed showed enthusiasm for the HOST Project, but the degree of enthusiasm differed both by

organization and individual. Among the larger organizations there appeared to be a general correlation between enthusiasm and the degree of participation (number of contracts) in HOST. There is some indication that the organizational enthusiasm also may be significantly influenced by the degree of enthusiasm of the HOST coordinator for that organization. It has been indicated by NASA personnel that the same organizational enthusiasm was evident prior to award of contracts. It seems that enthusiasm by a leader is contagious.

It appeared that those interviewed from universities, on the average, showed a greater degree of enthusiasm than those from industry, possibly because university personnel less often have the opportunity to be involved with a project of the magnitude of HOST. Other reasons for their enthusiasm were expressed in their interviews. For some it was the first opportunity for the results of their research to be used directly by an industrial concern. To find that what you are doing is useful to a large organization certainly can be exhilarating. HOST also permitted some researchers from universities to depart somewhat from their more academic activities and work on real problems relevant to industrial concerns. This type of work and interaction with engine manufacturers has the added benefit of bringing "the real world" into the classroom to guide students in the directions of problems presently facing at least one segment of the industrial world. Another benefit included guiding some graduate students towards employment in the aircraft engine industry because of this exposure.

A factor influencing the enthusiasm of university professors has been the workshops. At these annual meetings there has been opportunity for interaction with appropriate quality and quantity of industrial personnel. For some this has been a new experience. Previous relations with industrial personnel had been on a more limited basis to a few people they have met at society meetings, or to a few engineers in an industry where they have had a contract. Generally, they never have had the opportunity to interact with so many quality people from industry having interests similar to theirs.

Considerations for Future Contract Efforts

Although most comments received in the interviews were favorable on how the HOST Project was conducted and on the results obtained, some comments received could possibly provide some improvements relative to HOST in future contract efforts.

An often expressed comment from those interviewed concerned the earlier-than-expected termination of the HOST Project because of NASA budgetary considerations. Because of this early termination some programs were not able to be completed. The main concerns expressed were (1) experimental verification of computer codes is incomplete, and (2) reaction kinetics was not investigated in the combustor aerothermal modeling programs as originally planned. At this time it is uncertain when this added research can be completed. It may take years before funds are available to conduct the research. It would certainly be beneficial in future programming efforts to try to avoid early termination of successful projects.

As mentioned earlier, concern was expressed by some of the nonparticipants in instrumentation research. This research was deemed to be of little value to those except for the developer because the instruments developed were not available for purchase. Consideration should be given in program planning to evaluate the probable benefits to all participants or

to encourage third-party manufacturing of such developing technology.

The following comments expressed by only one or two individuals may not be a consensus of those interviewed, but many have merit and require consideration for future contract efforts:

1. Rather than fund so many research areas as in HOST, fewer areas should be more generously funded.

2. HOST was worthwhile, but from the company standpoint the benefit would have been greater with a hardware-oriented program that would have resulted in an advanced engine that could be marketed. (It should be pointed out that this was a minority comment. Many more of those interviewed stressed the value of a research-oriented program.)

3. More funds should have been made available in HOST for technology transfer from the organization doing the research to other organizations. As stated earlier in this paper, funding of an organization to provide support and updating of computer programs would be extremely beneficial.

4. Small organizations could not participate to any great extent in HOST unless they teamed with a larger organization.

5. Some contracts were awarded based upon estimated costs rather than on the organization's capabilities and expectations of producing all that was promised in the proposal.

6. Building NASA in-house facilities was overdone, particularly for thermomechanical fatigue testing.

Although not all of the above comments may be of a positive nature, there may be merit to many, and all should be given consideration.

SUMMARY OF FINDINGS

From interviews conducted with 41 industry, university, and government personnel soliciting their views on the impact of HOST the major findings can be summarized as follows:

1. There was 100 percent agreement that the HOST Project was highly successful and worthwhile.

2. The HOST approach for expending research funds was very effective. The emphasis on research rather than hardware development was viewed by several interviewed as the role NASA research centers should take to provide long lasting benefits to the aircraft industry. Having many organizations working to a common goal and many of the organizations having similar programs led to "cross fertilization" that improved the research for each organization.

3. HOST yielded advantages over traditional research and technology contracted efforts by providing a focus and acceleration to problems involving the entire hot section of engines. In addition HOST resulted in a working relationship between industry, academia, and government not previously experienced.

4. The annual workshops were a major contributor to the success of HOST. Critiques of the results presented were an aid in developing improved programs.

The information was distributed to all concerned in a more timely manner than waiting until reports were completed and distributed. The large gatherings of highly qualified research personnel from all major organizations having a common goal of improved engine reliability provided a timely interchange of information.

5. The computer codes and data bases that were generated will be useful to analysts for years to come. However, some of the larger codes may not be used by organizations which did not develop them because of lack of code support. These computer codes could have been made more useful by bringing in commercial software companies to provide code support, to keep the codes updated, and to market them for general use.

6. NASA was lauded for program concept and management. The program managers were deemed to be technically competent and helpful in overcoming problems that developed in various contracts.

7. While most of the comments on the HOST Project were favorable, comments critical of the project also may have merit and should be given consideration in future government sponsored projects.

8. A side benefit of HOST has been the potential for significantly reducing the cost of engine development using advanced design techniques developed by HOST-sponsored research.

9. The cost reductions in engine development plus savings from reducing service-revealed deficiencies (a result of better predictive capability in engine design) are projected to be orders of magnitude greater than the cost of the HOST Project.

10. At the present time there are not definitive answers to the question of whether the goals of the HOST Project of improved engine reliability and reduced maintenance costs have been met because engines have not yet been produced that utilize the improved technology resulting from HOST. There is reason to believe, however, that the superior design techniques coming from HOST research can result in better engine reliability, improved flight safety, and ultimately reduced maintenance costs.

CONCLUDING REMARKS

The HOST Project activities encompassed researchers from industry, academia, and government. Perhaps due to the size and visibility as well as the

difficult technical challenges of the project, high-caliber people were involved, including leading experts in each discipline. This quality of the researchers was always apparent in the technology developed.

The approach to addressing durability challenges can include one or more of the following: higher-temperature materials, more effective cooling techniques, advanced structural design concepts, and improved design analysis tools. Because of the potential gains and perhaps because of the timely growth in computer hardware and availability, the HOST Project's approach was on improved design analysis tools. To better understand the physics involved in the development of these design analysis tools for combustors and turbines, high-quality experiments were often conducted. Early project plans included significant testing in the new High Pressure Facility at NASA Lewis Research Center. However, technical problems that limited full testing capability, limited operating funds, and a move toward less component testing at Lewis led to mothballing of the facility early in 1986. This had a significant impact on HOST, first, in greatly reducing model/code verification testing and, second, in reducing immediate use of HOST-developed instrumentation for hot section research.

Most research results from HOST were generic. They were applied to both large and small turbine engines. In addition certain codes were used outside of the HOST Project for durability improvements in the Space Shuttle Main Engine as well as design analysis of an advanced communications technology satellite. There are, however, unique durability challenges in small turbine engines which could not be addressed in HOST because of funding constraints. These challenges include higher turbine blade attachment stresses, faster thermal transients, and different materials. Such challenges in today's small engines are believed to be the challenges in tomorrow's large engines.

Experience has shown that, in general, development of new design analysis tools is followed by slow user acceptance. This slow acceptance has appeared in some aspects of the HOST Project. Sometimes acceptance time is reduced during a crisis, such as in-service engine problems.

While a return on the investment in HOST has already been realized, additional return lies in the future as analysts use HOST codes more, and as such codes are used as the basis for developing new codes for design analysis applicable to high-temperature composite and structural ceramic materials. Technology development for these materials was outside the scope of the HOST Project.