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- Methodologies for Determining Clean Technology Alternatives—European Research and Development - 289

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Methodologies For Determining Clean Technology Alternatives—European Research and Development

by Michael Overcash, Liaison Scientist for Chemical Engineering and the Environment at the Office of Naval Research European Office. He is on leave from North Carolina State University where he is Professor of Chemical Engineering.

KEYWORDS: environment; waste management; life cycle analysis; ecofactors; ecobalance

INTRODUCTION

Major differences clearly exist between the United States and European countries in the level of environmental quality and industrial and municipal requirements for waste management. To understand the state of activities and direction that major European industrial countries are following, we must understand their analyses and strategies for environmental improvement.

For clean technology or pollution prevention, we can benefit from European research and development (R&D), particularly at the technology level of processes and products. However, their methodologies for determining what is "better," or "more green," offer interesting observations on the industrial and societal context in which manufacturing and consumers operate in Europe. The objective of this study was to examine evolving European R&D efforts in ensuring the quality of the environment.

Methodologies for studying green environmental optima in complex manufacturing systems actually represent several levels of technical and philosophical issues. At the most fundamental level is the life cycle analysis (LCA). Other terms used with LCA are input/output analysis and mass/energy balances. For this type of study, several components reoccur:

- Boundaries must be established to define the system under study and they must be clearly stated. These boundaries can include a single-unit process, a facility, a region, all stages from natural resources to final disposition of products (cradle-to-grave), etc. Relationships of successively larger boundaries and evaluation results remains largely unanswered.
- Data must be obtained; these are vital for assembling the LCA within any boundary. These are typically derived from manufacturers and from published literature. More advanced groups also generate basic information from design principles or experiments. LCAs are data-intensive, and the quality of information (from repeated comments by scientists) is a fundamental source of concern. With little "hard" data, lengthy sets of assumptions are necessary. This constrains the interpretation of LCA results.
- Basic information must be assembled and represented. Generally the context for interpretation is two or more products that are otherwise equal in end-use (such as meeting the same product specification, standard of safety, consumer use, etc.). In Europe, LCA does not appear to be used to describe a chemical or a material in an abstract sense, but only within the narrower context of comparing two or more products. In product terms, LCA information is a series of bar charts describing the individual chemical wastes, such as carbon dioxide, volatile organics, cadmium, nitrogen oxides, particulates, etc. This profile then allows product choices under investigation to be compared.
- Results of the LCA must be communicated to decision-makers or potential users. Software development and graphics are essential to convey the complex pictures obtained from the typical LCA.

The environmental life cycle analysis tool has been in conceptual form since about 1975. It will remain controversial until the scientific basis can be improved and greater standardization achieved.

This is the clear goal of many of the European researchers. However as the pressure to reach country-wide or European Community (EC) decisions escalates, the increase in LCAs is substantial and the scientific challenges become even greater.

The next level derived from LCA in the search for improved environmental choices emerges from a political or societal need. Simply stated, the LCA looks complicated and, therefore, there is significant pressure to simplify the results. Can the chemical profile involving many constituents be replaced by a single number? With such a number for comparison of choices, everyone could then judge the alternatives. Would the interpretation algorithms, which attempt to transform the complexity of the technical world into bits of information, then contribute to decision-making? At this level, concepts such as ecobalance, critical criteria, and risk assessment occur. (These are discussed later in the context of individual research efforts.)

The final level can be even more unclear, particularly for technical or decision-making issues. Here the European concept of sustainability is situated in reference to determining the environmental or green optimum path. Sustainability represents the interpretation of these transformed technical (e.g., chemical) profiles (that describe manufacturing, consumer products, life styles, etc.) into long-term goals. While sustainability also is not new, the increased use of long-term goals as a part of determining environmental directions strongly influences European industry and the societal system.

This report is organized according to country to describe the activities with respect to research on methodologies and with respect to contributions at the various levels of environmental optimization. Information from five countries was obtained from numerous visits and discussions. The European engineers and scientists were open, cordial, and generally interested in the exchange of ideas. However, there is a distinctive lack of published information. The general justification is that this represents a restraint imposed by the sources of funding (industry and government). There also appears to be less pressure to publish. Correspondingly, there is less (approaching negligible) peer review or collective critique. Hence extrapolation of quantitative information is difficult, although it is felt that direct collaboration and exchange with a given institution or university would be feasible.

SWITZERLAND

Swiss Federal Laboratories for Material Testing and Research (EMPA)

The origins of two recurring concepts (life cycle analysis and ecobalance) are described by EMPA as results from researchers at the St. Gallen Laboratories. Life cycle analysis is said to have started with a comparison of glass versus plastic containers for certain food products.[1] The ecobalance, as an algorithm to transform the mass emission information of an LCA, was also started in St. Gallen.

For LCA, the EMPA research group (headed by Drs. Ruth Forster and Ivo Fecker) pursues studies for industrial clients. They rely on two basic Swiss government documents containing data on processes and energy.[2,3] Their analyses extend from the production of natural resources to the final disposal of residues in landfills. As with others in Europe, the boundaries do not include:

- land-related effects in producing renewable or nonrenewable natural resources (i.e., mine spoils or non-point source pollution);
- human labor;
- emissions from the production of capital equipment and the physical plant necessary to conduct manufacturing; and
- any long-term effects from residue management.

Their intuitive feeling is that these elements are not large or that they just do not have any data with which to estimate these factors. The EMPA is currently in a six-month program to develop software to facilitate the calculations involved in LCA. This is also a recurring theme found in other advanced European research efforts on LCA methodologies.

"Ecobalance" has been developed and utilized for Switzerland to integrate LCA mass data into a less complex decision-making factor. The concept

of ecobalance begins by defining acceptable national emission capacities (typically mass per year) for individual chemicals species, bulk wastes, or energy usage. This was done for the country of Switzerland as a geographic region. The effort is very empirical and was done by a small group of three individuals. Typically the acceptable national emission is an existing national or international regulatory concentration of a chemical in air or water. With the total air resource throughput (similar to the bubble concept in U.S. air attainment areas) or the volume flows of rivers and lakes, and the acceptable concentrations, the acceptable national mass flows were estimated. Without regulatory values or for issues such as solid wastes, other judgmental values had to be adopted in the particular circumstances of Switzerland. Table 1 gives the Swiss parameters included in this ecobalance concept. It should be noted that the next evolutions of this approach are under consideration because of the very empirical basis of this first effort. In particular, efforts are focusing on whether critical emission values can be made to reflect human health or ecological impacts as these differ from current regulatory standards.

Actual Swiss national discharge or emission rates (also in mass per year) were then determined. Estimates were made from source terms (such as from a car), or from point source permit discharge limits, or from monitoring. Again assumptions had to be made from available data, and room for future improvement exists.

The final step is the calculation of an ecofactor for each chemical, waste, or energy. The ecofactor is the ratio of actual flow to critical flow, corrected by the magnitude of the actual emission or discharge. This correction creates a linear factor that is normalized to account for the relative magnitude of chemicals or wastes as used by society. The units of ecofactor are ecopoints per unit of annual mass discharged in the country of Switzerland, as a geographic region of Europe. The results are given in Table 1. Based on these calculations, improvement in the energy factor is possible since emissions from energy production are not accounted for, only the energy usage.

While researchers at St. Gallen did not develop the application, the work of the Migros Company to utilize the ecobalance concept are reported here. Migros is a large Swiss food store with many facilities. They have used the unified ecopoints system to analyze products or processes. As an illustration, they compared the "wobble bag" for milk with a cardboard container. For a boundary of the borders of Switzerland, the wobble bag had an environmental value of 5 while the cardboard container was 16. Additionally, the wobble bag was $0.04 cheaper. Against marketing arguments, they decided to place the milk in wobble bags, at the corresponding lower price, as a choice for customers, along with green marketing. Today 50 percent of their milk sales are in the wobble bags. Migros has developed software to facilitate calculations of ecofactors and makes it broadly available (about $5,500), but not yet in English. They have set targets for their stores and departments in terms of acceptable overall ecopoints, almost like an internal currency.

Several observations are needed. First, Switzerland has virtually no nonrenewable resources. With the boundaries of their LCA analysis at the Swiss border, the complexity of analysis is considerably less. In fact, it is possible that different decisions might actually result with the choice of other boundaries. Additionally, when scientists were questioned, no further major corporate application of ecobalance was observed in Switzerland beyond Migros, despite the large, advanced industrial base. Thus the propagation of this concept appears slow.

The EMPA staff and that of the nearby Hochshule Institute for Technology Management also described the evolution of environmental issues in Swiss corporations. They observed that since about 1990, the corporate structure has moved more rapidly to consider environmental issues in business decisions. By comparison to the U.S., these actions are still preliminary, and they felt that the greatest effort would remain technology for pollution control. This is essentially a regulatory-driven approach. However, in the education of management students, they see "environment" as joining the specialties of production management, quality, innovation, and time management.

Other observations regarding trans-European issues were made from the St. Gallen discussions. The use of LCA and ecobalances have differentiated product choices that are virtually the same in cost. Under these circumstances changes to products with lower ecofactors are more direct and less

Table 1 - Ecofactors for Switzerland[3]

Polluting Agent	Maximum Tolerable Flow, F_k	Total Flow, F	F/F_k, percent	Ecofactor in Ecopoints per gram
Air:				
NO_x (as NO_2)	67,200	191,000	284	4.23E+01
SO_x (as SO_2)	54,400	68,000	125	2.30E+01
CO_x (as CO_2)	34,700,000	43,400,000	125	3.60E−02
Hydrocarbons (without CH_4)	146,900	308,000	210	1.43E+01
HCl	—	5,770	—	4.23E+01
CFC (total)	1,075	5,200	484	4.50E+03
Water:				
Dissolved organics (C)	88,000	89,000	101	1.15E+01
Chemical oxygen demand (COD)	264,000	267,000	101	3.83E+00
Phosphorous (P)	2,300	4,000	174	7.56E+02
Chloride	4,420,000	511,000	12	2.62E−02
Nitrate (as N)	251,000	57,000	21	9.05E−01
Sulfate (SO_4)	4,420,000	1,500,000	34	7.66E−02
Ammonium (as N)	22,000	5,000	23	1.03E+01
Energy:				
Total potential energy	1,004,000	1,004,000	100	1.00E+00 (per MJ)
Solids:				
Municipal solid wastes	4,500,000	4,500,000	100	2.22E−01
Combustibles	80,000	130,000	163	2.03E+01

sensitive to other business decisions. No examples representing the broad consumer market were available from the Swiss experience in which higher costs for environmentally improved products had been successful. Switzerland does not appear poised to convert LCA or ecobalances into direct consumer labels (the so-called ecolabel), except as a part of an overall European program. They do not wish to create a competing system. EMPA staff were asked to define sustainability. There was no official version. Staff felt that the concept should be to maintain current quality of life, but to prevent any damage to nature.

Future programs at EMPA in clean technologies research on methods and strategies appears strong. They continue to have opportunities to actually conduct life cycle analyses. The Swiss government appears to have selected EMPA to coordinate an important expansion in research for this field. Referred to as Module 5 of the current Swiss Priority Program for Environment research effort, they will coordinate:

- food and processing LCA,
- LCA for washing products,
- agricultural production LCA,
- transportation LCA,
- use of fuzzy logic in LCA,
- methodological evaluation (re-evaluation of ecobalance),
- eco-control (corporate environmental balance sheets), and
- building materials LCA.

The information generated and the effort in software automation should be an important continuing contribution to the methodologies for selecting environmental optimal alternatives. This Module program is about $1.2 million for a three-year effort to begin in mid-1993.

The Product-Life Institute, Geneva

Dr. Walter Stahel mounted a long-term R&D effort to address the issues surrounding sustainability. His work at the Institute examines manufacturing and material flows (mostly as final consumer products) to understand at a practical level the improvements needed for optimizing environmental impacts. This could be referred to as "operational sustainability," since improved material and product flows are sought that are also favored on economic terms. Technical options for sustainability are thus described by Dr. Stahel and are reviewed here.

The conceptual theory for sustainable manufacturing of products is linked to redirecting items or components away from landfill disposal or incineration. This research has led to defining a series of cycles. That is, there is a series of technologies that return some or all of a product to some useful form (nondisposal). Thus this series of technologies must be understood, then the various cycles within each technology group. The series begins in the manufacturing phase (or even conceptually in the design stage) and proceeds through scrap material recycling. Priority is given to the first phase in terms of the least overall environmental impact, with the last phase in the technology series having the least prevention impact. Sustainability would imply utilization of the first choices. Technologies and cycles within each technical group are described:

1. Creation of products with essentially infinite life (e.g., lightbulbs with a 20-year operational life).

2. Design and creation of multifunctional products, thus eliminating waste and ultimate product disposal associated with the separate products that are replaced after a useful life (e.g., a single fax, printer, and copier to replace three separate machines).

3. Commercial waste prevention strategies,
   - selling the utilization of goods (e.g. photocopiers),
   - shared or multi-utilization of goods (e.g., apartment building clothes washer/dryer versus individual units, and
   - selling quality control services instead of selling products (e.g., motor oil analysis to determine engine wear and timing for oil change).

4. Product-life extension of goods, with cycles in the following priority,
   - direct re-use,
   - repair for re-use,
   - reconditioning, and
   - technological upgrading.

5. Product-life extension of components found in goods, with cycles in the following priority,
   - direct re-use,
   - repair for re-use,
   - reconditioning, and
   - technological upgrading.

6. Most forms of current recycling for materials (e.g., plastic, aluminum, etc.).

The first three technologies are pre-consumer and tend to be increasingly economical. The last three are post-consumer and may continue to be unattractive without major philosophical shifts on the part of society. The major effect of all these technologies is to slow the flow of materials through society. Hence, these represent major pollution prevention options that would have resulted from the manufacture of new products and ultimately product disposal. The definition of successive priorities shows that as the recycle or re-use cycle is extended in location or quality of goods there is an inevitable reduction of sustainability.

Research challenges arise from these efforts in sustainability. The first would be to compare these ranges of options with the life cycle type of analysis. That is, there currently is no means to determine how much better or worse for the environment would be the actual implementation of these technological choices. In these complex scenarios, the net effect is not now intuitively known. Second, what is sustainable? When asked for a definition that if achieved might describe sustainability, the Product-Life Institute advocates the return to a more agrarian or at least a highly dispersed world. This includes a commitment to erase borders to allow lowering of the global population density. This clearly represents a potential conflict of environmental goals with other societal principles.

Swiss Federal Institute For Water Resources and Water Pollution Control (EAWAG)

This research group at Dubendorf (headed by Prof. Peter Baccini) is focusing on particular areas of the methodologies necessary to chose optimal environmental alternatives. Their efforts address two principal objectives:

1. household life cycle analysis, based on their thesis that houses built and occupied represent the largest source of waste in industrialized societies (this is a broad definition of the house as the conduit of the bulk of all societal products and human activities), and

2. the relationship between households and the treatment technologies needed by municipalities for optimal overall environmental improvements.

Before describing the first objective, observations on treatment can help frame the Swiss emphasis in this LCA area. In Switzerland, municipal wastewater receives biological treatment, with the bulk of the sludge going to land application systems. Effluent is discharged to streams and lakes with increasing concern for eutrophication. Municipal solid waste is separated for the easily recycled materials, but then all remaining waste is incinerated. The regulatory principle is that only inorganic ash should be placed in landfills. Thus these dominant technologies are examined by Prof. Baccini's group in conjunction with detailed study of the source in households. The project is called METAPOLIS.

The objective of this research on household processes and life cycle analyses is to show that the methodology of mass balances can be applied to a domestic structure. The boundary is the house structure, per se, with all the inputs, outputs, and internal household processes (such as cooking). Eight chemicals as well as total solid, liquid, and air mass flows are being used (phosphorous, sulfur, chloride, total carbon, zinc, aluminum, iron, and copper). About 200 household inputs, mostly consumer products, were identified for analysis from an evaluation of about 40 houses.

The mass balances were conducted with product (or manufacturer-supplied) information or from citations from the literature. No direct chemical analyses were conducted as a part of this study. Dr. George Hensler, the principal investigator, has identified 14 household processes as producing the

bulk of all transformations and emissions. Heavy emphasis is given to the flow data and the complex flowcharts both within the house and then with the municipal structure. The mass balance is incomplete because any differences between inputs and outputs are represented as accumulation within the house. No independent accumulation measurement is thus available. In addition, the output is a difference function that separates industrial and household inputs in the mixed wastewater going to the treatment plant.

Conclusions from this project are now being developed. It illustrates the major difficulties in handling imprecise mass and concentration data. Numerous assumptions are needed to partition chemicals in various processes, and cumulative errors are significant. However some questions can be answered at this level of precision. For example, they found that few product prevention alternatives exist when phosphorous reduction is sought. Because phosphorous is currently restricted in washing products, most remaining phosphorous comes from food. Non-municipal choices or increasing treatment are thus needed to achieve further phosphorous improvement. Professor Baccini's group will be able to provide further information regarding improvements available from using LCA on the complex structure of the household.

As director of EAWAG, Prof. Alexander Zehnder has also been able to devote resources for the next few years to the question of sustainability. It is their position that the way to define and achieve sustainability is to first understand this issue with a suite of experimental efforts to improve basic knowledge. In a relatively small geographic location in Switzerland (as yet to be determined) EAWAG will begin a series of studies on all inputs, processes of transformation and use, and subsequent outputs. The purpose is to

- capture natural and anthropogenic processes,
- improve understanding of chemical and energy changes, and
- establish concepts for healthy or sustainable systems.

Transfer of this knowledge will help other parts of Switzerland set goals and achieve operational sustainability. Stay tuned.

FEDERAL REPUBLIC OF GERMANY

Fraunhofer Institute for Food Process Engineering and Packaging (FHG-ILV)

The research agenda of this Fraunhofer Institute is an important reflection of German advanced process engineering and biotechnology. Four groups comprise the FHG-ILV:

- Food Quality Assurance
- Technical Microbiology
- Process Engineering/Biotechnology
- Packaging Technology.

The environmental emphasis, particularly the Federal Republic of Germany's (FRG) packaging regulations, have had an obvious and large impact on their research agenda. A major direction for environmental research has emerged from the packaging technology group. This is the research effort to advance life cycle analysis as a tool for packaging design and specification. Results are expected to play a central role in determining what is actually environmentally improved packaging versus what is perceived as better (more green). The Director is Dr. Wolfgang Holley, with Dr. Horst-Christian Langowski, work leader for packaging technology. Researchers Drs. Dirk Rehmann and Nikolaus Leberle are directly involved in these advanced research efforts.

The objectives of FHG-ILV research on the methodologies for determining environmentally improved alternatives are principally focused on the level of life cycle analysis. Their specific goals for LCA are:

- development of a highly comprehensive database,
- in-depth evaluation of alternatives in packaging, with emphasis on using LCA to achieve process and product improvements, and
- creation of software for LCA.

The research group consists of about seven professionals and has been in operation for about three years. An estimated budget is $500,000 per year.

For the issues of LCA for packaging, the FHG-ILV has begun by establishing a boundary for analysis. This extends from the origins of

renewable or nonrenewable resources to the final disposal in landfills or as residue ash from incineration. Recycling is included within this boundary. The characteristic materials related to the packaging LCA that they have included for research are:

- glass
- plastic
- solid waste management
- paper and paperboard
- tin plate material
- aluminum
- commercial usage and packaging
- transportation
- copolymers and layered packaging.

The conceptual LCA framework is built on three areas of analysis and data management:

- transportation,
- processes for material production and use, and
- energy from known significant sources (this is further analyzed by European country to give the correct country-specific distribution of power-generation sources).

In each of these areas, one of the fundamental research issues to be answered relates to the allocation of emissions or wastes from multi-product manufacturing. In many cases, a system or facility produces 10-100 products from a set of input raw materials. From this facility, air, wastewater, and solid wastes are directly and indirectly related to the actual manufacturing. For a single product, how does one allocate the multi-media emissions? Generally this is not done with direct information on the number or type of unit processes utilized by a given product; it is done on an aggregate plant basis. The FHG-ILV is considering several bases for allocation, such as molar weighting, formation enthalpies, weight, or calorific value. The actual influence of these weighting factors is not currently known.

Outputs and conclusions from their research are not generally available, but the assumptions used to conduct this research were readily discussed. These provide a view of the research issues. Several chemical species are tracked in these analyses and, as expected, have vastly different results among packaging alternatives. Carbon dioxide illustrates the assumption sensitivity of the LCA. They have assigned all carbon dioxide from nonrenewable resources as air emissions, while carbon dioxide from renewable resources has zero value mass in the air emission. They feel that this is necessary to encourage the use of renewable resources. Nuclear energy, despite the essentially infinite sources, is not considered a renewable resource. Excluded from analysis are human labor, any land-related pollution, and the emission consequences from the physical structure of buildings and equipment. The latter assumption means that LCA is essentially the evaluation of the operating emissions without that of the capital investments.

Outputs from this research effort will be a chemical or waste profile integrated over the entire boundary of analysis. These single mass values are typically displayed for two products undergoing comparison. FHG-ILV works mostly in a Windows environment, with databases searched for information to feed into the calculational steps associated with elements of a particular area of evaluation. The C++ language has been used for programming the software. Output profiles are provided, but interpretation is left to the reader. FHG-ILV has not worked on the interpretation or the transformation of information for decision-making. They do, however, provide basic reports to decision-makers.

In a recent LCA, the liquefaction of mixed plastics was compared to the direct utilization for fuel value. The latter had significantly less environmental emissions, but then posed a dilemma for decision-makers. Currently, liquefaction is proposed as the clean technology alternative for mixed plastics waste, despite the consequence that it may actually be worse for the environment. From an environmental perspective, combustion for fuel value is viewed as inappropriate for plastics solid wastes—even though by another law in the FRG, only incinerated ash of municipal solid wastes can be considered for landfill disposal.

To summarize LCA research from the FHG-ILV, it is clear that they are building a tool or instrument for analyzing environmental improvement alternatives. It will thus open new doors as areas for potential improvement are identified. The LCA tool is complex, and the assumptions are not

clear. The sensitivity to assumptions does not appear to be an intended avenue of research. They are developing an inherent knowledge of the quality of the data; the general feeling is that the information derived ranges from approximate to poor, depending on the chemical species. This may be related to the direct mass balance approach. The product of their work is likely to remain an internal tool or for use only by direct industrial sponsors. Broader distribution and peer review or comparisons are less likely. No single material appears to emerge as the environmentally superior packaging choice. The framework of direct product comparisons (with all other usage specifications being equal) remains a requirement for their research.

University of Stuttgart — Institute für Kunststoffprufung und Kunststoffkunde

A dynamic group at this university is conducting research that emphasizes life cycle analysis as related to the automobile. Stuttgart is a center for this industry in the FRG, hence assuring opportunities for collaborative research. The challenges of LCA as a tool for environmental decision-making for automobile parts is formidable—there are 5,000-6,000 parts within a vehicle! Professor Peter Eyerer is the leader of this effort. The research team includes Dr. Schuckert, Mr. DeKorsy, and Mr. Saur, assisted by 20-30 undergraduate students working for shorter assignments as a part of their degree program. This research project was started in 1989.

The objectives of this focused research effort are:

- development of a comprehensive database (utilizing, very successfully, a large interaction with industry and related associations),
- research studies on parts utilized within the automobile, with an emphasis on product/material selection for environmental improvement, and
- creation of software to facilitate the continued LCA of automobile parts.

Their basis for the research on LCA has been to hold constant all operational, safety, and quality parameters of a part, and then to select the possible parts alternatives, followed by a LCA of those choices. Therefore, the emphasis is not on intrinsic properties of materials or related processes, but on the application as a particular car part.

The scientific and decision-making framework for the research begins with the automobile part for which technical criteria and economic factors already exist. They are thus adding an ecological component to these two factors. This is, in part, driven by FRG regulation to assure recycling of all automobiles and to include this as a responsibility of the manufacturer. The ecological factor is derived from the LCA and is based on the information output of their research. The output covers scrap, energy, air emissions, wastewater, and solid waste. These outputs are characterized by 50-100 chemical parameters. LCA information, as various chemical profiles, is transformed at the third stage into monetary units. That is, chemical emissions incur societal costs, e.g., sulfur dioxide creates effects on health or on buildings that can be assigned a financial value. Economic terms are used to establish the "windows" for product change costs that would balance the ecological factors. The final step requires a global evaluation to select the actions required in manufacturing automobiles as defined by the LCA and monetized information. The monetization and global evaluation are not part of Prof. Eyerer's research group's effort and, needless to say, have not proceeded very far. Nevertheless this monetization concept represents another alternative for transforming the LCA results into a context for decision-making.

In building the automobile-related ecological database, the researchers have included numerous assumptions. Boundaries for analysis are extended to the source of all nonrenewable and renewable resources and then proceed to the final disposition of all automobile materials. Emissions related to machines and plant structures are not included, nor are the ecological implications of human labor or land-related non-point sources of pollution included. When inorganic materials are used, emissions from manufacturing are allocated among inorganic products on the basis of weight. For organic materials (virtually all from petroleum refineries), the allocation basis is calorific value. They feel that this provides some mimic of the relative economic value of these chemicals. The heavy reliance on industry input for material and chemical

flows lowers the precision of information, and often mass balances are not complete. They then undertake a weak point analysis to determine further data needs.

Output from the LCA research represents the development of individual projects. Analyses include:

- air and oil filters
- intake manifolds
- paint processes, overspray wastewater, and sludge
- bumper systems for cars and trucks
- fuel tanks
- the whole car
- the car of the future.

The last three are either in progress or are planned for the future. The FRG government has placed significant pressure on industry; an early requirement is widespread LCAs and ecobalances (transformation of complex data to simple factors). Then ecoaudits are to occur to verify individual factory performance. Finally an ecolabeling is to convey the results to the public. The timeframe is not specified, but it is perceived to be less than 5 years (around 1995).

In summary, LCA research at the University of Stuttgart has been very successful in achieving industrial cooperation. This cooperation is critical for obtaining the necessary chemical and material flow information. For example, about 150 aluminum plants provide the input for this aspect of the LCA. The nature of the data collection by this research group leads to confidentiality restrictions; thus, less opportunity is available for broader use or review. No single material emerges as the superior ecological choice across the automobile parts studied, although a shift in the constituent make-up of cars will probably occur. Professor Eyerer's group has developed sophisticated flowcharts to better represent the LCA inputs, with corresponding computing software. Their major concerns are that LCAs and ecobalances are proliferating under FRG government expectations for results. The proliferation has been accompanied by poor or very incomplete data; rapid dissatisfaction and growing loss of credibility appears inevitable. The LCA concept is thus felt to be in serious jeopardy.

University of Stuttgart — Institute für Systemdynamik und Regelungstechnik

University researchers here, led by Prof. E.D. Gilles, are using a different approach for the inclusion and evaluation of ecological factors to achieve environmental optima in manufacturing. Their approach is not LCA; it proceeds from consideration of an overall quality function for environmental suitability. For them, quality is defined as the property of a product that makes it fit for use. They then assume that this quality property is a state variable W (in thermodynamic terms) and that it can be expressed as a function of other thermodynamic variables (temperature and pressure) and mass fractions of chemical constituents.

They then divide the ecological optimization into two parts. The first is simple modeling, which describes the overall transformations and separation of chemicals and materials in terms of W. Second, localized models are envisioned that will control actual operating machines or unit processes to achieve the desired values of the state function. In this way, they find the management and optimization of complex manufacturing and use scenarios. With the general outline of W and knowledge of the dependence on other parameters, they can establish the ecological issue. The partial derivatives of the state function (reflecting the shape dependence of the ecological state variable on thermodynamic and chemical constituent mass variables) are then used to formulate the problem of ecological optimization in theoretical terms.

At this stage, no ecological state variable (meaning one factor to encompass environmental goals) has been proposed by these researchers. Dr. Gilles has broadened classical manufacturing control theory to include a quality function that can be ecological. It can also be a state function expressing safety, product quality, etc. This transformation opens a variety of potential avenues that can build on the large body of control theory knowledge.

Global Challenges Network

Doctor Hans-Peter Durr is a member and advocate of an association called the Global Environmental Network (GCN). The effort, including some research by GCN, is to help define the issue

of sustainability, the final or highest level in ecological analysis and optimization. They do not really choose to define sustainability, only to enhance understanding of the issue.

The GCN correctly observes the occurrence of the Second Law of Thermodynamics in the actions of nature and the globe. There is some question about the interpretation that only recurring solar input can decrease entropy. They build on these concepts to observe the conflict between economic considerations and sustainability. The magnitude of the global situation and the controlling political system are also evident. However, GCN proposes certain large-scale actions that represent approaches to sustainability, not a definition of it. These are:

- Conversion of the former Iron Curtain border zone into an ecological reserve that (in an extended form) would stretch from Finland to the Bosporous Sea. (This is referred to as the ecological backbone of Europe.) The objective of this protected land mass would be to provide urban dwellers with a place to learn or relearn respect and commitment to natural ecological patterns.
- Preparation of an energy menu from a concise description of human (mostly not in the workplace) activities and the respective energy utilization. Each individual would then be challenged to achieve a goal of 1.5 kWh per hour or 13,000 kWh per year. This equals 1,300 liters of petroleum or 1.6 mt of hard coal per year. The 1.5 kWh per hour goal was based on their estimate of acceptable energy consumption under conditions of a limited energy resource for a global population of 5.4 billion.

These proposals represent further definitions of the decision-making level emerging from the types of methodological research underway, research that is seeking ways to truly improve the environment.

ITALY

Agency for Energy, Environment, and New Technology (ENEA)

Methods to differentiate the environmental consequences of products is a major interest to ENEA scientists as a result of their role in the EC Ecolabel Initiative. This initiative calls for study of the ecological factors of products and impact labelling based on results. The technical coordinator for these R&D efforts (located at laboratories in Casaccia, near Rome) is Dr. Raffaele Scialdoni. The EC Ecolabel project is based on life cycle analysis and hence is fairly quantitative in approach for defining environmental improvements. Other Ecolabel systems focus on practices and qualitative criteria.

The first phase of product groups to be studied for Ecolabels contains 20 entities (Table 2).

Each product group was given a budget of about $20,000; the balance was to be provided by the lead country. The initial time schedule called for a 2-year effort. The first plan for Ecolabel was that this would be like a competition with a single winner (the gold-medal approach). This has evolved such that 20-30 percent of products in a group may receive the Ecolabel. As the results appear, this number may increase. Providing the customer with a clear, concise ecological information for making purchasing decisions remains the fundamental EC reasons for the Ecolabel.

Boundaries for these LCAs are set in the conventional fashion by extending to the source of nonrenewable and renewable resources and then to the final disposal of products or residues of products. Emissions from land disturbance, human labor, and the materials and construction of physical facilities and the machines used for manufacturing are excluded. Two of these product groups that were the responsibility of ENEA (packaging and refrigerators/freezers) have achieved a preliminary report status. These illustrate some of the research issues that arise. Also, the need to transform the results of the LCA to simpler terms is stronger because decision-making for the Ecolabel is involved.

In the packaging group, one of the central issues is the relationship of LCA for packaging versus the material or product contained within the packaging. In certain cases, the inside material could have received an Ecolabel—but not the package; and so, the differentiation for the customer would be difficult. For this reason, the Ecolabel LCA study was to be input to any or all of the other 19 product groups to complete any LCA in which packaging was required. Thus the ENEA

Table 2. Product Groups for Ecolabels in the First Phase

Product Group	Lead Country				
	Denmark	Federal Republic of Germany	France	Italy	United Kingdom
Kitchen towels	x				
Copier paper	x				
Detergents for washing machines		x			
Paints and varnishes			x		
Packaging				x	
Washing machines					x
Writing paper	x				
Toilet paper	x				
Insulation materials	x				
Textiles	x				
Detergents for hand and machine dishwashing	x				
Household cleaning agents		x			
Solar systems/water heating		x			
Batteries/accumulators			x		
Building materials based on marble dust				x	
Refrigerators and freezers				x	
Dishwashers					x
Light bulbs					x
Soil improvers				x	
Hair sprays					x

Table 3. Packaging Materials Contained Within the Product

high-density polyethylene	low-density polyethylene
polypropylene	polyethylene terephthalate
polystyrene	high-impact polystyrene
polyvinyl chloride	paper—sulfate pulp
paper—bleached sulfate pulp	paper—sulfite pulp
paper—bleached sulfite pulp	tin-plate cans (virgin)
tin-plate cans, 50% recycle	tin-plate cans, 100% recycle
aluminum (virgin)	aluminum, 100% recycle
glass, 50% recycle	glass, 75% recycle
glass, 100% recycle	

results are for generic use. The packaging materials are listed in Table 3.

Outputs were grouped into:

- solid waste
- energy
- air emissions
- liquid wastewater
- raw material consumption.

Air and wastewater streams were further refined through a damage classification of high (toxic or carcinogenic), medium (long-term or chronic effects), or low (not particularly toxic or accumulative).

From the air and wastewater LCA components, some observations were made: Based on liquid impacts, the two bleached pulp and the sulfite unbleached pulp systems for making paper were distinctively higher. Kraft unbleached pulp was a low source, and even the bulk of the bleached Kraft pulp wastewater was in the low damage category. For air, the virgin aluminum was the only distinctively high source. Thus, the bulk of the packaging had similar profiles for air and wastewater. It remains difficult to judge such tradeoffs as larger streams but of low damage consequences.

A transformation algorithm to simplify the LCA chemical and waste output profiles was proposed as a part of the Ecolabel research project. It was observed that packaging energy requirements account for about 4 percent of the total EC energy consumption. The packaging LCA air emissions and wastewater masses were both about 2 percent of the respective total EC discharges. Finally, the packaging fraction of the total EC solid waste was about 20 percent. The ratio of these percentages gave a solid waste, energy, air, wastewater weighting factors of 10, 2, 1, and 1. With these weighting factors, the masses could be condensed to a single characterization factor. This weighting essentially assumes equal relative importance for these types of LCA outputs. In contrast, the ecobalance approach from Switzerland attempts to define relative importance based on the quality of these environmental media.

For the refrigerators/freezers category, ENEA has done a comprehensive characterization of the industry and the products on the market. Their work was able to compress the diverse products into categories of similar materials composition and energy use. This is a vital step in reducing the complexity of the LCA. A total of 12 classes of refrigerators/freezers for household use were defined. These generally represented a continuum of internal temperatures—from no-low-temperature-compartment refrigerators to -18°C chest freezers; they also differentiated between single and double door units. Because the single most important LCA or ecological factor is the energy consumption over the appliance life, size of the refrigerator/freezer was another critical variable. Thus in each of the 12 categories, standard models were defined that corresponded to size (roughly two sizes per category). These then became the matrix of specific cases in this product category. The average European lifetime of these appliances was 13.5 years.

Preliminary life cycle analyses identified significant missing information, particularly concerning LCA data on materials. However, energy consumption and management of CFC refrigerants were reasonably well defined and could be used to make initial observations. Within a category, energy use profiles were virtually the same among products of the same internal volume capacity. For ozone depletion and global warming factors, the critical factor is the existence and utilization of refrigerant recovery and treatment technology.

At this stage, ENEA and EC Ecolabel research projects show that preliminary directions can be obtained. The concept of identifying significantly poor products from an LCA appears viable. It does not appear that there will be large numbers of clearly poor choices, hence the need for decisions on what other differentiations can be made will remain the central debate. The ENEA transformation assumptions for simplifying the chemical and waste profiles from LCA represents one of the viable choices.

THE NETHERLANDS

National Institute of Public Health and Environmental Protection (RIVM)

In The Netherlands, the RIVM represents a large central Center of Excellence for environmental research and policy issues. Within this organization at Bilthoven is the Laboratory for Waste Materials and Emissions (LAE). The Laboratory has major responsibility for environmental standards and initiatives in The Netherlands. One research group in LAE has begun a methodical study of industrial manufacturing and environmental emissions. Its overall goal is steady improvement or optimization of environmental alternatives for The Netherlands. This group is led by Ir. Klaas Visscher with an associate Ir. Arnold Hoogenkamp.

The Laboratory research on methodologies for analyzing improvements in environmental quality has selected a different framework with which to describe the Dutch system. Instead of focusing on a product, as is typical of life cycle analysis, they have considered industrial plants or factories as the analysis base. Thus the boundary for mass and energy characterization is the manufacturing factory unit. The objectives of this large research project are:

- to collect and build an emission and production database reflecting the manufacturing structure of The Netherlands,
- to develop methods for evaluation of the geographic implications for the environment of Dutch industry, and
- to develop software suitable for future evaluations of alternatives and policies for environmental improvement.

Research in this field was begun in 1991. The effort involves many scientists (50-60) within the Laboratory, for which this research is part of their normal responsibilities. Additional direct budget expenditures were $200,000 in year 1 and $100,000 in year 2. These funds were for outside consultants and conferences. First-stage results are expected after year 2 (1993).

The scope of the project is to include about 80 separate manufacturing categories and to achieve a cross country distribution of facilities. This would certainly represent the bulk of the manufacturing base of The Netherlands. In each category, a description of the industry, corporations, locations, and economic profile are generated. Descriptions or flowcharts of the significant various manufacturing processes are produced. Because the boundary for analysis has been placed around the entire facility, the chemical, waste, and energy discharges are the aggregate of both manufacturing and existing pollution control technologies. In that regard this method focuses on the actual flows to the air, water, or land environment of The Netherlands. As many chemical species as are known and available as data are included in these factory balances. More often the emissions are known without full corresponding knowledge of the input sources, particularly for trace constituents. Because their concerns are the geographic concentrations of industry versus the carrying capacity of the country, this research has the corresponding boundary and results described above.

Following in-depth characterization of mass and energy flows for each industrial category, emphasis is next placed on interpretation and solutions. The local or regional implications of the

current distributions of types and numbers of industries can be used to determine critical chemicals or wastes for improvement. Independently within each category, technical solutions involving clean technology and pollution control are evaluated. Discussions with industry are on-going and focus on the industry developing an agenda for improvement. The quantitative information from RIVM, not only of a particular industry but of the geographic distributions of different industrial categories, assist the discussions on environmental improvement.

Observations and discussions of this large RIVM effort are providing some preliminary conclusions. Data, particularly the quality of data obtained over some reasonable time periods, remain major limitations in defining the type or precision of questions that can be addressed with this method. Following this first stage, more in-depth analyses within manufacturing facilities and involving individual unit processes are envisioned. The printing, dairy processing, and textile dye and printing industries are scheduled for the first evaluations. The results of each analysis stage will be generally available and widely discussed in The Netherlands (some reports are already available in English). Discussions between industry and government appear productive, although they are still in the learning phase. The view seems to be that the industry commitments are to move the less progressive members up to a current, moderately achievable floor of technology adoption.

University of Amsterdam

Methodology research at the University has made a sustained commitment to improving theories and analysis frameworks for assessing alternatives to achieving environmental improvement. Within the University the focus of this work is in the Interfaculty Department of Environmental Science (IDES), led by Dr. Hans van Weenen Their work originated in a large research project (concluding in 1991), called PRISMA (Project of Industrial Successes in Waste Prevention). In PRISMA they undertook the following:

- development of methodology for implementing waste reduction in manufacturing plants, and
- identification and demonstration of cost-effective solutions for waste prevention in five companies from the Amsterdam region.

This project was essentially to translate and adapt U.S. concepts in pollution prevention to the Dutch industrial and governmental systems.

Extended research was next, under the PROGRES project (starting in 1990). Industrial organizations in the province of Gelderland were used as a base. Research and development activities were initiated to arrive again at cost-effective demonstrations of waste reduction in manufacturing. The service industry was highlighted in PROGRES.

New methodological research of IDES and others in The Netherlands has now been supported by the EC under EUREKA (the European Industrial Research Initiative). The new directions were generated by observations of the field of product design. Criteria used in product design included recyclability, degradability, and disposability. In parallel with manufacturing, these were similar to end-of-pipe or add-on criteria. For product design, these criteria were thus considered end-of-use. What was needed, again by direct analogy, was product-integrated, product design, or performance specification criteria and methodologies to achieve a preventative goal. In this light, the new focus would be green design.

The research objectives for this group and others in the EUREKA project are:

- better understanding of how products are realized, as an iterative, multi-criteria process;
- formulation of green product design methodologies that can influence the above processes in the design stage to achieve environmental improvement;
- development of databases to facilitate research evaluations on which alternatives are actually better for the environment; and
- demonstrated successful application of principles for environmental improvement through product design efforts of several specific projects sponsored under Eco-Design (EUREKA-PREPARE PROJECT, covering 1991-1994 and the countries of Austria, Belgium, Denmark, Finland, FRG,

Italy, The Netherlands, Norway, Sweden, and the United Kingdom).

Results from the eco-design research in methodologies appear to have identified three common principles to evaluate alternatives:

1. requirement for a total life cycle analysis;
2. use of multiple evaluation criteria; and
3. necessary awareness of the dynamic, iterative nature of the design activity.

The LCA or mass/energy analyses remain central to optimization, and they continue to reveal complex profiles of chemical and waste emissions. The eco-design criteria used in decision-making include:

- simple design rather than overdesign
- less form for form-sake
- durability
- service function
- repairability
- recyclability
- raw material intensity
- material scarcity
- consumption volume
- product toxicity
- litter potential
- ease of disassembly.

In this context for criteria, these are generally qualitative and reflect political decision-making rather than quantitative environmental impact. In fact what is sought is the use of analysis and criteria that identify alternatives in design that still meet cultural and economic constraints. If found or conceptualized, these alternatives should be adopted and the resulting environmental improvement achieved. The driving force for such product design changes may be the goals of ecolabeling. While ecolabeling will be done for the EC, The Netherlands will proceed and probably develop a Dutch ecolabel. Along with the German and Scandinavian labels, the implications for consumers remains unclear.

Conclusions can be drawn from the University of Amsterdam and the EUREKA research. First, methods and theories are emerging that give separate and unique focus to eco-product design. Although these efforts grew from U.S. developments in pollution prevention, these product directions are now distinctive and possibly an area of greater emphasis in some parts of Europe. Transformation of the complex chemical and waste profiles associated with product alternatives do not appear to have been successfully converted into simplified decision-making criteria nor does this appear likely. Basic demonstration of cost-effective product design change will continue to be important for further environmental optimization. The use of qualitative not quantitative criteria is a distinctive alternative for actual determination of environmentally friendly choices.

Institute for Applied Environmental Economics (TME)

The TME is an independent research organization founded by Dr. H.Brezet; it has a particular emphasis on economic modeling. The leader of the research on methodologies for analyzing environmental improvements is Ir. Fred Schelleman, former Environmental Director in The Netherlands Ministry of Economic Affairs. Located in The Hague, the group is associated with two methodological concepts for optimizing environmental conditions of The Netherlands.

The first research effort centers on a Model for Sustainable Environmental Economic Scenarios (MOSES). This model uses a boundary around a single manufacturing plant or a uniform manufacturing category as the analytical basis. This is referred to as the source (implying the generation of air, water, and solid emissions). The source is characterized by some current profile of emissions. Technologies for reducing emissions are available to the source. (In the model these are stored in a database.) The inputs for study represent various forms of policies, including Command and Control and market-based incentives. The response of the source is both emission reduction (of some chemical parameter) and environmental investment and operating costs.

MOSES requires response curves for a particular industrial source to changes in regulation or economic instruments. These are not very transparent. Application of their new model has been

for the Brazilian government to assess implications and choices for water pollution policy. Interestingly, the model does not include preventative strategies for cost-effective changes in manufacturing. This is in fact true for most economic models for environmental management. From other studies for the Ministry, it was estimated that about 10-15 percent of The Netherlands current pollution can be reduced by pollution prevention.

The second methodological research effort involving TME is The Netherlands Ministry of Economic Affairs' Eco-design Programme. It was begun in March 1992 and has a budget of approximately $1.2 million for a two-year period. The project is chaired by the TNO Product Center, Delft. The objectives closely follow those of the EUREKA project described under the University of Amsterdam, but they emphasize actual Dutch demonstrations of successful change through design for environment. The specific manufacturing facilities and products are evolving, but three are already completed:

- the Vereninging van Bloemenveilingen in Nederland, VBN (Society of Flower Auctions in The Netherlands), for the design of a durable plant tray;
- Ahrend-Cirkel BV (design of an office chair); and
- Etna BV (design of a gas cooking plate).

Examining the second design case study, the process began with a need to reestablish market position and to reflect the more stable overall demand for office furniture. Environmental criteria were inserted in the early design preconditions. As usual, economic and ergonomic specifications were first fixed. The environmental emphasis was thus on more environmentally friendly materials, repairability (ability to be easily reupholstered), and recycling by third parties. From the first set of alternatives (developed by a company-wide team) the possible replacement of thermoset polyurethane was not adopted because of cost and functional reasons. However, continued priority is given for future alternatives. The chair base was selected to be a nylon glass fiber-reinforced plastic. This occurred only because the supplier agreed to recycle all bases that would be returned to the chair manufacturer. Without this guarantee, the base would have been replaced by another material with a better eco-profile, but without a guarantee of recycle.

The other two product reviews arrived at similar incremental improvements. Summarizing the research progress and results of the TME activities, it appears that in current eco-design methodologies it is pragmatic to select a single criterion and develop a successful alternative. The absolute reduction in material mass used in a product, on the basis of no increase in energy consumption, appears to be a clear-cut success. Other changes involving trade-offs are unclear in overall environmental criteria. A focus on use or a service rather than a product seems to improve the possibility of significant improvements for the environment (generally by discovering a new niche in the general economic business picture). Eco-product design changes are potentially significant for impact on current and future suppliers, hence the need for increased ability for rapid manufacturing response. The environmental factor is thus adding another variable to the mix already generating change in the marketplace.

Delft University Clean Technology Institute (INTERDUCT)

As one of the major universities in The Netherlands, the programs here in environmental research are expected to be strong. Such is the case, including the organization of the faculties under the INTERDUCT structure, thus representing about 80 percent of such research conducted at Delft. Within the many fields of the environment, research on clean technologies and methods for evaluating options is an important focus. INTERDUCT is led by Dr. Margot Weijnen.

The approach taken by the researchers for clean(er) technology is characterized by a focus on preventative approaches to environmental problems. Raw materials and energy may not be squandered (Dutch terminology). End products and waste materials must be reused in the economic cycle of raw materials and products. Emissions that enter the ecological cycle are permissible only when the environment will not suffer any lasting damage or when the effects can be controlled.

They view the bottleneck in the development of clean technology to be the diversity of environmental questions asked. Clean technology is not concerned simply with prevention of waste and effective use of raw materials. Energy efficiency must also be taken into account and attention paid to the quality of products and production processes. To prevent the environmental problem from appearing to be solved—when in reality it has only been moved to a different part of the environment or to another phase of the production route—it is necessary to consider the entire processing route. This route flows from raw material to end and waste products. The success of their approach to this issue depends on the use of integral life cycle management for which interdisciplinary cooperation is essential.

In their methodological research, production processes without any form of residues or emissions are inconceivable. In this sense it is appropriate to label their results as cleaner technology rather than clean technology. Since it takes 10 to 15 years in many branches of industry to bring out a new product or to replace a process, the range of possible basic research and rethinking is viewed as very broad.

The INTERDUCT program is a very engineering-oriented approach to the analysis of cleaner technology alternatives. They use the term precision manufacturing to point to higher efficiency and less waste. This is done in two areas,

- chemistry and process understanding to achieve optimum conversions, and
- process control advances to maintain optimal conditions in real manufacturing situations.

They continue to conduct research and develop models in both fields to assure future demonstrable improvements in the net environment.

CONCLUDING OBSERVATIONS

Life cycle analysis is rapidly increasing. It is evolving from the European conviction that, without knowledge of the entire implications for the chemical and energy factors that represent products, the potential advantages of process or product change will remain unclear. This is the rationale behind using the very large boundary limits in LCA. The intended use for LCA information in most European applications is to find new technological choices or influential factors that can be changed or would form the basis for research for future change. However, this search process is constrained by having to meet cost or other specification requirements. Some freedom for wider choice appears to be gained by a European focus on function (such as going from location A to B by car, rather than on owning a car as a consumer product) and then using LCA to explore other lateral alternatives.

Life cycle analysis is also a part of European decision-making. Hence, there is pressure on industry and research institutions to find other means to actually interpret LCA results. The typical profile in bar charts reflecting chemical species or waste masses is viewed as too complex. Thus transformation algorithms are sought to arrive at fewer parameters, and ideally a single ecofactor, by which choices could then be made. The transformation schemes found in Europe include:

- use of the relative environmental capacity of a region to the actual emissions to provide a weighting factor (the Swiss ecobalance),
- use of relative percentage contributions for a specific chemical or waste from a product category to the overall societal environmental emission of these chemicals or wastes (the Italian ENEA weighting in Ecolabeling),
- use of qualitative parameters (such as use of scarce materials or percent recycling) that reflect the societal debate and current interests to provide relative product characterization (as utilized at the University of Amsterdam), and
- use of monetization factors to convert emissions into aggregate costs of environmental damage (as proposed at the University of Stuttgart).

These algorithms basically introduce new adjustable variables that in some cases could be more political than ecological.

Finally, the overall European goal appears to allow the marketplace to reinforce more ecological products as these would have labels designating qualities that lead to an improved environment. In

this sense, the LCA-based concepts are less regulatory and rely on personal choice, although the system has a substantial set of requirements and policies. This also involves some major assumptions regarding how strong consumer price sensitivity is. What can be attributed to the purchase of goods not for direct value (such as quality, long life, superior design), but for indirect value (i.e., for the environment at some undefined locations)?

This overall system is underway in Europe with all the associated actions of universities, institutes, industries, and government. It is, in many ways, at the early stage of learning about the concrete value of such an approach. LCA and the attendant interpretations certainly can consume major amounts of time and resources. This process also clearly contains many political elements. There is frustration presently in Europe with this approach as it emerges into real terms.

A comparison to U.S. industrial activities in the similar areas of pollution prevention provides one type of insight into the European work on methodologies to assess net environmental improvement. Such a comparison and contrasts are offered here based on this author's experience and current knowledge. First, the U.S. has worked steadily toward goals similar to those put forward in Europe for LCA, namely, finding improvements to manufacturing that meet specifications, are cost-effective, and reduce waste or chemical losses.

The U.S. techniques for identifying opportunities for improvement are not generally by LCA with large boundaries, but by strong, direct characterization of losses (wastewaters, air streams, byproducts, solid or hazardous wastes). LCA depends totally on differences of inputs and outputs (usually both large masses) to determine losses, and then to infer which losses are actually to the environment. The U.S. chemical characterization approach may require greater resources, although the magnitude of analytical costs can easily be overrated relative to the magnitude of the decisions being made. Time requirements are not a clear advantage of either the LCA process or the direct manufacturing emission characterization approach. The former process involves complex information gathering and significant information quality control, while the latter needs some evaluation over time to be more reliable.

The ambiguity of Ecolabel is a major U.S. factor for considering alternative means of informing the public on environmental issues and choices. There is a clear lack of agreement in the U.S. and in Europe on the priority of pollutants or media as identified in LCA. Manufacturing or product alternatives selected based on LCA profiles are not generally of an overwhelming superiority for all chemicals or wastes. Hence Ecolabeling is potentially a greater issue for marketing than for clear consumer information or net environmental improvement. Since U.S. mechanisms for pollution prevention are less constrained compared to European pressure for LCA/ecoaudit/ecolabel, there may be greater progress in the U.S. This is judged on the significant improvement—well documented in industrial pollution prevention progress since 1987 and representing largely industrial initiatives rather than prescriptive regulation. However, the need to determine that pollution prevention yields a definitive net environmental improvement remains an important long-term goal for U.S. organizations.

There is a relatively narrow range of regulatory interpretation at the federal and state levels in the U.S. In Europe there is a commonly occurring difference between government policy and industrial or societal actions—the difference "between what is said and what is done." This difference is a clear factor that must be considered when interpreting which European concepts are, in fact, viable in the U.S. Another perception held by Europeans is that their approaches derive from having less environmental quality and less progressive industrial practices than the U.S.

Finally, in the field of prevention as a means for environmental protection, the European efforts are taking new directions. The U.S. success has been principally in pollution prevention applied to manufacturing processes. This was used to develop the hierarchy of approaches, the technical methodologies, and the achievement of cost-effective change. The Europeans are slowly adopting this process approach, but they are also pursuing research to transfer these ideas to products. Thus cost-effective product changes, including commitments at the design stage, are growing more rapidly in Europe than in the U.S. This is an area of potential transfer for research techniques and manufacturing results.

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Chemistry

Marine Corrosion and Fouling Subject of International Congress

by John R. DePalma, Profile Data Services, Lebanon, NH, and Joachim Lorenz, Federal Republic of Germany, both members of the International Committee for Research on Marine Materials

KEYWORDS: marine materials; corrosion; coatings; ship bottom fouling; antifoulants

THE CONGRESS

The 8th International Congress on Marine Corrosion and Fouling, held in Taranto, Italy, during 21-25 September 1992, was the eighth in a quadrennial series. As usual it was presented under the auspices of the International Committee for Research on Marine Materials (COIPM). For the first time, this year it was cosponsored by the Marine Corrosion Working Group of the European Federation of Corrosion (EFC). Scientists from 26 countries on 4 continents were in attendance. Seven plenary lectures, 50 contributed papers, and 22 posters were presented in the English language only.

There were somewhat fewer participants this time than attended the two previous congresses (Valencia in 1988, Athens in 1984), perhaps as a result of the worldwide economic situation. However, this smaller meeting provided the advantage of a single session, which brought into closer contact experts in the fields of corrosion, coatings, and biology. At the earlier congresses, papers on ship bottom fouling and seawater corrosion had been presented separately and concurrently. Today's marine construction problems are so wide ranging (offshore construction, power plant cooling systems, pollution, etc.) that complex, multidisciplinary solutions are now required.

This theme was clearly enunciated by R.G.J. Edyvean [University of Leeds, United Kingdom (U.K.)] in his plenary lecture on microbially induced corrosion. Professor Edyvean said, "Seawater is a highly specialized environment, both for corrosion and for biological activity. The interactions are complex and cannot be described solely by one methodology. An interdisciplinary and integrated approach is required." The importance of biological influences (both micro and macrofouling) on corrosion processes and on protected and unprotected metallic paints was also stressed in papers from workers from Canada, U.S., U.K., Italy, and Argentina.

FOULING COMMUNITIES

In his plenary lecture, Prof. Giulio Relini (University of Genoa, Italy) provided a comprehensive survey of macrofouling communities in the Mediterranean Sea, referencing 410 publications. Other papers and posters described local fouling communities of Italy, U.K., Argentina, Brazil, India, and Antarctica.

ANTIFOULING PAINTS

Environmental acceptance of toxic paints was of concern to participants. In another plenary lecture, Dr. Cl. Alzieu (IFREMER, France) described worldwide regulation of shipbottom paints containing tributyltin and discussed tributyltin toxicity thresholds. He suggested the following alternatives to tributyltin:

- tin copolymers with controlled leaching rates,
- toxicants with acceptable residual effects on non-target organisms,
- anti-adhesive paints, and
- systems that prevent the deposition of surface bacterial films.

In the discussion that followed his lecture, Dr. Alzieu confirmed that copper antifouling paints (even with co-biocides) can be effective biofoulants yet harmless to commercial oyster farming. Professor R.L. Fletcher (University of Portsmouth, U.K.) described his studies of copper-tolerant organisms, including one previously unrecorded copper tolerant fouling alga, Pseudoclonium submarinum. Dr. Gabriel Ferrari described efforts at TNO (Central Organization for Applied Scientific Research) in The Netherlands to develop new environmentally acceptable coating systems for ships. He found that sponge extracts mixed in a vinyl binder inhibited at least the first stages of fouling by barnacles.

A poster by R. Maggi and others at the CNR (Center for National Research) in Genoa, Italy, on studies with acetylacetone metal complexes showed a new development in antifouling coatings research. With the copper complex in a rosin/tar binder, a 70-80 percent freedom from fouling growth was observed after seven months. And the copper complex is nearly insoluble in water. Another poster by P. Durand and others (University of Toulon, France) showed results of a study to gain a self-polishing effect by using a copolymer from methyl-diphenyl-silyl-methacrylate with methyl-methacrylate (molar mass 62,000).

SURFACTANTS

Preventing the attachment of organisms by creating a low energy surface continues to be an important subject for research. Dr. I. Walker of International Paint (U.K.) reported on elastomer coating schemes that have proved effective. Unfortunately, Dr. Walker did not present enough details of this research program. Dr. Elek Lindner of the (former) Naval Ocean Systems Center (U.S.) was somewhat more forthcoming, however. His paper gave clear insight to theory and practice in the development of surface free energy/non-toxic antifoulants. His research showed that when perfluorated surfactants were mixed into a still-liquid polymer, the surfactant molecules formed a monolayer on the surface, where they become immobilized by the hardening polymer. Most of the additives lowered the critical surface tension of an epoxy coating matrix dramatically. With only a 10 percent addition of perfluoro octanoic acid, the critical surface tension of the epoxy was reduced from 45 to 16.3 dynes per centimeter. Even better results were observed with polymers with perfluorinated sidechains.

Proceedings of the congress will be available from:

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Materials

Crystallization of Polymers—A NATO Advanced Research Workshop

by Joseph H. Magill, Liaison Scientist for Polymeric Materials for the Office of Naval Research European Office. Dr. Magill joined ONR Europe from the University of Pittsburgh, Pennsylvania, where he held Professorships jointly in Materials Science and Engineering and in Chemical and Petroleum Engineering.

KEYWORDS: crystalline polymers; phase transformations; thermotropic; morphology; polyphosphazenes

INTRODUCTION

The macroscopic properties of crystalline polymers are determined by many structural variables. The dependence of these factors on molecular weight, molecular weight distribution, chain regularity, and crystallization conditions have not always been appreciated, despite their relevance to crystalline polymers.

To address this, the NATO Advanced Research Workshop, Crystallization of Polymers, was held at the University of Mons, Belgium, 7-11 September 1992. As a reflection of interest in this timely topic, the workshop was attended by scientists from 16 countries. This report follows the basic themes of the workshop. [The previous conference, Organization of Macromolecules in the Condensed Phase, was held at the University of Cambridge, United Kingdom (U.K.) and reported in Vol. 68 of the *Faraday Discussions of the Chemical Society* (1979).]

OVERVIEWS

The opening lecture (Professor Andrew Keller, University of Bristol, U.K., "A Unifying Scheme for Polymer Crystallization with Wider Implications for Phase Transformations," focused primarily on chain folded and chain extended crystallization, with polyethylene as the polymer paradigm. The metastable, relatively mobile hexagonal phase that is formed under high pressure is considered to be a thermodynamic pathway to three-dimensional chain extension. This transient phase has broad significance for "thickening growth" of crystals undergoing transformation.

Professor Leo Mandelkern (Florida State University, Tallahassee), in "The Structure of Crystalline Polymers," identified molecular weight, molecular weight distribution, structural regularity of the polymer chain, and crystallization conditions as the key parameters for determining polymer morphology. The overall scenario is best appreciated through a variety of experimental techniques. These techniques independently address discrete morphological moieties noted at microscopic and supermolecular levels of the crystalline state. This presentation was at variance in some respects with the presentation of Keller. Differences in kind existed between these lectures that were further addressed in related papers presented in this workshop.

The kinetics of crystallization was discussed in later lectures by using theory, modeling, and experiment. Professor Jean Jacques Point (University of Mons-Hainaut, Mons, Belgium) presented a theoretical/experimental paper on "The Structure and Growth of Polymer Single Crystals." He used morphological observations and theoretical analysis to point out that regime crystallization does not have a sound theoretical basis. It can be accounted for by changes in morphology that occur with undercooling, and these are not true signatures of the modes of interfacial transformation invoked by the Lauritzen-Hoffman (L-H) theory.

Despite this criticism, Prof. Paul Phillips, University of Tennessee ("Effects of Chemical

Microstructure on Refines in Polymer Crystallization") outlined the basis for Regime crystallization according to the L-H theory and presented experimental rate data that support this growth mode for several polymer systems. Phillips indicated that breaks in the growth rate with temperature were consistent with Regime growth. He further suggested that factors such as chain branching and molecular weight influenced the "break points" in the measured growth curves.

In a novel approach dealing with the "Melting of Polymer Crystals" (polyethylene melting monitored by neutron scattering), Dr. Peter J. Barham (University of Bristol, U.K.) pointed out that this process occurs on a time scale that is insensitive to molecular weight (MW). This suggests that the relaxation times for melting are much longer than the expected reptation times, even though a molecular weight dependence is indicated.

Professor J. G. Fatou (Instituto de Ciencia y Tecnologia de Polimeros, Madrid, Spain) described the "Kinetics of the Phase Transition in Semicrystalline Polymers and Polymer Liquid Crystals," in which a diversity of polymers were investigated. He presented a general analysis of isothermal crystallization of semicrystalline polymers from the molten state and noted the significance of crystallization conditions, molecular weight, etc., on transformation behavior. Crystallization regimes of the L-H type figured prominently on his analysis.

"The Current Status of Crystallization and Morphology of Polyphosphazenes" was presented by Dr. Joseph H. Magill (School of Engineering, University of Pittsburgh, PA, now at ONR Europe). The author emphasized the commonality in transformation behavior that existed for these "inorganic" type polymers, but also pointed to some of the behavioral features that violated the general crystallization pattern from a morphological, transitional, and crystallization viewpoint.

Dr. A. Toda (Department of Physics, Kyoto University, Kyoto, Japan) lectured on "Growth Kinetics of Polyethylene Angle Crystals." According to him, we still have only a limited understanding of polymer crystallization and nucleation kinetics. Inferences made here about morphological observations are somewhat speculative at times, and theories tend to become immersed in questionable molecular descriptions of the interfacial niceties of a morphological nature. By using Regime models, Toda comments that nucleation occurs from an interface of absorbed polymer chains. The general problem that arises is that "effects" are given causal interpretation. This interpretation is based on inadequate molecular evidence that is beyond experimental resolution of the interface, something that is not uncommon in this field.

Professor Stephen Z.D. Cheng et al. (Institute of Polymer Science, The University of Akron, Ohio) addressed the interesting and controversial topic of "Non-integral and Integral Folding Crystal Growth in Low Molecular Weight (Polyethylene Oxide) Fractions." These fractions of low polydispersity (≤ 1.04) were well characterized, and molecular weights ranged from 3000 to 23000 Daltons. The kinetics of phase transformations were monitored by using the Brookhaven Time-resolved Synchrotron Small-angle X ray (SAXS), difference scanning calorimetry (DSC), and transmission electron microscopy (TEM) experiments. The outcome of these experiment was that with increasing molecular weight the lamellar thickening and thinning processes are retarded; and

- non-integral folding (NIF) occurs initially upon solidification and, depending on subsequent conditions and molar mass will increase in crystallite dimensions with time when heated above their crystallization temperature T_c (normal lamellar thickening);
- integral folding (IF) will occur through a thickening or thinning process that takes place during or after NIF crystallization. Blocky end groups retard either process.

As expected, both kinetic and thermodynamic factors are responsible for these observation, but the precise energetic balance is still to be resolved in any given set of conditions. This investigation nicely complements the earlier work of Dr. André Kovacs on the conditions of pathological crystals in this polymer.

Professor H. Marand et al., (Virginia Polytechnic Institute and State University) presented a talk on the "Crystallization and Morphology of Polyrotaxanes." These materials are a new class of multicomponent polymers, composed of macrocycles threaded by linear chains, and they exhibit interesting crystallization behavior because of their novel architecture. The linear chain was either an

amorphous poly(urethane) or a semicrystalline poly(tetramethylene sebacete), and the crown ether macrocycle fractions "threaded" into the linear chain are monodisperse and crystallize when probed. A comparison of the polymer rotaxanes with blends of their respective components display a low rate of crystallization under corresponding conditions.

Theoretical Modeling and Computer Simulation of Growth

Papers and posters on both theoretical computer simulation and experimental aspects of crystallization were presented. A general framework for crystallization, "Nucleation of Polymer Crystals with Interval Structure," was provided by Prof. André Ziabicki (Polish Academy of Sciences, Warsaw). Presumably, this treatment of the nucleation of polymer crystals, which embodies thermodynamic and kinetic aspects of the internal structure of the polymer crystal, may be applied to any transformation provided the proper boundary conditions are used.[1]

Professor M. Hikosaka (Faculty of Engineering, Yamagata University, Japan) presented his current theory on "Lamellar Thickening Growth of an Isolated Extended Chain Crystal of Polyethylene." It dealt with the lamellar thickening growth of polymers during pressure crystallization. This is a sliding diffusion theory where the thickening rate decreases with undercooling ΔT, in contrast to the well-known lamellar growth rate that increases with ΔT. Hikosaka claimed that the thickening process mimics, in a sense, the Ostwald ripening process, now well-established for metals. This point was mentioned in Professor Keller's presentations where the broader implications of this type of thickening were addressed.

Computer Simulation and Crystallization Models

Various computer simulations of polymer crystallization were presented. Dr. Goldbeck-Wood (University of Bristol, U.K.) discussed "Computer Simulation of Polymer Crystallization." He described a versatile modeling approach to the lamellar growth of polymer crystals based on an entropy barrier model that leads to a limitation in lamellar thickness with ΔT. The model is claimed to apply to: short chain paraffins, copolymers, blends (involving co-crystallization), thickening growth that involves sliding diffusion (also represented by Hikoska), and even non-isothermal crystallization. Goldbeck-Wood's model was demonstrated to fit the experimental data of several polymers (polyethylene, polypropylene, PEEK, etc.). Some details have been published recently comparing it with other "theories."[2]

The isothermal crystallization process in polypropylene was fitted by using a modified Avrami theory over most of its transformation range. Dr. J.J.C. Cruz-Pinto (University of Minko, Department of Poly Engineering, Portugal) described "Modelling of the Isothermal Crystallization of Engineering Polymers." However this was simply a curve-fitting procedure for data interpolation, without consideration of molecular or morphological niceties involved in phase transformations.

Professor Bernhard Wunderlich (Department of Chemistry, University of Tennessee, Knoxville, and Oak Ridge National Laboratory) lectured on "Unsolved Problems of Crystallization of Flexible Macromolecules." The computer simulation concentrated on relatively short chain polyethylenes and polyoxyethylenes. Melting was also addressed in Wunderlich's simulation of the phase transitions, and graphical molecular illustrations were presented. However, long-chain polymers were not considered at this time since the entire modeling process was very demanding on computer time.

POLYMER STRUCTURE MORPHOLOGY

On the polymer structural side, Bernard Lotz (Institute Charles Sadron, CNRS, France) discussed "Asymmetries and Chirality in Polyolefin Crystal Structure and Morphology." From meticulous investigations of diffraction and morphology, he deduced new and convincing evidence for the α-form of isotactic polypropylene (iPP) and poly-(butene-1)(iPBu-1). It is based on an array of polymer sheets in which the chains possess alternating handiness from sheet to sheet. Syndiotactic polypropylene (sPP) was determined to exit as strict alternation of right- and left-handed helices. Streaks that are found in the diffraction patterns are attributed to defects obtained from chain chirality or the lack of it, depending on crystallization. The

chain conformation was verified by using atomic force microscopy (AFM). In colloborative work with Dr. Jean-Claude Whittmann and co-workers, also at CNRS, an epitaxial growth procedure has been established that enables the characterization of right or left handedess in chiral polyolefins. Indeed, by using organic substrates as a growth platform, these CNRS scientists have established general rules for determining helicity and morphology.[3,4]

Along similar lines, in a poster by Drs. S. Kopp, J. C. Whittmann, and B. Lotz (Institute Charles Sadron), the "Epitaxy and Crystal Polymorphism of Isotactic Poly(butene-1)" was established as having three different helical conformations:

- 3_1 phase I and I^1, hexagonal unit cell,
- 11_3 (phase II, tetragonal), and
- 4_1 (phase III, orthorhombic).

All structures were crystallized epitaxially on organic substrates. These substrates were carefully removed before investigating the polymer layer by electron diffraction and atomic force microscopy (AFM).

Professor David C. Bassett (Department of Physics, University of Reading, U.K.) lectured on "Lamellae in Melt Crystallized Polymers." He gave a detailed account of lamellar hierarchies in melt crystallized polymers, using chemical etching techniques to expose lamellae morphology. Permanganate etching (developed by the speaker and co-workers) as well as other techniques (perchlorosulphonate) were used to investigate the sequencing of lamellar growth with tune and quantification of polymer morphology. Bassett claims that the interval morphology of the specimens are composed of S-shaped lamellar moieties, which may be isolated but are still held together although not in intimate contact. The focus was:

- lamellar divergence (with growth),
- lamellar branching, and
- implication of the ordering at fold surfaces (in regard to properties).

It was maintained that during growth there was a repulsion between layers that rendered the lamellae not in contact. Divergence was attributed to the presence of cilia that tend to move the lamellae apart. They may also be parted by frictional forces as well as by material flux in the transforming specimens as they grow.

S-shaped morphology are attributed to deviation resulting from screw dislocations cross-members that are part of the same lamellae. The extent of surface fold disorder can be related to growth (slow-fast) that induces surface stress and hierarchial arrangement such as spherulites, etc. The morphogenesis of these lamellae are said to be "interpreted in terms of relative time scales to establish the interaction between neighboring surface folds." This description differs from the lamellar twist hypothesis encountered in polymer spherulites.

Interestingly, Lotz et al. have also explained the ringed texture of spherulites of polyethylene as made up of right- and left-handed twisting of lamellae. Asymmetry is linked with chain tilt as being a necessary element associated with inherent strain to account for the twist. In recent years, there has been considerable controversy on these chain conformational topics, so the significance of these meticulous investigations merits more consideration.

Several lectures and posters also dealt with many aspects of the crystallizability of poly(oxy-1,4-phenylene-oxy-1,4-phenylene-carbonyl-1,4-phenylene, PEEK, and related polymers. This appears to be almost ironic at a time when the inventors, Imperial Chemical Industries (I.C.I.), have decided to withdraw their market interest in the PEEK film business. However, the company will continue to manufacture PEEK polymer for other engineering applications.

"X-ray Diffraction Studies of Poly(aryl ether ketones)" were addressed by Drs. Ken H. Gardner, B.S. Hscao, and co-workers (Dupont R&D Fibers Experimental Station, Wilmington, Delaware). They investigated the polymorphism of PEKK, a copolymer of PEEK, that contains different para/meta ratio in the chain. Two forms, I and II, were found. Crystallization behavior (from melt and solvents) was also studied. They described a general coexistence curve that is dependent on morphology and the formation of phases with conditions. It was established that polymorphism depended on chain stiffness, which was also found to facilitate the formation of Form II. Simultaneous time-resolved small-angle X-ray scattering

(SAXS) and wide-angle X-ray diffraction (WAXD) investigations were made to determine the long period and crystallinity in PEEK-type polymers. It was concluded that the melting/crystallinity processes were consistent with the double melting peaks observed by DSC and explained on the basis of two lamellar thickness (primary and secondary).

"The Lamellar Morphology of PEEK-type Polymers" was also addressed by other investigators. Dr. David J. Blundell (ICI Wilton Research Centre, Wilton, near Cleveland, U.K.) pointed out that the lamellar thickness was surprisingly small ($\sim$50 Å) compared to polyethylene ($\sim$100Å), for example. The nature of the lamellar was influenced by specific monomer sequences that also affected their chain rigidity. Isothermally crystallized copolymers exhibited double melting peaks.

Dr. Douglas L. Dorset (Medical Foundation of Buffalo, Inc., Buffalo, NY) described "Electron Diffraction Structure Analysis of Linear Polymers—The Use of Direct Methods for Phase Determination." He pointed out the advantages and disadvantages of the quantitative determination of linear polymer crystal structures using the well-known X-ray diffraction and less familiar electron diffraction (ED) techniques. Dorset demonstrated, by example, that electron intensities obtained from thin lamellae were sufficient for ab initio structure analysis via traditional direct methods. Correct phase values have been assigned to many of the observed reflections obtained from a variety of different polymers (natural and synthetic) with as many as 50 reflections (and more sometimes). His ED approach was used to settle a recent controversy over two rival X-ray structural determinations. Some surprise was expressed by the lecturer over the discovery that the direct phase determination is more-or-less independent of multiple scattering perturbations to the observed intensities.

Another paper along similar lines on "Morphological Characterization and Crystallization Behavior of 1-octene Linear Low Density Polyethylene Fractions" was presented by F. De Foor (co-authored by P. Schoutenden and B. van der Heijden, Dow Benelux N.V., The Netherlands). The presentation described results obtained for well-characterized polymers. Conclusions included:

- the chain microstructure of these fractions was a determinant for crystallization and morphological behavior;
- short-chain branching influenced the curvature of lamellae, as does molecular weight;
- the transition from lamellae to spherulites is a secondary complex process; and
- increased side-chain branching results in spherulites of smaller dimensions (and also more disordered); and
- crystallinity decreased as chain branching increased.

"Radiation Effects in PEEK" was a topic for a co-authored paper from Dr. Alan S. Vaughan (Polymer Science Center, University of Reading, Reading, U.K.) who studied the influence of high electron irradiation (up to 260 MGy) on crystallization behavior, melting, and morphology. For doses $\leq$ 60 MGy, crystallization was completely inhibited. It was also pointed out that irradiation can be used to modify and control reorganizational kinetics and properties in PEEK, which could advantageous in some applications. Vaughan, like Gardiner et al., claimed that multiple melting was endemic to PEEK, not an artifact of lamellar reorganization prior to melting.Crystallite thickness were reported as typically 20-30 percent of the long period dimension, in line with estimated crystallinities and the results of other workers.

In an interesting paper on the "Controlled Nucleation of PET and PEEK," Prof. R. Legras (High Polymer Laboratory, Catholic University of Louvain, Louvain-le-Newe, Belgium) indicated that PEEK degraded rapidly under ultraviolet. light. A detailed study of the efficacy nucleants established that additives with - SO_3H groups have no nucleating effect, whereas - SO_3Na and other alkaline cations (Cs,K,Li) and alkaline-earth salts of Ca and Ba are very effective. Sodium salts and PET react with the enter linkages of this polymer creating sodium carboxylate chain ends when the system is at elevated temperatures. This appears to be responsible for the enhanced nucleation efficiency demonstrated by measurements. The relationship between lamellar thickness of crystals and ionic associations of chain oligomers was established.

Parametrial results in this paper were in accord with the measurements of Blundell and others already mentioned in this report. A poster by R. Legas et al. on "The Morphology of PEEK" concluded that the crystal and amorphous regions of this polymer are influenced by each other presence.

Professor K. Viras (Physical Chemistry Laboratory, University of Athens, Greece) reported on "Raman Scattering from Longitudinal Acoustic Modes (LAM-1) of Crystalline Oligomers" of a series of poly(ethylene oxides) with different end groups:

1. $CH_3(CH_2\ CH_20)_m\ CH_3$ (two methyl groups)
2. $HO\ (CH_2CH_2O)_m\ OH$ (two hydroxy groups)
3. $CH_3(CH_2)_{n-2}\ CH_2OH$ (n-alcohols)

In this investigation, good agreement was found for all sets of nonlinear plots of LAM-1 frequencies vs $(\text{chain-length})^{-1}$ when measured data are corrected for mass and force constants arising from intermolecular end-forces. This work neatly settles a long-standing controversy about the feasibility of using LAM-1 to measure the length of molecules.

A lecture by Prof. A.C. Alfonso and co-workers (University of Genoa, Institute of Industrial Chemistry, Italy) meticulously investigated ".. the Multiple Melting Endotherms of Polyethylene Single Crystals." By using DSC, optical and electron microscopy, and small-angle X-ray scattering, they examined the melting behavior of many polyethylene crystal of different habits (that are formed from a variety of solvents). Various heating rates were used for polymer crystals suspended in a non-solvent and also in the dry state. They concluded that the reported separate melting endotherms, previously attributed to two types of crystal sectors in polyethylene, was erroneous and that only a single sharp melting peak was observed. It was demonstrated that the melting range observed in crystals was indicative only of a continuous (overall) reorganization of the crystal. This is attributed to a sequence of in-situ melting and recrystallization processes, and is not to be associated with differential melting of different crystal sectors as many believe. Hopefully this controversial issue, that has plagued and complicated the interpretation of the morphology of polyethylene for decades, is now settled!

A systematic study of the "Crystallization of Linear Low Density Polyethylenes" (LLDPE) was presented by Profs. H. Reynaers and M. Peeters (Laboratory for Macromolecular Structure Chemistry, University of Leuven, Belgium). In essence, their systematic study of selected LLDPE fractions revealed that the mean crystalline lamellar thickness decreased with increasing degree of chain branching for a constant amorphous layer thickness. The amorphous layer dimensions were also found to increase for increasing molecular mass, pointing to significant factors that control polymer physical behavior.

The spherulitic growth kinetics and morphology problems were addressed in posters by Dr. M. Dosiére et al. (University de Mons-Hainaut, Mons, Belgium). Specific examples were investigated where two crystalline forms, A and B, coexist and grow at different sites. Various growth front shapes and overgrowths were involved in poly(oxyethylene)-resorcinol complexes of low molecular weight and of molecular stoichiometry. In addition to this morphological work, Dosiére et al. reported on other isochronous growth rates of twinned crystals of polyethylene. This procedure in the hands of the Mons School is a powerful one. It has been used to establish crystal growth rates on (110) and 310) twin faces that are ever focused to differ on the source face. Crystal growth may not be homothetic.

Polymer Blends

Polymer blends, now of commercial as well as academic interest, are found to possess more desirable properties when mixed homogeneously—at considerable cost-saving for industry. The "Crystal-Amorphous Interface in Semicrystalline/ Amorphous Polymer Blends" was an interesting topic addressed by Dr. D.Y. Yoon (IBM Almaden Research Center, San Jose, California). Modeling of the crystal-amorphous (c/a) interphase was approached by using the idea that in blends more chains must return (re-enter) the ordered (crystal) interface than is predicted in the homopolymer case. Blends of two polymers, A and B, that are miscible in the melt are unlikely to cocrystallize when they (the blend) is supercooled. By using the

well-known lattice model of Flory, Yoon and coworkers predicted that a favorable interaction energy, $-\chi$, was a requirement for miscibility, but more emphasis was placed on E_2, the energy disfavoring tight chain folds that dictated the nature of the interphase. Still, the thickness of the interfacial region depends on χ. $A_{\chi AB}V \sim 0$ implies that miscibility in the melt is possible except whenever crystallization has occurred. The more negative χ_{AB} the greater the penetration of A into B for example. Still, there is experimental evidence that does not support "mixing" of PMMA or PVP with PVDF, despite their strongly favored (predicted) interaction.

Polymer Mesophases

These proved to be of considerably more interest at this Mons Workshop than they did at the 1979 Faraday Discussion Meeting. This is not surprising in view of the developing interest in polymer liquid crystals, from an academic as well as technological viewpoint.

Dr. Ingrid Voight-Martin (Institute for Physical Chemistry, Johannes Gutenberg University, Mainz, Germany) lectured on "Defects in liquid crystalline polymers as obtained from contour plot and line profile analysis of electron diffraction patterns and from high resolution electron images." She addressed the problem of defects in discotic, smectic, and sanidic types of liquid crystals. From an analysis of electron diffraction maxima used to assess line shapes and defects, contour plots were used to distinguish between syndic and smectic materials where the displacements were characterized as periodic and aperiodic, respectively. By comparison, sanidic and discotic samples exhibited only short-range distortions, whereas in smectic samples the defects caused long range distortions, even though sharp electron diffraction profiles and line broadening were evident. Microstructural mesophase information was obtained by using phase contrast techniques, and ion etching for direct surface replication techniques were used to obtain specific details of defects. Observations in high-resolution images per se and diffraction evidence were also used. Characteristic diffraction patterns were presented and discussed. Diffraction data out to 1 Å resolution, with phase information, were used to calculate the diffraction image and the conformation of the chain molecules.

Professor E. Martuscelli and coworkers (Institute for Research and Polymer Technology CNR via Torano, Napoli, Italy) presented several posters on the crystallization, morphology, and properties of polymer blends. For poly(3-hydoxybutyrate)/poly (ethyleneoxide) they found that phase separation occurred in two steps upon solidification from the melt. However, the addition of saccharin, a heterogeneous nucleant, facilitated a single transformation—the crystallization of syndiotactic poly(styrene) based blends. Another poster dealt with copolymers of propylene with diene grafted poly(styrene) and poly(methyl methacrylate), and their phase behavior was systematized under isothermal and non-isothermal crystallization conditions in relation to chemical structure.

CONCLUSIONS

This was a useful and timely meeting that covered many aspects of polymer crystallization and morphology. Controversial (some long-standing) issues were addressed and new advances presented; these included:

- morphological feature of chain folding in the condensed state
- melting of polyethylene crystals in relation to topological features
- general rules for determining helicity in polyolefins
- stem length determinations using Raman Spectroscopy.

New items addressed were:

- the role of the hexagonal phase in polymer transformations
- new approaches to modeling crystallization
- structure determination by direct methods
- mesophase structures/morphology.

Controversial topics are still:

- mechanism of polymer crystallization
- general morphology of spherulites.

On balance, weaknesses in our understanding and acceptance of crystallization behavior were highlighted through the lectures and discussions. Progress was made in our comprehension of polymer crystallization and its implication in practice. We can only hope that the lessons learned will be thought-provoking and not be readily forgotten. Now, it is almost timely to think of the next conference!

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Ceramic Matrix Composites Programs in France

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KEYWORDS: ceramic matrix composites, materials, thermochemical, fracture, fatigue

SUMMARY

The experience of spending two months in France to establish contacts and collaborations and to explore technology opportunities was rewarding and productive. As also found by others, I was appreciative of the French approach to science and technology. They already practice what we preach in the U.S. Namely, they have a working scheme for collaborative industry/government/academic research programs. Industry takes the initiative. It identifies academic centers and government laboratories that have the expertise needed to solve the problem. The government then provides funds and other resources. Once the team has been created, there are mechanisms for ensuring that knowledge is circulated and objectives are met. One interesting mechanism is the choice of thesis committee, which involves joint supervision of graduate students. The committee of 5-6 includes one member of technical staff from industry, plus two outside members from other institutions participating in the team. This approach appears to be effective and could be implemented in the U.S. Implicit in the success of this mechanism is the willingness of the committee members to devote time and effort to the project.

The French program on ceramic matrix composites (CMC) is a team effort. One team is sponsored by the Société Européennee de Propulsion (SEP). This team is developing a technology base for ceramic matrix composites (CMCs) produced by chemical vapor infiltration (CVI). The materials for the research program are produced at SEP and supplied to the participants. The major academic center is the Laboratoire des Composites Thermostructuraux (LCTS) at Bordeaux. This academic center has the principal responsibility for thermochemical issues (processing, oxidation, interfaces) and for the investigation of mechanisms

of fracture and fatigue. There is a good continuum mechanics effort at Cachan (Paris) concerned with developing constitutive laws. Another laboratory in Bordeaux is developing ultrasonic procedures for characterizing damage (with good progress). The team is completed by laboratories at Lyon and Limoge, which are investigating fatigue, crack growth, and thermomechanical properties, plus an effort at Caen on creep. The laboratories at the French Aerospace Research Institute (ONERA) are also involved. The status of this team effort can only be appreciated by being involved because most of the technical output is in the form of theses and articles, in French. There is only a slow trickle into the English language technical journals in a seemingly (to the outsider) disconnected manner.

My assessment is that the team has made considerable progress is some areas but that the effort is not yet coherent. The problem is a typical one in the material development field. Namely, there are no direct lines of technical communication between the processing/manufacturing group and the performance group. This situation exists because the team does not have a modeling effort that provides relationships between performance and constituent properties. Nevertheless, they have good control and understanding of the processing, particularly of the fiber coating, which allows them to manipulate properties over an interesting and important range. They also have an outstanding testing capability, particularly for multiaxial loading, that has provided them with a good perspective about the nonlinear properties associated with multiple matrix cracking.

Another CMC program is motivated by Aerospatiale. The emphasis is on materials having either glass ceramic matrices or SiC matrices formed from organic precursors. This effort is more diffuse and probably is still exploratory.

While achievements of the CMC team are impressive, their future is ambivalent. On the positive side, substantial technological initiatives are planned. Conversely, they are concerned about the future of European programs in aerospace.

The dilemma is that, while SEP has unmatched experience in producing components that have performed well in tests and simulations, they do not know how to predict performance. Consequently, they do not have the means for interacting effectively with customers wishing to explore the potential of CMCs. Furthermore, this dilemma arises at a time when the pressure to secure sales to customers is increasing, while the potential military market is dwindling. This situation has, I believe, resulted in unprecedented willingness to discuss collaborations and joint ventures.

This report is organized in three sections. The first relates to notable laboratory and industrial activities in France on CMCs. The second addresses infrastructural issues. The third deals with technical issues.

LABORATORY AND INDUSTRIAL ACTIVITIES

Laboratoire des Composites Thermostructuraux, Bordeaux, France

I have been very impressed by the magnitude and scope of this laboratory's effort on CMCs, especially those produced by chemical vapor infiltration. The effort here has about 50 participants (faculty, postdocs, students, technicians), and is fully funded by SEP. They have four rooms with CVD reactors that they use both for basic research on CVD and for generating test specimens. They also have extensive experience in the modeling of CVD processing, including the chemical, thermal, and fluid flow aspects of the process. All of their processing discoveries have been patented by SEP, which has a representative at the Laboratory.

In this communication, I report on two topics that I believe to be important: fibers and interfaces. They have produced SiC fibers, starting with a polymer precursor, that have both microstructural stability and retain strength up to 1500°C. To achieve this, they have found that the oxygen present in the commercially available fibers (Nicalon) is introduced primarily upon curing. Consequently, they cure in the absence of oxygen, by using γ-rays. I cannot comment on the commercial viability of such a curing procedure. However, I am convinced by their data. It is unambiguous that "oxygen-free" curing provides a fiber with 2 GPa strength up to at least 1400°C.

They have a major effort on fiber coatings here, based primarily on C and BN. They have demonstrated a remarkably wide range of composite properties, dependent on the coating thickness,

the deposition conditions (which affect its structure), and the subsequent heat treatment. One of the most important factors is the role of the coating in inhibiting fiber strength degradation during CVI. Some coatings result in fibers with essentially pristine strength. The resulting SiC/SiC composites have correspondingly high strength (> 400 MPa) with good failure strain (1%). Such systems are much better than commercially available SiC/-SiC produced by CVI. In addition to their protective role, the coatings also influence the interface sliding stress τ. By varying τ from ~3 MPa to ~100 MPa, they have demonstrated a wide range of composite performance. The trends seem to be consistent with those expected from established models of matrix cracking and of ultimate failure.

Société Européenne de Propulsion (SEP), Bordeaux

I found the SEP group to be hospitable and proud of their achievements in developing carbon/carbon, SiC/SiC, and C/SiC composites for various aerospace applications. They have an impressive display at their facility. It contains hardware produced at SEP that had been tested in France and in the U.S. Some composites have an overall length exceeding 6 feet, often with intricate features around attachments and joints.

The buildings in which the composites are produced have a high level of automation. One (older) building is for C/C and another for SiC matrix materials. The latter contains six CVI units, all operated from a central computer. All units operate with thermocouples that control temperature gradients to < 10°C. One CVI unit is capable of producing composites more than 12 feet in diameter.

They have put considerable emphasis on the use of C fiber preforms with an automated stitching operation, which allows them to build up large, complex shapes having good rigidity and integrity. Apparently, this procedure obviates the need for the molds, which are normally used to retain the shape of the preform during infiltration. These preforms are used for both C and SiC materials. I was told that this stitching capability cannot be used for SiC fibers, which may explain the emphasis that SEP is presently giving to C fiber-reinforced materials.

The company has a unique high-temperature testing facility for their composites. It is unique because they produce grips from their own 4-dimensional (4-D) composites. This 4-D material can be threaded and drilled to produce fixtures that provide good alignment and good temperature uniformity in the gauge section. They routinely test specimens up to 2000°C.

While their facilities and achievements are impressive, their future is nebulous and ambivalent. On the positive side, substantial technological initiatives are planned. Conversely, they are concerned about the future of European programs in aerospace. For example, the future of HERMES is in doubt, which is a major problem for them. A significant part of their CVI capacity for SiC matrices was intended for components to be used on this vehicle, particularly the large diameter reactor. They are also experiencing the consequences of committing substantial resources at the early developmental stages of a new materials technology. They began CMC development in 1978, and have made major investments in each successive year. Now, the company executives are expecting sales to bring in appreciable revenue. However, acceptance of these materials by aerospace design engineers is still sparse and reluctant. One of the key issues is that design codes capable of predicting component performance do not exist. SEP recognizes that codes used for metals are not applicable, but there are no acceptable alternatives. Experience at SEP has indicated that the survival and integrity of components are much greater than present design codes predict (the opposite occurred for monolithic ceramics). While this is a good sign for the future of these materials, it does not facilitate engineering acceptability. I had the feeling that SEP underestimated the problems involved in developing a design capability for composites. Now, they appear not to have the resources and expertise required to conduct the analysis and testing for new design code development. Consequently, they have tried to make progress by adapting existing design methodologies.

The dilemma for SEP is that, while they have unmatched experience in producing components that have performed well in tests and simulations, they do not know how to predict performance. Consequently, they do not have the means for interacting effectively with customers wishing to

explore the potential of CMCs. Furthermore, this dilemma arises at a time when the pressure to secure sales to customers is increasing, while the potential military market is dwindling. This situation has, I believe, resulted in SEP's willingness to discuss collaborations and joint ventures. This is an opportunity not to be missed.

French Aerospace Research Institute (ONERA)

The high-temperature composites program at ONERA is also adjusting to the diminished European interest in HERMES and other aerospace programs. The facilities for thermal and oxidation testing at very high temperatures, by using laser heating, are very impressive. They have also installed equipment for processing CMCs. One system is used to generate 2-ft-wide plates by hot pressing, mostly for glass ceramic matrices. Another is for producing SiC/SiC materials by impregnation. In this case, they first use a slurry to infiltrate the preform with submicron SiC powders and then use a SiC organic precursor for subsequent infiltrations, followed by pyrolysis. Dow Corning has developed a similar processing approach.

Historically, the ONERA group has had better connections with Aerospatiale than with SEP. Consequently, their CMC program is more oriented toward materials produced by hot pressing and by fluid impregnation than those fabricated by CVI. Aerospatiale is a larger, more diffuse organization than SEP, and I could not locate individuals capable of giving me an overview of their composite effort. However, I was led to believe that their program is not particularly well coordinated, compared with the SEP effort on CMCs, and that their research and development on CMCs is still exploratory. This would be consistent with the content of the CMC program at ONERA.

I had the impression that future European aerospace programs may not be funded at a large enough level to justify a vigorous CMC effort at ONERA. They are very interested in collaborative programs that would use their facilities and expertise.

THE INFRASTRUCTURE

The French have developed a team approach to science and technology that provides them a balanced effort in the areas they have chosen to emphasize. The activity on ceramic matrix composites is largely motivated by SEP and is jointly funded by them, by federal programs, and by state programs at the universities. There are six principal centers of activity:

- Bordeaux (CVI processing and testing),
- Cachan (Mechanics),
- Caen (Creep),
- Lyon (Fatigue and Fracture),
- Limoge (Thermal Fatigue), and
- ONERA.

The largest program is at the Laboratoire des Composites Thermostructuraux in Bordeaux. In order to circulate information and establish collaboration, the groups meet frequently, exchange students, and sit on thesis committees. Also, SEP has a representative at the Bordeaux Laboratoire and usually has one member of its technical staff on each thesis committee.

Within this CMC group, an enormous amount of technical information exists that is not known to outsiders, even though the information is not confidential. There are many theses, in French, containing information that has not appeared in English language technical journals. This research has emphasized damage mechanisms, CVI processing, oxidation, and the development of constitutive laws. The materials are provided by SEP, and are selected to exhibit a range of macroscopic properties. This range is achieved by chemical treatment of the fibers and by using different fiber coatings, subject to various heat treatments.

Although this strategy is sound, it is my opinion that the CMC group has had mixed success. They lack cohesion because of a communication difficulty between those in the processing area (mostly chemists) and those responsible for the mechanical performance (materials and mechanical engineers). The latter group has emphasized a continuum approach to composite properties that does not connect composite performance to constituent properties. As a result, the processing group has no guidance from the properties group about the relative emphasis they should give to such issues as: improving fiber strength, changing the interface, modifying the matrix, etc. To address this limitation, they have tried to assimilate the

micromechanics conducted elsewhere, especially in the U.S. However, they have no experts in this area in France. Consequently, they often have problems in understanding the literature and applying the ideas in a coherent manner.

While this problem has limited the progress of the CMC group, I also emphasize that various individual efforts are outstanding. They have done comprehensive testing in tension, torsion, and shear to develop and validate nonlinear constitutive laws. They have used ultrasonic methods to establish how the components of the stiffness tensor are changed, upon loading, as multiple matrix cracks develop. They have developed comprehensive models of CVI matrix deposition. There is also some excellent work on oxidation, with and without external SiC coatings.

Since there is so much to learn about CMCs, both in processing and performance, a joint U.S./French effort would, I believe, accelerate the rate at which we acquire the basic knowledge needed to use CMCs effectively. Both countries have complementary expertise to offer. Let's start the dialogue now.

TECHNICAL ISSUES RELATED TO CERAMIC MATRIX COMPOSITES

The overall research program on ceramic matrix composites in France is impressive. It is coordinated. It involves combined industry, government, and academic efforts. There are especially strong efforts on materials produced by chemical vapor infiltration, through the combined expertise of SEP and the Laboratoire des Composites Thermostructuraux (LCTS) in Bordeaux, plus other academic programs in Paris, Lyon, Limoge, Caen, and at ONERA. The three main strengths are in:

- processing and process modelling,
- testing and constitutive laws, and
- ultrasonic measurements of damage.

They are limited by the lack of a technical bridge between processing and performance, because they have not developed expertise in the micromechanics of CMCs.

During my two-month internship at LCTS, I had the unusual opportunity to gain access to a large reservoir of experimental information on CVI materials. This information was contained in theses, in French, as well as thesis research in progress. The comparison of this body of information with micromechanics models of damage, nonlinear deformation, and failure has allowed important technical conclusions to be reached. These will be circulated in the form of joint technical articles that will appear in the open literature within the next few months. The basic conclusions are summarized below.

The joint SEP/LCTS team has the ability to manipulate the properties of SiC/C/SiC composites. This is achieved by a combination of chemical treatments to the Nicalon fibers, adjustments to the deposition conditions for the C fiber wetting, and by heat treatment of the composites (after the CVI has been completed). Although the processing details are proprietary, the properties and microstructures are in the public domain. As a result of their manipulations, three materials are being emphasized. These materials are described in a review paper, soon to be published, by Roger Naslain (in the Proceedings of the CWRU Conference held this year). The key points are as follows:

- SiC/SiC materials with a failure strain of $\sim 2\%$ can be reproducibly fabricated (compared with the 0.3% failure strain materials that have been commercially available in the U.S.);
- The stress levels at which the nonlinear deformation occurs can be adjusted by a factor of 2, with consequent implications for the notch sensitivity;
- Contrary to commonly held views, SiC/SiC materials exhibit the same damage mechanisms as SiC/glass ceramic materials (SiC/CAS, SiC/LAS, etc.). Notably, multiple matrix cracking occurs in the 0° bundles. This phenomenon dominates the nonlinear deformation. These deformations fit the same matrix cracking models developed for the glass ceramic matrix materials, albeit with different values of the interface sliding stress τ and debond energy γ_i. Furthermore, the shapes of the stress/strain curves are the same as those for SiC/CAS, with the flow stress being adjustable through manipulation of the interface (as manifested in τ and γ_i).

- The ultimate tensile strength (UTS) achieved when the fibers have been chemically treated can exceed that found for other CMCs reinforced with Nicalon fibers. It appears as if these treatments suppress fiber failure and allow global load sharing (GLS) conditions to be achieved. As a result, the UTS is consistent with predictions based on the GLS model (found in Curtin's paper).[1]

The above conclusions have been reached by using solutions from several published articles, including Refs.1-4, to elucidate the interface properties and the in situ fiber strengths, as well as the matrix properties, from various experimental measurements. These include:

- the unload/reload hysteresis to obtain the sliding stress,
- the nonlinear strain to obtain the residual stress and the debond energy,
- the saturation matrix crack spacing to check on the magnitude of sliding stress,
- fracture mirror measurements to obtain the characteristic fiber strength S_c,
- fiber pull-out measurements to check on τ and S_c,
- transmission electron microscopy to characterize fiber coatings and debonding mechanisms, and
- ultrasonic measurements of compliance changes caused by matrix cracking.

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Policy

German S&T Cooperation with Eastern Europe and the Former Soviet Union

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KEYWORDS: BMFT; DFG; BMBW; DAAD; AvH

INTRODUCTION

Germany is one of the leading European supporters of cooperation with Eastern Europe and the former Soviet Union (EE/FSU) in basic science and technology (S&T). In 1992 the Federal Ministry for Research and Technology (BMFT) in 1992 spent more than $16.8 million (27 million DM) for projects involving scientists from EE/FSU. It also coordinates the German-Russian Joint Commission for S&T, established in 1986, with the former Soviet Union.

The German Research Association (DFG), which is the primary source of funds for basic S&T at universities, has supported collaborative activities with EE/FSU scientists since the early

1960s. In 1992, the DFG spent approximately $3.75 million for such joint research projects, including an initiative for small equipment grants.

The Federal Ministry for Education and Science (BMBW) supports a variety of activities, totalling $12.5 million 1992, aimed toward educational reform in EE/FSU. Both the German Academic Exchange Service (DAAD) and the Alexander Von Humboldt Foundation have supported large numbers of EE/FSU scientists to carry out research fellowships in Germany.

THE FEDERAL MINISTRY FOR RESEARCH AND TECHNOLOGY (BMFT)

Description of Organization

The BMFT, with a 1993 budget of approximately $6 billion, is Germany's primary funding source for nonacademic research. Its current priorities are:

- rebuilding research capacities in former East Germany;
- a commitment to basic research (which accounts for about 40% of its budget);
- increased funding for environment and health research, including ecology, atmospheric and climate research, and medical research;
- promoting strategic technologies for the 21st century to improve the competitiveness of German industry; and
- continued European cooperation in space technology, through the European Space Agency.

The BMFT supports:

- the research institutes of the Max Planck Gesellschaft, the Fraunhofer Gesellschaft, and Germany's major national laboratories [Note: all of these institutions also receive lump-sum payments from state goverments].
- individual projects in preselected areas, such as climate, health, microelectronics, and biotechnology. All research performers are eligible, including private industry, small enterprises, universities, and research institutes of all kinds.
- international cooperation — cooperation covers both bilateral and multilateral activities, including such large expenditures as German participation in CERN, the European Space Agency, and EC fusion research (JET).

In the international sphere, the BMFT supports substantial programs of cooperation with Eastern Europe and the former Soviet Union that involve several of the BMFT's internal divisions. Cooperative projects are funded by the technical divisions, the International Division, and through special funds provided to the German Research Association (DFG).

S&T Cooperation Through BMFT Technical Divisions

In 1992, approximately $12.6 million was spent through the Divisions of Energy and Life Sciences, Information and Production Technologies, and Geosciences on projects involving EE/FSU scientists. There are no exchanges of funds with EE/FSU laboratories; the funding goes directly to German research units, including Germany's large national laboratories. For example, approximately 30 FSU scientists and technicians are currently engaged in short and long term projects at the DESY facilities in Hamburg, Germany's primary site for high-energy particle physics research. The BMFT's International Division is trying to obtain more accurate statistics from the technical divisions regarding data for specific EE/FSU countries through the establishment of a central data processing system. This will allow the BMFT to plan more targeted programs.

Cooperation Through BMFT International Section

In 1992, the INT/BMFT supported a program at the $6.25 million level. This program primarily funded research contracts in EE/FSU, although the funds were channelled through German research institutes. German laboratories submit applications

to the BMFT that identify EE/FSU institutes that conduct research in the German scientific interest.

Although the BMFT has clear interest in stimulating structural reforms in science in the FSU, the current political and economic situation makes this a difficult goal in the short term, according to BMFT officials. Therefore, BMFT prefers to channel funds to carefully selected small groups of scientists, on the advice of the German scientific community.

In many cases, these funds remain in Germany in special accounts, in view of the tax policies, particularly in Russia. Russia takes up to 40% of the hard currency paid to Russian research laboratories by foreign firms.

In 1993, the budget allocation for EE/FSU cooperation will be increased to $15.6 million, which includes an earmarked $9.4 million for space cooperation. [Note: The allocation for space does not include the German contribution of 23 million ECU for Russia through the European Space Agency.]

German-Russian Joint Commission for S&T Cooperation

This Commission was established in 1986. A framework agreement has been in force since 1987 for S&T cooperation between Germany and the former Soviet Union. This agreement includes special sector agreements on S&T cooperation in the peaceful use of nuclear energy (including reactor safety), health, and agriculture. A sector agreement to cooperate in the investigation and exploitation of outer space was signed in 1988. At present, this Commission continues with the Russian government and supports approximately 30-40 projects. Because of the political upheavals in 1992, no Commission meeting took place last year.

Cooperation with Ukraine, Armenia, and in the case of the exploitation of outer space, with Kazakhstan, continues provisionally without formal agreements, on the basis of the old agreement with the Soviet Union and in the framework of projects agreed to before 1992. (Note: Research Minister Riesenhuber visited Ukraine in August 1992, and discussed the establishment of a Joint Agreement similar to the one for Russia). Projects with Ukraine have focused on material research, molecular genetics, and astrobiophysics. Special interest continues also in cybernetics and space research. There are a small number of projects with Armenia in nuclear energy and space research, as well as in agriculture.

Under the sectoral agreements with Russia, there is cooperation in the following fields:

- Nuclear Energy
  - fast breeder reactors
  - gas-cooled high-temperature reactors
  - safety water-cooled reactors
  - handling of radioactive substances
  - controlled nuclear fusion and plasma physics
  - investigation of basic properties of matter
  - radiation protection and the environment

- Outer Space
  - extraterrestrial basic research
  - exploration of Mars
  - high-altitude research on the middle atmosphere
  - microgravitation research

- Health
  - medicinal information and documentation
  - oncology
  - brain research
  - cardiology and cardiochemistry
  - infectious diseases
  - molecular biology and biotechnology in the health care system

- Agricultural Research
  - biotechnology processes in plant and animal production
  - plant protection and pest control in relation to agricultural livestock
  - investigations to increase soil fertility
  - foodstuffs research
  - increasing the efficiency of forestry
  - agricultural planning and policy

Areas of Research Interest

In the case of Russia, cooperation on high-temperature superconductors and in maritime and polar research has developed substantially. Other areas of specific research interest are: laser technology, hypersonic technology, environmental research and biotechnology.

The former GDR had more than 60 governmental and sectoral agreements with the FSU; it was the Soviet Union's leading foreign partner in scientific and technological cooperation. Most of these agreements were invalidated after German unification. Those agreements of continued scientific interest have been incorporated into BMFT-supported programs. The BMFT has continued the GDR's many years of membership in the United Institute for Nuclear Research in Dubna, Russia, and has concluded an agreement for use of its installations. Approximately 25 German scientists are working at Dubna at present on a long-term basis.

Specific Priorities for Eastern Europe

While Joint Agreements were also signed with Hungary, Poland, and Czechoslovakia in the 1980s, the BMFT currently has special interests in supporting infrastructure development in the scientific communities of these countries. In Hungary, the BMFT has recently been involved in helping to establish industrially oriented research establishments modeled on the Fraunhofer Gesellschaft. Discussions have also been held in Poland on this subject.

Coordination of Information on EE/FSU-German S&T Cooperation

Because of the difficulties of coordinating overall information on S&T projects between EE/FSU and German researchers, the BMFT is supporting the establishment of an Eastern Europe Coordination Unit (OstEuropa Verbindungsburo) in the German Space and Aeronautics Research Establishment (Deutscheforschungsanstalt fur Luft und Raumfahrt). This unit will be responsible for collecting information on all S&T projects between EE/FSU and German researchers.

Additional BMFT Funding

Additional support for joint S&T projects with EE/FSU scientists, specifically for the initial stages, comes from a separate office in the International Section. This office has a budget of $11.25 million to launch bilateral cooperation worldwide. Administered through the international offices of a wide number of German research establishments, this program has provided substantial funds for initiating joint research with Poland.

THE GERMAN RESEARCH ASSOCIATION (DFG)

Description of Organization

The DFG, founded in 1920, is a primary source for individual research grants to German universities in the natural and engineering sciences, biology and medicine, and the humanities and social sciences. Its budget for 1993 is approximately $1.1 billion, out of a total budget (federal, state and private industry) for R&D in Germany that is 2.9% of the GNP. The current budget is guaranteed for a five-year period, with annual adjustment for inflation of 5%. About 97% of the total DFG budget is spent on research-related grants; the remaining 3% is allocated to administrative expenses, including staff salaries.

The DFG is not a direct agency of the German government, but rather is a unique German instrument called a "Verein", or private society. It is government-chartered and largely federally funded (about 80%) by a direct transfer of funds from Germany's federal treasury as a single line item in the budget of the German Ministry of Education and Science. The remaining 20% of the budget comes from the state governments (länder), as well as from membership dues of adhering bodies (universities, research institutes, etc.), individual private members of the society, and gifts from private foundations.

By using elected peer review committees for proposal evaluation, the DFG supports research grants, fellowships, post-doctoral awards, travel grants, and other types of infrastructure development such as equipment grants and facilities development. Proposal pressure has increased significantly over the past few years (the rate of successful applications is now below 50%), due in part to the recent large number of Ph.D.s pursuing research careers.

The DFG is headed by a President and Secretary General (currently Dr. Burkhardt Mueller). It is divided into four Directorates

- Central Administration,
- Research Promotion,

- Promotion Procedures, and
- Collaborative Research Centers,

and a separate Group for International Scientific Cooperation.

The DFG places a high priority on supporting international scientific collaboration and finances a wide variety of mechanisms to promote international research links. These include guest professorships and postdoctoral fellowships abroad, as well as joint research projects. The DFG is a member of the European Science Foundation, and, together with the German Ministry for Research and Technology (BMFT), enables German researchers to participate actively in several programs of the International Global Change Project.

PROGRAMS WITH EASTERN EUROPE AND THE FORMER SOVIET UNION EE/FSU

Within the Group for International Scientific Cooperation, Dr. Doris Schenk, former German Science Counselor in Moscow, heads a special Program for Eastern Europe and the Former Soviet Union. In 1992, the budget for this program was approximately $3.75 million. In the past, the majority of these funds came from a special allocation from the Ministry for Research and Technology (BMFT). In 1993, however, the funds will be shared by both BMFT and the Ministry for Science and Education. A small amount of supplemental funding will come from the central DFG budget.

The DFG has supported collaborative activities with EE/FSU since the early 1960s, and traditionally has received a special allocation from the federal government for this purpose. In the early 1970s, the DFG signed an Agreement with the Soviet Academy of Sciences, as well as with the Academies of Sciences in Hungary, Czechoslovakia, Poland, Romania, and Bulgaria. No agreements were ever concluded with either the former Yugoslavia or Albania. Because of the recent political changes affecting the structures of scientific funding in the EE/FSU, the DFG at present is disregarding these agreements. It now encourages proposals for joint research, involving a broad range of EE/FSU S&T institutes beyond the traditional partners in the Academies of Sciences. In addition, in the case of the FSU (excluding the Baltics), DFG is willing to finance both sides of the collaboration, provided that the projects proposed are primarily in the German scientific interest. This flexibility extends to certain other EE countries, such as Bulgaria, but not, for example, to Poland.

The DFG funds three types of activities:

- individual research visits (both ways) for periods of 2 weeks to 6 months;
- joint research projects, including exchange of researchers (airfare, per diem, medical insurance, and laboratory supplies).
- since January 1992, small equipment grants for FSU laboratories, with a budget ceiling of $12,500 per application. (This is similar to the Supplements Initiative carried out by the National Science Foundation in FY92).

In all of these cases, applications must be submitted by German scientists to the DFG (there are no annual deadlines), which also stipulates that the equipment must be delivered personally to the FSU laboratory by German researchers. In no cases are actual cash transfers made to FSU laboratories (because of the current Russian financial policies of taxing scientific grants).

There are approximately 130 currently active projects, with a rapidly rising number of applications for collaboration with FSU, mainly Russia. While the DFG Program does not have a country quota, the largest number of projects do involve scientists from the FSU, primarily in the areas of physics, biology, and chemistry. (At present, no projects are supported in the medical sciences.)

For EE, there are approximately 25 projects with Poland (including several in environmental sciences), 30 with Hungary (primarily in the biomedical field), 18 with Bulgaria (largely chemistry), and 20 from the Czech and Slovak Republics (many in engineering and technical sciences).

One important point to note is that approximately 25-30% of the applications come from research institutes of the Max Planck Gesellschaft (MPG). The MPG, with a network of more than 60 institutes located throughout Germany, is one of the most important performers of basic research in the country. It is financed largely by public funds from both the federal and länder governments. The

MPG is a member of the DFG. Most of the research budgets of the MPG institutes are not sufficient to provide special funds for dedicated EE/FSU collaboration, hence, the large number of applications to the DFG for this purpose.

FEDERAL MINISTRY FOR EDUCATION AND SCIENCE (BMBW)

Description of Organization

In Germany, the state governments have primary responsibility for education at all levels. The Federal Ministry for Education and Science has the principal federal-level responsibility for all matters relating to education, from preschool to graduate school including vocational schools. This includes everything from co-financing (with state governments) physical infrastructure to teacher salaries. The BMBW also develops educational policies, evaluates educational programs, publishes statistical reports, and sets national standards. The state governments, while enjoying legal primacy, nevertheless operate as full partners with the BMBW in most components of the educational system. In addition, the BMBW provides support for basic research in universities, principally through infrastructure. It is the principal federal contributor to the budget of the German Research Association (DFG).

Collaboration with EE/FSU

In cooperation with the Ministry of External Affairs and the Ministry for Research and Technology, the BMBW supports several types of projects with EE/FSU including projects in the following areas:

- Advice and information exchange for promoting reforms in the higher education system, including vocational schools. This includes providing stipends for postdoctoral and teacher exchanges.
- Support for structural reform (including curriculum development and teacher training) in institutions of higher learning, particularly in the fields of law, economics, and the social sciences.
- Support for improving library facilities, including the provision of textbooks, in particular for the teaching of German.
- Support on the topic of "legislative reform" in cooperation with the Council of Europe.
- The establishment of a Coordination Bureau in the German Rectors' Conference to promote information on academic exchanges.
- Special seminars and summer schools to promote researcher mobility, and also to improve teacher training.
- Providing computers to higher educational institutions.

In 1992, the BMBW allocated $12.5 million for these activities; for 1993 the budget allocation is $15 million. In addition, in 1993 BMBW will contribute approximately $1.6 million to targeted programs of the DFG.

THE GERMAN ACADEMIC EXCHANGE SERVICE (DAAD)

Description of Organization

The DAAD is a joint organization of the institutions of higher education in the Federal Republic of Germany. Its members are the student bodies and official representatives of all higher education institutions belonging to the German Rectors' Conference, including universities, technical schools, and special engineering institutions. The DAAD promotes university relations abroad, especially through exchange of students and academics. Following the unification of Germany in October 1990, the programs of the DAAD were also opened to higher education institutions in eastern Germany. German and foreign scholars, professors, and students representing all disciplines from almost every country in the world participate in this exchange.

Funding for the DAAD is largely provided by the German Foreign Office and the Federal Ministries of Education and Science and for Economic Cooperation. The DAAD receives additional contributions for specific activities and programs from the EC, the Federal Ministry for Research and Technology, and the German state governments.

The DAAD funds foreign students and academics to carry out research and education visits in Germany, as well as for German students and academics to travel and study abroad.

Over the past few years, and particularly in 1992, the DAAD experienced a large increase in the volume of applications for research visits to Germany from the former Soviet Union. Out of approximately 50,000 fellowships funded by the DAAD last year, approximately 20% were from Eastern Europe and the former Soviet Union. On the other hand, relatively few German students and academics are interested in traveling to the FSU because of deteriorating economic conditions. In the past, the Soviet Ministry of Education selected the candidates to come to Germany; presently the selection process in entirely in the hands of the DAAD. The DAAD recently opened an office in Moscow, and is now seriously considering how it might restructure its programs involving FSU students and researchers.

The Alexander Von Humboldt Foundation (AvH)

The AvH was first established in Berlin in 1860 in memory of the eminent German scientist and explorer Alexander Von Humboldt. Until 1923 it financed German academics carrying out research overseas. After losing its assets as a result of the two worlds wars, the AvH was reestablished in 1953 to significantly increase the number of foreign scholars spending longer research visits in Germany.

Although the AvH is a private foundation, up to 95% of its operating budget comes from the federal government, with 70% coming from the Ministry of Foreign Affairs. The Ministry for Research and Technology (BMFT) and the Ministry for Education and Science (BMBW) also contribute to the budget.

The Foundation's programs are quite broad, supporting foreign scholars at various age levels in Germany and supporting German scholars to go abroad. Historically, the largest number of foreign scholars have come from the United States. However, in 1991 for the first time, the largest number of foreign scholars came from the former Soviet Union.

The AvH has adhered to its policies of supporting the best applications, regardless of national origin, and has not established any new programs aimed at EE/FSU researchers. Also, despite the growing number of applications from these countries, the AvH has not received funding increases from the government to compensate for the higher number of applications.

Between 500-550 fellowships to foreigners are given annually, aimed at postdoctoral researchers under the age of 40. In 1988 only 4% of the successful applicants came from Russia. Through about 1990, the highest number of applicants came from Poland. However, now AvH is now seeing the number of Polish applicants decline as Polish researchers choose to go to the U.S. rather than to Germany.

Out of the approximately 2000 fellowship applications received in 1992, around 400 were from FSU scientists (300 from Russians alone). About 150 applications came from the U.S., 200 from China, 150 from India, and 100 from Poland. The application numbers for other Eastern European countries have been more consistent over the past few years, on the order of 50 each for Hungary and the former Czechoslovakia.

In 1992, 50 fellowships were granted to Russian researchers. According to AvH officials, the caliber of the Russian applications was excellent, and on a par with the applications received from the U.S. and Japan. The largest number of applications were in the fields of mathematics, physics, chemistry, and engineering. Those submitted in the biosciences and medicine were generally of a lower quality; very few applications have been received in the humanities. The fellowships are normally granted for a period of one year, although, in the case of FSU scientists, support for a second year is also possible.

While the AvH is sensitive to the issue of "brain drain," the Foundation traditionally has had a strong program of maintaining contacts with its former fellows. When Russian researchers return home, the AvH can also provide needed books and laboratory equipment; it can provide invitations and support to return to Germany for short visits as well as to attend international conferences. The AvH can sponsor German researchers wishing to collaborate with their FSU counterparts.

European Community Programs for S&T Collaboration with Eastern Europe and the Former Soviet Union

by Christine Glenday, Head of the National Science Foundation's Europe Office

KEYWORDS: ESPRIT; PHARE; PECO-92; FSU; Eastern Europe

SUMMARY

The European Community (EC) supports science and technology (S&T) collaboration with Eastern Europe and the former Soviet Union through several of its Directorates. The PHARE Program (for Eastern Europe) and TACIS Program (for the Commonwealth of Independent States and Georgia), while primarily aimed at technical assistance, both support research-related activities to some degree. The ESPRIT (European Strategic Program for Research and Development in Information Technologies) Program has well-developed research links with many institutes in Central and Eastern Europe. In 1992 for the first time, the EC allocated a special budget of $64 million (55 million ECU) [Note: 1 ECU = $1.167] for the PECO-92 Program, directly aimed at increasing scientific collaboration between EC and Eastern European researchers. To support collaboration with the former Soviet Union, the EC has proposed the establishment of an International Association for the Promotion of Collaboration with Scientists from the Independent States of the Former Soviet Union.

PHARE — TECHNICAL ASSISTANCE TO CENTRAL AND EASTERN EUROPE

The European Community's PHARE Program was created in 1990 to provide technical assistance aimed at economic restructuring in Poland and Hungary. The Program was later extended to Albania, the Baltic States, Bulgaria, the former Czechoslovakia, Hungary, Poland, and Romania. Its budget is $1.6 billion for the 1992-1994 period. Approximately 80% of the budget is intended for direct bilateral assistance; the remaining 20% is aimed at regional projects.

PHARE covers a broad area of technical assistance programs (i.e., consultancy services), including agriculture, food, environment, nuclear safety, energy, transport, telecommunications, health, public administration, and social and employment policy. PHARE does not provide loans. The program emphasizes reinforcing the country's institutional framework and capabilities to handle the transition to a market economy.

A limited portion of the PHARE program is devoted to R&D-related assistance, i.e, infrastructure support, particularly in energy, environment, and telecommunications. The telecommunications sector has been selected as a priority for assistance by Bulgaria, Poland, and the former Czechoslovakia. The PHARE program, whose assistance priorities are in general determined by the recipient countries themselves, has recently undergone a major reorganization within EC to more effectively coordinate its sector programs with individual country policies. An increased emphasis of the PHARE program may go to small and medium enterprise development, particularly with Poland, Hungary, and the former Czechoslovakia, to improve opportunities for foreign investment and other commercial ties with EC member countries.

TACIS—TECHNICAL ASSISTANCE TO THE COMMONWEALTH OF INDEPENDENT STATES AND GEORGIA

Technical assistance to the former Soviet Union (FSU) is the responsibility of the TACIS Program, which was created in 1991 and has a current budget of about $525 million. The TACIS Program focuses on training in the public and private sector, energy, transport, financial services, and food distribution. Although primarily aimed at U.S. Agency for International Development-type of

assistance, the TACIS Program under its energy sector will also provide funding for EC participation in the International Science and Technology Center in Moscow, as well as support other programs in nuclear safety. In January 1993, the EC ratified the agreement (signed in Moscow in November 1992), that established the Center. As a result of the political upheaval in the FSU since the creation of TACIS, and the need to renegotiate many agreements with the individual republics, TACIS has experienced delays in executing specific programs. However, TACIS has now developed a series of National Action Plans for several of the FSU republics.

COOPERATION AND ASSOCIATION AGREEMENTS WITH EASTERN EUROPE

The EC has signed trade, commercial, and economic cooperation agreements with Albania, the Baltic countries, Bulgaria, the former Czechoslovakia, Hungary, Poland, and Romania. With the former Czechoslovakia, Hungary, Poland, and Romania, the EC has signed so-called Europe Agreements, expected to be in force in 1993. These association agreements are aimed at improving trade ties, but they also involve cooperation in a number of research-related areas such as telecommunications.

S&T COOPERATION WITH EASTERN EUROPE

ESPRIT

Some existing EC programs, ESPRIT (European Strategic Program for Research and Development in Information Technologies) for example, have well-established research links with EE research institutes. ESPRIT, one of the main programs in DG-XIII (Telecommunications, Information Industries and Innovation), has developed an extensive database for cooperation in information technology, especially for Poland, Hungary, Romania, and the former Czechoslovakia. It has many "association" agreements for joint projects in these countries. Many of these projects are funded under the telecommunications component of the PHARE program. Under TACIS, approximately $8.2 million has been allocated for assistance in developing telecommunications systems in the FSU. In addition, ESPRIT has been exploring other small initiatives for joint collaboration with researchers from the FSU.

PECO-92

For the first time, in 1992 the EC set aside a targeted budget of $64 million that was directly aimed at increasing scientific collaboration and contacts between EC and EE researchers. The two Directorates General primarily involved in managing this new effort are DG-XII (Science, Research and Development) and DG-XIII (Telecommunications, Information Industries and Innovation).

In May 1992, a special call for proposals (PECO-92) was made, focussing on the following six areas:

- Scientific and Technical Mobility, already supported by EC's Go West and Go East programs. These programs provide for visits of up to three months by EE scientists to institutions of EC member states, and for relatively shorter visits by EC researchers to EE.
- Pan-European Scientific Networks, specifically the promotion of contacts between scientists, access to laboratories and scientific equipment, and information. It also covers administrative and technical infrastructure, including secretarial tasks, communications networks, and databases.
- Conferences, Workshops, and Seminars, in all areas of science, including the social sciences.
- Joint Research Projects. This category involves both fundamental and applied research in certain priority areas between organizations and enterprises, both public and private, of the EC and EE. Areas include the quality of life (environmental protection, health protection, social sciences, and societal problems) and industrial technologies (information and communications technologies, materials and production, agro and food industries).
- Participation in Community Programs. Organizations in EE were already eligible under the EC's Third Framework Program

to participate in existing and approved programs in the areas of environment, biomedical and health research, non-nuclear energy, nuclear fission safety, and human capital and mobility.

- Participation in COST Actions. The COST (Cooperation Europeene dans la Domaine de la Recherche et Technique) Program has existed since 1971. All OECD countries can participate in all areas of research. Planning is carried out jointly, but financing is on a national basis. The EC supports only the services of the secretariat and provides occasional financing for studies. Organizations and companies in EE were eligible to submit expressions of interest in participation in already-approved COST action.

By August 1992, the EC had received almost 12,000 applications, which vastly exceeded the EC's expectations.

The proposals received for Mobility, Networks, Conferences, and Joint Research Projects were spread across scientific areas as follows: Environment (11%), Biomedicine (15%), Social Sciences (13%), Information and Communications Technologies (16%), Material, Production, and Manufacturing (21%), Agro and Food Industries (8%), and Fundamental Sciences (16%) (particularly physics).

Almost 50% of the applications were for individual fellowship visits. The largest number of applicants came from Poland, Romania, and the former Czechoslovakia, primarily for visits to Germany, the U.K., and France. Joint research projects accounted for approximately 22% of the applications, mainly from Hungary, Poland, and the former Czechoslovakia, with Western collaborators from Germany (the highest number), followed by the U.K. and France. Conferences account for another 14%. A relatively small percentage of applications (13%) were received for involvement in the EC's other programs open to participation from non-EC countries. The largest number of applications in all areas were received in material production and manufacturing and in the fundamental sciences.

Proposals were evaluated by panels of 200 experts from both Eastern (40%) and Western Europe (60%) in a very rapid time frame, in order to commit the funds before the end of 1992. Priority was given to applications for fellowships, networks, and conferences, in part because these applications could be more rapidly processed and evaluated.

The final selection of proposals involved 2531 fellowships; 159 projects for scientific conferences, seminars, and workshops; 43 projects for the development of pan-European scientific networks; 30 joint research projects; 129 projects for participation in eligible Third Framework programs; and 147 projects for participation in current COST programs.

Because of the very high volume of proposals received last year, the EC has not yet decided whether to issue a new call for proposals in 1993, or to make the 1993 selection from last year's enormous backlog.

S&T COOPERATION WITH THE FORMER SOVIET UNION

To support collaboration in basic research with the former Soviet Union, the EC (with strong support from France and Germany), has proposed to establish an International Association for the Promotion of Cooperation with Scientists from the Independent States of the Former Soviet Union. This proposed association, which has been under discussion since April 1992, is to be a separate Belgian legal entity apart from the EC; it would be open to membership from both government and private organizations worldwide. It is to be completely unrelated to the International Science and Technology Center in Moscow, and will focus only on basic S&T. Its statutes stipulate that the Association "shall abstain from military research and from any political and commercial activities."

EC officials expect the Association to be operational by April 1993, and according to its statutes, will continue through December 1994. At that time, members will review the Association activities and decide on its future continuation. Types of activities to be funded are: joint research projects, fellowships, workshops and seminars, and support for the development of networks. The Association will consist of a General Assembly composed of member organizations, a Secretariat responsible for administration, and a Council of Scientists, which will include representatives from

the former Soviet Union. The headquarters are to be located in Brussels, unless otherwise decided by the General Assembly.

In 1992, the EC allocated 4 million EC for collaboration in basic S&T with the FSU, in addition to the 55 million ECU for the PECO-92 call for proposals. Since the FSU was not included in PECO-92, the EC received approximately 120 "unsolicited" proposals from member countries, primarily in the areas of physics, mathematics, biomedicine and health, and the environment.

These proposals are being evaluated by members of the EC's CODEST (Committee for the European Development of Science and Technology Committee. CODEST draws up proposals for new priority support areas and strategies, especially in basic research and in fields important to universities and scientific organizations. Its 24 members are prominent members of the research community and are appointed to the Committee by the EC.

For 1993 the EC plans to allocate 15 million ECU to the activities of this Association.

Psychology

The Twenty-Eighth International Applied Military Psychology Symposium (IAMPS)

by Stanley C. Collyer, Office of Naval Research, Arlington, VA, and H. Wallace Sinaiko, Smithsonian Institution, Alexandria, VA.

KEYWORDS: military psychology, stress, manpower, personnel, training

INTRODUCTION

The International Applied Military Psychology Symposium (IAMPS) is a forum for the exchange of information among military psychologists worldwide. It is attended by uniformed and civilian psy-chologists who are employed by their nations' defense research establishments. In addition, psychologists from academic and industrial organizations are occasionally invited to present research results of special relevance to military psychology.

The first IAMPS was held in the United States in 1963. Since then it has been hosted by many nations and has grown into a respected and useful annual forum. The 28th IAMPS, held in Berlin in June 1992, marked the third time it has been held on German soil. The meeting was hosted by the Military Psychology Service of the German Federal Ministry of Defense. The U.S. Office of Naval Research European Office (ONR Europe) has served as sponsor and coordinator of IAMPS since its inception.

Attendance at IAMPS meetings is restricted to provide an atmosphere that promotes discussion and informal interactions. Nevertheless, IAMPS has grown in size somewhat over the years, and the 1992 meeting was the largest in terms of total attendance (62), and the second-largest in the number of countries represented (17). Of special note is the fact that, for the first time, scientists from Poland, Hungary, and Czechoslovakia attended.

Because of the differences in the size and content of behavioral research programs among the nations represented, the focus of the symposium is intentionally kept broad. Topics that are typically covered include: personnel selection and classification, manpower planning and management, leadership, training, simulation, and human factors. Each year, however, one subject is chosen for special emphasis and more detailed treatment; in 1992 the special topic was stress.

OPENING PRESENTATIONS

Brigadier General von Uslar-Gleichen, Commander of the town of Berlin, welcomed the attendees and noted the historic significance of the occasion, namely that this was the first such meeting in Berlin in more than 50 years. He spoke of the unification process and the physical and emotional revitalization of the Federal Republic of Germany (FRG). The General said that Berlin would continue to be home to five sovereign nations—France, FRG, Russia, the United Kingdom (U.K.), and the U.S.—until the last of the Russian troops have departed in December 1994. Relationships are excellent, he said, with the Russian brigade serving as a "model of the future." He mentioned that the German Parliament has voted to make Berlin the seat of government of the unified nation, and most federal agencies of the FRG are preparing to move to the city. He pointed out that the Ministry of Defense would be occupying the building in which the failed coup d'état against Hitler was conceived nearly 50 years ago.

The General discussed the changing roles of the military forces of many nations (e.g., multilateral peacekeeping, international mediating) and noted the continuing importance of military selection and training, and of understanding the effects of stress on the performance of military personnel. He wished the symposium attendees well in their efforts to enhance the quality of military forces in the free world.

Brigadier General Volker Glatt, Chief of Military Personnel Matters for the FRG Ministry of Defense, echoed the comments of the preceding speaker with respect to unification, and warmly welcomed IAMPS participants to Berlin. Getting to the heart of this meeting, the General said that the new national security situation will require screening applicants for military service for new types of abilities.

Although a major war in Europe is highly unlikely, the General said, it is essential that all nations maintain a vigilant stance. General Glatt spoke about problems of merging the two German armed forces. Some units are to be disbanded, and some functions of the armed forces will be discontinued. Downsizing will be substantial, e.g., by the end of 1994 the combined force will drop from 520,000 to 370,000. A smaller force will have unanticipated consequences for former military families, and many who expected to serve until retirement will find themselves out of the forces. Some regional economies will be adversely affected.

The long-range political situation—a united Europe—will not result in a political entity comparable to the United States, according to General Glatt. NATO will continue to be an important instrument of political and military power. He predicted that the U.S. would increasingly focus on domestic matters but would not develop an "island mentality." In concluding, the General predicted that the 35th IAMPS (in 1999) would reflect the benefits of a then-united Europe, and that stress would continue to be an important subject for military psychology.

Doctor Arthur M. Diness, Scientific Director of the Office of Naval Research European Office, discussed the history of IAMPS from its start in 1963, when eight countries were represented. He noted with pleasure that this year, for the first time, delegates were in attendance from the three former Soviet Union (FSU) countries. The main purpose of IAMPS, he said, is the exchange of scientific information, and he commended the organizers for introducing special topical themes at the two most recent meetings. Doctor Diness mentioned the uncertainties of future research funding, although he said that American defense research and development support was still quite strong, and he explained the role of ONR's European Office in fostering collaboration between European and American scientists and technologists.

On a broader note, Dr. Diness said that a rapidly changing world is providing new challenges for psychology. National budget reductions have many implications for military manpower, personnel, and training, e.g., more simulation, more embedded training, and pressures to reduce selection and classification costs. As force downsizing proceeds, he said, we must maintain the high quality of people entering and remaining in the military. We also have to learn how to train for low-intensity conflict and we should explore the need for new decision aids. With more complex weapon systems coming on-line there is a continuing need to attend to human factors and related areas to which psychology can contribute. Doctor

Diness ended on the note that, with a new spirit of international cooperation, we can shift our world view from one of "interesting times" to "exciting challenges."

Mister Martin Rauch, Chief Psychologist of the German Ministry of Defense, spoke briefly about recent German history and the impact of many years of National Socialist Party rule. The negative propaganda of that era, he said, led many citizens into depression and withdrawal. On the other hand Rauch recalled the arrival, in 1945, of the U.S. Army, and noted that the optimism he saw in those young soldiers helped to overcome six years of wartime experiences: "the future has begun again." Rauch reiterated Dr. Diness' thoughts about living in exciting times, and he added that "understanding the dynamics of change won't make the process any easier."

The remainder of this article summarizes the technical presentations of the symposium.

STRESS

The special-focus topic for IAMPS this year was Stress Factors and Stress Management. Papers were solicited on the results of stress research relevant to military environments, including investigations of the multiple causes of stress, the effects of stress on performance, stress-coping strategies, and training interventions to reduce the effects of stress. Presentations on this subject are summarized below.

Professor Shlomo Breznitz, Director of the Center for Psychological Stress, Haifa University, described field research and laboratory experiments to determine the effects of information on performance under stress (see "Enhancing Performance Under Stress by Information About Its Expected Duration," *ESNIB*, this issue). He reported on recent field experiments in which squads of highly motivated, volunteer soldiers were sent on long marches. The principal variable under investigation was the nature of information provided about the duration of the marches and the time at which this information was given. It was found that individuals given full information about the length of a difficult march were more likely to endure its rigors than those who had no such information. Misleading, but optimistic, information (i.e., understating the distance to be covered) resulted in strong performance until soldiers learned the truth, at which point morale and performance dropped; presenting overly pessimistic information at the outset of the march caused the worst performance of any condition. Subsequent laboratory experiments investigated in greater detail the role of information in affecting the ability to withstand pain. Results supported the hypothesis that having full information about the duration of a stressful task will enhance endurance, and cast further light on the role of misleading information. A number of practical implications were discussed concerning ways to maximize endurance in both military and non-military contexts. Among these were the propositions that the shorter the expected duration at the start of a stressful task, the greater its endurance, and that successful endurance of one task increases the likelihood of enduring another task of a different nature. Endurance training may therefore be improved by maximizing early success on easier tasks.

Doctor Reuven Gal, Director of the Israeli Institute of Military Studies, summarized recent research on stress reactions in the Israeli civilian populace resulting from missile attacks during the Gulf War. By way of context he said that the Gulf War was, for Israel, the most dramatic and bizarre of that nation's six previous wars—the country was attacked, day and night, for six weeks without mounting any military response. Reserves were not mobilized. As Gal put it, the battle occurred on the streets of Tel Aviv and Haifa; soldiers were ordinary citizens; the fighting unit was the family. Furthermore, virtually everyone in the country was able to track events in real time, courtesy of Cable Network News and very frequent statements by Israel Defense Force (IDF) spokespersons. Citizens' main fears reflected concern about unconventional weapons, chemical or biological. It was a paradoxical war, Gal said: hundreds of buildings were destroyed by SCUD missiles, yet there was only one fatality. Gal said that in many ways the war itself, and the reactions to it, more closely resembled a terrorist attack than a conventional war: the missile attacks generated a great deal of fear; targets were nonspecific and virtually

random; attacks were normally preceded by threats; and reactions were generally unlike those normally seen on the battlefield.

With the onset of SCUD attacks, Gal's institute conducted a series of public opinion surveys. Among the many findings he reported were:

- the highest levels of fear were found in the cities, lowest in small towns;
- the most common symptoms reported were sleeplessness, anger, and abdominal pain;
- younger respondents expressed greater fear than older people;
- one-third of the sample were Holocaust survivors and they were found to show the least fear; and
- after fear, rage was the most common reaction.

Another interesting finding was that there was a great deal of confidence in the IDF spokesperson who was heard frequently on radio. This resulted in strong expressions of confidence toward the IDF and civil defense organizations, and demonstrated that with modern communication systems it is possible that just one credible spokesperson can calm and encourage an entire nation.

Gal urged that future psychological research attend to noncombatants, i.e., citizens who are likely to be involved in conflict of the type he reported. In response to a question on the implications of this research for how the government should communicate with the public, Gal said that *information* is critical, provided it is credible. The greatest contributor to fear is uncertainty. Also, he said, the government spokesperson should be someone who projects an image of authoritativeness. [N.B. The reader may wish to consider some interesting parallels with the research reported by Breznitz concerning the importance of timely and credible information to help people endure stress of a different kind (i.e., physical pain).]

In an interesting comment from the audience, it was noted that psychological studies during World War II found that strategic bombing, designed to terrorize and demoralize the population, had exactly the opposite effect—namely to increase the will to fight and endure. These findings have been ignored in many subsequent conflicts.

Lieutenant Colonel Michael Dovrat, a psychologist with Israeli Defence Forces, gave a paper titled "A Diagnostic Model of Steps Taken Under Emergency Situations: A Missile Attack." Dovrat began with a description of the work of a "think team," a group that is able to mount rapid-response surveys for the IDF General Staff. The team's surveys (usually done by telephone) are typically conducted among civilian respondents. During the Gulf War, the team made nightly surveys on attitudes about using protective equipment (gas masks), trust in the IDF, and the like. Dovrat said that the team makes action recommendations (e.g., for propaganda themes) and summarizes the psychological state of the populace (e.g., feelings of helplessness). The value of the team's activities, he said, relate to the importance of taking into consideration the public's actual perceptions of the situation, especially when those perceptions are substantially at odds with the facts. Without attending to such discrepancies (and where possible correcting them through an information campaign), recommendations and instructions issued by the government will probably have little effect.

Another Israeli participant noted that the government is fearful of panic reactions to some of its decisions in time of crisis, hence there is strong support for the approach reported above. Understanding the necessary conditions that can produce panic in a particular emergency can greatly aid the government in formulating the best course of action. Dovrat added that national authorities need survey-based information so they can act to counter sensationalism generated by the media.

Colonel James A. Martin, U.S. Army Medical Research Unit Europe, reported on post-deployment stress issues in the Gulf War. Martin and his colleagues were in the theater of operations to highlight mental health and organizational issues. He also conducted an extensive survey for the Walter Reed Army Institute of Research, his parent organization. Among the findings he reported were:

- the most important stressor during the war was worry about families back home;
- sustaining soldiers in an alien culture, along with uncertainties about how long they would be there, was a major source of stress;

- during the lengthy pre-combat phase (Desert Shield), high stress levels were reported, largely resulting from inactivity—for many, there was insufficient meaningful work to be done.

Other sources of stress were heat, crowding, lack of privacy in group living, the integration of female soldiers, and a lack of information for those soldiers deployed in the desert. He also noted that the period shortly after the fighting ended was the most dangerous time for U.S. soldiers because of emotional letdowns that caused reduced attention to the remaining dangers (e.g., unexploded ordnance).

One of the most significant differences from previous wars, Martin noted, was in the area of communications, where soldiers (and, indeed, the world) could learn of significant developments in nearly "real time." The level of communication with family members was also unprecedented. Long-distance telephone facilities were heavily used; for the first time in our history American soldiers could readily call home from the battlefield. Such calls were a mixed blessing, however, in that they could convey information about critical conditions at home, about which the soldier could do little but worry.

Shortly after the war ended, soldiers reported anxiety about the rate at which the Army began its downsizing, and the implications for their future military careers. The rate of change appeared to be more significant than the fact of change itself, according to Martin. Finally, Martin discussed the importance of providing soldiers the opportunity to discuss their personal traumas with others in their unit. Those who were physically injured experienced psychological problems brought on by being separated from their units when they were evacuated for treatment. The latter finding underscored a well-known phenomenon: the importance of the primary group or unit as an element of cohesiveness and morale.[1-3]

Lieutenant Colonel Dr. Sandro Tomassini, head of the Applied Psychology Division for the Italian Ministry of Defense, presented a paper (co-authored by Dr. Roberto Arbitrio) concerning ways to avoid engendering widespread stress (e.g., fear, frustration, uncertainty, sense of loss) during wartime by carefully managing the information that is provided to the populace. The speaker alluded to U.S. military engagements from Vietnam to the Gulf War in illustrating his thesis about the uncertainties of wartime events and emotional reactions to them. He discussed the role of communication strategies in minimizing the major sources of frustration in the population. Suggested communication principles included: minimizing delay in providing information about significant events; emphasizing the effectiveness and availability of military resources; minimizing imagery associated with loss of personnel; and providing plausible and logical explanations for tactical and strategic decisions. These recommendations were consistent with the research reported by Gal, described above.

Dr. Ross R. Vickers, a psychologist at the U.S. Naval Health Research Center, addressed stress-related issues as they pertain to cognitive performance in military jobs. He discussed the current status of various model-based approaches to describing the effects of stress on cognitive functioning, with primary emphasis on the effects of heat stress. He first presented a conceptual model of stress, incorporating three types of stress definitions commonly found in the literature:

- a focus on the environmental factors impinging on the organism;
- a focus on mobilization of resources in order to maintain homeostasis; and
- a focus on deviations from homeostatic baselines.

The conceptual model depicted the relationship between level of stress and failure rate and described three major segments:

- the "normal range" in which changes in the level of the stressor has little effect on performance;
- the "stress range" in which increased stimulus (stressor) intensity results in increase failure rate; and
- the "breakdown range" in which further increases in stressor intensity produce unpredictable and widely varying effects.

Vickers discussed the effects of environmental stressors on cognitive performance, largely with reference to heat effects. He presented data suggesting that for jobs requiring simple cognitive

functions, performance will be affected by heat intensity, but not by duration of exposure; for complex and cognitively demanding tasks, the effects of temperature and duration of exposure are roughly additive (i.e., both are important). He then discussed the way in which such information can be used to estimate the effects of heat stress on performance of various military jobs, i.e., by combining it with a model that relates cognitive abilities to job performance. He stressed, however, that much research remains to be done to increase the accuracy of such predictions. He also described work by Ackerman[4] to incorporate the role of practice into an ability-performance model; such a model should improve our understanding of how training can be used to improve resistance to stress. For example, evidence shows that training can result in shifts to less resource-intensive cognitive strategies[5] that should, therefore, be more resistant to stress effects.

Vickers summed up by saying that our current state of knowledge regarding stress effects allows us to make qualitative, but not quantitative, predictions about the effects of stress research on military performance. The availability of several recently developed conceptual models should make for rapid progress in the near future.

Dr. Günther Fleck, Austrian Military Psychological Service, described an ongoing field study to examine stress reactions and coping capacities, with applicability to pilot screening. The research, a collaborative effort with the University of Graz, is examining psychological, hormonal, and biochemical stress reactions in military pilot applicants when exposed to their first experience in aerobatics. The goal is to develop a measure of stress reactivity that would combine psychological measures to assess the quality of arousal (positive or negative connotation) with endocrinological measures to determine level of arousal. Although the interdisciplinary field of psychoendocrinology has recently been established,[6] Fleck noted that most stress research continues to be done in isolation. An integrated approach to assessing human stress reactions in real-life situations could prove useful in pilot screening and other military testing applications.

The focus of the research is on examining the relationship between stress coping capacity and controlled information processing (as distinguished from automatic processing[7]). The author hypothesizes that individuals with high coping capacity (resulting from a combination of coping strategies and physiological condition) are able to maintain higher information processing levels than people with low capacity. The research strategy was discussed, and the psychological and physiological measures were described. Behavioral tests include visual concentration, pattern recognition, critical flicker frequency, and subjective evaluations; endocrinological variables include blood glucose, testosterone, human growth hormone, catecholamines, cortisol, and magnesium. The research is ongoing, and results were not yet available.

Lieutenant Colonel Karol Wenek, Department of Military Psychology and Leadership, Royal Military College of Canada (RMC), summarized his research on cadet perceptions of stressors in the RMC. The work was conducted to assess the adequacy of existing psychological support services. The RMC is the source of more than 40 percent of Canadian officers, a proportion that will increase with downsizing of the force. The RMC's objectives are to provide BA-level education, bilingual skills, physical fitness, leadership skills, and a military ethos. As in most universities, there is a heavy academic workload, which is known to be a source of stress. Of the 750-cadet student body, 12 percent are female and about 10-15 percent are former noncommissioned officers. Wenek said that the traditional view of stress coping held by most senior faculty was that most students are sufficiently robust psychologically, and that if they cannot cope with the rigors of the program they don't belong at RMC.

To determine the need for professional counseling services, Wenek surveyed the entire student body (with a 62 percent return rate). Subjects answered a long questionnaire that dealt with perceived stress and its symptoms and presumed causes. A factor analysis turned up eight factors that could account for most of the stress experiences reported. Findings that Wenek reported included:

- fear of failure, test anxiety, and lack of privacy were major issues;
- most cadets turn to peers or friends for help and relatively few go to official sources such as the chaplain, the doctor, or professors; and
- many cadets are reluctant to seek help.

In general, results were consistent with findings from similar research.[8] However, academic concerns were found to be more important in the present study, presumably due to the intensity of the academic program at RMC.

Wenek noted that his fellow faculty members tended to be surprised at the high levels of stress that turned up in the survey. His recommendations for increased support services focused on three areas:

- awareness and educational programs to address concerns about harassment and vocational goal-setting;
- skill development programs to teach, for example, study skills and time management; and
- professional counseling services to handle a variety of short-term emotional disturbances and anxieties.

Mister Herbert Aschenbrenner, German Federal Armed Forces Central Personnel Office, Cologne, reported on recent activities of NATO Research Study Group 22, "Psychological Support for Military Personnel." The goals of RSG 22 are to collaborate in development of psychological support techniques and training methods to minimize the adverse effects of operational stress. Aschenbrenner described the state of psychological support activities in member nations. He pointed out the importance of providing basic information on stress effects and stress-coping techniques to personnel at all levels in the military hierarchy, with particular emphasis on training of high-level operational commanders. Activities of RSG 22 will focus on the development of simple and practical techniques to minimize combat stress reactions. Among these are self-help techniques, buddy-aid techniques, and intervention techniques for use by the military leader. Included in the latter category, for use at the platoon and squad levels, are various methods for setting a positive example, reducing soldier anxiety, and enhancing confidence and morale.

MANPOWER AND PERSONNEL

Doctor H. Wallace Sinaiko, Smithsonian Institution, presented a paper on "Military Manpower in an Era of Smaller Forces: Some Issues and Opportunities for Applied Psychology." In establishing the context for his remarks, Sinaiko said that restructuring has been a direct consequence of the end of the Cold War. Forces are shrinking dramatically and, at the same time, the nature of what they will be called upon to do is changing. Large-scale warfighting will diminish, and demands for peacekeeping and humanitarian assistance will increase. In addition, multi-national operations will call for new command and control mechanisms compatible with multicultural, multilingual situations. Sinaiko's paper reported on organizational downsizing experiences (both military and industrial), and suggested the work of Kozlowski et al.[9] as an excellent resource. He also spoke about the consequences of restructuring (for nations, military organizations, and individuals).

Most of Sinaiko's remarks dealt with opportunities for military psychologists as a result of the changes taking place. There are many issues to which psychology can contribute. Of particular relevance is a need for new techniques to select and train military personnel to adapt to unfamiliar, non-traditional tasks; the research of Mumford and Connelly[10] was cited as exemplary. Attaining the unit cohesion and effective leadership styles that will be demanded by new roles and missions, such as peacekeeping, is an important area. Psychologists should provide expertise in the development of high-quality, simulation-based training. This is important because of the excessive costs incurred in training for high-technology weapon systems. The new culture of military forces calls for supporting both individual and family stability, an area in which psychology has had considerable experience. With respect to attracting and recruiting the best young men and women as volunteers to our forces, we need to assist in preserving the military's strong image. And, in the current downsizing, we are in a position to contribute a great deal about "lessons learned" from current and past

organizational experiences. In closing, Sinaiko noted the importance of exchanging information among researchers on these matters, and he made some suggestions about how IAMPS could be a useful instrument in that regard.

Mister Wolfgang Weber, a senior psychologist with the German Armed Forces, described lessons learned when computer-assisted testing (CAT) was introduced into operational use as the principal diagnostic tool for testing German military personnel. Weber described the history of CAT in the German Armed Forces. A decision was reached in 1982 to switch from paper-and-pencil testing to computer-assisted tests. There was a great deal of contact between German Army psychologists and people in the U.S. and Canada who were working on CAT. In 1989 the system was introduced on an operational basis. CAT is currently in operation at 54 sites, and the full installation is expected to be on line by 1995. Weber said that the system has 60 different selection and classification tests presently installed, with a pool of more than 5000 items.

Many types of tests, including some that are adaptive, are in the system. A special proctor's station was developed that, among other things, has flexible control of all examinees and provides protection against false input. Testing results are immediately available, and outcomes can be presented in a variety of modes. A system of passwords and other lock-out techniques provides security against test compromise . A special-purpose keyboard is integral. Each examination site has 50 to 60 individual testing stations. Personnel who work in the testing units are trained in software management. Administrative support for the system resides in a central office in the Ministry of Defense. The German CAT system has been highly acceptable, both to applicants for military service and to senior officers. Weber said that paper-and-pencil testing is no longer done in installations that have CAT (except for backup in the event of power failure). German psychologists are not fully satisfied with the available tests, most of which are straightforward adaptations of the older paper-based tests. In part this is because the current tests do not take full advantage of the capabilities offered by computer-based systems to assess other kinds of cognitive skills. There are plans to continue the development of tests made possible by the use of interactive computer-based technology and to explore applications to computer-assisted training. Weber also indicated some use of experimental tests that have been in development at the U.S. Air Force's Learning Abilities Measurement Program (LAMP) facility at Brooks AFB. Weber said that the German Secretary of State has seen the Army CAT system and would like to promote CAT for use by public schools.

Professor Oldřich Mikšík, Czechoslovakian (now Czech Republic) Ministry of Defense, Advisor to the Deputy Minister of Defense for Social and Humanitarian Affairs, summarized his work on developing a computer-based diagnostic system to evaluate personality factors and predict changes resulting from stressful life events. It is based on a model of mental variability and autoregulation mechanisms. Such a system could be used both in personnel selection and as an on-the-job diagnostic tool to assess the need for interventions to prevent psychological failure (mental breakdown). A battery of 13 tests has been developed, covering a wide range of mental functions. His system has been evaluated in the context of the mental workload of power station operators and public transportation workers.

Captain António Roy Bruto da Costa and Col. Aurélio Pamplona, Portuguese Army Center for Applied Psychological Studies, Lisbon, described a study to evaluate the reliability of psychological interviews used in the selection process for Portugal's Military Academy. Selection for the Military Academy involves paper-and-pencil tests (both aptitude and personality tests), group activities (discussions and team problem-solving exercises), and interviews (both psychological and job-oriented). Prior to 1986, psychological interviews were entirely unstructured and did not have uniform evaluation criteria. In 1986 a standardized evaluation format was developed. It required interviewers to rate applicants on 14 factors (using a 5-point scale), while allowing them to retain substantial flexibility in the conduct of the interview. This study examined the extent to which the new format resulted in increased interview reliability. The results showed that there was still substantial variability across psychologists conducting the interviews, and that the evaluation factors were not interpreted in a consistent fashion. The authors concluded that the number of evaluation factors

should be reduced and defined with greater precision, and that a more structured interview format should be developed.

TRAINING

Doctor Kent Williams, Virginia Polytechnic Institute, reported on research in automating the process of doing detailed cognitive task analyses for intelligent tutoring systems. Williams reviewed the history of intelligent tutoring, as well as the theoretical research on which it is based, and he described various methodologies that have been used to develop authoring systems.[11]

Experimental research has shown significant gains (for example, in training radar console operators) when intelligent tutoring is used.[12] A fundamental component of these systems is an "ideal student model" of expertise. Such a model contains the knowledge that is to be acquired, and it is used as the criterion to which a trainee's performance is continuously compared. Building ideal student models is complex, labor-intensive, and costly. Largely for those reasons, training establishments have been slow to adopt intelligent tutoring. To reduce developmental costs, an automated authoring system was built. Williams described the authoring system, which elicits and structures, from subject-matter experts, the knowledge necessary to perform procedural tasks. The resultant cognitive task analysis becomes the ideal student model. Williams pointed out that the automated task analysis technique may also be used to determine the level of complexity of the system being taught. Following his talk, Williams demonstrated the authoring system.

Captain Dr. Jürg Stadelmann, Swiss Army Training Command, presented a paper on leadership training as a motivational tool for noncommissioned officers (NCOs, in this case, corporals). In his introduction, he pointed out that perceptions of national security threats have lessened significantly in Switzerland (as in most other nations), and that there have been pressures to decrease defense budgets. Switzerland has universal military service for all able males, resulting in a force of 540,000 militiamen who drill regularly. NCOs are recruited from among young conscripts. Stadelmann said that it has been increasingly difficult to recruit NCOs, e.g., only about one-third of those who agree to remain in the Army are true volunteers—the others have responded to some sort of coercion.

He reported a study that compared the attitudes of NCOs who had been given special leadership training with a group that had not been trained. (Outcomes of the study were based exclusively on the opinions of NCOs and the officers who trained them.) The former tended to see themselves as better NCOs, and most felt that the leadership training would be useful in their post-service civilian careers. Stadelmann concluded that the special training made more effective NCOs.

Professor Orlindo Gouveia Pereira, the New University of Lisbon, presented a paper co-authored by Jorge Correia Jesuino, that described the development of an experimental course for Navy and Marine first lieutenants; it was designed to improve leadership skills under stress. The course incorporates a number of principles developed in previous research. In particular, it stresses the importance of instilling trust and confidence among subordinates, of developing negotiation skills, and of fostering group cohesion.

The course was developed with a view toward promoting leadership at three levels:

- symbolic (conveying the meaning and consequences of the required actions),
- negotiating (overcoming resistance within the group, and coordinating group interactions), and
- social influence (convincing group members to follow the leader).

A 10-step model for the course was described; it consists of lessons to promote knowledge in the following areas: knowing your men; knowing yourself; understanding leadership by example; developing subordinates; developing yourself; promoting group processes and team building; identifying relevant leadership behaviors; planning the course of action; taking action; and evaluating results.

OTHER TOPICS

Professor Dr. Heinrich Wottawa, University of Bochum, FRG, summarized his research on personality characteristics of the two Germanys. His

focus was on the substantial differences between "Wessies" (citizens of what had been the Federal Republic of Germany prior to 1990) and "Ossies" (former German Democratic Republic citizens).

Wottawa hypothesized that personality reflects the political situation in which one lives, and discussed possible ways in which different political systems could produce personality differences. One explanation, he said, could be genetic differences resulting from population shifts due to migration. These differences would not be quickly reversible, given the relatively few Wessies willing to migrate to the East. Another explanation could be related to differences in reward systems: in the West, he said, the emphasis was on rewarding results, while the system in the East had tended to reward behavior. For example, in the East people were rewarded for the positions they attained, not for their work or professional effectiveness. Ossies tend to attribute their status to external influences, and they frequently perceive self-failure. Ossies also differ from their Wessie counterparts in that they are more restrained, less extroverted, have a higher need for social acceptance, are less flexible, have a higher frustration tolerance, and are more sensitive to (and influenced by) the behavior of powerful people.

Wottawa predicted that such personality differences would disappear, but only very slowly. Psychologists can accelerate the change, for example by training Ossies in certain social skills. There is a vicious circle operating, however. Wessies who manage formerly East German companies find their Ossie subordinates to be passive, obedient, and low in initiative. This leads the Wessie manager to take on more work himself because he believes that approach to be easier than motivating the Ossies. Passivity among the latter intensifies, the Wessie manager does still more work and gains still more influence and power.

In answer to a question about military applications of his research, Wottawa stated that Ossies would probably be less suitable as officer material. Another questioner expressed great surprise that such personality differences could take place in the span of only 45 years of separate Germanys but Wottawa held to his position.

Doctor Gertjan Oosterhuis, from the Royal Netherlands Naval College, presented an analysis of Naval officers' careers in the twentieth century. The study was presented in the context of two concepts in internal labor market theory. The concept of a *competitive internal labor market* pertains to organizations with firm specific skills and internal training programs; in such organizations, career mobility is related to employees' trainability, performance, and career history. A *confidential internal labor market* exists in organizations with more abstract goals, where the performance of workers is difficult to measure objectively. Career mobility in such organizations is related to factors such as seniority, age at entrance, and family ties. The present study attempted to determine the relative importance of these factors in the careers of Dutch Naval officers from 1890 to 1990.

The results showed that seniority was by far the most important factor in career mobility, with performance the second most important. This supports the hypothesis that the naval officer corps more closely resembles a confidential internal labor market. The relative importance of performance was found to increase in the latter stages of one's career; furthermore its importance has increased during the past few decades.

Lieutenant Colonel Colman Goggin, Military Psychology Branch, Irish Defence Forces, gave a paper on nationalism from a psychological perspective. Drawing largely on political philosophy, sociology, and some social psychology, Goggin speculated on the reasons why so many nation-states have disintegrated into fractious sectarianism. Most of his comments had to do with definitions of nationalism and how they explain the strength of some nationalist movements, e.g., Irish, Welsh, Scots. Beliefs and attitudes, he said, are important in understanding the dynamics of nationalism, including such factors as self-esteem, group solidarity, and social identity. He also cited the importance of language, ethnicity, and group origins as factors in nationalism.

Doctor Allesandra Mammucari of the Italian Ministry of Defense presented a paper (co-authored by P. Betti, M. Monda and A. Peri) that discussed an integrated approach to studying complex problem-solving, taking into consideration communication style, personality factors, responsibility levels, skills, and leadership styles. A four-person team, inexperienced in the task at hand, was observed while engaged in a complex activity involving

development of a propaganda campaign. Behavior of individual team members was examined in the context of cognitive styles described by Kolb.[13] Group behavior was analyzed in relation to the phenomenon of creative production, termed "groupthink" by Janis and Mann[14] (i.e., strong pressure toward uniformity and conflict avoidance). Groupthink was found to be totally absent, due in large measure to the nondirective style of the group leader. Even though group interactions were characterized by a great deal of conflict and argumentativeness, the team was more productive than would have been the case with an authoritarian leadership style, in the opinion of the authors. The value of non-authoritarian leadership for certain complex, unstructured tasks was stressed, even though this runs counter to the style necessarily present in most military activities.

Colonel Dr. Pawel S. Boesler, Department of Humanitarian Studies, Polish Academy of National Defense, described a social psychological approach to promoting safe driver behavior and reducing accidents by tracking the safety records of individual drivers and their units and publicizing this information as a means of influencing drivers' attitudes toward accident prevention. It was developed for use in military units or other institutions that employ large numbers of drivers. It consists of a tracking system to categorize drivers on the basis of their safety records, and a figure of merit for individual drivers, which takes into account their safety record and experience level. The author speculated that ready availability of this information should exert social pressure on drivers to improve their safety attitudes and behaviors.

CLOSING COMMENTS

As can be seen from this summary, IAMPS presentations cover various types of endeavors—ranging from controlled laboratory experiments to field studies, preliminary inquiries, analyses, and tutorials. This variety reflects the diversity of the activities across nations and the amount of resources available for research and development. The value of this symposium derives not just from the exchange of scientific results but also from a sharing of experiences and lessons learned from disparate societies and cultures, most of which are facing similar challenges in a rapidly changing world.

Military psychology is playing an increasingly important role in national defense, especially in view of the current climate of force downsizing and budget reductions. These factors demand an increased emphasis on using manpower resources efficiently, on training effectively, and on developing weapons systems that can be operated and maintained easily. The science and practice of military psychology provides many opportunities and challenges for increasing our understanding and prediction of human behavior, for developing innovative methods for education and training in the high technology environments of modern warfare, and for improving the integration of people and machines in the design of complex military systems. It is hoped that IAMPS will continue to be a useful and informative forum for these and other subjects in the future. Perhaps its true value will be measured in future years by the extent to which it serves as a catalyst for more tangible, cooperative activities such as joint research ventures, scientist exchanges, and special-focus workshops. Cooperation is clearly a theme of increasing importance to the research establishments of all our nations, and IAMPS, with its long history of promoting interactions among military psychologists, can help to lead the way.

We express our sincere gratitude and appreciation to the German Ministry of Defense for hosting IAMPS this year, and to the German Psychological Service (P II 4) for planning and organizing it in a truly superb fashion. Special thanks are owed to BGen Volker Glatt, Chief Psychologist Martin Rauch, and Dr. Friedrich Steege, as well as to many others who helped make IAMPS '92 a most worthwhile and enjoyable experience. Their gracious hospitality and extra efforts to make us feel welcome were truly appreciated.

This year the logistics arrangements were particularly difficult, due in part to the distance between Bonn, where most of the organizers worked, and the actual meeting site in Berlin. The effort paid off handsomely, however, as Berlin was a most appropriate site for the meeting. It was exciting to get a glimpse of the many changes that are taking place in that historic city, changes that symbolize, perhaps, the larger world scene. The

fact that we met in a location that was formerly part of East Berlin underscored the magnitude of these changes, and gave us a sense that we were witnesses to a significant milestone in the history of IAMPS.

One final note: for the first time in the history of IAMPS, a complete Proceedings volume has been published, thanks to the efforts of the German Psychological Service. A copy can be obtained from:

Bundesminister der Verteidigung
P II 4
Postfach 1328
5300 Bonn
Germany

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Enhancing Performance Under Stress By Information About Its Expected Duration

by Shlomo Breznitz, Professor of Psychology, University of Haifa, Israel

KEYWORDS: stress, information, performance, endurance, Cold Pressor Test

MAIN RESEARCH OBJECTIVES

In an important chapter in *The American Soldier*, Janis[1] describes the intense stress to which crews of American bombers were exposed during their nightly missions over Germany in World War II. Planes and crews were lost each night and had to be replaced by new ones. At some point, many members of these crews developed major symptoms of stress and often could not continue to fly.

Psychological analysis of these soldiers indicated that they felt caught in a no-hope situation. Each night brought new casualties, and from their point of view it was only a matter of time until their turn would come.

The U.S. Air Corps dealt with this situation in a psychologically elegant and effective way. The crews were informed that their tour of duty consisted of 40 missions, after which they would be relocated to a safer theater of operation. Although 40 missions were not fewer than they were flying before, and although planes were still being downed by enemy action just as before, psychologically the situation altered dramatically, with excellent results in terms of symptom reduction and prevention. Instead of counting forward (e.g., "today it was this friend, tomorrow it can be me"), the airmen started to count backward (e.g., "39 to go, 38 to go, etc."). Thus, with each new mission their subjective probability of coming out of the experience alive was augmented. Stated differently, by telling the airmen when the danger would be over, their expectations became much more positive, and hope was introduced into the situation.

In spite of the success of the "tour of duty" intervention, and in spite of its subsequent usage as standard policy in many areas of conflict, the underlying psychological mechanisms of this phenomenon were never systematically studied. This is particularly surprising in view of the high cost-effectiveness of increasing endurance and performance level by information management. The main objective of the present research was to analyze this paradigm in a laboratory setting. An experimental program controlling the relevant features of the information made it possible to map its potential to enhance functioning under stressful conditions.

In conjunction with the controlled laboratory experiments, some of the critical variables were pretested in the field, within the military context. This effort could establish the generalizability of our findings to real life situations, and provide the basis for the formulation of some practical guidelines to information management under stress. The discovery of the main parameters that optimize information management can provide decision makers with general policy considerations, as well as particular tactical guidelines in a variety of military settings.

BACKGROUND INFORMATION

McGrath,[2] Appley and Trumbull,[3] and Breznitz and Goldberger[4] point out that time may be one of the most important parameters of stressful situations, yet it has been one of the most neglected areas in stress research. Lazarus and Folkman[5] discuss the role of "temporal uncertainty" and "imminence" in affecting the stress reaction. It is interesting to note, however, that both temporal uncertainty and imminence have been studied exclusively in relation to the onset of stress, never in relation to its termination. Thus, in spite of the fact that duration of stress is widely considered a major factor in dysfunction and disease (most notably Selye[6,7]), the impact of psychological signaling of duration remains largely untested territory.

Data from two different sources suggest, however, the potential importance of information concerning termination of a stressor. These sources consist of:

- research on anticipatory stress, and
- research in the area of "goal setting."

The findings most relevant to our experimental program deserve special attention.

Anticipatory Stress

Information concerning the temporal aspects of threat plays a major role in determining stress levels during the anticipatory phase. Thus, information about the imminence of the anticipated danger (or otherwise stressful event) determines the intensity of the emotional reaction, as well as a host of cognitive and behavioral outcomes. Quality of decision making is particularly sensitive to indications of time pressure due to imminent stress (e.g., Janis and Mann,[8] Ben-Zur and Breznitz[9]).

In situations that provide the person with full information about the onset of the danger, and he/she is objectively helpless, *duration of anticipation increases the stress reaction*. Breznitz[10] uses the concept "incubation of threat" to describe this phenomenon, which has been by now replicated in several studies.[11-16] There is thus good reason to expect that information about the anticipated duration of the stress itself will have significant effects on stress level and performance.

Studies of "warning systems" clearly show that the frequency and pacing of information can determine the exact function, plotting fear levels overtime.[17,13] Depending on its serial position and timing, each warning signals differential levels of danger and/or safety. (See also the "safety signal hypothesis" in attempting to explain preference for signalled as opposed to surprise stressors[18,19]). This suggests that in addition to telling people when the stress will be over, it might be important to control the frequency and timing of ongoing feedback. In the case of the "tour of duty" phenomenon described earlier, the World War II pilots could simply count their missions, and thus had full and continuous information about the remaining duration of their ordeal.

Goal Setting

Within organizational and industrial psychology, a body of evidence developed that suggested that presenting workers with definitive goals can increase performance levels. This is of some relevance to the present analysis, since duration of a task may, in principle, be considered a case in which the goal is to persist on a task for a given period of time. The basic argument is one of increased motivation, although other benefits of goal setting have been mentioned. In a recent review of the evidence, Locke[20] reaches the following conclusions:

> "Results from a review of laboratory and field studies on the effects of goal setting on performance show that in 90 percent of the studies, specific and challenging goals led to higher performance than easy goals, "do your best" goals, or no goals." (p. 125)

It would be useful to identify a task that is stressful and at the same time lends itself to "goal setting" types of manipulation. Fortunately, there is a task that combines those ingredients and can serve as the basic paradigm for our experimental program.

Cold Pressor Test

The Cold Pressor Test (CPT) is a frequently used experimental paradigm in stress research. It provides an opportunity to study reactions to pain within a controlled setting. Typically, the subject is required to immerse one hand in water mixed with ice, maintained at 0-1°C. Since the most frequently tested outcome using the CPT is duration of pain tolerance, it is particularly well suited for purposes of the present research.

It is interesting to note that in spite of hundreds of experiments using this method, only one attempted to manipulate information about duration of the pain.[21] The results indicated that *the specification of the goal increased the mean tolerance times*. This is what should happen if the reasoning behind the present study is valid. Unfortunately, the above experiment did not go beyond the simplest manipulation of goal/no goal, and thus in

spite of its obvious importance, our main task remained undone.

SPECIFIC RESEARCH QUESTIONS AND HYPOTHESES

Expected Duration At Start

The simplest independent variable is information about the duration of a stressful task that is available at its onset. Our hypothesis is that the absence of such information reduces performance.

Encouraging vs Discouraging Information At Start

Although we hypothesize that most types of information are better than none, their differential effects depend on the implied duration. Thus, if a particular stressful task is expected to be relatively short, this implies "encouraging information" at start. By the same token, the duration specified at start may be perceived as longer than the person can reasonably expect to cope with effectively. This implies "discouraging information" at start. We hypothesize that "encouraging information" at start, as long as it is credible, enhances performance. Credible "discouraging information" at start reduces performance. Furthermore, deleterious effects of stress on performance are expected to appear earlier in the discouraging information situation.

Information En Route

Information en route to the goal can be given continuously, in a pattern of discrete signals, or not given at all. We hypothesize that the frequency and pacing of this type of information will have significant effects on task performance. In addition, it is expected to amplify the effects of information at start. Thus, for instance, we predict that feedback along the way may further enhance task performance if the information at start is encouraging, and leads to significantly greater performance deficit if it was discouraging.

Disconfirmation En Route

During task performance, new information, different from the one given at start, can be presented. This is often the case in real-life situations, since tasks may change during their performance. There can, of course, be encouraging disconfirmation, i.e., learning that the new duration is shorter than initially expected, or discouraging disconfirmation, implying the opposite. We hypothesize dramatic changes in task performance as a result of disconfirming information. This effect will depend on the timing of the new information in relation to passed time and to remaining time. In other words:

- the longer the duration spent with the initial information, the less significant the impact of the new information; and
- the longer the remaining duration following disconfirmation, the more significant the impact of the new information.

Information Credibility

A necessary outcome of disconfirmation is reduced credibility of the new information, as well as of subsequent information arriving from the same source. The effects of credibility loss on task performance during a second similar task will be tested. This long-term cost of disconfirmation will be evaluated, particularly in situations in which it can have potential short-term benefits.

Special Scenarios

There are countless situations within the military context in which this type of information management can be critical to a mission's success. Following the systematic analysis of the above-mentioned parameters, the study explicitly deals with two specific scenarios: the End Game Scenario, and the Selection Scenario.

The *End Game* scenario relates to a situation in which there is only one dominant consideration, namely, how to stretch human endurance to its maximum. It can be a case in which everything

depends on whether people can endure long enough before reaching safety or help. Thus, long-term arguments are irrelevant, and all available psychological know-how has to be harnessed for the sake of maximizing endurance. What is the best strategy to follow in such an extreme case? What information should be given, when, and how can encouragement be maintained along the way, for as long as possible?

The *Selection Scenario* raises questions that are almost diametrically opposite to the End Game scenario. It is conceivable that selection of individuals best suited for highly stressful tasks can take advantage of the effects of psychologically discouraging information. Thus, if our predictions are confirmed, instead of testing candidates for such tasks under objectively high stress for long durations, it might be more effective to test them by using highly discouraging information.The present research program allows the discovery of typical "breakdown points," some of which might be information-induced. The findings should help us to answer related questions such as: How and when is it best to encourage individuals? When is it best to remind them of the task yet ahead and when to divert their attention? What are some of the important costs of a policy of limited information? When, if ever, can false information have such an overwhelming advantage as to be pragmatically justified?

THE CORE PARADIGM

The entire experimental program closely followed a central theme that is best illustrated by considering one of our field experiments.

Soldiers in a highly selective unit were embarking on a difficult 50-kilometer march, carrying about 60 pounds of weight. Prior to starting they were randomly divided into four groups, each receiving different information about the distance of the march. The experimental design is described in the following table.

Thus, all were marching the same distance, although with different information. The maindependent variable was the percentage of soldiers successfully finishing the entire march.

The findings were unequivocal in supporting the "tour of duty" phenomenon. Thus, *the number of soldiers who endured the march was significantly different between groups*. Comparing the first two groups, full information was by far better than no information. In the initially encouraged group (30 + 20) soldiers reached the critical 29th kilometer in good spirits, since they believed that their ordeal was practically over. The response to the "bad news" was quite dramatic, and subjects in this group quickly lost morale; several dropped out shortly after the information change took place.

Field experiment: Distance = 50 km

Group	Information on Start	Information Change
Full information	50	N/A
No information	?	N/A
Encouraging information	30	+20 (at 29th km)
Discouraging information	70	−20 (at 29th km)

By far the most difficult condition was the initially discouraging one (70 - 20). About 30 percent of soldiers in this group broke down before reaching the point where they could hear the good news. In fact, many broke down during the initial 10 kilometers, a distance that was well within their capabilities. Apparently, the thought of having to march the entire 70 kilometers was too devastating, leading to hopelessness and both physical and psychological exhaustion.

Although endurance was obviously the most important dependent variable, it was not the only one. Thus, two officers marching with each unit of soldiers gave independent evaluations of their performance, morale, mutual help, as well as physical and emotional distress. The results corroborated the endurance data. In some field experiments that used the same design, blood samples were taken at the 29th kilometer to ascertain the biochemical impact of information and information change. These results are still being analyzed.

The basic paradigm used throughout the laboratory experiments followed essentially the same format.

LABORATORY EXPERIMENTS

Experimental Design

The target for the CPT was set at 4 minutes. In the *no information* condition, subjects were

asked to perform both tasks until the experimenter told them that the test was over.

In the *full information* condition, subjects were asked to keep their hand in the ice cold water for 4 minutes. A digital clock in front of their eyes precisely indicated the passage of time.

The *discouraging information* condition consisted of two groups of subjects asked to endure the CPT for 5 or 6 minutes respectively, with the correction taking place after 2:45.

Lastly, there were three groups receiving *encouraging information*, of either 1, 2, or 3 minutes, with subsequent correction to 4 occurring at 0:45, 1:45, or 2:45, respectively.

Dependent Variables

The present experiment focused primarily on the behavioral measures of endurance. Thus the frequency of subjects carrying out the task to its successful completion, as well as the exact time of "giving up" was measured. Heart rate was measured continuously throughout the entire experimental sequence. Subjective reports of stress, as well as responses to direct questions pertaining to various features of the experiment, were secured shortly after termination of the CPT.

Subjects

All subjects were students at the University of Haifa. They were recruited from the student body on a voluntary basis. A $12 stipend was offered for participation. All subjects were tested individually; only subjects who were in perfect health could participate. At the onset, as well as after learning the purpose of the study, subjects were reminded of their privilege to terminate the experiment at any moment, without prejudicing their remuneration. Only after obtaining a signed informed consent did the experiment begin.

RESULTS AND DISCUSSION

Information Enhances Endurance

Our first principle concerns the availability of information about the duration of a stressful task, irrespective of the actual content of that information. In other words, we shall examine the overall impact of having information (clock) as opposed to not having it (no-clock). The important issue of comparing different types of information will be treated separately. The claim that information enhances endurance relates to usual circumstances, and should not imply that all types of information are always better than no information at all.

To measure the effect of clock/no-clock on successful completion of the CPT, an analysis of variance was carried out by using data from all relevant groups. The results are compelling: *in the clock condition 56% of the subjects successfully completed the task; in the no-clock condition only 30% were able to do so* ($p < .001$).

The data clearly support the claim that having full information about the duration of a stressful task enhances endurance. To acquire deeper insight to some of the possible mechanisms that produce this outcome, the impact of the clock/no-clock conditions on the subjective reports of the participants was tested. Specifically, there were two questions with obvious relevance to this issue: a question about the perceived difficulty to endure the task (DIFFICULTY), and a question whether the subject was committed to finishing the task (COMMITMENT). The first consisted of a five-point scale, rating from greatest difficulty (1) through least difficulty (5). COMMITMENT was measured by a YES/NO dichotomy. Analyses of variance were carried out to measure the various effects.

Difficulty Is Related to Endurance

Success on the CPT is associated with smaller reported difficulty than failure ($p < .01$). This is perhaps not a major surprise, considering that the questionnaire was administered after the termination of the CPT experiment. Furthermore, the direction of the effect itself is in doubt, since subjects might have responded to the question inretrospect in view of what they knew about their success/failure on the task.

The above finding gains more value, however, in view of there being no significant relationship between clock/no-clock and DIFFICULTY. This suggests that *information affects endurance directly, without the mediation of subjective appraisal.* At the same time, when subjects fail in the task and know about their failure, subjective difficulty

is greater in the clock condition than in the no-clock one ($p < .05$). One potentially important route of beneficial influence of information on endurance is via its impact on COMMITMENT. *In the clock condition, subjects reported being less conflicted about carrying on with the task than those in the no-clock condition* ($p < .01$). This is doubly important in view of the fact that *COMMITMENT increases endurance* ($p < .001$).

The following analysis casts an interesting light on the mechanisms involved. If clock has a direct psychological impact on durance, we could expect that it would at least partially determine the exact timing of giving up. Thus, if subjects use the clock continuously as a measure of the task, they would be inclined to present themselves with intermediate goals. It stands to reason that these intermediate goals will consist of round numbers (i.e., 5 seconds, 10 seconds, 15, 20, 25, etc.) that are relatively easy to monitor.

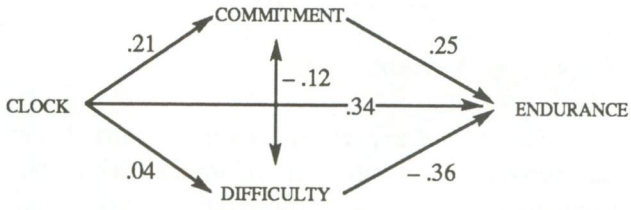
A close scrutiny of the exact durations of endurance of those who failed the task during the first minute yielded a highly significant round-numbers effect. Thus, *in the clock condition, 83 percent of failures occurred on round numbers and only 17 percent on non-round ones*. This is particularly striking since for any round number there are four non-round ones, and the expected a priori distribution is 20 percent vs 80 percent in the opposite direction ($p < .001$). In the non-clock (control) condition, the percentage of failures that occurred on random numbers was 37 percent only, and not significantly different from the expected chance level.

This finding supports the mechanism of *self-imposed intermediate goals*. The utilization of such a mechanism is clearly much easier in the clock paradigm, suggesting that this might be one of its important advantages.

Path analysis for testing the model that best fits the entire body of data was carried out. The variables of CLOCK, DIFFICULTY, and COMMITMENT were used as predictors of ENDURANCE. By using a series of multiple regression analyses and calculating the beta coefficients in each case, a variety of models were tested for goodness of fit, with reconstruction of the raw correlation coefficients between all the variables used. The raw correlation coefficients ($N = 184$) were:

	CLOCK	DIFFICULTY	COMMIT-MENT	ENDURANCE
CLOCK	1.00	.04	−.21	.38
DIFFICULTY		1.00	.11	−.37
COMMITMENT			1.00	−.36
ENDURANCE				1.00

The path analysis yielded the following model as having the best fit with the reconstructed correlation coefficients. The numbers in the model represent measures of influence ranging from zero to one.



The multiple regression on endurance is $r = 0.60$, explaining 36 percent of its variance. The model indicates that continuous information about the duration of the stressful task impacts endurance directly, as well as via commitment.

When Is Absence of Information Most Harmful?

One way to obtain a clue about the temporal features of the CPT is to consult our empirical data concerning the distribution of failures. The following table presents the percentage of failures according to time and information condition.

Percentage of Failures According to Time and Information Condition

Time	Clock	No-clock	Difference
1st min	27.3	43.7	16.4
2nd min	11.3	15.2	3.9
3rd min	0.8	6.9	6.1
4th min	4.5	4.4	−0.1

The results show a systematic picture. Endurance is most difficult during the first minute, with difficulty dropping steadily during the second and

third minute, with a slight increase in difficulty during the last minute in the clock condition. Comparing the two conditions, we find that the absence of information is most harmful during the critical first minute. This indicates that *information promotes endurance, particularly during the most stressful phase of the task.* From a practical point of view, this suggests that if information cannot be given continuously, it should at least be given when it can be most effective.

As the end of the CPT is approaching, awareness of the proximity of termination mobilizes attention to the task, and may augment the stress. A similar phenomenon often occurs in the "tour of duty" experience. When describing the beneficial effects of information about the number of dangerous missions that the U.S. pilots had to fly as their tour of duty, Janis[1] mentions that contrary to the overall reduction in level of anxiety, there was aparadoxical increase in anxiety during the last few missions. Having been through most of the ordeal, toward the end there was too much at stake. Considering the overall advantages of information, this is, however, a small price to pay, since even during that segment the clock condition is not worse than the no-clock condition.

Law of Expected Duration On Start

So far we have analyzed the role of information as such, irrespective of its content. Our discussion now progresses to content-related issues.

The Law of Expected Duration on Start relates to one such focal variable, and it reads as follows: "The shorter the Expected Duration on Start (EDS), the greater the endurance of a stressful task."

In psychological terms, this implies that if, at the time when a stressful task is about to begin, the information suggests that it will be of a short duration, the task appears to be manageable and information enhances its endurance. For this implication to be valid, the person who is about to start the ordeal must have some notion as to the nature of the task, and whether the implied duration is in fact short or long. It may very well happen that what appears as short when starting out, will turn out to be too long to endure. Ideally, EDS should be evaluated under conditions assuming prior experience with the particular stressor.

The present study provides the empirical evidence for the Law of Expected Duration on Start by comparing groups of subjects that differ on this variable. There are 6 different EDS conditions, ranging from 1 minute though 6 minutes. A fair comparison between them can be done only for the first minute, prior to providing subsequent disconfirming information. Thus, during the first minute of the CPT, different groups of subjects experienced the same conditions, with the exception of EDS. The following table presents the results.

Percent Endurance of CPT According to Expected Duration on Start

EDS	After 1st Min.	After 4th Min.
1 min	90	30
2 min	90	81
3 min	69	56
4 min	70	60
5 min	59	53
6 min	60	50

The data on endurance of the first minute are highly systematic. The six conditions appear to be grouped in three distinct categories, with EDS 1 and 2 grouped together, 3 and 4 grouped together, as well as 5 and 6. The observed distribution of success is significantly different from the expected one ($p < .05$), and systematically related to EDS. *The shorter the EDS, the better the chances of enduring the first minute of the CPT.* At the same time, the need to group the adjacent EDS levels together indicates that they have to be sufficiently different from each other to produce differential behavioral consequences.

Disconfirming Information En Route

Once we move beyond the first minute and compare the overall percentage of subjects who successfully finished the entire four minutes of the CPT, the issue becomes much more complicated. The chances of endurance during the later stages of

the task depend to some extent on the specific way that the EDS was altered. After all, in the clock paradigm, if the objective duration of the task is kept constant, the shorter the EDS, the longer must the subsequent correction be. In the present study, the correction ranged from +3 minutes in thegroup with EDS = 1, all the way to -2 minutes in the group starting with EDS = 6.

The results in the above table indicate that *relative change is by far more important than absolute change*. Furthermore, *the earlier the correction, the more influential it is in affecting endurance*. Any information management strategy that resorts to disconfirming information at some point during the task, must, of course, consider the chances of the person reaching the point of correction. Thus, for instance, if EDS is too long, the potential advantages of subsequent encouragement may well be offset by the fact that a significant number of people will give up prior to receiving the "good news." This was well illustrated in the field study with marching soldiers.

Resource Mobilization

Comparing the maximal heart rates of those who completed the task with those who failed, the means were 120.5 and 106.0 respectively ($p < .05$). This indicates that subjects who eventually completed the task reacted with higher heart-rate elevation during their maximal arousal than those who failed the CPT. It is important to note that high arousal may indicate the ability to mobilize greater resources when they are needed most (e.g., during a critical phase). The correlation between endurance on the CPT and the amplitude of the maximal heart-rate was found to be $r = 0.41$ ($p < .001$).

PRACTICAL IMPLICATIONS

The basic aim of this study was to investigate an area that has obvious applicability in a variety of military as well as non-military contexts. Consequently, the potential translation of our findings to practical usage was addressed throughout this report. The following propositions highlight the main points only.

- Information about the expected duration of a stressful task enhances endurance. This proposition refers to all instances in which the information is within the constraints of what appears to be a "reasonable" duration.
- Lack of information induces conflict about the task, and such conflict reduces endurance. Interventions that reduce conflict (such as commitment), have beneficial impact on endurance. On the other hand, "Do your best" type of instructions tend to increase conflict and reduce performance.
- Information about the expected duration of a stressful task facilitates the use of self-imposed intermediate goals.
- Information is most useful and its absence most deleterious during the most stressful phase of the task.
- The Law of Expected Duration on Start: The shorter the EDS, the greater the endurance of a stressful task.
- Change of information reduces the credibility of information on subsequent tasks. Its cost-effectiveness must be evaluated in the broader context, beyond the single task.
- Effective information management requires good knowledge of the differential difficulty of the stressful task at its various stages.
- Information facilitates the distribution of effort.
- Successful endurance of one task increases the chances of endurance of the next task, even if the two are different. Consequently, training for endurance may benefit by maximizing success on earlier, easier tasks. The information management principles discovered or reinforced by this study may provide guidelines for effective shaping of endurance.

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Solid State Physics

Europe Reclaims Its Historical Cultural Commitment to Scientific Research: Aspects of Solid Physics Research. Part 1.

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KEYWORDS: semiconductor microstructures; superlattices; CNRS; CNET; MPI-Stuttgart

INTRODUCTION

As a solid-state physicist working in semiconductor microstructures, I found my visits last summer to French and German research laboratories to be richly rewarding. Europe has fully reclaimed its historical cultural commitment to scientific research and teaching, even at a time when the American Physics establishment is feeling the pressure of an economic downturn. The French and German research facilities are dynamos of intense activity and exciting new ideas. This article reports on my visits to the French Centre National d'Etudes des Telecommunications (CNET) and Centre National de la Recherche Scientifique (CNRS) laboratories at Bagneux and to the German Max Planck Institut für Festkörperforschung at Stuttgart (Physik Dept.). To constrain the length of this article, my visits to other German research facilities last summer will be reported in a future *ESNIB* article (Part 2). Part 2 will include Universität Wurzburg, the Technische Universität München (Physik Dept.), the Schottky Institute, and the Universität Regensburg (Physik Dept.); also in western Berlin, the Technische Universität Berlin, and Freie Universität Berlin, and finally in the former East Germany, the Friedrich Schiller Universität at Jena, and the Humboldt Universität and the new Paul Drude Institut, both in the eastern part of Berlin. Naturally, my own research activities and interests weight the distribution of emphasis in descriptions of these research facilities, and I trust that, with this in view, the reader will be able to filter out a reasonably balanced perspective from this report.

CNET AND CNRS LABORATORIES AT BAGNEUX, FRANCE

As a leader in the field of telecommunication research, development, and application, France maintains the Centre National d'Etudes des Telecommunications (CNET) laboratory at Bagneux in the outskirts of Paris. A particularly striking line of research being carried out at CNET involves the recent (1990) experimental demonstration of Esaki-Tsu[1] miniband conduction and associated negative differential conductivity in GaAs/A1As superlattices.[2] The physics of this is rooted in the fact that subgroups of electrons accelerated by an electric field past the inflection point (of the superlattice energy-momentum mini-band structure relation) experience negative effective mass, which diminishes conduction as the electric field increases. The realization of this effect in materials fabricated by molecular beam epitaxy (MBE), twenty years after its prediction by Esaki and Tsu, promises a new generation of high-speed oscillators. The Physics of Microstructures and Interfaces group of J.F. Palmer, A. Sibille, and C. Minot is responsible for this achievement, and a robust stream of experimental and theoretical work[3] has followed their article in *Physical Review Letters* in 1990.[2]

The CNET laboratory at Bagneux, under the director A. Zylberztejn, also has other functioning research groups, as follows (group names are followed by the group-leader's names):

Physics, Materials and Microstructures - M. Bensoussan
Molecular and Quantum Electronics - J. Zyss
Microanalysis and Physics of Materials - F. Auzel
Optics, Physics and Microstructures - J.L. Oudar
Physics of Microstructures and Interfaces - J.F. Palmier
Optoelectronics and Semiconductor Materials - A. Mircea
Materials for Components and Microstructures - M. Quillec
Semiconductor Sources - J.C. Bouley
Guided Optics - A. Carenco
Microelectronics, Design and Technology - M. Bon
Modeling and CAD in Microelectronics and Optoelectronics Components and ICS Technology - A. Scavennec.

Outstanding recent fundamental research achievements of the CNET Bagneux laboratory include the development of a propagative quantum description of the formation of solitons in optical fibers (of key importance to maintaining the integrity/identity of an optic fiber signal); the first demonstration of a parametric oscillation using an organic crystal in the 0.9-1.6 μm band; and optical bistable structures with a record threshold of 5 $\mu W/mm^2$ (in collaboration with the CNRS-L2M Laboratory—see below), and development of an advanced technological approach for low-cost lasers. Appendix A is a formal summary by Director A. Zylberztejn of recent research at CNET. Readers interested in more detail may contact:

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The CNET laboratory is associated with Centre National de la Recherche Scientifique (CNRS), which has its Laboratoire de Microstructures et de Microelectronique (L2M) under the direction of Dr. H. Launois in an adjacent building at the same location in Bagneux, France. The research operations of the CNRS laboratory include a Nanostructures group led by H. Launois. This group has projects in nanostructure fabrication by electron lithography (Z.Z. Wang and eight collaborators, including postdocs and thesis students), and by X-ray lithography (F. Rousseau, and six collaborators) as well as a focused ion-beam project (G. Benassayag and one collaborator). Another major group at this laboratory is B. Etienne's Groupe EJM (MBE group), which is working on two-dimensional (2-D) gases and superlattices. It comprises projects on GaAs/GaA1As heterostructures (B. Etienne and six collaborators) and on short period GaAs/GaAlAs superlattices (R. Planel and six collaborators). An X-ray optics activity is also being developed (C. Khan-Malek). Finally, CNRS also houses the important Physique des Composants (Device Physics) group, led by J.L. Pelouard (with four collaborators). It should be noted that CNRS has had many significant collaborations with university and industrial laboratories (for example, with PICOGIGA, Thomson, IBM-France, Orsay-Physics).

The basic physics and electrical engineering/device research activities of the CNET and CNRS Bagneux laboratories are generally very closely linked. High purity samples of GaAs are prepared by molecular beam epitaxy (MBE), and are characterized in terms of transport, optical and high magnetic field properties. A1As/GaAs, short period superlattices, type II superlattices, heterojunctions, etc. have been examined. For example, Wigner crystals and 1-D structures have been studied in heterostructures. Also, mesoscopics, universal conductance fluctuations, and granular transport have been treated. Nanostructures have been fabricated by using lithographic techniques, and the electron beam machine has facilitated interesting physical experiments that demonstrate the Ahronov-Bohm effect, Coulomb blockade, and resonant tunnel diode physics. X-ray lithography with SiC has been carried out (to dimensions less than 0.1 μm), despite the difficulty of making a good mask using

tungsten (W) as a mask. In regard to device applications, there has been much Monte Carlo simulation activity; device processing and characterization, both static and dynamic; and the studies include transport, electro-optic sampling, time scales of less than 1 p.s. and cutoff frequencies of 100-200 GHz, with dynamic characteristics linked to Monte Carlo simulations.

The activities of the CNET and CNRS research laboratories at Bagneux are at the forefront of knowledge in the semiconductor microstructure area. Their work is well represented in the best journals, ranging from *Physical Review* to applied device journals, often in collaboration with American and European authors, making a fine demonstration of the strength of French microstructure physics. My appetite for quantum transport in semiconductors was well satisfied by direct contact with the Palmier-Sibille-Minot miniband conduction group at CNET. [In passing, I should also mention interesting CNRS work on electron-electron drag between parallel 2-D electron gas sheets[4] by M. Mosko (visiting CNRS from Czechoslovakia), who also recently made an important improvement in Ensemble Monte-Carlo simulation of electron-electron scattering, eliminating erroneous simulation results of earlier works.[5]]

MAX PLANCK INSTITUT FÜR FESTKÖRPERFORSCHUNG AT STUTTGART

The Max Planck Institut (MPI) für Festkörperforschung (1 Heisenberg Strasse, 7000 Stuttgart 80, Germany) with Nobel Laureate Professor Dr. Klaus von Klitzing, discoverer of the Quantum Hall Effect, needs no introduction. It is one of the world's great solid-state research institutions, splendidly equipped and massively staffed. This laboratory is dedicated to the investigation of structural, electronic, and vibrational properties of solids, particularly semiconductors and insulators. Optical, electrical, magnetic, and mechanical properties are examined for useful features. Strong emphasis is placed on the production of high-purity microstructured semiconductors by molecular beam epitaxy, and potential microelectronic applications are carefully studied. In addition to analyzing the properties of crystalline, polycrystalline, and amorphous semiconductors, transition metal and rare-earth cluster compounds are synthesized and treated, as well as ionic conductors. Techniques include X-ray diffraction and Raman spectroscopy as well as picosecond pulse investigations. With the development of theoretical computational methods, extensive studies of electronic structure and correlations are being carried out. MPI-Stuttgart operates the high-field magnet laboratory in Grenoble jointly with CNRS (France), where extensive studies of the electronic behavior of semiconductors and superconductors have been carried out.

It would be easy to write an entire book about the activities at MPI-Stuttgart. Just the list of publications for the single year 1991 (authors names, titles, and references) spans more than 100 printed pages. In the same year, there were 35 theses and 17 patents. The overall staff strength is about 300, more than 120 of whom are scientists. In addition there are about 89 guest scientists and 109 Ph.D. students. Every office and laboratory is packed with exceptionally talented and well-experienced researchers working with an abundance of state-of-the-art equipment. Visits are often discouraged because "not one more" can be fit into heavily stressed space and schedules. Activity at this highly productive and well-endowed facility is very intense.

The scientific divisions at MPI-Stuttgart are as follows (with division heads and research areas):

Theoretical Physics

- O.K. Andersen - Electronic structure, density functional calculations, application to Y $Ba_2Cu_3O_7$, optical spectra, chemical shifts.
- K. Efetov - Localization in disordered metals, Anderson metal-insulator transition, 2-D Quantum Hall effect, transport in low-dimensional quantum confined electron systems, mechanism for high T_c superconductivity and lattice dynamics.
- P. Flude - Electron correlations, heavy Fermion systems, high-T_c superconducting materials, molecules involving rare-earth or transition metal ions, conventional molecules, semiconductors, metals, insulators. Effort at unified description of strong and weak correlations

Experimental Physics

- M. Cardona - Optical and electron spectroscopies of semiconductors and high-T_c superconductors, electron-phonon interaction. Methods include Raman, hyper-Raman and Brillouin scattering, resonance Raman spectroscopy, spectroscopic ellipsometry, high-pressure optical measurements, electron-spin resonance, photoelectron spectroscopy and scanning tunneling microscopy, computation of electronic and vibronic band structure of materials treated, particularly in high-T_c experiments. Surface and interface structure analysis by X-ray diffraction and X-ray standing-wave measurements at synchrotron sources, emphasizing adsorbates on semiconductors and high T_c expitaxial thin films ($YBa_2Cu_3O_7$) on various substrates. Disordered semiconductors, point defects in crystals, particularly hydrogen-related complexes in crystalline Si and GaAs, and amorphous or microcrystalline Si; attention recently has been focused on siloxene in porous silicon ($Si_6O_3H_6$)
- H.J. Queisser - Semiconductors, extrinsic properties, interfaces, ultrafast carrier dynamics and high excitation phenomena, effects of dopants, defects and boundaries on optical, electronic, and transport properties of Si and III-V compound semiconductors. Stationary optical spectroscopy, admittance spectroscopy, capacitance spectroscopy, photoconductivity, noise measurements. Defect characterizations; transport studies, Schottky contacts and MIS tunnel diodes using admittance and noise spectroscopy. Pico and femtosecond spectroscopy (resolved to 50 fs) used to examine scattering of excitons and free carriers in 3-D and 2-D, tunneling in coupled quantum wells and high excitation effects. Extensive high magnetic field work at the Grenoble and Toulouse magnet laboratories, particularly in 2-D systems
- K. von Klitzing - Electronic properties of 2-D semiconductor heterostructures, quantum wells and superlattices, particularly relating to transport and optical response in magnetic fields up to 18 tesla and temperatures down to 50 mK. Phonon properties of low-dimensional systems studied by ballistic phonon techniques and fountain-pressure imaging. Vertical transport studied in tunneling and photoconductivity experiments. Techniques include far-infrared, time-resolved photoconductivity and luminescence measurements in magnetic fields. Analysis of influence of design parameters of samples on experimental results. Strong emphasis on 1-D and 0-D quantum confined electronic systems, both experimentally and theoretically

These activity listings are fairly well representative, but not exhaustive. There is also a Solid State Chemistry Division at MPI-Stuttgart (J. Maier, H.G. von Schnering, A. Simon), and the Laboratory is well provided with supporting service groups, including Chemical Service, Epitaxy Group, X-Ray Diffraction Group, High Pressure Group, Optics and Spectroscopy Service, Technology Group, Low Temperature Group. Appendix B provides a selection of noteworthy research projects in 1991.

Having provided an overview of research at MPI-Stuttgart, it seems worthwhile to further discuss particular features I found to be of direct interest. My visit was to the division of K. von Klitzing, particularly to talk with Dieter Weiss, Rolf Gerhardts, and Daniela Pfannkuche about their outstanding recent work on conduction in a weakly modulated 2-D electron gas in a magnetic field. They demonstrated, both experimentally and theoretically, that this system has associated commensurability oscillations in its conductivity. These arise from the interplay of the length scales of the modulation period and cyclotron radius at the Fermi energy. Recent developments in examining a doubly modulated 2-D electron gas having the Hofstadter Butterfly electron energy spectrum in magnetic field are under consideration at MPI-Stuttgart, and are receiving considerable attention at other laboratories and universities in Germany. This visit also gave me exposure to the work of H. Grahn on GaAs/A1GaAs superlattice vertical transport. Overall, von Klitzing's division is a major force in basic research on low-dimensional electronic systems, and it is appropriate to provide a

fuller summary of its main research activities during the last five years (these activities have resulted in more than 300 publications):

- Technology of Low-Dimensional Electronic Systems
  - Electron Beam Lithography
  - Holographic Lithography and Dry Etching
- Vertical Transport and Tunneling
  - Vertical Transport through Single Barrier Tunneling Structures
  - Vertical Transport: Tunneling and Hot Electrons
  - Picosecond Spectroscopy of Tunnelingbetween Quantum Wells
  - Miniband Conduction and Resonant Tunneling in GaAs-A1As Superlattices
  - Wannier-Stark Localization and Delocalization in GaAs-A1As Superlattices
  - Electric-Field Domains in Semiconductor Superlattices
- Transport in Periodically Modulated and Disordered Two-Dimensional Electron Systems
  - Magnetoresistance Oscillations in a Two-Dimensional Electron Gas (2DEG) in the Presence of a Weak Periodic Potential
  - Magnetotransport in a 2DEG Subject to a Weak Two-Dimensional Lateral Superlattice
  - Fabrication and Characterization of Antidot Systems
  - Influence of Repulsive and Attractive Impurities on Magnetotransport
- 2DEG in Strong Magnetic Fields
  - Transport in Tilted Magnetic Fields
  - The Metal-Insulator Transition in the Quantum Hall Regime
  - Spin Effects
  - PL-Spectroscopy in the Extreme Quantum Limit
  - Phonon-Drag Imaging in High Magnetic Fields
- Transport in One-Dimensional Systems
  - Transport in Laterally Confined Electronic Systems
  - Quantum Transport Devices
  - Lateral Field Effect in Focused-Ion Beam Written In-Plane-Gated Systems
  - Trench Insulated In-Plane-Gate Transistor
  - Point-Contact Spectroscopy on Tunable Constrictions in GaAs
  - Lateral Tunneling in Point-Contacts
  - Magnetotransport and Microwave Experiments on Quantum Wires
  - Quantum Hall Effect and One-Dimensional Edge Currents
  - Transmission of Edge Channels through Barriers
  - One-Dimensional Current Carrying Edge Channels in a Two-Dimensional Electon Gas
  - FIR-Photoconductivity Based on Photon-Induced Interedge Channel Scattering
  - Fountain-Pressure Imaging of the Dissipation in Quantum-Hall Devices
- Spectroscopy of Low-Dimensional Systems
  - Cyclotron Resonance Study of Impurity Scattering in a 2-D Electron Gas
  - Cyclotron Resonance in GaAs with Periodically Ordered Sheets of Doping Layers
  - Far-Infrared Spectroscopy of Quantum Wires
  - Quantum Dots and Antidots
  - Excitons and Exciton Polaritons in Quantum Well Wires
  - Photon Drag-Induced Entropy Transfer in a Two-Dimensional Electron Gas
- Other Topics
  - A New Phonon Focusing Effect Due to Elastic Mode Conversion on Surfaces
  - High-T_c-Films by Molecular Beam Epitaxy
  - Conducting Polymers as One-Dimensional Metals

CONCLUDING REMARKS

The French and German research facilities described in this article are of leading importance in world research on semiconductor/solid state physics. But they are just the first few examples of a mighty array of research establishments in a

Europe that reflect a profound commitment, indeed, dedication, by nations whose resources have long been limited, to improve their lot by creating and refining the understanding of nature to bend it to their national needs and well-being. This European heritage is perhaps best exemplified by the institutes of the Max-Planck Gesellschaft (MPG), of which MPI-Stuttgart is one. The MPG's institutes deal mainly with basic investigations in new areas of research that are not yet fully developed, or that are, because of their scope or administrative structure, less suitable for university research. There are about 64 Max-Planck Institutes, some 20 Independent Junior Groups (within the Institutes), and several Clinical Research Groups and Independent Research Groups distributed in western Germany, generally very near major universities. Of these, about 24 are focused on Physics, Chemistry, and Technology (and about 28 are focused on Biology and Medicine). This situation is in flux now, and with the absorption of the scientific community of East Germany, more MPIs are springing up. For example, at the site of the former DDR Academy of Sciences (Hausvogteiplatz 5-7, Berlin) one of the new facilities is a new working group of the Max Planck-AG Halbleitertheorie (semiconductor theory) to facilitate the absorption of former DDR researchers. In this connection, we may expect a dramatic expansion of German research facilities in the next few years, notwithstanding a temporary financial pinch during the transition. I will have much more to say about this in the second article to follow (Part 2), which discusses my visits to additional physics research facilities in Germany. I will also discuss at greater length the transitional circumstances relating to semiconductor physics in the former DDR.

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Appendix A

CNET - Summary of Recent Research
by A. Zylberztejn

During the past year, the Bagneux Laboratory has pursued its research efforts on technologies and components for future communications systems.

In cooperation with CNET system teams, it has been possible to demonstrate the feasibility of advance components developed for the CICERON program (Circuits Integres et Composants d'Emission et de Reception Optique Numerique). Significant results were achieved in the following areas:

- low-cost components: 1.3 μm BRS laser technology on 2-in. wafers, integrated laser-photodetector structure, BRS duplexer operating at 4 Mbit/s validated by the Lannion A Center;

- high bit rates: laser with 21 GHz bandwidth @ -3 dB, GaA1InAs MQW-DFB laser with a chirp of 0.47 nm at 5 Gbit/s (measured at Lannion B), quantum confined Stark effect and Wannier-Stark effect modulators, laser-MISFET integrated structure working at 10 Gbit/s, HBT circuits at 5 Gbit/s;

- coherent transmission: DFB-MQW laser with $\Delta\nu$ = 500 kHz at 21 mW, a laser tunable over 18 hopping modes by steps,

polarization diversity $LiNbO_3$ optical receiver, integrated balanced PIN-PET.

Our advanced technological approach for low-cost lasers has resulted in a request for a technology transfer by CIT-ALCATEL. In addition, PHILIPS MICROWEAVE LIMEIL started testing a power HBT fabricated in our Laboratory, for mobile radio applications.

A number of "world firsts" were achieved in some of our more fundamental research activities geared toward the longer term: propagative quantum description of the formation of solitons in optical fibers, first demonstration of a parametric oscillation using an organic crystal in the 0.9-1.6 μm band, and optical bistable structures with a record threshold of 5 $\mu W/mm^2$ (in collaboration with the L2M Laboratory).

The Bagneux Laboratory continues to participate actively in European research projects. For example, it will be a new participant in the future optical communications research project ATMOS, coordinated by ALCATEL.

Appendix B

MPI-Stuttgart - A Selection of Noteworthy Research Projects in 1991

Molecules, clusters, and C_{60}-compounds

The Electron localization function (ELF) in boron clusters
Cerocene - a molecule with strong electron correlation
Observation of supershells
Optical transitions in solid C_{60}
Electron interactions and electron-lattice coupling in C_{60}
Electronic properties of C_{60}
Solid C_{60} at high pressures

Low-dimensional physics

Size-dependent studies of the metal-insulator transition in the quantum Hall regime
Electron pinball in antidot superlattices
Persistent currents in mesoscopic normal metal rings
Quantum interference phenomena in metallic contacts
Resonant tunneling in oxidized semiconducting point contacts

Semiconductors

Isotope effects on the electronic excitations and phonons in germanium
How rapidly does a gas of electrons reach equilibrium?
Direct observation of energy up-conversion by Auger processes in modulation doped GaAs/GaA1As heterojunctions
Subpicosecond time-resolved measurements of the pressure-induced real-space electron transfer in a GaAs/A1As superlattice
Scanning tunneling microscopy and spectroscopy of Ge(111) surfaces

High-T_c superconductors and related topics

Investigations on $YBa_2Cu_3O_7$ films in the far-infrared using a reflection Fabry-Perot interferometer
Effects of Landau-damping on the Raman-active phonons of $YBa_2Cu_3O_{7-\delta}$
Ab-initio calculation of the charge and lattice modulation in $BaBiO_3$
Normal-state resistivity and electron-phonon coupling in high-T_c superconductors
Superconductivity in layered structures of rare-earth carbide halides
Defect chemistry of the high-temperature superconductors $(La,Sr)_2CuO_4$ and $YBa_2Cu_3O_7$
Incommensurate-to-commensurate, antiferromagnetic phase transitions in CuO single crystals: specific heat in magnetic field

New materials and ionic conductors

Visible luminescence from silicon
New complexes with gadolinium and samarium
Crystal structure of N_2O_3
Novel ternary pnictides: $Na_2M_3Y_4$(M=Sr,Eu; Y=P,As)

Excited singlet states of molybdenum(II) chloride clusters

Color centers in $SrTiO_3$: a probe to study redox kinetics in the solid state and a test for a generalized diffusion concept

Ionic space charges: detected and analyzed by impedance spectroscopy

New methods

Metallic waveguides for infrared radiation

Micropatterning of epitaxially grown YBCO thin films on ZrO_2-buvered silicon single crystals

Silicon liquid phase epitaxy stands the test for solar cells and MOS transistors in silicon-on-insulator

Picosecond characterization of metal-semiconductor-metal photodetectors

The solid-vapor macro interface as a mirror of vapor phase reactions.

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The Federal High Performance Computing Program

Executive Office of the President
Office of Science and Technology Policy
September 8, 1989

THE FEDERAL HIGH PERFORMANCE COMPUTING PROGRAM

High Performance Computing Systems

- Research for Future Generations
- System Design Tools
- Advanced Prototype Development
- Evaluation of Early Systems

Advanced Software Technology and Algorithms

- Support for Grand Challenges
- Software Components and Tools
- Computational Techniques
- High Performance Computing Research Centers

National Research and Education Network

- Interagency Interim NREN
- Gigabits Research and Development
- Deployment of Gigabits NREN
- Structured Transition to Commercial Service

Basic Research and Human Resources

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

In November 1987, my predecessor, William R. Graham, transmitted to Congress A Research and Development Strategy for High Performance Computing. That report laid out a five-year strategy for federally supported R&D on high performance computing, including hardware for state-of-the-art supercomputers, software, computer networks, and supporting infrastructure. It was written with the assistance of the Committee on Computer Research and Applications under the OSTP Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). This strategy document was to be followed by a detailed program plan.

I am pleased to transmit to Congress that program plan -- the result of an intense interagency effort by a special task force within the Committee on Computer Research and Applications. Following the general organizational structure of the 1987 strategy report, it lays out a broad R&D policy and program plan designed to advance U.S. leadership in high performance computing. This plan calls for a federally coordinated government, industry, and university collaboration to accelerate the development of high speed computer networks and to accelerate the rate at which high performance computing technologies -- both hardware and software -- can be developed, commercialized, and applied to leading-edge problems of national significance.

High performance computing is a vital and strategic technology, exerting strong leverage on the rest of the computer industry and other cutting-edge areas. However, U.S. leadership and diversity in the supercomputer industry itself has declined dramatically; and history shows that a scant 15 years separates the first appearance of a top-of-the-line supercomputer from the appearance of that same computing power in the higher end of the personal computer market. A future national high speed computer network could have the kind of catalytic effect on our society, industries, and universities that the telephone system has had during the twentieth century.

We cannot afford to cede our historical leadership in high performance computing and in its applications. We need to encourage the dynamism of the U.S. computer industry and, hence, our economy. I would ask all of the federal agencies with research programs in high performance computing to work toward implementing the recommendations in this report.



D. Allan Bromley
Director

Foreword

High Performance Computing is a powerful tool to increase productivity in industrial design and manufacturing, scientific research, communications, and information management. It represents the leading edge of a multi-billion dollar world market, in which the U.S. is increasingly being challenged. A strong, fully competitive domestic high performance computer industry contributes to U.S. leadership in critical national security areas and in broad sectors of the civilian economy, including the technical base for many national economic and military security needs. For this reason we are initiating the preliminary planning to address this important U.S. technology.

GOALS

Accordingly, the goals of the Federal High Performance Computing (HPC) Program are to:

- Maintain and extend U.S. leadership in high performance computing, and encourage U.S. sources of production;
- Encourage innovation in high performance computing technologies by increasing their diffusion and assimilation into the U.S. science and engineering communities; and
- Support U.S. economic competitiveness and productivity through greater utilization of networked high performance computing in analysis, design, and manufacturing.

COMPONENTS

The HPC Program is implemented through four complementary, closely coordinated, multidisciplinary Components:

- High Performance Computing Systems;
- Advanced Software Technology and Algorithms;
- The National Research and Education Network; and
- Basic Research and Human Resources.

POLICY

The Federal High Performance Computing (HPC) Program features increased cooperation between business, academia and government. While each of these sectors will retain its current role, the success of this Program will depend in large part on an effective transition from R&D to commercialization—an outcome of successful cooperation among the above sectors.

The measure of success of this Program in the area of R&D will be an increased rate of development of new computing concepts, systems, and architectures. A longer term measure of success will be the rate at which this technological progress shows up in commercialized products. The HPC Program will be consistent with the traditional roles of government, business and academia.

Specifically:

- The government will provide R&D support for HPC and will coordinate R&D among its agencies;
- Business will be the decision maker and source of capital investment for commercialization of HPC technology in response to its assessment of market opportunities; and
- Universities and Federal laboratories will be the primary institutions receiving government funding under this Program.

The government will, in addition, foster a number of mechanisms for increased collaboration and interaction among government, business and universities. Specifically:

- The government will continue to serve as a market for commercial prototypes and for commercial products. This particularly will be the case in the defense sector. These markets will exist in U.S. laboratories, Federal agencies, university centers of excellence and industrially led consortia;
- The government will assist in the development of industrially–led consortia in cases where appropriate (an existing example is SEMATECH); and
- The government will promote centers of excellence, jointly funded and staffed by government, academia, and industry. Technology transfer to industry from government and academia will happen automatically as a result of this ongoing collaboration.

Foreign policy objectives will be supported through existing or future international science and technology agreements. "Symmetry and reciprocity," protection of U.S. proprietary interests, and enforcement of intellectual property rights will continue to be guiding principles.

The Federal High Performance Computing Program will ensure the broadest possible national benefit by addressing:

- Many problems susceptible to computational solution;
- A wide geographic and demographic distribution; and
- The inclusion of government, academia and industry.

STRATEGY

To achieve the policy goals of the HPC Program, our strategy is to:

- Support computational advances through R&D effort to address U.S. scientific and technical challenges;
- Reduce the uncertainties to industry for development and use of this technology though increased cooperation among government, industry and academia and the continued use of government and government–funded facilities as a market for HPC prototypes and commercial products;

- Support the underlying research, network and computational infrastructures on which U.S. high performance computing technology is based; and
- Support the U.S. human resource base to meet needs of industry, academia and government.

ROLE OF FEDERAL, ACADEMIC AND INDUSTRIAL SECTORS

Federal agencies

- Funding for the Program will come from agencies their annual appropriations;
- User agencies will continue to define their respective missions and goals, though guided by the High Performance Computing Program goals and objectives; and
- OSTP, through its Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) Committee on Computer Research and Applications, will assist the agencies as part of its continuing responsibility for coordination and policy guidance. OSTP will also assist by recommending special computational opportunities. However, final priority setting will reside with the respective agencies.

Academia

Universities and colleges will participate in the HPC Program in the following ways:

- Responding to agency program announcements;
- Forming consortia with government and industry;
- Focusing research capabilities on specific areas of computational science;
- Enhancing curricula to take advantage of new generations of computing technologies, attracting additional manpower into various disciplines of computational science; and
- Bringing the Program to the attention of State leaders for potential leveraging of Federal funds.

Industry

- Private industry will develop hardware, software, and networks in response to the Program. Commercialization will be at the initiative and discretion of private industry;
- Industry will join and help finance university or government laboratory R&D activities (at its choosing) to obtain access to expertise and government funded facilities. As a result of these collaborative relationships, the partnership will supply industry with R&D and technology information;
- A broadly representative industry body will assist in making long-range demand and robustness projections for: high capacity research networks; the spectrum of

computer architectures; the adequacy of software development; and the level of the manpower pool. This body will help assure a smooth transition between successive generations of high performance computing systems; and

- Private industry suppliers will provide the network services to Federal agencies in the first two stages of the National Research and Education Network. Industry should plan to operate the NREN fully as soon as feasible.

FUNDING OF THE HPC PROGRAM

The magnitude of the program envisioned by this Program will require major new Federal R&D investment. It is assumed that existing Federal base funding for computer and information science and technology research and development, roughly $500 million annually, will continue. Preliminary planning estimates suggest that the first year of the program would require an augmentation of $150 million, which would then grow to an incremented annual level of $600 million by the fifth year.

MANAGEMENT OF THE HPC PROGRAM

The components of the Program will be managed by existing Federal agencies.

Oversight of the HPC Program will be the responsibility of the Office of Science and Technology Policy with the assistance of the FCCSET Committee on Computer Research and Applications and the help of a High Performance Computing advisory panel which will report to the Director of OSTP:

- The HPC advisory panel will interact regularly with the FCCSET Committee on Computer Research and Applications; and
- The HPC advisory panel will have representation from all sectors and will monitor the progress of the Program for cross-sector balance, breadth of applicability, network security, competitiveness versus international cooperation, and technology transfer effectiveness.

SCOPE OF THIS REPORT

This report is designed for agency-level planning purposes and does not represent the Administration's approval or support of any program not included in the President's budget requests. Programs discussed in this document are subject to budget constraints and Administration approval.

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1. Executive Summary

*High Performance Computing** is a pervasive and powerful technology for industrial design and manufacturing, scientific research, communications, and information management. A strong U.S. high performance computer industry contributes to our leadership in critical national security areas and competitiveness in broad sectors of the civilian economy.

The goals of the High Performance Computing Program are to:

Goals

- Maintain and extend U.S. leadership in high performance computing, and encourage U.S. sources of production;
- Encourage the pace of innovation in high performance computing technologies by increasing their diffusion and assimilation into the U.S. science and engineering communities; and
- Support U.S. economic competitiveness and productivity through greater utilization of networked high performance computing in analysis, design, and manufacturing.

Strategy

These goals will be accomplished through Federally coordinated government, industry, and university collaboration to:

- Support computational advances through a more vigorous R&D effort to expedite solutions to U.S. scientific and technical challenges;
- Reduce the uncertainties to industry for R&D and use of this technology through increased cooperation between government, industry and academia and the continued use of government and government–funded facilities as a market for HPC early commercial products;
- Support the underlying research, network and computational infrastructures on which U.S. high performance computing technology is based; and
- Support the U.S. human resource base to meet needs of industry, academia and government.

* *High performance computing* refers to the full range of advanced computing technologies including existing supercomputer systems, special purpose and experimental systems, and the new generation of large scale parallel systems.

The HPC Program

The Program will consist of four complementary, coordinated components in each of the key areas of high performance computing. The components are planned carefully to produce not only long term results but a succession of intermediate national benefits. Figure 1 shows the relationship of the components of the Program. The High Performance Computing Program will build on those programs already in place, providing additional funds in carefully selected areas to meet its goals. Selected computational challenges, which will have significant effect on national leadership in science and technology, will be used as focal points for these efforts.

High Performance Computing Systems: The United States' leadership in supercomputing is increasingly being challenged. We have developed new, more powerful supercomputing architectures based on innovations. Particularly in parallel processing, we must capitalize on these innovations. To do this, a long range effort involving Federal support will be required for basic research on high performance computing technology and the appropriate transfer of research and technology to U.S. industry, consisting of efforts in the following areas:

- Research for future generations of computing;
- System design tools;
- Advanced prototype development; and
- Evaluation of early systems.

Advanced Software Technology and Algorithms: Historically, software improvements have increased computational performance much more than hardware investments. Yet software productivity is generally poor, and existing software can seldom be re-used without modification. In computing systems for industrial, scientific and military applications, software costs have exceeded those of hardware more than fivefold. Advances in software will be critical to the success of high performance computers with massively parallel architectures. To improve software productivity, an interagency effort will support joint research among government, industry and universities to improve basic software tools, data management, languages, algorithms, and associated computational theory with broad applicability for the *Grand Challenge** problems. These complex problems will require advances in software that have widespread applicability to computational problems in science and technology.

* A *Grand Challenge* is a fundamental problem in science or engineering, with broad economic and scientific impact, that could be advanced by applying high performance computing resources.

Effort in this component focuses on:

- Support for Grand Challenges;
- Software components and tools;
- Computational techniques; and
- High performance computing research centers.

National Research and Education Network: For the past decade technology developed by the U.S. has been available to eliminate distance as a factor in computer access and in collaborations among high technology workers. To maintain our leadership, the U.S. government, together with industry and universities, will jointly develop a high-speed research network to provide a distributed computing capability linking government, industry and higher education communities. This network will serve as a prototype for future commercial networks which will become the basis for a distributed industrial base. This component will consist of:

- An interagency effort to establish an interim National Research and Education Network;
- Research and development for a billions of bits per second (gigabits) network adequate to support national research needs;
- Deployment of the gigabits National Research and Education Network; and
- Structured transition to commercial service.

Basic Research and Human Resources: U.S. universities are not meeting the expanding needs of industry for trained workers in computer technology. There is not an adequate number of high quality computer science departments in this country, and many industrial and Federal laboratories have inadequate research capabilities. Furthermore, existing university, government, and industrial groups do not collaborate effectively enough, and their interdisciplinary activities are too limited. To correct these deficiencies a long term effort to support basic research in computer science and engineering (creating computing systems) will be established by building upon existing programs. This component will also establish industry, university, and government partnerships to improve the training and utilization of personnel and to expand the base of research and development personnel in computational science and technology (using computers).

Organization

Leadership of the Program is the responsibility of the Office of Science and Technology Policy, through the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) Committee on Computer Research and Applications, whose members include representatives of the key agencies that fund R&D in high performance computing. Duties and responsibilities of the Committee include:

- Interagency planning and coordination;
- Technology assessment;
- Policy recommendations to OSTP; and
- Formal annual reports of progress to OSTP.

A High Performance Computing Advisory Panel will be formed, consisting of eminent individuals from government, industry, and academia. Members of the Advisory Panel will be selected by and will report to the Director of OSTP. The Panel will provide the Director and the Committee on Computer Research and Applications with an independent assessment of:

- Progress of the Program in accomplishing its objectives;
- Continued relevance of the Program goals over time;
- Overall balance among the Program Components; and
- Success in strengthening U.S. leadership in high performance computing, and integration of these technologies into the mainstream of U.S. science and industry.

This implementation plan was prepared by the FCCSET Committee on Computer Research and Applications under the leadership of the Office of Science and Technology Policy. It represents a broad spectrum of government, industrial and university interests. The Committee has established subcommittees that will be responsible for planning, organizing, monitoring and coordinating the components of the Program.

SCOPE OF THIS REPORT

This report is designed for agency-level planning purposes and does not represent the Administration's approval or support of any program not included in the President's budget request. Programs discussed in this document are subject to budget constraints and Administration approval.

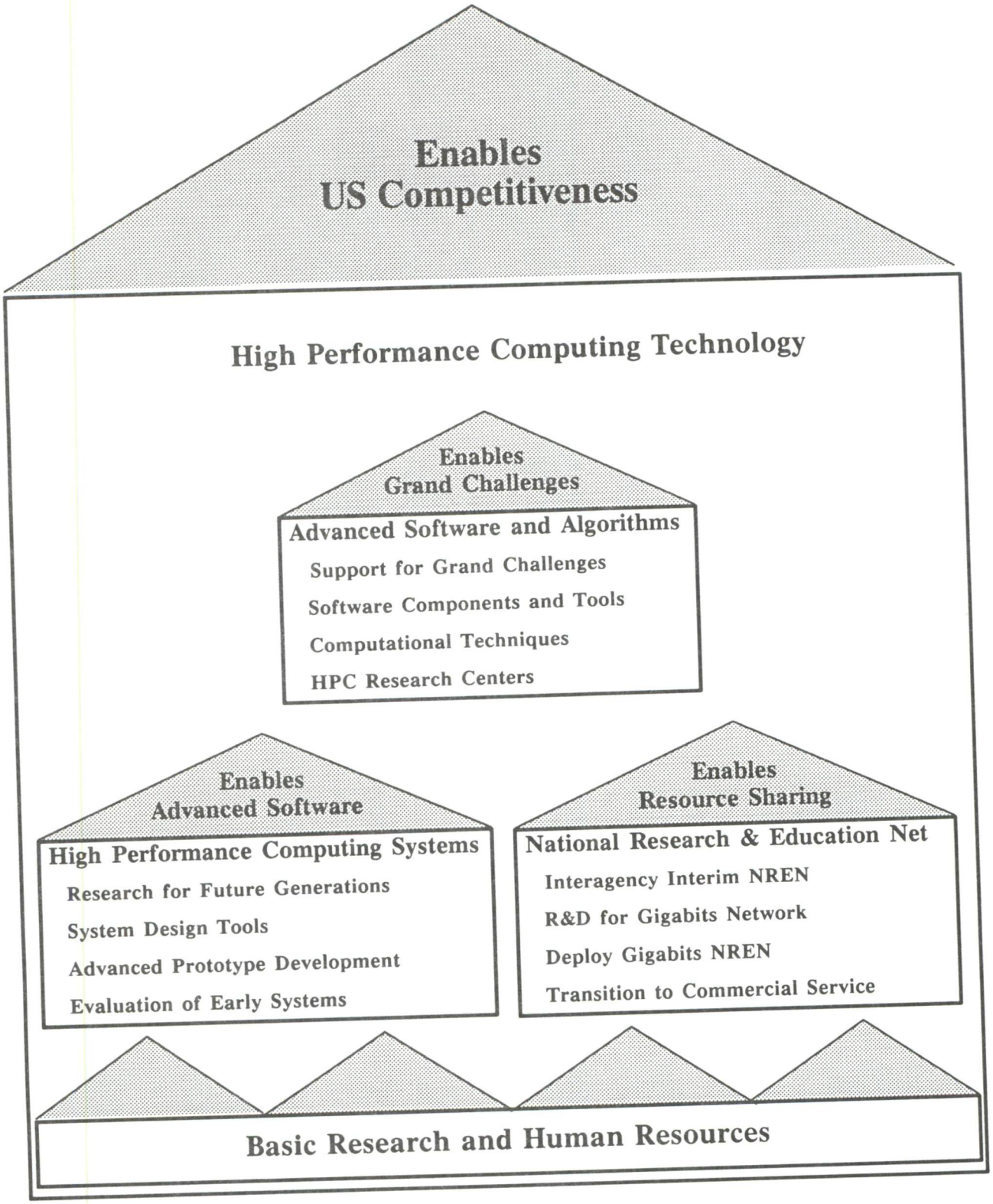


Fig. 1 – Relationship of HPC Program Components

2. Introduction

Purpose and Scope of Report

The purpose of this document is to provide the initial implementation plan for the U.S. High Performance Computing Program. This plan encompasses the first five year period and provides for periodic reviews to be conducted by the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) with the participation of government, industry, and university representatives.

This document discusses:

- National economic and technical issues associated with high performance computing;
- Goals and strategy of this Program;
- Plans for synergistic government, industrial, and university participation;
- Organizational structure to coordinate, manage and review the Program program;
- Economic and technical benefits of the Program; and
- Proposed budget for the first five years of the Program.

This implementation plan was prepared by the FCCSET Committee on Computer Research and Applications under the leadership of the Office of Science and Technology Policy. It represents a broad spectrum of government, industrial, and university interests. This report is designed for agency-level planning purposes and does not represent the Administration's approval or support of any program not included in the President's budget request. Programs discussed in this document are subject to budget constraints and Administration approval.

Background

The Federal Coordinating Council on Science, Engineering and Technology (FCCSET), chartered by the Office of Science and Technology Policy (OSTP), coordinates Federal interagency activities of broad national interest. The FCCSET Committee on Computer Research and Applications serves as the forum for developing a national agenda for computing technology needs, opportunities, and trends.

This FCCSET Committee has examined the scientific, technological and economic effects of high performance computing. The Committee issued reports as early as 1983

that assessed the status of high performance computing and possible supporting government activities. These studies have consistently demonstrated the need for a strategy to coordinate high performance computing related activities in the government, industrial and university sectors. Dramatic increases in foreign investments in computer related technology have been noted, which challenge the world leadership of the U.S. computing industry. The studies also emphasized that advances in critical areas of national security and broad sectors of the civilian economy depend strongly on high performance computing technology.

The unprecedented power of high performance computing systems has created a new mode of scientific research: computational investigations that complement the traditional modes of experiment and theory. Computational research is being applied to a wide range of scientific and engineering problems called Grand Challenges. *A Grand Challenge is a fundamental problem in science or engineering, with potentially broad economic, political, and/or scientific impact, that could be advanced by applying high performance computing resources.* While the Grand Challenges are already being addressed to some extent using existing supercomputers, progress is often severely limited by current computer speeds and memory capacities. Examples of Grand Challenges are:

(1) Computational fluid dynamics for the design of hypersonic aircraft or efficient automobile bodies and recovery of oil.

(2) Computer based weather and climate forecasts, and understanding of global environmental changes.

(3) Electronic structure calculations for the design of new materials such as chemical catalysts, immunological agents and superconductors.

(4) Plasma dynamics for fusion energy technology and for safe and efficient military technology.

(5) Calculations to improve our understanding of the fundamental nature of matter, including quantum chromodynamics and condensed matter theory.

(6) Machine vision to enable real-time analysis of complex images for control of mechanical systems.

The sample Grand Challenge areas provided in Appendix A are representative of the science and technology areas that will be affected by application of leading edge computational resources and supporting systems. Figure 2 illustrates some of the Grand Challenges that can be adequately addressed through existing high performance computing technology and problems that could be attacked much more successfully with a thousandfold increase in performance.

Agency Activities: In the early 1980's, Federal agencies initiated programs that provide the basis for the opportunities described in this Program. The NSF established the National Supercomputer Centers to provide high performance computers to the science and engineering community and interconnected them with the research community via the NSFNET. The centers and network have stimulated the development of innovative computational approaches to a wide range of scientific and engineering problems related to the Grand Challenges. NSF also reorganized to create a new Directorate of Computer and Information Science and Engineering (CISE) with increased emphasis and funding for computer and computational disciplines, with a focus on computer networking as a tool for scientific and engineering research.

DARPA initiated the Strategic Computing program to accelerate development of an alternate approach to building high performance computer systems. This program focuses on large scale parallel systems, custom VLSI and associated software, including symbolic processing for the advanced functionality characterized by artificial intelligence. Strategic Computing stimulated the first generation of commercially available scalable parallel computer systems using conservative components and packaging. Early production models of these systems were acquired by several agencies for experimental use. A second generation of these systems is being developed, using custom VLSI. The military services have participated in this program, providing applications focus and technical consultation.

The Office of Naval Research, Air Force Office of Scientific Research, and Army Research Office have separately sponsored important research and development in basic research for advanced computing.

The DOE expanded the National Magnetic Fusion Computer Center and its MFE Network to serve all energy research users in national laboratories, universities, and industry. Several of the National Laboratories have formed computational groups to experiment with novel high performance computers and to develop algorithms that exploit the power of those computers. Special funding was provided to enable university, industry, laboratory collaborations with the national laboratories to acquire parallel computer prototypes to test ideas for advanced high performance computing architectures.

NASA upgraded the computational capability at several of its research and flight centers and established a data network to link them together. At the Ames Research Center, the Numerical Aerodynamics Simulation (NAS) was set up to provide a focused attack on computational aerodynamics employing the highest powered computers available surrounded by data reduction and visualization systems.

HPC Strategy: In 1986 Congress requested that OSTP conduct a study of the critical problems and options for communication networks that support the U.S. high

performance computing environment. The charter of the FCCSET Committee on Computer Research and Applications was broadened to include the technical aspects of this study. A number of working groups were formed to ensure a perspective that spanned all aspects of the U.S. high performance computing environment. In addition a consortium of government, industry and university experts focused on national infrastructure requirements for high performance computing.* The FCCSET study is documented in "A Research and Development Strategy for High Performance Computing" also known as the *High Performance Computing Strategy (HPC Strategy)*, published by the Office of Science and Technology Policy (included as Appendix B). It provides the foundation for this Program.

The *HPC Strategy* findings were:

- A strong domestic high performance computer industry contributes to maintaining U.S. leadership in critical national security areas and in broad sectors of the civilian economy.
- Research progress and technology transfer in software and applications must keep pace with advances in computing architectures and microelectronics.
- The U.S. faces serious challenges in networking technology which could become a barrier to the advance and use of computing technology in science and engineering.
- Federal research and development funding has established laboratories in universities, industry, and government which have become the major sources of innovation in the development and use of computing technology.

The recommendations of the *HPC Strategy* form the basis for the four components of the High Performance Computing Program.

Four National Research Council reports issued in the period following publication of the *HPC Strategy* have confirmed its findings and emphasized the need to carry out its recommendations: *Toward a National Research Network* (1988), *The National Challenge in Computer Science and Technology* (1988), *Global Trends in Computer Technology and Their Impact on Export Control* (1988), and *Information Technology and the Conduct of Research* (1989).

In December 1988, the Office of Science and Technology Policy charged the FCCSET Committee on Computer Research and Applications to develop this implementation plan for the High Performance Computing Program. The goals, strategy, and actions to implement the Program are discussed in the following sections.

* *A National Computing Initiative*,
Society for Industrial and Applied Mathematics, Philadelphia, PA 1987.

What is High Performance Computing?

High Performance Computing refers to a productive computing environment that includes high performance components, system and applications software, networking, and the underlying research and human resource infrastructure.

High performance computing systems are those at the forefront of the computing field in terms of computational power, storage capability, input/output bandwidth, and software. These systems include high speed vector and pipeline machines, special purpose and experimental systems, scalable parallel architectures, and associated mass storage systems, input/output units, and systems software. Underlying these advanced systems are microelectronics, optoelectronics, logic devices, and storage technologies.

Advanced software technology and algorithms includes general-purpose operating systems for high performance computer systems and tools and utilities, such as compilers, analysis tools, debuggers, and data management systems. Mathematical algorithms and other general purpose libraries facilitate the use of high performance computers for science and engineering. Software tools will allow high performance computing systems to be embedded transparently in a distributed environment which includes applications specific software and other specialized methods and algorithms. The technology base required to build such environments includes software engineering and data management tools, and basic research in high-level languages and algorithms. Improving these capabilities will greatly enhance scientific and engineering software productivity.

Computer network technology consists of communications and switching capable of providing a very high speed backbone on which the high performance computing environment is distributed. Internetworking and feeder network technology connects local or mid-level high speed networks to the national high speed network. User services such as directories are also essential components of an effective networking environment. Advanced networks will provide improved access to high performance computing systems and increased collaboration opportunities for universities, industry, and government.

Development of high performance computing environments requires a long term, continuing investment in basic research over a wide spectrum of computer and computational science and engineering. A basic infrastructure of knowledge, research, computing facilities, and people are required to create and exploit high performance computing technology.

Why is High Performance Computing Important to the U.S.?

During the last two decades computing has become an important complement to experimental and theoretical research. Computer aided design and engineering

techniques are replacing manual ones. Computer assisted and automated manufacturing is increasing productivity and improving the value and reliability of industrial products, while reducing the time required for engineering and manufacturing cycles. New knowledge and new industries are increasingly dependent upon computing.

Most of these advances in computing have originated in the United States. However, many of them have been most successfully applied in other countries, where their use has eroded the competitive edge that the U.S. had previously enjoyed. This Program is intended to maintain the U.S. edge by focusing our research advantage in high performance computing toward applications with high value to our economy and national security. Fortunately, current U.S. leadership in high performance computing offers a strategic opportunity to maintain our industrial momentum. The HPC Program provides a way to do this.

The national economic benefits of a strong high performance computing industry are recognized and pursued by other countries. Those nations have formed and funded collaborations between their private and public sectors. Their successes constitute vigorous competition for technological and economic leadership in high performance computing. Foreign computing industries benefit tremendously from government support. To retain our leadership, domestic industrial efforts must be encouraged by a strategy that shares the economic risk of innovation in this capital-intensive field.

National economy: High performance computing is by definition the leading edge of computing technology, which in turn supports many areas of science and technology. Computing constitutes a significant portion of the U.S. economy. For example, in 1988 the U.S. computing industry accounted for 10% of GNP, and almost 10% of all capital investment.* The pace of innovation that it sets pervades the domestic computing industry technology and economics. In terms of capability, today's supercomputer is tomorrow's desk-top workstation and the following day's classroom tool. Thus, U.S. competitive success in the world computing market is supported by leadership in high performance computing.

National security: High performance computing technology is used in critical national security areas. Examples include advanced computer systems architectures, computer network communication technology, and signal processing techniques. Continued acceleration of this technology, including availability of U.S. sources of production, is important to U.S. national security.

Science and technology: High performance computing provides a basis for other innovative scientific and engineering efforts. The pace of rapidly developing technologies, such as robotics, artificial intelligence, communications, high definition

* *The National Challenge in Computer Science and Technology*, National Academy Press, Washington, D.C., 1988, p. 7.

television (HDTV), campus network applications, semiconductor design, superconductivity, transportation, speech recognition, and data visualization are all dependent on a strong and innovative high performance computing industry.

Manufacturing: High performance computing constitutes an important tool for many industries. Its use in simulation and design improves the productivity of large industries such as aircraft production and automobile manufacturing and is rapidly being extended to other industries. Recent vigorous growth in use of high performance computing in electronics, energy, chemical and pharmaceutical industries illustrates the role of computing in the long term strength of the U.S. economy.

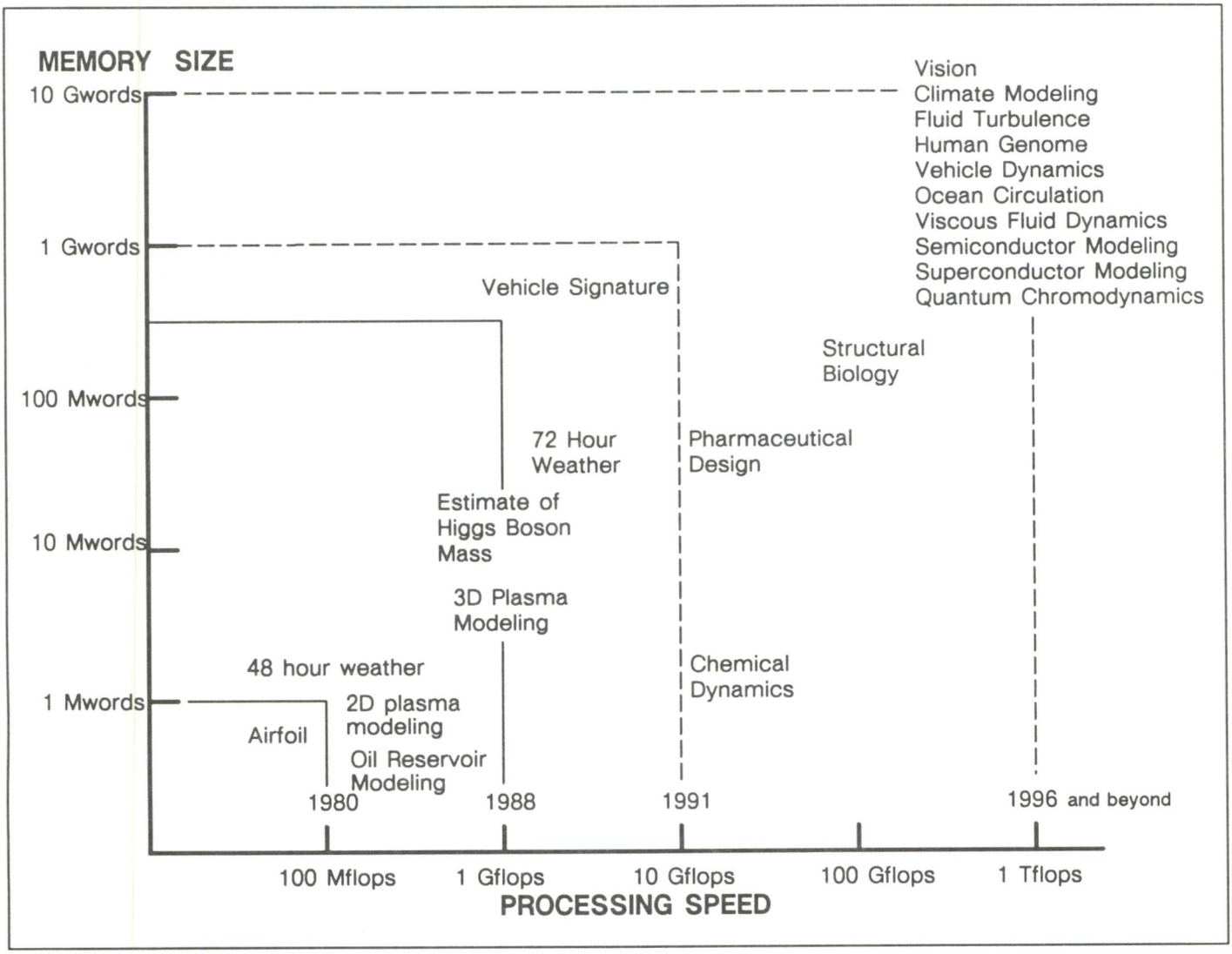


Fig. 2 – Some Grand Challenges and their Projected Computational Requirements

3. Program Plan

Introduction

The goals of the High Performance Computing Program are to:

- Maintain and extend U.S. leadership in high performance computing, and encourage U.S. sources of production;
- Encourage innovation in high performance computing technologies by increasing their diffusion and assimilation into the U.S. science and engineering communities; and
- Support U.S. economic competitiveness and productivity through greater utilization of networked high performance computing in analysis, design, and manufacturing.

To achieve these goals, a strategy has been established to:

- Support computational advances through R&D efforts to address U.S. scientific and technical challenges;
- Increase the use of this technology by reducing the uncertainties to industry for R&D and by increasing cooperation among government, industry, and academia;
- Continue use of government and government-funded facilities as a market for HPC early commercial products;
- Support the underlying research, network and computational infrastructures on which U.S. high performance computing technology is based; and
- Support the U.S. human resource base to meet needs of industry, academia and government.

The HPC Program is composed of four coordinated program components: High Performance Computing Systems, Advanced Software Technology and Algorithms, the National Research and Education Network, and Basic Research and Human Resources. Each of the four program components stimulates the development of progressively more advanced products for use throughout computing technology. The four areas build upon each other and upon the existing research base, as illustrated in Figure 1. Each component carries out a recommendation of the November 20, 1987 *HPC Strategy* (see Appendix C.)

Although the program components are described separately, they are interdependent, so that success of the Program depends on balanced support for all of them. For example, the development of high performance computing systems depends on development of advanced software technology and algorithms, because algorithm and software requirements largely determine the corresponding architecture of successful

computing systems. Similarly, as the new computing systems become available, new algorithms and software systems are required to take advantage of their capabilities and allow the systems to be used in practical ways.

The High Performance Computing Program requires an unprecedented level of coordination among agencies of the Federal government that are involved in high performance computing. The agencies involved have already begun cooperation to meet this challenge in order to mount a sufficiently comprehensive program in support of U.S. competitiveness.

The remainder of this section describes the goals for each of the four components of the Program, the actions that will be taken to achieve these goals, and the responsibilities of each of the participating federal agencies. Although the Program builds on the existing research base, its goals extrapolate significantly from those of the base and will require significant additional funding. This funding is presented in Table 1 at the end of the plan, with the funding elements keyed to each component and action of the Program.

High Performance Computing Systems

Recommendation: The U.S. Government should establish a long range strategy for Federal support for basic research on high performance computer technology and the appropriate transfer of research and technology to U.S. industry. [*HPC Strategy*, 1987]

Goals

High performance computing systems consist of processors, memory, mass storage, input/output, and associated system software. The systems are characterized in this report by overall sustained performance on large problems. They will be designed so that memory capacities, storage sizes and input/output rates scale to provide sustained performance in proportion to processing.

The goal is to support the development of high performance computing systems which will be capable of sustaining trillions of operations per second on significant problems. The program builds upon present government supported efforts which have established U.S. leadership in developing large scale computer systems and the underlying component technologies. However, achieving and effectively exploiting this thousandfold improvement in performance will require developing a new technology base through a program of research in computer architectures, microelectronics and packaging, and associated systems software .

A primary objective of the plan is to assist the continued viability of domestic sources of high performance computers and their critical components that meet the requirements of U.S. industry and Federal programs, both civil and defense. The plan will focus Federally funded research and promote transfer of results between Federally-funded research programs and U.S. industry. This requires close collaboration of researchers in the nation's universities and government laboratories with industrial scientists and engineers. Government funding will also assist risk reduction in critical areas and will complement private capital in the computer market.

To date Federal investment in high performance computing systems has taken two forms: (1) purchase of early market and production model systems and (2) research and development which has the led to commercial high performance systems. In both cases Federal funding has reduced the R&D risk of the high performance computing systems for U.S. manufacturers. Because many foreign computer manufacturers are willing to accept greater R&D risk due to their financial environment, the Federal strategy has been important in maintaining U.S. technical leadership in high performance computing systems.

Early purchase has served several critical functions. It has often provided essential financial assistance and early technical feedback to manufacturers during production of

their first model of a new high performance computing system. The substantial computational resources provided by these early purchases have maintained the rapid technological advance of the U.S. in both civil and defense sectors, thereby supporting the nation's economic and military security. Early users have devised efficient ways of exploiting the capabilities of new systems, providing a performance characterization of the design. They have also furnished significant new concepts to be incorporated in the designs of succeeding generations. This information has often led to improvements leading to more viable commercial products.

For example, NASA and DOE encouraged industry to develop a more advanced supercomputer to meet their research needs, which resulted in the Cray 2 supercomputer. This powerful new machine with greatly expanded memory might not have achieved market acceptance without the identified high performance computing requirement and subsequent acquisition by these Federal agencies. DOE and NASA acquired the first Cray 2 systems, and their early experience showed the broader market for computational research the importance of memories of hundreds of million words and provided valuable feedback that led to engineering changes for better performance.

Federal research and development investment has facilitated advanced research partnerships between industrial firms and university researchers. Industry provides practical knowledge and advanced manufacturing technology to produce high performance computing systems, while universities have developed new concepts and experimental systems. The results of these partnerships have often been significant in supporting the U.S. economy and national security.

The DARPA Strategic Computing program, DOE, and NASA have funded industry/university partnerships which have established U.S. leadership in scalable, highly parallel, high performance computing systems. Unlike the present generation of supercomputers, the resulting systems employ hundreds to thousands of processors. These architectures are generally scalable to higher levels of parallelism and, in the future, can exploit higher performance components and packaging with corresponding increases in sustained performance. This program has produced very promising results: the first generation of scalable parallel systems are now commercially available and have demonstrated high performance in both numeric and non-numeric applications. The second generation of this class of high performance computers is now emerging and scientific, engineering, defense, and business users are preparing for their arrival. Additional results include enhanced performance for workstations, personal computers, mass storage, graphics and input/output systems.

This Component of the HPC Program will build on recent experience in coordinated funding by different agencies of high performance computing systems research and development. For example, the Strategic Computing program at DARPA invested in R&D for an advanced parallel computer which was subsequently commercialized by

Thinking Machines Corporation. DARPA then collaborated with DOE and NASA to facilitate early use of this system in their research laboratories. The NSF recently funded a Science and Technology Center at Rice University, California Institute of Technology, Argonne National Laboratory, and Los Alamos National Laboratory which will consider more effective applications of this and other parallel architectures.

Action Plan

The focused high performance computing systems projects in this plan will be undertaken in cooperation with the software development projects. The systems also must be coordinated with advances in networking to ensure that their potential performance is available to remote users via the National Research and Education Network. The advanced research tasks provide excellent training grounds for the next generation of computer and computational scientists and engineers. Collaboration among these components is essential to the success of the Program.

Research for future generations of computing: Research in computer science, scalable parallel computer architectures, high density packaging technology, VLSI technology and optoelectronics will be increased. New packaging and component technologies will be developed together with associated design, analysis, simulation, and testing tools to enable their use in implementing larger scale computer architectures. This includes creating and extending models of computation, together with sufficient efforts in adaptation of fundamental algorithms, operating systems, and programming languages. These systems-specific activities complement the more generic and applications-focused software described in Advanced Software Technology and Algorithms where the emphasis is to develop the full potential of the new architectures.

System design tools: Support for rapid design, prototyping, and integration is essential to reach the capabilities needed for the Program. Progress in research, development and manufacturing of high performance computing systems is presently limited by lack of adequate automated design and analysis tools. A new generation of design tools and techniques will be developed for integrated, computer-assisted design and manufacturing of high performance computing systems from functional specifications through full systems. The tools will be developed so as to provide rapid prototyping in support of research, interfaced with the latest advances in automated manufacturing so as to boost U.S. industrial capabilities in addition to increasing research and development productivity. These facilities will make use of the latest high-density packaging technology which will be required to create systems at the targeted level of performance.

Transfer of technology to stimulate advanced prototypes: Cooperative university/industry high-risk research and development projects will provide rapid technology transfer from research results to working prototypes. Revolutionary concepts

are emerging from the frontiers of research in computer science and engineering, innovative computer architectures, mass storage systems, input/output systems, high density packaging, Very Large Scale Integration (VLSI) and optoelectronics. Government funds will be invested where opportunities exist for leverage to accelerate the transfer of the Federally-funded computing technology to American industry and vice versa. Advanced application-specific integrated circuits (ASICs) will be utilized where appropriate in these general purpose high performance computing systems. Joint projects in high risk areas will be pursued on a cost sharing basis with industry in close collaboration with government laboratories and academia. The focus of these projects will be to accelerate transition of high risk, revolutionary concepts from research laboratories into the commercial market while encouraging a domestic means of production for all critical components.

By the mid 1990s, it is expected that commercial advanced prototypes will be capable of sustaining two or three orders of magnitude better performance than today's systems for complex science, engineering, and defense applications, and for other problems of national importance. System software, including operating systems, programming languages, and software analysis tools, will be developed to determine the computational potential of the commercial systems. Performance analysis and measurement tools will be improved to enable the design and configuration of heterogeneous systems.

Evaluation of Early Systems: Evaluation of early production models of new high performance computing systems will be undertaken using representative problems. These systems will be acquired at the smallest scale that can evaluate their potential performance. The resulting evaluations will form a basis for decisions to develop the associated generic software and specific large scale applications in the Advanced Software Technology and Algorithms component. Needs of the Grand Challenges will be considered fully, and some early production models of high performance computers may be utilized in one or more of the Grand Challenges, at the sites performing this research.

This component of the HPC Program does not include acquisition of full scale systems. Some of these will be acquired under the High Performance Computing Research Centers in the Advanced Software Technology and Algorithms component; others will be purchased by Federal agencies to fulfill their missions. This investment will sustain the U.S. competitive edge and must be protected by ensuring appropriate export controls.

Rationale

Improvements in materials and component technology are advancing computer capability rapidly. Memory and logic circuits are continuing to improve in speed and density, but as fundamental physical limits are approached, advances are being sought through improved computer architectures, custom components, and software and

algorithms. Application-specific integrated circuits, such as for real-time signal processing, are being incorporated into special purpose computing systems. Computer architectures have begun to evolve into large scale parallel systems. Scalable architectures provide a uniform approach that enables a wide range of capacity, from workstations to very high performance computers.

At current performance levels our ability to model many important science, engineering, and economic problems is still limited. Computational models which have been developed for these problems require for realistic solutions speeds of trillions of operations per second and corresponding improvement in memory size, mass storage, and input/output systems. *Achievement of this performance level in the next five years is feasible, based on extrapolations of processor capability, demonstrated architectures, number of processors, and improved software performance.*

Responsibilities

NSF, NASA, DOE and DOD share responsibility for long-range research on the foundations of high performance systems. Within the DOD this responsibility will rest with DARPA, the Army Research Office (ARO), the Office of Naval Research, (ONR) and the Air Force Office of Scientific Research (AFOSR). These agencies have all been involved in this area and have considerable knowledge of the status and opportunities.

DARPA will carry the prime responsibility for high-risk research and development leading to commercialization of highly parallel high performance computing systems and will work with ARO, ONR, and AFOSR to achieve this end. DARPA will also have the lead responsibility for supporting research facilities for rapid design, prototyping, and integration of these systems, using advanced components and packaging. DARPA's unique style of managing high risk, large scale projects is particularly effective for transfering technology in joint university and industrial efforts.

The DOE, NASA and DARPA will continue to acquire first production models of high performance computing systems. The diversity of interests represented by these agencies has been important to the broad range of systems developed by industry in the U.S.. This healthy arrangement will continue.

NIST will expand its program for development of measurement techniques and performance modeling for high performance computer systems, and will support transfer of this technology to industry.

Advanced Software Technology and Algorithms

Recommendation: The U.S. should take the lead in encouraging joint research with government, industry, and university participation to improve basic tools, languages, algorithms, and associated theory for the scientific Grand Challenges with widespread applicability. [*HPC Strategy*, 1987]

Goals

Sustained improvements in computing hardware performance and sophistication have resulted in a shift from hardware and architecture to software and algorithms as the primary determiners of the power, flexibility, and reliability of major computing systems. Today the ability to exploit computing technology to address scientific and technological problems of competitive and national importance is determined primarily by software capability.

Breakthroughs in software technology enable computer solutions to problems whose scale, complexity or evolving nature previously inhibited any organized approach. Breakthroughs in algorithm design improve problem solving performance by orders of magnitude, making tractable computational solutions in problem areas where previously no solutions of any sort, or only traditional analytical or experimental methods, were available.

The goal for the Software Technology and Algorithms component of the High Performance Computing Program is to develop a base of software technology and algorithms that (1) will enable solution of Grand Challenge application problems in science and engineering, and that (2) will have broad national impact on software productivity and on systems capability and reliability.

The approach taken is to develop the advanced algorithms and software technology required to address applications problems on the scale of Grand Challenges, while ensuring that the generic technology developed can be applied to a broad range of computational problems. This investment may lead to the development of commercial products, but only after the new concepts have been illustrated and their feasibility demonstrated. Therefore, specific investments will be made to reduce the risks associated with the transition and adoption of these advanced technologies.

The U.S. lead in many areas of science and technology will be closely linked to advances made on important fundamental problems identified as Grand Challenges. Grand Challenges come from many fields from basic science to applied technology. Their solutions will have significant, national-level impact across diverse fields of interest to many Federal agencies. Appendix A describes several Grand Challenges and the agencies concerned with their solutions.

Improvements in algorithm design and implementation are as important to total "user realized" system performance as are performance improvements in the computer

systems in which these algorithms will be executed. High performance computing offers scientists and engineers the opportunity to simulate conditions that are difficult or impossible to create and measure. This new paradigm of computational science and engineering offers an important complement to traditional theoretical and experimental approaches, and it is already having major impact in many areas. New approaches combining numeric and symbolic methods are emerging. Development of new instruments and data generation methods in fields as diverse as genetics, seismology, and materials is accelerating demand for computational power. As problems grow to the size and complexity of Grand Challenges, and as computer architectures grow more complex in order to provide increased computing power, the software and algorithms challenge becomes significantly greater.

Effective exploitation of the performance potential of the emerging parallel systems poses a special challenge both to software technology and to algorithm design. The required software technology has many dimensions, ranging from systems software, advanced compilers, and languages, to programming environments for developing and adapting software, to large scale distributed data repositories. Also included are techniques for analyzing and constructing software with high reliability and numerical accuracy, design of high performance algorithms for solving generic problems on specific architectures, and development of algorithmic and software architectural approaches specific to solving the Grand Challenges.

Research in fundamental parallel algorithms is needed to provide a sufficient base of algorithms for high performance architectures. The characteristics of the generic algorithms are often strongly dependent on the computational model embodied in a particular machine architecture. Various models of parallelism yield different algorithms, as do heterogeneous systems configurations involving hybrid computational models.

Networking technology will also have significant influence on the design of algorithms for distributed systems. Fundamental algorithms must be specialized and combined to provide application–specific algorithms appropriate for the Grand Challenges. Algorithm design, development, optimization, and validation requires substantial resources and collaboration. Experimental facilities are a critical tool for developing and demonstrating applications and systems software, computer architectures, and networks.

Action Plan

Support for Grand Challenges: A principal focus of activity will be providing advanced software technology support to research groups collaborating to address the Grand Challenges. The purpose of this is not to provide sustaining support for this research, but rather to provide a means to reduce the risks assumed by Grand Challenge researchers when adopting innovative high performance computing technologies.

3. Program Plan:
Advanced Software Technology and Algorithms

Collaborative groups will include scientists and engineers concerned with Grand Challenge areas, software and systems engineers, and algorithm designers. These groups will be supported by shared computational and experimental facilities, including professional software engineering support teams, linked together by the National Research and Education Network. Groups may also create a central administrative base, which can be located anywhere on the network. Experimental facilities, often called testbeds, are included in the network in order to provide real-time access to data streams and support for rapid validation of computational models.

Technical contributions arising from this investment will include development of application-specific codes for innovative high performance computing systems, design and analysis of algorithms for Grand Challenge problems, and architecture and performance assessment as it relates to specific applications.

Agencies will select Grand Challenge applications to be included in this Program on the basis of the national importance of the specific area and the extent of cost-sharing from sources directly concerned with the specific scientific and engineering applications. An additional consideration will be the leveraging potential in other areas, in particular the commercial domain. Investment related to high performance computing will complement the traditional sources of support for Grand Challenge research by enabling exploratory use of advanced computational techniques.

Software components and tools: The Grand Challenge applications groups will have common needs in many areas of software technology including programming environments for code development and adaptation, advanced compiler technology. Also needed will be tools for optimization and parallelization, data management and interoperability, analysis and performance measurement, user interaction and visualization, debugging, and instrumentation. Advances in these generic software technology areas will have broad national impact, beyond the immediate scope of the Grand Challenge applications.

In order to provide these tools in a manner that is responsive to the needs of the applications researchers, collaborative groups will be formed that cut across the Grand Challenge areas in order to coordinate and share supporting software technology. This will enable multiple applications groups to sustain more easily a fast pace of innovation in the underlying software technology. These groups will include industrial, academic, and government researchers. Innovative approaches will be used to provide incentive for industry to participate and share costs.

A major focus of systems design and engineering will be developing advanced software applications that exploit the high capacity of the National Research and Education Network to provide new capabilities to researchers. An important example is a distributed operating system that permits high capacity interactions among programs at multiple network sites. This capability will enable a researcher to develop applications that may involve several high performance computers located at diverse sites to work

together effectively. Other applications include distributed shared data and program libraries, research report dissemination systems, and advanced user interaction and visualization systems. For example, security support and data interoperability are required to enable distributed databases that exploit the National Research and Education Network.

Computational techniques: Developing software tools and components is basic to fundamental research in computational technology. It is this research that yields the fundamental algorithms, models of computation, new approaches to program analysis, and language approaches that provide fundamental generational advances.

Research in computational techniques includes the areas of parallel algorithms, numerical and mathematical analysis, parallel languages, and program refinement techniques. Also included are models of computation, formal methods for high assurance, theoretical and empirical techniques for algorithm analysis, and related areas.

Results in design and theory of algorithms are as important to breaking down computational scaling barriers as are performance improvements in computing hardware. Algorithm breakthroughs continue to be made on even fundamental problems such as linear algebra that are often assumed to be well understood. Breakthroughs can yield thousandfold speedup factors above and beyond hardware advances, as illustrated in Figure 3.

Parallel computing is the principal source of opportunity to improve computational performance. There are many differences among the models of computation embodied in parallel computers, and all of these differ from the purely sequential model that dominated the first half-century of computing. Algorithm theory has already yielded scalable parallel solutions to many computational problems that were assumed by most practitioners to be inherently sequential. In order to realize the potential for performance and scaling implicit in the parallel computer technology, research in the design of algorithms will be supported.

The evolution of parallel computing technology has also stimulated renewed activity in the area of high level programming languages. Languages that have inherently sequential semantics force programmers to make unnecessary and undesirable computational commitments that must, in any case, be undone by optimizing compilers. Efforts will be funded to develop higher level languages that will enable computational scientists to consider separately the abstract computational problem being solved and the specific implementation approach. This will also enable use of emerging programming tools that integrate program transformation and optimization with analysis to yield implementations with higher assurance and predictable numerical characteristics.

High performance computing research centers: The HPC Program will support deployment of innovative high performance computing architectures to computational

scientists and engineers working on Grand Challenge applications, and to other computer scientists and engineers. Centers will be established to accelerate transition to new generations of high performance computing technology by enabling researchers to explore applications of this new technology.

Information gained from evaluating prototypes of new architectures as part of the High Performance Computing Systems Component will aid the choice of architectures to support the Grand Challenges. As the risks associated with application of innovative systems diminishes in individual Grand Challenges, the costs associated with the facilities will be transferred to the interested sponsors of the applications research. In this component we include computing hardware, network access to the operating systems of scientific instrumentation, and operational support for the Grand Challenge cooperative groups.

Facilities will also be provided to researchers in computing technology in order to support a more rapid transition to the new technology base. Researchers in areas such as algorithms, software environments, and operating systems require experimental access to new generation hardware. For example, there are a number of theoretical models for parallel computation in general use among algorithm designers, but only through empirical work can these models by adjusted to reflect more faithfully the models embodied in the parallel systems. Crucial systems parameters, for example, the relation of processing time to communications time and memory speed, interact with algorithm design parameters in ways that can best be explored empirically.

It is expected that many of the facilities allocated as part of Advanced Software Technology and Algorithms component will be used to facilitate transition of Grand Challenge applications to the new high performance computing systems. The remaining portion will be provided to computing technology researchers in order to support the development of generic algorithms and software technology. These facilities are in addition to those which will be provided as part of the High Performance Computing Systems component of the Program as a means to accelerate the transition from prototypes into products.

Responsibilities

DOE, NASA, NSF, NOAA and **DARPA** share responsibility for clearly defining the computational requirements of the Grand Challenges. They will select Grand Challenge applications areas in which collaborative groups are to be formed, and are responsible for providing advanced software technology support to the research groups collaborating to address the Grand Challenges applications in their domains.

NASA will carry lead responsibility for organizing and chairing the Federal Advanced Software, Technology and Algorithms Coordinating Committee. DOE, NSF, DARPA and other DOD research activities will be among the agencies participating in this committee.

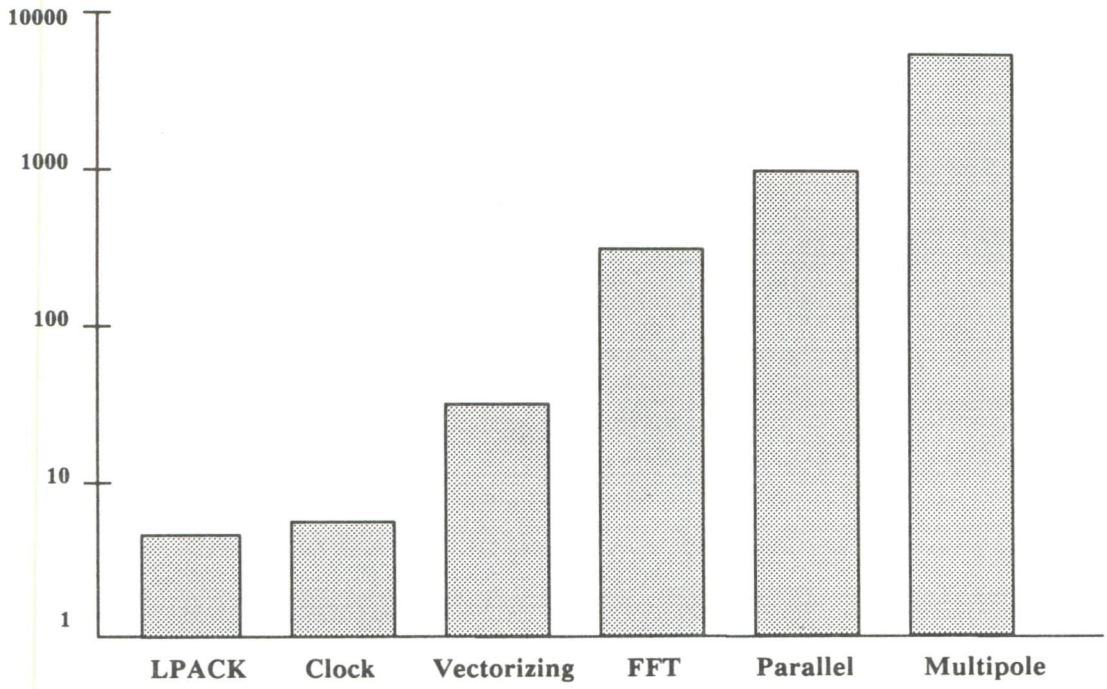
3. Program Plan:
Advanced Software Technology and Algorithms

NASA, DARPA, NSF and **DOE** will support development of software tools and standard components for use across the spectrum of the Grand Challenges. DOE and NASA share responsibility for exploiting the nearer term potential for commercialization of these software developments.

DOE, NASA, NSF and **DARPA** will incorporate early production models of the high performance computing systems into high performance computing laboratories. These high performance computing laboratories will include the advanced software tools and components, innovative computational techniques and the application-specific algorithms and experimental code for the Grand Challenges. These facilities will support the required integrated research, and will be available to users through the National Research and Education Network.

NSF, DOE, NOAA and **NASA** will build on their existing supercomputer centers which will provide the facilities for several high performance computing research centers, accessible to the national research community.

NOAA will be responsible for organizing the coordination of R&D in data management, and will play a lead role in supporting basic research in tools and techniques required for management and analysis of large-scale scientific data bases and distributed data handling.



Factors in Computational Speedup

Examples using vectors of length n=4096 (2^{12})

Method	Type	Order	Speedup
LAPACK: BLAS1->BLAS3 {Dongarra, et al.}	Algorithm & Software	constant	4
Hardware Clock Speed {1976 to 1989}	Microelectronics	12ns->2 ns	6
Vectorizing Compilers {CFT, VAST, KAP}	Algorithm & Software	32*scalar	32
Fast Fourier Transform {Cooley and Tukey}	Algorithm	$O(n^2)$->$O[n*\ln(n)]$	340
Parallel Processors {Gustafson, Montry and Benner}	Algorithm & Architecture	Linear in nr. of processors	1000
Fast Multipole Method {Greengard & Rokhlin}	Algorithm	$O(n^2)$->$O(n)$	4000

Fig. 3 – Speedup Due to Advances in Algorithms

The National Research and Education Network

Recommendation: U.S. Government, industry and universities should coordinate research and development for a research network to provide a distributed computing capability that links the Government, industry, and higher education communities. [*HPC Strategy*, 1987]

Introduction

The United States must develop a National Research and Education Network (NREN) to support communication between persons and organizations involved in open research and scholarly pursuits in the United States. This need has become increasingly obvious to the research community, especially among those who have experienced the benefits of electronic mail and database access, exchange of files between computers, and remote access to specialized and high-performance computing systems. As networking technology grows in power, network-based collaboration continues to allow substantive improvements in research effectiveness. These themes are well expressed in the recent National Research Council report *Toward a National Research Network* (1988). In developing the plan for this component the growing importance of the interrelationships between the network, the research components of the Program, and the U.S. academic community became increasingly clear. *Education* has been included in the name of the network in explicit recognition of this importance.

Today, all major organizations and government agencies use computer networking to some extent, and those with the most progressive and demanding missions have organized major transcontinental networks. A number of these networks are interconnected, notably those of the National Science Foundation (NSFNET), the Department of Defense (ARPANET and MILNET), the Department of Energy (ESNET), and the National Aeronautics and Space Administration (NASA Science Internet). These and many other commercial and regional networks collectively form the Internet, which currently supports a large portion of the U.S. science and engineering research community.

Today's Internet is far from uniform in the type and quality of service provided, and it does not yet reach the entire research community. Even so, expanding the Internet and enhancing its performance as far as technology allows will fall far short of what can and should be accomplished. The goal of this component is to create a new NREN which operates at rates of gigabits per second nationwide. This tremendous challenge is within the grasp of the United States in the next ten years. A network with this level of performance will provide another major improvement in the effectiveness of the national research community and their resulting ability to contribute to U.S. competitiveness.

3. Program Plan:
The National Research and Education Network

Availability of the NREN will provide an environment which enhances collaboration both for software technology development and for basic research and scholarship nationally. In return the development of the NREN will benefit from advances in software technology, particularly in the area of network services.

The eventual impact of the NREN on national competitiveness may well extend beyond such gains in research productivity. The NREN should be the prototype of a new national information infrastructure which could be available to every home, office and factory. Wherever information is used, from manufacturing to high-definition home video entertainment, and most particularly in education, the country will benefit enormously from deployment of this technology.

Stages of the NREN: The stages of NREN development as articulated in the *HPC Strategy* are:

> The *first stage* involves an upgrade of the existing Internet to 1.5 megabit per second trunks. (This process is underway.)
>
> The *second stage* will deliver upgraded network services to 200 to 300 research installations, using a shared backbone network with 45 megabit per second capacity.
>
> The *third stage* will deliver one to three gigabit per second networking service to selected research facilities, and 45 megabit per second networking to approximately 1000 sites nationwide.

The stages of the NREN are illustrated in Figure 4.

Government/Industry/University roles: The Federal government plays a dual role in the development of computer networking. Federal funding has supported networking research and technology development in academic, industrial, and (to a lesser degree) government laboratories. The government also supports operational networks and network services. These are expected eventually to create a commercially viable market whose needs can be supplied by the private sector. In this latter role, the government has supplied networks as value-added services on communication circuits leased from the common carriers, and has subsidized their use by segments of the scholarly and research communities.

Universities play a major research role in advanced networking technology. Whereas most of the improvements in *communications* technology have come from industry, many of the most important *networking* technologies have been developed by universities. Educational institutions are also the primary users of networking nationwide, both for access to high performance computing and for collaboration among themselves and with government and industry.

To date, the role of industry has mostly been to provide communications links and produce equipment for networking. This situation is changing and in fact must be

radically altered in order to develop the high speed networks of the future. At data rates of gigabits per second the switching elements of the network need to be integrated with the communications links within the facilities of the communications industry. Applications of networks within and between industrial groups should also increase to support a more competitive U.S. industrial posture.

It is anticipated that the government will continue to fund networking research in partnership with academia and industry, and will continue to support parts of the national research networking infrastructure which do not yet have a sizable market. This will be necessary both to build the market for private offerings as well as other commercial goals. It also will be necessary for those government agencies sponsoring development of advanced networking to coordinate the work of multiple government laboratories, industrial, and university groups.

Action Plan

The Federal Research Internet Coordinating Committee (FRICC), a collaboration of the NSF, DARPA, DOE, NASA, and the Department of Health and Human Services (HHS), has begun transforming the present day Internet toward the goal of an NREN. This is being accomplished through sharing communications circuits, network access points, and even entire networks, leading to streamlined operations and reduced costs. The FRICC has established coordinating members in other agencies and national networking organizations and has developed a program plan for implementing the NREN. While these activities have provided a healthy start for the NREN, an additional effort will be necessary to achieve the ultimate goals of the High Performance Computing Program. FRICC, while not formally a part of the FCCSET structure of OSTP, works closely with the Committee on Computer Research and Applications and conducts its activities consistent with the policy guidance of the HPC Program.

Interagency effort to produce an interim NREN. Coordinating an interagency project as large as the NREN will not be easy. It is clear that a unified focus for management is necessary. It is equally clear that the project will not be fully supported by the diverse agencies involved unless they have a decisive role in shaping the project, and are kept in constant, close communication so that the resulting network fills their needs.

In *Stage 1* the agencies will continue to upgrade their networks to 1.5 megabit per second (T1) trunks. This effort is already well underway. In addition, DARPA project known as the *Research Internet Gateway (RIG)* is acquiring a prototype platform for development of "policy-based routing" mechanisms which will allow interconnection of these trunks. Also the FRICC has plans to develop enhanced capabilities such as directory services in support of network users.

As the Internet expands, issues of *network security* have become a source of increasing concern. Recent incidents have demonstrated the vulnerability of computers attached to

national networks. A significant effort in implementing the NREN will be development and implementation of mechanisms to enhance the security of the connected computing systems, and mechanisms to protect the networks themselves. These mechanisms will rely on policy-based routing capabilities, and also on recent advances in public-key cryptography.

In *Stage 2* the agencies are planning to acquire a common set of 45 megabit per second transcontinental trunks, the *Research Interagency Backbone (RIB)*. The ability to share backbone trunks, resulting in lower costs and improved service for all agencies, will be enabled by gateways with policy-based routing capabilities. When the RIB is fully operational, it will be interconnected with the NSFNET backbone; the result will be the interim NREN. Another equally important result will be the stage 2 technologies, which will provide a base from which commercial providers can offer compatible networking services nationally.

Research and development for billions of bits per second (gigabits) net. The ultimate structure of the *Stage 3* network will not become clear until this research effort is complete. However, it is clear that fiber-optic trunks now being installed by communications carriers will become increasingly important, new switching systems and network protocols must be developed, new high-speed interconnections to workstations and supercomputers will be needed, and some form of interconnection with the Stage 2 network will be needed. An additional goal of stage 3 is to support such advanced capabilities as remote interactive graphics, nationwide data files, and network-based high definition displays for education. Managing the dynamics of these activities will be a major challenge, but the payoff for success in terms of national capabilities will be enormous in terms of research productivity and, subsequently, in the form of technologies and services available from commercial sources.

Deployment of gigabits NREN. Stage 3 culminates in an operational national network with gigabits trunks. Deployment is not expected to begin until the middle to late 1990's.

Structured transition to commercial service: Mid-level networks organized on a regional basis or by other limited constituencies have sprung up indigenously (for example BITNET and several state-funded networks). Other mid-level networks have been formed with seed funding from NSF, NASA, and DARPA. These have become, in varying degrees, part of the existing Internet. They provide an important vehicle for the economic participation of state and local governments and of industry by providing access to the national network and by giving these other sectors a stake in its operation, thus reducing the funding burden on the Federal government. Moreover, each of these networks is typically a private and autonomous (although possibly subsidized) business entity; thus elements of the emerging national network have already become part of the private sector. Continuation of this trend will result in

opportunities for many companies to become involved in leading-edge data communications.

By the end of Stage 2, it is expected that every university and major laboratory will be connected to the NREN through a mid-level network. Present regional offerings vary widely in reliability and scope. To provide homogeneous and universal networking service, interaction of the Federal government with mid-level networks must increase. It is also to be expected that competition and other market forces will come into play between these networks.

Each of the services developed for the NREN must become available commercially at the earliest practical time. The intention is that networking infrastructure should be a commercial offering nationwide. The government and its contractors would then purchase network connections from companies which would provide service to subscribers in general.

Eventually, computer networking should be as pervasively available as telephone service is today. The corresponding ease of inter-computer communication will then provide the benefits associated with the NREN to the entire nation, improving the productivity of all information-handling activities. To achieve this end, the deployment of the Stage 3 NREN will include a specific, structured process resulting in transition of the network from a government operation to a commercial service.

Agency Responsibilities

NSF will be the lead agency for deploying the operating NREN within the HPC Program. NSF has assumed responsibility for supporting a backbone for the NREN, and will coordinate collaboration among Federal agencies in this area. The NSF role of support and coordination will expand as the NREN grows; NSF will upgrade and extend the operational network, providing advanced network services, and collaboration technology. NSF will also support and participate in the interagency networking testbed.

DARPA will be the lead agency for the Program's advanced networking technology research and development. DARPA's research leading to the advanced networking technology for gigabit speeds (Stage 3) will take place within its Command, Control, and Communications programs as the primary contribution of the Department of Defense to the NREN. DARPA will also create a testbed, jointly funded with other participating agencies, for advanced network technology and inter-agency collaboration.

DOE will provide networking support for the energy research community and participate in the interagency networking testbed.

NASA will provide networking support for the aerospace research community, participate in the interagency testbed, and support research on aerospace applications and technology with a focus on telescience research and development.

3. Program Plan:
The National Research and Education Network

DARPA, NSF, DOE and NASA will continue their active roles in governance of the Internet, and will expand these roles by providing representatives on the council which sets policy for the NREN.

NOAA will provide networking in support of the climate and global change research community and will participate in the interagency testbed.

NIST will participate by establishing networking standards, with particular emphasis on protocols and security standards. NIST will continue its traditional role of coordinating developing technologies such as Broadband ISDN with service providers, computer manufacturers, telecommunication manufacturers, system integrators and end users through the standards process.

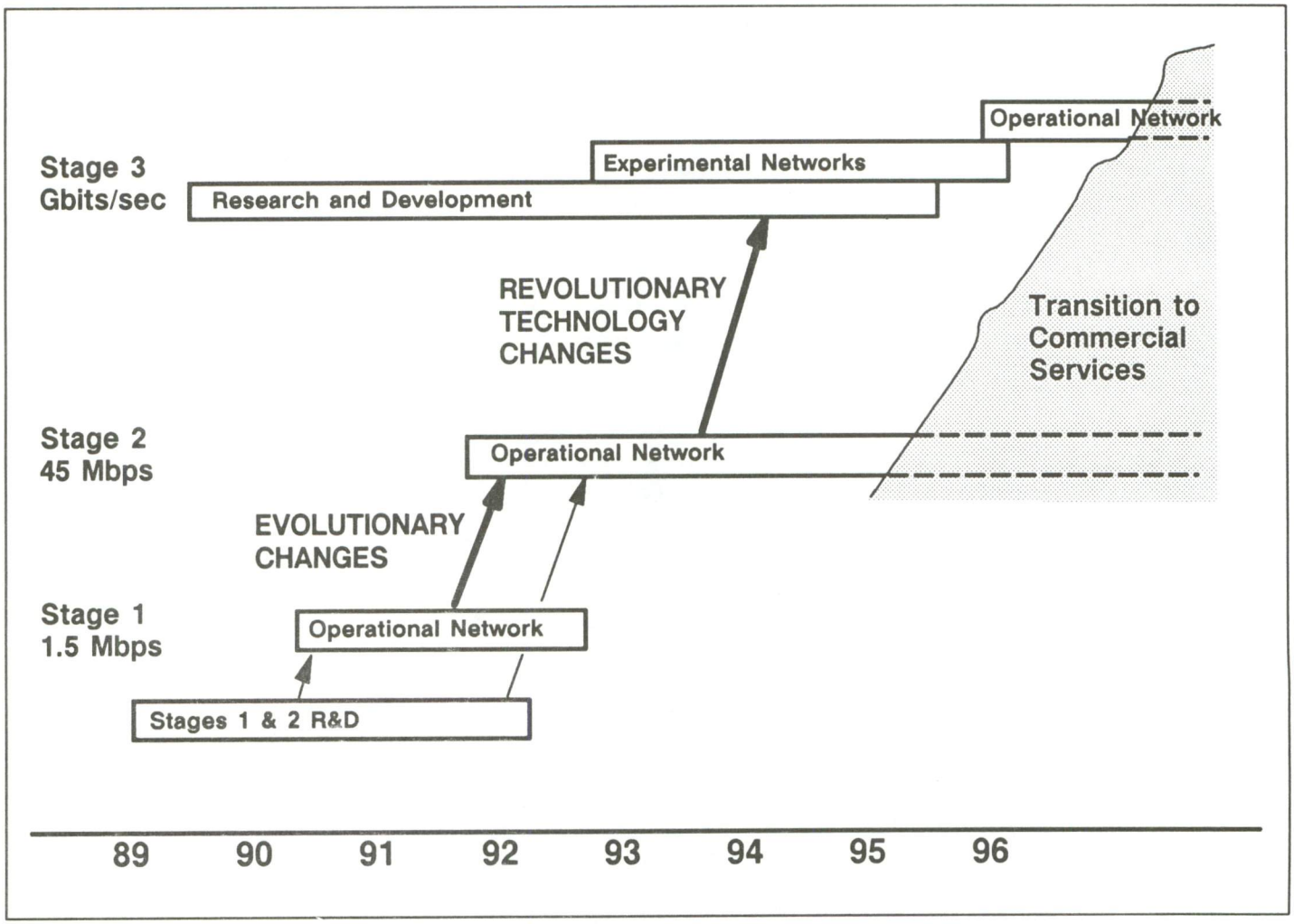


Fig. 4 – Timetable for the National Research and Education Network

Basic Research and Human Resources

Recommendation: Long term support for basic research in computer science should be increased within available resources. Government, industry, and universities should work together to improve the training and utilization of personnel to expand the base of research and development in computational science and technology. [*HPC Strategy*, 1987]

Goals

This component of the High Performance Computing Program addresses longer term national needs for high performance computing. The rapid growth of computing technology and computational science and engineering has created extraordinary demands for more rapid innovation, significantly increased manpower, and accelerated transfer of technology. The basic research community plays a major role in addressing these needs.

We must sustain a rapid pace of innovation in computer science and in computational science by investing in long term basic research.

Proprietary control is difficult to retain in an industry that is characterized by periodic major structural innovations, such as the shift now in progress from central timeshared computing to distributed networked workstations. Because of this, industry has little incentive to invest in long term approaches unless costs and risks are shared. For this reason, most of the major breakthroughs in computing have been the result of basic research activity. Examples include timesharing, local and national networks, VLSI design technology, personal computing, parallel computing, artificial intelligence, and many others. Each of these breakthroughs has had an enormous impact in the marketplace.

Increased numbers of qualified people are needed both in computational science and engineering, and in computer science and engineering. Universities are beginning to create new academic programs in areas of computational science and engineering that develop skills in both computer technology and in specific areas of science and engineering. The rapid evolution of this technology requires practitioners with a broad range of generic skills.

There is a need to reduce risk to industry in adapting and applying new technology. Technology is transferred rapidly from research into practice when the research community is an active participant in the process and when there is consensus in the research community on basic technical issues. The diversity of parallel computing models and algorithmic approaches now emerging provides unusual opportunity for application. The rapid pace of technology development in computing and computational science demands active participation of basic researchers in accomplishing transfer of the emerging technologies.

3. Program Plan: Basic Research and Human Resources

Support for basic research must be supported in several respects. The High Performance Computing Program addresses this need through direct basic research support, improved infrastructure to increase research productivity, and facilitation of collaboration. The goals of this component of the Program are:

- **Basic research.** Ensure an adequate level of basic research activity to produce the next generation of innovative results in computing technology.
- **Human resources.** Support basic research, education, and training in order to meet the needs of research, personnel, and transition support in both computing technology and in computational science and engineering.
- **Support for collaboration.** Promote collaborations involving the basic research community, industry, and government to allow attacks on larger scale problems and accelerate dissemination of results.
- **Infrastructure.** Supprt the effectiveness of the research community by providing facilities and research infrastructure, including experimental high performance computers, networks, associated systems software, and applications software components.

The Basic Research Enterprise. Basic research programs already underway and supported by current Federal funding provide a base from which many computing applications goals can be achieved, but this base is already under great pressure even without the demands of important new thrusts[1]. The pace of expansion of computing technology and its applications greatly exceeds the rate of expansion of basic research, with consequent strain on the basic research community[2].

Effectively integrating new high performance computing technology into the US technological and scientific mainstream will require sustained research effort across the spectrum of computing technology. Some examples are microsystems component technology and packaging, computer architecture, fundamental algorithms and complexity, software engineering languages and tools, networking and distributed computing, artificial intelligence, numerical algorithms, and applications-specific algorithms.

Human Resources. Several studies in the past 10 years have documented the human resources challenges to the continued development and exploitation of computer technology[3]. A particular focus of these studies has been the severe undersupply of computer scientists and computer engineers at advanced degree levels. Computational scientists and engineers are in even shorter supply.

1. *The National Challenge in Computer Science and Technology*, Computer Science and Technology Board of the National Research Council, National Academy Press, Washington, 1988.
2. Gries, D., et al. *Imbalance Between Growth and Funding in Academic Computer Science: Two Trends Colliding*, Communications of the Association for Computing Machinery, 29(9), Sept 1986.

3. Program Plan:
Basic Research and Human Resources

Addressing the Grand Challenge applications requires large scale collaborative effort involving diverse groups of scientists, engineers, and mathematicians. The manpower shortage in computing technology and in computational science and engineering is hindering progress in these areas.

Collaboration. Interactions among multiple research teams and potential technology recipients contribute significantly to reducing the risks associated with transfer of major technologies into production. Collaboration can be facilitated in the basic research community by ensuring a high level of access to the network applications software based on the National Research and Education Network and by involving basic research groups in Grand Challenge applications.

The network support software will include capabilities for activities such as rapid distribution and sharing of research results, software distribution and configuration management support mechanisms, high-capacity interaction support for remote computers, access to instrumentation in remote experimental laboratories, rapid search and retrieval in distributed library databases, and so on.

Infrastructure. Scarcity of funds in computing technology research has hindered modernization of university computing research and education facilities. A rapid pace of technological innovation requires aggressive investment to ensure that universities remain at the forefront. Networked access to high performance computing with advanced software support is important for training computational scientists and engineers. The potential for using networks to disseminate results and conduct collaborative research at all educational levels is just beginning to be realized.

Basic infrastructure for computer research has been a concern for some years. Several agencies have programs that support the needs of the HPC Program. The Institutional Infrastructure Program at NSF has helped to equip approximately 25 computer science and computer engineering departments in the past eight years. DARPA for many years has been instrumental in building a core research base at major universities. The University Research Instrumentation program of the Department of Defense has provided important equipment and research support. The DOE research program has provided modern parallel computer facilities to several of its national laboratories and universities to promote basic research in high performance computing and to provide training facilities for graduate students and young faculty in all the disciplines involved in computational sciences. NASA maintains several research institutes and centers of excellence to interface with universities.

3. Gries, *op. cit.;* Feldman, Jerome A. and William R. Sutherland. *Rejuvenating Experimental Computer Science*. Comm. ACM 22, 9 (Sept. 1979), 497–502.; Kosaraju, S. Rao., et al. *Meeting the Basic-Research Needs of Computer Science,* Study report of the NSF CCR Advisory Committee, December, 1986; *Profiles -- Computer Science: Human Resources and Funding,* National Science Foundation report 88–324, February, 1989.

Action Plan

Several specific approaches are taken to address the goals. These approaches will, in most cases, be implemented as possible expansions of existing research funding programs.

Expand basic research. Increase basic research activity in computing technology areas that influence high performance computing, including algorithms, software languages and tools, architectures, systems software, microsystems, networks, distributed computing, and symbolic processing.

Attain a level of 1000 computer science Ph.D.s per year by 1995. Strengthen the human resource infrastructure for basic research. Support university risk investment in computational science and engineering degree programs. This should be done by expanding the number of universities capable of providing high quality advanced education in computer and computational science and engineering.

Promote at least 10 computational science and engineering degree programs. Sponsor interdisciplinary programs in universities to accelerate the maturing of computational science and engineering subdisciplines.

Upgrade 10 university computer science departments toward the standards of current 10 best. Include facilities for research in high performance computing. Also, upgrade an additional 25 computer science departments to nationally competitive quality.

Provide National Research and Education Network access for every U.S. university and major laboratory. Every university and major laboratory will be connected to the National Research and Education Network through a mid-level network.

Improve facilities available to support basic research and advanced education. High performance computing facilities currently available to researchers are in such demand that there is only limited availability for educational usage in computational science and engineering degree programs. The effective introduction of computational science and engineering techniques into industry requires students to receive exposure to high-performance machines.

Improve ties between computing technology and other disciplines. Many breakthroughs in computational science and engineering applications result from interactions with computer scientists. Correspondingly, computer science, through exposure to the needs of computational science and engineering, is producing technology to address future needs. Funding will be directed to promote these interactions.

Provide access to professional engineering support. Professional engineering staff should be available to basic research groups for assistance in construction and maintenance of large scale prototype systems, including software and hardware. This

can be accomplished through industrial collaborations or through placement of professional staff in university laboratories.

Responsibilities

Federal agencies historically have supported activities which advance basic research by developing and improving infrastructure for the nation's knowledge and human resource base in computing. The HPC Program will exploit existing mechanisms to meet needs in these areas.

The **DOE** has established advanced computational science research facilities at several national laboratories and universities. Although the DOE labs already maintain a strong university cooperation program, more needs to be done to provide closer ties with the academic computational science community below the top echelon. For example, an expansion of the summer program for high school students using national facilities would be beneficial in providing interested and trained students to the universities.

The national laboratories are ideal training centers for graduate students in the sciences because of the wealth of experience in solving real world problems. This environment makes a valuable addition to the training of new scientists and should be made available to many more senior graduate students, post-doctoral fellows and young faculty than is currently possible.

The **NSF**'s primary mission is broad support of basic research and human resources in science and engineering. NSF recently reorganized to support a new research directorate, Computer and Information Science and Engineering (CISE), to focus resources on computing as a strategic research area. CISE supports research grants for academic institutional improvement as well as research. The research community supported by CISE will be primary participants in this Program.

Several NSF Centers (Science and Technology Centers, Engineering Research Centers, and Supercomputer Centers) focus on topics central to the HPC Program. These Centers illustrate the type of university-industry and interagency programs which can be employed directly as testbeds and sources of high performance computing technology.

The five NSF National Supercomputer Centers, for example, have provided advanced hardware and software to advance the utility of computational science across an entire spectrum of researchers. More than 11,000 scientists at some 300 institutions have used these facilities during the past few years. The research facilities and advanced experimental systems developed under the Program can be made available broadly to the entire U.S. research community through the National Research and Education Network.

NASA supports leading-edge applications of high performance computing technology. It also supports development of computational science programs in universities.

3. Program Plan:
Basic Research and Human Resources

NASA Institutes (ICASE, RIACS, ICOMP, CESDIS) and Centers of Excellence (CASIS, ICLASS) provide settings at NASA Centers or at Universities where computer scientists and computational scientists can work together using state of the art equipment on a permanent or temporary basis (summers, sabbaticals, etc.) These programs would be for undergraduates, graduate students, postdoctorals, university faculty, and researchers from industry and government.

NASA has supercomputer facilities at several of its field centers (Ames, Goddard, Langley, Lewis, and Marshall). NASA has also established the Numerical Aerodynamics Simulation (NAS) Facility, which is a national facility for aerospace applications which operates not only state-of-the-art supercomputers, but advanced parallel computers like the Connection Machine. NASA has also established a significant Artificial Intelligence Laboratory in the Information Sciences Division at ARC. These facilities are used for a wide range of mathematical, algorithm, systems software, and computer architectural research. These facilities are available to NASA centers, institutes, and grantees, and to the aerospace community. Under this program NASA facilities will be expanded to include scalable testbeds to support interdisciplinary research which combines mathematics, algorithms, systems software, and computer architecture.

NOAA has supercomputer facilities, and has also created generic, broad spectrum workstation design facilities to support the Program for Regional Observing and Forecasting Systems (PROFS). Under this Component, NOAA will expand the opportunities for collaborative research at its facilities for development of algorithms and techniques for large scientific data bases, use of artificial intelligence in data management, and development of climate prediction models.

DARPA provides high performance computing systems for research community use on two scales: small-scale for experimentation, software and algorithm development by computer and computational science research groups, and medium-scale for shared-use facilities intended for access by dozens of groups via the National Research and Education Network. DARPA funding also supports key university and industrial labs for research and advanced development in computer and network architecture, network protocols and management, microsystems design and prototyping, advanced components and packaging, software tools and parallel algorithms.

4. Organization

Leadership of the HPC Program is the responsibility of the Office of Science and Technology Policy. It will be coordinated through the FCCSET Committee on Computer Research and Applications, whose members include representatives of the key agencies. The Committee will work closely with the President's Science Advisor and the various government funding agencies to ensure the continuing success of the Program. The components of the program that implement the Program will be executed by the cognizant agencies. Duties and responsibilities of the Committee include:

- Interagency planning and coordination;
- Policy development and technology assessment;
- Liaison with the industrial and university sectors; and
- Annual reporting of progress to the Office of Scientific and Technology Policy.

A High Performance Computing Advisory Panel will be formed, consisting of eminent individuals from government, industry, and academia. Members of the Advisory Panel will be selected by and will report to the Director of OSTP. The Panel will provide the Director and the Committee with an independent assessment of:

- Progress of the Program in accomplishing its objectives;
- Continued relevance of the Program goals over time;
- Overall balance among the Program components; and
- Success in strengthening U.S. leadership in high performance computing, and integration of these technologies into the mainstream of U.S. science and industry.

A broadly representative industry body will assist in making long-range demand and robustness projections for: high capacity research networks; the spectrum of computer architectures; the adequacy of software development; and the level of the manpower pool. This body will help assure a smooth transition between successive generations of high performance computing systems.

The FCCSET Committee on Computer Research and Applications has established subcommittees that will be responsible for planning, organizing, monitoring and coordinating the components of this Program. This includes liaison with the industrial and academic sectors, and published annual reports.

5. Budget

Budgets for the Program are presented in Table 1. Each budget element corresponds to a key activity in one of the four components of the HPC Program. The activities are described for each component in Section 3 of this plan. The yearly additional funding requested for this Program corresponds to the estimate given in the *HPC Strategy*, with some adjustment to yearly funding levels as a result of more detailed planning and inflation. Significant portions of the Program's funding will be allocated in each of the three participating sectors: universities, industry, and government laboratories.

Currently, the four principal funding agencies are spending about $500 Million per year on research and development for high performance computing. It is important that this funding continue with coordination by the FCCSET Committee as discussed in this plan, because the ability of the Program to achieve its goals depends upon maintenance of the broad base of computational and computer science and engineering research presently funded by the Federal government.

Preliminary planning estimates suggest that the first year of the program would require an augmentation of $150 million, which would then grow to an incremental annual level of $600 million by the fifth year.

Special attention has been devoted to the subcomponents "Early Systems for Evaluation" and "High Performance Computing Research Centers". There is an explicit strategy for investment in emerging high performance computing systems (including associated software) in these activities, to ensure that adequate funding is available. It is intended that the Early Systems for Evaluation budget sustain acquisition of the smallest scale systems which will allow characterization of their potential performance. For systems which prove to have good performance potential, the High Performance Computing Research Centers budget will support scaling these systems up, to demonstrate that potential in the Grand Challenges or other advanced applications. This will reduce risk to both producers of the systems and researchers using them, to provide the necessary incentive for early deployment in the most advanced applications.

The Basic Research and Human Resources component also requires special discussion, because it is funded in two ways. First, ten percent of the Program funding is set aside for this component. Second, it is intended that an additional fifteen percent of the total Program funding in the other three components will consist of basic research, carried out largely in Universities, which will also support the Program goals in Basic Research and Human Resources. Integrating this research with the rest of the Program allows a smooth flow of research from basic ideas through to applications.

Summary of Additional Funds

(Millions of Dollars)

Reference Page	Component	Year 1	Year 2	Year 3	Year 4	Year 5
17	**High Performance Computing Systems**	**55**	**91**	**141**	**179**	**216**
19	Research for Future Generations	11	17	24	32	37
19	System Design Tools	10	18	21	25	25
19	Advanced Prototype Development	22	36	65	86	116
20	Evaluation of Early Systems	12	20	31	36	38
23	**Advanced Software Technology and Algorithms**	**51**	**90**	**137**	**172**	**212**
24	Support for Grand Challenges	9	19	34	43	48
25	Software Components and Tools	15	30	41	60	78
26	Computational Techniques	6	10	18	19	31
26	High Performance Computing Research Centers	21	31	44	50	55
31	**National Research and Education Network**	**30**	**50**	**95**	**105**	**110**
33	Interagency Interim NREN	14	23	55	50	50
34	Gigabits Research and Development	16	27	40	55	60
34	Deployment of Gigabits NREN		(Funding begins after Year 5)			
34	Structured Transition to Commercial Service		(Funding begins after Year 5)			
37	**Basic Research and Human Resources**	**15**	**25**	**38**	**46**	**59**
		NOTE:	15% of the other three Components is also commited to this general area			
	TOTAL High Performance Computing Program	**151**	**256**	**411**	**502**	**597**

Table 1 – Budget Summary by Program Component

ACKNOWLEDGMENTS

Office of Science and Technology Policy guidance was provided by William R. Graham, Tom Rona, Robert Post, and Paul Huray. The Plan Drafting Committee was chaired by David B. Nelson from the Department of Energy; and included J. Mark Pullen, William L. Scherlis, and Stephen L. Squires from the Defense Advanced Research Projects Agency; Donald Austin, Daniel Hitchcock, Thomas Kitchens, and Norman H. Kreisman from the Department of Energy; Paul H. Smith from National Aeronautics and Space Administration; and Melvyn Ciment, Peter Freeman, and Stephen Wolff from the National Science Foundation. Special thanks are due to Sandy Merola and Dennis Hall from the Lawrence Berkeley Laboratory, for editing and production assistance.

APPENDIX A: SUMMARY OF GRAND CHALLENGES
FOR WHICH SOLUTION IS LIKELY TO BE POSSIBLE USING SYSTEMS DEVELOPED UNDER THIS INITIATIVE

PREDICTION OF WEATHER, CLIMATE, AND GLOBAL CHANGE. The aim is to understand the coupled atmosphere, ocean, biosphere system in enough detail to be able to make long range predictions about its behavior. Applications include understanding CO2 dynamics in the atmosphere, ozone depletion, climatological perturbations due to man made releases of chemicals or energy into one of the component systems, and detailed predictions of conditions in support of military missions.
Agencies: DOE, DOD, NASA, NSF, NOAA

CHALLENGES IN MATERIALS SCIENCES. High performance computing has provided invaluable assistance in improving our understanding of the atomic nature of materials. These have an enormous impact on our national economy. A selected list of such materials includes: semiconductors, such as silicon and gallium arsenide and superconductors such as the high Tc copper oxide ceramics that have been shown recently to conduct electricity at about 100 degrees Kelvin.
Agencies: DOD, DOE, NSF, NASA

SEMICONDUCTOR DESIGN. As intrinsically faster materials, such as gallium arsenide are used, a fundamental understanding is required of how they operate and how to change their characteristics. Essential understanding of overlay formation, trapped structural defects, and the effect of lattice mismatch on properties are needed. Currently, it is possible to simulate electronic properties for simple regular systems, however, materials with defects and mixed atomic constituents are beyond present capabilities.
Agencies: DOD, DOE, NSF

SUPERCONDUCTIVITY. The discovery of high temperature superconductivity in 1986 has provided the potential of spectacular energy-efficient power transmission technologies, ultra sensitive instrumentation, and devices using phenomena unique to superconductivity. The materials supporting high temperature superconductivity are difficult to form, stabilize, and use, and the basic properties of the superconductor must be elucidated through a vigorous fundamental research program.
Agencies: DOE, NSF, DOD

STRUCTURAL BIOLOGY. The function of biologically important molecules can be simulated by computationally intensive Monte Carlo methods in combination with NMR of crystallographic data. Molecular dynamics methods are required for the time dependent behavior of such macromolecules. The determination, visualization, and analysis of these 3D structures is essential to the understanding of the mechanisms of enzymic catalysis, recognition of nucleic acids by proteins, antibody/antigen binding, and many other dynamic events central to cell biology.
Agencies: DOE, HHS, NSF

DESIGN OF DRUGS. Predictions of the folded conformation of proteins and of RNA molecules, by computer simulation is rapidly becoming accepted as a useful, and sometimes primary tool in understanding the properties required in drug design.
Agencies: DOE, HHS, NSF

HUMAN GENOME. Comparison of normal and pathological molecular sequences is our current most revealing computational method for understanding genomes, and the molecular basis for disease. To benefit from the entire sequence of a single human will require capabilities for more than three billion subgenomic units, as contrasted with the ten to two hundred thousand units of typical viruses.
Agencies: DOE, HHS, NSF

QUANTUM CHROMODYNAMICS. In high energy theoretical physics, computer simulations of QCD are yielding first principle calculations of the properties of strongly interacting elementary particles. New phenomena have been predicted including; the existence of a new phase of matter, and the quark-gluon plasma. Properties under the conditions of the first microsecond of the big bang, and in the cores of the largest stars have been calculated by simulation methods. Beyond the range of present experimental capabilities, computer simulations of grand unified "theories of everything" have been devised using QCD (Lattice Gauge Theory).
Agencies: DOE, NSF

ASTRONOMY. Data volumes generated by Very Large Array (VLA) or Very Long Baseline Array (VLBA) radio telescopes currently overwhelms the available computational resources. Greater computational power will significantly enhance their usefulness in

exploring important problems in radio astronomy, resulting in better return on a major national investment.
Agencies: NASA, NSF

CHALLENGES IN TRANSPORTATION. In the nearer term, substantial contributions to vehicle performance can be made using more approximate physical modeling and reducing the amount of interdisciplinary coupling. Examples include, modeling of fluid dynamical behavior for three dimensional flow-fields about complete aircraft geometries, flow inside of engine turbomachinery, duct flow, and flow about ship hulls.
Agencies: NASA,DOD,DOE,NSF,DOT

VEHICLE SIGNATURE. Reduction of vehicle signature (acoustic and electromagnetic, and thermal characteristics) is critical for low detection military vehicles.
Agencies: NASA, DOD

TURBULENCE. Turbulence in fluid flows impacts the stability and control, thermal characteristics, and fuel performance of virtually all aerospace vehicles. Understanding the fundamental physics of turbulence is requisite to reliably modeling flow turbulence for the analysis of realistic vehicle configuration.
Agencies: NASA, DOD, DOE, NSF, NOAA

VEHICLE DYNAMICS. Analysis of the aeroelastic behavior of vehicles, as well as the stability and ride analysis of vehicles are critical assessments of land and air vehicle performance and life-cycle.
Agencies: NASA, DOD, DOT

NUCLEAR FUSION. Development of controlled nuclear fusion requires understanding the behavior of fully ionized gasses at very high temperatures under the influence of strong magnetic fields in complex three dimensional geometries.
Agencies: DOE, NASA, DOD

EFFICIENCY OF COMBUSTION SYSTEMS. To attain significant improvements in combustion efficiencies requires understanding the interplay between the flows of the various substances involved and the quantum chemistry which causes those substances to react. In some complicated cases the quantum chemistry required to understand the reactions is beyond the reach of current supercomputers.
Agencies: DOE NASA, DOD

ENHANCED OIL AND GAS RECOVERY. This challenge has two parts: to locate as much of the estimated 300 billion barrels of oil reserves in the US and then to devise economic ways of extracting as much of this as possible. Thus improved seismic analysis techniques as well as improved understanding of fluid flow through geological structures is required.
Agencies: DOE

COMPUTATIONAL OCEAN SCIENCES. The objective is to develop a global ocean prediction model incorporating temperature, chemical composition, circulation, and coupling to the atmosphere and other oceanographic features. This will couple to models of the atmosphere in the effort on global weather as well as having specific implications for physical oceanography.
Agencies: DOD, NASA, NSF, NOAA

SPEECH. Speech research is aimed at providing a communications interface with computers based on spoken language. Automatic speech understanding by computer is a large modeling and search problem in which billions of computations are required to evaluate the many possibilities of what a person might have said within a particular context.
Agencies: NASA, DOD, NSF

VISION. The challenge is to develop human-level visual capabilities for computers and robots. Machine vision requires image signal processing, texture and color modeling, geometric processing and reasoning, as well as object modeling. A competent vision system will likely involve the integration of all of these processes with close coupling
Agencies: NSF, DARPA, NASA

UNDERSEA SURVEILLANCE FOR ASW. The Navy faces a severe problem in maintaining a viable anti-submarine warfare (ASW) capability in the face of quantum improvements in Soviet submarine technology, which are projected to be so substantial that evolutionary improvements in detection systems will not restore sufficient capability to counter their advantages. An attractive solution to this problem involves revolutionary improvements in long-range undersea surveillance which are possible using very high gain acoustic arrays and active acoustic sources for ASW surveillance. These methods will be computationally intensive; even taking advantage of inherent parallelism and judicious design of algorithms, computational demands for the projected post-2000 era submarine threat mandate achieving signal processing computation rates of in excess of a trillion operations per second.
Agencies: DOD

APPENDIX B: GLOSSARY

bits– binary digits (the smallest units of digital information); also an abbreviation for "bits per second"

broadband ISDN (BISDN)– broadband integrated services data network, an evolving standard commercial communications offering which will provide data rates of hundreds of megabits per second

byte– one character of computer storage

common carrier– a regulated commercial company which offers communication services in an open market

flops– abbreviation for floating–point operations per second, a unit which characterizes the performance of a computer for certain scientific and engineering calculations

giga– prefix meaning billion, e.g. "gigaops" means "billion operations per second" and "gigabits" means "billion bits per second"

links– long–distance communications circuits, also known as "trunks"

mega– prefix meaning million, e.g. "megaops" means "millions operations per second" and "megabytes" means "million characters of storage"

mid–level network– a computer network with scope which falls between a nationwide network and a local network, such as one of the state or regional networks

ops– abbreviation for "operations per second", a general measurement of computer performance

policy–based routing– a computer network function which treats data packets in different ways depending on some policy, for example certain packets may be given high priority, certain others may be rejected as not authorized to use some portion of the network

telescience– science practiced at a distance, using telecommunications

tera– prefix meaning trillion, e.g. "teraops" means "trillion operations per second"

testbed– an configuration intended to allow experimentation with systems in an application environment

trunks– long–distance communications circuits, also known as "links"

value–added services– services provided in addition to basic communication links (and at extra cost); for example, computer networking using communications provided by a common carrier

A Research and Development Strategy for High Performance Computing

Executive Office of the President
Office of Science and Technology Policy
November 20, 1987

APPENDIX C: *HPC Strategy* REPRINT

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

This year the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) Committee on Computer Research and Applications began a systematic review of the status and directions of high performance computing and its relationship to federal research and development. The Committee held a series of workshops involving hundreds of computer scientists and technologists from academia, industry, and government. A result of this effort is the report that follows, containing findings and recommendations concerning this critical issue. It has been sent to the appropriate committees of Congress for their review.

A consistent theme in this report is the need for industry, academia, and government to collaborate and exchange information on future R&D efforts. Partners need to give one another signals as to their intent for future activities, and this report is a necessary first step in that process. The vision it represents must continue to grow. For that reason, I have asked the Committee to initiate the appropriate forums for discussing it further with the computing community.

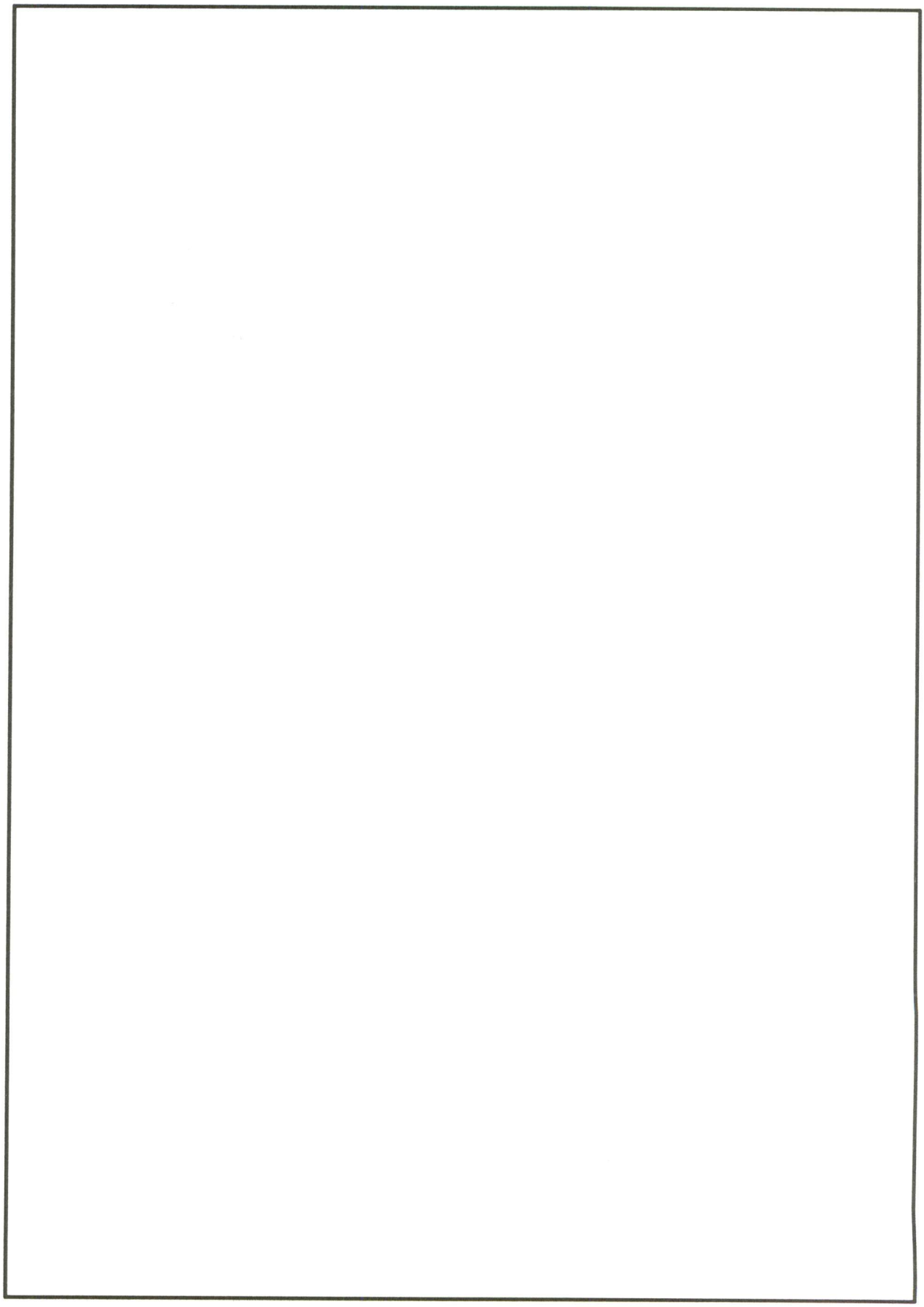
Another theme has come out of this report: within four decades, the field of computer science has moved from a service discipline to a pervasive technology with a rigorous scientific basis. Computer science has become important to our national security and to our industrial productivity, and as such it provides the United States with many opportunities and challenges. Three of those opportunities are addressed in the report's findings and recommendations: High Performance Computers, Software Technology and Algorithms, and Networking. The fourth recommendation involves the Basic Research and Human Resources that will be required to conduct the other initiatives.

One thing is clear: the competition in an increasingly competitive global market cannot be ignored. The portion of our balance of trade supported by our high performance computing capability is becoming more important to the nation. In short, the United States must continue to have a strong, competitive supercomputing capability if it is to remain at the forefront of advanced technology. For that reason the Office of Science and Technology Policy is encouraging activities among the federal agencies together with the academic community and the private sector.

William R. Graham

William R. Graham
Science Adviser to the President and
Director, Office of Science and Technology Policy

APPENDIX C: *HPC Strategy* REPRINT



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SUMMARY OF FINDINGS ON COMPUTER RESEARCH AND APPLICATIONS

1. **HIGH PERFORMANCE COMPUTERS: A strong domestic high performance computer industry is essential for maintaining U.S. leadership in critical national security areas and in broad sectors of the civilian economy.**

   - U.S. high performance computer industry leadership is challenged by government supported research and development in Japan and Europe.
   - U.S. leadership in developing new component technology and applying large scale parallel architectures are key ingredients for maintaining high performance computing leadership. The first generation of scalable parallel systems is now commercially available from U.S. vendors. Application-specific integrated circuits have become less expensive and more readily available and are beginning to be integrated into high performance computers.

2. **SOFTWARE TECHNOLOGY AND ALGORITHMS: Research progress and technology transfer in software and applications must keep pace with advances in computing architecture and microelectronics.**

   - Progress in software and algorithms is required to more fully exploit the opportunity offered by parallel systems.
   - Computational methods have emerged as indispensable and enabling tools for a diverse spectrum of science, engineering, design, and research applications.
   - Interdisciplinary research is required to develop and maintain a base of applications software that exploits advances in high performance computing and algorithm design in order to address the "grand challenges" of science and engineering.

3. **NETWORKING: The U.S. faces serious challenges in networking technology which could become a barrier to the advance and use of computing technology in science and engineering.**

   - Current network technology does not adequately support scientific collaboration or access to unique scientific resources. At this time, U.S. commercial and government sponsored networks are not coordinated, do not have sufficient capacity, do not interoperate effectively, and do not ensure privacy.
   - Europe and Japan are aggressively moving ahead of the U.S. in a variety of networking areas with the support of concentrated government and industry research and implementation programs.

4. **BASIC RESEARCH AND HUMAN RESOURCES: Federal research and development funding has established laboratories in universities, industry, and government which have become the major sources of innovation in the development and use of computing technology.**

SUMMARY OF RECOMMENDATIONS FOR A NATIONAL HIGH PERFORMANCE COMPUTING STRATEGY

1. HIGH PERFORMANCE COMPUTERS: The U.S. Government should establish a long range strategy for Federal support for basic research on high performance computer technology and the appropriate transfer of research and technology to U.S. industry.

2. SOFTWARE TECHNOLOGY AND ALGORITHMS: The U.S. should take the lead in encouraging joint research with government, industry, and university participation to improve basic tools, languages, algorithms, and associated theory for the scientific "grand challenges" with widespread applicability.

3. NETWORKING: U.S. government, industry, and universities should coordinate research and development for a research network to provide a distributed computing capability that links the government, industry, and higher education communities.

4. BASIC RESEARCH AND HUMAN RESOURCES: Long term support for basic research in computer science should be increased within available resources. Industry, universities, and government should work together to improve the training and utilization of personnel to expand the base of research and development in computational science and technology.

APPENDIX C: *HPC Strategy* REPRINT

A Research and Development Strategy for High Performance Computing

High performance computing refers to the full range of supercomputing activities including existing supercomputer systems, special purpose and experimental systems, and the new generation of large scale parallel architectures.

The Challenge

In the span of four decades, computing has become one of the most pervasive and powerful technologies for information management, communications, design, manufacturing, and scientific progress.

The U.S. currently leads the world in the development and use of high performance computing for national security, industrial productivity, and science and engineering, but that lead is being challenged. Through an increased foreign industrial capability, the U.S. technology lead in computing has diminished considerably in recent years, but the U.S. continues to maintain strength in basic science and technology. The technology is changing rapidly and the downstream rewards for leadership are great. Progress in computing can be accelerated through the continued pioneering of new hardware, software, algorithms, and network technology and the effective transition of that technology to the marketplace. A shared computing research and development vision is needed to provide to government, industry, and academia a basis for cooperative action. The successful implementation of a strategy to attain this vision and a balanced plan for transition from one generation of technology to the next can result in continued strength and leadership in the forthcoming decades.

High performance computing technology has also become essential to progress in science and engineering. A **grand challenge** is a fundamental problem in science or engineering, with broad applications, whose solution would be enabled by the application of the high performance computing resources that could become available in the near future. Examples of grand challenges are: (1) Computational fluid dynamics for the design of hypersonic aircraft, efficient automobile bodies, and

extremely quiet submarines, for weather forecasting for short and long term effects, efficient recovery of oil, and for many other applications; (2) Electronic structure calculations for the design of new materials such as chemical catalysts, immunological agents, and superconductors; (3) Plasma dynamics for fusion energy technology and for safe and efficient military technology; (4) Calculations to understand the fundamental nature of matter, including quantum chromodynamics and condensed matter theory; (5) Symbolic computations including speech recognition, computer vision, natural language understanding, automated reasoning, and tools for design, manufacturing, and simulation of complex systems. Many of these could be considerably advanced by the use of computer systems capable of trillions of operations per second.

THE STRATEGY

A **High Performance Computing Strategy**, involving close coordination of existing programs and augmented effort, is required to address this national challenge. This strategy involves the coordinated pursuit of computing technology goals through joint efforts of government, industry, and academia. The strategy will have impact in clarifying and focusing the direction of Federally-funded computing research, which continues to be the major source of innovation for computing technology and a primary catalyst for industrial development. Government support should be highly leveraged with resources provided by industry participants. To be effective, the strategy should also be defined and continually updated in cooperation with industry and academia by making them participants in developing and implementing a shared vision of the future to ensure continued U.S. leadership.

The high performance computing strategy is designed to sustain and focus basic Federally-funded research and promote the transfer of basic science from the laboratory to U.S. industrial development and finally to the marketplace. Technology development will be encouraged as appropriate to meet immediate needs as well as to create a foundation for long term leadership. Strong emphasis will be placed on continued transfer of the results of government funded R&D to industry and on cooperation with industry to insure the continued strength of American high technology trade in the international marketplace.

The basic elements of the strategy are research and development programs in high performance computer architecture, in custom hardware, in software and algorithms, and in networking technology, all supported by a basic research foundation. In each of these areas, major opportunities exist that require coordinated support and management, building on existing government programs. Access to high performance computing is essential for providing scientists and engineers at research institutions throughout the country with the ability to use the most advanced computers for their work. The strategy needs to concurrently address the appropriate Federal role in each

of the basic elements of the R&D process—basic research, applied research, and industrial development—in order to meet long term, intermediate, and short term technology development goals. Explicit attention must be directed to the flow of technology from basic to applied areas and to the marketplace, as well as back into the research community to create the next generation of computing infrastructure, achieving a cumulative effect. Technology developments within individual element areas will contribute extensively to other activities. Simultaneous and coordinated pursuit of the areas is therefore an important element of the strategy.

CURRENT STATUS AND TRENDS

• **High performance computing systems.** Improvements in materials and component technology are rapidly advancing computer capability. Memory and logic circuits are continuing to improve in speed and density, but as fundamental physical limits are approached, advances are being sought through improved computer architectures, custom hardware, and software. Computer architecture has begun to evolve into large scale multiple processor systems, and in the past four years a first generation of scalable parallel systems has progressed from the research laboratory to the marketplace. Scalable architectures provide a uniform approach that enables a wide range of capacity, from workstations to very high performance computers. Application–specific integrated circuits, such as for real–time signal processing, are being incorporated into special purpose computers.

At current performance levels our ability to model many important science, engineering, and economic problems is still limited. Formulations of computational models presently exist that for realistic solutions would require speeds of teraflops (trillions of floating point operations per second) and equivalent improvement in memory size, mass storage, and input/output systems. In addition, symbolic processing is complementing and enhancing numeric approaches. Achievement of this performance level in the next 5 years appears to be a feasible goal, based on credible extrapolations of processor capability, number of processors, and software sophistication. In developing the new architectural approaches, however, careful collaboration will be required with the applications community to assess the various approaches and to achieve transition to the new approaches where appropriate. As transitions are made, the high performance computing industry should strive to maintain its continued leadership and competitveness.

• **Software technology and algorithms.** As high performance computing systems evolve and become more critical in science, engineering, and other applications domains, software technology becomes an increasingly central concern. As experienced in many U.S. space and defense programs, for example, software can become the dominant computational cost element in large systems because of the need to support evolution throughout the system life cycle from design and

development to long term maintenance and transition to the next generation. Future software environments and tools should support the development of trustworthy systems capable of evolution, while increasing productivity of developers and users of the systems. Effective exploitation of the performance potential of the emerging parallel systems poses a special challenge both to software and to algorithm design.

High performance computing offers scientists and engineers the opportunity to use computer models to simulate conditions difficult or impossible to create and measure in the laboratory. This new paradigm of computational science and engineering offers an important complement to traditional theoretical and experimental approaches, and it is already having major impact in many areas. New approaches combining numeric and symbolic methods are emerging. The development of new instruments and data generation methods in fields as diverse as genetics, seismology, and materials accelerates demand for computational power. In addition, the opportunity is created to coordinate and focus effort on important grand challenges, such as computational fluid dynamics, weather forecasting, plasma dynamics, and other areas.

• **Computer network technology.** A modern high speed research network is one of the elements needed to provide high performance distributed computation and communication support for research and technology development in government, academia, and industry. A coordinated research network based on very high bandwidth links would enable the creation of large-scale geographically distributed heterogeneous systems that link multiple high performance workstations, databases, data generation sources, and extremely high performance servers as required, in order to provide rapid and responsive service to scientists and engineers distributed across the country. The existing national network is a collection of loosely coupled networks, called an internet, based on concepts pioneered in the U.S.

Technical issues being addressed include utilization of fiber optics to improve performance for the entire research and higher education enterprise of the nation. An additional issue of pressing concern, particularly within the governmental and industrial sectors, is that of computer and network security to ensure privacy and trustworthiness in a heterogeneous network environment. At present, responsibility for privacy and the assurance of trust are vested principally in the computers and switching nodes on the network. Further research, already actively underway, is urgently needed to develop models, methodology, algorithms and software appropriate to the scale of a coordinated research network.

• **Basic research and human resources in Computer and Computational Science.** Federal funding has historically been, and will likely remain, a major source of support for important new ideas in computing technology. Carefully managed and stable funding is required to maintain vigorous research in computer and computational science and sufficient growth in computer science manpower. It is important to maintain the strength of the existing major research centers and to develop new research activity to support the growth in computer and computational science. Interactions should be fostered among academia, industry, and national laboratories to address large problems and to promote transfer of technology. In the longer term, enhancement of the computing technology base will have significant impact in productivity, efficiency, and effectiveness of government, industry, and the research community.

IMPACT

Computing technology is vital to national security. Advanced computer systems and software are now integral components in most major defense, intelligence, and aerospace systems. Computing technology has a central role in energy research, oil exploration, weapons research, aircraft design, and other national security technology areas.

Major advances in science and engineering have also accrued from recent improvements in supercomputing capability. The existence of machines with hundred megaflop (hundreds of millions of floating point operations per second) speed and multimillion word memories has allowed, for the first time, accurate treatment of important problems in weather prediction, hydrodynamics, plasma physics, stress analysis, atomic and molecular structure, and other areas. The emerging machines with 1 to 10 gigaflop (billions of flops) speed and 100 to 300 million word memories are expected to produce comparable advances in solving numeric and symbolic problems.

Many of these advances in science and engineering are the result of the application of high performance computing to execute computational simulations based on mathematical models. This approach to science and engineering is becoming an important addition to traditional experimental and theoretical approaches. In applications such as the National Aerospace Plane, supercomputing provides the best means to analyze and develop strategies to overcome technical obstacles that determine whether the hypersonic vehicle can fly beyond speeds of Mach seven, where wind tunnels reach their maximum capability. The list of applications for which supercomputing plays this kind of role is extensive, and includes nearly all high-technology industries. The extent of its usage makes supercomputing an important element in maintaining national competitiveness in many high technology industries.

The high performance computing strategy will have impact in many sectors of the economy. Nearly all sectors of advanced industry are dependent on computing infrastructure. Any improvement in computing capability will have substantial leveraged impact in broad sectors, particularly as applications software increases in power and sophistication.

The computer hardware industry alone amounted to $65 billion in 1986, and U.S. technical market dominance, long taken for granted, is now challenged in this and other critical areas, including networking, microsystems and custom high-performance integrated circuit technology. Foreign investment in computing research and technology has grown considerably in the last decade.

As stated in the report of the White House Science Council, *Research in Very High Performance Computing*, November 1985, "The bottom line is that any country which seeks to control its future must effectively exploit high performance computing. A country which aspires to military leadership must dominate, if not control, high performance computing. A country seeking economic strength in the information age must lead in the development and application of high performance computing in industry and research."

BACKGROUND

The Federal Coordinating Council on Science, Engineering and Technology (FCCSET) was established by Congress under the Office of Science and Technology Policy (OSTP) to catalyze interagency consideration of broad national issues and to coordinate various programs of the Federal government. The FCCSET in turn, established a series of committees, with interagency participation to assess and recommend action for national science and technology issues. The committees have become recognized as focal points for interagency coordination activity, addressing issues that have been identified by direct requests through the OSTP and indirect requests by member agencies (such as the NSF requirement to provide an update to the Lax Report on Large Scale Computing in Science and Engineering). These studies have enabled the FCCSET Committee on Computer Research and Applications to develop a national view of computing technology needs, opportunities, and trends.

From its inception, the FCCSET Committee on Supercomputing (the original name of this committee) was chartered to examine the status of high performance computing in the U.S. and to recommend what role the Federal Government should play regarding this technology. The committee issued two reports in 1983 that provided an integrated assessment of the status of the supercomputer industry and recommended government actions. The FCCSET Committee on Computer Research and Applications concluded that it would be proper to include an update of the earlier reports to address the changes that have occurred in the intervening period as a complement to the technical

reports. The review was based upon periodic meetings with and site visits to supercomputer manufacturers and consultation with experts in high performance scientific computing. White papers were contributed to this report by industry leaders and supercomputer experts. The report was completed in September 1987 and its findings and recommendations are incorporated in the body of this report.

In developing the recommendations presented in this report, the FCCSET Committee reviewed findings and recommendations from a variety of sources, including those mentioned above. A related activity has been the preparation by the White House Science Council (WHSC) Committee on Research in Very High Performance Computing of the report *Research in Very High Performance Computing*, November 1985. The WHSC Committee, composed of respected individuals from academia, industry, and government, made recommendations related to the issues more recently addressed by the FCCSET Committee. In the areas addressed by both committees, there is a significant consistency of recommendations, and, indeed, progress in recent months further strengthens the case for the recommendations. The convergence of views expressed in the many reports, the strong interest in many sectors of government in developing a policy, the dramatic increase in foreign investment and competitiveness in computing and network technology, and the considerable progress in computing technology development worldwide are all indicators of the urgency of developing and implementing a strategy for nationwide coordination of high performance computing under the auspices of the government.

One of the of the direct requests that this report responds to is in Public Law 99–383, August 21, 1986, in which Congress charged the Office of Science and Technology Policy to conduct a study of critical problems and of current and future options regarding communications networks for research computers, including supercomputers, at universities and federal research facilities in the United States. The legislation asked that requirements for supercomputers be addressed within one year and requirements for all research computers be addressed within two years. Dr. William R. Graham, Director of the Office of Science and Technology Policy, subsequently charged the Federal Coordinating Council on Science Engineering and Technology (FCCSET) Committee on Computer Research and Applications to carry out the technical aspects of the study for OSTP.

It was recognized by the FCCSET Committee on Computer Research and Applications that networking technology needs to be addressed in the context of the applications of computing and the sources of computing power that are interconnected using the network technology. This report, therefore, presents an integrated set of findings and recommendations related to Federal support for computer and related research.

Three subcommittees carried out the work. Each of these committees contributed to the Findings and Recommendations contained in this report. The result is an integrated set of recommendations that addresses the technical areas.

- The **Subcommittee on Computer Networking, Infrastructure, and Digital Communications** invited experts in government, industry and academia to write white papers on networking trends, requirements, concepts applications, and plans. A workshop involving nearly 100 researchers, network users, network suppliers, and policy officials was held in San Diego, California in February 1987 to discuss the white papers and to develop the foundation for the report. Workshop leaders and other experts later met in Washington to summarize the workshop discussions and focused on six topics: access requirements and future alternatives, special requirements for supercomputer networks, internet concepts, future standards and services requirements, security issues, and the government role in networking. As a result of this work, the participants recommended that no distinction should be made between networks for supercomputers and other research computers and that the final report to the Congress should address networks generally. The requirements for both supercomputers and for other research computers are, therefore, addressed in this report.

- The **Subcommittee on Science and Engineering Computing** assessed computing needs related to computational science and engineering. The committee focused its deliberations on requirements for high performance computing, on networking and access issues, and on software technology and algorithms. Under the auspices of the Society for Industrial and Applied Mathematics (SIAM), and with the support of NSF and DOE, a workshop involving 38 recognized leaders from industry, academia, and national laboratories was held at Leesburg, Virginia in February 1987 on research issues in large-scale computational science and engineering. This workshop focused on advanced systems, parallel computing and applications. As a result of the workshop report, recommendations were made related to the role of computing technology in science and engineering applications.

- The **Subcommittee on Computer Research and Development** assessed the role of basic research, the development of high performance computing technology, and issues related to software technology. Contributing to this activity were two workshops. The National Science Foundation (NSF) Advisory Committee for Computer Research reviewed the field and produced an Initiatives Report in May 1987. This report recommended investment in three areas, including parallel systems and software technology. In September 1987, the Defense Advanced Research Projects Agency (DARPA) held a workshop on advanced computing technology in Gaithersburg, Maryland involving 200 researchers from academia, industry, and government. The workshop focused on large-scale parallel systems and software approaches to achieving high performance computing.

APPENDIX C: *HPC Strategy* REPRINT

An important result of the activity of the FCCSET Committee on Computer Research and Applications and its subcommittees is that increased coordination among the Government elements is necessary to implement a strategy for high performance computing. The findings and recommendations presented here represent a consensus reached among the subcommittees and convey the powerful and compelling vision that emerged. As a result of this process, the next step would be for the members of the Committee on Computer Research and Applications to develop a plan to help ensure that the vision is shared between government, academia, and American industry. Subsequently, the Committee should develop an implementation plan for Federal government activities, including a detailed discussion of overall priorities.

1. High Performance Computers

- **FINDING: A strong domestic high performance computer industry is essential for maintaining U.S. leadership in critical national security areas and in broad sectors of the civilian economy.**

U.S. prominence in technology critical to national defense and industrial competitiveness has been based on leadership in developing and exploiting high performance computers. This preeminence could be challenged by dependency upon other countries for state of the art computers. Supercomputer capability has contributed for many years to military superiority. In addition, industrial applications now constitute more than half of the supercomputer market and are an important factor in U.S. industrial competitiveness. However, continued progress in computational science and engineering will depend in large part on the development of computers with 100 to 1000 times current capability for important defense, scientific, and industrial applications. These applications are represented by the grand challenges.

- **U.S. high performance computer industry leadership is challenged by government supported research and development in Japan and Europe.**

The U.S. currently leads the world in research, development, and use of supercomputers. However, this leadership faces a formidable challenge from abroad, primarily from the Japanese. The 1983 FCCSET report stated that "The Japanese have begun a major effort to become the world leader in supercomputer technology, marketing, and applications." Most of the analyses and projections advanced in support of that statement have proven to be accurate.

Japanese supercomputers have entered the marketplace with better performance than expected. Japanese supercomputer manufacturers have attained a high level of excellence in high speed, high density logic and memory microcircuits required for advanced supercomputers. As a result, some U.S. computer manufacturers are dependent on their Japanese competitors for sole supply of critical microcircuits. Japanese manufacturers, universities, and government have demonstrated the ability to cooperate in developing and marketing supercomputers as well as in advancing high performance computing. Recent successes in dominating related high-technology markets underscore their financial, technical, and marketing capability.

- **U.S. leadership in developing new component technology and applying large scale parallel architectures are key ingredients for maintaining high performance computing leadership. The first generation of scalable parallel systems is now commercially available from U.S. vendors. Application-specific integrated circuits have become less expensive and more readily available and are beginning to be integrated into high performance computers.**

  The current generation of supercomputers achieve their performance through the use of the fastest possible individual components, but with relatively conservative computer architectures. While these computers currently employ up to eight parallel processors, their specific architectures cannot be scaled up significantly. Large scale parallel processing, in which the computational workload is shared among many processors, is considered to be the most promising approach to producing significantly faster supercomputers. The U.S. is currently the leader in developing new technology as well as components. However, exploiting these techniques effectively presents significant challenges. Major effort will be required to develop parallel processing hardware, algorithms, and software to the point where it can be applied successfully to a broad spectrum of scientific and engineering problems.

  Government funded R&D in universities and industry has focused on an approach to large-scale parallelism that is based on aggressive computer architecture designs and on high levels of circuit integration, albeit with somewhat slower individual components. Unlike current supercomputers, the resulting systems employ 100s to 10,000s of processors. Equally important, these architectures are scalable to higher levels of parallelism with corresponding increase in potential performance.

  The first generation of scalable parallel systems is now commercially available from U.S. vendors. These systems have demonstrated high performance for both numeric and non-numeric, including symbolic processing. Comparable systems do not yet exist outside the U.S. The second generation, with higher speed individual components and more parallelism, is already in development here. Experience with these systems has shown that, even with existing software, they are effective for certain classes of problems. New approaches to software for these large-scale parallel systems are in the process of emerging. These approaches suggest that parallel architecture may be effective for wide classes of scientific and engineering problems. An important benefit of the scalable architectures is that a single design, with its attendant components and software, may prove to be useful and efficient over a performance range of 10 to 100 or more. This allows one design to be used for a family of workstations, mini-supercomputers, and supercomputers.

- **RECOMMENDATION: The U.S. Government should establish a long range strategy for Federal support for basic research on high performance computer technology and the appropriate transfer of research and technology to U.S. industry.**

The program should build upon existing government supported efforts. However, government funding should not be viewed as a substitute for private capital in the high performance computer marketplace. A primary objective is to ensure continued availability of domestic sources for high performance computers that are required for Federal programs, both civilian and defense. These actions should include:

- Government should support, when appropriate for mission requirements, the acquisition of prototype or early production models of new high performance computers that offer potential for improving research productivity in mission areas. These computers could be placed in centers of expertise in order to allow sophisticated users to share initial experiences with manufacturers and other users, and to develop software to complement the vendor's initial offerings. These initial acquisitions should not require the vendor to supply mature operating systems and applications software typical of production computers. However, a criterion for acquisition should be that the hardware designs reflect a sensitivity to software issues, and that the computer has the potential for sustained performance in practical applications that approaches the peak hardware performance.

- Government agencies should seek opportunities to cooperate with industry in jointly funded R&D projects, concentrating especially on those technologies that appear scalable to performance levels of trillions of operations per second (teraops) for complex science, engineering, and other problems of national importance. Systems are needed for both numeric and symbolic computations.

However, since government mission requirements typically exceed those of industrial applications, cooperating with industry in R&D for computers to meet these missions will help to assure that the necessary computers are available. It will also drive supercomputer development at a faster pace than would be sustained by commercial forces alone, an important factor retaining and increasing U.S. leadership in this area.

- Government agencies should fund basic research to lay the foundation for future generations of high performance computers. Steps should be taken to ensure that development of state-of-the-art computers continues to be monitored for appropriate export controls.

2. Software Technology and Algorithms

- **FINDING: Research progress and technology transfer in software and applications must keep pace with advances in computing architecture and microelectronics.**

  - **Progress in software and algorithms is required to more fully exploit the opportunity offered by parallel systems.**
  - **Computational methods have emerged as indispensable and enabling tools for a diverse spectrum of science, engineering, and design research and applications.**
  - **Interdisciplinary research is required to develop and maintain a base of applications software that exploits advances in high performance computing and algorithm design in order to address the "grand challenges" of science and engineering.**

A **grand challenge** is a fundamental problem in science and engineering, with broad application, whose solution will be enabled by the application of the high performance computing resources that could become available in the near future.

As high performance computing systems evolve and are applied to more challenging problems, it is becoming increasingly clear that advances in software technology and applications are essential to realize the full performance potential of these systems. Software development, analysis, and adaptation remain difficult and costly for traditional sequential systems. Large scale complex systems including parallel systems pose even greater challenges. Market pressures for the early release of new computing system products have created a tradition of weak systems software and inadequate programming tools for new computers.

Current approaches to software development provide only limited capabilities for flexible, adaptable, and reusable systems that are capable of sustained and graceful growth. Most existing software is developed to satisfy nearer term needs for performance at the expense of these longer term needs. This is particularly the case for applications in which specific architectural features of computers have been used to obtain maximum performance through low level programming techniques. The lack of portability of these programs significantly raises the cost of transition to newer architectural approaches in many applications areas. Approaches are beginning to emerge in the research community that have a potential to address the reuse and portability problems.

Experiments with parallel computers have demonstrated that computation speeds can increase almost in direct proportion to the number of processors in certain applications. Although it is not yet possible to determine in general the most

efficient distribution of tasks among processors, important progress has nonetheless been made in the development of computational models and parallel algorithms for many key problem areas.

Access to advanced computing systems is an important element in addressing this problem. Experience has shown that the quality of systems and applications software increases rapidly as computing systems are made more available. Initial generic operating systems and extensions to existing programming languages can provide access through coupling high performance computers with existing workstations using either direct or network connections. However, in order to achieve the full potential impact of large scale parallel computing on applications, major new conceptual developments in algorithms and software are required.

The U.S. leads in many areas of software development. The Japanese, however, also recognize the need for high quality software capability and support in order to develop and market advanced machines. They have demonstrated the ability to effectively compete, for example in the area of sophisticated vectorizing compilers.

The U.S. will need to encourage the collaboration of computer scientists, mathematicians, and the scientists in critical areas of computing applications in order to bring to bear the proper mix of expertise on the software systems problem. Such collaboration will be enhanced by network technology, which will enable geographically dispersed groups of researchers to effectively collaborate on "grand challenges." Critical computer applications include problems in fluid dynamics, plasma physics, elucidation of atomic and molecular structure, weather prediction, engineering design and manufacturing, computer vision, speech understanding, automated reasoning, and a variety of national security problems.

- **RECOMMENDATION: The U.S. should take the lead in encouraging joint research with government, industry, and university participation to improve basic tools, languages, algorithms, and associated theory for the scientific "grand challenges" with widespread applicability.**

  Software research should be initiated with specific focus on key scientific areas and on technology issues with widespread applicability. This research is intended to accelerate software and algorithm development for advanced architectures by increased early user access to prototype machines. It would also provide settings for developing advanced applications for production machines. Software technology needs to be developed in real problem contexts to facilitate the development of large complex and distributed systems and to enable transition of emerging parallel systems technology into the computing research community and into the scientific and engineering applications communities.

  As part of a mixed strategy, longer term and more basic software problems of reliability and trust, adaptability, and programmer productivity must continue to be addressed. Languages and standards must be promoted that permit development of systems that are portable without sacrificing performance.

  In applications areas including computational science and engineering, technology should be developed to support a smooth transition from the current software practice to new approaches based on more powerful languages, optimizing compilers, and tools supported by algorithm libraries. The potential of combining symbolic and numeric approaches should be explored. Progress in these areas will have significant impact on addressing the "grand challenges" in computational science and engineering. Although there are many pressing near term needs in software technology, direct investment in approaches with longer term impact must be sustained if there is to be significant progress on the major challenges for software technology while achieving adequate system performance.

  Applications include (1) distributed access to very large databases of scientific, engineering, and other data, (2) high bandwidth access to and linking among shared computational resources, (3) high bandwidth access to shared data generation resources, (4) high bandwidth access to shared data analysis resources, such as workstations supporting advanced visualization techniques.

3. NETWORKING

- **FINDING: The U.S. faces serious challenges in networking technology which could become a barrier to the advance and use of computing technology in science and engineering.**

  - **Current network technology does not adequately support scientific collaboration or access to unique scientific resources. U.S. commercial and government sponsored networks presently are not coordinated, do not have sufficient capacity, do not interoperate effectively, and do not ensure privacy.**
  - **Europe and Japan are aggressively moving ahead of the U.S. in a variety of networking areas with the support of concentrated government and industry research and implementation programs.**

Computer network technology provides the means to develop large scale distributed approaches to the collaborative solution of computational problems in science, engineering, and other applications areas. Today, researchers sharing a local area network are able to exploit nearly instantaneous communication and sharing of data, creating an effect of linking their workstations and high performance servers into a single large scale heterogeneous computing facility. This kind of capability is now appearing in larger scale campus-wide computer networks, enabling new forms of collaboration. National networks, on the other hand, have low capacity, are overloaded, and fail to interoperate successfully. These have been expanded to increase the number of users and connections but the performance of the underlying network technology has not kept pace with the increased demands. Therefore, the networks which in the 1970s had significant impact in enabling collaboration, are now barriers. Only the simplest capabilities, such as electronic mail and small file transfers, are now usable. Capacity, for example, is orders of magnitude less than the rates required, even if the network is used only for graphics.

Other countries have recognized the value of national computing networks, and, following the early U.S. lead, have developed and installed national networks using current technology. As a result, these countries are now much better prepared to exploit the new opportunities provided by distributed collaborative computing than the U.S. is at the present time. The basic technologies for later generations are also being developed in the U.S., but there have been no major efforts to apply them to address the needs.

A longer term goal is the creation of large scale geographically distributed heterogeneous systems that link multiple superworkstations and high performance supercomputers to provide service to scientists and engineers distributed across the country. A well-coordinated national network could link these resources together when required on an *ad hoc* basis to provide rapid response to computational needs as they arise. This could reduce the number of sites needed for the physical presence of supercomputers. Present access to computer networks by researchers is dependent upon individual funding or location. There is unnecessary duplication in the links from various agencies to each campus. The development of improved networking facilities could greatly stimulate U.S. research and provide equitable access to resources.

Many scientific research facilities in the U.S. consist of a single, large, and costly installation such as a synchrotron light source, a supercomputer, a wind tunnel, a particle accelerator, or a unique database. These facilities provide the experimental apparatus for groups of scientific collaborators located throughout the country. Wide area networks are the logical mechanism for making data from such facilities more easily accessible nationwide. An important issue is that of computer and network security to ensure privacy and trustworthiness in a heterogeneous network environment. At present, responsibility for privacy and the assurance of trust are vested principally in the computers and switching nodes on the network.

Existing government-supported wide-area networks include ARPANET, HEPNET, MFENET, NSFNET, NASNET, MILNET, and SPAN, as well as private and commercial facilities such as TYMNET, TELENET, BITNET, and lines leased from the communication carriers. Longer-range estimates vary, but it is expected that by the year 1995 the nation's research community will be able to make effective use of a high capacity national network with capacity measured in billions of bits per second. Without improved networks, speed of data transmission will be a limiting factor in the ability of researchers to carry out complex analyses. The digital circuits most widely available today with transmission speeds of 56 kilobits per second (kb/s) are impediments to leading edge research and to optimal remote high performance computer use.

Point-to-point connections require interconnects through multiple vendors with cumulative costs. Greater network speed can reduce the time required to perform a given experiment and increase both the volume of data and the amount of detail that can be seen by researchers. Scientists accessing supercomputers would benefit because access speed is often critical in their work. Improved functionality frees scientists to concentrate directly on their experimental results rather than on operational details of the network. Increased network size extends these opportunities to thousands of individuals at smaller academic institutions throughout the nation. These modernization measures would significantly enhance the nation's position in scientific research. A national network would help maintain the U.S. leadership position in computer architectures,

microprocessors, data management, software engineering, and innovative networking facilities, and promote the development of international networking standards based on U.S. technology.

Integrated Systems Digital Networks (ISDN–voice and data) have been installed abroad on a national or regional scale. Research abroad is being conducted on service up to 1 Gb/s. Within the next five years, Integrated Services Digital Network (ISDN) circuits ranging from 64 kb/s to 1.5 Mb/s will be available in the larger metropolitan areas of the U.S. However, these services will fall short of the requirements for computer networks. By 1988 more than fifty Campus Area Networks will be operational at speeds approaching 100 Mb/s. Wide area networks operating at 1.5 Mb/s or less will not be able to handle the data volume expected.

Japan and Europe have extensive efforts with experimental nets in intermediate (40Mb) and high (gigabit) range. Japan is studying operational aspects of fiber nets using their national research network as a testbed, which includes exploring the feasibility of fiber optic services to residences.

To estimate the network bandwidth needed to support research at a major installation, the kinds and volume of traffic that would be used have been estimated at a representative campus, extrapolated ten years into the future. Three models were used to compute three independent estimates of the requirements for bandwidth needed by type of work, information needs by type of user, and information flowing at the installation boundary. In each model, the peak bandwidth was estimated for each type of service. For example, in the Task model, the need is dominated by that of at least one researcher to receive full color and full–motion high resolution images. A high–resolution color image contains about 30 megabits of information, so that a display rate of 30 frames per second requires a bandwidth of nearly one gigabit per second (Gb/s). In the User model, a research university with 35,000 students and 3,000 faculty and research staff using a mix of bandwidths again requires an aggregate bandwidth of approximately one Gb/s. In the Edge of the Installation model, bandwidth is estimated by the types of remote facilities being accessed and the expected number of simultaneous users; typical facilities include particle accelerators, supercomputers, and centers for imaging and/or animation. The aggregate bandwidth needed is one Gb/s. Thus three independent means of estimating bandwidth arrive at nearly the same requirement for a large research installation, and one Gb/s can confidently be used as a lower bound on the bandwidth of a national research network.

- **RECOMMENDATION: U.S. government, industry, and universities should coordinate research and development for a research network to provide a distributed computing capability that links the government, industry, and higher education communities.**

A research network should be established in a staged approach that supports the upgrade of current facilities and development of needed new capabilities. Achievement of this goal would foster and enhance the U.S. position of world leadership in computer networking as well as provide infrastructure for collaborative research. The FCCSET Committee on Computer Research and Applications should provide a forum for interagency cooperations. Elements of the plan should include:

- *Stage 1.* Upgrade existing facilities in support of a transition plan to the new network through a cooperative effort among major government users. The current interagency collaboration in expanding the Internet system originated by DARPA should be accelerated so that the networks supported by the agencies are interconnected over the next two years.
- *Stage 2.* The nation's existing networks that support scientific research should be upgraded and expanded to achieve data communications at 1.5 Mb/sec for 200 to 300 U.S. research institutions.
- *Stage 3.* Develop a system architecture for a national research network to support distributed collaborative computation through a strong program of research and development. A long-term program is needed to advance the technology of computer networking in order to achieve data communication and switching capabilities to support transmission of three billion bits per second (3 Gb/s) with deployment within fifteen years.
- Develop policy for long term support and upgrading of current high performance facilities, including timetables for backbone and connection development, industry participation, access, agency funding, tariff schedules, network management and administration. Support should be given to the development of standards and their harmonization in the international arena.

Until the national research network can replace the current system, existing networks should be maintained and modified as they join the national network. Remedial action should be initiated as soon as possible. Upgrading the backbone to at least 1.5 Mb/s should be accomplished by 1990. This will ensure that the new generation of high performance computing can be effectively interconnected.

Industry should be encouraged to participate in research, development, and deployment of the national research network. Telecommunication tariff schedules

which have been set for voice transmission should be reviewed in light of the requirements for transmission of data through computer networking.

Prompt effective coordination is needed to increase user participation in the standards development process, to get requirements for standards expressed early in the development process, and to speed the implementation of standards in commercial off-the-shelf products. It is essential that standards development be carried out within the framework of overall systems requirements to achieve interoperability, common user interfaces to systems, and enhanced security.

4. Basic Research and Human Resources

- **FINDING: Federal research and development funding has established laboratories in universities, industry, and government which have become the major sources of innovation in the development and use of computing technology.**

  Many of the advances in computer science and technology in the U.S. were made possible by Federal programs of research support to universities and industry. For example, the advances that have occurred since 1983 in the area of parallel computing are the direct result of Federal research investment through agencies including DARPA and NSF. In the area of application of supercomputers to science and engineering, the majority of this investment came from the NSF Advanced Scientific Computing centers. In the area of parallel architectures, the major investment came from the DARPA Strategic Computing Program. Programs sponsored by DOE, NASA, and Defense to support critical mission needs have been a major source of investment in computational applications research. In industry, support for basic research is only a small fraction of industry research most of which is focused on nearer term product development. This can be attributed in part to the long term and high risk nature of basic research, but a more significant inhibitor of investment is the difficulty in the computer industry of maintaining proprietary protection for certain kinds of key fundamental advances.

- **RECOMMENDATION: Long term support for basic research in computer science should be increased within available resources. Industry, universities, and government should work together to improve the training and utilization of personnel to expand the base of research and development in computational science and technology.**

  Maintain vigorous research in Computer Science and sufficient growth of computer science manpower to support the scientific/technological basis of the computer field. Foster interactions among academia, industry, and national laboratories by creating interdisciplinary teams to address large scale problems. Extend the technology base to attain significant impact on competitiveness and industrial productivity.

  Innovative very high performance computing systems should be made available to universities and basic research laboratories in order to assist in the evaluation and exploitation of new technology and new industrial innovations.

Continue the following successful approaches to basic research and development: (1) The practice of loosely coordinated and flexible basic research supported through various federal sectors and applied to a diversity of institutions, (2) The mixed strategy of peer review to support a broad range of exploratory basic research throughout the academic community and the complementary technical program management approach of larger scale experimental systems programs which exploit new opportunities as they emerge, (3) Support for individuals and small groups in theoretical areas, (4) The practice of supporting the relevant basic research as part of larger experimental systems projects.

IMPLEMENTATION

Success of the National High Performance Computing Strategy will require an attitude of cooperation in which academia, industry and government work effectively together in developing and assessing new technology and in achieving the transition of promising new ideas into the marketplace. The rapid pace of developments in computing technology creates a number of implementation challenges that must be addressed explicitly if the Strategy is to have maximum impact.

The FCCSET Committee on Computer Research and Applications provides an appropriate forum for coordination of Federal agency programs. Specifically:

- The subcommittee on Computer Networking, Infrastructure, and Digital Communications will develop a coordinated implementation plan for the national research network.

- The subcommittee on Science and Engineering Computing will review the *grand challenges* through the use of high performance computing systems, including the research that will be involved.

- The subcommittee on Computer Research and Development will review the need for advanced software, algorithms, and hardware for future high performance computing systems.

All of the subcommittees will consider appropriate action to secure a foundation of basic research and human resources. In all three subcommittees we expect some overlap of responsibility and interchange of ideas to be compatible with success.

As has been firmly stated, the full cooperation through a shared vision between government, industry and the research community will be a necessary ingredient for the successful implementation of this strategy. The FCCSET Committee on Computer Research and Applications therefore calls for timely consideration of the vision and strategy by representative bodies of the research community and industry.

It is essential, however, that implementation of the strategy be undertaken in a timely manner. There is a need to follow through on the breakthroughs that occurred partially as a result of federal investment in the early 1980s. The fast pace of development dictates that appropriate Federal efforts are needed to help ensure continued excellence in high speed networking technology and leadership in high performance computing. Foreign investment in technology development in these key areas has increased dramatically. The prudent strategy is to maintain a consistent strong lead in research and to transfer the results as quickly as possible to American industry.

COST ESTIMATES

Many of the basic elements of the high performance computing strategy are already being implemented as part of ongoing agency programs at DOE, DARPA, NSF, NASA, and other Federal agencies, and important progress is being made. The FCCSET Committee activity has contributed to achieving a shared vision, and early coordination is already occurring in anticipation of implementation of the strategy. Implementation of the strategy involves three principal funding components, including the national research network, joint research to address the "grand challenges," and basic research in high performance computing architecture, custom hardware design, software, algorithms, and supporting technologies. Multiple agencies are involved in the implementation and funding of each of these components.

The funds that would be associated with each of these components are described below. Obviously, any incremental funding must be evaluated and approved within the context of current activities and research needs in other high priority fields. Currently, the Federal government is spending about $500M per year on all aspects of high

Summary of Additional Funds
(Millions of Dollars)

Current Funds			Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
50 [a]	National Research Network	Stage 1	5	5	5	0	0
		Stage 2	5	5	55	55	55
		Stage 3	40	40	40	40	40
150 [b]	Joint Research in Computational Science and Engineering		30	60	90	120	150
300	Basic Research in Computer Science and High Performance Computing		60	120	180	240	300
500	TOTAL (above current funds)		140	230	370	455	545
	Funding Increase by Year (noncumulative)		140	90	140	85	90

a Estimated network research and support in grants and contracts.
b Estimated operating costs for existing computational science facilities.

performance computing. Funding for the activities recommended in this report would increase this base by $140M in additional resources for the first year, growing to an additional $545M per year in 5 years.

National Research Network. Current operating costs for the present collection of research-support networks operated by DARPA, NSF, DOE, and NASA is approximately $50M per year; the figure is uncertain because many subnetworks are funded by increments on research grants and contracts, rather than being centrally supported. Currently the interconnection of existing agencies' networks is planned within existing budgets. A significant increase in investment is needed to achieve the required capability. This investment could occur in three concurrent stages.

The *first stage* activity would involve an immediate upgrade to 1.5 Mbit/sec of the existing research-support networks. This would cost $15M over three years.

The *second stage* would expand upgraded network services (45Mbit/sec) to 200 to 300 research installations, using primarily fiber-optic trunk facilities. Development costs for this stage would be $5M per year of additional funding. Operation of the upgraded network would commence in three to five years, with operating costs of approximately $50M per year. Since the transition from the first stage to the second stage network could not be instantaneous, initially the full operating cost of the second stage network would necessitate additional funding; that requirement will diminish to the extent that the first stage network is phased out.

The goal of the *third stage* would be to deliver one to three Gbit/sec to selected research facilities, and 45 Mbit/sec to approximately 1000 research sites. Research and development costs for this project are estimated at $400M of new funds, spent over ten years; after ten years, operating costs would be about $200M per year unless some tariff relief is achieved.

Joint Research in Computational Science and Engineering. Current operating costs for existing computational science laboratory facilities is approximately $150M per year. Additional investment would be required to upgrade the existing facilities and/or to establish additional joint research activities, with government, industry, and university participation, to address approximately specific problem areas, including selected *grand challenges*. Many of these joint research efforts will involve multiple physical sites connected by the research network. The investment in these research activities supports pursuit of the grand challenges. This includes personnel to develop computational approaches in terms of theory, algorithms, and software, and the acquisition of modern computing equipment. Estimated Federal costs average $15M per year to establish and sustain each grand challenge. The joint research activities would be introduced at the rate of two per year. Overall investment will be approximately $30M per year initially, increasing to $150M per year in five years as new grand challenges are added.

Basic Research in Computer Science and High Performance Computing. Current Federal investment in advanced computer research is estimated at $300M in FY88. Over the past four years, investment in these areas has grown at 15% per year. The rate of increase appears to be declining, however, at a time when increased investment appears to be needed. Sufficient resources should continue to be allocated to take full advantage of the high performance computing opportunities that now exist including design and prototype development of systems capable of trillions of operations per second. A second important element is stable funding, which is required to preserve the long-term strength of the research community.

Other countries are also devoting considerable resources in this area. For example, the Japanese government supports two projects which directly address supercomputer development: The Fifth Generation Project and the Superspeed Project. Support for each of these is estimated to be in excess of $100M per year. In addition to this government support, Japanese industry is investing considerably more to develop high performance computers. Japanese government and industry are also investing amounts comparable to those recommended here to develop high bandwidth research networks.

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APPENDIX C: *HPC Strategy* REPRINT

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Report of the Defense Science Board Task Force on the NATIONAL AEROSPACE PLANE (NASP)

September 1988

Office of the Under Secretary of Defense for Acquisition
Washington, D. C. 20301-3140

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301-3140

DEFENSE SCIENCE
BOARD

September 21, 1988

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION)

SUBJECT: Report of the Defense Science Board Task Force on the National Aerospace Plane (NASP)

I am pleased to forward the final report of the Defense Science Board Task Force on the National Aerospace Plane (NASP). The Task Force, chaired by Dr. Joseph F. Shea, was charted to evaluate the degree to which the technology base can support the decision to transition the NASP into Phase III, detailed design, fabrication, and flight test of the selected configuration. As you will note from Dr. Shea's forwarding letter, the Task Force completed its review during the summer of 1987.

Since the completion of the review, the results have been briefed extensively within the Air Force, DARPA, NASA, and the DoD. Dr. Shea briefed both you and your predecessor. You may know that, in some circles, the findings were viewed as being critical of the program. I can assure you, however, that the Task Force was, and is, committed to strengthening the program.

Publication of the final report has been delayed for a number of reasons, principally related to its public releasability. An entire appendix of the report, alleged to be competition-sensitive, is omitted from this version, so that it may be cleared for wide dissemination.

I share Dr. Shea's conviction that the NASP is a vitally important national program, and that the program is stronger today than when his Task Force undertook its review.

Robert R. Everett
Chairman

Attachment

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301-3140

DEFENSE SCIENCE
BOARD

April 25, 1988

Mr. Robert R. Everett
Chairman
Defense Science Board

Dear Mr. Chairman,

I am pleased to submit to you the final report of the Defense Science Board Task Force on the National Aerospace Plane (NASP). The Task Force was charted to evaluate the degree to which the technology base can support the decision to transition the NASP into Phase III, detailed design, fabrication, and flight test of the selected configuration. Our review began early in 1987 and was basically complete by the summer of that year.

The technology efforts supporting the NASP are funded through a Technical Maturation Program (TMP) which was initiated late in 1986. The technologies critical to NASP are hypersonic aerodynamics, propulsion, structures, materials, guidance and control, and computational fluid dynamics. We reviewed the TMP and related contractor efforts in these disciplines.

We found that, although the Technical Maturation Program was a good start, it fell far short of what would have been required to enter Phase III on the then existing schedule with any acceptable degree of risk. More importantly, major technology issues in all disciplines were not being addressed.

As a major national program, NASP should be planned realistically. We believe that the level of technical uncertainty is too high to commit to schedule or cost at this time.

We recommend that quantitative technical milestones be established for all critical technology needs. Transition to Phase III should occur when these milestones are met. During the present phase, NASP should be a milestone driven program, not an event driven program. The funding balance within the NASP should be adjusted so that the TMP can support these milestones.

In addition to our technical review, and not part of the Terms of Reference, I am compelled to point out that the concept of heavy cost sharing by the contractors is not realistic. The near term business potential to be derived from the program is not large enough to invite corporate investment in competition with other opportunities that have a more assured payback.

The Task Force members were exceptionally well qualified, with University, industry, and ex-government experience in program management and the technologies related to NASP. The Task Force strongly supports the goals of the program because of the major potential benefits to space launch vehicles, projection of military presence anywhere in the world in a matter of hours, and to commercial air transport.

The Phase III NASP design will be an experimental airplane to explore the hypersonic flight envelope, not a prototype of any mission-oriented vehicle.

The results of this study have been briefed extensively within the Air Force, NASA and DoD. I believe our recommendations have been accepted, and the program today appears to be more soundly planned than when we started our efforts.

Sincerely,

Joseph F. Shea

Joseph F. Shea

Report of the Defense Science Board Task Force on the NATIONAL AEROSPACE PLANE (NASP)

Dr. Joseph F. Shea

Chairman

CLEARED
FOR OPEN PUBLICATION

SEP 2 9 1988 12

DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW (OASD-PA)
DEPARTMENT OF DEFENSE

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SUMMARY

The NASP started in 1984 as a DARPA Program to explore hypersonic air breathing propulsion. It transitioned during 1985 to a program with the dual goals of demonstrating single stage to orbit and hypersonic cruise with the same vehicle. When President Reagan included the NASP in his 1986 State of the Union Message, it became a major national program.

Early estimates of vehicle size, performance, cost and schedule were extremely optimistic. Hypersonic technology had been dormant in the United States for over a decade. It took about a year for both Government and Industry to recognize the technical deficiencies which existed in all the critical technologies, and the lack of ground test facilities to explore the hypersonic environment. Late in 1985, DARPA formed a committee, chaired by Dr. Victor Reis, to review technical and management issues on the program. Among their recommendations was the initiation of a Technology Maturation Program (TMP) to better integrate technology efforts with the design program and to address the most critical technical gaps. Implementation began early in 1987.

This Defense Science Board Task Force was chartered in late 1986 to review the sufficiency of the TMP to support a decision to proceed with detailed design and fabrication of a flight test vehicle by the end of 1989.

When our review began, the program was supported by five airframe and three engine contractors doing Phase 2, Part II configuration studies. The Technology Maturation Program brought in additional contractors

and Government Laboratories for specific tasks, and was supplemented by contractor Independent Research and Development efforts.

Late in the Summer of 1987, the planned down select to three airframe and two engine contractors occurred. The program is now in Phase 2, Part II, tentatively scheduled to complete during 1990, at which time one contractor would enter Phase 3 detailed design, fabrication and flight test of the flight test article.

The National Aerospace Plane Program today is significantly different from that envisioned at its outset in 1985. Vehicle weight has grown considerably, as have program cost estimates. Schedules continue to lengthen because of both technical and budgetary issues. We believe more such change can be expected.

The Task Force held four meetings in which the overall program and the Technology Maturation Program were reviewed, four sub-panel meetings on specific technologies and one three day meeting with the contractors. Several of the members have had extensive involvement with the NASP either through membership on the Reis Panel or through consulting assignments directly from NASA or the Air Force.

The recommendations from the Task Force members are unanimous.

Basically, we believe that, as a significant national program, the NASP should be realistically presented to its sponsors within DoD, its supporters in Congress and ultimately, through the White House to the American public. We define "realistic" as a program with a reasonable chance (above 75%, to choose an arbitrary measure) of meeting the performance, schedule and cost goals projected by its proponents. In today's budgetary environment, lack of realism which leads to significant overruns or performance shortfalls can result in loss of program support, and the national embarrassment of a major technical effort poorly executed.

Having looked in some depth into the technologies of importance to the NASP, we are impressed with the progress being made. But we are even more impressed by what has yet to be done to reduce the remaining uncertainties to a reasonably manageable level.

Until these uncertainties are reduced, the NASP should not be a schedule driven program. Rather, it should be paced by events. In particular, we recommend that a set of technical milestones be established which must be demonstrated before a configuration is baselined and Phase 3 detailed design, fabrication, and flight test initiated.

The following sections summarize the Task Force charter and our response to the terms of reference, the major areas of technical concerns, the concerns expressed by the contractors and our conclusions and detailed recommendations. Six appendices

discuss the critical technologies in more detail. The seventh appendix summarizes individual contractor comments.

The Task Force strongly supports the overall goals for the National Aerospace Plane Program. We believe our recommendations suggest a realistic path by which those goals can be achieved.

During the period of our review, the program has continued to evolve. This report contains our interpretation of data gathered January-June 1987 and reflects NASP program status and information current as of that time. We believe management has already begun to respond to the recommendations of the Task Force which have been extensively briefed to DARPA, The Air Force, NASA and DoD.

TERMS OF REFERENCE

The Task Force was chartered to address, but not be limited to, the following issues:

1) The overall sufficiency of the Program's Technology Maturation Plan (TMP).

2) The degree to which the overall program effort adequately supports the achievement of the technical objectives of Phase 2 of the NASP Program.

3) The need for additional technology development efforts which would extend beyond the time frame of the Phase 2 program.

4) The adequacy and viability of criteria to be satisfied in order to justify a decision to proceed to Phase 3 of the NASP Program.

5) The range of missions for the NASP and variants to the degree required to identify technology issues. New capabilities provided by the NASP which offer the potential for new mission possibilities.

RESPONSE TO ISSUES POSED

Detailed conclusions and recommendations are presented in later sections. This section summarizes the Task Force response to the issues raised in our terms of reference.

1) Although the Technology Maturation Plan is a good start, it is far short of what will be required to enable the NASP Program to enter Phase 3 on the present schedule with any degree of acceptable technical risk.

2) The TMP does not adequately support the objectives of Phase 2. Some tasks provide data too late to help in the configuration decisions which are required to start Phase 3. More importantly, major technology issues in structures and materials, propulsion, aerodynamics, controls, validation of computational aerodynamic codes and ground testing are not being addressed.

3) To close the risks in the areas indicated above, funding of the Technology Maturation Program should be increased. We estimate that twice as much as presently planned could usefully be invested. Since total program funding is unlikely to increase, this means that the configuration efforts in airframe and propulsion should be scaled back to a level sufficient to provide a focus for the technology effort.

4) No quantitative criteria have been established to justify a decision to proceed to Phase 3 of the program.

5) The Task Force did not review the range of missions for NASP. Such studies are still in an embryonic state. However the Task Force members believe that the NASP is a vitally important national program because of the missions, both military and commercial, it will enable, and the technology which will be matured.

Hypersonic, air breathing propulsion can attain a Specific Impulse approaching 2000 seconds, compared to about 460 seconds for conventional high energy cryogenic fuel rocket engines. A single stage to orbit, reusable air breathing vehicle is a possibility for low cost to orbit transportation.

Hypersonic cruise vehicles will enable our Military to project American presence anywhere in the world within a few hours, providing timely response for crisis intervention, strategic reconnaissance and terrorist attack. Civilian hypersonic transports will further shrink the world.

The National Aerospace Plane is a necessary precursor to these three classes of vehicles. As an X-airplane it will explore the realm of hypersonic flight, gathering the data necessary to overcome the limitations of analysis and ground test facilities. Of equal importance, the NASP will provide a focus for the development of the six technologies critical to hypersonic vehicle design, aerodynamics, supersonic mixing and fuel-air combustion, high temperature materials, cooled structures, control systems and computational fluid dynamics.

The following sections address the technical concerns encountered in our review.

DISCUSSION

The technologies critical to the NASP are aerodynamics, propulsion, materials, structures, controls and computational fluid dynamics (which must support several of the disciplines).

The recommendations of the Task Force are based on review of these technologies and the technical and management experience of the Task Force members. This section summarizes the major concerns which shaped our recommendations.

The appendices contain more detailed discussion of each area.

Aerodynamics

The NASP requires an unprecedented degree of integration of the airframe with the propulsion system. Although this is well recognized by program management and the contractors, the problems of integration are formidable. Because of a lack of adequate ground test facilities above about Mach 10, some of the critical design issues may only be resolved by flight test of the vehicle.

The largest uncertainty is the location of the point of transition from laminar to turbulent flow. Estimates range from 20% to 80% along the body span. That degree of uncertainty significantly affects the flow conditions at the engine inlet, aerodynamic heat transfer to the structure and skin friction. These in turn affect estimates of engine performance, structural heating and drag. The assumption made for the point of transition can affect the design vehicle gross take off weight by a factor of two or more.

Computational fluid dynamics cannot predict transition because turbulence must be introduced into the calculations empirically, and no relevant data base exists for the high mach number flight regime. In addition, while CFD is reasonably accurate for two dimensional laminar flows, calculations of three dimensional flow around structural details usually needs to be calibrated by experimental data. Therefore estimates of local heating conditions will be imprecise.

Historically, calculations of aerodynamic performance have been validated in ground test facilities. For Mach numbers between ten and twenty five no ground test facilities exist which can produce true stagnation enthalpy and full scale Reynolds numbers. One or several of the critical parameters can be simulated separately in existing or proposed facilities, and these will provide useful data which may narrow the uncertainties. However there is currently no way to validate methods for combining such partial simulation results to represent the true flight environment.

The uncertainties of aerodynamic performance will affect all aspects of the NASP design.

The NASP program has initiated a major analytic and experimental effort to understand the nature of transition. It would seem prudent to delay initiation of detailed vehicle design until that effort has narrowed the uncertainty in location of the transition point to an acceptable tolerance.

The air breathing propulsion system for the NASP must operate from a standing start to Mach 25. It will consist of three distinct cycles, low speed (up to about Mach 1), ram jet (subsonic combustion), and scram jet (supersonic combustion).

The low speed cycle is a significant design challenge, but can be adequately tested in ground facilities and independent flight, as can the ram jet. Transition from ram jet to scram jet could be the most critical stage of flight, when a normal shock must be forced through the diffuser, combustor and nozzle without flameout or loss of thrust so that the vehicle can continue to accelerate. The system must avoid any strong shock waves that might be caused by fuel injection or details of the variable geometry in the engine flow path required to optimize performance over the wide flight regime. Unwanted shocks could destroy performance or cause unstart which could place heavy demands on the vehicle attitude control system.

Very little is presently known about the mixing and combustion of hydrogen at very high supersonic velocities. It is possible that some of the reactions will not be completed in the combustion chamber, or even in the nozzle, which would result in a loss of performance. Fundamental research in this area has been proceeding slowly because of computational and experimental limitations.

Calculations of flow through the engine will have larger uncertainties than those discussed for aerodynamics because of the uncertainty in inlet conditions, the more complex geometry of the flow path and the introduction of combustion kinetics. Ground test facilities will not provide data much above Mach 8, and full scale testing will probably not exceed Mach 4. Valid testing at higher Mach number will only be done by expanding the flight envelope of the full scale vehicle. It is highly likely that flow anomalies will be encountered in the propulsion system which will require redesign before the flight test program can proceed. Non intrusive instrumentation which can provide the data to resolve such problems must be developed.

The NASP program should consider conducting the equivalent of a limited pre-flight readiness test (PFRT) for the NASP propulsion system, as is conventional practice for a manned aircraft program. This would require a ground test facility with continuously variable Mach capability to as high a velocity as practical. Ability to demonstrate ram jet to scram jet transition would be very desirable. To this end, modification of the Aeropropulsion Systems Test Facility (ASTF) tunnel at Tullahoma, Tennessee should be studied.

Materials

Based upon the preliminary design and performance estimates presented to the Task Force, surface temperatures of the NASP structure will range from in excess of 3000^{o}F to less than 1200^{o}F. For a typical configuration, some 15% of the wetted

area might be exposed to temperatures above 2600°F, 20% to temperatures between 1800°F and 2600°F, about 50% to temperatures between 1200°F and 1800°F, with only 15% below 1200°F where "conventional" materials are available. The higher temperature requirements force the vehicle designer to make a choice between new, promising materials which are in various stages of advanced development (in general, available only in laboratory quantities), or active cooling of a major fraction of the structure.

There appeared to be a discrepancy between consideration of the advanced materials for the high temperature structure and the availability of such material on a schedule compatible with vehicle fabrication. Development of new materials including scaled up production facilities is estimated to take twelve to fifteen years. At the time of our review, the NASP program schedule would have allowed only five to seven years. We also noted that no funds were programmed to facilitate whatever scale up is finally required, although the new materials would not see immediate demand outside the NASP Program and therefore would not be likely to attract private investment.

The lack of scaled up production processes also affects the quality of the material characterization data available to the structural designer. Small quantity lots will not provide the range of material properties required to establish design allowables, damage tolerance and fatigue characteristics for production materials.

The NASP structure will be exposed to high temperature, high enthalpy, disassociated gas. Reusable coatings will be essential to protect the materials.

In areas where the structure is exposed to hydrogen at high temperature and pressure (such as active cooling channels), the hydrogen molecules can penetrate the material and cause embrittlement. The problem is not well understood. The program is raising contractor awareness of the problem, but no funded effort was underway at the time of our review.

It is the opinion of the Task Force that availability of suitable materials in production quantities will be the pacing element in the NASP schedule, and that resources must be identified to fund the necessary scale up and characterization effort.

Structure

The structural designer has the fundamental task of designing an optimum structure to acceptable minimum margins of safety commensurate with man rating the NASP. To do that requires that:

1) The materials to be used must be fully characterized from material reasonably close to or in production, not from small laboratory samples.

2) The complete operating environment must be reasonably known.

3) The analysis methodology to determine external loads and derive therefrom internal loads must be available, verifiable, accurate and reasonably efficient.

4) The design can be verified through adequate ground and flight test.

Because of the uncertainties noted in earlier sections in aerodynamic loads and heating, materials availability, precision of computation and lack of ground test facilities to replicate thermal and structural flight loads, the current ability to meet the structural designers requirements are marginal to non existent.

To achieve the NASP performance goals, the vehicle structural weight fraction will have to be twenty five to thirty per cent less than the Shuttle.

In most conventional aircraft the prime loads are aeroelastic. Environmental loads (thermal, acoustic, dynamic response) may be critical locally, but are not usually coincident with the critical aero loads and are normally analyzed as separate design conditions. But for the NASP the loading is aero thermal elastic acoustic and is coincident at the critical design conditions. Achieving the required structural mass fraction in the face of existing computational capability and uncertainties in the load and material data bases is problematic.

Effort must also be directed at fabrication methods for the new materials. Fastening poses a particular problem because some of the materials demonstrate extreme brittleness in certain temperature ranges, as well as a negative coefficient of thermal expansion.

Because of the lack of structural test facilities, adequate instrumentation with real time data transmission will be a flight safety requirement. Transmission through the plasma sheath which will envelope the vehicle at the higher Mach numbers presents a severe challenge.

The Task Force believes it would be prudent to establish technical milestones to develop the data bases required for structural design with acceptable tolerances and refine analytic methods. These milestones should be accomplished before proceeding with detailed design.

Controls

The National Aerospace Plane (NASP) Program has some of the most demanding design problems of any flight vehicle development program to date. The extent of coupling between the NASP control system and the vehicle airframe/propulsion system requires that they evolve simultaneously. The degree of uncertainty regarding available component technology and associated performance complicates the task of control system development and mandates early identification of principal design sensitivities and trades. Also, uncertainties regarding environment characteristics demand development of control strategies which maximize available adaptability and authority and minimize the adverse influence of hostile environment effects. All these considerations are as applicable for development and testing of a research vehicle as for an operational system. Less specific knowledge of the environment during early test flights may actually demand more control system adaptability.

To successfully develop the NASP control system, it is necessary to identify the most significant design concerns involving vehicle control and to initiate a technology development plan capable of addressing the issues. The effort should occur early enough to influence overall vehicle design in a manner that will assure successful vehicle and control system integration.

The issues which must be addressed include:

- attitude control (with accuracy to, perhaps, 0.1 degrees while the vehicle undergoes thermoelastic deformation).
- trajectory optimization
- propulsion optimization, including algorithms and sensors to control both throttle and variable geometry
- stability and control with large uncertainties
- sensors and instruments for the high Mach number regime
- handling qualities
- abort scenarios
- integrated guidance and control system

Most of these issues are vehicle design dependent. Therefore, a satisfactory vehicle design cannot be developed independent of the on board control system.

The Task Force found the technology road map developed by the flight systems working group has the elements described to provide an adequate understanding and effective development program for NASP. However, it is not being adequately funded. Controls and flight dynamics optimizations can relieve environments inimical to successful realization of key but very uncertain technologies involved with structures, structural materials, and propulsion systems, for instance. At the levels of program funding currently applied to the flight systems technologies, it is doubtful that these optimizations can be examined adequately and that alternatives will be available on a schedule compatible with the air frame/ propulsion developments. As a rough example of the disparity, it now appears that approximately 1 to 2% of the currently identified funding in the program is intended to cover this functional area. It is our experience for aerospace vehicles that avionics represent a much larger per cent of the total value of the vehicle. It will not be possible to reach the goals of the program at the level of funding now allocated to the controls and guidance functions.

Computational Fluid Dynamics

The preceding sections highlighted the question of the accuracy of the CFD codes. Much progress has been made in this discipline in recent years, but there is still a long way to go, particularly at the higher Mach numbers. The Task Force found that the CFD team had a realistic view of the limitations of their calculations, and a

well thought out plan for improved capability. However the program must guard against exaggerated claims about the efficacy of CFD as a substitute for wind tunnel or flight test data. If expectations are raised too high too soon, CFD could be put in the unfortunate position of losing credibility when, in fact, the community will have been making significant advances that should be recognized as such.

Today, two dimensional calculations are good; three dimensional capability is evolving. But even where the codes are good, they must be calibrated and validated from real world data. This arises from the need to insert certain empirical data such as the onset and length of the transition to turbulence and turbulence characteristic length. In Mach and Reynolds number regimes where no data, or incomplete data exist, the calculations will be precise but not necessarily accurate. The calculations are also strained when all relevant parameters, such as combustion kinetics, must be included.

CFD is essential to the NASP program. But it must be recognized that the accuracy attainable over the next few years will fall short of what is required for vehicle design and performance estimates.

Another potential problem is the computational requirements. Some of the codes take a long time on a powerful computer to converge, on the order of 24 hours. It is likely that several thousand such runs will be required to design the vehicle. Measures should be taken to assure that computer resources will be available, as well as effort directed at reducing execution time.

CONTRACTOR RESPONSE

The Task Force met with all eight contractors to review their technology efforts and explore their views of the issues critical to the program. Each meeting lasted approximately three hours, thirty minutes of which was a private session with the Task Force.

The following paragraphs summarize the observations and concerns common to most of the eight discussions. (The meetings occurred in late June, 1987, and reflect perceptions of the program at that time).

- The NASP is truly an experimental vehicle, not a prototype of a space booster or a hypersonic cruise airplane. It will be a success if it achieves high Mach number flight. Design iterations may well be required before orbital insertion is achieved.

- There is little confidence that the aero-breathing propulsion alone will be sufficient to gain orbit in the early phases of the program.

- There are approaches to compensate for the uncertainties in the aero-breathing propulsion, e.g. rockets to help achieve orbital velocity and/or very low drag designs.

- Uncertainties in aerodynamic data, particularly as they affect temperature estimates and propulsion performance, drive the vehicle configuration. Estimates of gross take off weight range

from about 300,000 pounds to 500,000 pounds. Confidence in these numbers is not yet high.

- Materials development and manufacturability pace the program. Materials characterization and scale up for production are not adequately funded. The time required for these efforts is too long to support the (then) existing Phase 3 schedule.

- The Technology Maturation Program is a good start, but is not sufficiently focused on the requirements of the most probable configurations. Although information exchange is good, stronger contractor participation in defining the program might help.

- Teaming of airframe and engine contractors would be welcomed. Coordination among several contractors presents a significant burden.

- A variable Mach number wind tunnel is required.

- The (then) scheduled Phase 3 schedule was not realistic.

- The (then) planned Phase 3 funding was not realistic.

The Task Force found these thoughts congruent with our own observations.

CONCLUSIONS

Based on our review of the NASP program which extended over a six month period, the Task Force reached the following conclusions:

1) The NASP program goals are valid. The technologies which NASP will develop will make significant contributions to our national military and space capabilities and our civilian economy as we enter the twenty first century.

2) The NASP is truly an X-Vehicle. Expectations of short term operational utility should not be raised.

3) Technical uncertainties in all critical disciplines must be narrowed before detailed design is initiated. Uncertainties are too large to estimate with any degree of accuracy the cost, schedule or performance which can be achieved in Phase 3.

4) Readjust the program funding priorities to favor the Technology Maturation effort, while retaining sufficient effort in definition airframe and propulsion configuration to provide focus for the technology work.

5) An experimental program of this type should be event driven, not schedule driven. Demonstration of quantitative technical milestones in all critical disciplines should pace the program.

6) Hypersonic flight will be important to the United States in the decades ahead. Adequate national ground test facilities must ultimately be provided.

RECOMMENDATIONS

These findings lead the Task Force to make the following recommendations:

1) Maintain the present program objectives. A manned hypersonic vehicle, with the potential of demonstrating a single stage to orbit and extended hypersonic cruise, provides challenging focus for the development of the critical technologies.

2) Complete a rigorous risk identification and closure analysis. Identify the funding, schedule and technical resources required to reduce the risks to a level commensurate with the experimental nature of the vehicle.

3) Establish a quantitative set of technical milestones in all critical disciplines which must be demonstrated before entering Phase 3.

4) In anticipation of the results of the risk closure analysis, begin now to replan the program by making the start of Phase 3 dependent upon demonstration of the technical milestones and by significantly increasing the portion of program funding devoted to maturing the technology.

5) Emphasize the experimental nature of the program. Once flight test begins, several design iterations may be expected before orbital insertion is achieved. Program planning should anticipate the resources which will be required.

6) Proceed with the planned down select for both engine and airframe contractors. To reduce the number of design combinations which must be considered, team airframe and engine contractors at an early date.

7) Focus the Technology Maturation Program to support the selected configurations. Strengthen the contractor's input to the definition of Technology Maturation Tasks.

8) Develop a plan to man rate the air breathing engine. Investigate the addition of a variable Mach number nozzle to the Aeropropulsion Systems Test Facility tunnel at Arnold Engineering Development Center to provide a ground test propulsion facility.

9) NASA and DoD should study the possibilities for national hypersonic test facilities for aero-thermal, propulsion and structures.

10) Materials availability will be a pacing item for the program. Develop a plan to scale up to production quantities for the materials selected and to provide characterization data for structural design.

11) Fund the flight control system technology road map tasks to a level commensurate with the importance of integrated flight controls to the program.

12) Continue strong support to CFD validation and the narrowing of the uncertainty in location of the point of transition to turbulence.

13) Identify the computational resources which will be required to support the detailed design phases of the NASP.

We have refrained from making detailed recommendations in each of the technology areas in the belief that the risk closure analysis recommended above will provide the definitive plan required for the program.

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THE UNDER SECRETARY OF DEFENSE

WASHINGTON, DC 20301

12 DEC 1985

ACQUISITION

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference--Defense Science Board Task Force on the National Aerospace Plane (NASP) Program

You are requested to organize a Defense Science Board Task Force to review the National Aerospace Plane (NASP) concept, technical basis, program content and missions.

The NASP is a joint Department of Defense/National Aeronautics and Space Administration research program directed towards an entire new generation of aerospace vehicles. The specific objective of the program is to develop, and then demonstrate in an experimental flight vehicle, the technology which will enable the Nation to develop both military and civil aircraft capable of sustained hypersonic flight within the atmosphere and space launch vehicles capable of delivering payloads into orbit at greatly reduced costs. The NASP is envisioned as an airbreathing, liquid hydrogen-fueled, horizontal takeoff-and-landing vehicle with single-stage-to-orbit capability.

During the past decade substantial progress has been made in hypersonic airbreathing propulsion, advanced materials and structures, and computational technologies leading to a consensus that hypersonic, transatmospheric vehicles may be technically feasible around the turn of the century. Proof of that feasibility will rest on the development of an adequate data base supporting the individual and integrated disciplines of propulsion, structures, avionics and aerodynamics. The NASP Program is designed to provide that data.

During the next thirty-six months a joint DOD/NASA team led by the Defense Advanced Research Projects Agency will be conducting the Technology Development and Assessment Phase of the Program, Phase II. The principal challenge facing the team is the integration of the individual technology investigations with the major contracted efforts in propulsion module design and fabrication and in vehicle design and component development.

The issues that the Task Force should address include, but are not limited to:

1. The overall sufficiency of the Program's Technology Maturation Plan (TMP).

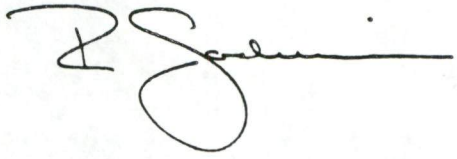
2. The degree to which the overall program effort adequately supports the achievement of the technical objectives of Phase II of the NASP Program.

3. The need for additional technology development efforts which would extend beyond the time frame of the Phase II program.

4. The adequacy and viability of criteria to be satisfied in order to justify a decision to proceed to Phase III of the NASP program.

5. The range of missions for the NASP and variants to the degree required to identify technology issues. New capabilities provided by the NASP offer the potential for new mission possibilities.

The Assistant Secretary of Defense (Research and Technology)/Director, DARPA, Dr. R. C. Duncan, will sponsor the Task Force and Dr. Joseph Shea will serve as Chairman. Dr. Craig Fields will be the Executive Secretary, and Colonel D. Fang, USA, will be the DSB Secretariat Representative. It is not anticipated that your inquiry will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code.



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NATIONAL AEROSPACE PLANE (NASP)

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APPENDIX A

Aerodynamics

Configuration

The configuration selected for the NASP Demonstration prototype will not necessarily represent any particular application and will certainly not represent the optimum configuration for any of the several objective applications stated for the program:

1) Low-cost payload space launch vehicle

2) Hypersonic transport

3) Quick-reaction orbit and return military vehicle

Therefore the NASP will be an experimental aircraft to explore new regimes of flight especially with respect to air-breathing propulsion and its interactions with the airflow around the vehicle.

As an aerodynamic test vehicle, the NASP will be analogous to the X-1, X-2 and X-15 which pushed manned flight through the speed of sound and up to Mach 6 and not analogous to the X-29 (forward-swept wing) which demonstrated a specific aircraft configuration and design concept. On the other hand the test of the scram jet propulsion system of the NASP is more nearly a design/configuration related prototype of possible future operational system hardware.

The main problem in the design of aircraft for sustained flight at hypersonic speed up to orbital or near orbital velocities (Mach 20) lies in providing a propulsion system capable of giving sufficient

thrust per unit of engine weight and volume and sufficiently high specific impulse, I_{sp}, to meet the desired range (semi-global) for a transport, or Δv, (30-35,000 f.p.s.) for an orbital vehicle, with a vehicle of minimal lift-off weight. With (non-nuclear) rocket propulsion, the highest achieved lox-hydrogen I_{sp} is 460 and in terms of theoretical and practical limits this is considered not to be capable of much extension with conventional fuels and oxidizers. In order to achieve high thrust (ruling out such systems such as electric and ionic propulsion) I_{sp}'s in the range of 1000-3000 which are needed to meet the most demanding of the mission objectives over the flight regimes up to Mach 25+ in a single stage vehicle, air-breathing propulsion is called for.

Conventional turbojet, turbofan, ram jet suffer excessive inlet losses as Mach numbers of 6 are approached and also have problems in heat addition to air already at extremely high--near stagnation--temperatures. Thus, the propulsion system of choice for high hypersonic flight conditions is the supersonic combustion ram jet in which the flow remains supersonic in its passage through the propulsion system.

Given the scram jet propulsion installation and integration, the air vehicle configurations being favored are relatively conventional and in many ways simply an extension of the well known body-delta wing configuration used in many supersonic designs.

Boundary Layer Transition

A major aerodynamic problem in design and performance assessment of the NASP is that of determining the location of the region of

transition of the boundary layer from laminar to turbulent flow. Transition location has profound effects not only on the drag and other aerodynamic forces on the air vehicle but also on the engine inlet flow which can have major impact on propulsive efficiency. The scram jet thrust is particularly sensitive to inlet kinetic energy efficiency. Also heat transfer rate rises severly in transition from laminar to turbulent flow and thereby also affects the structure and the fuel flow rates required for structural cooling, thereby having marked effects on vehicle weight.

For complex geometries, the transition point location is often difficult to pin down even in subsonic and supersonic flow, but a vast quantity of empirical data and approximate and semi-empirical analysis methods exist. Experienced aerodynamicists using these data and methods can usually make valid judgments for design in lower speed flows. For the hypersonic Mach number ranges, most important for the NASP, there is not a substantial data base and only partly validated analysis methodology. In view of the potential impact of uncertainties in the transition location, this is by far the single area of greatest technical risk in the aerodynamics of the NASP program.

Propulsion System Integration

The supersonic combustion ram jet by its very nature requires an unprecedented degree of integration of the aerodynamic design of the airframe with the engine installation. Thus, the entire nose of the aircraft forms part of the inlet and the entire aft end of aircraft can behave, in effect, as part of the exhaust nozzle. This is well recognized by the program managers and the contractors

in the NASP program and a high degree of overlap between the analysis, design, and test activities of airframe and engine contractors is being maintained. Nevertheless the problems of integration are formidable and many critical issues in aerodynamics and propulsion technology remain to be resolved.

If some of the uncertainties bearing on the thrust of the engine and the drag of the airframe cannot be sufficiently narrowed, there is the possibility that for any given vehicle a "hypersonic speed-barrier" (much like the "sonic barrier" of the immediate post-war period) may be encountered.

Experimental Facilities

The problems of estimating such a fundamental performance measure as the thrust versus drag at high Mach numbers are compounded by two main factors. One is the high degree of interaction of the airframe and propulsion system and the other is the lack of ground test facilities capable of simultaneously simulating all of the important parameters of hypersonic flight particularly in the M=10 to M=25 range. Computational fluid dynamics (CFD) is being heavily relied on in the program to resolve many of the aerodynamics and propulsion problems in this Mach number range. However, validation of the empirical components (e.g., turbulence models in "real" gas flow) for M=10-25 with true stagnation enthalpy and full scale Reynolds number cannot be accomplished in any existing or proposed ground test facility. One or several of these parameters can be simulated separately in a number of facilities but there is currently no way to validate methods for combining such partial simulation results to represent the true flight environment.

Flight test data which are available for validating CFD codes from the Shuttle and ballistic missile reentry data, as well as from the ASSET and PRIME flight test programs, probably represent the closest simulation conditions for combined parameter sets. For various reasons, mainly differing flight corridors, fundamental configuration differences, and scale, none of these flight data completely represent some of the most critical high Mach number points for NASP flight profiles. If, after more detailed accumulation and analyses of data from ground facilities in relation to the existing flight data, significant gaps in understanding and discrepancies are found to exist, and if these bear on particular aerodynamics/propulsion performance sensitivities of the NASP vehicle, serious consideration should be given to undertaking additional unmanned model flight tests in support of the NASP program. Particular attention should be given to problems of engine inlets and exhaust flow interactions with the airframe since none of the previous flight tests in the high hypersonic regime (Shuttle, ASSET, PRIME, and RV's) involved air-breathing propulsion specific parameters peculiar to inlets and exhausts.

APPENDIX B

NASP Propulsion

Summary

The purpose of this appendix is to describe some of the critical issues involved in the design and development of NASP propulsion and then, keeping these issues in mind, to comment on the technology maturation program which is to provide the data and tools required for their resolution.

Our examination of the propulsion technology maturation program indicates that it is not likely to have a timely influence on the presently scheduled NASP design and development process. To decrease the development risks, we recommend that greater emphasis be placed on the propulsion technology maturation program, giving serious consideration to the possible need for fully integrated engine tests in a variable Mach number wind tunnel.

Design and Development Issues

A) Low Speed Propulsion

NASP is conceived as propelled over most of its flight regime by a ram jet and scram jet which are to accelerate it to orbital velocities. Neither ram jets, nor scram jets are capable of producing any thrust at standstill. For this reason the NASP propulsion must involve, in addition to the ram jet and scram jet, one other propulsive system capable of providing the take-off thrust and acceleration through the high drag, transonic region. For this purpose conventional

turbojets, rockets, air-turborockets, and ejector-rockets are are all being considered. Of these only the turbojets and rockets are ready for use, the others remain to be developed.

Regardless of which will eventually be chosen, it is clear that the selected system will, by adding weight, reduce the payload that would be obtainable if such a system would not be necessary. Therefore one important criterion for selection must be minimum additional weight. Furthermore this additional, low-speed system will have to be integrated into the ram jet and scram jet configurations with a minimum detriment to their performance and, also, when inactive, will have to be protected from the effects of the very high heat generated within the engine. The capability to design a detriment-free integration into the ram jet and scram jet configurations is, at present, not well in hand. This because the assessment of the flow perturbations created within the ram jet and scram jet by the low speed system is likely to be difficult to analyze and may require very many, lengthy, three-dimensional fluid dynamics computations and/or extensive developmental testing.

B) Ram Jet Propulsion

All of the options for a low speed propulsion system discussed above become less efficient than the ram jet at about Mach number 3. Indeed for higher speeds some require special devices (such as inlet air pre-coolers) to operate at all. But the scram jet becomes more efficient than the ram jet somewhere between Mach numbers 6 and 8. For this reason the ram jet

serves as an intermediate propulsion system during the transition between the low speed and the scram jet propulsion. While the ram jet is very similar to the scram jet, and should relatively easily fit within the scram jet envelope, its conversion to supersonic burning requires a solution to many difficult design and development problems for which, at present, relevant design data is unavailable. For example during such a conversion, while the vehicle continues to accelerate, a normal shock must be forced to pass through the diffuser, combustor and nozzle without flameout or loss of thrust. The data relevant to the understanding of the intricacies and control of such a process is currently lacking and probably will have to be obtained in a variable Mach number wind tunnel. Similar data is also needed for the conversion from low speed to ram jet operation.

C) Scram Jet Propulsion

1) Avoidance of Strong Shocks

In the scram jet one must not allow any strong shocks to form because such shocks, when occurring during high flight speeds, would severely affect its performance. The avoidance of strong shocks anywhere inside the engine is difficult to accomplish because, for efficient heat addition, the fuel must be homogeneously distributed by injection within the air stream and this may require insertion of nozzles, flame holders, etc. which by blocking the flow, may trigger the unwanted shocks. Such unwanted shocks may also be created inside the diffuser, particularly at off-design conditions,

when the shock configuration does not properly match the engine inlet contours usually triggering undesirable, strong, local, adverse pressure gradients which may separate the boundary layer. In addition, as already mentioned, the integration of the low-speed and intermediate propulsion systems with the scram jet may result in a configuration conducive to the creation of strong shocks. Since such shocks may also be caused by the interactions between engine components, and the external flow, it is important to have a detailed understanding of three-dimensional flow at all times inside and outside the complete engine. Such understanding is presently lacking.

2) Regenerative Cooling

The very high speeds at which NASP will operate within the atmosphere are capable of creating very high wall temperatures at which materials suitable for NASP construction lose their structural integrity. To prevent this from happening it is proposed to cool critical (or selected) external and internal NASP surfaces regeneratively, utilizing the very high heat capacity of liquid hydrogen. To design such a system requires a good understanding of heat transfer processes both outside and inside the engine. However the estimation of the external heat transfer at high speeds is hampered by inadequate knowledge of boundary layer transition and the estimate of internal heat transfer is similarly hampered by inadequate understanding of supersonic burning. In addition, since the ram jet and scram jet must continuously vary

their configurations with the every increasing flight velocity, the design of the regenerative cooling for such continuously adjustable surfaces will be very complex. Complex designs need thorough experimental verification. Thus fundamental research into issues such as shock-on-shock or corner heat transfer and extensive developmental testing will be required to produce a satisfactory design of the regenerative cooling system.

3) Supersonic Combustion

The very high heating value of hydrogen (51570 Btu./lb. of fuel) and its high cooling capacity make it a very appropriate fuel for scram jets. However very little is presently known about the process of its supersonic combustion at very high velocities. For example one important question which is yet to be answered before the design and development of NASP can be undertaken is: can the expected heat addition to the air stream be carried out in a reasonable combustion chamber length? It is possible that at the very high velocities existing in the combustor some of the reactions will not be completed within the combustion chamber, or even in the nozzle, thus adding less heat to the air flow than expected and producing less than expected performance. Another important question which remains to be answered concerns the stability of the combustion process. Fundamental research into these complex issues has been advancing very slowly because of a lack of appropriate experimental facilities and because of

severe complications that combustion kinetics introduce into the fluid dynamics equations.

D) Terminal Propulsion

For scram jets at high velocities (>18000 ft/sec.) the specific impulse tends to decrease appreciably with increasing flight speed and the drag to thrust ratio tends to increase. Because of this effect scram jets ability to accelerate at high velocities becomes marginal and orbital injection by use of inertial forces instead of thrust is usually not feasible.

To improve the acceleration at flight velocities beyond, say, 18000 ft per second, it is often proposed to add rocket propulsion for the final boost from atmosphere to orbit (a rocket must also be used for deboost from orbit). This of course reduces the effective specific impulse, increases vehicle "dry" weight and, if not done judiciously, may also increase external drag (all along the trajectory and not just at high velocities) or grossly complicate scram jet's internal design and impose additional penalties on its performance.

E) The Testing Problem

1) Low Speed and Supersonic Testing

As already discussed, the development of air-breathing orbital boosters will require a lot more information than is currently

available. Up to Mach 8 such information will have to be obtained in suitably modified ground facilities to allow not only component, but, also, completely integrated engine testing. Such integrated engine testing will be needed to provide the data for design of engine controls and also to verify overall accelerating engine performance. Indeed, it would be desirable to conduct such accelerating engine tests in a suitably modified, variable Mach number, wind tunnel.

2) Hypersonic Testing

At high (>10) Mach numbers even the barest design data required for the development of scram jet engines is at best meager, or completely lacking. Such design data is essential to assure the validity of analytical performance computations. In addition, scram jet engines will have to be fully aerothermodynamically integrated, the details of their mixing and combustion processes well understood, their heat transfer and cooling well manageable, their structural integrity assured, unsteady behavior under control, etc., before they will be considered ready to use. This means that to acquire the needed data in ground facilities one will need tunnels which will simulate not only the Reynolds and Prandtl numbers but also the total enthalpy and total pressure for adequate periods of test time. But such tunnels require tremendous amounts of power, and therefore are not likely ever to be built.

For these reasons the development of scram jet engines

able to operate at Mach >10 must heavily depend on computational fluid dynamics (external and internal), computational aerothermophysics and computational chemistry and chemical kinetics. Although the state of the art of these techniques is, as yet, not sufficiently well developed to depend on them for extensive support of such a development program, great advances in this field are being made very rapidly and we are already able to solve numerically three dimensional, unsteady, compressible laminar and turbulent (but averaged in the Reynolds manner and containing some empirical relations) Navier-Stokes equations with strong viscous-inviscid interaction.

Even the most ardent advocates of computational methods recognize that the risk in the development of engines is so great that the use of proven verification methods by means of tests cannot be abandoned. Since ground facilities for meaningful complete engine testing will not be available, much more emphasis will have to be put on restricted simulations of individual component behavior by limiting test parameters, as appropriate. But even these techniques, though not entirely satisfactory, will probably require new and expensive high speed test facilities.

Completely integrated scram jet engines will have to be tested in flight. But flight testing is inconvenient and often constrained by the ability to transmit large amounts of test data so that rarely is it able to provide as much detailed information as may be gathered on the ground. Furthermore

for scram jets, which will have to be boosted to, say, Mach 7, and will have extensive flight range, the logistics of the testing operations will be difficult and the testing itself very expensive.

Comments On Technology Maturation Program

A) Introduction

As is well known the scope of the air-breathing hypersonic propulsion research has been very limited since the mid-sixties. To fill this void, the propulsion technology maturation program tries to resolve the critical issues and to provide the data base and techniques which will be needed for the design and development of NASP propulsion. The comments and recommendations which we are making here resulted from examination of: (i) the Technology Maturation Plan (Version "A"- December 1986), (ii) the Technology Maturation Task Plans for Propulsion and Computational Fluid Dynamics, (iii) presentations which we received from NASA on February 23-24, 1987 in Cleveland, (iv) presentations by industrial contractors on June 23-25, 1987 in Washington and (v) from a number of discussions held between the Task Force's members.

The Technology Maturation efforts are divided into two overlapping groups: low and high speed propulsion. To more clearly see the relation between the comments and the program we will use the same division in our discussion even if this will cause some repetition.

B) Low Speed Propulsion

1) General Comments

This part of the maturation program addresses critical technology issues from takeoff to ram jet-scram jet transition. Part of the effort is concentrated on the development and verification of computational codes for aerodynamic components such as inlets and nozzles. Some of the effort is also devoted to special system experiments, diffuser and combustor development, thermal management, dynamic modeling, controls and development of suitable instrumentation. Many of the so obtained results should be useful regardless of which of the possible low-speed systems is finally chosen.

2) Combustion Instability

Inlet buzz, inlet unstart and other types of unsteady phenomena are often triggered by the instabilities of the combustion process and for this reason a thorough understanding of this process is essential even for subsonic combustion. The technology maturation program does have tasks which are oriented towards code development and verification for subsonic combustion but none of these seem to provide design data on the effect of, say,

unconventional fuel injector shapes (such as may be needed for supersonic burning) on combustion stability. An expansion of effort in this area is recommended.

3) Verification Of Dynamic Modeling

Some of the most difficult problems likely to be encountered by the developers of the propulsion system are those related to internal engine dynamics. To insure that such dynamic behavior does not lead to a loss of thrust, it will have to be sensed and controlled. The Technology Maturation Program does have some tasks devoted to propulsion system dynamic modeling (which is essential to such a control) but these do not seem to be directed at the special problems which will occur during operational transition from the low-speed system to the ram jet and again from the ram jet to the scram jet. Furthermore the codes used for this modeling will be verified in individual component tests and this is hardly adequate. For this reason we recommend that serious consideration be given to the verification of dynamic modeling in extensive ground testing of a complete engine during the periods of conversion from the system providing low-speed propulsion to the ram jet, and from the ram jet to the scram jet. If at all possible such tests should be carried out in a variable Mach number tunnel.

5) Global Performance Codes

The CFD codes capable of handling the complete engine (that is integrated diffuser, combustor and nozzle codes) which are being developed by SAI for the engine contractors are currently two-dimensional. These codes are used to obtain estimates of global engine performance parameters such as kinetic energy efficiency, thrust coefficient, etc. But two-dimensional codes are incapable of handling three-dimensional effects caused by, say, the side walls between adjacent engine passages or by the angles of attack and yaw. For this reason the so estimated engine performance may be in considerable error. Three-dimensional versions of these integrated codes will not be ready for some time.

C) High Speed Propulsion

1) General Comments

This part of the technology maturation program pertains to propulsion issues over a wide range of operating speeds (from M=3.5 to orbital insertion). By covering the range from M=3.5 the program wisely overlaps some of the issues common to ram jets and scram jets thus attempting to find the best conditions for transfer from one to the other. The effort is focused on providing basic data and design methodology for inlets, combustors and nozzles for

the very high speeds at which they will operate. For the Mach 5-8 range two engine test facilities of sufficient scale are being constructed to conduct and support the prime engine contractors' tests. These facilities should be able to furnish much of required overall (but not necessarily basic design) engine data up to Mach 8. However for higher speeds the ground testing is very limited by the conditions that can be duplicated and by the testing time. Thus for higher speeds, ground testing, at best, can offer but meager and incomplete bits of the required information. Therefore much of the basic data for high speed propulsion will have to be obtained by use of computer simulations, many of which cannot, and will not, be fully validated.

2) Boundary Layer Transition

Our present knowledge of transition between the laminar and turbulent boundary layers at hypersonic speeds is very meager. Though some empirical rules exist, their validity has not been satisfactorily tested. But the inlet "cone" for the very high speed scram jet will have to be very slender and long thus causing substantial growth of the boundary layer possibly leading to the laminar-turbulent transition. Such a transition can drastically affect the geometry and heat protection of scram jet inlets and its thorough understanding is therefore

essential to the design and development process. The present program lacks sufficient efforts in this area. We recommend therefore a much greater emphasis on the analytical and experimental studies of transition at high hypersonic speeds including the effects of pressure gradients, real gas composition, cooled walls and three-dimensionality of the flow.

3) Turbulent CFD Codes At High Speed

The CFD codes for turbulent flow consist of Navier-Stokes equations time averaged in the Reynold's manner. At present, to solve such equations it is necessary to use empirical relations instead of the so called Reynold's stresses. These relations need to be validated at the very high velocities. Since the CFD codes will be crucial to the design of NASP we recommend increased emphasis on the validation of CFD codes for turbulent flow at high speeds. Such experimental validation should encompass the effects of pressure gradients, real gas composition, cooled walls, and three-dimensional flow.

4) Supersonic Combustion

As previously explained, the essence of scram jet's superiority over the ram jet lies in the maintenance of combustion at supersonic speeds.

This makes the protection of combustor components very difficult and also complicates ignition, flameholding and fuel-air mixing, especially since the flow must remain essentially shockless throughout the engine. Film cooling may protect the wall and reduce friction but is not conducive to rapid mixing. The supersonic combustion technology maturation program concentrates on combined analytical and some limited experimental studies but the results will not be available until late in FY 1989.

Furthermore none of the effort seems to be directed towards the studies of supersonic combustion instabilities which can be so important to engine performance and are not at all understood. Because of this we recommend that the technology maturation program increase its emphasis on studies of combustion and combustion instabilities at high speeds.

5) SAI Combustion Kinetics Codes

The combustion kinetics codes developed by SAI use a large number of chemical reactions but, to avoid lengthy computer runs, these chemical reactions are cleverly uncoupled from the corresponding conservation equations. This procedure has presumably been used to describe nozzle flows in rockets with a considerable degree of success. Nevertheless it is not clear whether such uncoupling will also be appropriate for the scram jet combustion because

the conditions in the scram jet combustion chamber are quite different from those in the rocket. Careful validation of this procedure is therefore essential before application to engine design.

6) Variation Of Engine Configuration

Single stage to orbit requires continuous thrusting to ever higher velocities. Ram jets and scram jets can efficiently provide such thrusting only by changing their physical configuration. However these changes may trigger undesirable transient behavior, and strong shocks which may result in a loss of thrust. The technology maturation program does not seem to have any elements which either analytically or experimentally address this very important issue at high speeds and we recommend that the program be appropriately reformulated to include it.

7) Off-Design Performance

Ideally, the NASP should be powered by a regeneratively cooled engine with a continuously varying configuration. However, stepwise configuration changes are likely to be much easier to achieve. But such stepwise changes will necessitate compromising engine performance between the changes. To facilitate such an approach off-design engine performance at high speeds will have to be well understood

and therefore we recommend the inclusion of the study of high speed engine performance at off-design conditions into the technology maturation program.

D) Engine-Airframe Integration

The propulsion technology maturation program concentrates on problems peculiar to the so called basic configuration. This configuration is more suitable for a cruising vehicle than a booster. Cruising vehicles resemble airplanes while boosters resemble flying engines. For this reason the engine-airframe integration problems of boosters will be quite different than those of cruise vehicles and the present concentration of the propulsion technology maturation program on the problems of the basic configuration may be somewhat misdirected. Indeed other engine configurations more suitable to NASP's mission as a single stage orbital booster, are presently emerging. We recommend that the propulsion technology maturation program be appropriately modified to also pursue the issues involved in these new configurations.

APPENDIX C

Materials

The present program Technology Maturation Program in materials consists of seven funded tasks in the areas of Advanced Metal Matrix Composites, Rapid Solidification Titanium, Titanium Composites, Exothermic Dispersion Processes, Carbon-Carbon Composites, Ceramic Composites, and Coatings which were discussed, and a series of contractor funded efforts which were not covered.

The program is well planned and well coordinated among the Government and Industry personnel involved. The goals are ambitious but not yet tightly defined, not surprising since the temperature-strength properties which will ultimately be achieved by these materials will determine where they can be used and the degree of active cooling which will be required.

Based upon preliminary design and performance estimates, surface temperatures for the NASP range from in excess of 3000^{o}F to less than 1200^{o}F. Some 15% of the wetted area will be exposed to temperatures above 2600^{o}F where carbon-carbon and ablation materials, or active cooling, will be required, 20% will see temperatures between 1800^{o}F and 2200^{o}F, where ceramic composites show promise, about 50% will reach between 1200^{o}F and 1800^{o}F, where titanium aluminides may be used. Titanium can satisfy the remaining 15% of the structural needs.

Rapid Solidification Titanium compounds were said to be the baseline for a NASP configuration. Data presented showed that Ti_3A_L alloys begin to lose strength at 1000_oF, Ti A_L alloys hold strength to 1500_oF, but are extremely brittle at temperatures below 1000_oF. "Designer" microstructures hold promise of improvement, but control of desired particle sizes and dispersions are challenges. Effects of exposure to hydrogen and dissociated oxygen are severe problems. The XD technology may contribute. The material is promising. Forming, fabricating and fastening needs effort.

Titanium based Metal Matrix Composites also show promise. Reactivity between fibre and matrix requires coating system development. Concerns exist about hydride formation at high temperatures and pressures.

Advanced Metal Matrix Composites appear to have very high payoff but are also extremely high risk because investment only started last year.

There is an existing data base on Carbon-Carbon materials, which show promise of utility up to temperatures above 3000^oC. However the gauges required for NASP are much thinner than those used on the Shuttle. The material is very brittle, and exhibits a negative temperature coefficient at lower temperatures ($<1000^o$).

Problems exist with coatings and coating life under oxygen exposure. Fastening will be a challenge. Fabrication cycle is complex, requiring up to six months to make a part.

Fiber reinforced ceramics have the potential of retaining strength up to temperatures between 2500°F and 3000°F. Material options are still being explored. Issues include reactivity with the fibers, fiber coating, fiber degradation at temperature, porosity and cracking during fabrication. Joints, attachments and interfaces are just being addressed.

Coatings will be essential for these materials. They will be exposed to high temperature, high enthalpy, dissociated gasses with high temperature gradients. Coatings tend to be catalytic, which may not be the best approach. Lifetime is also a concern.

Embrittlement from exposure to high temperature, high pressure hydrogen is a problem which will pervade the NASP materials. It is not well understood. The program is now raising contractor awareness of the problem, but has not begun an active program to seek a solution.

The leader of the materials technology team observed that normal materials development takes time - twelve to fifteen years. The NASP accelerated schedule allows only five years.

This disparity was rationalized on the basis that NASP is an experimental vehicle with a relatively short service life, MIL Handbook data properties were not required, and the progam was building off existing technology.

The other side of that coin is that NASP will be a high visibility, manned program in which the technological competence of the United States will be on the line to be judged not just by our own

population, but by the world. If that standard is used, knowledge of material properties at commitment to configuration needs to be almost as good as the MIL-Handbook would require.

The risk in the materials maturation program was summarized as "not a clear go or no-go," rather "how close will we come" and "how soon will we get there."

But "how close will we come" for a vehicle so finely tuned as the NASP is asking how far short of mission objectives will we fall. "How soon will we get there" is an euphuism for "how much will we miss the schedule" and "how much will the cost overrun be."

If the NASP design is based on RSR Titanium alloys and Titanium Metal Matrix materials the ongoing Technology Maturation program is sound, but may not provide necessary data by the presently scheduled date for commitment to configuration decision.

Data required are:

- materials properties
- materials-process compatibility
- damage tolerance
- environmental suitability
- fatigue, fracture and design allowables
- process scaleup

If the other materials discussed above are to be used, the program is grossly underfunded and unrealistic in schedule.

Overall it would appear that the program funding emphasis is out of balance. Too much money may be going into trying to define configuration before the basic data, on which the choice of configuration depends, has been developed.

APPENDIX D

Structures

Summary

A review of mission and specification requirements for the NASP, as related to a structural technology assessment, indicates a structural weight fraction 25-30% less than the current shuttle orbiter and a large increase in mission life.

For some of the missions, performance requirements may dictate higher maximum use temperatures and overall heat loads than seen in the shuttle. Maximum use temperature is probably the limiting factor on desired performance.

The structural designer then has the fundamental task of designing an optimum structures to knowledgeable minimum margins of safety commensurate with man-rating the NASP for flight.

The structural designers' requirements to do this are noted in the following:

1) The material to be used most should be fully characterized from production material (or reasonably close to) - not from small laboratory specimens.

2) The complete operating environment must be determinable and reasonably known.

3) The analysis methodology to determine external loads and therefrom internal loads must be available, verifiable, accurate, and reasonably efficient.

4) Verification of the preceding through adequate ground and subsequent flight tests.

Simply stated, the current ability to meet these structural designers' requirements is marginal-to-not-available. It is considered that Phase 3 cannot realistically be initiated (without excessive risk) until a satisfactory data base is available to the structural designer.

In consideration of all these factors, it is judged that Phase 3 should not be initiated until this required data base is available. The Technology Maturation program should be expanded to include material selection and facilitization as required to produce production size material for characterization and component development.

Material Characterization

The history of development of new materials and construction resulting therefrom indicates a time period of 10-13 years for adequate characterization and maturation of producible designs. While this can probably be accelerated somewhat given funding and manpower, there is no indication that this is happening at this time, nor is it credible to assume that it will be accomplished in the current schedule.

Material characterization is further exacerbated by the extreme thermal/acoustic environment imposed by the mission requirements. Accumulation of this data base is made more difficult because of the facility and instrumentation requirements to test at these temperature and acoustic levels.

A subset of the material characterization deals with methods of fastening - in itself a significant development item dependent upon availability of material.

It is considered that there is insufficient time as currently planned prior to initiation of Phase 3 to accomplish the required task of material characterization and factory facilitization to produce the material necessary for fabrication. It is strongly urged that the time and funding necessary to accomplish these tasks be provided.

Operational Environment and Loads

In most conventional aircraft the structural designer is concerned primarily with aeroelastic loads. Environmental loads (thermal, acoustic, dynamic response) may be critical locally, but are not usually coincident with the critical aero loads and are normally analyzed as separate design conditions.

In addition, the data base and correlation and validation through ground testing is generally well established. Man-rating the flight vehicle for structural integrity is then relatively straightforward.

Such is not the case for the NASP. The loading is aero thermal elastic-acoustic and is coincident at the critical design conditions. The external loading will have to be calculated through the usage of 3D CFD codes which are not yet developed. The uncertainties with respect to flow transition (laminar to turbulent), surface irregularities and potential large deflections caused by thermal gradients (lower to upper surface) combined with the inability to correlate

or validate CFD codes through ground testing make it very difficult to establish the accuracy of the external loading (and therefore, the internal loads and resulting strain levels). In addition, the flight path used to perform the mission has a significant effect on peak temperatures (variations in dynamic pressure and angle of attack). The ability to accurately control the flight path during the mission and the deviations therefrom introduces another variable in the external loading.

The designer is then faced with the dichotomy of attempting to minimize structural weight while considering the range of loading introduced by the uncertainties in the analysis methodology, flight path, surface irregularities, et al. The lack of any significant data base further exacerbates this problem.

The structure cannot be ground tested and man-rating the NASP for structural integrity will be difficult. Since there will be no static or flight test data available, margins of safety based only on allowable strains will not be sufficient. Other safety factors such as limiting material temperatures to values below maximum use temperature ($200^{o}F+$) must be considered. Development of the analysis methodology coupled with whatever correlation can be obtained from ground testing is a task which must be addressed.

Verification

Validation or correlation of structural and heat transfer codes can be accomplished to some extent up to Mach 10 in ground testing. No correlations of these codes above Mach 10 will be available until

flight testing into this regime. The need for adequate instrumentation with real time data transmission is therefore a flight safety requirement, if envelope expansion is made by a manned flight article.

Static testing of the complete vehicle cannot be accomplished in ground testing. Verification of structural integrity must therefore be generated from a sufficient quantity of component and element testing.

Requirements for certification of structure subjected to combined thermal and mechanical loads are not firm, and current high temperature test techniques and instrumentation are far from satisfactory. Both of these areas need resolution and improvement in order to solidify the component and element test data base.

Conclusion

The impact of structural efficiency on attaining the desired performance is significant and probably ranks equally with the propulsion system. Attainment of a very low structural weight fraction and the ability to operate at the highest maximum use temperatures through an extended life time are critical to success.

The ability of the structural designer to do this requires that the loads (external and internal) be known to a high degree of accuracy which leads to a requirement of a substantial data base on aero-thermal elastic-acoustic loads, comprehensive material characterization, and validated accurate structural and heat transfer codes.

The loading data base and CFD code validation (for Mach 10) will only come from reduction of substantial flight test data in these high Mach regimes. The accuracy of current structural and heat transfer codes is questionable and certainly they are not efficient tools for the structural designer. Required material characterization is not available or scheduled early enough.

To proceed into Phase 3 with this current status of information available to the structural designer is considered an unacceptable risk to program success and in fact could impose serious flight safety risks.

Comprehensive material characterization combined with component testing and improvements in accuracy and efficiency of analysis methodology combined with correlation through ground tests for Mach numbers up to 8-10 probably make the risk manageable by judicious use of design margins (temperature and strain), careful flight test planning and adequate real time data transmission flight instrumentation.

It is recommended that the Technology Maturation program be augmented to obtain adequate material characterization (limited production facilitization is a coincident requirement) and the required improvements in analysis methodology.

Whether the desired and/or required structural efficiency can be obtained with the margin requirement to cover the boundary of uncertainties in the loads is a moot point at present.

APPENDIX E

Control

Overview

The National Aerospace Plane (NASP) Program has some of the most demanding design problems of any flight vehicle development program to date. The extent of coupling between the NASP control system and the vehicle airframe/propulsion system requires that they evolve simultaneously. The degree of uncertainty regarding available component technology and associated performance complicates the task of control system development and mandates early identification of principal design sensitivities and trades. Also, uncertainties regarding environment characteristics demand development of control strategies which maximize available adaptability and authority and minimize the adverse influence of hostile environment effects. All of these considerations are as applicable for development and testing of a research vehicle as for an operational system. Less specific knowledge of the environment during early test flights may actually demand more control system adaptability.

To successfully develop the NASP control system, it is necessary to identify the most significant design concerns involving vehicle control and to initiate a technology development plan capable of addressing the issues. The effort should occur early enough to influence overall vehicle design in a manner that will assure successful vehicle and control system integration. The following material provides a review of the major issues, and summarizes a technology development road including identification of highest priority tasks.

Technology/Design Issues

Resolution of a wide range of issues will be required to successfully control the NASP. The following subsections (the order of which has no particular significance) detail the most serious concerns that are currently recognized. The highly coupled nature of vehicle design and control is apparent in the discussions.

A) Attitude Control Issue

The successful operation of the NASP propulsion system is coupled to the accuracy of attitude state knowledge and control, with the latter subject to effector capability uncertainty.

At high Mach numbers, the air-breathing engine performance will be very sensitive to the vehicle nose shock position relative to engine inlet lip. The shock location is a function of forward body geometry, boundary layer characteristics (tied to Reynolds number effects) and angle of attack. Very small attitude errors would either cause unacceptable shock impingement inside the engine or shocked flow spillage losses which make it difficult for thrust to exceed drag. Accomplishment of the necessary control precision requires good free stream flow data, precise knowledge of the current and projected angle of attack (which partly depends on vehicle thermoelastic geometry changes), and crisp effector response to small attitude change commands.

The control effectors for attitude state management probably will include aerosurfaces, reaction control thrusters, and/or thrust

vector control during powered flight. Aerosurface effectiveness is influenced by boundary layer, wake, aerothermoelastic properties, and physical blockage effects. Thruster torques are affected by plume interaction with the vehicle flow field. Thrust vector control characteristics are tied to propulsion performance which is affected by many of the factors mentioned previously. A versatile technique for blending all available control effectors is necessary to overcome the performance limitations of each type of system, while good sensory data and estimation techniques are required to assess the current authority of a particular effector in order to adapt the control law.

The authority of all rotation control effectors is influenced by vehicle mass property changes (including center of mass shifts) due to propellant depletion. Integrated mission, vehicle, and flight control design must be accomplished to assure that a control strategy exists for successful flight with at least a minimum acceptable attitude control margin.

B) Trajectory Design and Control Issues

Trades between design constraints and propulsion system performance will influence nominal trajectory design and mission feasibility while environment uncertainties will require trajectory adjustments which are limited by coupled vehicle performance and control system robustness. A variety of physical inequality constraints (e.g. dynamic pressure, wing loads, specific force, and thermal loads) strongly influence the acceptable ascent flight trajectory, introducing

critical aero/propulsion design trades, and requiring some parametric trajectory assessment. Higher flight profiles can produce less loading, with associated propulsion performance losses. The higher altitudes also introduce more stochastic variation in the ambient atmospheric conditions which necessitates development of an adaptive control design capable of compensating for the uncertainty. These issues must be assessed in parallel with vehicle design definition.

C) Throttle Dynamics

The air-breathing engine throttle setting is a critical control system parameter. Time response dynamics cannot be arbitrary for stable control. However, the complexity of hypersonic propulsion combustion chemistry introduces some propellant flow demand uncertainty, and active cooling to limit engine strut temperatures and inlet flow boundary layer thickness can introduce a substantial lag in the propellant injector response. An understanding of theses dynamical relationships and associated control system design constraints is required soon.

D) Vehicle Technology and Model Uncertainties

A range of technologies for vehicle subsystem design is under consideration. Considerable uncertainty regarding performance and expected element mass applies to many of the design options. Development of analysis tools which treat design and control with respect to a range of mission objectives in an integrated manner is necessary to assure successful vehicle development. Performance and payload impact and controllability sensitivities

of each major subsystem should be assessed, and a simultaneous determination should be made of those for which detailed knowledge is most critical. In the process the most fruitful technology development activities would be identified.

Partitioning the control system design (including software) into elements sensitive to particular vehicle design characteristics will help isolate and simplify changes necessary to accommodate hardware limitations identified as the vehicle design matures. Early avionics and software architectural characterizations are necessary to achieve this objective. Critical control path test definition, and verification procedure will be simplified too, if given attention in early definition of design elements.

E) Some Real-Time Control Considerations

The following issues will influence the complexity of real-time control requirements and adaptability demands.

- Atmosphere dynamics
- Compensation for most likely anomalies
- Abort scenarios
- Propulsion and aerosurface performance uncertainties
- Manual handling qualities
- Crew control intervention requirements

Flight computer capabilities, the power of real-time trajectory prediction algorithms, and the robustness of control strategies

will collectively determine the extent to which the above list of concerns can be accommodated. However, excepting the atmosphere dynamics and crew intervention requirements, all the issues are vehicle design dependent. Therefore, a satisfactory vehicle design cannot be developed independently of the on-board control system.

Flight Systems Technology Road Map

To accommodate to the issues discussed above, a flight systems technology road map for the NASP has been devised and is structured to be responsive to those items considered critical for program success and the Phase 3 decision point. The main features of the road map, if implemented as planned, appear to have coverage adequate to the task. The first five areas have especially high priority. It must be emphasized however that the highly coupled NASP air frame/propulsion/control system design problem requires the simultaneous development of analytical tools and studies of the integration of the key elements of this complex development. Failure to pursue the full gambit of issue identification and problem solution across the board could leave open a vulnerability fatal to the realization of a successful program. The combination of control related issues and the very broad performance spectrum make the system realization at an early date questionable. On the other hand, the focus provided by the systems concept makes the outlined road map tractable for a technology development.

Highest Priority Road Map Studies

The Flight Systems Team has identified five potential technology

show stoppers in the flight systems area requiring early investigation and development to resolve critical design issues. They include:

1) Integrated control

2) Stability and control in the face of large uncertainties

3) Manual control and flight qualities

4) Evolution of the vehicle in an integrated sense

5) Sensors and instruments

1) Integrated Control

The design of a highly interactive and integrated flight control system utilizing controls to meet a number of usually contradictory requirements will be exaggerated in the case of the aerospace plane. For example, the requirement to stabilize the vehicle attitude along the desired trajectory, to hold the controls, including throttle, in their optimum position for performance, and to adaptively control the vehicle in real time along its trajectory with the required precision is considered to be a major challenge to the present state of the art of integrated control Simultaneous optimization of performance, stability, and flight path control needs to be investigated as one basis of meeting the challenge, and perhaps as a means to identify ways to exploit interaction for performance gains. A task has been structured to ensure that sufficient understanding of this issue is gained to permit the design of the control system for the NASP Vehicle. Fundamental studies of control precision requirements should be made to examine the ability of the flight

control systems to meet those that come from both aerothermal and propulsive system effects. An AFWAL-sponsored study activity should be integrated with the technology maturation activity by forming associate contractor arrangements between contractors. Concepts for on-line trajectory solutions for hypersonic aircraft would be provided to the NASP companies for use in their overall flight trajectory system design. Generation of on-line trajectories for vehicle missions, even during the flight tests of the NASP, is essential to a successful NASP development program.

Successful concepts applied to the SR-71 integrated flight and propulsion control system for Mach 3 cruise will be studied for possible adaptation to the NASP. These have been reviewed extensively within NASA, and have been the basis for successful flight experiments.

2) Stability and Control In The Face Of Large Uncertainties

It is critical to provide sufficient control robustness to assure overall vehicle stability and control in the presence of atmospheric uncertainties, aircraft performance uncertainty, and unmodeled or poorly understood vehicle subsystem models. Shuttle entry experience has shown that significant variations exist in the upper atmosphere which could pose a difficulty for vehicles which operate routinely in that area and require complex control for stabilization or critical trajectory control. There are three elements of this activity that are considered as part of the flight systems technology maturation effort. The first is the creation of an Air Data/Atmospheric Specialists Subgroup

which will collect, develop, and distribute the best data available to describe the upper atmosphere model for the purpose of control system design. The Air Data and Atmospheric Subgroup will have cognizance over the upper atmospheric models issue and air data sensor technology development, and will report to the Flight Systems Team.

The second area identifies vehicle model uncertainty which is always an issue in the flight control system design of any vehicle. As the flight envelope increases, the development of accurate models becomes more crucial in the design and analysis of avionics systems. The vehicle models include the airframe, propulsion system, and all other subsystems which are crucial to describing the operation of the flight control system, but which cannot be studied over the entire flight envelope in ground facilities. These issues should be examined to establish both criteria and approaches for robust flight control in the presence of larger uncertainties than normally considered. This could impact, for example, stability margin criteria.

The third area addresses poorly modeled elements. For the NASP there are modeling issues which have little or no precedent in previous flight control system design. Paramount among these is the issue of closed loop design with aerothermoservoelasticity effects, that is, the aeroservoelasticity effects that are compounded by thermoelasticity with the heated vehicle which, among other things, create challenges in air data interpretation. The Flight Systems Technology Team intends to work cooperatively with the structures task leader in the development of these

models, and then establish unique tasks in the technology maturation effort to accommodate.

3) Manual Control and Flight Qualities

There will be a requirement for piloted control of the NASP. Failure overrides, and abort intervention are always necessary in manned vehicles. Currently there are no handling qualities guides or criteria for many parts of the flight envelope of this vehicle class. In addition, recent work in approach and landing flying qualities of aerospace craft needs to be reviewed for applicability to the NASP design. Handling qualities guides and vehicle response criteria will be generated in conjunction with the NASP contractors in order to assure a common basis for the design of both the vehicle closed loop response and the manual flying qualities of the vehicle. Placement of control surfaces may be influenced by these criteria.

A significant issue is related to the visibility requirements for landing. Landings in early flight tests always start with manual operations, which in the case of the space shuttle have been shown to be difficult. Resolving visibility issues is critical to program success. It is likely that forward vision will not be easily achieved in the design of the vehicle. Technology has advanced in the areas of displays (large format and helmet-mounted) such that it may be possible to utilize them to full benefit to provide a high degree of confidence in the ability to land the vehicle without forward vision. A major study and experimental tests must be conducted to provide this design option to the NASP contractors.

The man-machine interface design for the NASP will be forced to deal with some new and difficult issues. The top level task allocation between the crew, the on-board systems, and the ground systems has not yet been examined in detail. It is probable that focused technology maturation activity will be required in this area as the trade results emerge. The Flight Systems Team should work very closely with the companies to identify technology voids in the design or realization of these systems, and to establish required technology maturation tasks.

4) Evolution Of The Vehicle In An Integrated Sense

The Flight Systems Team will sponsor studies of flight test options for support of the technology maturation areas. Piloting, trajectory, and heating studies must be included. Modeling and simulation are key, with real time capability required to accommodate man-in-the-loop capability. Studies of guidance and navigation requirements to provide autonomy will be needed to deal with the expansive range of eventual high Mach number flight tests, and the blackout from ionized sheaths expected around the vehicle. Flight tests could gradually evolve. For example, one option might be to flight test a propulsion module at subsonic to low supersonic speeds on a testbed aircraft for both technology validation and flight qualification. Other possibilities include the acquisition of aerothermal data from on-going high speed vehicle programs.

Preliminary flight tests plans for the NASP will be developed to the extent required to identify flight test impact on the vehicle itself, and to identify long-term requirements for ground facilities, ground handling, and ground processing to support a timely, productive, and safe envelope expansion of the NASP. An Edwards test team, composed of AFFTC and NASA personnel, is in place. Issues here involve the balance between the flexibility of having man-in-the-loop flight tests and the costs associated with assuring his safety.

5) Sensors and Instruments

The derivation of accurate air data information (Mach number, angle of attack, sideslip) is a potential barrier technology for the NASP vehicle. The degree of control precision of angle of attack and sideslip my require precise estimates (a few tenths of a degree) not possible with current systems. Atmospheric variations and the speed limit for conventional pressure-derived air data probes/sensors make this a very difficult problem. There already is difficulty in achieving the accuracy and reliability of air data measurements at high speed and high altitudes. For example, the shuttle air data system is not employed until the shuttle slows to Mach 3.5. Upper atmosphere disturbances and anomalies may not allow the use of inertial navigation derived parameters solely as a basis of providing the state variables to the flight control system of the NASP. The Air Data and Atmospheric Subgroup (ADAS) should be used to guide the task development in the area.

Tasks need to be pursued which will address the potential development of flush and optical air data systems. In addition an AFWAL SBIR-funded activity should be technically managed from the Flight Systems Team to focus R&D efforts on this problem area.

The thermal environment of the NASP vehicle will create special problems due to direct thermal constraints on subsystem design, and control feedback requirements to limit thermal effects. Hydraulic systems, actuators, avionics, buses, power systems, and other distributed subsystems may be required to be placed in areas where active cooling is not practical or possible. At this time, these areas are considered design grade issues, and focused technology maturation tasks in hardware technology will await the definition of peculiar NASP requirements in the conceptual/preliminary design. If work on high temperature, light weight, low volume, high authority actuators is not initiated early, hinge moments will not be satisfied when they are demanded, as one example.

Additional Recommended Road Map Studies

There are other synergistic and/or long lead time technology studies that have been identified as areas warranting early support. They include:

1) Avionics architecture studies

2) Development of hypersonic-rated hardware

3) Crew vehicle systems

1) Avionics Architecture Studies

The overall architecture of the integrated control system for reliability and fault tolerance for the NASP vehicle is being studied by each NASP company. Considerations include the distribution and level of redundancy of critical sensors, processing systems, buses and bus controllers, actuators and actuator electronics, power, cockpit controls, and software. These issues are being faced in every advanced vehicle design today, and there are many significant engineering design challenges in this area for the NASP, as well. There is also significant government and company R&D activity in this area. If the NASP vehicle preliminary design generates unique requirements for architectural or validation/certification technology, tasks should be developed to address the critical issues.

2) Development of Hypersonic-Rated Hardware

The NASP preliminary design studies have identified several potentially serious hardware deficiencies as it works toward the ultimate realization and implementation of advanced flight systems.

A major issue related to aerospace plane flight systems hardware is in the requirement for extremely light-weight, high power, extreme temperature tolerant flight systems, due to the impact of weight and volume deltas on vehicle design and performance.

Lightweight systems have been highlighted by NASP contractors. The development of specific tasks should be planned to follow

detailed discussions with airframe companies and vendors to determine the level of Internal Research and Development efforts and potential government-sponsored work in this area. Trade sensitivities and technology risk associated with new actuation systems, for example, and weight penalties of less advanced systems should be examined by the companies, and would provide the basis for establishing specific tasks.

Some advanced fuel cell Research and Development (R&D) (solid oxide technology) was sponsored prior to the start of Phase 2. Power generation is still being treated as a trade issue and specific technology maturation tasks should be developed when some convergence is evident.

Applicable antenna data and experience from reentry vehicle development and operations will be gathered for study by the NASP companies. The degree of autonomy and telemetry ties for the NASP is currently a trade issue, and will have a big impact on antenna requirements. When these issues are developed to sufficient degree, specific technology maturation tasks will be considered. A major issue may evolve in the cruise regime where plasma sheaths must be understood before communication with the air vehicle by any means and for any purpose can be guaranteed.

There is some evidence that the design of the NASP vehicle may force ground speeds above those normally utilized in high performance aircraft of today. AFWAL is sponsoring an R&D activity in the area of high speed tires. The Flight Systems Team has decided to track this area very carefully and also

monitor the ground speed issues related to the NASP preliminary design. Should ground speed become a design issue, the AFWAL activity should be accelerated via the technology maturation program. In addition, study activities and results should be relayed to the NASP contractor for vehicle design consideration.

3) Crew Vehicle Systems

Crew escape is of paramount importance in achieving a safe, man-rated design. The trade activities on-going do not indicate new technical areas which should be included in the Technology Maturation Plan. Specific tasks should be considered as more definition of the crew escape issues is developed.

A task should be planned so that the experience gained in crew systems R&D activities related to the space shuttle and the space station will be transferred to the NASP contractors.

Conclusions and Recommendations

The technology road map developed by the flight systems working group has the elements described to provide an adequate understanding and effective development program for NASP. What is not evident is funding and prioritization sufficient to the job done. Controls and flight dynamics optimizations can relieve environments inimical to successful realization of key but very uncertain technologies involved with structures, structural materials, and propulsion systems, for instance. At the levels of program funding currently applied to the flight systems technologies not devoted to the airframe and propulsion systems, it is doubtful that these optimizations can

be examined adequately and that alternatives will be available on a schedule compatible with the airframe/propulsion developments. As a rough example of the amount in contention, it now appears that approximately 1 to 2% of the currently identified funding in the program is intended to cover this functional area. It is patently impossible to reach the goals of the program at the level of funding now allocated to the controls and guidance functions.

APPENDIX F

Computational Fluid Dynamics

The NASP is and of necessity must be the most highly integrated airframe yet to be designed. The thrust must exceed the drag over a wider Mach number range than ever attempted before. The thrust on a jet engine is primarily due to the difference of momentum flux between inlet and exhaust, and the difference of the axial component of the pressure area integral between the inlet and the exhaust nozzle. At low speeds the main contribution to the thrust is the change in momentum. The primary effect of the pressure area integral in the thrust direction is on the "diffuser", which exceeds the pressure area integral over the exit nozzle. As the Mach number increases this balance shifts, the difference in the momentum flux is less, so the axial component of the pressure area integral on the exhaust nozzle is of increasing importance. Thus small changes in pressure, or slopes of surfaces are very important in calculating the thrust from the engine. This implies an accuracy that may well strain the current limits of CFD. Including real gas effects and chemical effects, to say nothing of transition, increases the strain. But the problem is more complex. To accelerate the vehicle, the thrust must exceed the drag. Again, a difference between axial components of pressure-area forces on slender surfaces is required. In addition the skin friction and effects of heat transfer must be included in this difference. Also real gas chemistry and laminar-transition-turbulent-boundary layer transition issues must be dealt with. Thus the ability to accelerate depends on the differences of

two numbers of almost equal size; each of these numbers is itself the difference of two large numbers.

Assuming for the moment that only limited experimental facilities will be available, the first issue will be development of CFD codes. There is evidence that perfect gas Euler codes will work properly for reasonable shaped configurations. However, these codes require about 24 hours to converge at Mach numbers of 20-25. It is not clear how modifications for real gas effects, or how the influence the grid configurations will increase the run time. Automatic adaptive grid procedures are developing rapidly. Thus the increased complexity in the equations may be counterbalanced by a reduced number of grid points. However, including viscosity, chemistry and heat transfer cannot help but increase run times. Inclusion of transition and the effect of turbulent boundary layer is a serious complication, even assuming that one knows how to do it. It is not clear that we do.

Once a code exists, it needs validation at best, or calibration at worst. Validation implies that field data computed by the code have been compared with either experimental data for the same geometry and angles of attack, side slip, Mach numbers and Reynolds numbers, if possible, or with field data from codes that have been previously validated. The range of validation of each of these variables must be determined by individual comparisons. One condition for the comparison is not enough. Once a code is validated the user can feel confident about results within the validation hyperspace. Calibration implies the code is useful after "post processing".

Herein lies the dilemma. Without adequate experimental facilities, validation of data generated by the code is essentially impossible. Even if data from several codes agrees, there is a nagging doubt. Where differences in large quantities are needed to define performance of an aircraft, the doubt is real.

The resolution of the dilemma will be incomplete at best. It will also be untidy, in all probability. Some data will be generated at high Mach numbers using the Langley Research Center helium tunnel. Other data will come from shock tunnels, or other facilities. All this data is likely to be surface conditions. We cannot expect field data in the next few years. The operators of the several available codes will each compute these few cases. Then a judgment will have to be made as to "best" programs.

There is need for clever experiments based upon good physical insight and understanding of what will stress a code. If one is clever enough these experiments should illustrate effects one at a time, and then 2x2 and more. Chemistry and combustion will be one dominant problem. Another is the start and length of transition. A third, is the nature of turbulence at M=15 or 25. Finally there is the effect of shock on shock, shock-boundary layer and shock-radiation interaction. Note the latter includes three unknowns, skin friction heat transfer rate and gray body emissivity. Clearly design of aerodynamic experiments and the apparatus will be challenging.

One perfect gas Euler calculation can require about 24 hours of computer time at M=25 to converge. The ATF design required about 6500 points to fill the data base. A point is a geometry, angle of attack, angle of sideslip, Mach number, altitude, cg location throttle setting and presumably Reynolds number. Rate effects must ultimately be included to determine handling qualities. For the number of independent variables, this is a reasonably sparse data base. Estimates should be developed for the NASP computational requirements.

APPENDIX G

Contractor Response

The Task Force met with the eight Phase 2, Part II contractors during the period June 23 to June 25, 1987. Each meeting included a half hour closed session with only contractor personnel and Task Force members present.

The Appendix, containing summaries of points made in each of those discussions, is withheld from this copy of the report, because of the potential for competition sensitivity.