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Assessment of Government Tribology Programs

September 1985

Prepared for the U.S. Department of Energy
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ASSESSMENT OF GOVERNMENT TRIBOLOGY PROGRAMS

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September 1985

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Energy Conversion and Utilization
Technologies Division
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EXECUTIVE SUMMARY OF TRIBOLOGY SERIES

Experts estimate that in 1978 over four quadrillion Btu of energy were lost in the United States because of simple friction and wear--enough energy to supply New York City for an entire year. This translates to a $20 billion loss, based on oil prices of about $30 per barrel.[a] Because of the enormity of this energy loss, the Energy Conversion and Utilization Technologies (ECUT) Program in the U.S. Department of Energy (DOE) initiated a program in 1983 to study tribology--the science of friction and wear--to learn more about the causes of these energy losses (or tribological "sinks") and how to reduce them.

The ECUT Program itself was started in 1980 to encourage research to improve energy conversion and utilization efficiency. The enormous energy loss in tribological sinks has been targeted by the ECUT program as having significant potential for energy conservation. One goal of the ECUT Tribology Program is to reduce these energy losses by developing improved lubricants and more durable materials.

To support initial Tribology Program planning, ECUT conducted six surveys to gather three types of information about the current tribology problem in the U.S.:

1. The identification of typical industrial sinks
2. A survey of current U.S. Government tribology projects
3. The identification of tribology R&D needs based on industry perceptions.

The six ECUT-sponsored surveys are listed in Table ES.1. Each survey is being published as a separate volume with its own summary. This executive summary, which also appears in each of the six volumes, presents an overview of results from the six surveys and their implications for energy conservation. The results of these six surveys and their implications for energy conservation are presented in this summary. These results will be used to support further research planning for the ECUT Tribology Program.

TABLE ES.1. ECUT Surveys Reviewed in this Summary

1. A Review of Tribological Sinks in Six Major Industries. Imhoff, et al. PNL-5535, Pacific Northwest Laboratory, Richland, Washington.
2. Reduction in Tribological Energy Losses in the Transportation and Electric Utilities Sectors. Pinkus and Wilcock, Mechanical Technology Incorporated. PNL-5536, Pacific Northwest Laboratory, Richland, Washington.
3. Identification of Tribological Research and Development Needs for Lubrication of Advanced Heat Engines. Fehrenbacher, Technology Assessment and Transfer, Incorporated. PNL-5537, Pacific Northwest Laboratory, Richland, Washington.
4. Energy Conservation Potential of Surface Modification Technologies. Le Khac, DHR, Inc. PNL-5538, Pacific Northwest Laboratory, Richland, Washington.
5. Assessment of Government Tribology Programs. Peterson, Wear Sciences Corporation. PNL-5539, Pacific Northwest Laboratory, Richland, Washington.
6. Assessment of Industrial Attitudes Toward Generic Research Needs in Tribology. Sibley and Zlotnick, Tribology Consultants Incorporated. PNL-5540, Pacific Northwest Laboratory, Richland, Washington.

IDENTIFYING TYPICAL TRIBOLOGICAL SINKS AND MECHANISMS

ECUT's first step in collecting information about tribology was to identify significant tribological sinks and mechanisms. This information was needed to focus research on key technological problems. Because the industry, transportation, and utilities sectors account for most of the

(a) Calculations in this summary are based on a $30 figure.

energy consumed in the U.S., ECUT concentrated first on the tribological energy sinks and mechanisms found in these three sectors. The report by Imhoff, et al., describes the most important tribological sinks typically found in industry, and the report by Pinkus and Wilcock describes tribological energy losses in the transportation and utilities sectors. Two specific studies assessed tribological problems in the metalworking industry and in the advanced diesel engine.

To identify areas in which tribology has a significant impact, the authors examined the energy consumed, the fuels used, and the primary products and processes found in the transportation, industrial, and utilities sectors. Once energy losses were identified, their magnitude was estimated. The estimates include both friction losses (direct losses) and material wear losses (indirect losses). The authors also estimated the energy savings potential in each sector and recommended some specific R&D programs to help achieve these energy savings.

The Industrial Sector

Tribological energy losses are pervasive throughout industry. Because reviewing all industries and industrial processes in detail would be impossible, the Imhoff, et al. survey, instead chose six representative industries (Mining, Agriculture, Primary Metals, Chemicals/Refining, Pulp and Paper, and Food Processing) that appeared to have the most significant tribological sinks and energy losses. These industries were selected because of their 1) major, nonthermal energy streams (such as machine drives); 2) high material wear rates and friction; 3) significant material transportation/alteration processes; and 4) total energy use.

The study identified important tribological sinks in each selected industry, based on both friction and material wear energy losses and on the tribological mechanisms and materials involved. Figure ES.1 and Table ES.2 show the key results for each of the six industries.

The first conclusion from this study confirmed earlier claims that losses from material wear are greater than energy losses from friction; the wear losses in five of the industries were found to be more than twice as large as the friction losses.[a] The study also concluded that reducing material wear rates to improve equipment life

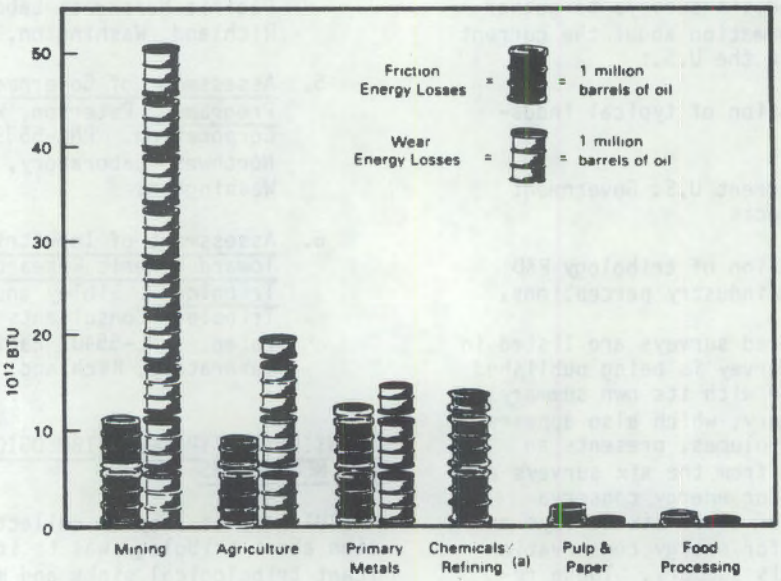

FIGURE ES.1. Annual Friction and Wear Losses in Surveyed Industries

(a) These five industries had estimates of both friction and material wear losses; the sixth, Chemicals/Refining, did not have estimates of wear losses.

TABLE ES.2. Primary Mechanisms in Friction Energy Losses and Principal Materials Involved in Wear Energy Losses

Industry	Mechanisms	Materials
Mining	3-body Abrasion Friction	Iron, Steel & alloys, Aluminum, Rubber
Agriculture	3-body Abrasion Friction	Steel, Rubber, Lubricants
Primary Metals	Hot Rolling Inefficiencies	Steel & alloys
Chemicals/Refining	Friction, Erosion Abrasion	Not studied
Pulp & Paper	Friction	Steel & alloys, Chromium-Molybdenum alloys Grinding stones
Food Processing	Erosion, Abrasion	Steel & alloys

and reliability would also significantly improve industrial productivity. The industry representatives interviewed strongly emphasized the positive impacts that tribological research could have on operational productivity.

Tribology in the Metalworking Industry

In addition to the general review of tribological sinks in industry, ECUT sponsored a more specific study of tribology in the metalworking industry by Le Khac at DHR, Inc. The study estimated the energy conservation potential of using advanced surface modification technologies in this industry. These surface modification technologies are thermal, chemical, or mechanical treatments that reduce friction and wear at a material's surface without changing its bulk properties. The advanced surface modification technologies considered were ion implantation, laser surface hardening, electron beam surface hardening, and wear-resistant coating deposition. The author studied 70 percent of the metal-forming and metal-cutting machines used in the United States (except those associated with primary metals processing), identified tribological mechanisms, and estimated friction and wear energy losses. Potential energy savings from using surface-modified tools were also estimated.

The metal-forming machines studied were punches, presses and forges, and the metal-cutting machines studied were turning, drilling, milling, broaching, and sawing machines. Models were developed to estimate friction and wear energy losses and potential savings. The friction losses were estimated by adding friction losses at the motor drive system and at the tool-workpiece interface. Estimates of energy consumption were based on standard operating conditions (known friction coefficients, total working time, etc.) The indirect losses from wear were estimated based on the replacement costs of all metalworking tools used and discarded in one year.

Based on actual experimental or production data, the author estimated that the friction losses in all U.S. metalworking machines amount to 20.2×10^{12} Btu per year, or $104.5 million. Of this energy loss, 1.8×10^{12} Btu per year, or 9%, could be saved using surface modification technologies to reduce friction. The wear loss was estimated to be 7.7×10^{12} Btu per year.(a) Possible energy savings using surface modification technologies to reduce wear could conserve 5.5×10^{12} Btu per year, or 71%.

Finally, the author estimated that tribological energy losses in all U.S. metalworking machines total 27.9×10^{12} Btu, equivalent to 4.8 million barrels of oil or $144 million annually. More than a quarter of this loss could be saved using surface modification technologies to reduce friction and wear. These results are shown in Figure ES.2.

(a) Using 19.2 million Btu per ton as the embodied energy in steels.

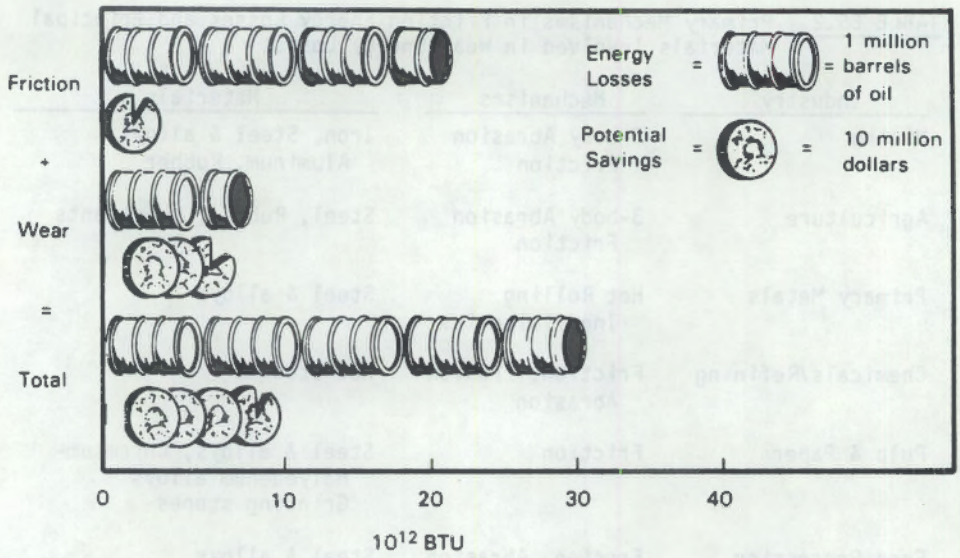

FIGURE ES.2. Annual Friction and Wear Energy Losses in the Metalworking Industry, and Potential Savings from Surface Modification Technologies

The Transportation Sector

The transportation sector is important both in terms of its energy consumption (26% of total U.S. annual energy consumption, or 19×10^{15} Btu, equivalent to $98 billion), and because of the high level of tribological losses. The Pinkus and Wilcock study primarily focused on the highway fleets (passenger cars, buses and trucks), which consume 77% of the total energy used in the transportation sector. The survey primarily addressed the conventional Otto cycle engine. However, other concepts were also considered, such as the adiabatic diesel, the gas turbine, and the Stirling engine; in addition, the Fehrenbacher report evaluated tribological activity in advanced diesel engines.

Figure ES.3 shows the principal automotive tribological sinks and the estimated energy savings. The principal automotive energy sinks are caused by the mechanical inefficiency of the engines and drive trains; most of the energy losses are due to friction.

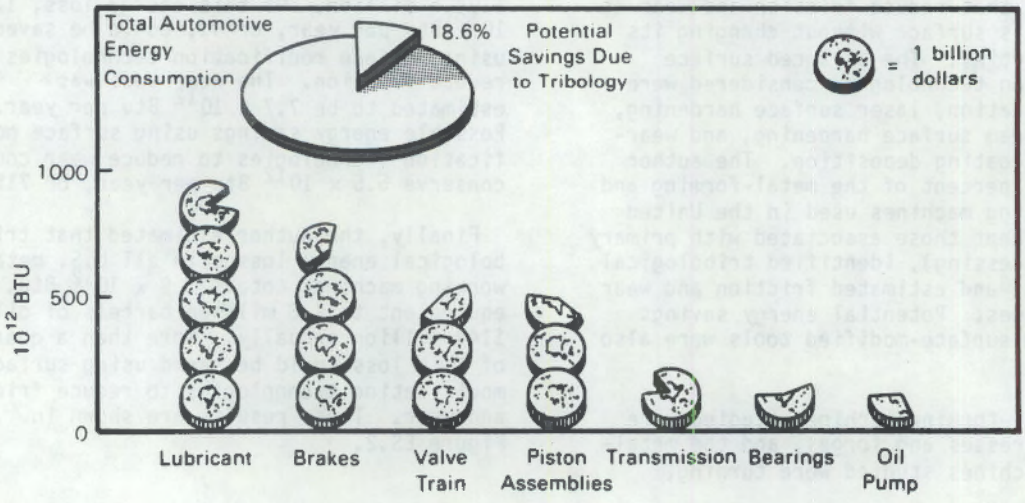

FIGURE ES.3. Potential Energy Savings Per Year for the Conventional Engine (Based on highway fleet size in 1976)

The survey by Pinkus and Wilcock revealed several tribological areas of particular concern for conventional engines, such as the piston ring assembly and the long-range effect of low-viscosity oil on engine wear. As shown in Figure ES.3, tribological improvements could save 18.6% of the total annual energy consumed by automobiles, or $14.3 billion.

Research on conventional engines often applies to unconventional engines as well. Except for the adiabatic diesel, the energy savings possible from tribological improvements to unconventional engines are less significant than those of the conventional Otto cycle engine. The major problems in unconventional engines are related to high-temperature tribological problems. Introducing adiabatic and minimum friction engines into the bus and truck fleets of the U.S. could save up to 2.9% of total U.S. energy consumption.

This survey also revealed the difficulties with devising adequate performance tests to quantify energy losses and evaluate new designs and products. Laboratory tests that accurately reflect real-world conditions are badly needed. The ability to test entire systems is vital, since tribological energy losses are often caused by complex interactions between all the components of a system.

Advanced Diesel Engines

Because of the great potential for energy savings, the ECUT study by Fehrenbacher examined the lubrication of advanced diesel engines in detail. The efficiency of these engines could be improved by about 10%; however, higher operating temperatures (1000°F and higher in the upper cylinder area) are required to reach this greater efficiency. As a result, the primary development challenge for these engines concerns friction, wear, and lubrication of the upper cylinder region. In fact, tribological advancements in these areas are essential if diesel engine performance and durability goals are to be reached. This study assessed these vital tribological concerns in both current and future technologies and recommended tribology R&D topics for further advanced engine development.

Both the mechanical design of the upper cylinder and the chemical effects of lubricants and fuel determine the friction and wear characteristics of the upper cylinder region. These two factors interact in a complex and sometimes synergistic manner. The geometry of the piston, piston ring, and cylinder directly affect the rate and nature of deposit formation, oil consumption, and friction. Efforts have been made to optimize the upper cylinder geometry in current diesel engine technology; this will also be a critical area in future developments. However, problems with upper cylinder deposits, bore polishing, and oil consumption still exist. This study indicates that these problems are caused by the chemical interactions between upper cylinder materials, oil degradation products, and fuel combustion by-products. Therefore, lubricants, oil degradation rates, and mechanisms will continue to be important research areas.

Although a great deal of research has been conducted on liquid lubricants, in most cases the lubricants have been tested without considering the tribological factors specific to the upper cylinder. Since the lubricants interact with the materials and environment of the upper cylinder, they must be developed and tested under similar conditions.

The ECUT study also pointed out that future advanced engine concepts will require ceramic upper cylinder materials able to withstand the higher operating temperatures. New lubricants will have to be developed, and solid lubricants are likely to play a major role. A major research effort will be needed in this area; again, the research must be conducted on a total system basis to be most effective.

The study concluded that many problems with current diesel engines will continue to exist in advanced diesel engines. Tribological problems in the upper cylinder region will be most critical in terms of engine performance and wear. Lubricant R&D is still a major research area in current technology, but total system materials and design considerations should be emphasized. Advanced diesel concepts will require new design approaches, but the tribology of the upper cylinder region will still be critical and may even be the limiting factor in achieving higher engine efficiencies. Extensive materials R&D will be required for advanced designs as well, especially in ceramics, ceramic composites and solid lubricants.

The Utilities Sector

The utilities sector was also reviewed for significant tribology sinks. This sector accounts for roughly 28% of total U.S. energy consumption. ECUT's review revealed that tribological improvements in efficiency and reliability could save 2.3% of the total energy annually consumed by utilities, or about $2.5 billion. As in the transportation sector, efficiency is a major factor.

However, reliability (especially in generating units) is just as important for energy conservation.

The data used in these studies were primarily for the utilities' power plants. The average power plant operates at an efficiency (output energy/input energy) between 30 and 40%. Mechanical losses account for 17-26% of the total energy used. Reliability problems that lead to generator shutdown require using standby equipment, which generally has less efficient fuel consumption. This causes losses both in terms of fuel economy, and revenue and labor costs. Tribological problems are estimated to cause as much as 5% of the reliability problems that require shutdown. Furthermore, tribology-caused shutdowns increase with the size of the power generating unit.

The ECUT survey found several tribological areas with significant energy savings potential, including gas path leakage, seals, and bearings on both the main turbine generator and on the various accessories. Different forms of bearing and lubricant problems (contaminated oils, pump problems, etc.) and vibrations are the leading causes of the plant shutdowns.

Figure ES.4 summarizes potential savings from improving tribological problems in the electric utilities. For accessories, the major concern is sealing problems with feedwater pumps. Friction and wear are implicated in much of the seal and bearing losses. The major problems identified in this study will require research on lubrication theory and advanced materials and coatings developments.

CURRENT U.S. GOVERNMENT PROGRAMS

The second part of ECUT's information collecting efforts involved identifying tribology R&D currently being sponsored or conducted by the U.S. Government. This information was needed to avoid duplicating existing research and to locate those areas that need more research support. The Peterson study identified 215 current projects sponsored by 21 different government organizations. The study classified these projects by subject, objective, energy conservation relevance, type of research, phenomena and variables being investigated, materials, and applications. The principal government sponsors include the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), National Bureau of Standards (NBS), and DOE.

The study located these tribology projects initially by using information from literature searches. Data bases used included the Smithsonian Science Information Exchange, the Defense Technical Information Center's Research and Technology Work Unit Information System, and the Materials Science Abstracts of the National Technical Information Service (NTIS). The study located a

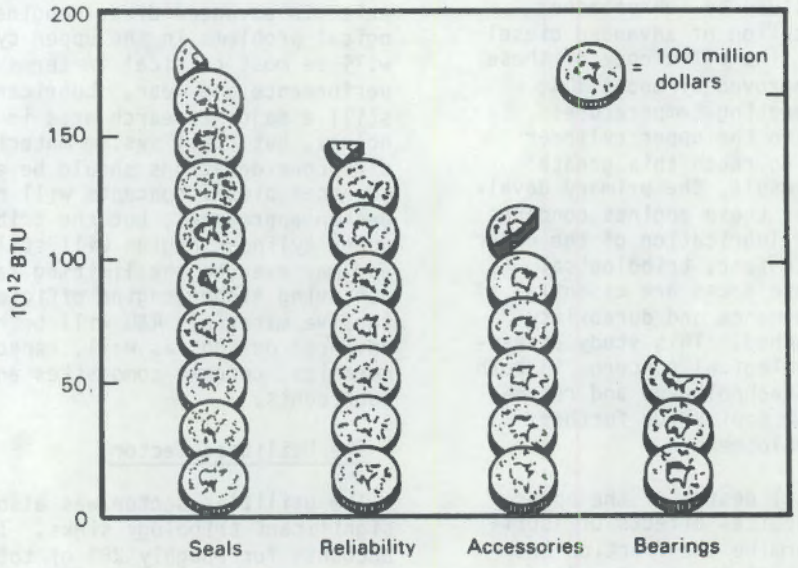

FIGURE ES.4. Potential Energy Savings for the Utilities (Based on estimates of installed capacity in 1983 and on an energy cost of $30 per barrel.)

total of 640 government-sponsored projects covering the fiscal years 1978-1983. These organizations were then contacted by mail, followed by visits and/or phone discussion. Of the original 640 projects, 215 were found to be current. A detailed description of each project is included in the report.

According to this study, until several years ago tribology research emphasized component development, fluid film and elastohydrodynamic lubrication, and concentrated contacts. Since then the emphasis has shifted dramatically, and research efforts now concentrate on lubricants, materials and coatings, and friction and wear mechanisms. There is still considerable interest in rolling contact bearings and seals, as well as in early failure detection in maintenance technology.

The study also concluded that most current tribology research is related to DOD objectives of longer life, low maintenance/failure-free machinery, and the basic understanding of friction, wear, materials, and coatings. High-temperature lubrication also continues to be a major objective in tribology research; the effects of new materials and solid lubricants on current temperature limitations are also being studied. Coatings are receiving the most attention in general materials development. Figure ES.5 shows a breakdown of the materials considered in the 215 projects.

The author also concluded that current programs generally do not emphasize energy or materials conservation. Design predictability and composite materials are other areas that are receiving little attention. Finally, the study concluded that current U.S. Government high-temperature lubrication work is the most applicable to energy conservation goals.

INDUSTRY PERCEPTIONS OF GENERIC RESEARCH NEEDS IN TRIBOLOGY

Because transferring information to industries is a major part of the ECUT program, ECUT conducted a survey of industry perspectives on tribology R&D needs. This survey, conducted by Sibley and Zlotnick, involved interviewing industry contacts to discover what research results are needed.

The authors held in-depth discussions with engineers and managers from 27 companies. These companies were chosen by defining different tribological categories (such as transportation, power plants, seals, gears, aerospace, etc.). At least one company was then selected for each category, and two or three were chosen for categories that are particularly important to the ECUT program. The purpose of this study was not to produce statistically significant findings, but rather to represent many different viewpoints and a variety of interests.

The authors' main emphasis was on determining the engineering limitations imposed by tribology considerations. They also tried to determine the type and funding level of current generic tribology R&D in each company, although only non-proprietary information was available.(a)

Based on the levels of generic tribology R&D in the 27 individual companies, the authors then estimated total tribology R&D in each industrial segment. Although this approach is obviously limited, reasonably

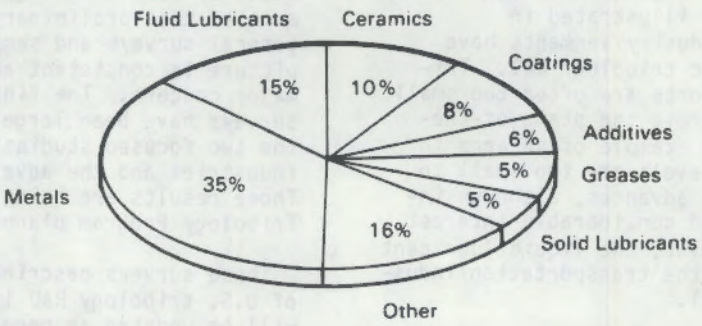

FIGURE ES.5. Materials Under Consideration in the 215 Current Government-Sponsored Tribology Projects

(a) "Generic" R&D in this case is basic research that is not directed toward a specific end use or product.

TABLE ES.3. Estimate of Generic Tribology R&D and Total R&D Budget for Representative Industries (In $M)

Classification	Company	Total R&D[a]	Generic Tribology R&D[b]
Liquid Lubricants	Mobil	188	1
Transportation	Ford	1764	1
Aerospace	Pratt & Whitney	835	0
Powerplants	Caterpillar	234	0
Seals	Crane	10	<1
Rolling Elements	TRW	109	>0
Gears	Eaton	100	>0
Sliding Bearings	Tribon	0	>0
Filters	Pall	7	0
Small Mechanical	Xerox	565	>0
Ceramics	Norton	26	<1
Coatings	Union Carbide	240	<1
Forming	Bethlehem	46	<1
		4124	6

(a) From the report to the Securities and Exchange Commission for 1982. (Source: "Business Week," June 20, 1983.)
(b) Based on discussions with research staff and referring to only company-funded generic tribology R&D.

accurate estimates were developed of the amounts of generic tribology R&D being conducted in each of the industrial segments. The results for the individual companies are summarized in Table ES.3.

These authors concluded that industry funds only a very limited amount of generic tribology research. Some 'hidden' generic R&D is incorporated into the companies' design manuals, but much of this information is proprietary. As illustrated in Table ES.3, some industry segments have little or no generic tribology R&D. Tribology research efforts are often too small to be likely to improve the state-of-the-art; ceramics is an example of an area in which the funding levels are too small to promote significant advances, although industry has expressed considerable interest in this area. However, the liquid lubricant research budget in the transportation industries is substantial.

The industry representatives expressed interest in the ECUT Tribology Program, and also in obtaining a fundamental physical understanding of tribological mechanisms. The industry contacts also requested more effective presentations of research results, especially results in a form that design and development engineers could readily use. Another industry concern involved developing more realistic laboratory tests and more rational performance standards.

CONCLUSIONS

The six ECUT surveys summarized here were conducted to provide an overview of the major tribological sinks and the current state of U.S. tribology research. Although much of this preliminary ECUT work involved general surveys and samplings, the overall picture is consistent and reveals areas of major concern. The findings in the general surveys have been largely substantiated by the two focused studies on metalworking industries and the advanced diesel engine. These results are being used to support ECUT Tribology Program planning.

These surveys describe the current status of U.S. tribology R&D in 1984; the findings will be updated as necessary. Much of the information is necessarily somewhat speculative and theoretical, and many of the general findings have not yet been fully corroborated. This is due in part to the lack of previous research; improving this initial information should be an important goal of current research. In particular, identifying tribological mechanisms should

be emphasized in order to define specific research projects. Further discussion with industry representatives is also needed.

The five key results from these ECUT studies are listed below:

1. Advanced tribo-materials, coatings, and lubricants must be developed to further improve energy efficiency. Although tribological improvements can be made with the current technology, new and innovative materials and designs (such as the advanced diesel engine) are needed to significantly increase energy efficiency.

2. Tribological mechanisms that shorten equipment life and cause excessive downtime and repair should be identified and studied. Initial research shows that these indirect energy losses from material wear are often greater than the direct energy losses from friction. In addition to the energy conservation impacts, reducing these losses could also significantly improve industrial productivity.

3. Generic tribological research will affect all three major sectors, since similar tribological mechanisms are found in many different processes. Although the transportation sector has the largest tribological energy loss and the greatest potential for energy savings, there is significant energy savings potential in all sectors. Thus research results must be effectively transferred to all sectors.

4. Meaningful performance tests and standards must be developed so that new designs and products can be accurately evaluated. Laboratory tests that accurately reflect real-world conditions are badly needed. Total system testing is vital, since tribological energy losses are often caused by complex interactions between all the components of a system.

5. Continuing communication with industry is critical to ensure that industry research needs are addressed and that the results are adequately transferred.

These results supported the development of the ECUT Tribology Program plan for 1985. The research program is divided into two parts. The Mechanisms component includes such areas as advanced tribo-materials R&D, identifying and characterizing tribological mechanisms, and developing performance test requirements. Projects in this area include developing new tribological materials, and modeling and experimental efforts to determine physical and chemical interactions and processes in tribological systems. Liquid and solid lubricants, tribological coatings and surface modifications, and ceramic and cermet materials are specific topics to be considered. The Mechanisms area also includes efforts to develop novel characterization and testing procedures and diagnostic tools and equipment to assess the performance of tribological systems.

The second part of the research program, Design, includes such topics as design and reliability modeling of components, systems, and system assemblies. Industry is directly involved in these projects. The Design area will also establish a data center to gather and disseminate information on tribology. These projects concentrate on generic tribology R&D, including energy losses from material wear.

Clearly, tribology research can have a major impact on energy use and conservation in the U.S. Much of the needed research identified in these studies is innovative and high-risk, which makes tribology a vital and appropriate area for ECUT support. Thus the ECUT Tribology Program, with industry participation and cooperation, will continue its efforts to reduce the enormous energy losses caused by friction and wear.

CONTENTS

TABLES

SUMMARY

An assessment has been made to determine current tribology research and development work sponsored or conducted by the government. Data base surveys and discussions were conducted to isolate current projects sponsored primarily by 21 different government organizations. These projects were classified by subject, objective, energy relevance, type of research, phenomenon being investigated, variables being studied, type of motion, materials and application. An abstract of each project was prepared which included the classification, sponsor, performing organization and a project description. It was found that current work is primarily materials oriented to meet military requirements. Other than the high temperature programs very few of the tribology projects accomplish energy related objectives.

INTRODUCTION

The Department of Energy established the Energy Conversion and Utilization Technologies (ECUT) Program to develop and promote utilization of an expanded technology base and advanced concepts in energy conversion and utilization. In 1983 the ECUT Tribology Project was established within the ECUT program to explore innovative lubrication and material concepts for mitigating friction and wear in order to save 11% of the total U.S. annual energy consumption. Beginning in 1983 the Tribology Project under the direction of Dr. Joseph A. Carpenter, Jr. began supporting research in two areas: Mechanisms and Design. To support this research, certain assessments were also undertaken. Wear Sciences was funded under PO 86X-47967V from Oak Ridge National Laboratory to conduct one such assessment, "Identification of Tribological Research and Development Supported by the U.S. Government". This is the final report of that assessment.

BACKGROUND

Tribology is defined as the science and technology of interacting surfaces in relative motion and the practices related thereto. Principal subjects included within the scope of tribology are listed in Table 1. As can be seen, the field covers surface phenomenon, materials and lubricants, mechanical components, and their application to major systems such as metal working, engine design and operation, transmissions, etc. Tribology is not only an important consideration in the design of equipment but in its maintenance. Tribological problems, either scheduled or unscheduled, represent (along with corrosion and fatigue) one of the primary reasons for removal of equipment from service. Costs for such removals could include repair costs, machine down time, loss of production, loss of mission, and depleted resources.

Historically the government's role in tribology was mainly limited to its ownership of a large variety of mechanical equipment. It provided design requirements, specifications, and maintenance of such equipment and conducted research to upgrade performance and to improve reliability.

However, in the past ten years a variety of social concerns have arisen which have required that the government expand its role in this field of technology. Those concerns are environmental matters, foreign competition and productivity, materials conservation, and energy utilization. Examples of the role of tribology in each of these areas are listed in Table 2. Accordingly, a variety of new research has been initiated with objectives unrelated to equipment ownership. One of the most important of these concerns effective energy conservation and utilization.

Under the auspices of DOE, a workshop was held in Washington, D.C. on February 7-9, 1977, to assess the possible impact of tribology on energy conservation and to identify those areas where the application of existing or new tribological knowledge would yield major benefits. Based upon this workshop, DOE tasked the Research Committee on Lubrication (ASME) to prepare

a broad tribological R&D plan for possible implementation by government. RCL organized task forces in various industry sectors which considered how various tribological research programs could reduce energy consumption. A summary report was published by ASME (1). This report was updated in 1981 (2). As part of its early program DOE made a substantial contribution to the preparation of the Wear Control Handbook (3), a project of the Research Committee on Lubrication of ASME.

In 1981 at the request of Dr. Joseph A. Carpenter, Jr. of Oak Ridge National Laboratory ASME's Research Committee on Lubrication appointed a task force to review the recommended projects and assign priorities. The task force report (4) submitted in November 1982 gave priority to the following projects:

Tribology Utilization
Adiabatic Diesel Requirements
Viscometrics and Friction Modifiers
Bearings for Bottoming Cycles
High Speed Rolling Bearings
Metal Processing Friction and Lubrication
Traction Drives

The Tribology Project is part of the ECUT division of the Office of Energy Systems Research. This office is assigned to the Deputy Assistant Secretary for Conservation of DOE. Tribology work was initiated in FY 1980 under the ECUT Materials Program. In October 1982, tribology was elevated to project status within ECUT with Dr. Joseph A. Carpenter, Jr. serving as acting project manager. In 1984, Terry Levinson was appointed ECUT Tribology program manager and the project assigned to Argonne National Laboratory under the direction of Dr. Manfred Kaminsky. A long-range program is currently being developed. The overall objective of this program is to explore innovative lubrication and materials concepts for mitigating friction and wear in energy conversion and utilization devices in order to save 11% of the total U.S. annual energy consumption. This study was initiated to assist in the long-range planning process. An assessment was conducted of current government projects in tribology in order to gain an understanding of the nature of this research, to avoid duplication and to identify existing programs which have energy saving potential.

DATA ACQUISITION PROCEDURE

To initiate this project several data base searches were conducted to identify tribology projects.

A search was made of the Smithsonian Science Information Exchange (research in progress) using the indexing terms listed in Table 3. These indexing terms were selected from a review of the thesaurus for that data base. The number of unique projects contained in this data base for each term is listed in Table 3. From this, 480 tribology projects were identified.

A second search was made using the Defense Technical Information Center's Research and Technology Work Unit Information System using the search terms

listed in Table 4. A total of 768 abstracts were received and reduced to 180 projects by elimination of nonrelevant and duplicate ones in the SSIE.

A third search was made using the Material Science Abstracts of NTIS. A collection was made of abstracts of reports covering the calendar years 1982, 1983, and 1984. These were collected to identify completed projects and to provide abstract material for current projects. This search also identified ongoing programs which were not ertered into the previous data bases.

From these searches, a total of 640 projects were selected which covered the years FY 78 to FY 83. These were then reviewed to identify the major sponsoring (Table 5) and performing organizations (Table 6). A letter was written to each of the listed organizations requesting information on current tribology projects. Follow up visits and phone discussions were held to obtain detailed information.

All of the above information was used to prepare a detailed listing of projects which were then used to assess current government tribology research.

TRIBOLOGY CLASSIFICATION

Table 7 shows the project description form used for each project. Projects are described by title, investigators, performing organization, sponsor, schedule and funding, objective, abstract description, and a classification scheme which includes subject, objective, type research, type motion, variables being studied, the phenomenon or process being considered, the materials, and the application.

The subjects are those listed in Table 1. This list prepared by Winer at Georgia Tech is used by ASME in its classification of papers submitted for publication. This list was found to be satisfactory and complete but did not uniquely classify projects. Projects could usually have two subjects, e.g. solid lubricants for rolling contact bearings. However, wherever possible this was reduced to one by deciding whether it was really a study of solid lubricants or bearings. This could be done since both solid lubricants and bearings appeared under the materials and application classification. The subject classification was primarily an overview.

The program objectives (Table 8) were not predetermined but selected based upon a review of the stated project objectives. The first objective, "Long Life etc.", covers that research and development carried out to improve design and performance to meet new requirements. Much of the current work falls within this category. Fundamental understanding covers the basic type of research. Although "High temperature lubrication" can be a design requirement, this category covers that research or development where no design requirement is stated. The same condition holds for materials development. An investigator may be working on a wear resistant coating (e.g. filled anodizing) with no specific application or requirement in mind. "Design predictability" is listed as the objective when efforts are being made to establish techniques to predict life, wear, failure, load capacity, etc. of

tribological components. The "energy or materials conservation" objective identifies ongoing projects whose stated objective is to conserve energy or materials. The final three objectives (cost effectiveness, quiet operation, and improved health and safety) are self-explanatory.

The "energy and materials conservation" objective is intended for specific conservation projects. However, other research may contribute to energy objectives. To identify such projects, the classification of "energy relevance" was established. Energy relevant categories are listed in Table 9 along with examples of specific projects which might be included in each category.

Advances in "High Temperature Lubrication" allows heat engines to operate more efficiently and reduces energy losses in cooling. Improved high temperature lubricants would also allow selection of optimum operating or processing conditions without the current thermal barriers.

Materials selection and development has previously ignored energy considerations; energy intensive materials and heat treatments have been widely used when low energy coatings could meet the application requirements. Product lives could also be extended with improved materials which would conserve both the materials and their embodied energy. Studies of failure prevention would accomplish the same objectives.

Friction reduction would yield direct energy savings. Thus, any study which leads to a better understanding of frictional processes would accomplish energy objectives. In addition, any project to develop friction reducing additives would be of significant value for energy saving. Of particular interest is the hydrodynamic to boundary transition where friction increases onehundred times. Any additives, materials, or conditions which enhanced fluid film lubrication would be very significant.

Like materials, designs have not necessarily been energy efficient. Studies such as low energy approaches to power transmission and friction reduction in material processing would serve energy objectives. Process fluid lubrication proposes to use other working fluids as lubricants and eliminate conventional lubrication systems. This action would reduce weight and improve efficiency. Improved sealing would also have positive energy impacts. Reduction of gas path leakage and reduction of seal friction are particularly important.

A more detailed classification for the selected tribology projects is shown in Table 10. The purpose of this classification is to learn more about the project scope and how it was carried out.

Each of the projects were classified according to the system described above and that classification used in an analysis of the current government research.

RESULTS

The basic project data used in this assessment are contained in Appendix 1 which lists current projects. Broad interpretation should be given to the term current since some of the listed projects have been concluded and some are projects not yet under way. The purpose here is not precision but an attempt to obtain a general understanding of current tribology research and where it is carried out. In the following paragraphs various aspects of tribological research is discussed.

SPONSORS

A list of the major government organizations which sponsor tribology projects is shown in Table 5. This table lists the organizations in order of the number of citations found in the data bases for FY 78 to FY 83. From year to year the order will change; furthermore, certain organizations like NASA or NSRDC Annapolis have many projects listed under one citation. A list of current projects was prepared for each of the listed sponsors. These are given in Tables 11-35. Information on current projects was obtained from discussions with the Program Manager and from the data bases.

U.S. NAVY

The Navy carries out a wide range of tribology programs from basic research to demonstration projects in support of both ship and aircraft activities. Basic research is supported by the Office of Naval Research (Table 11) and conducted by the Naval Research Lab (Table 12). The Office of Naval Research supports research primarily through longer term university grants. Current work (Table 11) is heavily concentrated in the areas of materials, wear, and failure processes. The Naval Research Laboratory has several groups working in the tribology area with major efforts in advanced lubricant development and coatings (Table 12). Current lubricant research is devoted to evaluating the potential of deuterated lubricants. In deuteration heavy hydrogen replaces normal hydrogen, improving the lubricant stability. NRL has also set up ion implantation facilities and is conducting research on the friction and corrosion properties of ion implanted metals.

Several of the Navy laboratories do a wide range of tribology work. Although much of this work is concerned with new requirements and specifications, a large amount of basic research is also undertaken. Major programs in the Fuels and Tribology Branch of the Naval Ship Research and Development Center in Annapolis are listed in Table 13. Areas of major concern are rolling contact bearings, main shaft seals, and lubricant properties. NSRDC also administers the Marine Tribology Block program for NAVSEA. In this program a "block" of money is provided yearly to this laboratory with broad mission objectives. NSRDC defines specific projects and funds them in-house, in other Navy laboratories, or by contract.

The Naval Air Propulsion Center and the Naval Air Development Center conduct tribology projects to support the Naval Air Systems Command requirements. The Propulsion Center at Trenton is involved primarily in programs to meet

The Aeropropulsion Laboratory conducts in house and contract research in all aspects of propulsion system tribology. This includes bearings, gears, seals, lubricants and tribological materials. A list of current and future projects is shown in Table 19. Much of their work is applied research concerned with new turbine engine requirements and evaluation of new lubrication techniques. For the past 35 years, operating temperatures and rotative speeds of the aircraft gas turbine engine have increased. This laboratory has had the responsibility of providing the appropriate tribological advancements. New programs include solid lubrication of bearings and gears, improved oil analysis techniques, improved rolling contact bearing materials and 600F lubricant capability. Close cooperation is reported between this laboratory and NAPC-Trenton and the AF Materials Laboratory.

Examples of Air Force Materials Laboratory Programs are shown in Table 20. Much of this work is concerned with the development of lubricants and hydraulic fluids and seals for the 500-600F temperature range. The current fluids (diesters) are limited to a bulk oil temperature of approximately 375F. The perfluoroalkyl ethers and the polyalphaolefins will extend this range somewhat. Major emphasis however is being placed into the development of the silahydrocarbons. Work recently concluded was a major effort to develop the technology of unlubricated and solid lubricated high temperature rolling contact bearings and life prediction techniques. Reports summarizing the results of this DARPA/HUGHES program are listed in references 6-14. A new space related activity concerned with bearing lubrication in hard vacuums for 10-15 year life is under consideration. On a more fundamental basis a lubricant modeling program is being prepared using dynamic models which predicts the needed properties of lubricants to achieve optimum bearing performance for a given set of bearing operating parameters. Such a model could be used to tailor fluids for minimum friction in a given application.

A major new effort is in the area of solid lubricants. A new DARPA/HUGHES program will study solid lubricant/ceramic materials interactions. Another effort will be to develop solid lubricants and solid lubricant application techniques for rolling contact bearings.

U.S. ARMY

The Army Research Office began a major research program in tribology in 1979 supported by the Solid Mechanics Division. This program has been carried out in the Mechanical Engineering and Mechanics Department of RPI under the direction of Professor F. F. Ling, Department Chairman. A list of current projects is shown in Table 21. This is basic research undertaken to gain a better quantitative and fundamental understanding of wear in boundary and micro-elastohydrodynamic lubricated systems.

The Materials Sciences Division supports the work at RPI and also sponsors additional research. A new three year program has recently been started with Professor Furey at Virginia Polytechnic Institute. It is concerned with the polymers formed in the contact area during lubricated sliding and how they affect lubrication.

the new turbine engine requirements. This includes bearings, seals, and lubricants. Some recent projects are listed in Table 14. One recent major program has been the development of corrosion resistant bearings by ion implantation. This program began with simple bench tests several years ago and has progresses to field tests in the J79 and T58 engines. Since corrosion is one of the major reasons for bearing removal, this development could significantly reduce maintenance costs. NAPC also conducts a program on new lubricants and materials for advanced propulsion systems where new ideas are evaluated. Current work under this program is involved with ceramic bearing materials and lubricant preconditioning for gears.

Table 15 illustrates the programs being conducted by the Lubricants laboratory at the Naval Air Development Center. Most of the work is either basic or applied research but they also are responsible for the airframe lubricant military specifications and have developed lubricants and qualified products to meet those specifications. A new research program to study the mechanisms of corrosion with oil wetted surfaces has recently been started. The Naval Air Engineering Center at Lakehurst had until recently a major tribology program concerned with oil analysis, wear particle analysis, and ferrography. Most of this work has been successfully concluded. One program is currently under way (Table 16) which is involved with the sensitivity of spectrometers used by the Navy in its fleet oil analysis program.

The Naval Air Systems Command, Materials and Processes Branch, sets lubricant requirements and supports projects at the various Navy laboratories and through contracts to meet those requirements. A number of the programs previously listed were sponsored by this group. One contractual program on ceramic bearings has been under way for a number of years at SKF Industries. In this project a silicon nitride bearing has been run with a graphite cage at 50,000 RPM and 1000F for 30 minutes. New efforts with ceramic bearings involve hostile environments such as salt water.

The Naval Air Systems Command, Maintenance Engineering Division has in the past supported tribology projects related to reducing maintenance and increasing the service life of aircraft. Tribological problems were shown to be one of three major reasons for removal of aircraft from service; the others being corrosion and fatigue. Major problem areas identified, based upon maintenance man-hours were leakage of actuators, bearing corrosion and wear, excessive lubrication requirements, surface erosion and daily inspections for early failure detection of tribological components. No current efforts were reported.

U.S. AIR FORCE

Basic tribology research is limited at the Air Force Office of Scientific Research; that function being carried out at Wright-Patterson AFB. The Chemistry Division does support basic synthesis work on high temperature fluids which can be considered for lubricants and hydraulic fluids (Table 18). Most of the tribology work in the Air Force is the responsibility of the Materials Laboratory and the Aeropropulsion Laboratory at Wright-Patterson AFB Ohio.

The Army Mechanics and Materials Research Center in Watertown, Mass. has no formal tribology group. However, research and development projects are carried out in several different sections (metals, ceramics, etc.). A list of current projects is given in Table 23.

The Fuels and Lubricants Laboratory of the U.S. Army Mobility Equipment Research and Development Command has technical responsibility within the Department of the Army for fuels, lubricants, power transmission/functional fluids, greases, and corrosion preventatives.

In support of their mission, this laboratory carries out basic and applied research as well as exploratory RDTE programs. The program primarily addresses the specific needs of Army combat/tactical equipment. Research work is carried out at Fort Belvoir, Va., and at a unique government-owned, contractor-operated facility located at Southwest Research Institute in San Antonio, Texas. This facility, which was established in 1958, is known as the U.S. Army Fuels and Lubricants Research Laboratory and is considered an "in-house" facility of MERADCOM. Major programs under way are listed in Table 24. A major new program just getting under way is the development of lubricants and lubrication systems for advanced Army engine systems which includes the adiabatic diesel. A new improved grease has been developed and is currently undergoing field trials in preparation for its introduction into the system.

Research is also under way at several other Army laboratories in support of their specific missions. At Watervliet Arsenal, Dr. R. Montgomery has been conducting tribology research for many years on subjects related to armaments. Recent research has been concerned with gun tube erosion; current projects are listed in Table 25. The Armament Command also sponsors research in tribology at Picatinny Arsenal (Table 26). Aviation-type research is carried out at Fort Eustis. The Fort Eustis work represents the closing effort on a major program to develop diagnostic capability for helicopter engines and transmissions.

NASA

The Lewis Flight Propulsion Laboratory of NASA has conducted tribology research for the past 40 years. Efforts were first directed to piston engines then gas turbine engines, rocket engines, space lubrication, and currently advanced engine concepts. A list of current projects is shown in Table 28. Recent research has focused on obtaining a basic understanding of the frictional behavior of well-characterized materials in accurately controlled environments. Correlations are established between the frictional behavior and the measurable material properties. As shown in Table 28, current efforts cover a wide range of phenomena including friction, wear failure mechanisms, lubrication, coatings, fretting, abrasion, erosion, cavitation, adhesion, and solid lubricants. Emphasis has been on high temperatures and a number of solid lubricant films and composites have been developed to meet engine and aircraft requirements. A major program of the Bearing Section headed by Erwin Zaretsky is in Advanced Power Transmission Technology. Current efforts include studies of advanced transmission techniques such as traction drives and appropriate components development.

NATIONAL SCIENCE FOUNDATION

Two groups within the National Science Foundation support tribology research: The Mechanical Systems Branch of the Engineering Science Division, and the Materials Research Division. Current projects are listed in Tables 29 and 30. A recent study (5) carried out under a National Science Foundation grant to ASME recommended tribology research to be carried out in five areas: Modeling of Tribo-Systems, Materials Behavior in Tribo-Elements, Tribo-System Diagnostics, Tribo-Technology Transfer, and Novel Concepts in Tribology. A description of these areas taken from reference 5 is given in Table 31. More recently, tribology has been given program status at NSF.

NATIONAL BUREAU OF STANDARDS

Two groups within the National Bureau of Standards conduct research in tribology: The Metallurgy Division and the Inorganic Materials Division. Research in the Metallurgy Division is listed in Table 32. The activities of this group address the measurement and standards needs concerned with the application of metals including metallic coatings to wearing situations. Principal emphasis in the various projects listed in Table 32 concerns the effects of metallurgical parameters, the need for better understanding of basic mechanisms involved, and better wear measurement methodology including standards and reference materials.

The Tribo Chemistry group has recently completed a major study to establish standards for recycled oil. The base technology developed in that program is now being expanded into other areas primarily to an understanding of friction mechanisms in fluids (Table 33). Key components in base oils that affect friction and wear are being identified. The ultimate goal is to assess the effects of molecular structure on friction and wear. Such an understanding will provide a basis for optimizing frictional behavior in mechanical components. A new effort just beginning concerns the frictional behavior of ceramic materials at elevated temperatures.

DEPARTMENT OF ENERGY

DOE has, in the past, supported tribology research and development through its various departments originally to support materials for nuclear applications and more recently through its Office of Energy Research (Table 34). Tribology investigations are currently being conducted by the Fossil Energy Materials program on mechanisms of galling and abrasive wear in connection with coal gasification and on materials and lubrication for the adiabatic diesel program. References 15-20 are reports of research programs sponsored by the Office of Vehicle and Engine R&D.

In 1981, tribology research was conducted as part of the ECUT Materials program. Since achieving project status, a number of research and assessment programs have been initiated (Table 35). Research has been primarily in two areas: fluid friction mechanisms and the sliding behavior of ceramics. In preparation for a much expanded tribology program a number of assessments

have been conducted to determine major energy losses in mechanical equipment and identify current tribological research being conducted which could reduce these losses.

One of the assessment recommendations to the ECUT Tribology Program was to prepare a long-range plan covering the next 10 years. Such a plan is currently being prepared by Dr. Manfred Kaminsky at Argonne National Laboratory. Proposed elements being considered for incorporation in the plan are listed in Table 36.

The ECUT Tribology Program is a program in the Office of Energy Systems Research which is under the Deputy Assistant Secretary for Conservation. Terry Levinson is the program manager. This program is described in more detail in reference 21.

PROJECTS REVIEW

The classification system used allows a review to be made of the current projects shown in Appendix 1. The subjects under study are listed in Table 37. By far, the most emphasis is being placed on lubricants, materials and coatings, and friction and wear mechanisms. This emphasis is quite different than several years ago when more work was being done in component development, fluid film and elastohydrodynamic lubrication, and concentrated contacts. There are no obvious reasons for this change except the natural cycle of events which turns to new unknowns when solutions to current problems are achieved. The major new emphasis has been in the field of wear. Ten years ago there was no work and little interest in this subject. The first work in this country was sponsored by the Office of Naval Research and then material scientists became interested. New techniques of surface analysis allowed wear mechanisms to be accurately defined and classified. With this understanding, new techniques for wear reduction have been proposed and are being evaluated. There is still considerable interest in the subject as evidenced by the excellent response in both papers submitted and attendance at the International Wear Conference held every two years.

There is continuing interest in rolling contact bearings and seals. Much of this interest arises from the increasingly severe temperature and life requirements of the aircraft gas turbine engines. Leaking seals, however, are a perennial problem in most machinery and are, at least for aircraft, the major reason for service removals.

Early failure detection has received major emphasis in maintenance technology and that emphasis has prompted renewed interest in tribological failures. Work in this area centers on appropriate failure detection instrumentation for rolling and sliding contacts and obtaining an understanding of thermomechanical failures.

Objectives of current R&D are listed in Table 38. Most of the programs are conducted to obtain longer life, low maintenance, failure free machinery or

a fundamental understanding (friction, wear, materials, coatings). The improved machinery category is the most obvious objective since it includes new designs to meet new requirements and problem oriented developments.

Fundamental research in tribology is conducted on a continuing basis since this is the mission of a number of government organizations. Demand for improved performance and increased severity for operation of equipment has intensified the need for a better understanding of lubricating mechanisms. This is particularly evident in certain areas such as frictional behavior, solid lubrication and wear, where little progress can be made without additional research. This fundamental research could well lead to important advances relevant to energy use. A great deal of work is being done to define wear mechanisms but very little on friction and solid lubrication.

High temperature lubrication has been a major objective in tribology for the past forty years and will continue to be in the future. The primary driving force has been the aircraft gas turbine engine but space power, metal working of super alloys, higher temperature automotive engines, and metal cutting have also contributed. Past research has been evolutionary as incremental improvements were made in rolling contact bearing materials, synthetic lubricants, piston ring and seal materials, solid lubricants, and wear resistant coatings. Current research driven by the needs of advanced heat engines such as the adiabatic diesel and the small gas turbine appears to be more revolutionary in nature. New materials (ceramics, composites) are being considered as well as new solid lubricants (intercalated layer lattice compounds, new dichalcogenides, oxides and double oxides). New techniques for supplying solid lubricants are being considered and evaluated. These new approaches may provide the necessary breakthrough to allow major temperature increases in propulsion systems and machinery. Temperature limitations on the lubricant has always been a major obstacle.

General materials development has proceeded with coatings receiving the most attention. A wide variety of techniques have been developed for applying controlled compositions and controlled thicknesses. This has allowed coatings to be used in close tolerance applications such as rolling contact bearings and spool valves. Mixed metals and ceramics can be applied as required

One of the most interesting developments has been in the area of composite coatings which use electroplating and electroless plating technologies. This includes both hard particles and lubricating particles in a variety of metal substrates. This technology has great potential since it allows tailoring of the surfaces to meet the requirements of the application in regard to both friction and wear characteristics. In fact, it appears feasible to transfer many of the additive functions (extreme pressure, antiwear, anticorrosion, friction modification, etc.) from the lubricant to the bearing surface. With this approach, efforts could be concentrated on high temperature fluid stability.

Very few of the current government programs have design predictability as their objective. Obviously the need exists to make rational choices of materials and designs to achieve a given life or load capacity. Although the government does not design the equipment it uses, it has a vested

interest in machinery reliability. Industry, even more than government, needs improved design techniques for tribological applications. Much work needs to be done in this area, particularly in the materials area.

As yet, tribology has not been specifically addressed to energy or material conservation objectives. The ten programs listed in Table 38 are primarily those currently supported by ECUT.

The energy relevance of the work is listed in Table 39. This table identifies those programs which are not conducted for improved energy utilization; they may, however, contribute to that end. It can be seen that if the 32 high temperature lubrication programs are subtracted, only 43 of programs make some contribution. There is much room for new energy-significant research in a variety of subject areas.

An applications breakdown is shown in Table 40. Almost all of the work is involved in bearing and seals for machinery and their lubrication. Other component work is limited.

The materials involved in the tribology studies are listed in Table 40. Obviously, the most interest is in metals and fluid lubricants for current applications. However, because of the higher temperatures anticipated in new propulsion systems, most research organizations are beginning to look at ceramics and solid lubricants. New rigs are being constructed at several different laboratories to study the frictional behavior of ceramics to 1500C. In addition, new research is being contemplated to gain a better understanding of solid lubricant mechanisms and to apply them to tribological components.

As shown in Table 41, very little development work is being carried out with either polymer or metal composites for tribological applications. However, significant advances have been made in the past 20 years in improving the wear rates and temperature capabilities of such materials.

HIGHLIGHTS

Table 41 lists some of the highlights of the current research efforts. For each subject category there is listed some of the major efforts which are currently under way in a variety of laboratories. In fundamentals, work is under way to gain a better understanding of both fluid friction under boundary lubricating conditions and solid friction. The major effect, however, is to better define wear and surface damage machanisms which occur in sliding and rolling contacts. Lubrication transitions are also being studied, especially the transition from fluid film to boundary lubrication. Analytical and experimental work is being conducted to model this process in terms of the surface topography, fluid properties, and materials properties. A new wave of interest has developed in high temperature operation which has prompted new interest in ceramic friction and wear. Many of the laboratories surveyed are constructing new friction and wear test devices for operation to 1500C. The increasingly severe requirements of the gas turbine engine has prompted renewed efforts to find 600F synthetic oils. The Army is also interested in higher temperature engine oils for tactical vehicles as well as improving current oils. Solid lubricant studies have been almost nonexistant since space research received less government emphasis. However, new programs are planned to identify new solid lubricants with broad temperature range capability and to find new ways to use them. What is also needed is systems work which will define the capability of solid lubrication in a broad range of components such as bearings, gears, etc. The application of solid lubricants in coatings and polymers has continued with significant improvements being made in the wear lives of such materials. Coating technology has made significant advances in recent years and this is now being applied to wear resistant coatings. The significant development is that controlled thickness, composition, and structured coatings can be applied which makes them much more practical for use in close tolerance machinery and components.

In order to develop more reliable, higher speed rolling contact bearings, new fracture and corrosion resistant materials have been developed which are now being introduced into service. Improved bearing designs are also being evaluated to meet the higher speed and load requirements of advanced engines and transmissions. Of particular significance is the research which demonstrates that power loss can be reduced significantly with appropriate technology.

CONCLUSIONS

1. Over the past six years approximately 650 tribology projects have been conducted under government sponsorship. Approsimately are current programs sponsored by 21 different government organizations.

2. Other than high temperature lubrication projects, very few of the current tribology research and development programs accomplish energy related objectives. Tribology has not been adequately addressed to energy objectives.

3. Almost all of the tribology work is related to the objectives of the Department of Defense. Of the 21 major sponsors, 15 are DOD organizations. Of the remaining 6, two carry out either sponsored or similar work. Industrial tribology areas are receiving very little attention.

4. Past work has been primarily evolutionary in nature with little exploratory work being carried out with novel tribological systems.

5. Most of the projects are either basic or applied research in friction, wear, materials, and coatings. Wear research has increased from almost no effort several years ago to a major effort today. In contrast, work on improved tribological components is decreasing.

6. Work on high temperature lubrication continues with emphasis on materials (engine oils, rolling contact bearing materials, high temperature, corrosion resistant greases, extended wear life dry bearing materials, controlled property coatings, and ceramic friction and wear).

7. These materials developments along with the components research conducted in previous years has set the stage for significant advancements to be made in the development of high temperature systems.

8. New techniques for applying controlled property and controlled thickness coatings are being applied to improve the performance and reliability of tribological components.

9. Many organizations are assembling test equipment and personnel for a major emphasis on ceramic friction and wear studies at high temperatures.

10. Tribology areas which are receiving little attention are design predictability and composites materials. Fundamental work on friction and solid lubrication is also needed to achieve energy objectives.

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Table 1

TRIBOLOGICAL SUBJECTS

1. Boundary Lubrication
2. Friction and Wear Mechanisms
3. Surface Mechanics, Thermal Behavior, & Modeling
4. Surface Analysis & Test Techniques
5. Concentrated Contact Phenomenon
6. Lubricants/Greases/Hydraulic Fluids
7. Solid Lubricants
8. Tribological Materials & Coatings
9. Component Failure Analysis & Diagnostics
10. Erosion/Cavitation/Abrasion
11. Sliding Bearings & Bushings
12. Power Transmission & Traction Devices
13. Gears
14. Metal Working Tribology
15. Engine Tribology
16. Filtration
17. Fluid Film Bearings
18. Rolling Element Bearings
19. Seals
20. Brushes & Electrical Contacts
21. Miscellaneous Components & Studies

Table 2

TRIBOLOGICAL SIGNIFICANCE

ENVIRONMENT

- Utilization or Disposal of Used Oils
- Wear Due to Lead Removal from Gasoline
- Seal Leakage of Contaminating Chemicals
- Removal of Heavy Metal Coatings

FOREIGN COMPETITION AND PRODUCTIVITY

- Reduced Maintenance in Both Manufacturing and Products
- Improved Tool Life through use of Hard Coatings
- Development of High Speed Data Processing Equipment
- Innovative Tribological Component Designs

MATERIALS CONSERVATION OF CRITICAL MATERIALS

- Removal of Cobalt from Wear Resistant Alloys
- Substitution for Chromium in Bearing Steels
- Replacement of Tungsten in Tool Steels
- Increased Product Lives through Improved Tribological Components
- Use of Nonmetallic Coatings for Corrosion and Wear Resistance

ENERGY CONSERVATION

- Higher Efficiency through High Temperature Lubrication
- Utilization of Tribological Materials with Low Embodied Energy
- Reduced Friction in Mechanical Components and Metal Working
- Lubrication with Process Fluids
- Loss of Engine Efficiency through Seal Leakage
- Substitution of Coatings for High Temp Wear Resistant Heat Treatments
- Loss of Efficiency through Component Wear

Table 3

SSIE CITATIONS

1978-1982

Lubricity, Lubrication	11
Friction	316
Wear	431
Lubricants	239
Bearings	83
Seals	184
Gearing, Power Transmission	-
Brakes	34
Clutches	1
Valves	119
Fretting	15
Wear Reduction	11
Erosive Wear	175
Hydraulic Fluids	33
Greases	24
Solid Lubricants	20
Failure	922
Surface Properties	6,633

Table 4

SUBJECT SEARCH TERMS

DTIC

PHENOMENON	MATERIALS	APPLICATION
Friction	Fluid Lubes	Fluid Film Bearing
Wear	Solid Lubes	Rolling Bearing
Lubrication	Hydraulic Fluids	Gas Bearing
Fretting	Greases	Bushing
Erosion	Additives (Lubricant)	Rings
Adhesion	Bearing Materials	Spline
Abrasion		Coupling
Oil Analysis		Clutch
		Valve
		Seals
		Gears
		Brakes
		Brushes
		Cams
		Filters

Table 5

MAJOR SPONSORS

ORGANIZATION	NAMES
Office of Naval Research	W. Ruff
AF Propulsion Lab	H. Jones
AF Materials Lab	B. McConnell
Army Research Office	F. Schmedeshoff G. Mayer
AF Office of Scientific Research	A. Matuszko
MERADCOM Ft. Belvoir	M. LePera
National Science Foundation (Materials)	J. Thomas, Jr.
Army Materials & Mechanics Research Center	P.R. Smoot R. Middleton
DOE Office of Energy Research	O. Manley
NASA Cleveland	D. Buckley
Naval Air Propulsion Center, Trenton	A. D'Orazio R. Valori
Watervliet Arsenal	R. Montgomery
National Science Foundation (Engineering)	R. Marsh
Naval Air Systems Command, Washington DC	P. Weinberg
DOE Office of Conservation	T. Levinson
National Bureau of Standards	W. Ruff S. Hsu
Naval Research Lab, Washington DC	J. Murday
Applied Technology Lab, Ft. Eustis	B. Poteate
NSRDC, Annapolis	J. Dray
Naval Air Development Center	N. Reibuck
Pitcatinny Arsenal	W. Ebihara

Table 6

ORGANIZATIONS CONDUCTING TRIBOLOGY RESEARCH

GOVERNMENT

Naval Research Laboratory
Naval Ship Research and Development Center - Annapolis
U.S. Army Fuels and Lubricants Laboratory, Ft. Belvoir
Army Mechanics and Materials Research Center
National Bureau of Standards
AF Propulsion Laboratory
AF Materials Laboratory
NASA - Cleveland
Naval Air Propulsion Test Center
Naval Air Development Center
Watervliet Arsenal
Picatinny Arsenal
Oak Ridge National Laboratory
Argonne National Laboratory
Lawrence Berkeley Laboratory

UNIVERSITIES

Rensselaer Polytechnic Institute
Massachusetts Institute of Technology
Northwestern
Georgia Tech
University of California - Berkeley
Penn State
Ohio State
North Carolina State
University of Pennsylvania
Columbia
University of Connecticut
Virginia
Virginia Polytechnic Inst.
Cornell
New Mexico
Missouri
Dartmouth
Oklahoma State
Minnesota
Delaware
Illinois
Vanderbilt

INSTITUTES

Battelle
Southwest Research Institute
Midwest Research Institute
Franklin Institute
Dayton Research Institute
Draper Labs

CORPORATIONS

Pratt and Whitney Aircraft
Mechanical Technology Inc.
SKF Industries
General Electric - Evendale
Westinghouse Research
Teledyne
Geo-Centers
Ultrasystems
Ford Research
Advanced Mechanical Technology
Ball Brothers
Sikorsky Aircraft
Cummins
Hughes Aircraft
Effects Technology
Boeing

Table 7
PROJECT DESCRIPTION

Title	
Investigators	Organization
Sponsor	Schedule and Funding FY 83 FY 86 FY 84 FY 87 FY 85 FY 88
Classification Type Research Type Motion Variables Process Materials Application	Subject Objective Energy Relevance
Objective	
Description	

Table 8

PROGRAM OBJECTIVES

1. Long Life, Low Maintenance, Failure Free Machinery
2. Fundamental Understanding
3. High Temperature Lubrication
4. Materials Development for Improved Performance
5. Design Predictability
6. Energy or Materials Conservation
7. Cost Effectiveness
8. Quiet Operation
9. Improved Health and Safety

Table 9

ENERGY RELEVANCE

1. HIGH TEMPERATURE LUBRICATION

   Materials, Solid Lubricants, Synthetic Lubricants, Lubricant Delivery Systems, Tribocomponent Design & Operation.

2. DEVELOPMENT OF IMPROVED TRIBOMATERIALS

   Materials and Coating with Extended Wear Life or Low Embodied Energy. Wear Models.

3. STUDIES OF LUBRICATED FRICTION BEHAVIOR

   Friction Reduction Additives, Understanding of Boundary Friction & Lubrication Processes, Traction, Studies of Boundary to Fluid Film Transition.

4. FAILURE PREVENTION

   Transitions, Failure Prediction, Surface Temperatures, Role of Surface Reaction Films.

5. ENERGY EFFICIENT DESIGN & OPERATION

   Component Design for Minimum Friction, Low Energy Approaches to Power Transmission, Process Fluid Lubrication, Improved Seals, Friction Reduction in Material Processing.

Table 10

PROJECT CLASSIFICATION CATEGORIES

TYPE RESEARCH	TYPE MOTION	VARIABLES
Basic	Unlubricated Sliding	Load/Pressure
Applied	Unlubricated Rolling	Velocity
Exploratory Development	Unlubricated Slide/Roll	Temperature
Technology Development	Impact	Environment
Demonstration	Reciprocating	Dist/Time/Amp
Commercialization	Lubricated Sliding	Geometry
	Lubricated Rolling	Finish/Lay
	Lubricated Slide/Roll	Composition
	Oscillating	Structure
		Physical Properties
		Thermal Properties
		Chemical Properties

PROCESS OR PHENOMENON	MATERIALS	APPLICATION
Friction	Metals	Fluid Film Bearing
Wear	Ceramics	Rolling Bearing
Lubrication	Polymer	Gas Bearing
Surface Damage	Coatings	Bushing
Failure	Polymer Composites	Sliding Contact
Fretting	Metal Composites	Rings
Erosion	Fluid Lubes	Spline
Adhesion	Solid Lubes	Coupling
Abrasion	Hydraulic Fluids	Clutch
Fatigue	Greases	Valve
Load Capacity	Additives	Tool/Die
Surface Temps	Carbons	Seals
Surface Stresses	Elastomers	Gears
Film Formation	Fuel	Brakes
Oil Analysis		Brushes
Life		Cams
Filtration		Cables
Noise		Engine
Leakage		Transmission

Table 11

OFFICE OF NAVAL RESEARCH

TRIBOLOGY PROJECTS
A.W. Ruff

	PROJECT	INVESTIGATOR
1.	Transfer Films/Debris	W. Glaeser (Battelle)
2.	Wear-in/Microstructure	P. Blau (NBS)
3.	Thermal Effects/Brushes	[illegible]. Dow (N. Carolina State)
4.	Temperature Effects	D. Wilsdorf (Univ. of Virginia)
5.	Thermomechanical Failure	F. Kennedy (Dartmouth)
6.	Asperity Interactions	F. Ju (Univ. of New Mexico)
7.	Seal Materials	S. Karpe (NSRDC - Annapolis)
8.	Mild, Severe Wear Transition	L. Ives (NBS)
9.	Scuffing	K. Ludema (Univ. of Michigan)
10.	Surface Additives	N. Suh (MIT)

Table 12

NAVAL RESEARCH LABORATORY

TRIBOLOGY PROGRAMS
J.S. Murday

PROJECT	INVESTIGATOR
1. Deuterated Lubricants for Greater Stability	J. Capana
2. Thin Film Degradation in Instrument Bearings	R.L. Mowery
3. Miniaturized Sensors (in-line) Oxidation Monitor	R.L. Mowery
4. Ion Implantation and Surface Treatments for Wear Resistance	I. Singer
5. Tribology of Ceramics	C.M. Wu

Table 13

NSRDC ANNAPOLIS

FUELS AND TRIBOLOGY BRANCH

J. Dray

PROJECT		INVESTIGATOR
1.	Marine Tribology Block Program	J. Belt
2.	Mixed Lubrication Model	T. Daugherty
3.	Asperity Interaction Model	C. Pan
4.	Main Shaft Seal Improvement	T. Brown
5.	Filter Development for LM 2500 Engine	P. Strandell
6.	Fiber Optics Bearing Performance Monitor	G. Philips
7.	Pump Bearings for Deep Submarines	G. Philips
8.	Bearing Condition Monitoring	G. Philips
9.	Bearing Stave Materials Studies	T. Daugherty
10.	Marine Corps Tribology Program	R. McQuaid
11.	Synthetic Hydrocarbon Hydraulic Fluids	M. Bieberich
12.	Weapon Lubricant Reduction Program	J. Taylor
13.	Methods to Determine Lubricant Changes	R. McQuaid

Table 14

NAVAL AIR PROPULSION CENTER

Trenton

PROJECT		INVESTIGATOR
1.	Improved Fracture Toughness Bearing	R. Valori/Popgoshev
2.	Corrosion Resistant Propulsion Bearings	R. Valori/Popgoshev
3.	Lubricants and Materials for Advanced Propulsion Systems	A. D'Orazio
4.	Microtopographic Effects in Tribology	A. D'Orazio
5.	Lubricant Preconditioning Effects on Load Capacity	A. D'Orazio
6.	High Speed Counter Rotating Cylindrical Roller Bearings	R. Valori/Popgoshev
7.	Ceramic Bearing Development and Evaluation	R. Valori/Popgoshev

Table 15

NAVAL AIR DEVELOPMENT CENTER

TRIBOLOGY PROGRAMS

PROJECT	INVESTIGATOR
1. Fretting Wear, Lubricants Coatings	P. Kennedy
2. Intercalated Solid Lubricants	A. Conti
3. Deuterated Lubricants	N. Reibuck
4. Spline Wear	E. Jewel
5. Competitive Additive Adsorption	P. Kennedy
6. Corrosion Resistant Lubricants	L. Stallings
7. Water Base Solid Film Lubes	N. Reibuck
8. Grease Lubricated Helo Transmission	L. Stallings
9. Grease Evaluations/Tactical Vehicles	N. Reibuck

Table 16

NAVAL AIR ENGINEERING CENTER

PROJECT	INVESTIGATOR
1. Spectrometer Sensitivity for Oil Analysis	P. O'Donell

Table 17

NAVAL AIR SYSTEMS CMD

MATERIALS

Phil Weinberg

PROJECT	INVESTIGATOR
1. Ceramic Bearing Development and Evaluation	SKF Industries

Table 18

AF OFFICE OF SCIENTIFIC RESEARCH

CHEMISTRY DIVISION

A.J. Matuszko

PROJECT	INVESTIGATOR
1. Fluorocarbon Fluids Synthesis (High Temperature Lubricants)	R. Lagow (U. of Texas)
2. Fluorocarbon Additives	K. Pacionek (Ultrasystems)
3. High Molecular Weight Elastomers	D. Burton (U. of Iowa)

Table 19

AF AEROPROPULSION LAB
H. Jones

PROJECT		INVESTIGATOR
1.	Foil Bearings for Gas Turbine	R. Dayton
2.	HiSpeed Cyl Roller Bearings	J. Schrand
3.	Improved Fracture Toughness Bearing	J. Dill
4.	Bearing Research Advanced Concepts	R. Dayton
5.	Corrosion Resistant Bearings	J. Artuso
6.	Counter Rot. Roller Bearings	R. Dayton
7.	Seal Dynamics	-
8.	Improved T/E Damper	S. Drake
9.	Taper Roller Bearings	R. Dayton
10.	Solid Lubricated Bearings	J. Dill
11.	Magnetic Bearing Feasibility	-
12.	Dry Lube Gear Technology	-
13.	Expanded Capability Spectrographic Oil Analysis	-
14.	Lubrication/Analysis Techniques	-
15.	Engine Lubricant Development and Evaluation	A. Beane
16.	Fluids Research	P. Centers
17.	Lube Life Assessment	P. Centers
18.	In-Line Oil Monitors	L. Debrohun

Table 20

AF MATERIALS LAB

B. McConnell

	PROJECT	INVESTIGATOR
1.	High Temperature (600-700F) Gas Turbine Oils for Advanced High Performance Turbine Engines	C. Tamborski L. Gschwender
2.	High Performance Elastomeric Seals	W. Griffin/J. Sieron
3.	Wide Temperature Range Lubricants/Seals for Advanced Turbine Engines	L. Gschwender
4.	Nonflammable Hydraulic Fluids/Seals	C. Snyder
5.	Advanced Hydraulic System Materials	L. Gschwender
6.	Furdamentals of Solid Lubricated Ceramics	M. Gardos
7.	Solid Lubricants for Space Applications	K. Mecklenburg
8.	Solid Lubricant Powder Materials/ Technology for Application in Turbine Engine Rolling Element Bearings	K. Mecklenburg
9.	Surface Modification of Metal/Ceramic Substrates via Ion Implantation	K. Mecklenburg
10.	Traction Properties of Advanced Aerospace Lubricants	S. Sharma
11.	Traction Model Development	J. McCool

Table 21

U.S. ARMY RESEARCH OFFICE

SOLIO MECHANICS

F. Schmedeshoff

PROJECT	INVESTIGATOR
1. Surface Mechanics - Smooth Surfaces	F. Ling M. Dawson
2. Surface Mechanics - Finite Roughness	M. Murray S.F. Murray
3. Observations of Deformation and Wear Processes in SEM	S.F. Murray S. Calabrese
4. Elastostatic Charging in Sliding Contacts	S.F. Murray W. Holzhauer
5. Analysis of Worn Surfaces with IEM, LSI, PLIM, and SEM	J. Lauer
6. Surface Reaction Kinetics Related to Wear Processes	J. Hudwon
7. Transport Processes in the Contact Line Region	P. Wayner, Jr.

Table 22

ARMY RESEARCH OFFICE

MATERIAL SCIENCES DIVISION
G. Mayer

PROJECT	INVESTIGATOR
1. Metal/Lubricant/Polymer Interactions	M. Furey (VPI)

Table 23

ARMY MECHANICS AND MATERIALS RESEARCH CENTER

PROJECT	INVESTIGATOR
1. Advanced Gear and Bearing Materials	R. Middleton
2. Ceramic (SiN) Dies for Isothermal Forging	E.N. Kinas
3. Refractory Metal Coatings for Gun Tube Erosion	M. Levy S. Pan
4. Metal Matrix Composite Abrasion	P.R. Smoot

Table 24

MERADCOM

BELVOIR FUELS AND LUBRICANTS DIVISION
M. LePera

PROJECT

1. Effect of Fuel Components on Engine Wear
2. Relationship Between Grease Thickness and Base Oils
3. Universal Engine Oils
4. Lubrication Criteria for Advanced Engine Systems
5. Improved Fluids for Helo Transmissions
6. Nonflammable Hydraulic Fluids
7. DOD Long Life Grease
8. User Testing of Improved MIL-G-10924 Grease

Table 25

ARMAMENT R&D COMMAND

WATERVLIET ARSENAL

PROJECT	INVESTIGATOR
1. Mechanisms of Material Transfer Under Sliding Conditions	R. Montgomery
2. Design and Materials for Recoil Bearings	R. Montgomery

Table 26

U.S. ARMY ARMAMENT COMMAND

PICATINNY ARSENAL

PROJECT	INVESTIGATOR
1. Wear Resistance of Powder Metallurgy Tool Steels	J. Burlingame
2. Evaluation of Improved Gear Materials	J. Burlingame
3. Chromized Coatings for Nickel Alloy Gun Erosion	W. Ebihara
4. Low Temperature Deposition of Refractory Metals	W. Ebihara
5. Composite Coatings with Porous Nickel Plate	W. Ebihara

Table 27

AVIATION RESEARCH AND DEVELOPMENT CMD

FT. EUSTIS

PROJECT	INVESTIGATOR
1. In-line Oil Debris Monitor	B. Poteate

Table 28

NASA TRIBOLOGY BRANCH
D. Buckley

	PROJECT	INVESTIGATOR
1.	Synthetic Lube Structures (>300C)	M. Meador
2.	Additives/ZDP/TCP	D. Wheeler
3.	Lube Thermal Degradation	F. Morales
4.	Lube/Metal Catalyzation	W. Jones
5.	Plasma Coating Morphology	T. Spalvins/R. Avni
6.	Brake Materials Composites	R. Fusaro
7.	High Temperature Solid Lubes	H. Sliney
8.	Wear Resistant Sputter Coats	P. Aron
9.	New Solid Lube Structures (400C)	B. Good
10.	EHL Transitions Theory	B. Hamrock
11.	EHL Roughness	J. Tripp
12.	Transitions/Experimental	E. Kingsbury
13.	Ceramics (Rig & Theory)	T. Jacobson
14.	Amorphous Metal Friction	K. Miyoshi
15.	Adhesion Theory	J. Ferrante
16.	Static Friction Correlations	S. Pepper
17.	Fretting	K. Goto
18.	Erosion Wear	P. Roa
19.	Corrosion Wear	G. Reigsdorf
20.	Cavitation	P. Roa
21.	Gear Materials	D. Townsend
22.	Transmission Evaluations	E. Zaretsky
23.	Hybrid Transmission	S. Loewenthal
24.	Traction Drives	D. Parker

Table 29

NATIONAL SCIENCE FOUNDATION

ENGINEERING SCIENCE

E. Marsh

PROJECT	INVESTIGATOR
1. Metal Forming with Solid Coatings	W. Wilson (Northwestern U)
2. Wear Behavior of Laser Transformed Cast Iron	R.A. Molian (Iowa U)
3. Three-dimensional Effects in Fluid Film Lubrication	C. Ettles (RPI)
4. Engineering Research Equipment in Tribology	K.M. Marshek (U of Texas)
5. Investigation of Multi-facet Drill	S.M. Wu (U of Wisconsin)
6. Metallic Traction Rolling Contact	S. Kumar
7. Prediction of Surface Pitting in Gears	H. Cheng (Northwestern U)

Table 30

NATIONAL SCIENCE FOUNDATION

MATERIALS RESEARCH DIVISION

B. Wilcox

PROJECT		INVESTIGATOR
1.	Surface Layer Damage Due to Indentation	T.W. Chow U. of Delaware
2.	Wear Resistance of Hadfield Manganese Steel	W.C. Leslie U. of Michigan
3.	Basic Mechanisms of Sliding Friction and Wear	D.A. Rigney Ohio State U
4.	Role of Structure in Wear Process	J.J. Wert Vanderbilt U
5.	Role of Chemical Affinity in the Frictional Behavior of Ceramics	N.H. MacMillan Penn State U

Table 31

RECOMMENDATIONS TO NSF (5)
ASME

MODELING OF TRIBO-SYSTEMS

Tribo-elements are part of a larger mechanical system and the interactions among the tribo-elements and other components in the system are determining factors in the system performance. This modeling includes dynamic, thermal, chemical, nonlinear material properties, and real surface geometry effects. The modeling should include the full range of lubrication regime behavior (hydrodynamic, elastohydrodynamic, mixed film, boundary, and unlubricated). It should cover not only tribo-element behavior during successful system operation but also the limits of tribo-element behavior in terms of wear and various modes of failure.

MATERIAL BEHAVIOR IN TRIBO-ELEMENTS

The tremendous range of environmental conditions to which tribo-elements are subjected require a large variety of materials. The environments include thermal, chemical, and stress both steady and unsteady. Material development is a never ending frontier of tribology. Because the near surface region of material is of primary importance to Tribological applications not only the bulk material, but surface layers and surface modifications are important to materials studies in tribology.

TRIBO-SYSTEM DIAGNOSTICS

Tribo-element failures are often causes of mechanical system failure and downtime. The development of reliable on-line tribo-system performance monitoring techniques can help reduce unscheduled system downtime and therefore system reliability and productivity. On-site methods of monitoring and non-destructive testing in tribology should be developed.

TRIBO-TECHNOLOGY TRANSFER

Fundamental knowledge in Tribology must be transferred to the design and maintenance personnel to be of value. Computer database systems ("expert systems") should be developed to aid in the transfer of new information developed as well as existing tribological knowledge. Tribology as a field has many similarities in its state of development with those areas where advances in expert systems have been made (e.g., natural resource exploration and medical diagnostics) and would be a very appropriate field in which to advance the fundamental state of expert systems.

Table 32

NATIONAL BUREAU OF STANDARDS

METALLURGY OIVISION

A.W. Ruff

PROJECT		INVESTIGATOR
1.	Microstructure Effects in the Wear of cu/al Alloys	P. Blau
2.	Vacuum/Atmosphere Friction Studies	P. Blau
3.	Nickel Alloy Tribological Coatings	A.W. Ruff
4.	TEM Studies of Worn Microstructures	L. Ives
5.	Abrasion Protection with Solid Lubricants	L. Ives
6.	Mild/Severe Wear Transition	L. Ives
7.	Dynamic Hardness Measurement	R. Polvani
8.	Properties of Tribological Coatings	A.W. Ruff
9.	Effect of Material Properties on Galling	K. Bhansali

Table 33

NATIONAL BUREAU OF STANDARDS

INORGANIC MATERIALS DIVISION

S. Hsu

PROJECT	INVESTIGATOR
1. Standards for Recycled Oil	S. Hsu
2. Friction Mechanisms in Fluids	S. Hsu
3. Ceramic Tribology	S. Hsu

Table 34

DEPARTMENT OF ENERGY

OFFICE OF ENERGY RESEARCH

O. Manley

PROJECT		INVESTIGATOR
1.	Air Flow and Tire Rolling Resistance	W.J. Rae (CALSPAN)
2.	Piston Ring Friction and Vehicle Fuel Economy	D.P. Hoult (MIT)
3.	Loss Characteristics of Cord Rubber Composites	S.K. Clark (U of Michigan)
4.	Characterization of Bearing Surface Roughness	J.I. McCool (SKF)
5.	Friction Induced Vibrations	V. Aronov (IIT)

Table 35

DEPARTMENT OF ENERGY

OFFICE OF CONSERVATION AND RENEWABLE ENERGY
J. Eberhardt, T. Levinson, J.A. Carpenter,Jr.

	PROJECT	INVESTIGATOR
1.	Lubrication Qualities of the Constituents of Base Stock Oils	S.M. Hsu NBS
2.	Heats of Adhesion of Separated Fractions of Base Stock Oil	F. Lockwood Martin Marietta Lab
3.	Friction and Wear of Ceramics	F. Carignan Advanced Mechanical Technology
4.	Ceramic Friction Surface Analysis	C. S. Yust Oak Ridge
5.	X-Ray Methods for Analysis of Ceramic Wear Surfaces	C.R. Houska Virginia Polytechnic
6.	Hot Spots and the Theory of Ceramic Wear	W. Winer Georgia Tech
7.	Tribological Coatings	M. Kaminsky Argonne
8.	Assessment of ECUT Role Tribology	J. A. Carpenter, Jr, ORNL C.H. Imhoff, PNL
9.	Tribology Energy Sinks Transportation/Utility	D.F. Wilcock Mechanical Technology
10.	Tribology Energy Sinks Industrial	R. Erickson Battelle Columbus
11.	Tribology R&D Private Industry	L.B. Sibley M. Zlotnick, Tribology Consultants
12.	Tribology R&D in Government	M.B. Peterson Wear Sciences

Table 36

PROPOSED ELEMENTS

ECUT TRIBOLOGY PROGRAM

High Temperature Liquid and Solid Lubricants

Surface Modification for Improved Tribological Coatings

Exploration of Advanced Lubrication Concepts

Characterization and Testing of Tribosystems

Development of Friction and Wear Models

Diagnostics for Performance Monitoring

Development of a Tribology Data Base

Table 37

SUBJECT CLASSIFICATIONS

1.	Boundary Lubrication	8
2.	Friction and Wear Failure Mechanisms	37
3.	Basic Mechanics/Thermal Behavior	10
4.	Surface Analysis and Test Techniques	7
5.	Concentrated Contacts	5
6.	Lubricants/Hydraulic Fluids	33
7.	Solid Lubricants	14
8.	Materials and Coatings	36
9.	Failure Analysis/Diagnostics	8
10.	Erosion Cavitation	4
11.	Sliding Bearings	4
12.	Power Transmission/Traction Devices	2
13.	Gears	0
14.	Metal Working Tribology	0
15.	Engine Tribology	4
16.	Filtration	1
17.	Fluid Film Bearings	1
18.	Rolling Element Bearings	11
19.	Seals	6
20.	Electrical Contacts	1
21.	Miscellaneous Components & Studies	8

Table 38

PROGRAM OBJECTIVES

1.	Long Life, Low Maintenance Failure-Free Machinery	60
2.	Fundamental Understanding	55
3.	High Temperature Lubrication	33
4.	Materials Development for Improved Performance	17
5.	Design Predictability	5
6.	Energy or Materials Conservation	10
7.	Improved Cost Effectiveness	3
8.	Quiet Operation	1
9.	Improved Health and Safety	1

Table 39

ENERGY RELEVANCE

High Temperature Lubrication	41
Studies of Lubricated Friction Reduction	22
Energy Efficient Design and Operation	13
Development of Improved Tribomaterials	11
Understanding Tribological Failures	7

Table 40

APPLICATIONS

Rolling Bearings	30
Engine Lubrication	22
Seals	12
Transmissions	6
Gears	5
Fluid Film Bearings	4
Rings	4
Tools/Dies	3
Gas Bearings	2
Bushings	2
Sliding Contact	2
Brakes	2
Brushes	2
Tires	1
Splines	1
Valves	1
Cables	1
Couplings	0
Clutch	0
Cams	0

Table 41

MATERIALS

Metals	74
Fluid Lubricants	31
Ceramics	22
Coatings	18
Additives	12
Greases	11
Solid Lubricants	10
Polymer	9
Hydraulic Fluids	4
Carbons	3
Elastomers	3
Polymer Composites	2
Metal Composites	1
Fuel	1

Table 42

HIGHLIGHTS

1. FUNDAMENTALS

   1. Friction of Fluid Components of Oils and Solid Surfaces
   2. Improved Definition of Wear and Surface Damage Mechanisms
   3. Microelastohydrodynamics and Roughness Effects in Lubrication
   4. Thermoelastic Surface Models of the Failure Process

2. CERAMICS

   1. New Test Rigs to Study Ceramic Friction and Wear
   2. Silicon Nitride Rolling Contact Bearings Materials Being Evaluated
   3. Structure Effects in Friction and Wear Being Investigated

3. ENGINE OILS

   1. Expand Temperature Capabilities to 600F (Silahydrocarbons)
   2. Evaluation of Friction Modified Engine Oils
   3. Universal Engine Oils Being Evaluated
   4. Effect of Fuel Components on Engine Wear

4. SOLID LUBRICANTS

   1. Double Oxides, Dichalcogenides, Intercalated Layer Lattice Compounds, and Mixed Fluorides Being Considered as High Temperature Solid Lubricants
   2. Solid Films, Composites, and Cage Supply Techniques Being Studied; No Efforts on Powder, Stick, or Vapor Lubrication

5. COATINGS

   1. Solid Lubricants to 1500F
   2. Controlled Composition/Thickness Ceramics
   3. Composite Solid Lube/Wear Resistant Coatings
   4. Ion Implanted Corrosion and Wear Resistance Surfaces

6. POLYMER AND METAL COMPOSITES

   1. High Temperature, Long Wear Life, Polyimide Composites

7. ROLLING CONTACT BEARING MATERIALS

   1. Fracture and Fatigue Resistant Materials
   2. Corrosion Resistant Materials and Coatings

8. ROLLING CONTACT BEARINGS

   1. 3 Million DN Bearings
   2. Solid Lubricated and Dry Operation

9. GAS BEARINGS

   1. Foil Bearings for Wide Temperature Ranges

APPENDIX 1

PROJECT DESCRIPTIONS

Title

A Study of the Chemical Mechanism in Lubrication

Investigators	Organization
S. Hsu	National Bureau of Standards

Sponsor	Schedule and Funding
Department of Energy Office of Basic Energy Sci. Engineering Research Program	FY 83 FY 84 50K FY 85 60K FY 86 90K FY 87 FY 88

Classification

Type Research		Subject	1
Type Motion		Objective	2
Variables		Energy Relevance	3
Process			
Materials			
Application			

Objective

Determine role of chemical reactions in friction and wear.

Description

Chemical mechanisms in concentrated contacts under lubricated conditions are largely not understood. This project will study systematically the nature and the extent of influence of chemical reactions in the contact zone on friction and wear. Surface topography of worn surfaces will be characterized to predict oil film thickness under different speed, load ranges in a NBS developed four-ball wear tester. Micro-asperity temperatures and the wear film temperatures of the oil film will be calculated using Archard-Jaeger equations as well as finite-element analysis techniques. Pure model structures will be used as lubricants to test the effects of chemical functional groups on friction and wear. Chemical kinetic studies on tribochemical reaction rate constants for various classes of compounds under wearing conditions will be compiled. A theoretical model linking elastohydrodynamic theories to tribochemical rate constants with materials properties will be attempted to predict lubrication effectiveness a priori.

Title

Heats of Adhesion of Separated Fractions of Base Stock Oils

Investigators	Organization
F. Lockwood	Martin Marietta Laboratories
Sponsor	**Schedule and Funding**
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion
Variables - Chemical Properties
Process - Film formation
Materials- Fluid lubricants
Application

Subject 1
Objective 2,6
Energy Relevance 3

Objective

To correlate frictional behavior with basic surface properties of materials such as contact angle heats of adsorption and work of adhesion

Description

The heat of immersion of base stock oils on 52100 steel surfaces is being determined from contact angle measurements and surface tension values for these fluids as a function of temperature. The contact angle is measured using a contact angle goniometer, and the surface tension of the fluid can be calculated from the drop profile.

Title	
Surface Reaction Kinetics Related to Wear Processes	
Investigators J.B. Hudson	**Organization** RPI-Materials Engineering
Sponsor ARO-Mechanics	**Schedule and Funding** FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Chemical Properties
Process - Film formation
Materials - Metals, fluid lubricants, additives
Application

Subject 1
Objective 2
Energy Relevance

Objective

To understand mechanisms of lubrication and surface film formation.

Description

Studies are being carried out in three related areas.

The first area of research involves the detailed study of the kinetics of surface chemical reactions in systems pertinent to the wear environment. At present we are studying the decomposition of simple hydrocarbons on a pure iron surface. As time permits, similar studies will be carried out with iron alloy samples and with other vapor species such as nitrogen- or boron-containing molecules. Results of these studies will increase our knowledge of the interaction between lubricant and metal during wear and provide information on the kinetics of additional hardening processes. The second area includes the effect of lubricant additives and wear surface composition on the rate of uptake of lubricant components into the bulk of the solid. The results obtained in this engineering study will complement the information obtained in the more fundamental measurements of surface reaction kinetics. Thirdly, in addition to the projects outlined above, studies are in progress of the near-surface composition of engineering materials which have been subjected to in-service wear. This study is being made using the scanning Auger microprobe and will provide the final link between the fundamental studies of surface reaction kinetics, through the studies of samples subjected to wear in the laboratory environment, to the behavior experienced in the real world. It is expected that this broad approach to the problem will lead to criteria for the optimum choice of lubricant and surface chemistry in the prevention of wear.

Title

Surface Mechanics - Engineering Surfaces of Finite Roughness

Investigators	Organization
M.C. Murray S.F. Murray	RPI Mechanical Engineering
Sponsor	**Schedule and Funding**
ARO - Mechanics	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Basic	Subject	1
Type Motion	- Lubricated sliding	Objective	2
Variables	- Finish	Energy Relevance	3
Process	- Fraction, lubrication		
Materials	- Metals		
Application			

Objective

To determine the effect of surface texture on mixed film lubrication.

Description

Currently, there is a lack of experimental evidence relating the effect of surface texture to the performance of a sliding system. Theoretical work has produced simple models which assume homogeneous material properties and idealized surface features. However, experimental verification of the validity of these models has not been realized. For this reason, basic sliding tests are being run in the mixed film regime of lubrication using a pin-on disc machine in conjunction with computer-aided profilametry (CAP). Through the use of CAP, statistical properties of the surface can be determined and compared with experimental results. In this manner, the important geometric properties of the sliding surfaces can be identified.

Two material combinations,bronze on steel and steel on steel, have been evaluated with two different lubricants, methylphenyl silicone and mineral oil. Because the silicone oil is a poor boundary lubricant for steel sliding on steel, but is effective in lubricating bronze on steel, the importance of mixed film lubrication is emphasized by the results. The use of CAP also provides a means for discriminating between the effect of initial surface texture and the texture of surfaces developed by run-in.

Title

Surface Mechanics - Smooth Surfaces

Investigators	Organization
F.F. Ling M.C. Dawson	RPI - Mechanical Engineering
Sponsor	**Schedule and Funding**
Army Research Office Mechanics	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Physical properties
Process - Friction
Materials
Application

Subject 1
Objective 2
Energy Relevance

Objective

To understand frictional behavior of smooth surfaces.

Description

Ideally, solid surfaces in relative motion can be visualized as smooth, layered structures. These layers could consist of a top layer of adsorbed or chemisorbed lubricant covering a layer of metal oxide. Below the oxide is a polished Beilby layer which is followed by a region of gross deformation that gradually fades into undeformed metal.

Three aspects of this problem are being investigated: First, being conducted is a systematic study of the complex nonlinear thermoelastic equations with the intent of finding a "boundary layer" set of equations as an approximation. Second, analytic methods of prescribing surface activities are being pursued to include relevant conditions. Third, the role of anisotropy in near surface behavior is being considered with the goal of establishing near-surface approximations that would permit better insight into the physical processes involved in a particular case, say, high speed sliding.

Title

Fundamental Studies on the Effects of Thin Polymeric Surface Films in Reducing Fretting Corrosion and Wear.

Investigators	Organization
N. Eiss M. Furey H. Mabie	VPI-Mechanical Engineering
Sponsor	**Schedule and Funding**
Army Research Office Material Science	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables- Chemical properties
Process - Film formation
Materials - Fluid lubricants
Application

Subject 1
Objective 2
Energy Relevance

Objective

To understand the mechanisms and the role of polymer film formation in lubrication

Description

The primary objective of this proposed research is to investigate in a systematic way the effects of thin polymeric surface films on fretting corrosion, metallic contact, and wear under both oscillatory and unidirectional sliding contact; emphasis will be on fretting phenomena in steel-on-steel systems. Variables to be studied will include polymer type and structure, film thickness, and mode of film-formation--including the "in situ" formation of protective polymeric films on rubbing surfaces proposed by one of the principal investigators.

Title

Friction Mechanisms in Fluids

Investigators	Organization
S. Hsu	NBS

Sponsor	Schedule and Funding
DOE ECUT	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables-
Process - Friction, wear
Materials - Metals
Application

Subject 1
Objective 6
Energy Relevance 3

Objective - The objective of this study is to develop and standardize measurement methods of friction and wear between interacting surfaces under different conditions (temperatures, surface topography, materials combinations). Through these measurements, it is hoped that the nature of friction and wear mechanisms can be understood and modelled.

Description

State-of-the-art analytical techniques will be used to identify/isolate the key components in base oils that affect the oxidation stability and friction and wear characteristics of lubricants. Model compounds will be used to confirm the identification. An initial correlation model will be used to systematically assess the effects of molecular structures on oxidation stability, and friction and wear.

Title

Development of a Model for Mixed Lubrication

Investigators	Organization
T. L. Daugherty	DT-NSRDC Annapolis

Sponsor	Schedule and Funding
NSRDC - Bethesda	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Finish geometry
Process - Lubrication
Materials - Fluid lubricants
Application - Fluid film bearings

Subject 1
Objective 2
Energy Relevance 3

Objective

To develop a model for sliding surface bearings which extends hydrodynamic theory into the region of mixed lubrication.

Description

Detailed studies are being conducted to develop a finite element model incorporating solution to Reynolds, the energy, and elasticity equations. This model will be applied to a tilt-pad thrust bearing with longitudinal roughness and will include variable viscosity, side leakage, introduction of various surface shapes, skewed roughness distribution, and roughness on both the bearing and mating surfaces.

Experiments to test the model are being conducted on tilt-pad thrust bearings.

Title

A Study of the Oxidational Theory of Mild Wear, Based on Oxidational Kinetics, Surface Analysis and Surface Modifications Applied to Stainless Steels

Investigators	Organization
T.F.J. Quinn (M.E.) R.F. Hochman (CE/MET)	School of Mechanical Engineering School of Chemical Engineering/Metallurgy Georgia Institute of Technology
Sponsor	**Schedule and Funding**
GTRI	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic	Subject	2
Type Motion - Unlubricated Sliding	Objective	2
Variables - Load/Pressure, Velocity, Temp	Energy Relevance	2
Process - Friction and Wear		
Materials - Metals		
Application - Sliding Contact, Engines		

Objective

To understand, predict, and possibly reduce the wear of stainless steels.

Description

Experiments are being carried out on two pin-on-disk wear machines. One is providing information about the 'hot-spots' formed when stainless steel pins are worn against a sapphire disc, whereas the other is providing thermal and wear data about the wear of stainless steel pins against stainless steel discs. Some experiments are planned with specimens that have had their surfaces modified by an ion-implantation technique. The results of these experiments are being correlated with parallel static oxidation tests via the oxidational wear theory.

Title

The Oxidational Wear of Low-alloy Steels at Elevated Temperatures

Investigators	Organization
T.F.J. Quinn	School of Mechanical Engineering Georgia Institute of Technology
Sponsor	**Schedule and Funding**
GTRI (E-Funds)	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated Sliding
Variables - Load/Pressure, Velocity, Temp
Process - Friction and Wear
Materials - Metals
Application - Sliding Contacts

Subject	2
Objective	2
Energy Relevance	1

Objective

To be able to understand and possibly predict the mild wear behavior of low alloy steels at elevated temperatures.

Description

An elevated temperature pin and disk wear machine is being used to study the wear patterns of low-alloy steels (i.e., the graph of wear rate versus load) as functions of both speed and disc temperature. An oxidational wear theory (modified to allow for oxidation when a given part of the surface is not in contact) is being applied to these results.

Title

Synthesis and Structure Property Studies of Toughened Epoxy Resins via Functionalized Polysiloxanes

Investigators	Organization
J.E. McGrath G.L. Wilkes N.S. Eiss, Jr.	Virginia Polytechnic Institute and State Univ
Sponsor	**Schedule and Funding**
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unidirection Sliding, Unlubricated
Variables - Load, Distance, Physical Properties
Process - Friction, Wear, Fatigue
Materials - Polymers
Application - Sliding Contact

Subject	2
Objective	2
Energy Relevance	2

Objective

To determine the friction and wear properties of polysiloxane modified epoxy materials.

Description

The incorporation of rubbers in epoxies has improved the fracture toughness of the epoxies. To improve the temperature range over which the rubber modifiers are effective, polysiloxane curing agents have been used instead of CTBN or ATBN rubbers. During curing the polysiloxane migrates to the surface to create a low surface energy surface.

The friction and wear characteristics of the polysiloxane modified epoxies have been measured in a pin (steel ball)-on-disk (epoxy) experiment in which the surface stress is varied by choosing various combinations of load and ball radius. With surface stresses below the yield strength of the epoxy, the wear track initiates after several hundred disk rotations. Measurements include friction, no. of disk rotations to wear initiation, wear rate after initiation, and the relation of segregated elastomeric domains to the initiation of the wear track. Variables include the percent polysiloxane in the epoxy and the chemical composition of the polysiloxane.

Title

Friction and Wear of Polymers in Oscillatory Motion

Investigators	Organization
F.E. Kennedy	Dartmouth College

Sponsor	Schedule and Funding
NSF-Mechanical Systems	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Reciprocating
Variables - Load, Velocity, Surface Finish, Temp
Process - Friction, Wear
Materials - Polymer
Application - Bushing

Subject 2
Objective 2
Energy Relevance

Objective

To understand the mechanisms of polymer wear in reciprocating motion and the influence of variables on wear and friction.

Description

This project involves four tasks:
1. An experimental study of the effect of surface roughness, load, oscillation amplitude, and velocity on friction, wear, and third body formation in oscillatory motion of polyethylene against stainless steel.
2. An experimental study of the role of temperature in friction, wear, and third body formation in oscillatory motion of polyethylene against stainless steel.
3. Analytical prediction of surface temperatures and near surface temperature gradients in sliding of polymer against metal.
4. Development of a qualitative model to describe wear mechanisms and third body formation in oscillatory motion of polymers against metals.

Title

Dynamic Friction of Metals on Ice

Investigators	Organization
F.E. Kennedy N.P. Huber	Dartmouth College

Sponsor	Schedule and Funding
U.S. Army Cold Regions Research & Engineering Lab	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables - Temperature, Surface Finish, Velocity
Process - Friction, Surface Temp
Materials - Metals, Ice
Application

Subject	2
Objective	2
Energy Relevance	3

Objective

To increase the understanding of the effect of surface finish and temperature on dynamic friction of metals on ice.

Description

Dynamic friction experiments are being performed using cylindrical metallic rods of different surface roughnesses pressed against a rotating cylinder of ice. Temperature is being varied by independently controlling ambient temperature, metallic bulk temperature, and sliding velocity. Concurrently with the test program, a numerical thermal analysis is being carried out to get a better understanding of the sliding surface temperature and its effect on friction.

Title

Fretting Studies

Investigators	Organization
K. Goto	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Reciprocating
Variables - Environment
Process - Fretting
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To determine basic mechanisms of fretting.

Description

A fretting test rig has been set up which has provisions for environmental control including evacuation. This rig is being used to evaluate fretting wear and damage with elemental metals using different environments.

Title

Wear Behavior of Laser Transformed Cast Iron

Investigators	Organization
R.A. Molian	Iowa University

Sponsor	Schedule and Funding
NSF - Mechanical Systems	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Basic
Type Motion - Sliding, impact
Variables
Process - Wear, surface damage
Materials - Metals
Application

Subject 2
Objective 4
Energy Relevance

Objective

Description

A study is being conducted to determine the fatigue and wear behavior of laser transformed hardened gray and ductile cast irons.

Title

Investigation of Wear of Ceramics on Ceramics for High Temperature Application

Investigators	Organization
T.F.J. Quinn W.O. Winer	School of Mechanical Engineering Georgia Institute of Technology
Sponsor	**Schedule and Funding**
DOE (ECUT Program)	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated Sliding
Variables - Load/Pressure, Velocity, Temp
Process - Friction and wear
Materials - Ceramics
Application - Sliding contact, Engines

Subject 2
Objective 2,3
Energy Relevance 1

Objective

To study the wear of selected ceramic materials and its relation to 'hot spot' temperatures.

Description

Si_3N_4, PSZ, and other ceramic pins are being slid against Al_2O_3(sapphire) discs at various loads in order to deduce the wear pattern (i.e., wear rate versus load) as a function of speed. The roles of plastic flow and chemical reaction at the surfaces during sliding are being examined. The direct measurement of 'hot spots' by infrared detection through the transparent sapphire is an important feature of these studies.

Title	
ZETa-Corrosion - A Proposed Wear Mechanism	

Investigators	Organization
T.R. Beck	Electrochemical Technology Corp.

Sponsor	Schedule and Funding
DOE Office of Energy Research	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Chemical properties
Process - Wear
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

Evaluate the Zeta corrosion mechanisms in wear

Description

Hydraulic control valves in commercial jet airplanes have been subject to "erosion" in service with phosphate ester fluids. This "erosion" process, now solved, was caused by corrosion from generation of electrokinetic streaming currents (zeta corrosion). An equation to calculate zeta corrosion current densities that would be generated on the surfaces of lubricated journal bearings and roller bearings had been developed. Many aspects of bearing wear reported in the literature appear to be qualitatively consistent with the zeta corrosion mechanism.

A program is under way to test the correctness of the zeta corrosion mechanism and develop a quantitative basis for application to minimize wear of lubricated machinery.

Title

Investigation of Role of Subsurface Zones in Wear of Materials

Investigators	Organization
R. Solecki S. Rice	Univ of Connecticut
Sponsor	**Schedule and Funding**
DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding & impact
Variables - Composition, stress, velocity
Process - Surface damage
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To characterize the surface damage from sliding and impact.

Description

Experimental characterization of the formation, composition and morphology of both subsurface zones and wear debris for material pairs making solid contact both in sliding and repetitive impact modes; experimental investigation of the roles of nominal contact stress, relative sliding velocity and effective contact stiffness of subsurface zone formation, composition and morphology; analytical prediction of the equilibrium configuration and subsurface morphology for a work hardening elastoplastic material subject to give load cycling and temperature distributions; model development which allows prediction of composition and morphology of subsurface zones for selected materials subjected to both sliding and impulsive contact; and postulation and experimental investigation of in situ development of wear resistance.

Title

Interactions Between Friction Induced Vibrations and Wear

Investigators	Organization
V. Aronov A.F. D'Souza	IIT - Mechanical Engineering
Sponsor	**Schedule and Funding**
DOE - Office of Energy Research	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Rigidity
Process - Friction
Materials
Application

Subject 2
Objective 2
Energy Relevance

Objective

To investigate the interaction between friction induced vibration and wear.

Description

The objective of this project is to improve our understanding of the influence of system rigidity and vibrations on friction and wear. There is increasing evidence, both from our previous studies and from the very limited literature available, that in addition to the role of various physical, chemical and mechanical parameters, the dynamic characteristics of the equipment or machinery involved also have a significant influence on wear. This project involves an interdisciplinary study to investigate the interactions between friction-induced vibration and wear. The major experimental parameters are the normal and tangential rigidity in a sliding system and different lubricating conditions, with observations and analysis of wear surfaces and particles with scanning electron microscopy. Among the subjects being studied are the regimes of load and speed at which transitions from mild to severe wear occur with self-excited vibrations. A stability theory is being developed to explain the onset of different types of vibrations. Physical and mathematical models of oscillations are also being developed, including the effects of surface alterations due to wear.

Title

Experimental Observations of Surface Deformation and Wear During Sliding

Investigators	Organization
S.F. Murray S.J. Calabrese	RPI-Mechanical Engineering
Sponsor	**Schedule and Funding**
ARO-Mechanics	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Time, composition
Process - Damage
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To define deformation process in sliding contacts

Description

Basic pin-on-cylinder sliding tests have been run in the chamber of a scanning electron microscope (SEM) to permit direct observations--at high magnifications-- of the wear processes involved. The sliding metal specimens were metallographically polished and lightly etched prior to testing so that the effect of the alloy microstructures could be observed. The test alloys included: low and high carbon steels, stainless steels and copper-based alloys. Considerable insight into the process of surface deformation and wear has been gained with this technique. These experimental sliding evaluations are being expanded to include the behavior of solid lubricant films, thin metal plating and thin, condensed films of surface-active compounds.

Related studies of the behavior of a single polycrystalline abrasive grit sliding against a hardened M-50 tool steel cylinder in the SEM have also shown that much can be learned regarding metal removal and metal finishing processes, such as grinding and lapping by observing the character of the wear track produced by the abrasive.

Title

Role of Structure in Wear Process

Investigators	Organization
J.J. Wert	Vanderbilt University
Sponsor	**Schedule and Funding**
NSF-Materials Science	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated Sliding
Variables - Structure
Process - Wear
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To determine the effect of specific microstructural parameters on wear mechanisms.

Description

This is a fundamental study on the effect of specific micro-structural parameters (i.e., stacking fault energy, degree of chemical order, and lattice instabilities--such as displacive phase transformations and grain boundaries) on mechanisms of wear of metallic materials. There are two approaches to this research: (1) microscopic determination of the lattice defect structure and distribution on lightly surface deformed specimens, using analytical and high voltage electron microscopy; and (2) macroscopic-direct correlation of the microscopic observations with material loss rates during wear and coefficient of friction measurements on identical materials. The materials under study include Cu-Al, Fe-Ni and Fe-Mn alloys. It is expected the results of this research will lead to an understanding of wear mechanisms of metallic materials, and serve as the basis for the synthesis of wear-resistant alloys.

Title

Basic Mechanisms of Sliding Friction and Wear

Investigators	Organization
D.A. Rigney	Ohio State University

Sponsor	Schedule and Funding
NSF Materials Sciences	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Physical properties
Process - Friction
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance 3

Objective

To establish basic mechanisms of sliding friction and wear.

Description

The materials systems to be tested include Cu-Be (an age-hardening system), Cu-Al_2O_3 and Cu-Cu_2O (dispersion-hardened systems), dual phase steels (for comparison with fatigue data), dilute aluminum alloys, and coated systems (e.g. Cd or Sn on Cu). Our successful friction model will be extended so that it can be easily used with experimentally determined stress-strain curves. Worn samples and debris will be studied with the aid of a wide range of analytical techniques, including microhardness tests, X-ray diffraction, SEM, TEM, STEM, EDS, and WDS. The actual sequence of the experiments, and the analysis of the results will be guided by the predictions resulting from our energy-based model of friction, and by our recent results on the relation of the accumulation of transfer material to both friction and wear.

Work is being extended to single crystal copper and HCP-Co, using a method for measuring local orientations changes caused by sliding. The method, which we developed, uses automatic analysis of STEM Kikuchi patterns by a mini-computer.

Title

The Effect of Aluminum on the Work Hardening and Wear Resistance of Hadfield Manganese Steel

Investigators	Organization
W.C. Leslie H.R. Larson	University of Michigan
Sponsor	**Schedule and Funding**
NSF Materials Sciences	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding, impace
Variables - Composition
Process - Abrasion, erosion
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To determine the effects of aluminum additions on the work hardening and gouging wear resistance of Hadfield manganese steel.

Description

In a previous study, it was shown that the work-hardening characteristics of this steel are due to dynamic strain aging produced by the reorientation of Mn-C couples in the cores of dislocations. Others have shown that the gouging wear resistance of this steel increases with carbon content. Therefore, the wear properties of the alloy may be improved, while retaining a tough, single-phase austenite structure, by adding a substitutional solute that lowers the activity of carbon in austenite. The effects of additions of aluminum to the steel will be examined. A series of alloys containing up to 1.75%C and 4% Al will be cast. The work hardening characteristics, high-stress abrasion resistance, gouging abrasion resistance and toughness of the alloys will be determined. Experiments will be performed to measure the effect of aluminum on the activity of carbon in the austenite of Hadfield steel and to determine the rate of precipitation of carbides from solid solution. This is the first year of a new three-year continuing grant.

Title

A study of Surface Layer Damage Due to Indentation Fatigue

Investigators	Organization
I.G. Greenfield T.W. Chow	University of Delaware
Sponsor	**Schedule and Funding**
NSF - Mechanical Systems	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Impact
Variables - Physical Properties
Process - Erosion
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To study basic mechanisms of impact erosion.

Description

The proposed research during the first two years was intended to gain some fundamental understandings of material fatigue under repeated impact by indenters. A near-rigid indenter was used to repeatedly impact a fixed location on a target material to perform simplified yet highly controlled experimentation. The aim of the research was to understand the complete process of crack initiation, growth and eventually the spalling of the surface layer of the indenter material.

The objective of the following two years' proposed research was to further the understanding of surface layer damage due to indentation fatigue. Both normal and oblique impacts were performed with single and multiple indenters to assess the interactions among neighboring impacts. Key mechanical properties examined were plastic deformation, work-hardening, crack nucleation and propagation, and adiabatic heating during repeated impacts. Particular attention was paid to the synegistic effects of strain-hardening and residue stresses under cyclic loading.

The main goal of the research during the next year was to combine the physical observations made in the past into a basic model of erosion.

Title

Prediction of Surface Pitting in Gears

Investigators	Organization
H. Cheng	Northwestern University
Sponsor	**Schedule and Funding**
NSF-Mechanical Systems	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Basic
Type Motion - Lubricated Slide/roll
Variables - Finish, Time
Process - Life
Materials - Metals
Application - Gears

Subject 2, 13
Objective 2
Energy Relevance 4

Objective

To develop an analytical model which predicts surface pitting.

Description

An analytical model has been set up which predicts life based upon fracture mechanics. Inputs are roughness, lubrication (λ) and texture. The probability of pitting is predicted based upon an initial distribution of cracks.

Title

Mechanisms of Wear in Single and Two Phase Materials

Investigators	Organization
N. H. MacMillan	Penn State

Sponsor	Schedule and Funding
DOE-ECUT	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated
Variables - Composition, structure, physical properties
Process - Wear
Materials - Ceramics
Application

Subject 2
Objective 3
Energy Relevance 1

Objective

To study effect of the nature of surface and relative motions on wear.

Description

The aim of this project is to study the way in which wear processes depend on (i) the natures--i.e., the microstructures and the elastic-plastic responses--and (ii) the relative motions of bodies which come into contact. To this end specimens of four monophasic materials (a high Pb silicate glass, Al_2O_3, Pb and Cu) and four diphasic composites of tailored microstructure made from these (containing 30-80 vol.% of $\sim$200 μm particles of either Al_2O_3 or Cu in matrices of either Pb or the high Pb silicate glass) have been prepared and characterized in various ways, and are now being subjected to rolling-tumbling-sliding wear, slurry erosion and low-velocity solid particle erosion in a variety of specially constructed apparatus, using angular WC-8 wt.& Co particles approximately 500 μm in diameter as the erosive medium. Various supporting experiments are also to be undertaken.

Title

Wear Resistance of Powder Metallurgy Tool Steels

Investigators	Organization
J. Burlingame	AARDCOM-Picatinny
Sponsor	**Schedule and Funding**
AARDCOM-Picatinny	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Unlubricated sliding
Variables - Physical properties, structure
Process - Wear
Materials - Metals
Application - Tool/die

Subject	2
Objective	2
Energy Relevance	2

Objective

To evaluate the effect of structure on wear resistance.

Description

Studies are being conducted to determine the effects of different processing techniques on wear. Powder metal tool steels are being prepared with different structures. Basic friction and wear data is being obtained as well as physical property data. Materials are also made into punches and evaluated as production punches.

Title

Mechanisms of Material Transfer During Sliding

Investigators	Organization
R. Montgomery	ARRADCOM Research Branch Watervliet
Sponsor	**Schedule and Funding**
Benet WPN Lab	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Composition
Process - Friction, wear, adhesion
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To understand transfer and adhesion mechanisms

Description

Pin on disk experiments (dry) are being conducted at high velocity and short times (100 m sec). Friction, wear, and transfer patterns are recorded for metals and plastics.

Title

Study of Corrosive Wear

Investigators	Organization
G. Rengsdorff	NASA

Sponsor	Schedule and Funding	
NASA	FY 83 FY 84 FY 85	FY 86 FY 87 FY 88

Classification

Type Research - Basic	Subject	2
Type Motion - Lubricated sliding; reciprocating	Objective	2
Variables - Environment	Energy Relevance	
Process - Friction, wear		
Materials - Metals		
Application		

Objective

To determine the role of corrosion in the friction and wear of metals.

Description

A fundamental experimental investigation is being conducted to determine the interaction of various corrosive media with iron during simple sliding friction and wear experiments. A slow speed reciprocating test device is used to study friction and wear in corrosive media such as acids, bases, and salt solutions in water. Changes in friction, wear and surface morphology are determined as a function of concentration. Metals being stucies are Fe and Ni in sodium hydroxide solutions.

Title

Frictional Behavior with Amphorous Metals

Investigators	Organization
K. Miyoshi	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Physical properties, composition
Process - Friction, life
Materials - Metals
Application

Subject 2
Objective 4
Energy Relevance 2

Objective

To determine the friction and wear characteristics of metallic glasses.

Description

A variety of studies have been conducted on metallic glasses. This improved friction behavior of such materials is due to their better mechanical properties. Friction coefficients are related to oxide species on the surface. For example, at temperatures above 500C the low friction is due to formation of BN films. At lower temperatures other oxide films are formed which change the friction and wear behavior.

The work of Miyoshi has covered a broad scope of materials. In addition to the ferrites and silicon carbide, he is studying the performance of both oxide and nonoxide ceramics, amorphous metals, and interfacial adhesion of plasma deposited coatings.

Title

Static Friction Effects at the Metal Ceramic Interface

Investigators	Organization
S. Pepper	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Environment
Process - Friction
Materials - Metal ceramic
Application

Subject 2
Objective 2
Energy Relevance

Objective

To determine how character of surface contributes to metal ceramic bonding.

Description

Static friction studies in controlled atmospheres are being used to measure the bond strength between metals and ceramics. Adsorbed species such as H_2 or H_2O are found to lower friction substantially. Friction is reduced more on SiO_2 than on Al_2O_3.

Title

Role of Surface Films in Mild/Severe Wear Transitions

Investigators	Organization
L. Ives	NBS

Sponsor	Schedule and Funding
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables- Load
Process - Friction wear
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance 4

Objective

To study the effect of materials properties on transitions

Description

SEM and TEM are being used to study microstructure effects which occur at the mild/severe wear transition and how material properties affect it.

Title

Vacuum Friction and Wear

Investigators	Organization
P. Blau	NBS

Sponsor	Schedule and Funding
NBS	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Atmosphere
Process - Friction
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To study the effect of controlled environments on friction and wear problems.

Description

Work is nearing completion on construction of a controlled atmosphere tribometer with high vacuum capabilities. Within the next four months, computer interfacing of the device should be completed. Studies of surface contamination effects and controlled atmospheres on long-term transitions in wear mode and on running-in behavior are planned, to isolate the influence of combinatory factors responsible for net friction and wear values. Changes in the contact conditions during the tests (particularly the gas atmosphere composition) are also planned for systematic study.

Title

Effects of Coatings on Hardness/Friction Relationships

Investigators	Organization
P. Blau	NBS

Sponsor	Schedule and Funding
NBS	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Reciprocating
Variables -
Process - Friction
Materials - Metals Coatings
Application

Subject 2
Objective 2
Energy Relevance 3

Objective

To understand the relationship between hardness and deformational frictional behavior.

Description

Metal and nonmetal coatings are applied to pure well characterized metal surfaces. Friction and wear is measured and correlated with quasi states and scratch hardness values.

Title

Bi-Directional Effects in the "Run-in Process"

Investigators	Organization
P. Blau	NBS

Sponsor	Schedule and Funding
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research -Basic
Type Motion - Reciprocating Sliding
Variables -
Process - Friction
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To gain an understanding of run-in processes and factors which affect it.

Description

Point by point friction measurements are made in a reciprocating pin on disk machine from the initiation of sliding until the friction coefficient stabilizes. Friction coefficients at identical points in successive traverses (both reversing and continuous) are compared using copper and iron base alloys. Changes in friction are correlated with structural changes taking place in the alloy and comparisons made between the two sliding motions.

In a second project the effect of surface contamination is being studied. Controlled atmospheres are being used to change the nature of the surface contamination.

Title

Mechanisms of Galling and Abrasive Wear

Investigators	Organization
K. J. Bhansali	NBS

Sponsor	Schedule and Funding
DOE/Morgantown	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables - Load, temperature
Process - Surface damage
Materials - Metals
Application - Values

Subject 2
Objective 1
Energy Relevance

Objective

To obtain a better understanding of the affect of material properties on galling severity.

Description

A study is being conducted to gain a better understanding of galling processes in metals. As a first step in the study, it was necessary to determine a method of measuring the severity of galling.. A variety of techniques were investigated. It was found that changes in galling surface damage could be measured by changes in surface topography. The best measures were maximum peak to valley roughness and displaced volume. An instrument is presently being constructed to measure these quantities for test specimens.

The maximum peak to valley roughness (P_t) is used to investigate the effects of a number of material, design and operating variables on galling. Variables studies are load, finish, alignment, area, shape, and a variety of material properties such as stacking fault energy, microstructure, hardness, elongation, work hardening index and oxide films.

Title

Surface Treatments and Processes in Wear

Investigators	Organization
D. Kuhlmann-Wilsdorf	University of Virginia Department of Material Science
Sponsor	**Schedule and Funding**
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables
Process - Wear
Materials - Coatings/Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To devise methods for the calculation and/or determination of flash temperatures at contact spots during sliding with or without current passage, and to assess the effects of local temperature rises on wear and electrical contact behavior.

Description

Surface modifications through ion implantation, platings, or other are unstable at elevated temperatures. Local temperature spikes arise at contact spots. Their magnitude and relative incidence therefore determines the rate and magnitude of changes in surface properties of surface-modified materials. Beyond that, also homogenous materials are affected by increased temperatures. Apparatus and theoretical considerations are developed to assess the values of flash temperatures under different conditions and their effects.

Title

Microstructure Mechanisms of Wear of Ceramics

Investigators	Organization
C. M. Wu R.W. Rice	Naval Research Lab
Sponsor	**Schedule and Funding**
NRL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding unlubricated
Variables - Structure
Process - Wear
Materials - Ceramics
Application

Subject	2
Objective	2
Energy Relevance	1

Objective

Determine wear mechanisms in ceramics

Description

Pin on disk and abrasion tests are used to study the friction and wear of ceramic materials. Investigations concern microstructure and how it affects sliding behavior. It was shown that wear correlates reasonably well with porosity in carefully performed experiments. Wear increases significantly at 20% porosity.

Title

Friction and Wear Study of Composites: Microstructural Effects

Investigators	Organization
N.P Suh et al	MIT

Sponsor	Schedule and Funding
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding Dry
Variables -
Process - Friction, wear
Materials - Polymer composites
Application

Subject 2
Objective 2
Energy Relevance

Objective

To understand wear mechanisms in composites.

Description

According to the Delamination Theory of Wear, Microstructures have significant effects on friction and wear behavior of materials. It is shown that fibers oriented perpendicular to the surface wear the least, and that matrix material and structure affects both friction and wear behavior. In this talk, the tribological behavior of graphite fiber/polyurethane composites and perlitic steels will be presented including mechanisms of wear and friction of these materials. Then, an analytical solution for wear of graphite reinforced polyurethane will also be described which predicts the experimentally determined wear rates quite well.

An analytical solution was not presented.

Title
Quantitative Correlations Between Microstructural Parameters and Tribological Behavior in Several Alloy Systems

Investigators	Organization
P. J. Blau A. W. Ruff	National Bureau of Standards

Sponsor	Schedule and Funding
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding dry
Variables - Structure, Physical properties
Process - Wear
Materials - Metals
Application -

Subject 2
Objective 2
Energy Relevance

Objective

To correlate wear with the metalurgical properties of materials.

Description

Wear and friction studies are carried out with several alloy systems. Correlations are attempted with such parameters as microstructure, hardness-depth spectrum, grain size and others.

Title

Transfer Processes in Dry and Lubricated Wear

Investigators	Organization
W.A. Glaeser A. Rosenfield D.A. Rigney	Ohio State University & Battelle Columbus
Sponsor	**Schedule and Funding**
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding dry, Sliding lubricated
Variables -
Process - Film Formation
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance 4

Objective

To understand transfer processes and how they affect friction and wear.

Description

This project involves Battelle and The Ohio State University. The details of the near surface microstructure and surface structure and chemistry associated with both dry wear and lubricated wear are being investigated. From these analytical efforts, a model for wear based on micro-scale elastic-plastic fracture mechanics is being developed. They have proposed a critical transfer stress for asperities.

Title

Fundamental Mechanisms in Tribology and Their Implications

Investigators	Organization
Nam D Suh K. Komvopoulos N. Saka	MIT
Sponsor	**Schedule and Funding**
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables -
Process - Friction, wear, film formation
Materials
Application

Subject 2
Objective 2
Energy Relevance

Objective

To elucidate the basic mechanisms of friction and wear and to use this information to solve field problems.

Description

This research work is done to elucidate the basic mechanisms of friction and wear between sliding surfaces. The mechanism of subsurface crack propagation will be studies as a means of clarifying the relationship between friction and wear.

The authors see wear and surface damage as a material response to frictional behavior at the surface.

The latest work studies the role of oxide film. They are proposing to find a lubricant additive which forms hard wear resistant films - rather than soft films.

Title

Fretting Surface Damage at Low Amplitude Slip

Investigators	Organization
Paul Kennedy	Naval Air Development Center

Sponsor	Schedule and Funding
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Reciprocating
Variables - Distance
Process - Surfaced damage, fretting
Materials - Metals
Application -

Subject 2
Objective 1
Energy Relevance

Objective

To determine the effect of slip amplitude on fretting damage.

Description

Fretting tests are run at a variety of slip amplitudes with different materials. Damage and chemical changes are noted as a function of amplitude.

Title

Effect of Asperity Interactions on Scuffing (ONR Symposium)

Investigators	Organization
John I. McCool	SKF

Sponsor	Schedule and Funding	
NAPC Trenton	FY 83 FY 84 FY 85	FY 86 FY 87 FY 88

Classification

Type Research - Basic
Type Motion - Sliding/rolling, lubricated
Variables - Finish, load
Process - Surface damage, failure
Materials - Metals
Application - Gears

Subject	2
Objective	1
Energy Relevance	4

Objective

To determine the effect of microgeometry on scuffing load capacity.

Description

Geared roller tests were run at NAPC to provide scuffed and unscuffed specimens. Surface microgeometry measurements were made and used in a computer model which calculates asperity force, area, and number based on microhertizian elastic assumptions. Correlations are made between these parameters and scuffing load. Average asperity force x number of contacts is a significant parameter.

Title

Initiating Mechanisms of Scuffing and "Run in"

Investigators	Organization
K. Ludema	Department of Mechanical Engineering University of Michigan
Sponsor	**Schedule and Funding**
ONR U.S. Navy	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding, Lubricated
Variables - Time
Process - Surface damage & film formation
Materials - Metals
Application

Subject 2
Objective 2
Energy Relevance

Objective

To develop a test and test procedure.

Description

Studies of scuffing are being conducted under lubricated conditions with a cylinder sliding on a flat plate. Surface profile is measured as a function of time. Measurements being taken are: Kurtosis, Skewness, & Roughness. Surface chemical analysis is also performed. Changes in the surface are being determined as a function of time.

Title

Thermal Phenomena in Tribology

Investigators	Organization
Ward O. Winer	School of Mechanical Engineering Georgia Institute of Technology
Sponsor	**Schedule and Funding**
National Science Foundation	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research -	Basic	Subject - 3
Type Motion -	Variable	Objective - 2
Variables -	Numerous	Energy Relevance - 1
Process -	Surface Temperature	
Materials -	Open	
Application -	Various	

Objective

To develop a basic understanding of selected problems associated with thermal phenomena in tribosystems.

Description

The objective of this program will be to develop a basic understanding of selected problems associated with the thermal phenomena in tribosystems, utilizing the capability developed in this laboratory. The focal point for the research will be the determination of the role of frictional hotspots in wear and load capacity limitations of tribocontacts. A longer term objective is the systematic understanding of thermal phenomena in tribosystems.

Hotspots have already been observed in this laboratory in several tribosystems. What is now required, and proposed, is to quantify the temperatures and determine the transient dynamics of the hotspots. These measurements can be made with a tribosystem already available in this laboratory with the addition of the scanning infrared camera required in this proposal. A high speed data acquisition system and a microcomputer is available but will require additional mass storage which is also requested in this proposal.

The optics of the requested IR system can scan an area approximately four millimeters on a side with an areal resolution of approximately 30 micrometer diameter. The 30 micrometer areal resolution was chosen because the hotspot photographs indicate that is the typical hotspot size.

Title

Transport Processes in the Contact Line Region

Investigators	Organization
P.C. Wayner, Jr.	RPI-Chemical Engineering
Sponsor	**Schedule and Funding**
ARO-Mechanics	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Physical properties, chemical properties
Process - Lubrication
Materials - Fluid lubricants
Application

Subject 3
Objective 2
Energy Relevance 3

Objective

To study the physiochemical processes of wetting, and heat, mass, and momentum transport in ultra thin films.

Description

The physiochemical processes of wetting and heat, mass, and momentum transport in ultra-thin films which have a thickness $\delta < 10^{-5}$ (including the contact line region, $\delta \to 0$) are being studied. These processes are controlled by a gradient in the chemical potential which is a function of temperature, composition, and film thickness. In these thin film systems, experimental results have demonstrated that interfacial effects are magnified and that a small amount of a second component can cause dramatic changes in wetting and fluid flow. Therefore, a systematic study of the effect of changes in the bulk composition on wetting and transport processes in non-isothermal ultra-thin films is being performed. Since lubrication is a non-isothermal process, controlled heat transfer experiments are used so that the effects of temperature gradients are present.

Our initial models emphasized the effect of the shape of the thin film on fluid flow and heat transfer. New models that include the combined effects of shape, composition and temperature gradients on fluid flow and mass transfer will be developed to describe these experimental results. Moreover, the effect of concentration on the shape of an equilibrium film needs to be modeled for reference. As soon as possible more sophisticated optical techniques based on polarized light should be used to measure the film profile and concentration gradient near the contact line where the thickness approaches a monolayer. For this purpose, an ellipsometer capable of viewing a small area is needed.

Title

Elastostatic Charging of Plastics Sliding on Metals

Investigators	Organization
S.F. Murray W. Holzhauer	RPI-Mechanical Engineering
Sponsor	**Schedule and Funding**
ARo - Mechanics	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Time
Process - Film formation, adhesion
Materials - Polymers
Application

Subject 3
Objective 2
Energy Relevance

Objective

To study the formation of transfer films and their effect on subsequent sliding behavior.

Description

The development of static charges on dielectric surfaces--as a result of contact or sliding motion--is a phenomenon which has been known since ancient times. Yet, even today our knowledge of the cause and significance of this effect is far from complete. The current trend toward the use of plastics and ceramics for both structural elements and tribological devices makes this subject very pertinent at the present time.

The work in progress in this laboratory deals with one very specific aspect of the problem; nemely, the formation of adherent transfer films and the effect of these films on subsequent sliding behavior and wear of the plastic. It has been well established that many plastics deposit a transfer film on metal surfaces during the initial stages of sliding the plastic against a metal. Sliding then becomes the case of bulk plastic sliding against a thin, transferred film of plastic on a metal substrate. Many investigators believe that the formation and durability of these transferred films is the key to effective sliding, particularly with certain plastics such as Teflon. While electrostatic charging may not have a significant effect on the adhesion of bulk solids, it could certainly play a major role in the formation and effective life of thin transfer films.

Title	Three D Effects in Fluid Film Lubrication

Investigators	Organization
C. Ettles	Rensselaer Polytechnic Inst.

Sponsor	Schedule and Funding	
NSF-Mechanical Systems	FY 83 FY 84 FY 85	FY 86 FY 87 FY 88

Classification

Type Research - Basic
Type Motion- Lubricated sliding
Variables
Process -
Materials - Fluid Lubricants
Application

Subject 3
Objective 2
Energy Relevance

Objective

To include in fluid film bearing theory the differential temperature distributions in the film.

Description

As a result of different shear rates across the fluid, film temperatures vary and heat disapation is different at opposing surfaces. An analytical program is under way to determine how this affects bearing temperatures ard performance. Results are compared with literature data on bearing temperature distributions.

Title

Asperity Interaction in Mixed Lubrication

Investigators	Organization
C. Pan	

Sponsor	Schedule and Funding
NSRDC-Annapolis	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Finish, geometry
Process - Lubrication
Materials - Metals
Application - Fluid film bearings

Subject	3
Objective	2
Energy Relevance	3

Objective

To assist with analysis of asperity interaction model development of sliding surface bearings operating in mixed lubrication.

Description

The study shall (A) provide procedure to incorporate moment balance, cavitation conditions, and stochastic asperity interactions into two dimensional model of thrust bearing with longitudinal roughness, (B) develope procedures to include end leakage into three dimensional model, (C) introduce skewness in roughness features, and (D) develop physical means to measure and characterize realistic interactive surfaces as they relate to developed models.

Title

Thermomechanical Effects in High Speed Seal Rubs

Investigators	Organization
F.E. Kennedy	Dartmouth College

Sponsor	Schedule and Funding
NASA	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research -Applied
Type Motion - Unlubricated Sliding
Variables - Velocity
Process - Wear, Abrasion
Materials - Metals
Application - Seals (gas path)

Subject 3,19
Objective 2
Energy Relevance 5

Objective

To gain a better understanding of thermal and mechanical phonomena associated with high speed rubs.

Description

Recent attempts to improve the efficiency of aircraft gas turbine engines have led to the reduction of clearances in the many gas path seals used in modern engines. Reductions in seal clearances increase the likelihood that rubbing will occur between stationary seal components and high speed rotating components. This project aims at a better understanding of the thermal and mechanical phenomena associated with high speed seal rubs and the material and design parameters which influence these phenomena. The experimental phase of the project employs a unique single-pass rub test device build specifically for this purpose. The analytical phase of the project relies on the use of finite element programs suitable for modelling the temperatures and deformations in high speed rubbing contacts.

Title

Adhesion Studies

Investigators	Organization
J. Ferrante Y. Yanada	NASA
Sponsor	**Schedule and Funding**
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Impact
Variables - Load
Process - Adhesion
Materials - Metals - polymers
Application

Subject	3
Objective	2
Energy Relevance	3

Objective

To understand metal/metal and metal/polymer adhesion

Description

Although metallic adhesion has played a central part in much tribological speculation, few quantitative theoretical calculations are available. This is in part due to the difficulties involved in such calculations and in part due to the fact that the theoretical physics community is not particularly involved with tribology. The calculations currently involved in metallic adhesion show that this can be generalized into a scaled universal relationship. It is also shown that relationships exist to other types of covalent bonding such as cohesive, chemisorptive, and molecular bonding. A simple relationship between surface energy and cohesive energy is offered. This relationship can be used to predict metal/metal and metal/polymer adhesion. A micro-tensile test has been set up to correlate theoretical with experimental metal polymer adhesion.

Title

Traction Model Development

Investigators	Organization
J. McCool	SKF

Sponsor	Schedule and Funding	
WPAFB-ML	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Applied
Type Motion - Lube Slide/Roll
Variables
Process - Lubrication
Materials - Fluid Lubes
Application

Subject 3
Objective 5
Energy Relevance 4,6

Objective

Develop improved traction models as subroutines for advanced dynamic computer models.

Description

Currently available traction models are being assessed for their deficiencies in providing accurate reliable traction values for advanced aerospace lubricants. Improved traction models will be developed which handle the varied properties of advanced synthetic hydrocarbon and fluorinated base stocks. The goal is to develop traction models for simulating the operation/performance of lubricated components.

Title

Thermomechanical Effects in Sliding Wear

Investigators	Organization
F.E. Kennedy	Dartmouth College

Sponsor	Schedule and Funding
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - unlubricated sliding
Variables- Load, velocity, temp., phy properties, composition.
Process - Failure
Materials - Metals
Application - Seals

Subject 3
Objective 1
Energy Relevance 4

Objective

To determine the contact conditions in mechanical face seals and the influence of those conditions on seal failure.

Description

The purpose of this project it to get a better understanding of the modes of failure of mechanical face seals and of the design parameters which affect them. An experimental effort is aimed at determining the contact conditions (size and number of contact spots, contact pressure, and temperature) which occur in actual face seals. A unique contact probe has been designed and used for this purpose. The influence of seal surface waviness and roughness on contact conditions is also being studied. A concurrent analytical effort, using finite element technique, is studying the temperature and stress distribution near the contact patches on the seal surface.

Title

Three-Dimensional Model of a Moving Asperity for Thermal Cracking

Investigators	Organization
F. Ju	University of New Mexico

Sponsor	Schedule and Funding
ONR	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables - Time, load
Process - Stress, temperature, Surface damage
Materials - Metals
Application - Seals

Subject 3
Objective 2
Energy Relevance

Objective

To study failure resulting from excessive frictional heating in sliding.

Description

Analytical model predicts mechanical and thermal stresses of a moving asperity. Results show that the maximum stress occurs at a depth .1 the asperity size. Fracture occurs there, near the trailing edge of the asperity.

Title

Assessment of X Ray Methods for Analysis of Ceramic Wear Surfaces

Investigators	Organization
C.R. Houska	Virginia Polytechnic Institute

Sponsor	Schedule and Funding
ECUT DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research -Basic
Type Motion
Variables - Composition
Process - Surface damage
Materials - Ceramics
Application

Subject 4
Objective 2,6
Energy Relevance 1

Objective

To develop a theoretical foundation for novel nondestructive xRay diffraction and flourescence techniques for analysis of ceramic wear surfaces.

Description

Title

Lubrication of Engineering Surfaces II

Investigators	Organization
J.I. McCool	SKF Industries

Sponsor	Schedule and Funding
DOE-Office of Energy Research	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables - Finish
Process - Lubrication
Materials
Application

Subject 4
Objective 5
Energy Relevance 4

Objective

Characterization of bearing surfaces.

Description

The objective is to study on the characterization of bearing surfaces for applications in the design of high performance traction drives, gears, bearings, etc.. Software developed in a previous project uses a simulation model to determine the real contact area, load, and asperity pressure when two microscopically rough surfaces are brought into contact. These values measure the severity of the contact and hence the propensity for wear and surface fatigue. The model is driven by nine parameters (bispectral moments) which describe the statistical microgeometry of a general anisotropic surface. The model assumes that the surface heights, shapes, and curvatures follow a multidimensionsl gaussian distribution and that the surface asperities are mechanically and statistically independent. In the current project the effort has been devoted to: 1) quantification of the random and systematic errors incurred in processing stylus profile data to obtain the nine surface parameters as functions of the processing parameters, e.g., sampling frequency and sample length; 2) assessing the effect of the multidimensiona gaussian assumption on predictions of the contact conditions; 3) assessing the effect of the assumption of mechanical and statistical independence of asperities; and 4) developing rules for setting a filter pass band for surface profile processing to yield values of the roughness parameters appropriate for specific applications.

Title

Analysis of Worn Surfaces Using Infrared Emission Microspettroscopy (IEM) Laser Speckle Interferometry(LSI) and Phase-Locked Interface Microscopy (PLIM)

Investigators	Organization
J.L. Lauer	RPI-Mechanical Engineering

Sponsor	Schedule and Funding
ARO-Mechanics	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated Sliding;lubricated Rolling
Variables - Time
Process - Film Formation
Materials- Fluid lubricants, additives
Application

Subject 4
Objective 2
Energy Relevance

Objective

To understand lubrication mechanisms by determining surface conditions and film formation in lubricated sliding.

Description

(a) Surface chemical reaction rates of bearing surfaces related to surface texture, wear, and reliability of performance.. Specifically, M-50 surfaces will be examined by PLIM, LSI and surface deposits (including friction polymers) by IEM. Tracks will be produced in (i) a dry and humid atmosphere and (ii) under different lubricants containing such additives.

(b) Solubilities of surface-active agents in lubricants under bearing pressures. Are there Krafft points (critical micelle concentrations) in non-aqueous media? What is the effect of moisture? Of cationic or anionic agents? Of polarity of additives? This work is aimed at an ability to specify lubricant packages for specific operating conditions, but the approach is a fundamental one. How does the surface energy relate? Most of the work will be done with a high pressure diamond cell.

(c) Elastohydrodynamic lubrication. How does the molecular alignment vary along a conjunction line through a Hertzian contact? The IEM techniques are now sensitive enough to examine areas of 20 um diameter. Because a simple relation between molecular alignment and flow speed has been established the latter can be deduced from the alignment. This would allow the mapping of the flow speed through a contact and the determination of whether some lubricants solidify to form glasses.

Title

Development of Standards for Recycled Oil

Investigators	Organization
S. Hsu	NBS

Sponsor	Schedule and Funding
NBS	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Lubricated sliding
Variables - Load
Process - Friction, wear
Materials - Metals
Application - Engine

Subject 4, 15
Objective 6
Energy Relevance 3

Objective

To develop a scientific and technical data base for establishing criteria for the performance testing of recycled lubricating oils; to develop and evaluate bench tests and other performance-type test procedures necessary to establish the required characteristics of recycled lubricating oils.

Description

Friction and wear test procedures have been developed and are being correlated with service performance tests. A friction test has been developed which correlates well with the ASTM 5 car Demo Engine Test. A wear test has been developed which correlates with the ASTMSequence 3D Engine Test.

Title

Measurement of Dynamic Hardness

Investigators	Organization
R. Polvani	NBS

Sponsor	Schedule and Funding
NBS	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory Development
Type Motion - Impact
Variables
Process - Surface Stresses
Materials - Metals
Application

Subject 4
Objective 2
Energy Relevance

Objective

Develop and construct a machine to measure dynamic hardness.

Description

An electro-magnetic device has been set up to measure dynamic hardness. Contact times can be varied from 10^{-4} sec to hours. A given force/time wave/ovm is applied and the penetration displacement is observed. Results are now being assembled on different materials.

Title

Characterization of Friction and Wear in Automobile Engines

Investigators	Organization
S. Gassel	Franklin Institute

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technical development
Type Motion - Lubricated sliding, rolling
Variables--
Process - Friction
Materials- Lubricant, fluid
Application - Engine

Subject 4, 15
Objective 6
Energy Relevance 5

Objective

Develop a test to evaluate fuel saving effects of lubricants.

Description

An engine has been set up and various test sequences run in order to develop a procedure which will measure the fuel saving effects of different lubricants.

Title
An Automated System for Surface Topography Measurements Using SEM Stereo Micrographs

Investigators	Organization
B.B. Aggarwal	SKF

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory Research
Type Motion -
Variables - Finish
Process - Surface damage
Materials
Application

Subject 4
Objective 2
Energy Relevance

Objective

To develop a non contact surface profile measurement system.

Description

A non contacting optical instrument was devised to measure surface profile

Title

Roughness Effects in EHL

Investigators	Organization
J. Tripp	

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated rolling
Variables - Finish
Process - Lubrication
Materials
Application

Subject	5
Objective	2
Energy Relevance	3

Objective

To develop EHL models which include roughness.

Description

Analytical models have been developed which predict film thickness, load capacity, pressure distributions, and temperatures in concentrated contacts in terms of the geometric and material variables. In this program, efforts are being made to incorporate the effects of surface roughness. Results are being correlated with experimental data.

Title

Transient EHL Effects in Starved Ball Bearings

Investigators	Organization
E.P. Kingsbury	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated rolling
Variables- Time, chemical properties
Process - Film formation, lubrication
Materials- Fluid lubricants
Application - Rolling contact bearings

Subject	5
Objective	2
Energy Relevance	5

Objective

To study transient effects in film thickness which influence EHL calculations.

Description

The independent variables used in most calculations for EHL film thickness in ball bearings involve lubricant properties, contact elasticity, load and bearing kinematics. The calculations are for steady state, and give a time-constant film thickness. Experiments have shown four distinct processes in starved ball bearings which are explainiable assuming a time-varying film thickness. This contribution describes these four processes, as well as another transient EHL effect which does not involve the thickness of the film. A simple model, based on experimental considerations, allows direct calculation of several of the thickness transients.

Title

Study of EHL Transitions

Investigators	Organization
B. Hamrock E. Kingsbury	NASA
Sponsor	**Schedule and Funding**
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated rolling
Variables - Load, velocity
Process - Lubrication
Materials - Metals
Application - Rolling contact bearings

Subject	5
Objective	2
Energy Relevance	3

Objective

To define surface processes which occur during the transition from EHL to boundary lubrication.

Description

Current work includes theoretically the effect of surface roughness and temperature on EHL model. Experimental work studies the transition from fluid film lubrication to boundary lubrication with a rolling contact bearing. During this transition it was shown that a polymer film is formed on the bearing surface which protects it from surface damage and influences EHL lubrication.

Title

Lubricant Modeling

Investigators	Organization
H. Bandow	WPAFB - Materials Lab

Sponsor	Schedule and Funding	
WPAFB-ML	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Basic
Type Motion - Lubricated Rolling Contact
Variables
Process - Lubrication
Materials - Fluid Lubricants
Application - Engine

Subject	5
Objective	5
Energy Relevance	3

Objective

To develop a computer model based on bearing dynamics which predicts lubricant properties required for optimum performance.

Description

A program is being prepared using dynamic bearing models which predicts the needed properties of lubricants to achieve optimum bearing performance for a given set of bearing operating parameters. This information will be used to tailor fluids for a given application. The addition of traction models to bearing models is an important element of this program. The use of a hydraulic pump is being considered to confirm the model.

Title

Traction Properties of Advanced Aerospace Lubricants

Investigators	Organization
S. Sharma	University of Dayton Research Institution

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Slide/Roll
Variables
Process - Friction
Materials - Fluid Lubes
Application

Subject 5
Objective 5
Energy Relevance 4,6

Objective

Determine the traction properties of experimental aerospace fluids and lubricants.

Description

A unique microprocessor controlled twin-disk traction rig having the capability to measure traction and generate traction curves on small volumes (250ml) is being used to evaluate the traction properties of a number of experimental fluids and lubricants. The small volume allows characterization of newly synthesized base stocks or experimental formulated fluids early in their development cycle in order to optimize their traction and lubrication performance/behavior.

Title

Corrosion Protection from Propellant By-products by MIL-L-63460 (CLP) Lubricants

Investigators	Organization
S.M. Whalen	ARDC Picatinny Arsenal

Sponsor	Schedule and Funding
ARDC - Picatinny	FY 83 45K FY 86 50K FY 84 0 FY 87 FY 85 50K FY 88

Classification

Type Research - Applied
Type Motion - Lubricated Slide/Roll
Variables - Environment
Process - Film Formation
Materials - Fluid Lubricants
Application - Various

Subject 6
Objective 1
Energy Relevance 3

Objective

Develop laboratory test to screen out ineffective corrosion preventive CLP lubricants prior to their testing on M-60 machine guns.

Description

Compare corrosion protection of proven adequate and inferior CLP lubricants on steel panels exposed to the heat and corrosive energetic gases experienced by the M-60 machine gun.

Title

Thin Film Degradation in Instrument Bearings

Investigators	Organization
R.L. Mowery	Naval Research Lab
Sponsor	**Schedule and Funding**
NAVAIR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research
Type Motion
Variables
Process
Materials - Fluid lubricants
Application - Rolling contact bearings

Subject 6, 18
Objective 2
Energy Relevance

Objective

To improve the performance and reliability of precision instrument ball bearings and other rotating devices used in naval aircraft and missile guidance or control systems.

Description

Films of instrument lubricant will be laid down on appropriate bearing metal surfaces and subjected to various environmental stresses (heat, wear, etc.). Changes in lubricant additive/surface chemistry will be monitored. Results will be employed to improve lubricant. Additive or metal properties in order to increase lubricant/bearing reliability. Electroactive polymers (EAPS), E.G. Polyacetylene, will be modified by ion implantation and other appropriate means to determine their applicability as antistatic packaging material for precision bearings.

Title	Evaluation of Lubricants for Shipboard Arresting Gear Wire Rope Applications

Investigators	Organization
R.L. Jentgen	Battelle - Columbus

Sponsor	Schedule and Funding
NAEC-Lakehurst	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion - Lubricated reciprocating
Variables - Compositions
Process - Lubrication, wear
Materials - Fluid lubricants
Application - Cables

Subject 6
Objective 1
Energy Relevance

Objective

To select lubricants for arresting gear cables.

Description

Candidate lubricants for shipboard arresting gear wire rope applications were evaluated in selected standard and nonstandard laboratory bench-scale tests. Most of the lubricants did not meet two or more of the target requirements which were deemed to represent good performance of lubricants in purchase cable service. However, three of the lubricants showed clearly superior properties in all but one of the tests. It was recommended that these three lubricants be pointedly reformulated by their manufacturers and submitted for further study.

Title

New Approaches to the Synthesis of Functionalized Fluorocarbons

Investigators	Organization
D. Burton	University of Iowa

Sponsor	Schedule and Funding
AFOSR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion
Variables - Temperature
Process - Synthesis
Materials - Elastomers
Application

Subject 6
Objective 3
Energy Relevance 1

Objective

To develop hi-temperature elastomer materials.

Description

Professor Donald Burton at the University of Iowa is looking at new approaches to the synthesis of functionalized fluorocarbons.

Title

Fluorocarbon Oxidation Inhibitors

Investigators	Organization
K. Paciorek	Ultrasystems Iruine, Calif.
Sponsor	**Schedule and Funding**
AFOSR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion
Variables - Temperature
Process - Synthesis
Materials - Additives
Application

Subject 6
Objective 3
Energy Relevance

Objective

To develop specific additives for use in fluorocarbons.

Description

Ultrasystems in Irvine, California, synthesized for the first time a series of monophospha-s-triazines and diphospha-s-triazines.

In addition, several derivatives of these newly made compounds containing fluorocarbon ether side groups have been found to be effective as anti-corrosion and antioxidation additives for various fluorocarbon ether fluids.

The Ultrasystems research group is currintly working on the synthesis of higher molecular weight fluorocarbon ether substituted phosphatriazine elastomers.

Title

Synthesis of Perfluoropolyethers

Investigators	Organization
R. Lagow	University of Texas

Sponsor	Schedule and Funding
AFOSR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion
Variables - Temperature
Process - Synthesis
Materials - Fluid lubricants
Application

Subject 6
Objective 3
Energy Relevance 1

Objective

To develop methods to synthesize fluorochemicals

Description

Recently, a new general synthesis for perfluoropolyethers was developed in Lagow's laboratory. The unique advantage of this new synthetic technique is that it makes possible the synthesis of very highly branched polyethers which is not possible using the conventional polymerization technology.

Title

Time-Temperature Studies of High Temperature Deterioration Phenomena in Lubricant Systems: Synthetic Ester Lubricants

Investigators	Organization
Steffan Korcek	Ford Scientific Research Lab

Sponsor	Schedule and Funding
AFOSR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion -
Variables - Time, Temperature
Process - Wear
Materials - Fluid Lubricants, Additives
Application

Subject 6
Objective 2
Energy Relevance 1

Objective

To obtain basic information on lubrication deterioration and metal corrosion occurring at high temperatures.

Description

A kinetic and mechanistic study of the autoxidation of liquid pentaerythrityl tetraheptanoate, PETH, in a stirred flow reactor at 180 to 220C was completed. The results are consistent with the occurrence of a chain reaction scheme similar to that proposed for n-hexadecane autoxidation.

Laboratory studies showed that small degrees of autoxidation produce large increases in metal wear when PETH functions as a boundary lubricant. The results indicate that monoesters of dicarboxylic acids produced in reaction are the products which in conjunction with hydroperoxides result in the increased wear.

Based upon the results of these inhibited autoxidation studies a method of establishing the relationships between structure and thermoxidative stability of synthetic ester lubricants has been developed.

Title

User Testing of Improved MIL-G-10924 (GAA) Grease

Investigators	Organization
J. Beeson	MERADCOM Fuels & Lubricants
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Rolling contact
Variables - Composition
Process - Lubrication, life
Materials - Greases
Application

Subject 6
Objective 1
Energy Relevance

Objective

To conduct field performance evaluations of improved GAA to insure satisfactory lubrication when subjected to severe environmental testing and to validate laboratory developed data.

Description

Identify specific applications and environements warranting inclusion in field tests. Solicit cooperation from DOD activities to secure representative vehicle and equipment test beds and conduct controlled field testing.

Title

DOD Long Life Grease

Investigators	Organization
J. Beeson	MERADCOM - Fuels & Lubricants
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Composition, environment
Process - Lubrication, life
Materials - Greases
Application

Subject 6
Objective 1
Energy Relevance

Objective

To develop a high performance grease that prevents corrosion and satisfactorily performs under all geographic and environmental conditions with extended service capabilities.

Description

Identify specific applications for this grease and develop target requirements. Select candidate products for laboratory screening and field testing. Identify other areas of consolidation with military specification greases and proprietary products.

Title

Develop Non-Flammable Hydraulic Fluid

Investigators	Organization
J.H. Conley	MERADCOM - Fuels & Lubricants

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Composition
Process - Lubrication
Materials - Hydraulic Fluids
Application

Subject 6
Objective 1
Energy Relevance

Objective

To develop a hydraulic fluid that eliminates the fire threat to armored vehicles associated with hydraulic fluids.

Description

Evaluate performance of candidate fluids being jointly developed with ASAF by conducting laboratory and system/component testing

Title	
	Improved Fluids for Existing and Advanced Design Helicopter Transmissions

Investigators	Organization
	MERADCOM Fuels & Lubricants
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Temperatures, Loads, Compositions
Process - Lubrication
Materials - Fluid lubricants
Application - Transmissions

Subject 6
Objective 1
Energy Relevance

Objective

To develop a helicopter transmission fluid/gear combination for advanced designed helicopter transmission systems suitable for operation at high temperature and loads. To formulate short-term solutions to current field problems.

Description

Develope a cooperative test plan with US Army, US Navy, and Air Force. Select candidate fluids/material. Conduct laboratory evaluations and component testing. Identify potential problems prior to rig testing. Conduct full scale testing.

Title

Lubricants for New Engine Systems

Investigators	Organization
	MERADCOM - Fuels & Lubricants
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Temperatures, composition
Process - Lubrication
Materials - Fluid lubricants, additives
Application - Engine

Subject 6
Objective 3
Energy Relevance 1

Objective

To develop lubrication criteria for new/advanced engine systems such as the adiabatic diesel.

Description

. Screen candidate lubricants using high-temperature CLR diesel Engine test
. Evaluate high-temperature stability/effectiveness of various additives
. Investigate supplemental antioxidants' ability to control oil thickening

Title

Universal Engine Lubricants

Investigators	Organization
	MERADCOM Fuels and Lubricants
Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Composition
Process - Life
Materials - Fluid lubricants
Application - Engines

Subject 6
Objective 7
Energy Relevance

Objective

To develop multiviscosity/extended drain oils for combat and tactical ground equipment.

Description

. Screen candidate multiviscosity engine oil technologies to verify suitability for expanded seasonal operation

  - 2 and 4 cycle diesel engines
  - Power transmission systems

. Define low-temperature use parameters for diesel engines (e.g., pumpability and flow properties)

Title	
Relationship Between Grease Thickeners and Base Oils	
Investigators	Organization MERADCOM - Fuels & Lubricants
Sponsor	Schedule and Funding FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion
Variables - Composition
Process - Life
Materials - Greases
Application

Subject 6
Objective 2
Energy Relevance

Objective

To define physical/chemical structural requirements needed to develop more stable and versatile automotive/artillery grease.

Description

Employ powerful/new techniques to determine the intermolecular relationship between grease thickeners and base oils and correlate this information with field test data IPS

- NMR and SEM to establish cation role.
- RP-HPLC to determine absorption role.
- Determine effects of thickener structure, oil composition, and cation selection.

Title

Methods to Determine Lubricant Changes

Investigators	Organization
R. McQuaid	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables - Environment
Process - Life
Materials - Fluid lubricants, greases
Application

Subject 6
Objective 7
Energy Relevance

Objective

To develop and standardize methods to determine changes in composition in oils and greases. Determine whether compositional changes observed in service are likely to alter performance of the product.

Description

Determine infrared (IR) spectra, high pressure liquid chromatograph (HPLC) and gas chromatograph/mass spectra (GC) properties or other appropriate property measurements of qualified products as received from manufacturer, determine iR, HPLC, and GC after varying lengths of time in service to determine compositional changes during use. Identify changes and estimate effect of changes on lubricating and other performance properties of lubricant or hydraulic fluid. Attempt to simulate compositional changes by thermal and oxidative means. Determine whether differential thermal analysis or scanning calorimetry provides a means for predicting compositional changes or measuring compositional changes after they have occured.

(U) (8302-8310) work complete in FY83 gas chromatographic determinations, infrared spectra and high performance liquid chromatographic determinations are required to fully characterize any oil product, infrared spectra is the only determination applicable to greases.

Title

Ship Lubricant Reduction Program

Investigators	Organization
J. Taylor	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion
Variables
Process - Lubrication
Materials - Fluid lubricants, greases
Application

Subject 6
Objective 7
Energy Relevance

Objective

To revise and update weapons lubricant list of tech manual OD 3000 to eliminate maximum number of MIL-SPec and proprietary lubricants.

Description

There is a Navy wide program to reduce the required number of lubricants used aboard ships. This is to be done by reducing the number of military specification lubricants and replacing a proprietary produce whenever possible with a military specification. The result will be a reduction in lubricant inventory and an overall reduction in lubricant cost. Lubricants for new construction ships are being reviewed and recommendations will be reported.

Title

Synthetic Hydrocarbon Hydraulic Fluids

Investigators	Organization
M. Bieberich	NSRDC-Annapolis

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion
Variables
Process
Materials - Hydraulic fluids
Application

Subject 6
Objective 1
Energy Relevance

Objective

To determine the feasibility of replacing MIL-F-17111A hydraulic fluids (petroleum) with synthetic hydrocarbon base fluids having improved fire resistance.

Description

MIL-F-17111A fluids derived from petroleum oil are used to operate Navy ordnance systems such as gun mounts and guided missile launching systems. The MIL-F-17111A fluids are relatively flammable and a more fire resistant replacement fluid is needed. Polyalphaolefin synthetic hydrocarbon fluids have significantly higher flash and fire points. They also have outstanding low temperature fluidity properties which are required for fluids operating ordnance systems. Modifications to existing MIL-F-17111A type polyalphaolefin fluids will be made to improve certain performance properties, and the most promising formulation will be evaluated in a hydraulic loop.

Title	Marine Corps Tribology

Investigators	Organization
R. McQuaid	NSRDC-Annapolis

Sponsor	Schedule and Funding
Marine Corps Hdq.	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion
Variables - Environment
Process - Wear, lubrication
Materials - Fluid lubricants, greases
Application

Subject 6
Objective 1
Energy Relevance

Objective

To provide lubricating grease and engine lubricating oil capable of protecting working parts from seawater contamination.

Description

Marine Corps amphibious landing vehicle, tanks, self-propelled artillery, and motor transport have experienced early failure of lubricated parts due to seawater or dirt contamination in service. The failures are due primarily to inadequacies in the lubricating grease and oil in current Marine Corps use. Field trials are being conducted of existing products with properties expected to be superior to those in current use in Marine Corps equipment.

Title

Grease Lubricated Helo Transmissions

Investigators	Organization
L. Stallings	NADC

Sponsor	Schedule and Funding
NADC	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Applied research
Type Motion
Variables - Compositions
Process - Lubrication
Materials - Greases
Application - Transmissions

Subject 6
Objective 1
Energy Relevance

Objective

To determine requirements and specifications for greases for helicopter transmissions.

Description

Helicopter transmissions are normally oil lubricated. Although these are effective both from a lubrication and a cooling standpoint, leakage is always a problem and is the most frequent cause of service removal. Greases are a possible alternative and in fact some transmissions are now grease lubricated. For military service it is necessary to prepare specifications for such greases and to define their requirements. This is the purpose of this program.

Title

Competitive Additive Adsorption

Investigators	Organization
P. Kennedy	NADC

Sponsor	Schedule and Funding
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion
Variables - Composition
Process - Film Formation
Materials - Additives
Application

Subject 6
Objective 2
Energy Relevance 3

Objective

To understand mechanisms of preferential additive adsorption

Description

Heats of adsorption and desorption are measured on metal oxides using a flow calorimeter and an isothermal titration calorimeter which is connected to an IBM computer to analyse the data. Use of a computer is important since much more precise data is obtained.

Cyclohexane is used as a fluie carrier. Current experiments use Dodecenyl succinic anhydride on NiO and Fe_2O_3 and other rust inhibitors. Basic absorption data can be used to predict competitive absorption and surface packing.

Title	Spline Wear

Investigators	Organization
E. Jewel	NADC

Sponsor	Schedule and Funding	
NADC	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Exploratory development
Type Motion - Reciprocating
Variables - Composition
Process - Wear
Materials - Additives
Application - Splines

Subject 6
Objective 1
Energy Relevance

Objective

To develop a grease which will reduce wear of splines.

Description

Splines are subject to rapid wear due to fretting. Lubrication is difficult due to the small amplitude; oil is prevented from flowing into the contact area. As a result greases have a limited life where they are effective in a spline. Different greases do, however, have different lives. The reason for this has not beed adequately defined. The purpose of this research is to define those life extending properties by using a spline test with different greases and to develop a grease which minimizes wear. The approach used is to select a synthetic hydrocarbon grease and evaluate the effects of different additives.

Title

Deuterated Lubricants

Investigators	Organization
N. Reibuck	NADC

Sponsor	Schedule and Funding
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Rolling contact
Variables - Composition
Process - Live
Materials - Grease
Application - Rolling contact bearing

Subject 6
Objective 4
Energy Relevance

Objective

To develop lubricants with improved oxidative stability.

Description

Early work by NADC identified the advantages of deuteration of lubricants in increasing the oxidation resistance of hydrocarbons. In cooperation with the NRL Program NADC is assisting in the NRL program by analyses of bearing failures and preparing greases for evaluation.

Title Evaluation of the Oxidative Stabilities of a Deuterated and Non Deuterated Neopentyl polyester

Investigators	Organization
S.G. Pande R.N. Bolster	Geo-Centers Inc.
Sponsor	**Schedule and Funding**
NAVAL Research Lab NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Temp
Process - Lubrication
Materials - Greases
Application

Subject 6
Objective 4
Energy Relevance

Objective

To extend motor bearing life with deuterated fluids as grease base stocks.

Description

Several deuterated and nondeuterated neopentyl polyol ester basestocks have been evaluated for oxidative stability at 220°C using systematic screening and characterization tests. Also, experimental lubricating greases have been prepared from selected basestocks for motor bearing life tests.

Assuming bearing life to be solely dependent on lubricant oxidative stability, the deuterated grease prepared from a pentaerythritol perdeutero tetrahexanoate (98.6 atom) ester with low alkali metal content, is expected to exhibit a fivefold longer life than its nondeuterated analog, also with low alkali metal content. Nondeuterated lithium stearate was used as the grease thickener. A significant enhancement in oxidative stability occurs on combination of the dual effects of deuteration and alkali metal concentration in the presence of an amine-type antioxidant. The test data indicate that lubricants formulated in this manner have potential operating temperatures as high as 230°C.

Title

Development and Use of Deuterated Lubricants

Investigators	Organization
J. Capana R. Bolster	Naval Research Lab

Sponsor	Schedule and Funding
NAVSEA DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables
Process - Life
Materials - Lubricants, fluid
Application

Subject 6
Objective 4
Energy Relevance

Objective

To extend the life of equipment by using deuterated hydrocarbons as lubricants.

Description

Deuterated fluids have been shown to have improved oxidative and thermal stability. In house ability to deuterate fatty acids is being pursued using biosynthesis techniques. In addition, blower motor bearing tests are being run to evaluate the effects of greases made from deuterated esters. Deuterated esters gave 14 x the oxidative stability as non-deuterated esters.

Title

Turbine Engine Lubricant Development

Investigators	Organization
A. Beane	WPAFB - Propulsion Lab
Sponsor	**Schedule and Funding**
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion -
Variables - Temp
Process - Lubrication
Materials - Lubricants, Fluid
Application - Engine

Subject	6
Objective	3
Energy Relevance	1

Objective

To develop new lubricants and define requirements for advanced engines.

Description

Develop new lubricants and define requirements for current and proposed turbine engine and power generation systems.

Provide engine lubricant requirements to industry in terms of physical properties and performance criteria. Conduct oil testing laboratory and full scale engine to ensure oils meet these requirements, and to study advanced lubricant capabilities. Evaluate the toxicological characteristics of lubricant formulations and additives considered suspect.

Title

Lubricant Life Assessment

Investigators	Organization
W.E. Rhine	Univ. of Dayton Research Institute
Sponsor	**Schedule and Funding**
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables - Time
Process - Life
Materials - Lubricants, Fluid
Application

Subject 6
Objective 5
Energy Relevance

Objective

To develop a low cost method of measuring remaining useful life (oxidation)

Description

Lubricants degrade during use with the loss of oxidative stability being the first and most affected property. The oxidative stability of used lubricants is referred to as the "Remaining Lubricant Life" and cannot be determined by typical oil analyses such as total acid number or viscosity measurements. The long term stability tests used for the evaluation of production lots are not suitable for the evaluation of small quantities of used lubricants.

In this effort a rapid, low-cost method for determining the "Remaining Lubricant Life" will be developed and will be used to support the elimination of scheduled oil changes. Continued use of lubricants with remaining useful life will provide savings in lubricant costs, disposal of waste oil costs, manpower costs for conducting oil changes, analytical costs and insure that only lubricants with remaining useful life remain in service.

Title

Turbine Engine Lubricant Research

Investigators	Organization
P. Centers	WPAFL-Propulsion Lab
Sponsor	**Schedule and Funding**
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion -
Variables - Temp
Process - Lubrication
Materials - Fluid lubricants
Application - Engines

Subject 6
Objective 3
Energy Relevance

Objective

To assess lubricant and lubrication needs.

Description

Objectives of this effort are (1) Establish basic parameters of turbine engine lubricant degradation from which new and improved methods and guidelines for assessing and defining the performance capabilities of current and advanced high temperature lubricants can be developed. (2) Correlate the physical and chemical characteristics of wear particles with the mechanisms of wear, (3) Investigate and develop lubricant and debris monitoring techniques for lubricant systems. Effort will provide for improved utilization of lubricant, reduced maintenance costs and higher temperature capability lubricants.

Title

Study of Additive Action Mechanisms in ZDP/TCP

Investigators	Organization
D. Wheeler	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Applied research
Type Motion - Sliding
Variables
Process - Film formation
Materials - Additives
Application

Subject	6
Objective	2
Energy Relevance	3

Objective

To understand anti-wear and antiseize mechanisms in ZDP and TCP.

Description

Friction and wear studies are being conducted along with surface analysis techriques to understand the antiwear and antiseizure mechanisms of two well known additives. It has been shown that a phosphide is formed in an o_2 defficient atmosphere and a phosphate in an o_2 rich atmosphere; these act as low shear strength films.

Title

Study of Synthetic Lubricant Structures for Temperatures Above 300C

Investigators	Organization
M. Meador, F. Morales, Wm. Jones, -& Wm. Loomis	NASA
Sponsor	**Schedule and Funding**
NASA	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Basic
Type Motion - Sliding, rolling
Variables - Temperature
Process Oxidation
Materials - Fluid lubricants
Application - Engines

Subject	6
Objective	3
Energy Relevance	1

Objective

To isolate molecular structures which can be used as engine lubricants to 300C

Description

The fundamental processes occurring during the thermal and oxidative degradation of hydrocarbons is studies. Particular emphasis is given to various classes of liquid lubricants such as mineral oils, esters, polyphenyl ethers, C-ethers and fluorinated polyethers. Experimental techniques for determining thermal and oxidative stabilities of lubricants are considered. The role of inhibitors and catalysis is also covered.

Currently studies are being carried out with perfloroalkylethers. Several different investigators are studying oxidation, thermal stability, lubricity, and metal catalyzation reactions

Title

Advanced Hydraulic System Materials

Investigators	Organization
L. Gschwender	WPAFB - Materials Laboratory

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Structure, Properties
Process - Lubrication
Materials - Hydraulic Fluids
Application - Actuators, Pumps

Subject 6
Objective 1
Energy Relevance

Objective

To develop low temperature MIL-H-83282 hydraulic fluid for current alert aircraft. Develop advanced high temperature fluids for future aircraft systems.

Description

Formulations with PAO base stocks having -65^{o}F viscosity properties without sacrificing fire resistance are sought. Viscosity index improvers may be used to improve viscosity properties over operational temperature range. Advanced base stocks based on silahydrocarbon materials are synthesized and their structure-property relationships established. Economical synthesis routes for silahydrocarbons are sought.

Title

Nonflammable Hydraulic Fluids/Seals

Investigators	Organization
C. Snyder	WPAFB - Materials Laboratory

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Structure, Properties
Process - Lubrication
Materials - Hydraulic Fluids
Application - Actuators, Pumps

Subject 6
Objective 1
Energy Relevance

Objective

To develop hydraulic fluids/seals for nonflammable hydraulic systems for future aircraft.

Description

Candidate nonflammable hydraulic fluid is chlorotrifluoroethylene (CTFE). Model compounds are synthesized for study as base stocks. Additives are selected/formulated for effective response as antiwear and anitcorrosion inhibitors. Elastomeric seal materials with compatibility performance in CTFE are synthesized/formulated/evaluated. Candidate formulations are evaluated in pump test stands and actuator rigs for performance.

Title

Wide Temperature Range Lubricants/Seals for Advanced Gas Turbine Engines

Investigators	Organization
L. Gschwender	WPAFB - Materials Laboratory

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Temperature
Process - Lubrication
Materials - Fluid Lubes
Application - Engines

Subject	6
Objective	3
Energy Relevance	1

Objective

Develop 4cSt -60° to 400°F GAS Turbine Oil (GTO) for advanced turbine engines.

Description

Currently used diester based GTO's are limited to 325°F bulk oil temperature. Base stocks and additives are sought which permit formulations having -60° to 400°F bulk oil temperatures with 4 centistoke viscosity at the operating temperatures. Formulations meeting these and other requirements, including bench tests, are forwarded to the Air Force Aero Propulsion Laboratory for further tests and final engine evaluation.

Title
High Temperature (600° - 700°F) Gas Turbine Oils for Advanced High Performance Turbine Engines

Investigators	Organization
C. Tamborski L. Gschwender	WPAFB - Materials Laboratory

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied		Subject	6
Type Motion		Objective	3
Variables - Temperature		Energy Relevance	1
Process - Lubrication			
Materials - Fluid Lubes			
Application - Engines			

Objective

Develop high temperature thermally, oxidatively stable GTO candidate materials for use at 600° - 700°F.

Description

Initial efforts will establish fundamental understanding and sound technology base in the highly fluorinated fluids and additives. Perfluoroalkylether (PFAE) base fluids will be synthesized and characterized for structure-property relationship. Fluorinated additives which exhibit response in these fluids are sought and their interaction with base fluids and surfaces will be investigated and characterized.

Title

New Solid Lubricant Structures for 400C Usage

Investigators	Organization
B. Good	NASA

Sponsor	Schedule and Funding
NASA	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Applied
Type Motion - Sliding
Variables - Temperature
Process - Friction, Wear
Materials - Polymers, Solid Lubes
Application

Subject 7
Objective 3
Energy Relevance 1

Objective

To isolate high temperature polymers materials.

Description

A theoretical examination of polymeric molecular structures tailored for tribological applications.

Title

Friction and Wear of Lamellar Composites

Investigators	Organization
N.P.Suh N. Saka	MIT-Lab for Manufacturing and Productivity
Sponsor	**Schedule and Funding**
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Structure
Process - Friction, wear
Materials - Metals
Application

Subject 7
Objective 2
Energy Relevance

Objective

To determine the effect of interlammelar spacing and volume fraction on wear.

Description

Friction and wear behavior pearlite steels, typical of lamelar composites, is being investigated. Both composition and heat-treatments were varied to obtain composites of different interlamellar spacing and volume fraction of pearlite in the ferrite matrix. Experimental results indicate that both the lamellar spacing and volume fraction of pearlite, although influence hardness, do not affect friction and wear behavior. However, the orientation of the lamellae with respect to the sliding surface appears to have substantial effect.

Finite element analysis of the lamellar structure is being conducted to identify the wear mechanism. It is found that the wear of the pearlite steel varies with the orientation of the cementite phase. At present interfacial shear strain between ferrite and cementite and normal strain in the cementite phase are being computed.

Title

Solid Film Rolling Element Bearings

Investigators	Organization
S.A. Barber J.W. Kannel	Battelle-Columbus
Sponsor	**Schedule and Funding**
AFWAL/DARPA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory Development
Type Motion - Lubricated Rolling
Variables - Temperature, Stress
Process - Life
Materials - Solid Lubricants
Application - Rolling Contact Bearings

Subject 7, 18
Objective 3
Energy Relevance 1

Objective

To determine feasibility of lubricating rolling element bearings with solid lubricants.

Description

A substantial weight reduction in limited-life turbine engines could be realized by replacing liquid lubricated main engine bearings with bearings lubricated by a replenishable solid film lubricant. The feasibility of this approach was evaluated by examining:(1) The effect of solid film on contact stresses within the bearing, (2) The effect of alternate cage intervals on bearing stability at high speeds and temperatures, and (3) The use of the retainer material as a possible solid lubricant source. Experimental investigations of solid film transfer mechanisms were conducted, as well an analytical investigations of stresses and bearing stability.

Title

Investigation of Corrosion Reduction by Use of Non Graphitic Lubricants in Air Force Engines

Investigators	Organization
K.F. Duframe R.L. Jentgen	Battelle Columbus
Sponsor	**Schedule and Funding**
Warner Robbins, ALC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Environment
Process - Corrosion
Materials - Solid Lubricants
Application- Engines

Subject 7
Objective 1
Energy Relevance

Objective

To determine corrosion problems associated with the use of graphite solid film lubricants.

Description

A survey is being made of the current uses of graphite-containing lubricants with Air Force engines and corrosion problems associated with that usage. Recommendations will be made on an engine-by-engine basis for use of alternate lubricants as appropriate.

Title

Metal Forming with Solid Coatings

Investigators	Organization
W. Wilson	Northwestern - Mechanical Engineering

Sponsor	Schedule and Funding
NSF-Mechanical Systems	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables - Physical properties
Process - Friction
Materials - Coatings
Application - Tools, dies

Subject 7
Objective 4
Energy Relevance 3

Objective

To relate mechanical properties of solid coatings to their performance as solid lubricants in metal forming operations.

Description

A study is being made to determine mechanisms of lubrication using solid films in a variety of metal forming processes. Soft coatings (polymers, waxes, etc.) are applied to various work piece materials. The effect of material properties on film thickness, friction, break down stress, and plastic flow are being investigated.

Title

Water Based Solid Film Lubricants

Investigators	Organization
N. Reibuck	NADC

Sponsor	Schedule and Funding
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables_ _- Compsition
Process - Life
Materials - Solid Lubricants
Application

Subject 7
Objective 4
Energy Relevance

Objective

To evaluate lithium silicate as a substitute for sodium silicate in MIL-L-813229 bonded solid film lubricant.

Description

A need exists for a water resistant high temperature solid film lubricant which provides corrosion protection. Specification MIL-L-81329 covers a water based solid film lubricant which contains milybdenum disulfide and graphite and uses sodium silicate as a binder. This material has excellent high temperature capabilities 400°C (752°F), but is seriously deficient in water resistance and corrosion preventive capabilities.

The dual objectives of this program are to develop a high temperature water based solid film lubricant with good water resistance and corrosion protection properties superior to specification MIL-L-81329 and to develop a water based version of specification MIL-L-8937 material to eliminate the use of organic solvents.

Solid film lubricants using water soluble organic resins as binders were studied as possible replacements for MIL-L-8837 solvent based materials. The best material studied of this type showed only half the endurance life required for specification MIL-L-8937 materials.

Title Intercalated Solid Lubricants

Investigators	Organization
A. Conte	NADC

Sponsor	Schedule and Funding
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Compositions
Process - Friction, Life
Materials - Solid Lubricants
Application

Subject 7
Objective 2
Energy Relevance 3

Objective

To develop improved solid lubricants by intercalation with other compounds.

Description

Using graphite as a model host compound the process of intercalation, i.e. the insertion of foreign atoms or molecules between molecular plance of layer lattice solids has been shown to provide new materials with intrinsic lubricating properties. A three year research program has been carried out to establish basic scientific guidelines for the use of intercalated graphite compounds as improved solid lubricants. The falex test apparatus was used to determine the endurance life and load capacity of such compounds. Results were compared with MiS_2 and graphite. Transition metal chlorides of Co, Fe, Cu, and Ni when intercalated into the graphite structure increased the endurance life of the solid film lubricants by a factor of 2.4 and the load carrying ability by a factor of 2.2. Transition metals Co and Fe increased endurance life up to 4.5 times. A mechanism has been proposed based upon thermal analysis and kinetic rate observations to explain this lubricating action. Using this approach an alternative to MoS_2 can be made available.

Title

Dry Lubricated Gear Technology

Investigators	Organization
	WPAFB-Propulsion Lab

Sponsor	Schedule and Funding
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated slide/roll
Variables - Temperature
Process - Lubrication
Materials - Metals
Application - Gears

Subject 7, 13
Objective 3
Energy Relevance 1

Objective

To consider the feasibility of using solids as gear lubricants.

Description

This is a new program in the planning stages.

Title

Solid Lubricant Design Methodology

Investigators	Organization
B.B. Aggarwal R.L. Bovenkerk	SKF Technology Services

Sponsor	Schedule and Funding
NASA-Lewis	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Applied	Subject	7
Type Motion	- Lubricated slide/roll	Objective	3
Variables	- Load, velocity, temperature	Energy Relevance	1
Process	- Lubrication		
Materials	- Solid lubricants		
Application	- Rolling contact bearings		

Objective

To define effective operating ranges for solid lubrication and to develop a design methodology.

Description

Solid lubrication design methodology is being developed which is analogous to the elastohydrodynamic theory for liquid lubricated rolling element bearings. The proposed approach consists of experimental tasks in which various solid lubricants will be studied in rolling/sliding contact. The test conditions selected for these tasks encompass the range of bearing temperatures, contact stresses, and sliding speeds projected during the operation of turbocharged adiabatic diesel engines. Concurrent analytical tasks are aimed at developing models for the solid lubricant systems. The outcome of this program will include experimental data on the solid lubrication of advanced materials and analytical guidelines necessary for the design of solid lubricated rolling element bearings, and other solid lubricated components.

Title	
Hi Temp Lubricating Materials	

Investigators	Organization
H. Sliney	

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated sliding
Variables - Temperatures
Process - Friction, wear
Materials - Coatings, solid lubes
Application

Subject 7
Objective 3
Energy Relevance 1

Objective

To develop high temperature lubricating coatings.

Description

Advanced technology engines such as the adiabatic diesel and the small, efficient gas turbine have severe lubrication and wear problems at the temperatures beyond the capabilities of any of these lubricants. Here, self-lubricating ceramics and inorganic composites for use at 1000^{o}C or higher are of interest.

To meet this need a program is under way to develop 1500C ceramic lubricating coatings and infiltrated NiCr alloys.

Title

Solid Lubricant Powder Materials/Technology for Application in Turbine Engine Rolling Element Bearings

Investigators	Organization
K. Mecklenburg	WPAFB - Materials Laboratory

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Development
Type Motion - Rolling
Variables - Properties
Process - Lubrication
Materials - Solid Lubricants
Application - Rolling Bearings

Subject	7
Objective	3
Energy Relevance	3

Objective

Develop solid lubricant powder materials for use as dry lubrication techniques for rolling element bearings.

Description

This effort will augment Aeropropulsion Laboratory program to design/develop a powder lubrication system for turbine engine bearings. Emphasis will be on selection/characterization of solid lubricant materials which are effective lubricants in free-flowing powder form. The effort will provide a concentrated study of the powder materials and their properties leading to selection of candidates for evaluation as powder lubricants carried in an air/gas stream through rolling element bearings.

Title

Solid Lubricants for Space Applications

Investigators	Organization
K. Mecklenburg	WPAFB - Materials Lab

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Development
Type Motion - Rolling
Variables - Temperature, Environment
Process - Life
Materials - Solid Lubes
Application - Rolling Bearings

Subject 7
Objective 1
Energy Relevance 3

Objective

Develop solid lubricant materials/techniques for use in precise spacecraft components operating in the low pressures and temperatures of space.

Description

Develop materials and techniques for applying solid lubricants to rolling element bearing components used in ultra-precision gimbals. Design concepts for providing orders of magnitude improvement in pointing accuracy are sought. Solid lubricant materials for temperatures of -150^{o}F are sought along with techniques for application to rolling element bearings operated in oscillatory mode for long durations (10 years).

Title

Fundamentals of Solid Lubricated Ceramics

Investigators	Organization
M. Gardos	Hughes Aircraft Co.

Sponsor	Schedule and Funding
DARPA/ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Fundamental
Type Motion
Variables - Chemical Properties
Process - Adhesion, Friction, Lubrication
Materials - Solid Lube, Ceramic
Application

Subject 7,8
Objective 2
Energy Relevance 1

Objective

To develop the fundamental understanding of solid lubricant/ceramic materials interactions leading to a sound technology base for application in weapon systems.

Description

A highly interdisciplinary program using subcontracted expertise has been planned to delve into the basic intrinsic properties of solid lubricant materials and ceramic substrates to develop the necessary understanding of the fundamental surface properties/interactions to allow development of high temperature solid lubricated ceramic systems.

Title

Antimony Thioantimonate: Lubricating Properties and Mechanisms

Investigators	Organization
L.K. Ives J.S. Harris M.B. Peterson	NBS
Sponsor	**Schedule and Funding**
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables - Composition
Process - Friction, Wear
Materials - Solid lubricant
Application

Subject 7
Objective 4
Energy Relevance

Objective

To understand the mechanism of lubrication of $SbSbS_4$.

Description

A variety of tests are being run to evaluate the benefits of $SbSbS_4$ as a grease additive. A new abrasion test device has been developed to measure lubricant abrasion and abrasion resistance.

Title
Tribological Systems Operating in Extreme Conditions: Novel Surface Modification Processes

Investigators	Organization
M. Kaminsky	Argonne National Lab

Sponsor	Schedule and Funding
DOE ECUT	FY 83 FY 86 X FY 84 X FY 87 X FY 85 X FY 88 X

Classification

Type Research - Applied
Type Motion
Variables - Properties
Process - Friction, Wear
Materials - Coatings
Application

Subject 8
Objective 4
Energy Relevance 2

Objective

Develop surfaces with improved friction, wear, corrosion or erosion behavior for tribological applications.

Description

Theortical and experimental studies are being conducted to develop novel materials/surfaces for tribologicals. Modeling studies of recoil and direct implantation of single and multiple species into binary and tertiary compounds. The experimental effort will include recoil and direct implantation into alloys and the characterization and the testing of the implanted material for tribological applications.

Title

Development of Hard Coatings for Tribological Coatings.

Investigators	Organization
M. Kaminsky	Argonne National Laboratory

Sponsor	Schedule and Funding
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables
Process
Materials - Coatings
Application

Subject 8
Objective 2, 6
Energy Relevance 2

Objective

To develop the base technology of coatings and solid lubricants for tribological applications under extreme conditions.

Description

This program will establish and verify the correlation between the theoretical predictions on improvement in tool life based on a thermomechanical model of the tool wear process, and the performance of hard coated, high speed cutting tools. The program will help in providing the tools and knowledge necessary to design and produce novel coatings with greatly improved tribological properties.

Title

Steady State Frictional Behavior of Thin Film Coatings

Investigators	Organization
Yutaka Shimazaki/Ward Winer	School of Mechanical Engineering Georgia Institute of Technology
Sponsor	**Schedule and Funding**
Georgia Institute of Technology	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	Basic	Subject - 8
Type Motion	Reciprocating	Objective - 2
Variables	Various	Energy Relevance - 2
Process	Film Formation	
Materials	Metals and Coatings	
Application	Various	

Objective

To determine the time dependent friction and wear behavior of solid film lubricants.

Description

Steady state frictional behavior of thin film coatings are studied with the main emphasis on the effect of the applied coating thickness.

Four coating materials are studied, of which three are solid lubricants (MoS_2, WSe_2, WSe_2/In/Ga) and one is wear resistance material (TiN). They are deposited by magnetron assisted sputtering on a steel substrate. Friction tests are performed with dry sliding under a normal atmosphere. The test configuration is a spherical slider sliding against a coated flat. The parameters studied include film thickness, substrate roughness, applied load and substrate hardness. The effect of these parameters on the transition and steady state friction coefficients are evaluated.

The results show that the steady state friction coefficients of MoS_2, WSe_2, WSe_2/In/Ga coatings vary with the applied coating thicknesses. The minimumn and maximum friction coefficients obtained from each coating are $\mu_{max} = 0.66/\mu_{min} = 0.07$ for MoS_2, $\mu_{max} = 0.73/\mu_{min} = 0.05$ for WSe_2, $\mu_{max} = 0.75/\mu_{min} = 0.20$ for WSe_2/In/Ga. For the MoS_2 and WSe_2 coatings this variation is considered to be related to the change in the deformation mode of the coating. With the thicker coatings the wear track is fully covered with deformed coating material and the friction coefficients become higher. The steady state friction coefficient of WSe_2/In/Ga coatings are considered to be determined by the behavior of the debonded and resmeared coating material. The substrate hardness seems to play the most dominant role upon the behavior of the resmeared film.

A high value of the steady state friction coefficient is obtained with the TiN coatings ($\mu_{max} = 0.90$, $\mu_{min} = 0.57$). During the steady state sliding is considered to be occurring between the slider and transferred slider material. The effect of coating thickness in the TiN case is not significant.

Title
Studies of Dynamic Contact of Ceramics and Alloys for Advanced Heat Engines

Investigators
K.F. Dufrane
W.A. Glaeser

Organization
Battelle - Columbus

Sponsor
DOE/DRNL

Schedule and Funding
FY 83
FY 84
FY 85
FY 86
FY 87
FY 88

Classification

Type Research - Basic
Type Motion - Reciprocating
Variables - Materials, Environment, Load, Speed
Process
Materials - Ceramics (monolithic and coatings) and metals
Application - Advanced heat engines

Subject 8
Objective 3
Energy Relevance 1

Objective

Develop generic understanding of friction and wear behavior of ceramic interfaces under conditions typical of advanced heat engines.

Description

An experimental study is being conducted with a laboratory apparatus to reproduce the important conditions of advanced heat engines. The primary focus is on the piston ring/cylinder interface. Materials are to be well-characterized before and after testing to provide basic data on the sliding process. Models are to be developed from the results of the tests to predict the friction and wear behavior of monolithic ceramics and ceramic coatings as functions of applied stress, oscillatory frequency and stroke, temperature, time, environment, and macroscopic material properties.

Title

Gear Materials

Investigators	Organization
D. Townsend	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated rolling
Variables - Temperature
Process - Surface damage, fatigue
Materials - Metals
Application - Gears

Subject 8,13
Objective 4
Energy Relevance

Objective

To provide gear material technology for aerospace applications.

Description

Studies include lubrication, gear materials, processes and design.

Title Surface Analysis of Ceramic Sliding Contacts

Investigators	Organization
C.S. Yust	Oak Ridge National Labs

Sponsor	Schedule and Funding
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Sliding
Variables - Temperature
Process - Surface damage
Materials - Ceramics
Application

Subject 8
Objective 2, 6
Energy Relevance 1

Objective

To understand the nature of the surface damage in ceramic sliding contacts.

Description

A detailed surface examination is being made of ceramic wear test specimens. Observations are made of the wear tracks at various time increments to permit detection of early stages of sliding damage. Damage features are being correlated with wear mechanisms.

Title

Friction and Wear of Dissimilar Ceramics at Elevated Temperatures

Investigators	Organization
F.J. Carignan	Advanced Mechanical Technology Inc.

Sponsor	Schedule and Funding
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables - Temp
Process - Friction, wear
Materials - Ceramics
Application

Subject 8
Objective 2,6
Energy Relevance 1

Objective

To understand the tribological behavior of ceramic materials.

Description

Load/time matrix tests are being run on a pin on disk test apparatus at high temperatures in order to determine the tribological characteristics of ceramic combinations.

Title

Tribology of Cylinder/ring Pairs in Adiabatic Diesel Engine Service

Investigators	Organization
A.V. Levy	Lawrence Berkley Labs

Sponsor	Schedule and Funding
DDE ECUT	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables - Temperature
Process - Wear, surface damage
Materials - Ceramics, coatings
Application - Ring/cylinder

Subject 8, 15
Objective 3
Energy Relevance 1

Objective

Testing material pairs that are candidates for the cylinder wall liner and piston rings of the adiabatic diesel.

Description

This project is sponsored by the ECUT program at ORNL. It entails testing a number of materials pairs that are candidates for the cylinder wall liner and piston rings of the Cummins Engine Company-Tacom adiabatic diesel engine. The cylinder wall liner for all of the tests is the Kaman Sciences Corp. chromia impregnated Y_2O_3-ZrO_2 CTBC or its successor. A number of different hard coatings are being applied by the Koppers Company to represent piston ring coatings. Tests will be run at temperatures up to 750C using washer on disc test specimens in a modified Falex 6 wear test machine. The Falex 6 tester modifications will be completed by the end of January at which time testing of the materials, all supplied by the Cummins Engine Company, will commence.

Title

Hard and Soft Coatings for High Temperature Tribology

Investigators	Organization
W.O. Winer	Georgia Tech-Mechanical Engineering

Sponsor	Schedule and Funding	
DARPA/Hughes	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Applied	Subject	8
Type Motion - Lubricated rolling contacts	Objective	3
Variables - Temperature	Energy Relevance	1
Process - Life		
Materials - Solid Lubricants		
Application - Rolling contact bearings		

Objective

To evaluate coatings as lubricants for rolling contact bearings.

Description

A thrust bearing tester is used to evaluate the life of coatings used to lubricate a rolling contact bearing at temperatures to 600V and above. Variable loads (to 200 lbs) and speeds (to 2000 rpm) are used to evaluate various ceramic and transfer coatings.

Title

Ceramic Frictional Studies

Investigators	Organization
Paul Sutor	Midwest Research Inst.

Sponsor	Schedule and Funding
DARPA/Air Force	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Sliding
Variables - Temperature
Process - Friction, wear
Materials - Ceramics
Application

Subject 8
Objective 3
Energy Relevance 1

Objective

To determine the friction and wear properties of ceramic-ceramic and ceramic-metal sliding pairs, and to demonstrate effective solid lubrication of ceramics and metals.

Description

Eighteen graphite fiber-reinforced, polyimide composites containing inorganic solid lubricants were extensively studies as high temperature lubricants for M-50 steel and hot-pressed silicon nitride. SEM/EDX was employed to study the sliding surfaces and mathematical models of the wear process were developed and evaluated. Unlubricated ceramic tribological studies were conducted at various loads, sliding velocities, and geometries of contact. Ceramics employed included silicon nitride, silicon carbide, and partially stabilized zirconia. Ceramic matrix composites, in which one phase was a high temperature lubricant, were evaluated for improved wear, friction, and transfer properties, sliding versus silicon nitride and steel. Auger spectroscopy and SEM/EDX was employed to characterize the sliding surfaces. The ceramic matrix composites included several silicon nitride-boron nitride compositions, silicon carbid-calcium fluoride/barium fluoride eutectic, and silicon carbide-graphite fluoride.

Title	
Performance Ranking of Marine Seal Materials	

Investigators	Organization
N. Saka K.C. Kim	MIT - Lab for Manufacturing and Productivity
Sponsor	**Schedule and Funding**
NSRDC - ANnapolis	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research- Applied
Type Motion - Lubricated sliding
Variables - Compositions
Process - Wear
Materials - Metals
Application - Seals

Subject 8, 19
Objective 1
Energy Relevance

Objective

To rank the seal materials according to wear rates.

Description

Generally the performance (or life) of a marine face seal is evaluated by conducting tests under conditions that approximate service. But such a testing scheme fails to rank materials because either the wear rates are extremely low or the seal design significantly affects the experimental results.

The objective of this study, therefore, is to rank the seal materials according to the wear rates. Experiments are being conducted on hard materials (e.g. SiC. Stellite, Inconel) and various carbon/graphites and polymeric materials with pin-on-disk geometry. All tests are run under water, but in the boundary lubrication regime at higher nominal pressures than the operating values.

Title

Role of Chemical Affinity in the Frictional Behavior of Ceramics

Investigators	Organization
N.H. MacMillan	Materials Research Laboratory Penn State University
Sponsor	**Schedule and Funding**
NSF-Materials Science	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated
Variables - Structure, environment
Process - Friction, surface damage
Materials - Ceramics
Application

Subject 8
Objective 3
Energy Relevance 1

Objective

To determine the effect of crystal structure, composition, and chemical affinity on frictional behavior.

Description

This project seeks to investigate the way in which the frictional force generated between, and the damage done to, ceramic surfaces in sliding contact depends on the chemical nature of those surfaces. It is proposed to measure the coefficient of friction, over a range of temperature in air, in argon and in vacuo, using like and unlike pairs of surfaces prepared in the test environment by fracture or abrasion.

The data obtained will be used to seek out and to test empirical relationships between frictional behavior and crystal chemistry and those properties derived from it.

Title	
Friction and Wear of Ceramics at High Temperatures	

Investigators	Organization
N. H. MacMillan	Penn State University

Sponsor	Schedule and Funding
US Army TACOM	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied		Subject	8
Type Motion - Unlubricated sliding		Objective	3
Variables - Environment, composition		Energy Relevance	1
Process - Friction, surface damage			
Materials - Ceramics			
Application - Ring/cylinder			

Objective

To evaluate materials for diesel ring/liner combinations.

Description

The objective of this work is to obtain friction and wear data needed in the development of the ceramic diesel engine. To this end it is proposed to study the sliding contact behavior under accurately simulated engine operating conditions (5-12 cm stroke, 0-300- rpm, 25-1200C, in air/hydrocarbon environments) of six friction couples, representing the six possible (like and unlike) combinations of piston and cylinder liner that can be made from the three candidate materials--sintered alpha silicon carbide, partially stabilized zirconia and a zirconia-coated metal. Note that accurate simulation fundamental understanding of friction and wear phenomena makes it dangerous to extrapolate data obtained from a test under one set of conditions to predict service life under different conditions.

Title

Filled Porous Nickel Coatings for Wear Resistance

Investigators	Organization
W. Ebihara	AARADCOM-Picatinny

Sponsor	Schedule and Funding
AARADCOM-Picatinny	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables - Composition
Process - Wear
Materials - Coatings
Application - Gun tubes

Subject 8
Objective 1
Energy Relevance 2

Objective

To develop wear resistanc coatings

Description

Efforts are being made to deposit porous nickel coatings by electroplating. The pores are then filled with teflon or nylon to yield a low friction wear resistant coating. Ring and block tests are being run to evaluate the coatings. Applications include a variety of sliding mechanisms in guns.

Title

Low Temperature Deposition of Refractory Metals for Gun Tube Coatings

Investigators	Organization
W. Ebihara	AARADCOM-Picatinny

Sponsor	Schedule and Funding
AARADCOM-Picatinny	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables- Composition
Process - Erosion Wear
Materials - Coatings
Application - Gun Tubes

Subject 8,21
Objective 1
Energy Relevance

Objective

To develop erosion resistant coatings for small guns.

Description

Attempts are being made to develop a low temperature deposition process for coating gun tubes. The iodide is used in place of the flouride. Mechanical swaging and explosive compaction is being used to form films 2 to 3 mils thick.

Title

Chromized Nickel Alloys as Gun Tube Materials

Investigators	Organization
W. Ebihara	AARADCOM-Picatinny

Sponsor	Schedule and Funding
AARADCOM-Picatinny	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables - Compositions
Process - Erosion
Materials - Metals, coatings
Application - Gun tubes

Subject 8, 21
Objective 1
Energy Relevance

Objective

To improve erosion resistance in gun tubes.

Description

Chromized Inconel 718 is being evaluated as a replacement for cobalt-base liners currently used. Initially different coatings were evaluated with liner inserts. Current work includes complete liners made with the optimized coatings.

Title

Improved Ceramic Bearing Materials

Investigators	Organization
G. Harris	DARCOM-AMMRC
Sponsor	**Schedule and Funding**
DARCOM	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied Research
Type Motion - Unlubricated rolling
Variables - Physical properties
Process - Fatigue
Materials - Ceramics
Application - Rolling contact bearings

Subject 8, 18
Objective 1
Energy Relevance 1

Objective

To study specified ceramic materials to determine their potential as ceramic bearings.

Description

The objective of this project is to study specified ceramic materials to determine their potential as ceramic bearings. Materials to be tested include silicon nitride (NC-131) as the standard. Silicon nitride with yttria additives in the range of 8 percent to 15 percent. Sintered stabilized zirconia .

The materials will be machined into cylinders and life tested on the rolling contact fatigue (RCF) tester.

Title

Refractory Metal Coatings for Gun Tube Erosion

Investigators	Organization
M. Levy S. Pan	AMMRC - Watertown
Sponsor	**Schedule and Funding**
Picatinny, Dover N.J.	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion -
Variables - Chemical prop/thermal properties
Process - Erosion
Materials - Metals
Application - Guns

Subject 8
Objective 1
Energy Relevance

Objective

Establish methods for the electrodeposition of refractory metal alloys as a means of controlling gun tube erosion.

Description

Processes will be developed for electrodepositing refractory metals and alloys from molten salt baths on gun steel and superalloy substrates. Electrodeposition from aqueous solutions will also be explored utilizing co-deposition and pulsed-current deposition. Apparatus will be assembled and steel specimens coated with selected combinations of erosion-resistant materials of selected thicknesses. The coatings-substrate systems will be characterized with respect to microstructure, mechanical properties, hot hardness and erosion resistance in order to optimize the processing parameters.

Title

Ceramic (Silicon Nitride) Dies for Isothermac Forging

Investigators	Organization
E. N. Kinas	AMMRC- Waterton

Sponsor	Schedule and Funding
AMMRC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Lubricated sliding
Variables
Process - Surface damage
Materials - Ceramics
Application - Tools/dies

Subject 8, 14
Objective 4
Energy Relevance 5

Objective

To evaluate silicon nitride as a die material.

Description

A die of silicon nitride has been made and used to forge steel (2000F) and titanium (1650F). Results (wear, material condition, surface damage etc.) are compared with the results for steel dies.

Title

Evaluation of Advanced Gear and Bearing Materials

Investigators	Organization
R. Middleton	DARCOM M&M Research Center Watertown, MA
Sponsor	**Schedule and Funding**
DARCOM AMMRC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated sliding/roll
Variables - Composition load speed
Process - Wear
Materials - Metals
Application - Bearings, gears

Subject 8, 13, 18
Objective 4
Energy Relevance

Objective

To develop better materials for future high performance Army components of Army aircraft and ground vehicles.

Description

Current studies include the effects of carbides size, distribution, etc. in 52100 steel on wear rate. Efforts are being made to improve the wear rate by redistribution of carbides in the metal matrix. A pin/disk machine is being used to measure wear.

A disk/disk test is also being set up to evaluate gear materials at conditions beyond catalog loads and speeds. First work will consider carbides but other metallurgical properties will also be investigated. Eventually new materials will be introduced.

Title

Lubricants and Materials for Advanced Propulsion Systems

Investigators	Organization
R. Valori D. Popgoshev	NAPTC - Trenton
Sponsor	**Schedule and Funding**
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables
Process
Materials - Fluid lubricants, metals
Application - Engines

Subject 8,6
Objective 3
Energy Relevance

Objective

To assure the availability of lubricant/steel combinations for future propulsion systems which have optimum reliability with respect to bearing and gear performance.

Description

A continuous program is under way at NAPC to upgrade rolling contact bearing and gear materials. A rolling contact disk test is used. Materials evaluated include corrosion resistant steels ceramics, ion implanted metals and coatings. Several different projects are under way:

1. Effect of microtopography on scuffing resistance.
2. Effect of microtopography on life.
3. Effect of preconditioning on life and scuffing.
4. Screen Industry Materials & Coatings.

Title

Corrosion Resistance of Turbine Engine Bearings

Investigators	Organization
L. Stallings	NADC

Sponsor	Schedule and Funding	
NAVAIR	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Basic
Type Motion - Rolling contact
Variables - Environment
Process - Surface damage
Materials - Metals
Application - Rolling contact bearings

Subject 8, 18
Objective 1
Energy Relevance

Objective

Determine mechanisms of corrosion of bearings in engine oils.

Description

Corrosion is one of the main reasons for removal of bearings from service over a broad range of applications. This has been shown to be true for jet engine bearings from military service. There is almost no data available to explain how such corrosion takes place. In this program a simulative test will be set up, and electrochemical techniques will be used to study corrosion mechanisms in new and contaminated oil. Static bearing tests will be used in initial experiments.

Title

Improved Fracture Toughness Bearing

Investigators	Organization
Eric Bamberger	G.E.

Sponsor	Schedule and Funding
WPAFB-APL NAPC-Trenton	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied research
Type Motion - Lubricated rolling
Variables - Physical properties
Process - Fatigue
Materials - Metals
Application - Rolling contact bearing

Subject 8,18
Objective 1
Energy Relevance

Objective

To develop and evaluate bearing materials with improved fracture toughness.

Description

A long term program is under way to find improved materials for aircraft gas turbine engine bearings. The basic problem is fracture of the ring due to high centrifugal stresses at high speeds. Screening tests were run on a large number of materials. A material was developed (M50NIL) which is a carburizing grade of M50. This material is now undergoing full scale bearing tests.

Title

Evaluation of Sliding Surface Damage of Ceramic Materials

Investigators	Organization
K. Ludema	Univ. of Michigan - Mechanical Engineering

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated reciprocating
Variables - Temperature
Process - Surface damage
Materials - Ceramics
Application - Ring/cylinder

Subject 8
Objective 3
Energy Relevance 1

Objective

Evaluate the surface damage of ceramic materials characteristics of diesel engine rings.

Description

A new approach for evaluating tribological materials has been proposed. Instead of relying on tests that try to duplicate contact conditions, it is proposed to devise a test in which the wear damage is the same as in practice. Worn auto engine cylinders are being used to characterize practical wear. Then a test will be developed to simulate that damage. Materials used in the investigation are ceramics.

Title

Composite Materials for use in Braking Systems

Investigators	Organization
R. Fusaro	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development	Subject	8
Type Motion - Unlubricated sliding	Objective	1
Variables - Temperature	Energy Relevance	
Process - Friction		
Materials - Polymers,composites		
Application - Brakes		

Objective

To develop high temperature brake materials.

Description

This program is a follow on to recent work on the development of filled polymers (especially polyimides) for 400C environments. Consideration is now being given to the use of these materials in brake systems where high friction is required. Further material modifications are being made and the resulting composites are being in pin/disk experiments.

Title

Frictional Behavior of Ceramics at Hi Temperatures

Investigators	Organization
Tom Jacobson	NASA

Sponsor	Schedule and Funding
NASA	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Applied
Type Motion - Sliding
Variables - Temp
Process - Friction
Materials - Ceramics
Application

Subject 8
Objective 3
Energy Relevance 1

Objective

To determine tribological behavior of commonly used ceramic materials.

Description

Three different test devices are being used to study the frictional behavior of ceramic materials. A basic rig which operates at 1500C consists of a sphere on flat and allows surface analysis to be performed in situ. A pin on disk rig operates to 800C in air. A new rig is being constructed for the 1200C to 1500C temperature range which can accomodate different test geometries. Materials include both special ceramics prepared "in house" and commercial materials.

Title

Wear Resistant Sputter Coatings

Investigators	Organization
Paul Aron	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables - Structure
Process - Friction, adhesion
Materials - Coatings
Application

Subject 8
Objective 4
Energy Relevance

Objective

To isolate effective wear resistant coating.

Description

Sputter coatings of refractory metal carbides, silicides, and borides are being prepared. Scratch hardness tests are being used to measure adhesion and "pin on disk" tests are used to determine friction and wear life.

Title

Plasma Coating Morphology

Investigators	Organization
T. Spalvins R. Avni	

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables
Process - Friction, wear
Materials - Coatings
Application

Subject	8
Objective	4
Energy Relevance	2

Objective

To correlate the friction properties with coating morphology.

Description

Studies are being conducted with silicon nitride and silicon carbide films which have been deposited from gases by RF plasma deposition. This is only the most recent investigation in a series of investigations concerned with tribological coatings. Plasma deposited coatings have included a wide variety of materials including molybdenum disulfide, soft metals and layered coatings. In addition, more recent work studied ion nitriding processes.

Title
Surface Modification of Metal/Ceramic Substrates via Ion Implantation

Investigators	Organization
K. Mecklenburg	WPAFB - Materials Laboratory

Sponsor	Schedule and Funding
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research- Development
Type Motion
Variables - Properties
Process - Friction, Wear
Materials - Coatings
Application

Subject	8
Objective	4
Energy Relevance	2

Objective

Enhance the tribological properties of bearing surfaces via altering properties/composition with ion implanted species.

Description

Ion implantation will be used to alter the surface/subsurface properties of both steels and ceramics. Improved hardness, toughness and friction and wear of these materials are sought. Species which react with the host material or diffuse to the surface to react with the environment or other materials will be investigated. Characterization of the surfaces and/or altered materials will be emphasized to establish a sound fundamental understanding of this approach to achieving increased tribological performance.

Title
High Performance Elastomeric Seals

Investigators	Organization
W. Griffin J. Sieron	WPAFB - Materials Lab
Sponsor	**Schedule and Funding**
WPAFB-ML	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Sliding
Variables - Structure, Temperature
Process
Materials - Elastomers
Application - Seals

Subject	8
Objective	3
Energy Relevance	1

Objective

To develop high temperature seals for gas turbine engine oils/fuels.

Description

Polymers of fully fluorinated fluorocarbon ether nitrides will be synthesized for use as elastomeric materials leading to use as oil/fuel seals at 700^{0} - 800^{0}F in advanced gas turbine engines. Advanced cross linking agents and reinforcement technology will be utilized to obtain optimum mechanical properties of these advanced seal materials.

Title

Study of Ceramic Tribology

Investigators	Organization
S. Hsu	NBS

Sponsor	Schedule and Funding
NBS	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated
Variables - Temperature
Process - Friction, wear, surface damage
Materials - Ceramics
Application

Subject	8
Objective	3
Energy Relevance	1

Objective

To study the role of fracture and fatigue in friction and wear

Description

A machine is being designed and constructed to measuring friction and wear to temperatures of 1500C. With this machine studies of ceramic friction and wear will be investigated. Initial studies will concentrate on the effect of structural parameters (composition, grain size and processing techniques) on lubricated and unlubricated sliding.

Title

Study of Alloy Coatings for Wear Resistance

Investigators	Organization
A.W. Ruff	NBS

Sponsor	Schedule and Funding
NBS	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Unlubricated sliding
Variables
Process - Wear
Materials - Coatings
Application

Subject 8
Objective 4
Energy Relevance 2

Objective

To correlate coating properties with friction and wear characteristics.

Description

Steels are being coated by electrodeposition (Pulsed, DC, AC) and electron beam surface alloying. The plated coatings are cobalt/nickel/phosphorous compositions. The E-beam studies are conducted with steels. The surface of the steels are alloyed with chromium and nickel. Wear tests are run in both the dry and lubricated condition using the crossed cylinder, the ring-block, and the pin-disk machines.

Title
Load-carrying Capacity of Advanced Material-Lubricant Combinations

Investigators	Organization
R. Wendryzcki	Naval Air Propulsion Center

Sponsor	Schedule and Funding
NAVAIR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Applied	Subject	8, 13
Type Motion	- Sliding/Rolling lubricated	Objective	4
Variables	- Composition, Load	Energy Relevance	4
Process	- Load capacity		
Materials	- Metals		
Application	- Gear		

Objective

To isolate gear materials which will operate at higher temperatures, higher loads, and greater pitch line velocities.

Description

In this program, advanced gear materials (VASCO X-2, CBS 600M, CBS1000M, Cartech EX-00053 and EX-00014) in combination with non-additive synthetic basestock, qualified MIL-L-23699, and advanced XAS-2354 type lubricants are evaluated on the Ryder Gear Machine (ASTM-D-1947). The evaluation is concerned with determining the load carrying capacity or scuffing/scoring resistance of each material and lubricant combination.

Future evaluations will be conducted on other advanced materials and lubricants as they become available.

Title

Tribological Properties of Ion Implanted Alloys

Investigators	Organization
I. Singer	Naval Research Lab

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory Development
Type Motion - Sliding unlubricated
Variables - Composition, physical properties
Process - Friction, Wear
Materials - Coating
Application

Subject	8
Objective	4
Energy Relevance	2

Objective

To determine implantation parameters which optimize tribological performance.

Description

The objective of this program is to determine ion implantation parameters (e.g., ion species, fluence, energy,...) which optimize tribological performance of components. This approach combines friction and wear studies, designed to examine the behavior of the very thin implanted layer, with surface chemical and microstructural analysis.

Title
Development of Wear Resistant Surfaces by Laser Surface Modification Techniques.

Investigators	Organization
J. Mazumber C. Cusano	University of Illinois

Sponsor	Schedule and Funding
ONR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory Development
Type Motion - Sliding, unlubricated
Variables
Process - Friction wear
Materials - Coatings
Application

Subject 8
Objective 4
Energy Relevance

Objective

Use of Laser to develop wear resistant surfaces.

Description

Laser surface alloying, laser cladding and laser chemical vapor deposition are being investigated to develop wear resistant surfaces. Fe-Cr-Mn-C system is being studied for laser surface alloying and cladding whereas TiC is being studied for laser chemical vapor deposition. Some samples from Stellite 6 and WELCO (PA 158D) have also been studied for cladding in order to generate baseline data.

Title

Advanced Lip Seals and Seal Materials for Stern Tube Applications

Investigators	Organization
L.W. Winn	Mechanical Technology Inc.

Sponsor	Schedule and Funding	
MARAD	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research	- Exploratory development	Subject	8, 19
Type Motion	- Sliding	Objective	1
Variables	- Composition, geometries	Energy Relevance	5
Process	- Wear		
Materials	- Polymers		
Application	- Seals		

Objective

To improve performance of lip seals in ship stern tubes.

Description

Test equipment for sliding lip seal performance was built under the program. Wear testing of nitrile rubbers filled with dry lubricants was conducted.

A new lip seal design potentially capable of meeting the low pressure sensitivity and shaft excursion requirements was conceived. An analysis of this configuration showed that these goals could be met. Following the analysis, manufacturing drawings were produced, and lip seals of the new design were fabricated for test.

Title

Research on Slippery Rubber for Stern Tube Bearing Staves

Investigators	Organization
S. Gray	Mechanical Technology Inc.

Sponsor	Schedule and Funding
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Sliding
Variables - Composition
Process - Friction, Wear
Materials - Polymers, Additives
Application - Bearing, fluid film

Subject 8,11
Objective 1
Energy Relevance 3

Objective

To identify dry lubricant additives which can be compounded into Buna N rubber to reduce friction and wear in stern tube bearings.

Description

Ten different dry lubricant additives have been selected. These include various percentages of natural and synthetic graphites, MoS_2, CdO, silver and PTFE, and they have been compounded into Buna-N specimens for comparison with a reference base Buna-N in both static and dynamic testing.

Static testing covers a check of mechanical and physical properties before and after extended exposure to synthetic seawater and includes tensile strength, hardness, elongation, weight and volume changes.

For the dynamic friction and wear evaluations, a new six position, pin-on journal tester is being used.

Dynamic tests of five hundred hours duration have been completed and have shown significant improvements in friction levels and wear rates with the following additives:

(a) CdO + graphite + Ag
(b) CdO + MoS_2 + Ag, and
(c) MoS_2, compared to the base Buna-N

Title

Develop Engine Oil Monitors

Investigators	Organization
R.L. Mowery R.N. Bolster	Naval Research Laboratory
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion
Variables
Process - Oil Analysis
Materials - Fluid Lubricants
Application - Engines

Subject 9
Objective 1
Energy Relevance

Objective

To develop instrumentation which will determine lubricant condition.

Description

1. A spectrograph is used to monitor anti-oxidant levels. Changes in line strength determine when the additive is depleted and the oil should be changed.

2. Sensors are being developed to measure fuel dilution and water content of engine oils.

Title

In-line Oil Debris Monitoring and Fine Filtration

Investigators	Organization
W.A. Huggens Blair Poteate	AVRADCOM - Ft. Eustis
Sponsor	**Schedule and Funding**
AVRADCOM	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion
Variables - Environment
Process - Oil analysis
Materials - Fluid lubricants
Application - Engine, transmission

Subject 9
Objective 1
Energy Relevance

Objective

To develop an advanced oil debris detector.

Description

In 1978, the U.S. Army established an R&D effort to develop an advanced oil debris discrimination and filtration system for the UH-1/AH-1 helicopter with a potential for use in all helicopters. The system was designed to detect failures reliably, reduce nuisance chip indications and help reduce no-fault removals while improving component life and extending oil change intervals. A flight test evaluation was performed at Fort Rucker and more than 70,000 flight hours have been logged to date.

The full-flow chip detection system was completely effective in detecting all oil-wetted component failures, including transmi ssion mast and pinion and engine shaft bearing failures. Due to the high level of oil filtration, spectrometric oil analysis (SOAP) gave no indications.

Title

Bearing Acceptance Testing and Condition Evaluation

Investigators	Organization
G. Phillips	NSRDC-Annapolis

Sponsor	Schedule and Funding
USN Parts Control Center	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion - Lubricated rolling
Variables
Process - Noise
Materials
Application - Rolling contact bearings

Subject 9, 18
Objective 1
Energy Relevance

Objective

To determine the conformance of noise tested ball bearings with military specification MIL-B-179310.

Description

Verification inspection (vibration and metrology) is conducted on samples of all lots of new noise tested bearings which are offered for delivery to the government.

Title

Fiber Optics Bearing Performance Monitoring

Investigators	Organization
G. Phillips	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 84 FY 85 FY 86 FY 87 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables
Process - Failure
Materials
Application - Rolling element bearing

Subject 9
Objective 1
Energy Relevance

Objective

To improve bearing reliability by condition monitoring.

Description

Reliable prediction of ball bearing failures and/or noise degradation as well as adequate post-assembly bearing installation checks are essential to prevent replacement simply on a time basis, to avoid"infant mortality" problems, and more importantly, to prevent a casualty to a critical machine during a mission. Recently, it has been shown that light reflected from the faces of rolling contact bearings can be conditioned to accurately describe bearing performance. Fiber optic probes are the transmitting media for the light source. A portable fiber optic bearing monitor was developed under the previous project. Developmental testing of the FOBM will continue with this current project.

Title

Oil Analysis Spectrometer Sensitivity

Investigators	Organization
P.ODonnel	Naval Air Engineering Center

Sponsor	Schedule and Funding
NASL-Wash	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables - Composition
Process - Oil Analysis
Materials - Fluid Lubricants
Application

Subject 9
Objective 1
Energy Relevance

Objective

To improve the spectrometric oil analysis technique's sensitivity to large wear particles.

Description

A study is under way to determine existing size limitation of spectrometric wear particle analysis and the factor/factors controlling this size limitation and explore possible solutions, alternatives to this limitation and complete laboratory testing and filed testing of the optimal solution.

A study was also conducted of bulk oil effects, dwell time and transport efficiencies.

Title

Lubrication Analysis Techniques

Investigators	Organization
	WPAFB-Propulsion Lab

Sponsor	Schedule and Funding
WPAFB-PL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables
Process - Oil analysis lubricants
Materials - Lubricants, fluid
Application - Engines

Subject 9
Objective 1
Energy Relevance

Objective

To develop new lubricant analysis techniques.

Description

Preliminary in house research on new lubricant analysis techniques to include:

Test methods
Wear particle analysis
Lubricant quality
Other

Title

Expanded Capability Spectrographic Oil Analysis

Investigators	Organization
	WPAFB - Propulsion Lab

Sponsor	Schedule and Funding
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion
Variables
Process - Oil Analysis
Materials - Lubricants, Fluid
Application - Engines

Subject 9
Objective 1
Energy Relevance

Objective

To install more accurate SOAP equipment.

Description

Examine feasibility of installing more accurate SOAP equipment at bases doing oil analysis.

Title

In-Line Lubrication Monitors

Investigators	Organization
L. Debrohun	WPAFB-Propulsion Lab
Sponsor	**Schedule and Funding**
WPAFB	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion
Variables
Process - Oil analysis
Materials - Fluid lubricants
Application - Engines

Subject 9
Objective 1
Energy Relevance

Objective

To develop in-line monitors to measure engine and lubricant condition.

Description

A program is planned to develop and flight test in-line instruments which wi'l detect wear particles or lubricant oxidation which would indicate a variety of engine problems. One such instrument is an X-ray flouresence model. This device will be developed to detect 4 metals, evaluated, and then flight tested.

Title

Erosion of Materials

Investigators	Organization
A.V. Levy	Lawrence Berkelly Laboratory

Sponsor	Schedule and Funding
DOE-Fossil Energy Office	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Impact
Variables - Composition, Physical Prop, Chemical Prop., velocity
Process - Erosion
Materials - Metals
Application

Subject 10
Objective 1
Energy Relevance

Objective

To study erosion of materials used in coal gasification .

Description

1. Develop erosion model and evaluate it experimentally using 1018 steel and 30455.

2. Determine effect of strain hardening coefficient and other erosion sensitive properties on the erosion rate using alloys with tailored properties.

3. Determine effect of elevated temperatures near heat treatment temperature on the erosion rates of 6061 AL, 410SS, 4340 steel.

4. Refine and evaluate the two phase flow fluid mechanics model using data from the literatures.

5. Complete the testing of surface modifying materials systems at room and elevated temperatures.

6. Conduct erosion corrosion studies.

7. Oetermine erosion rates of materials in liquid Slurry flows.

Title

Metal Matrix Composite Abrasion

Investigators	Organization
P.R. Smoot	DARCOM-AMMRC, Watertown

Sponsor	Schedule and Funding
AMMRC	FY 83 50K FY 86 FY 84 50K FY 87 FY 85 50K FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated Sliding
Variables - Compositions
Process - Abrasion
Materials - Metal Composites
Application - Sliding Contacts

Subject 10
Objective 2
Energy Relevance

Objective

To evaluate abrasion resistance of aluminum-silicon carbide metal matrix composites.

Description

A dry sand rubber wheel abrasion test is being used to evaluate 70 Al/30 SiC metal matrix composites. Other mechanical properties such as tensile strength, fracture toughness, and corrosion resistance are also being measured.

Title

Cavitation Resistance

Investigators	Organization
D. Roa	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Impact
Variables - Time
Process - Surface damage, fatigue
Materials - Metals
Application - Fluid film bearings

Subject 10
Objective 2
Energy Relevance

Objective

To determine the cavitation erosion mechanisms of different bearing metals and alloys in mineral oils.

Description

Experiments are carried out in an ultrasonic magnetostrictive oscillator. Surface profile measurements are taken of the worn surfaces of metals. Wear rates are determined in water and oils.

Title

Erosion Wear Studies

Investigators	Organization
P. Roa	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Impact
Variables - Time, pressure
Process - Erosion
Materials - Metals
Application

Subject 10
Objective 2
Energy Relevance

Objective

To correlate fundamental properties of materials with solid particle impact erosion.

Description

A test rig has been set up which fires erodent particles at a target metal. A variety of metals and alloys are used and correlations attempted with properties of materials such as melting paint, elastic modulus, binding energies, yield strength, and others.

Basically the test rig consists of a sand blasting facility. Spherical glass beads and crushed glass are used. Studies of the sizes and shape of wear pits are conducted as well as the wear rates. Various wear time curves have been identified.

Title

Improved Turbine Engine Damper

Investigators	Organization
S. Drake	WPAFB - Propulsion Lab
Sponsor	**Schedule and Funding**
WPAFB - APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion - Reciprocating
Variables
Process - Friction, Wear
Materials - Metals, ceramics
Application - Sliding contact

Subject 11
Objective 1
Energy Relevance

Objective

To develop viscous damper technology.

Description

An analytical and experimental program is being conducted to develop viscous fluid film dampers for aircraft gas turbine bearings.

Title

Development of Designs and Materials for Gun Recoil Bearings

Investigators	Organization
R. Montgomery	ARRADCOM Research Branch Watervliet
Sponsor	**Schedule and Funding**
Benet WPN Lab	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated sliding
Variables - Velocity, compositions
Process - Wear, abrasion
Materials- Metals
Application - Sliding contacts

Subject 11
Objective 1
Energy Relevance

Objective

Tc explore wear and new concepts involving thick film lubrication and soft bearing materials to enhance the wear properties of Recoil Bearings/Seals.

Description

Using a simulated concentric bearing system, the present and soft metallic and/or organic bearing materials will be examined in the presence of pure versus controlled contaminated hydrualic fluid. Means for increasing film thickness, and its effects on wear in a contaminated fluid will be examined. Shaft and bearing/seal wear as a function of the above parameters will be measured and metallographic examination pursue to ascertain the mechanisms of wear and the ability of a soft material to encapsulate a contaminated particle with minimal wear.

Title

Bearing Stave Materials Study

Investigators	Organization
T. Daugherty	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology
Type Motion - Lubricated sliding
Variables
Process - Wear
Materials - Elastomers
Application - Bushings

Subject 11
Objective 1
Energy Relevance 2

Objective

To improve military specifications for water lubricated bearings.

Description

A variety of bench tests are being used to select improved materials for main shaft stave materials. Experimental studies will also be conducted using a bearing test machines. Friction and vibration are monitored for each material. The primary variable is the rubber composition. Determinations are made as to how composition and finish influence stick slip behavior.

Title	Magnetic Bearing Feasibility for Gas Turbine

Investigators	Organization
-	WPAFB-Propulsion Lab

Sponsor	Schedule and Funding	
WPAFB	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research	- Applied	Subject	11
Type Motion	- Unlubricated sliding	Objective	1
Variables		Energy Relevance	5
Process	- Load capacity		
Materials			
Application	- Engine		

Objective

To determine the feasibility of using magnetic bearings in the aircraft gas turbine engine.

Description

This is a new program in the planning stages.

Title

Helicopter Transmission Technology Development

Investigators	Organization
E. Zaretsky	NASA Lewis
Sponsor	**Schedule and Funding**
NASA/Army	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research -Exploratory development
Type Motion
Variables
Process
Materials
Application - Transmissions

Subject 12
Objective 1
Energy Relevance 3

Objective

To provide base technology for performance improvement in transmissions.

Description

1. A hybrid transmission which consists of both traction rolls and gears is being evaluated to evaluate the concept. Efficiency, noise characteristics, and reliability are being evaluated.

2. An OH58 - 300 horsepower transmission is being evaluated. New bearing and gear technology is being introduced to allow 500 HP to be transmitted.

3. Using the OH58 transmission the effect of different lubricants meeting the same mil-spec are being evaluated. Wide variations in power loss (30 percent) are found with the different lubricants (probably attributed to friction or surface chemistry changes). Changes in fatigue life are also noted.

4. A test stand has been set up to evaluate the OH68, 3000 HP helicopter transmission. A variety of studies are being conducted including performance mapping, thermal characteristics, and lubricant effects on transmission power loss.

5. Advanced transmission concepts (e.g. bearingless Planetary; split torque).

Title

Traction Drives

Investigators	Organization
S. Lowenthal	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Exploratory development	Subject	12
Type Motion	- Lubricated rolling	Objective	1
Variables		Energy Relevance	5
Process			
Materials			
Application	- Transmissions		

Objective

To develop the basic technology of traction devices

Description

1. A basic study is under way to understand and model traction phenomenon in rolling contacts. Current work considers lubricant effects and how they affect contact behavior.

2. Advanced models of gear efficiencies are being developed which allows power losses to be predicted as a function gear geometries. Results show that in certain circumstances design changes can cut the power loss in half. Computer programs are available so this technology could be easily transferred to industrial applications.

3. The compliance characteristics of traction devices is being studied for possible utilization in servopositioning and robotic applications since there is no hysterisis losses in the contact. Torsional compliance and stiffness effects are being studied.

4. In the materials area solid lubricated rollers and low modulus roller materials are being considered.

Title

Piston Ring Friction and Vehicle Fuel Economy

Investigators	Organization
D.P. Hoult J.J. Rife	MIT - Energy Laboratory
Sponsor	**Schedule and Funding**
DOE - Office of Energy Research	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Lubricated sliding
Variables -
Process - Friction
Materials - Metals
Application - Rings

Subject 15
Objective 6
Energy Relevance 5

Objective

Development of a physical model for piston ring-lubricant systems design.

Description

This project addresses the development of a physical model for piston ring-lubricant system design. The experimental base will come from a series of experiments to be conducted in a high speed photographic rig, a friction engine, and from flow visualization models. During the first year, a theoretical model was developed to describe the motion of the piston ring in a groove during the operation of a four cycle engine. This model is based conceptually on the work of Rangert, and is three dimensional with three degrees of freedom. The model predicts oil film thickness, oil consumption and friction throughout the cycle. At present the calculations have been in the quasi-steady regime. The turning points of the ring motion, when it changes orientation, remain to be studied in detail. The second major area of research was the design and construction of a test facility for the visualization of piston ring motion. Preliminary runs have been made to develop the experimental methodology. During the next year experiments will be used to evaluate, calibrate and extend the model.

Title

Tribology in Automotive Fuel Economy

Investigators	Organization
W. O. Winer	Georgia Tech - Mechanical Engineering

Sponsor	Schedule and Funding
DOT	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables
Process - Lubrication, friction
Materials -Coatings, fluid lubricants
Application - Engines

Subject	15
Objective	6
Energy Relevance	5

Objective

Friction reduction in automotive applications with improved rheological behavior and coatings.

Description

An extensive program of study into several aspects of the role of tribology in automotive fuel economy has recently been completed. The program had two main aspects. These were the role of the lubricant rheology and the potential role of hard and soft surface coatings. A significant portion of the indicated horespower produced in the combustion process is dissipated in tribocontacts by shearing the lubricant. The lubricant rheological properties are a direct indication of the amount of energy that will be dissipated for the kinematics of the tribocontact. The study was to determine the rheological behavior of typical automotive lubricants and how it depends on the composition of the lubricant. The second aspect of the study was the development and evaluation of both hard and soft surface coatings for automotive use. These coatings were put on current materials of construction as well as on several lightweight and non-strategic materials. Hard coats of titanium nitride were found to afford durable wear protection on several substrates.

Title

Effect of Fuel Components on Engine Wear

Investigators	Organization
	MERADCOM - F&L
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Basic
Type Motion - Lubricated sliding
Variables - Environment
Process - Wear
Materials - Metals
Application - Engine

Subject 15
Objective 1
Energy Relevance 1

Objective

To investigate the role of sulfur, oxygen, and nitrogen containing heteroatomic fuel components on compression-ignition engine deposits and wear.

Description

Operate a single-cylinder research engine using a highly controlled base fuel (JP-7) doped with specific heteroatomic compounds. Measure the differences in deposits and wear and investigate the related mechanisms.

Title

Gas Film Bearings for High Temperature Engines

Investigators	Organization
R. Colshur	Franklin Institute

Sponsor	Schedule and Funding
Cummins	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Sliding
Variables -
Process - Load capacity
Materials -
Application - Gas film bearings

Subject	15
Objective	1
Energy Relevance	1

Objective

To develop gas film bearings for piston rings for adiabatic diesel.

Description

An analytical program was carried out to evaluate the potential of gas lubrication of piston rings in diesel engines. Three different designs were considered. One design was selected as having sufficient load capacity to warrant further development.

Title	Improved Shipboard Fuel Contimination Control for Gas Turbine Engines

Investigators	Organization
P. Standell	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion
Variables
Process - Filtration
Materials - Fuels
Application - Engines

Subject 16
Objective 1
Energy Relevance

Objective

To define a prefilter necessary to meet LM2500 engine comtamination requirements.

Description

This program aims to optimize shipboard fuel purification systems. The program will take advantage of previous OTNSRDC and NAVSSES experience, plus the continuing investigations in fuel purification of other laboratories.

Title

Development of Foil Bearings for Gas Turbine Engines

Investigators	Organization
R. Dayton	WPAFB-Propulsion Lab

Sponsor	Schedule and Funding
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Demonstration
Type Motion - Unlubricated sliding
Variables - Temp
Process - Lubrication
Materials
Application - Gas bearings

Subject 17
Objective 3
Energy Relevance 1

Objective

To demonstrate the feasibility of using foil gas bearings in small gas turbine engines.

Description

Laboratory tests have shown that foil bearings (inconel+a solid film lubricant) will support the loads, speeds, environments and practical conditions encountered in small turbine engines. Current work includes the design of such bearings consistant with engine requirements. A follow on program will build and operate this gas bearing in a demonstration engine and provide a design manual.

Title

Advanced Rolling Element Bearing Research

Investigators	Organization
H. Scibbe	NASA

Sponsor	Schedule and Funding
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion- Lubricated rolling
Variables - Speed, load
Process
Materials
Application - Rolling bearing

Subject 18
Objective 1
Energy Relevance

Objective

To develop technology which will allow bearings to operate at higher speeds and loads, and lower temperatures.

Description

1. A transient thermal analysis has been developed which predicts temperature gradients in spherical roller bearings. This program allows engineers to modify designs to achieve minimum bearing operating temperatures. A rig is being build to compare theory with experiment.

2. A program is being conducted to increase the speed and temperature capabilities of tapered roller bearings.

3. A new bearing concept "three piece inner race" is being applied to high speed cylindrical roller bearings. The inner race (two flanges and contact surface) are made separately. This allows different materials to be used for different contact conditions; improved finishes; and different contact geometries. Such bearings are being evaluated.

4. An analytical computer program (XCAV) has been developed which predicts bearing temperatures based upon the ratio of oil to air in the bearing cavity. Experimental results show that this is a critical factor in determining bearing temperatures.

Title

Ceramic Bearing Development and Evaluation

Investigators	Organization
D. Popgoshev	NAPC
Sponsor	**Schedule and Funding**
NADC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Exploratory development	Subject	18, 8
Type Motion	- Unlubricated rolling contact	Objective	3
Variables	- Temp, materials	Energy Relevance	1
Process	- Life, surface damage		
Materials	- Ceramics		
Application	- Rolling contact bearings		

Objective

To evaluate potential of silicon nitride rolling contact bearings.

Description

Ceramic roller bearings made completely of silicon nitride are being run in a J402 turbine engine. The bearing is run at a DN of 9×10^6; bearing temperatures reach 650 to 700F. The bearing is first "run in" lubricated and then the lubricant is shut off. Current life is 53 minutes. Failure modes are investigated and improvements made to give longer life. One of the problems now being worked on is the differential thermal expansion between the bearing and housing. Other investigations include:

1. Life improvement for hybrid bearings.
2. Evaluating NDE source for subsurface damage.
3. Optimizing silicon nitride materials
   - increased fracture toughness
   - less grinding damage

Title

Corrosion Resistant Bearings

Investigators	Organization
R. Valori D. Popgoshev	NAPTC - Trenton
Sponsor	**Schedule and Funding**
	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory research
Type Motion - Lubricated rolling;lubricated sliding
Variables - Environment
Process - Life
Materials - Metals, coatings
Application - Rolling contact bearings

Subject 18, 8
Objective 1
Energy Relevance 2

Objective

To develop bearings with improved corrosion and wear protection.

Description

Based on several programs, an implantation technique was developed. Ion implanted M50 bearings were bench tested and engine tested and showed satisfactory performance. The J79 engine, the T58 engine and the H46 hinge pin bearings are now being used for field evaluation.

Title	
Ceramic Bearing Evaluation	
Investigators P. Weinberg	**Organization** Naval Air Systems Command
Sponsor NAVAIR	**Schedule and Funding** FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Rolling contact
Variables - Temp, environment
Process - Life
Materials - Ceramic
Application - Rolling contact bearings

Subject 18, 1
Objective 3
Energy Relevance 1

Objective

To evaluate the potential of Si_3N_4 ceramic bearings.

Description

A continuing program has been conducted by SKF Industries to provide a data base for a complete Si_3N_4 bearing. A carbon graphite cage is used to lubricate the bearing. A series of tests have been run to evaluate bearing life under a variety of conditions. The current investigation evaluates the effect of a salt water environment.

Title

Solid Lubricated Rolling Contact Bearing Development

Investigators	Organization
J. Dill	WPAFB - Propulsion Lab
Sponsor WP AFB-APL	**Schedule and Funding** FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Rolling contact
Variables - Temperature
Process - Life
Materials - Metals, Ceramics
Application- Rolling contact bearings

Subject 18, 7
Objective 3
Energy Relevance 1

Objective

Develop 1200F solid lubricated bearing technology.

Description

A selection will be made of bearing materials, lubricants, and lubrication systems which have maximum temperature capability. Appropriate bearings will be designed, manufactured and tested. Test results will be used to improve materials and designs.

Title

Tapered Roller Bearings for Gas Turbine Engines

Investigators	Organization
R. Dayton	WPAFB-Propulsion Lab
Sponsor	**Schedule and Funding**
WPAB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology Development
Type Motion - Lubricated rolling contact
Variables -
Process - Life wear
Materials - Metals
Application - Rolling contact bearings

Subject 18
Objective 1
Energy Relevance

Objective

To evaluate the tapered rolling bearing concept for feasibility in the gas turbine engine.

Description

Bearings were designed and tested. The concept looks good and further development is planned.

Title

High Speed Cylindrical Roller Bearing Development

Investigators	Organization
J. Schrand	WPAFB - Propulsion Lab (Pratt & Whitney Aircraft)
Sponsor	**Schedule and Funding**
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology
Type Motion - Lubricated rolling
Variables - Velocity
Process - Life
Materials - Metals
Application - Rolling contact bearing

Subject 18
Objective 1
Energy Relevance 5

Objective

To design a three million DN cylindrical roller bearing for turbomachinery applications.

Description

A new design is being prepared to avoid problem areas encountered in the original design.

Title

Counter-Rotating Roller Bearing Development

Investigators	Organization
R. Dayton R. Valori	P&W and GE
Sponsor	**Schedule and Funding**
WPAFB-APL Navy-NAPC	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion - Lubricated rolling
Variables - Velocity
Process - Life
Materials - Metals
Application - Rolling contact bearing

Subject 18
Objective 1
Energy Relevance

Objective

To design and evaluate a bearing system for a counter rotating shaft gas turbine engine.

Description

Advanced engine configuration studies conducted at P&WA have shown large Life Cycle Cost (LCC) advantages for an engine with contrarotating spools and a rotor support system in which the high rotor is straddle mounted with an intershaft support bearing downstream of the high pressure turbine. As a result, advanced engine designs are incorporating intershaft support bearings with operational requirements up to 3.7 million DN, and roller rotational speeds up to 170,000 rpm which is twice conventional levels.

The objective of this program was to select an appropriate intershaft bearing size, mounting configuration and key design parameters for an advanced engine configuration, update bearing design analysis methodology to address intershaft bearings in contrarotation, and to conduct bearing tests on eight bearing configurations to evaluate two levels each of four key bearing geometry parameters relative to a baseline bearing.

Such bearings have been designed and operated in bearing tests. Long term bearing tests (several thousand hours) to determine wear life are in progress.

Title

Improved Corrosion Resistant Bearings

Investigators	Organization
J. Artuso	WPAFB-Propulsion Lab
Sponsor	**Schedule and Funding**
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion- Lubricated rolling
Variables - Environment
Process - Surface damage
Materials - Metals
Application - Rolling contact bearings

Subject 8,18
Objective 1
Energy Relevance

Objective

To obtain gas turbine engine bearings with improved corrosion resistance.

Description

In previous work (24) a number of materials were selected which might be suitable as rolling contact bearing materials. Three of these materials were selected based upon fatigue and corrosion bench tests. Full scale bearing tests will be run with these materials to determine life. Results will be compared with M50. The materials are CRB7, MRC2001, and Armalloy coated M50.

Title

Bearing Research for ROP Power Systems

Investigators	Organization
In - House	WPAFB-Propulsion Lab
Sponsor	**Schedule and Funding**
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Rolling contact
Variables
Process - Life
Materials - Metals, coatings
Application - Rolling contact bearings

Subject
Objective
Energy Relevance

Objective

In-house research to develop better bearing systems.

Description

A variety of investigations are conducted to improve understanding of materials and lubricants for engine rolling contact bearings:

1. Friction studies on lubricants
2. New and improved solid lubricant materials
3. Rolling contact fatigue tests on new materials
4. Full scale bearing dynamic studies (larger amplitudes)

Title

NAVSEA Quiet Bearing Program

Investigators	Organization
R. Craig	NAVSEA

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Exploratory development
Type Motion - Rolling
Variables - Finish, Geometry
Process - Noise
Materials -
Application - Rolling Contact bearings

Subject 18
Objective 8
Energy Relevance

Objective

To better understand the nature of bearing noise (applicable to submarine machinery).

Description

NAVSEA is planning a major tribology program concerned with bearing noise. Low noise and vibration are needed in submarines to avoid detection. Noise requirement desired are specified in MILB 17931. Noise is usually classified as rigid body noise which relates to surface irregularities and elastic contact noise which relates to surface roughness. Noise is dependent upon both operating conditions and bearing geometries such as dimensional variations curvature, finish, tolerance, clearance, waviness, etc. This program will attempt to determine which variables are most important and what can be done to manufacture quiet bearings.

Title

Wear Testing and Seal Life Predictions

Investigators	Organization
R.C. Erickson	Battelle - Columbus

Sponsor	Schedule and Funding
WPAFB/Hughes	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion - Sliding
Variables - Environment, Compositions
Process - Wear
Materials - Polymers
Application - Seals

Subject 19
Objective 5
Energy Relevance

Objective

To predict wear life of polymer seal materials.

Description

Friction and wear experiments are being performed at liquid nitrogen temperature in a gaseous helium environment using a specially prepared experimental apparatus. The resulting data will be analyzed along with other tribological and material property data to formulate life predictions for polymeric seal material intended for use in V-M Coolers.

Title

Development of Main Shaft Seals for Surface Ships

Investigators	Organization
R. Brown	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83, FY 84, FY 85, FY 86, FY 87, FY 88

Classification

Type Research - Technology Development
Type Motion - Sliding
Variables
Process - Wear
Materials - Carbon
Application - Seals

Subject 19
Objective 1
Energy Relevance

Objective

To improve main shaft seals for surface ships and evaluate new seal materials.

Description

It is necessary that the Navy conduct a program to improve existing seals and evaluate new seal designs because main shaft seals for surface ships cause significant maintenance problems. The most common problems are failure of the bond at the split ends, corrosion and wear of the shaft sleeve under the seal, and wear of the seal gland.

A Navy-developed seal design will be evaluated for performance in terms of leakage, wear of faces and ability to accommodate large shaft motions.

Title

High Speed Air Oil Seal Design

Investigators	Organization
	P&W GE

Sponsor	Schedule and Funding	
WPAFB-APL NAPTC-Trenton	FY 83 FY 84 FY 85	FY 86 FY 87 FY 88

Classification

Type Research - Technology development
Type Motion - Unlubricated sliding
Variables -Velocity, temperature
Process - Wear
Materials - Metals, ceramics, carbons
Application - Seals

Subject	19
Objective	1
Energy Relevance	1

Objective

To develop a new generation of seals for gas turbine engines .

Description

Current Engine Bearing face seals consist of carbon seals and aluminum oxide or chrome carbide runners. They operate dry to temperatures of 500F and speeds of 400-500 ft/sec. For advanced engines, higher velocities (800 ft/sec) and higher temperature (800F) seals will be required. This may require new materials and new designs. Programs have been initiated to develop such seals.

Title

Seal Dynamics

Investigators	Organization
Lt. Gainer	WPAFB-APL

Sponsor	Schedule and Funding
WPAFB-APL	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Unlubricated sliding
Variables - Velocity
Process -
Materials
Application - Seals

Subject 19
Objective 1
Energy Relevance 5

Objective

To develop a mathemetical model for the dynamic behavior of face seals.

Description

An analytical model will be developed and correlated with experiment.

Title

Tribological Research for Improved Aero-Engine Efficiency

Investigators	Organization
A.F. Emery J. Wolak	University of Washington
Sponsor	**Schedule and Funding**
NASA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied		Subject	19
Type Motion - Sliding		Objective	6
Variables - Velocity & Geometry		Energy Relevance	5
Process - Wear			
Materials - Metals			
Application - Seals			

Objective

To minimize the deleterious effects of blade tip/seal rub interactions in aero-turbine engines.

Description

Special apparatus has been constructed to permit experimental studies of similar high intensity rubbing processes under laboratory conditions. The controlled parameters associated with the blade tip specimen are its material, the geometry of the tip, and the speed of rubbing, which can be set between 0.01 m/s to 150 m/s. The parameters associated with the seal are: its material, the geometry of its internal construction, the geometry of the path of rubbing, the depth of incursion, and the rate of incursion, which may be set between 1.0×10^{-5} mm and 0.1mm per pass of the blade. The parameters measured experimentally are the forces of interaction, the temperatures at the blade-seal interface, and the wear of both specimens.

These studies are augmented with theoretical analyses of energy generation and dissipation during rubbing, of associated stress and temperature fields, and of the effect of temperature on the properties of materials adjacent to the rub interface.

Title

Observations from a Five-inch Seal Test Machine

Investigators	Organization
S.A. Karp V. Suprenent R.G. Brown	DTNSRDC Annapolis

Sponsor	Schedule and Funding	
NAVSEA	FY 83 FY 84 FY 85	FY 86 FY 87 FY 88

Classification

Type Research - Applied
Type Motion - Sliding, lubricated
Variables - Composition
Process - Wear, leakage
Materials - Matals, ceramics
Application - Seal

Subject 19
Objective 1
Energy Relevance

Objective

To develop longer life submarine seal materials.

Description

A Navy submarine seal materials task was structured to provide inputs to a general program established to develop seals with a longer service life. One element of the task is to rank seal-face combinations having better resistance to wear than material combinations currently used. A test rig was developed for this purpose.

Data are being accumulated to provide a statistically sound basis to correlate the wear performance of the mating materials to material composition, structure, and properties.

Title

Influence of Thermal Expansion and Wear on Contact of High Current Density Electric Brushes

Investigators	Organization
T. Dow D. Lawson	North Carolina State
Sponsor	**Schedule and Funding**
CNR	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion - Sliding
Variables -
Process- Temperatures, wear
Materials - Carbon
Application - Brushes

Subject 20
Objective 1
Energy Relevance

Objective

Determine the influence of thermal effects and interaction with viscosity, thermal expansion, surface contact.

Description

A research program is aimed at studying the influence of thermal effects and interaction with:

1. Lubricant viscosity in EHD contact
2. Thermal expansion of surface in EHD contact
3. Contact in unlubricated or boundary lubricated sliding surfaces

Title

Improved Service Life of Transient Coach Brakes

Investigators	Organization
S.A. Barber	Battelle Columbus

Sponsor	Schedule and Funding	
National Academy of Science / NCTRP	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Exploratory development
Type Motion - Unlubricated sliding
Variables - Temperature
Process - Life
Materials - Polymer
Application - Brakes

Subject 21
Objective 1
Energy Relevance

Objective

To investigate possible solution schemes toward reducing drum and lining temperatures.

Description

New Advanced Design Buses used in urban transit system now experience reduced brake lining life compared to older buses. Increased drum and lining temperature due to higher stopping speeds is suspected to be the main cause. This program is investigation possible solution schemes toward reducing drum and lining temperatures.

Title	Pump Development for Deep Submergence Submarines

Investigators	Organization
G. Phillips	NSRDC-Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology
Type Motion - Lubricated rolling contact
Variables
Process - Noise
Materials
Application - Rolling contact bearings

Subject 21
Objective 1
Energy Relevance

Objective

To develop and apply design and materials technology to eliminate recognized mechanical and acoustic deficiencies.

Description

The ability to operate submarines at greater operating depth requires that sea-connected pumps be redesigned to provide required performance throughout the submarine operating envelope. For most systems, redesign is required since simple strengthening is unacceptable from both mechanical and weight/volume considerations. The NSW pump being developed must include in addition to a stronger casing, recent materials and acoustic design technology as well as improved bearing and seal systems to overcome recognized deficiencies in existing pump systems.

Title

Marine Tribology Block Program

Investigators	Organization
J. Belt	Naval Ship R&D Center, Annapolis

Sponsor	Schedule and Funding
NAVSEA	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Applied
Type Motion
Variables
Process
Materials
Application

Subject 21
Objective 1
Energy Relevance

Objective

To improve quietness, performance, and reliability of surface ship, submarine, and Marine Corps equipment thru the application of tribological advances in the development of new and improved bearings, seals, lubricants, and lubricating processes.

Description

Increase ball bearing service life to match design fatigue life application of new bearing capabilities in bearing technology. Long life shaft seal face materials, compliant bearing materials, improved greases for ship services, improved lubricating oils for ships, non toxic fire resistant hydraulic fluids, high K factor gear lubricants, high K factor gear materials, fatigue resistant coupling elastomers, main propulsion thrust bearings, and high speed journal bearing materials.

Title

Tribological R&D in Government

Investigators	Organization
M.B. Peterson	Wear Sciences Corp

Sponsor	Schedule and Funding
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion
Variables
Process
Materials
Application

Subject 21
Objective 6
Energy Relevance

Objective

To identify government sponsored tribology projects.

Description

A study is being conducted to identify government sponsored tribology work either in house or contractual. Computer data bases were used to select 650 projects conducted the past six years. Visits and discussions were conducted with 21 major sponsors and approximately 150 performing organizations to identify 215 current projects. Each project was classified in a variety of ways so that conclusions could be drawn as to the nature of the tribology work in progress.

Title

Tribological R&D in Private Industry

Investigators	Organization
L.B. Sibley M. Zlotnick	Tribology Consultants Inc.
Sponsor	**Schedule and Funding**
ECUT DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Technology development	Subject	21
Type Motion		Objective	6
Variables		Energy Relevance	
Process			
Materials			
Application			

Objective

To obtain form industry their view on tribology research needs and determine research in progress.

Description

Visits were made to twenty selected industrial organizations to determine current tribology R&D and to assess industrial conceptions of R&D needs. Preliminary findings confirm the view that only a small amount of generic research in tribology is being conducted and that total expenditures by industry is small. Most of the work can be characterized as product development and testing. However the need for generic research was acknowledged,emphasizing fundamental mechanisms.

Title

Tribological Energy Sinks in the Transportation and Utility Sectors

Investigators	Organization
D.F. Wilcock	Mechanical Technology Inc.

Sponsor	Schedule and Funding	
ECUT DOE	FY 83	FY 86
	FY 84	FY 87
	FY 85	FY 88

Classification

Type Research - Technology Development		Subject	21
Type Motion		Objective	1, 6
Variables		Energy Relevance	5
Process			
Materials			
Application			

Objective

To determine energy flows in transportation and utilities machinery and propose schemes on how to reduce frictional and other parasitic losses.

Description

In order to determine tribology projects with the greatest energy saving potential, an assessment is being made of tribological energy sinks in the transportation and utility sectors. A selected number of visits were made to determine energy flows and recommendations made for appropriate development programs.

Title

Tribological Energy Sinks in the Industrial Sector

Investigators	Organization
R. Erickson	Battelle Columbus

Sponsor	Schedule and Funding
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research - Technology development
Type Motion
Variables
Process - Friction and wear
Materials
Application

Subject 21
Objective 6
Energy Relevance 5

Objective

To determine tribological energy sinks in industry.

Description

In order to determine tribology projects with the greatest energy saving potential an assessment is being made to quantify industrial energy sinks. Energy intensive industries were first selected followed by detailed reviews of different energy sectors. Different tribology contributions to each sector are being suggested.

Title

Assessment of ECUT Role in Tribology

Investigators	Organization
J.A. Carpenter, Jr. C.H. Imhoff	Oak Ridge National Lab Pacific Northwest Labs

Sponsor	Schedule and Funding
ECUT/DOE	FY 83 FY 86 FY 84 FY 87 FY 85 FY 88

Classification

Type Research	- Technology development	Subject	21
Type Motion		Objective	6
Variables		Energy Relevance	
Process			
Materials			
Application			

Objective

To provide a basis on which ECUT can establish its most effective role in supporting tribological research and development.

Description

This effort is intended to provide the basis on which ECUT can establish its most effective role in supporting tribology research and development. That role will be determined by taking into account the tribological energy sinks in the industrial, transportation, and utility sectors and the potential of current government and industrial research to meet energy related objectives.

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