AIR FORCE
MATERIALS SYMPOSIUM 70

TECHNICAL SPECIALIST SESSIONS
SUMMARY ABSTRACTS

AIR FORCE MATERIALS LABORATORY

AIR FORCE SYSTEMS COMMAND

WRIGHT–PATTERSON AIR FORCE BASE, OHIO 45433

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FOREWORD

This document contains the 100-word abstracts of all the papers presented in the Technical Specialist Sessions of the Air Force Materials Symposium '70 held in Miami Beach, Florida on 18-22 May 1970. These abstracts were submitted by the authors for inclusion in this publication and summarize the main subject of the oral presentations. They are primarily intended to inform the attendee of: the session topic; presentation title, author, organization and subject matter; and other session participants. If further information is desired on any presentation topic or subject area it is suggested that you communicate with the author. No other printed proceedings are planned as part of this Symposium.

The Technical Sessions in this document are grouped according to materials related subject areas. The Final Program agenda should be used for determining the Session scheduling, location and attendance restrictions. The abstracts in this publication have been granted unrestricted distribution, however, some of the Session presentations may have publication restrictions.

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SESSION 1A: STRUCTURAL ALLOYS

Tuesday 0900-1200, 19 May 1970

Chairman: C. M. Pierce, Air Force Materials Laboratory

Co-Chairman: P. L. Hendricks, Air Force Materials Laboratory

1A1 -- STATUS AND FUTURE OF STRUCTURAL ALLOYS FOR AIRFRAME CONSTRUCTION

C. Pierce and J. Hall, Air Force Materials Laboratory

Several alloy systems are examined from the point of view of structural efficiency in current and future airframes. The relative merits of each alloy system are highlighted by considering the possible design criteria, reliability considerations, producibility, fabrication characteristics and cost.

Specific attention is paid to those materials deficiencies having the greatest impact in airframe design, and promising development efforts to overcome these drawbacks are discussed.

1A2 -- SERVICE EXPERIENCE AND INTEGRITY OF STRUCTURAL ALLOYS

H. Zoeller, Air Force Materials Laboratory

Proper design, materials selection, manufacturing processing, quality control, and full scale structural testing of airframe components are required in obtaining desired material integrity and maximum life expectancy. The laxity in fulfilling many of the above important areas, particularly quality control, will result in early material failure and the incorporation of expensive engineering modification. Service failures related to and resulting from each of these areas will be discussed. The action taken to correct these discrepancies will also be reviewed. Particular emphasis will be placed on fatigue failures. Testing procedures and methods used on various aerospace components and airframe fuselage sections will be discussed to relate their importance in airframe design life assurance. The necessity for the design, materials, production, and quality control engineers to work as a coordinated team to assure structural integrity is emphasized.

1A3 -- TITANIUM ALLOYS FOR AIRFRAME APPLICATIONS

A. Sommer and J. Williams, North American Rockwell Corp.

This discourse will briefly review the evolution and rationale which have led to the current matrix of commercial titanium alloys. The relationship between micro-structure and the static and dynamic mechanical behavior of typical alpha, beta and various multiphase alloys will be discussed. Examples of candidate alloy selections for various airframe applications will also be cited. A discussion of these selections with regard to both the mechanical behavior of the material required in the final component configuration as well as the candidate fabrication procedure(s) available to produce the specific component in titanium will be presented.

1A4 -- TRENDS IN HIGH STRENGTH ALUMINUM ALLOYS

T. Ronald and I. Perlmutter, Air Force Materials Laboratory

The current status and trends of the 7000 series of alloys as structural materials, particularly with respect to tensile, stress corrosion, and fatigue properties are discussed. The relationship of properties to microstructure and heat treatment is considered and

1A4 -- TRENDS IN HIGH STRENGTH ALUMINUM ALLOYS (Continued)

current approaches (including alloy development) to compromising between strength and stress corrosion resistance are reviewed. The theoretical and practical potential for future developments are stressed.

1A5 -- HIGH STRENGTH STEELS FOR AIRFRAMES

D. Kalish, Lockheed-Georgia Company

The principal types of high strength steel employed in airframes are medium carbon 4100 or 4300 alloys (or their modifications). The increasing size and cost of aircraft components and concurrent higher performance demands require a re-evaluation of the limitations of these steels.

Problems with low alloy quench and temper steels may arise from: limited hardenability and formation of non-martensitic microconstituents; ambient temperature strain tempering; untempered martensite formation by conversion of retained austenite or local reaustenizing on machining; or embrittlement by impurities. Chemical inhomogeneity, particularly likely in large forgings, can promote these sources of trouble.

Improved vacuum melting procedures, special higher alloy steels, novel thermal and thermomechanical processes, and more realistic mechanical behavior performance parameters are among the future trends in utilizing steels in airframes.

SESSION 2A: STRUCTURAL ALLOYS

Wednesday 0900-1200, 20 May 1970

Chairman: I. Perlmutter, Air Force Materials Laboratory

Co-Chairman: E. Dulis, Crucible Steel Company

2A1 -- FABRICABILITY OF TITANIUM STRUCTURES

R. Juergens and J. Spehr, McDonnell-Douglas Corp.

The criteria used in selecting alloys for advanced titanium structures are discussed and compared with data for the alloys screened but not selected. Fabrication considerations, for titanium alloys in both the annealed or heat treated and aged conditions, are presented; these include production operations such as forming, machining and welding. The problems and trade-off considerations encountered when assembling titanium structures are also discussed. Adhesive bonding, welding and mechanical fastener selection are evaluated. Steps in fabrication are shown, which demonstrate how continuing developments have made possible the production of titanium structures.

2A2 -- POTENTIAL OF MARAGING STEELS FOR AIRCRAFT

C. Carter, The Boeing Company

Heavy sections for landing gear and airframe applications are discussed with emphasis placed on the potential cost savings offered by maraging steel. Major attention is given to the 250 and 300 grades, and current applications are reviewed. The mechanical properties relevant to structural application are summarized and contrasted with those of currently used low alloy steels. Problem areas in maraging steel technology are identified. Enhancement of strength and toughness by impurity element control, alloy content modification, and heat treatment are discussed. The properties of high strength, stainless maraging steels (e.g. PH 13-8 Mo, Custom 455) are briefly described.

2A3 -- IMPROVING MATERIALS AND DESIGN TO AVOID FATIGUE

A. McEvily, University of Connecticut

Fatigue is the most structure-sensitive of mechanical failure processes and, for this reason, improvements in fatigue behavior can be achieved through control of the weakest links in the metallurgical structure. Vacuum melting, close control of alloy content, and thermo-mechanical processing are examples which specifically have proven to be effective in improving fatigue properties. Special processing treatments such as shot-peening, coining, and prestressing also find practical application in minimizing fatigue. Special design approaches such as "lead-before-burst" exemplified by the pressurized Sikorsky helicopter rotor blades, provide novel means for detecting fatigue cracks prior to catastrophic failure. Advances in non-destructive test techniques coupled with analysis based upon fracture mechanics also provide a potential for avoiding structural failure due to fatigue.

This presentation will review current advances being made in each of these areas.

PANEL DISCUSSION -- FUTURE OF STRUCTURAL ALLOYS IN AIRFRAMES

Moderators:
- H. Burte, Air Force Materials Laboratory
- A. W. Bethune, The Boeing Co.

Members:
- H. Gegel, Air Force Materials Laboratory
- G. Pfanner, Fairchild Hiller Corporation
- H. Siegel, McDonnell-Douglas Corporation
- [illegible]. Stacher, Lockheed-Georgia Co.
- A. Tetelman, U.C.L.A.
- D. King, Brush Beryllium Co.

SESSION 3A: ADVANCED COMPOSITE TECHNOLOGY DEVELOPMENT STATUS

Wednesday 1330-1700, 20 May 1970

Chairman: R. G. Loewy, University of Rochester

Co-Chairman: L. R. McCreight, General Electric Company

3A1 -- BORON-ORGANIC COMPOSITES PERSPECTIVE

R. L. Kapson, Air Force Materials Laboratory

The boron filament-organic matrix composites are the most highly developed of the advanced composite materials available today. Sufficient experience has been acquired in the areas of materials characterization, design methods, and fabrication techniques to place these materials at the point of imminent application to production aircraft. The materials have successfully accomplished the transition from laboratory to pre-production status, but only after the solution of several technological challenges related to process scale-up. The current status of boron-organic composites will be discussed in terms of product availability, reproducibility, production capacity, and specific problem areas which still require solutions.

3A2 -- EMERGING ORGANIC COMPOSITES

J. D. Ray, Air Force Materials Laboratory

High performance nonmetallic composite materials are playing an ever-increasing role in the advancement of aerospace technology. They are being considered for numerous applications because they possess a unique material property, offer a balance of properties, and are available in a multitude of forms for use in making composite structures unlike those of other engineering materials.

It is becoming evident that in all likelihood no single resin or reinforcement will evolve to fulfill all the requirements for composites for aerospace applications. It is the development and characterization of high performance resins, reinforcements and subsequent composites that form the substance of this paper.

3A3 — METAL MATRIX COMPOSITES PERSPECTIVE

Major J. P. Kershaw, Air Force Materials Laboratory

Metal matrix composite technology has included the production and characterization of reinforcements, study of the chemical compatibility of the reinforcement and metallic matrix, optimization of fabrication parameters for the various production techniques, characterization of the composites, and the construction and evaluation of several prototype composite engineering structures. The present status of these materials will be summarized along with predictions of some of the short and medium range material developments which might reasonably be expected. The potential of directionally solidified eutectics and whisker reinforced metals will be compared with the more highly developed filamentary reinforced composites.

3A4 — ENGINEERING DATA AND DESIGN ALLOWABLES CRITERIA

P. D. Shockey, General Dynamics Corporation

L. M. Lackman, North American Rockwell Corporation

Extensive characterization of boron-epoxy material systems have been conducted and the current status of the resulting test data is discussed. The characterizations of graphite-epoxy which have been conducted are also

3A4 -- ENGINEERING DATA AND DESIGN ALLOWABLES CRITERIA (Continued)

discussed. The characterization data include mechanical properties for the basic lamina and oriented laminates. Results of uniaxial static tests are reported in which the data were evaluated for statistical significance and batch-to-batch variability and results of some biaxial tests are also disucssed. The fatigue performance of advanced composite materials is described along with results of special studies such as creep, damping, and strain-rate effects. The influence of several environmental factors on the mechanical properties are also reported. The methods utilized in establishing design allowables for advanced composite materials are discussed and the relationships of the experimental data to prominent design allowables criteria are described.

3A5 -- STRUCTURAL DESIGN WITH COMPOSITES

C. W. Rogers and M. E. Waddoups, General Dynamics Corp.

Composite design technology has been firmly established for applications in which the primary loads are resisted in the plane of the laminate; i.e., membrane stressed structure. Design procedures applicable to membrane stressed structures will be presented together with specific design examples.

The problem of design objective selection and relation of the composite material variables to complex system requirements other than minimum weight will be discussed.

Design procedures for both mechanical and bonded joints will be discussed with the primary emphasis on problems related to deviations from pure membrane stress in the vicinity of joints.

3A6 -- EMERGING EXPLORATORY DEVELOPMENTS

P. A. Parmley, Air Force Flight Dynamics Laboratory

Because of the tremendous weight-saving properties of advanced composites, the technology has been pushed toward building aircraft components as soon as possible. Exploratory Development programs are now being conducted to supplement the hardware development and provide structural design techniques for composites which can be used with confidence. This paper presents recent information and describes remaining problems in the technical areas of biaxial properties, strength theories, cutouts, design criteria, interlaminar shear behavior, and joints. Results of aeroelastic design studies for a swept wing will be discussed and the increase in aeroelastic performance possible by tailoring the anisotropic properties of composites to provide the proper bending-torsion coupling will be shown.

3A7 -- COMPOSITE MANUFACTURING TECHNIQUES

T. M. Cornsweet, Air Force Materials Laboratory

Many different types of components are being designed and fabricated utilizing advanced composite materials. These components vary in manufacturing complexity from multiple ply flat plates to complex curved honeycomb panels and complex three-dimensional solid fittings. The multitude of both component designs and fabrication techniques in current use require an examination of the fabrication techniques used for each component, followed by a comparison of the approaches to similar types of structures and an overall look at the methods in use. Examples of the manufacturing techniques and equipment to be examined include continuous tape, broad goods, and chopped tape; hand layup, semi-automated layup, and continuous machine layup; and metal matrix tape and sheet fabrication techniques.

SESSION 4A: COMPOSITES - AIRCRAFT AND HELICOPTER STRUCTURAL DEVELOPMENT

Thursday 0900-1200, 21 May 1970

Chairman: H. Ashley, Stanford University

Co-Chairman: H. C. Schjelderup, McDonnell-Douglas Corp.

4A1 -- APPLICATION OF COMPOSITE MATERIALS TO HELICOPTER ROTOR BLADES

D. Hoffstedt, Boeing Vertol

Development of boron helicopter main rotor blades. The Vertol Division of the Boeing Company is engaged in a program to develop and test flightworthy rotor blades pre-fabricated with boron filament reinforced epoxy. Current development is under contract to the Air Force Materials Laboratory with participation with USAAVLABS. The materials, design, pre-fabrication development and test experience are reviewed. The elements in the presentation center around test and boron goods material, quality and handling characteristics, problems encountered in pre-fabrication and their solutions, and quality assurance experience to date. Experience gained in correlation of calculated versus measured section properties and validity of weight control assumptions is reviewed. Results of fatigue test program on full scale blade sections is also discussed.

4A2 -- ADVANCED COMPOSITE HORIZONTAL STABILIZER TECHNOLOGY

J. R. Blacklock, General Dynamics Corporation

F-111 boron horizontal stabilizer research programs will be reviewed. Current efforts include boron structure design improvements and component test evaluations. The results of the fatigue test of the second F-111 boron horizontal stabilizer article as well as the results of the static test to failure of the F-111 boron horizontal stabilizer article will be presented. The review will examine the various manufacturing, quality control and tooling techniques available for manufacture of similar aircraft boron component parts. Information regarding the first horizontal stabilizer flight and the new production development program will be presented.

4A3 -- OPERATIONAL EVALUATION OF COMPOSITE STRUCTURES

W. M. Purcell, Air Force Aeronautical Systems Division

The Air Force Aeronautical Systems Division has recently initiated a program that will lead to substantial production and flight experience with advanced composite structural materials. The objectives and status of this program will be presented in this paper. Since the program has recently been initiated and will continue for several years, the detailed results and conclusions will be "as of the date of the meeting". The final results of the program will be appropriate for presentation at a future date. The program will include structure on the F-4, F-111, C-5A and F-15 Aircraft.

4A4 -- COMPOSITE WING STRUCTURES

H. A. Wood, Air Force Flight Dynamics Laboratory

The AFML has two programs working on the development of advanced composite wing structures using boron epoxy materials. The Grumman wing program is a technology oriented effort to develop the required design, analysis and fabrication techniques and demonstrate the design validity on a large structural part. This is the first attempt to design and fabricate a rib-spar-cover type structure from advanced composites. The North American boron wing skin

4A4 -- COMPOSITE WING STRUCTURES
(Continued)

program will build and demonstrate, in both ground and flight test, substitutional composite wing skins on the existing aircraft substructure. The skin will range up to over 300 plies thick, is approximately twenty feet by five feet and will be the largest thick boron laminate ever attempted. Problems associated with achieving the maximum use of composites in wing design are also discussed.

4A5 -- COMPOSITE FUSELAGE STRUCTURE
J. E. Ashton, General Dynamics Corporation

Until recently, the areas of hardware application for the advanced fibrous composite materials were restricted to membrane states of stress. However, hardware involving non-sandwich plate and shell structures, as well as direct load applications through composite lugs and fittings, are now feasible. These new structural elements require an increased understanding of the bending and horizontal shear behavior of laminated composites. Analytical techniques under development and experimental investigations presently being performed provide considerable insight into the unique bending and shear behavior of anisotropic laminated materials, and provide a prelude to hardware applications of the indicated structural elements. These investigations and their areas of application will be reviewed.

SESSION 5A: COMPOSITES

Thursday 1330-1700, 21 May 1970

PANEL DISCUSSION — ASSESSMENT OF TECHNOLOGICAL ADVANCES AND IDENTIFICATION OF TECHNOLOGICAL NEEDS

Moderator: Prof. H. Ashley, Stanford University

Members: Robert G. Loewy, University of Rochester
Ira G. Hedrick, Grumman Aerospace Corporation
George C. Martin, The Boeing Company
Robert H. Belt, McDonnell Aircraft Company
William L. Lehmann, Office of Assistant Secretary of the Air Force (R&D)

SESSION ON MISSILE/SPACE AND AEROPROPULSION STRUCTURAL DEVELOPMENT.
Co-Chairmen: E. C. Simpson, Air Force Aeropropulsion Laboratory
W. Doll, Pratt & Whitney Aircraft

5A1 -- APPLICATION OF ADVANCED COMPOSITES TO MISSILE/SPACE STRUCTURES
Maj. H. S. Reinert, Jr., Air Force Materials Laboratory

Advanced composite materials are being applied to missile and space structures under a new Air Force hardware development program. This effort presents new areas of utilization for these materials, which offer outstanding potential payoff for future systems. The structural and environmental needs which composite materials fulfill in these vehicles, are related to specific applications and missions of interest. Hardware development will be discussed in terms of materials selection; and design, fabrication, and test of vehicle components and subcomponents.

The advantages to be gained from the application of advanced composites to space and missile structures will be presented in terms of weight savings and systems performance gains.

5A2 -- APPLICATION OF ADVANCED COMPOSITES TO TURBINE ENGINE COMPONENTS
K. G. Boll, Pratt & Whitney Aircraft

A major development effort has been undertaken by Pratt & Whitney Aircraft, under Air Force Contract F33615-69-C-1651, to develop and test full-scale supersonic engine fan subcomponents. These subcomponents include: a first-stage fan blade, third-stage fan blade, third-stage fan disk, and fan intermediate case structure. This fan section of the advanced engine requires composite materials design and fabrication technology capable of utilization to 600°F. Both boron and graphite fibers as well as metal and polymer matrices are being utilized. A final 25 hour proof test will be conducted in a fan/compressor rig incorporating the subcomponents developed and including a balance of aeromechanical and environmental testing.

5A3 -- AEROPROPULSION APPLICATIONS TECHNOLOGY
W. J. Schulz, Air Force Materials Laboratory

An assessment of the state-of-the-art of advanced composites as applied to aeropropulsion systems will be presented. Particular emphasis will be devoted to the technology base established for both organic and metallic matrix materials. Available data on mechanical properties, foreign object damage, erosion, and attachment concepts will be presented. Emerging application areas and materials

5A3 -- AEROPROPULSION APPLICATIONS TECHNOLOGY (Continued)

will be discussed. Unique design concepts will be explored and future requirements, both immediate and long term will be defined.

5A4 -- CONCLUDING REMARKS

G. P. Peterson, Air Force Materials Laboratory

(Abstract not available)

SESSION 1B: MATERIALS FOR REUSABLE SPACE TRANSPORTATION SYSTEMS

Tuesday 0900-1200, 19 May 1970

INTRODUCTION AND OVERVIEW
Chairman: L. N. Hjelm, Air Force Materials Laboratory

1B1 -- SPACE TRANSPORTATION SYSTEMS - INCENTIVE AND CONCEPTS
E. Love, NASA-Langley Research Center

The development of the intent in space transportation will be reviewed with discussions of the incentives and the issues that affected the selection of concepts of interest. These concepts will be reviewed to identify the influence and interactions of factors such as risk, schedules, technology and other effects.

1B2 -- MATERIAL REQUIREMENTS IMPOSED BY SPACE TRANSPORTATION SYSTEM CONSIDERATIONS
K. Graff, Aerospace Corp.

Potential missions are reviewed to establish system requirements having materials implications. A general vehicle system is described and alternative vehicle concepts meeting system requirements are indicated. Conclusions of cost effectiveness analyses and system considerations leading to selected vehicle concepts are briefly discussed. In particular, the thermal environment and uncertainties in its prediction are presented and the considerations imposed thereby on technology development, design and testing are reviewed. Candidate high temperature materials are reviewed in relationship to vehicle requirements and areas requiring improvement are indicated. The importance of advanced materials concepts (such as composites) is related to vehicle performance and areas of beneficial usage are described. Finally, the critical materials considerations imposed by a space transportation system are summarized.

THERMAL PROTECTION MATERIALS
Chairman: N. M. Geyer, Air Force Materials Laboratory

1B3 -- THERMAL PROTECTION SYSTEMS FOR HYPERSONIC FLIGHT VEHICLES
P. Lane, Air Force Flight Dynamics Laboratory

The ability of a successful hypersonic vehicle to cope with the effects of aerodynamic heating rests with the efficient integration of thermal protection into the total vehicle design. Programs, including flight tests, which have contributed to thermal protection system (TPS) development will be reviewed. The interaction of TPS and hypersonic vehicle concepts will be discussed in relation to vehicle performance and physical characteristics. Present limitations and future requirements of TPS also will be outlined.

1B4 -- LONG LIFE, REUSABLE, RADIATIVE HEAT SHIELDS
N. Geyer, Air Force Materials Laboratory
D. Kummer, McDonnell Douglas Astronautics Company

The reuse capability, coating damage tolerance and overall status of coated refractory metals are discussed. Fused slurry silicide coated columbium has demonstrated a reuse capability of greater than 50 one-hour flights when tested to time-temperature-pressure-stress profiles typical of flight conditions for a reusable space vehicle.

1B4 -- LONG LIFE, REUSABLE, RADIATIVE HEAT SHIELDS (Continued)

Representative heat shield constructions have shown a high tolerance for the local absence of coating, particularly on internal surfaces. This finding has a major impact on post flight inspection requirements and confidence level on safety of flight. The heavier tantalum alloys may be used to higher temperatures and they have been evaluated for use to 3500°F. However, above 3000°F their reuse capability appears limited. The relative status of other heat shield construction materials, including superalloys and exposed hardened insulation, will be summarized briefly.

1B5 -- CERAMIC COMPOSITES FOR REUSABLE NOSE CAPS AND LEADING EDGES

L. Kaufman, ManLabs, Inc.

A new class of boride composites which possess unique capabilities for long time applications in oxidizing environments at temperatures between 2500°F and 5000°F have been developed. These materials exhibit high strength and resistance to thermal stress under conditions which simulate the lifting reentry environment. Conventional hot pressing techniques are employed in the fabrication of these composites, which can also be machined within compositional limitations. Current part size limitations are in the one half to one foot range.

Multicycle exposure to ten or more are plasma tests (at stagnation pressure near 5 psi, enthalpy of 10,000 BTU/lb, and heat flux of 500 BTU/ft^{2}sec, with surface temperatures near 4500°F) result in low material recessions, typically 20 mils after 23,000 seconds of exposure. This behavior, at conditions simulating a three inch radius nose tip at an altitude of 180,000 ft and a velocity of 22,000 ft/sec, is unrivaled by any other known material system. Performance of various other refractory materials under similar environmental conditions, will be summarized and compared.

Simple leading edge components of these composites have successfully undergone four cycles of high L/D reentry simulation testing at high wing loading conditions. Leading edge components for a hot Scramjet concept successfully passed a full scale test under extreme mechanical and vibrational loads.

1B6 -- THERMAL INSULATION

H. Marcus, Air Force Materials Laboratory

A brief description of the various types and classes of thermal insulations (and systems) is presented, plus the most recent thermo-physical property data that are available. The emphasis will be placed on systems which are subject to various degrees of high temperature loading depending upon the application. Some of the more interesting and most recent developments in thermal insulation are isolated and discussed in greater detail with accompanying thermal data. Some of the problems associated with measuring specific properties over a wide spectrum of temperatures are also discussed and approaches and/or solutions, if any, are presented. Finally, some discussion is devoted to future Air Force needs and suggested approaches in thermal protection.

SESSION 2B: THERMAL PROTECTION - REENTRY MATERIALS

Wednesday 0900-1200, 20 May 1970

Chairman: M. Minges, Air Force Materials Laboratory

2B1 -- REENTRY VEHICLE PERFORMANCE AS AFFECTED BY MATERIALS

S. Zeiberg and R. Williams,
Aerospace Corporation

The performance of high ballistic coefficient reentry vehicles will be described as a function of the methods and materials used to provide thermal protection. Emphasis will be placed on the problems encountered during ICBM and IRBM reentry of vehicles having military application. In addition to the issue of physical survival of the thermal environment, the discussion will include points regarding optimization of materials design selection, coupling of materials response to vehicle dynamic motion and trajectory perturbation, and the effects of materials on radar and optically sensed signatures.

2B2 -- GRAPHITE FOR NOSE TIPS

C. Pratt, Air Force Materials
Laboratory

Graphite materials are reviewed, with emphasis on recently developed candidate materials for nose tip application. Property and processing information of importance and relatable to parameters of significance in nose tip applications are included for the candidate graphite materials. Observations pertaining to both materials variables and test performance are utilized to provide a definition of areas where close coupling between "users" and "producers" is necessary. Reproducibility and uniformity requirements are assessed for both materials and evaluation tests with a listing of future projected improvements in each area.

2B3 -- CARBON/CARBON COMPOSITES FOR NOSE TIPS AND HEAT SHIELDS

J. Latva, Air Force Materials
Laboratory

The numerous methods of producing carbon/carbon composites are categorized along with a descriptive outline of the processing steps used by the many organizations actively involved in this research area. Comparisons are given of important carbon/carbon composite properties such as ablation response, mechanical strength and thermal conductivity. The intrinsic features of these composites which make them attractive for reentry applications are discussed along with important shortcomings that exist at present. Trends in property improvements are indicated together with predictions of ultimate systems utilization for this class of composites.

2B4 -- MULTIDIMENSIONAL REINFORCED PLASTIC COMPOSITES FOR NOSE TIPS AND HEAT SHIELDS

S. Channon, Aerospace Corp.

The state-of-the-art in application of multidimensional reinforced plastic composites to reentry vehicle nose tips and heat shields is reviewed. Fabrication methods, materials selection and evaluation are discussed. Comparisons are made between competing concepts in terms of manufacturing problems, properties and limitations. Emphasis is placed on orthogonal and interwoven arrangements of quartz and carbon fiber composites with cured resin binders and pyrolyzed resin binders. The application of high modulus graphite fibers in integrated structure/heat shield composites is discussed. Problems in the design and fabrication of attachments

2B4 -- MULTIDIMENSIONAL REINFORCED PLASTIC COMPOSITES FOR NOSE TIPS AND HEAT SHIELDS (Continued)

to other structural components are reviewed together with projections of future trends and developments.

2B5 -- POROUS MATERIALS FOR TRANSPIRATION CONCEPTS

Lieutenant J. Tesson, Air Force Materials Laboratory

The several active transpiration cooling concepts which have been investigated for advanced ballistic reentry systems will be reviewed and categorized. Material approaches including porous sintered metal matrices, metal matrices with the introduction of discrete holes, non-metallic porous matrices, and other methods for achieving the appropriate permeability and distribution will be presented. The advantages and disadvantages of each concept will be discussed and contrasted, with emphasis on material properties and requirements. Material influences together with the surface fluid and boundary layer interaction aspects which are considered to have the greatest impact on performance characteristics will be discussed. The concepts demonstrating current promise and an assessment of potential future transpiration activities will be presented.

2B6 -- MATERIALS OBSERVABLES AND PENETRATION

P. Zavitsanos and J. Cresswell, General Electric Company

For the various approaches to the penetration-aid concepts there exists one or more materials problems. Each of the approaches will be stated and associated materials problems will be discussed. Those related to electron generation or removal in the gas phase will be discussed in greater detail. Past and present state of development and applications will be presented. Data on present penetration systems studies will be shown to demonstrate degree of success and will outline requirements for future development effort.

SESSION 3B: THERMAL PROTECTION - REENTRY PHENOMENOLOGY

Wednesday 1330-1700, 20 May 1970

Chairman: G. Denman, Air Force Materials Laboratory

3B1 -- FACILITIES AND ENVIRONMENTAL SIMULATION FOR TESTING THERMAL PROTECTION MATERIALS

W. E. Welsh, Jr., Aerospace Corporation

An important step in the development of a reentry-thermal protection system component is the testing of that component on the ground under conditions simulating those of reentry. With such test results, an evaluation can be made of the adequacy of material selection and design technique before a flight test. A description will be given here of the components, materials, simulation parameters, test facilities, and interpretation of reentry simulation tests. Ground test facilities will be described under the categories of: low-temperature aerothermodynamic, high-temperature aerothermodynamic, and thermo-structural. Simulation parameters and typical test modes will be given for representative facilities in each category.

3B2 -- CHEMICAL ABLATION: AEROTHERMOCHEMICAL AND KINETIC CONSIDERATIONS

D. E. Rosner, Yale University

Fundamental aerothermochemical and chemical kinetic questions arising in the prediction and experimental determination of chemical ablation rates are discussed, with emphasis on (i) the relevance of thermochemical rate predictions, and (ii) chemical kinetic phenomena associated with the local environment prevailing at the gas/condensed phase interface. Topics to be covered include: chemical nonequilibrium at the interface, chemical nature of the prevailing surface, surface reactions of energetic or ablation interest, combined sublimation-chemical attack phenomena, and unusual kinetic phenomena in dissociated gas mixtures. Simulation implications and research needs will be outlined. The presentation is based on work supported in part by AFOSR under Contracts AF 49 (638)-1654 and AF 49 (638)-1637.

3B3 -- ABLATION PERFORMANCE OF REFRACTORY MATERIALS

R. Rindal, Aerotherm Corp.

Phenomenological aspects of refractory material surface degradation due to thermal, chemical, and mechanical action is considered in the general context of reentry thermal protection systems requirements. Environmental regimes associated with present and future reentry systems are defined in the context of thermal protection requirements. On this basis principal material candidates and anticipated degradation mechanisms are identified. A brief overview is given of present analysis techniques and empirical design guidelines. The relative magnitude of present uncertainties in boundary condition evaluation, material thermal dynamic properties, and mechanical erosion treatment are discussed and areas of required future effort are indicated.

3B4 -- EROSION PERFORMANCE OF COMPOSITE MATERIALS

V. DiCristina, AVCO Corp.

Under high stagnation pressure conditions, the ablation rate of plastic composites exceeds that which is calculated if based on thermochemical considerations alone. This phenomenon appears to be the result of both external and internal forces operating on the material surface and char regions. The external forces include aerodynamic shear, pressure gradients, and inertia forces. Internal forces include pressure differences within the

3B4 — EROSION PERFORMANCE OF COMPOSITE MATERIALS (Continued)

char resulting from pyrolysis of the resin, thermally induced stresses, and compression resulting from high stagnation pressures. This presentation will describe the erosion performance of current composite materials which are subjected to flight simulated environments.

3B5 — STRUCTURAL ANALYSIS AND MODELING TECHNIQUES

F. A. Field, Aerospace Corp.

Some recent advances in structural mechanics are discussed with particular attention given to the impact of these advances on requirements for material properties. Examples involving applications to reentry vehicles are presented to show current analytical capability in the areas of shell structures, axisymmetric bodies and wave propagation. Specifically, these analytical models are discussed with respect to their correlation with experimental data; their utility in materials selection and property testing; and the input material properties which are required. Specific recommendations are made with regard to the deletion of certain tests and the addition of others in the mechanical characterization of materials for reentry vehicle application.

SESSION 4B: ROCKET PROPULSION - NOZZLES AND THRUST CHAMBERS

Thursday 0900-1200, 21 May 1970

Chairman: D. Hart, Air Force Rocket Propulsion Laboratory

4B1 -- ROCKET PROPULSION TRENDS

D. Hart, Air Force Rocket Propulsion Laboratory

Principle paths toward advanced rocket propuls.on technology will be reviewed. The basis for path selection i.e., applications orientation will be examined first. This will be followed by an analysis of the specific technical problems to be solved with special emphasis on materials and fabrication techniques. The interplay (and conflict) between design goals such as high specific impulse and low weight will be treated. Examples of system (vehicle) payoffs based upon the projected advancements will be presented.

4B2 -- NON-TUBULAR FABRICATION CONCEPTS FOR REGENERATIVELY COOLED THRUST CHAMBERS

D. Fulton, Rocketdyne/NAR

The status of regenerative cooling for thermal protection of high performance rocket engines is reviewed. Problems associated with coolant flow patterns, lower melting point materials, and control of erosion profiles have limited applicability of the regenerative technique in earlier rocket engine usage. A discussion of the advantages of non-tubular regenerative cooling techniques for bell and annular thrust chambers is presented. Process parameters, structural limits, dimensional repeatability, and non-destructive inspection methods are discussed for various non-tubular techniques. Emphasis is placed on future trends and directions in regenerative cooling for near term and future high performance rocket engines.

4B3 -- RECENT ADVANCES IN TRANSPIRATION COOLING OF ROCKET ENGINES

D. Penn, Air Force Rocket Propulsion Laboratory

The status of transpiration cooling for thermal protection of high performance rocket engines is reviewed. Problems associated with porosity control of materials for thrust chamber and nozzle liners severely limited the transpiration concept in initial configurations. An assessment of porosity control concepts and flow rate control for various past and present transpiration cooling schemes is presented. A discussion of the advantages of the presently utilized discreet slot fabrication techniques, wherein etched metallic pl as are stacked to form the transpiration wall is included. Emphasis is placed on future trends and directions in transpiration cooling techniques for near term and future high performance rocket engines.

4B4 -- DESIGN AND PERFORMANCE OF SEALS FOR THRUST VECTOR CONTROL

J. Herbert, Lockheed Propulsion Company

This paper discusses the development of the elastomeric seal for thrust vector control application; in particular, importance of materials selection to the performance of the system will be examined. The elastomeric seal as applied to thrust vector control systems is constructed of two basic elements; a layer of elastomer to permit rotation, and a layer of reinforcing material to prevent structural failure. The performance of the seal is based on two factors; the geometry of these layers, and the properties of the materials used for these layers. The geometric

4B4 -- DESIGN AND PERFORMANCE OF SEALS FOR THRUST VECTOR CONTROL (Continued)

consideration in seal design will be discussed. The effects of the properties of the materials will be discussed in detail to show the effects on the performance, life, and cost of the seal.

4B5 — JOINING OF COMPOSITES

J. Einchman, Thiokol Chemical Corporation

Techniques for joining highly loaded, fiberous composite, structural elements have been developed and demonstrated in solid rocket motor case applications. Metal reinforced mechanical joints and elastomeric bond joints, that efficiently provide for the development or utilization of the total strength of the structural elements are discussed. Strong correlations between analytic predictions and experimental evidence were realized and the impact of manufacturing tolerances was determined. Like most designs that are amenable to general application, these joining techniques are very basic and logical. The extension of these technologies to future applications and to structural elements utilizing the more advanced fibers is presented.

SESSION 5B: ROCKET PROPULSION - NOZZLES AND THRUST CHAMBERS

Thursday 1330-1700, 21 May 1970

Chairman: P. Propp, Air Force Materials Laboratory

5B1 -- MATERIALS APPLICATIONS TO VARIABLE AREA NOZZLES

W. Armour, Aeronutronics/Philco-Ford Corp.

Investigations to determine applicability of several materials were directed toward multiple pulse, variable area nozzles for solid rocket motors. The investigations consisted of thermal and structural analyses, laboratory studies and pintle rocket motor firings and considered only uncooled nozzles. Materials which were investigated included tungsten of various types, pyrolitic graphite, ablative plastics, and polycrystalline graphite. Post test analyses were conducted to define material degradation during exposure to a 5700°F, 16% aluminized solid rocket exhaust. Results of these tests and areas for which materials related problems exist are presented.

5B2 -- GRAPHITE TECHNOLOGY

C. Pratt, Air Force Materials Laboratory

Typical nozzle and motor applications are reviewed for utilizing graphitic materials. Emphasized are some of the factors to be considered in materials usage by both materials producers and component builders. Design considerations are intermeshed with materials selection and available materials utilization criteria such as performance factors, costs and availability. Pertinent materials fabrication aspects are briefly described to elucidate those aspects which can be used to advantage for specific applications. Some examples of problems, based upon experience, are included to emphasize pitfalls in materials selection, design and fabrication.

5B3 -- ADVANCEMENTS IN COMPOSITE ROCKET NOZZLE AND THRUST CHAMBER MATERIALS

P. Pirrung, Air Force Materials Laboratory

The pyrolyzed reinforced plastics are a relatively new advancement in the area of ablative composite materials and they have found use in areas where high strength to weight ratios and where high thermal stability are required. These materials, however, have some limitations such as oxidative susceptibility at high temperatures, and erosion by gas dynamic shear. Improvements can be made by various refractory coatings and infiltrations.

Pyrolyzed plastic thrust chambers containing in-place carbides, distributed throughout the reinforced pyrolyzed plastic have been developed and tested. New multidimensional woven fabric composites are expected to further advance the materials for rocket nozzles and thrust chambers.

5B4 -- HARD THROAT MATERIALS FOR LIQUID ROCKETS

R. Hale, Aeronutronics/Philco-Ford Corporation

In order to take advantage of the performance gain offered by increased pressure, the nozzle throat must have minimal erosion. To circumvent the problems of a cooled nozzle, uncooled hard throats are an attractive alternate. In order to evaluate the applicability of various refractory hard materials as nozzle throats in a nitrogen tetraoxide-hydrazine rocket engine, a series of subscale firings were conducted. Throat materials included in the heat flux simulation tests were the borides and oxides of zirconium, the carbides of silicon and titanium, and modified graphites. The results in a comparison

5B4 -- HARD THROAT MATERIALS FOR LIQUID ROCKETS (Continued)

of these results will be presented along with an analysis of findings as applied to hard throat liquid rocket nozzles.

5B5 -- MATERIALS FOR HIGH PRESSURE SOLID ROCKET NOZZLES

E. Olcott, Atlantic Research Corporation

High combustion chamber pressures in solid rocket motors increase the applied stresses to the structural components, increase the combustion temperatures, the heat transfer coefficient to the materials surface, and the shear forces acting on the materials surfaces. The increased severity resulting from these sources requires improved nozzle materials for satisfactory performance. Candidates for high pressure nozzle throat insert service include tungsten, pyrolytic graphite, and refractory carbides. Dense graphites are suitable for limited duty and high char forming ablatives can be used at the higher area ratios.

The requirements for lightweight, low-cost, high-pressure nozzles require further development of the preferred materials systems as indicated by test data available to date.

5B6 -- LOW COST ROCKET ENGINE MATERIALS

H. Blaes, Aerospace Corp.

The elements of low effective cost rocket engine materials are discussed. Low cost materials, ablatives, are discussed in terms of engine size and anticipated production. Low cost fabrication methods are discussed, including economical variations of aerospace processes. The performance of some low cost materials are presented. Materials systems amenable to low cost utilization are discussed as well as desirable support technology.

SESSION 1C: FUNCTIONAL COATINGS

Tuesday 0900-1200, 19 May 1970

THERMAL CONTROL COATINGS

Chairman: C. P. Boebel, Air Force Materials Laboratory

1C1 -- SPACECRAFT THERMAL DESIGN PROBLEMS AND COATINGS APPLICATIONS

J. Bevans, TRW, Incorporated

The spacecraft thermal analyst demands inexpensive, easily applied coatings with predictable, stable, and variable thermal properties. They should be predictable for consistency in manufacturing; they must be stable in the charged particle and ultra-violet environment of space; and the coating properties must be variable at his will over a wide range and ratio of solar absorptivity and emissivity. The analyst has yet to prevail. Instead, he must accept what coatings are available and design with and around them. A very brief review of the available primary thermal coatings will be presented and critiqued in terms of the above demands of the analyst. Examples of design adjustments or compromises on past TRW spacecraft will then be discussed.

1C2 -- NASA-THERMAL CONTROL COATINGS OVERVIEW

C. Mook, NASA Headquarters

The ultimate goal of a long-term stable, low solar absorptance high thermal emittance spacecraft coating has not been achieved. This fact along with the requirement for a refurbishable thermal control coating may lead toward the use of adhesive tapes having thermal characteristics. However, the greater flexibility offered by paints means that we will continue to support this specific research. During the past year studies of damage mechanisms associated with exposure of white pigments to actual and simulated space environments were aimed at selection of new pigments and in stabilizing our workhorse pigment, zinc oxide. A future manned flight experiment is expected to be a joint NASA-Air Force effort. The roles of several of the various NASA Centers in these and other activities are described.

1C3 -- IMPROVED WHITE SPACECRAFT THERMAL CONTROL COATINGS

G. Zerlaut and J. Gilligan, Illinois Institute of Technology Research Institute

A brief history of the use of white thermal control coatings will be presented and will include a general survey of the advantages and disadvantages of pigmented coatings, and a discussion of the major problems that have been encountered. Criteria for the selection of specific pigmented coatings will be discussed briefly and will be oriented towards the implications of both pre- and post-launch environments. The effects of the various components of the space environment, both singly and combined, will be reviewed: actual data, both laboratory and flight, will be cited. Current thinking on damage mechanisms, both for crystalline pigments and polymeric binders, will be reviewed.

1C4 -- MULTILAYER AND COMPOSITE COATINGS FOR PASSIVE TEMPERATURE CONTROL SYSTEMS

A. Eagles and S. Babjak, General Electric Company

To fill the lead time gap in the availability of low α/ϵ ratio thermal control paints stable in the space

1C4 -- MULTILAYER AND COMPOSITE COATINGS FOR PASSIVE TEMPERATURE CONTROL SYSTEMS (Continued)

environment for periods of up to five years, various flexible second surface mirror and ceramic composite coatings have been investigated. Environmental screening tests, including a combined space radiation experiment, in the GE Combined Radiation Effects Facility were conducted in conjunction with the development program. Results from the simulated tests indicate that a composite coating and second surface mirrors utilizing either FEP or Al_2O_3 as the dielectric are all stable to UV, proton and electron radiation. A specially formulated silicone and Butvar were also evaluated as dielectric layers however, they degraded significantly in both the UV and combined environments.

1C5 -- CORRELATION OF FLIGHT AND SIMULATION DATA OF THERMAL CONTROL COATINGS EXPERIMENTS

W. Slemp, NASA-Langley Research Center

NASA thermal control flight experiments on unmanned spacecraft are described. Specific flight experiments are those conducted on the Lunar Orbiters, Pegasus, Mariners, OSO's, and the ATS which cover a variety of orbits and therefore, quite different particulate radiation environments. Correlation of data from these flight experiments with combined effects space simulator data is presented. Crucial areas of thermophysics that need attention for the immediate future are outlined together with those current programs directed to the solution of these problem areas.

1C6 -- AIR FORCE THERMAL CONTROL COATING FLIGHT EXPERIMENTS - PRESENT AND FUTURE

C. Boebel, Air Force Materials Laboratory

Air Force thermal control coating flight experiments on unmanned satellites are described. Specific Air Force flight experiments include those flown on the OV1-10 and OV1-17 satellites which were placed in near earth polar orbit. Results of the performance of experimental coatings flown on the OV1-10 will be discussed. Correlation of these results with simulated radiation exposure conducted in the laboratory are included. Objectives for future space experiments will be outlined.

PROTECTIVE COATINGS

Chairman: W. L. Lehn, Air Force Materials Laboratory

1C7 -- HIGH TEMPERATURE RESISTANT SILICONE PROTECTIVE COATINGS

R. Stout, Air Force Materials Laboratory

The requirements for improved high temperature protective coatings for use on high speed supersonic aircraft and missiles will be presented. Catalytically cured, air drying, stable coatings with retained reflectances exceeding eighty(80) percent (after elevated temperature exposures) were developed. Analysis of Florida weathering data indicates that these coatings, when properly applied to titanium, stainless steel and aluminum alloys, have excellent adhesion, corrosion resistance, and are extremely resistant to solar discoloration, thus making them excellent candidates for high speed aircraft and missiles. Based on the laboratory, weathering and flight test results, a silicone-base coating which will dry under ambient temperature conditions (75 ± 2°F), and remain serviceable for use up to 700°F for short periods and 600°F for prolonged periods, has been developed.

1C8 -- DEVELOPMENT AND EVALUATION OF HIGH TEMPERATURE POLYMERIC COATING MATERIALS

C. Hathaway, J. Butler and
L. Cash, Monsanto Research
Corporation

General conclusions relating polymer structure and coating formulations to polymeric coating physical and thermo-oxidative stability properties will be presented. The most promising coatings investigated and developed will be described, including polyimide, silicone, sulfone and in situ formed silica and metal phosphate coatings. Finally, coating evaluation techniques will be discussed and areas for further research work suggested.

SESSION 2C: COATINGS

Wednesday 0900-1200, 20 May 1970

FUNCTIONAL COATINGS SESSION
Chairman: W. L. Lehn, Air Force Materials Laboratory

2C1 -- HIGH TEMPERATURE ELECTRICAL WIRE INSULATION

N. Bilow, Hughes Aircraft Co.

The evolution of aircraft operating at speeds in excess of Mach 2 has resulted in markedly increased temperature requirements for aircraft "hook-up" wire. Temperatures around 550°F are commonly experienced on current aircraft, while temperatures up to 800°F and possibly higher will be experienced on future, very high speed aircraft. Requirements for high temperature electrical hook-up wire will be reviewed and compared with the properties of the current state-of-the-art materials which are specified for military use.

The development of new and improved polymeric coatings for electrical hook-up wire which are stable to temperatures above 500°F (up to 800°F) for use on future, high speed aircraft and missile systems will be presented.

2C2 -- COATINGS FOR LIGHTNING PROTECTION OF REINFORCED PLASTICS

J. Quinlivan, The Boeing Co.

Boron and graphite reinforced plastics are presenting new problems to the designer concerned with lightning protection. The fiber array can conduct enough current to cause significant structural damage when subjected to lightning discharge. Continuous metal layers provide the most effective lightning protection to these dielectrically inhomogeneous composites. Metallic coatings have been developed which minimize the damage at the lightning stroke attachment point. At a very small increase in weight, these systems provide an adequate path for lightning currents, thereby preventing the flow of detrimental current through the structural fibers.

2C3 -- TRANSPARENT HYDROPHOBIC POLYMER COATINGS

O. Maltenieks, Lockheed-Georgia Company

A research program has been pursued to develop hydrophobic polymers for long term use as rain-repellent coatings on aircraft windshields and canopies. The existing rain repellents retain their hydrophobic properties for only a short period of time and therefore, do not satisfy the requirements desired for aircraft applications.

The polymer systems which have been investigated to provide longer periods of service life include organic compounds of silicones and fluorocarbons. These types of polymers provide a key to the kind of molecular structure needed in a hydrophobe. Selections for synthesizing the silicone-type polymers are based on current theories and mechanisms of compounds which are capable of forming a hydrophobic surface and of adhering satisfactorily to glass or plastic substrate. The proper combination of physical and mechanical properties as well as application methods and also decomposition rates have been studied.

2C4 -- THERMAL DEGRADATION AND FLAMMABILITY OF AROMATIC URETHANE POLYMERS

I. Einhorn, N. Sonpal, J. Seader and M. Kanakia, University of Utah

The thermal degradation and flammability characteristics have been studied using a Mettler Thermoanalyzer which

2C4 -- THERMAL DEGRADATION AND FLAMMABILITY OF AROMATIC URETHANE POLYMERS (Continued)

permitted simultaneous thermogravimetric analysis, differential thermal analysis, derivative thermogravimetry, and temperature monitoring.

A 3^2 factorial designed experiment was used for the degradation studies to permit analysis of the effects of heating rate and test environment on the degradation process.

The results obtained in the dynamic heating studies were used to determine the initiation of thermal decomposition and the temperature of maximum degradation in the multi-phase decomposition reactions. Isothermal studies were then conducted with temperatures being chosen to bracket the regions of interest.

The results of infrared photography studies are presented to elucidate the mechanisms of char formation, combustion and smoke development.

MATERIAL EROSION SESSION
Chairman: W. P. Johnson, Air Force Materials Laboratory

2C5 -- PROBLEMS AND REQUIREMENTS FOR EROSION RESISTANT MATERIALS
G. Schmitt, Air Force Materials Laboratory

The current operational problems on aircraft and missile radomes, helicopter rotor blades, and turbine engine compressor blades will be presented. Present and future requirements for protection in the subsonic and supersonic flight regimes will be discussed with emphasis on thermal capabilities, radar transmission, and erosion resistance. Inhouse results on the AFML rotating arm apparatus demonstrating erosion damage on ductile and brittle materials will be shown.

Composite materials erosion behavior and also potential areas for advancement in erosion resistance will be described.

2C6 -- SUPERSONIC RAIN AND SAND EROSION RESEARCH
N. Wahl, Bell Aerosystems Co.

The details of a "rotating-arm" test apparatus in which materials are subjected to the continuous impingement of rain or sand, simulating protracted flight through these environments at subsonic or supersonic velocities up to 3360 ft/sec and the erosion results obtained using this new apparatus, will be presented. Mechanisms of rain and sand erosion will also be discussed.

2C7 -- DATA EVALUATION OF SUPERSONIC RAIN EROSION TESTS
Lieutenant A. Krabill, Air Force Materials Laboratory

An investigation has been made on the short time supersonic rain erosion resistance of ceramic, plastic, metallic and composite materials at velocities ranging from Mach 1.5 to 4.0.

Evaluation was made of the resultant data by computer analysis. The weight loss/unit area and mean depth of penetration rate (MDPR) were determined quantitatively. Further analysis was done using the erosion rate-velocity relationship

$$\text{MDPR} \sin\theta = K (V \sin\theta)^{\alpha}$$

where $V \sin\theta$ is the normal velocity component. The velocity exponent, α expressing the erosion rate dependence velocity was found to be five or greater for most materials.

SESSION 3C: MATERIAL EROSION AND PROTECTION

Wednesday 1330-1700, 20 May 1970

Chairman: W. P. Johnson, Air Force Materials Laboratory

3C1 -- POLYURETHANE COATINGS FOR SUBSONIC RAIN EROSION PROTECTION

J. Moraveck, Olin Corporation

A rotating arm apparatus using sand or simulated rainfall proved invaluable in the development of erosion-resistant polyurethane coatings. Polyurethanes with widely different physical properties were synthesized and tested extensively in either rain or sand in an attempt to correlate structure and physical properties to dynamic performance. Further, these tests showed that coating performance and modes of failure of a particular formulation were also dependent upon the substrate construction, primer used and coating thickness.

3C2 -- SUPERSONIC RAIN EROSION RESISTANT CERAMIC COATINGS

J. D. Walton, Georgia Institute of Technology

Research is being conducted to develop improved ceramic coatings for the protection of selected radome substrates and aircraft structural materials against rain at supersonic speeds up to Mach 3. Emphasis is placed on the protection of radome substrates. Progress i reported on the establishment of optimal process parameters for the production of plasma-sprayed coatings which are applied directly and for the production of slip-cast coatings which are applied indirectly. Qualification is on the basis of rotating arm, ballistic, sled, and static point-load tests. A manufacturing program for application of ceramic coatings to radomes, in which the coatings are sprayed in a mold and then "picked up" by laminating to the coating, will also be described.

3C3 -- STUDY OF MECHANISMS OF METAL REMOVAL BY DUST PARTICLES

W. Compton, Solar/International Harvester Company

This paper stresses the materials sciences approach to understanding dust erosion mechanisms. An experimental effort studying the effects of material and environmental variables such as alloy composition and heat treat conditions is discussed. Additional variables include dust particle velocity, size, concentration, kinetic energy, temperature, and impingement angle. All test variables were chosen to simulate engineering conditions and erosive environments encountered by gas turbines in helicopter installations. Actual erosion data are compared with predictions by existing theories. Included is a diagnostic phase programmed to detect and study visible phenomena associated with the erosion processes using high magnification electron microscopy. Probable physical models which explain the erosion mechanisms are defined. The paper finally suggests a new erosion mechanisms theory based on the electron microscopy data.

3C4 -- ELECTROPLATED NICKEL COATINGS FOR SAND AND RAIN EROSION PROTECTION

J. Weaver, Air Force Materials Laboratory

Development of reinforced composite components for use on supersonic aircraft and advanced missile weapon systems is receiving wide spread emphasis. Recognizing the limitations of these materials to high speed rain and sand erosion, an extensive research effort was initiated to investigate the use of electrodeposited nickel coatings for rain and sand erosion resistance.

3C4 -- ELECTROPLATED NICKEL COATINGS FOR SAND AND RAIN EROSION PROTECTION (Continued)

Procedures have been established for the electrodeposition of nickel on composites and aluminum substrates. Nickel deposits with a wide range of mechanical properties were developed and extensively evaluated for erosion resistance. These coatings have been evaluated on rotating arm test apparatus at 500 MPH in 1-inch per hour of simulated rainfall and in a simulated sand environment.

Advances in protection of glass-epoxy, graphite-epoxy and boron-epoxy composites with varying thicknesses of hard and soft nickel will be described.

3C5 -- EROSION OF AIRCRAFT TURBINE ENGINE COMPRESSOR BLADES AND VANES

H. Green, General Electric Co.

Erosion of many air foil shaped components including compressor blades and vanes is a serious operational problem for any flight vehicle using unprepared, unclean, or otherwise rough fields. This problem has been lessened by the use of separators and filters; but erosion by fine particles still occurs. Each blade and vane material erodes at different rates when compared in one engine.

A dependable method of laboratory testing is described which has been shown to rank materials erosion rates in the same order as actual engine running. Titanium erodes rapidly and laboratory evaluation of an effective TiC coating is described in detail.

PANEL DISCUSSION -- CURRENT PROBLEMS

Moderator: G. F. Schmitt, Air Force Materials Laboratory

Members: Dr. F. G. Hammitt, University of Michigan
T. J. Norbut, Air Force Aeropropulsion Laboratory
N. E. Wahl, Bell Aerosystems Company
G. J. Tatnall, Naval Air Development Center
J. D. Walton, Georgia Institute of Technology

SESSION 4C: WET CORROSION AND OXIDATION

Thursday 0900-1200, 21 May 1970

Chairman: C. T. Lynch, Air Force Materials Laboratory

4C1 -- ASSESSMENT OF AIR FORCE CORROSION PROBLEMS

J. Myers, Air Force Institute of Technology

A wide variety of corrosion problems continues to result in excessive economic loss which adversely affects accomplishment of the Air Force mission. The most serious problems are described and discussed, including: (1) stress corrosion of aircraft landing gear components, (2) hot corrosion in gas-turbine engines, (3) exfoliation of aluminum alloys, (4) corrosion in missile silos, (5) corrosion in power plant and steam distribution systems, and (6) corrosion of POL storage tanks. Proper design, materials selection, and fabrication, and the use of inhibitors, cathodic protection, and protective coatings are emphasized as effective means of obtaining corrosion control for Air Force equipment and real property.

4C2 -- CORROSION CONTROL IN AIR FORCE SYSTEMS

B. Cohen, Air Force Materials Laboratory

The Air Force Materials Laboratory has continuously, and at an increasing rate, waged its war against the often cataclysmic effect of corrosion on aerospace systems. Frustrating barriers which have prevented rapid solution of these problems and also, lack of fundamental knowledge of the corrosion mechanisms include: material and fabrication costs, demand for high strength/weight, quality control and logistics, maintenance and overhaul problems. This paper explains the new contractual requirements for corrosion control on a total system basis. The lack of agreement between laboratory corrosion testing and operational experience is presented to again show the need for future, useful applied research.

4C3 -- AFLC CORROSION CONTROL PROGRAM

A. B. Richter, Air Force Logistics Command

The purpose of the Air Force Logistics Command (AFLC) Corrosion Control Program is to protect in-service military equipment from degradation due to corrosion. Some of the service testing currently being conducted by AFLC includes evaluation of polyurethane and acrylic nitrocellulose lacquer paints for aircraft skin protection and service testing of coating systems for protection of aerospace ground equipment (AGE). The AFLC Standardized Test Program for the evaluation of jet engine coating systems for corrosion protection and the various storage techniques used to protect aircraft and engines from corrosion at the Military Aircraft Storage and Disposition Center (MASDC) are being examined. Each of these test projects will be discussed briefly.

4C4 -- RECENT DEVELOPMENTS IN USAGE OF MAGNESIUM ALLOYS

P. George, Dow Chemical Co.

This paper will review reasons why magnesium has gotten into trouble, on occasion, from the standpoint of corrosion -- such as its inherent susceptibility, mis-applications, lack of education on the part of designers as to causes of magnesium corrosion and how to prevent them, inertia in government specifications, habitual unsatisfactory practices, reluctance to invest in new equipment, etc. The audience will be

4C4 -- RECENT DEVELOPMENTS IN USAGE OF MAGNESIUM ALLOYS (Continued)

alerted to available corrosion preventive technology which, right now, if these measures were properly employed, would greatly upgrade serviceability.

Finally, we will discuss some of the protective developments and promising ideas which are on the threshold of bearing fruit such as: application of epoxy coatings by electrostatic or electro-phoretic deposition, the improved stannate theory, meta-vanadate anodizing, fluidized bed coating, improved methods of aluminum deposition, and tin plating (instead of cd or zn) of steel hardware.

4C5 -- RECENT PROGRESS IN THE HIGH-TEMPERATURE OXIDATION OF METALS AND ALLOYS

R. Rapp, Ohio State University

The recent literature has been surveyed for theoretical and experimental contributions to the understanding of scale formation in the high-temperature reaction of metals and alloys with gases. The graphical representation of thermodynamic data is used to identify possible reactions between metals and alloys and gas mixtures. From a knowledge of the predominant vapor species in metal-oxygen systems and some limited vapor pressure data, graphical representations can be used to predict the vaporization rates of metals and their oxide scales as a function of oxygen activity.

Recent theoretical contributions in alloy oxidation are discussed. The role of grain boundaries of the scale in the dissociative mechanism for protective scale growth has been clarified. An alternating diffusional growth and scale fracture mechanism seems to account for the linear kinetics of scale formation in niobium oxidation. Impurities in the oxide scales of refractory metals probably account for the irrational dependences of these oxidation reactions on oxygen pressure.

The design of oxidation-resistant refractory metal alloys is discussed. Minor additions of rare earth and alkaline earth metals to oxidation-resistant alloys continue to be used to effect reduced scaling kinetics and improved scale adherence; the rationalization of this behavior is yet incomplete.

4C6 -- BACKSCATTER MOSSBAUER TECHNIQUES APPLIED TO DETERIORATION MODES IN METALS

C. Naiman, Mithras/Sanders Associates, Inc.

Discovery of the Mossbauer Effect (ME) in 1957 has given researchers a helpful tool for probing the microstructure of materials. The complex instrumentations and specialized specimen preparation, however, have essentially restricted use of the Mossbauer Effect to transmission experiments in a laboratory. MITHRAS has pioneered in development of the "Backscatter" Mossbauer method where sample preparation is not necessary and the specimen need not be "touched" except by the Mossbauer γ-rays.

"Backscatter" Mossbauer techniques, as a non-destructive testing tool, have been applied to a variety of problems in steel with deterioration modes having been observed, including: surface stress, dissolved hydrogen, nitriding, and early stages of corrosion formation.

A portable Reflection Mossbauer Technique (REMOTE) instrument has been designed by Sanders Associates and a discussion of the operation will be given, stressing its potential field applicability.

SESSION 5C: STRESS CORROSION

Thursday 1330-1700, 21 May 1970

Chairman: H. B. Kirkpatrick, Air Force Materials Laboratory

5C1 -- STRESS-CORROSION BEHAVIOR OF HIGH STRENGTH ALLOY SYSTEMS

B. Brown, Naval Research Laboratory

The stress-corrosion cracking of modern high strength alloys will be discussed against a background perspective review of the stress-corrosion cracking problem in general. The paper, therefore, will include an historical account of stress corrosion, commencing with the season cracking of brass and extending up through the stress-corrosion cracking of titanium alloys. The review will include a summary of the various theories which have been advanced for the mechanisms involved in various alloy systems. The special implications of stress corrosion to the high strength steels, which in general possess restricted tolerance for cracks, will be emphasized. The presentation will be designed for the special benefit of the design engineer and materials engineer.

5C2 -- EMBRITTLEMENT OF METALS IN HYDROGEN

W. Chandler, Rocketdyne/NAR

Metals are susceptible to environmental hydrogen embrittlement and to internal hydrogen embrittlement. The recent, and less extensive, investigations of environmental hydrogen embrittlement, particularly that from high pressure hydrogen at ambient temperature, will be reviewed. Comparisons will be made between the characteristics of environmental hydrogen embrittlement and that from internal hydrogen.

Effects of hydrogen environments at pressures up to 10,000 psi on the tensile properties of a number of structural alloys will be described. Negligible hydrogen environment embrittlement occurred for aluminum alloys, copper and stable austenitic stainless steels. Recent studies on Inconel 718 and Ti-6Al-4V show that the degree of environmental embrittlement is sharply reduced as temperature is lowered below room temperature and prior heat treatment appears to have a significant effect on the susceptibility of Inconel 718. The implications of these results will be discussed.

5C3 -- STRESS CORROSION BEHAVIOR OF TITANIUM ALLOYS AND HIGH STRENGTH STEELS

R. Staehle, F. Beck, and M. Fontana, Ohio State University

The stress corrosion cracking of titanium alloys and high strength steels is being investigated in order to elucidate fundamental mechanisms. The cracking of titanium is being investigated in aqueous and methanolic environments using electrochemical techniques. The cracking of high strength steels is being investigated using sonic, electrochemical, hydrogen permeation, and ellipsometric techniques. Fundamental studies are also underway using field ion emission and LEED techniques for the purpose of identifying the very early stages of reaction on the surface.

The initiation of cracks in titanium alloys is shown to depend on state of stress, applied potential, salt water concentrations in methanol, and the rolling direction. Cracking in high strength steels depends on pH of buffered solutions and increases with decreasing pH and potential. Studies in growth kinetic of passive films show that the steady state thickness of films depends on the electrochemical

5C3 -- STRESS CORROSION BEHAVIOR OF TITANIUM ALLOYS AND HIGH STRENGTH STEELS (Continued)

potential. At a given potential the film thickness approaches an asymptotic thickness.

5C4 -- AN ACCELERATED STRESS-CORROSION TEST FOR HIGH-STRENGTH FERROUS ALLOYS

A. Freedman, Northrop Corp.

An accelerated laboratory test has been developed for evaluating the susceptibility of high-strength ferrous alloys to stress corrosion cracking (SCC) in a seacoast environment. Single-edge-notched and fatigue-cracked specimens are tension loaded in an NaCl solution (200gm per liter distilled water), and the threshold stress-intensity factor for stress corrosion (K_{ISCC}) is determined. Identical specimens were tension loaded in racks, exposed at the seacoast, and their K_{ISCC} values were established as standards for evaluating the accelerated test.

The accelerated test requires a maximum test time of 1000 hours. Test times are one to three orders of magnitude shorter than those required for similar specimens in a seacoast environment. The acceleration of test time is produced by the aggressive corrodent, the presence of a crack, and the plane-strain loading conditions.

Twenty of the twenty-three combinations of material, heat treatment, and welding conditions showed good to excellent agreement between the K_{ISCC} values obtained in seacoast and in accelerated tests. The significant differences between seacoast and accelerated test results in the other three materials were attributed to experimental problems.

5C5 -- THE SIGNIFICANCE OF ACCELERATED STRESS-CORROSION CRACKING TESTS

D. Sprowls, ALCOA

One of the prime requirements of an accelerated stress-corrosion cracking test is to produce the same type and path of fracture in stress corrosion susceptible alloys that have been demonstrated in service. Obviously the best criterion for an accelerated test is direct correlation of test results with service experience. Because the spectrum of service loadings and environments is unknown, accelerated tests must be correlated with the results of long time exposures to natural environments anticipated in actual service. Unfortunately, for some alloys, many years' exposure to service environments may be required before meaningful stress-corrosion cracking results are obtained.

The true significance of any accelerated stress corrosion test, naturally, depends also upon many other complex factors associated with selection of type of test specimen, method of loading, test stress levels, method of sampling the experimental material, test duration and choice of suitable quantitative expressions of the test results.

PANEL DISCUSSION -- STRESS CORROSION RESEARCH AND DEVELOPMENT OF A STANDARD TEST

Moderator: H. B. Kirkpatrick, Air Force Materials Laboratory

Members: A. Sommer, North American Rockwell Corporation
A. Freedman, Northrop Corp.
R. Staehle, Ohio State University
D. Sprowls, ALCOA
B. Brown, Naval Research Laboratory
S. Goldberg, Naval Air Systems Command

SESSION 1D: MATERIALS AND PROCESSES FOR ELECTRONIC AND MAGNETIC COMPONENTS

Tuesday 0900-1200, 19 May 1970

INTRODUCTORY SESSION
Chairman: Lt. Col. D. J. Iden, Air Force Materials Laboratory

1D1 -- ELECTRONIC AND MAGNETIC MATERIALS AND PROCESSES

Lt. Col. D. J. Iden, Air Force Materials Laboratory

The area of electonic and magnetic materials research, development, and manufacturing technology is one of ever increasing importance to the Air Force. The viewpoint of the Air Force relative to this area is presented, through the medium of this symposium, in six specialized technical sessions:

- 1D-II Advanced Display Materials
- 2D Microwave Devices and Components; Materials and Processes
- 3D-I Materials for Infrared Sensor Applications
- 3D-II Lasers and Nonlinear Optical Materials
- 4D Materials for Power Conversion Applications
- 5D Microelectronics; Materials and Processes

Other areas of high potential to the Air Force that could not be included in this symposium due to classification limitations are development of radar absorbing materials, infrared suppression materials, and electromagnetic antenna window materials. The Air Force Materials Laboratory has a strong interest in all aforementioned areas because it bears primary responsibility for exploratory development and manufacturing technology of electronic and magnetic materials and processes to meet the needs of the Air Force. Such efforts are vitally required to provide a basis for the development of advanced weapon systems that can give the Air Force clear-cut superiority over potential adversaries.

1D2 -- MANUFACTURING METHODS EFFORTS IN ELECTRONICS

J. Wittebort, Air Force Materials Laboratory

The USAF manufacturing technology mission attempts to fill the gulf between exploratory development and the system applications in the USAF. Too often our planners are unable to rapidly bridge this gulf and take advantage of the new and viable exploratory developments because of the intervention of manufacturing difficulties and the great costs involved. The problem of insufficient reliable information dampens early acceptance and also, the component development is still a tedious, iterative process in spite of our increased analytical capabilities. Physical and chemical phenomena, materials process techniques and testing must interact successfully to achieve reliable electronic components useful in systems. The role of manufacturing technology in combining materials, processing, quality control and design selection will be discussed relative to the AFML program in electronics.

1D3 -- ELECTRONIC MATERIALS - PAST, PRESENT AND FUTURE

H. Gatos, Massachusetts Institute of Technology

The recent revolution in solid state electronics is based primarily on advances or progress in understanding and controlling the structure, purity, and homogeneity of electronic materials (semiconductors, magnetic materials, optical materials, etc.). With nearly

1D3 -- ELECTRONIC MATERIALS - PAST, PRESENT AND FUTURE (Continued)

every advance in materials, the basic physics and electronic applications followed immediately. A striking result of these efforts is the intimate interaction of a number of disciplines (chemistry, chemical engineering, metallurgy, electrical engineering, and others) in a way unprecendented in the history of science.

ADVANCED DISPLAY MATERIALS SESSION
Chairman: P. M. Hemenger, Air Force Materials Laboratory

1D4 -- DISPLAY MATERIALS AND DEVICES
M. Aven, General Electric Co.

An overview of potential and available materials and devices for various Air Force display requirements will be presented. D.C. injection luminescence, A.C. electroluminescence, liquid crystals, plasmas, and phosphers will be among the topics discussed. The potential and limitations of each for display units will be examined in view of the display problems that must be solved. Emphasis will be given to recent progress in solid state display devices.

1D5 — APPLICATION OF SOLID STATE LUMINESCENT DEVICES
M. Russ, Bowmar, Canada, Limited

Systems in which solid state light emitting devices are being employed or could be with state-of-the-art materials will be described. For example, units such as navigational read-outs, high speed annotation devices, displays for low power portable instruments, and communication links will be among the topics discussed. Emphasis will be given to the advantages gained by using solid state light sources rather than more conventional devices.

PANEL DISCUSSION -- ADVANCED DISPLAY MATERIALS

Moderator: P. Hemenger, Air Force Materials Laboratory

Members: M. Aven, General Electric Co.
M. Russ, Bowmar, Limited
Lt. R. Callahan, Air Force Materials Laboratory
Lt. J. Lawrence. Air Force Flight Dynamics Laboratory

SESSION 2D: MATERIALS AND PROCESSES FOR MICROWAVE DEVICES AND COMPONENTS

Wednesday 0900-1200, 20 May 1970

Chairman: J. I. Wittebort, Air Force Materials Laboratory

2D1 -- FUTURE AIR FORCE SYSTEMS NEEDS AND REQUIREMENTS IN ELECTRONIC DEVICES

H. Grove, Air Force Avionics Laboratory

The plans office projects Air Force systems needs by maintaining direct contact with other Air Force organizations. These projections are used as "policy" for guidance and shaping of programs in the various divisions of the Avionics Laboratory. Projection as to component needs, which may be composed of several devices, are made. This paper will report on a study now in progress and will relate device needs for the near ten to fifteen years.

2D2 -- MICROWAVE SOLID STATE DELAY DEVICE TECHNOLOGY

F. Olson, Microwave Electronics/Teledyne

Microwave acoustic transducers have been developed in this last year which will effect a significantly greater use of delay lines in microwave systems. The information storage capability coupled with airborne computers will permit automatic jamming over wide bandwidths. This potential will be realized on a large scale when the costs of delay lines are significantly reduced. The types of delay lines and their apparent frequency ranges are discussed. These include surface wave as well as bulk-shear and bulk-longitudinal wave delay lines.

2D3 -- SAMARIUM-COBALT MAGNETS FOR MICROWAVE TUBES

W. Harrold, Raytheon Company

The intermetallic samarium-cobalt magnet exhibits the highest known stored energy of all magnet materials. Its outstanding characteristics are extremely high coercive force and fabrication by high speed, finished-to-size, powder metallurgy. Sintering technology will be briefly discussed.

This material can produce a cost-weight effectiveness in all microwave tubes. New crossed field devices with inherent magnetic circuit inefficiencies can realize a cost-weight advantage over conventional magnet materials.

A power klystron has been focused with samarium cobalt affecting a 3-1 weight saving over present materials. In the PPM, TWT format for which the magnet was developed, it out-performs all permanent magnet materials including the expensive, precious metal magnet platinum cobalt.

2D4 -- PHASE SHIFTERS FOR AVIONICS ARRAYS

J. Rippin, Jr. and R. Plak, Air Force Avionics Laboratory

This paper summarizes phase shifter electrical characteristics needed to satisfy requirements of typical avionics array with multimode applications being considered. The difficulty of meeting these requirements with a single type of phase shifter is emphasized. Characteristics obtained from production runs of approximately 5000 each of elements (phase shifter/driver/radiator) for two airborne radar phased arrays are reviewed. A study program designed to select one or more phase shifter

2D4 -- PHASE SHIFTERS FOR AVIONICS ARRAYS (Continued)

design requirements that warrant establishment of semi-automatic production techniques is discussed and a test program is recommended.

2D5 -- SOLID STATE MICROWAVE DEVICES

T. Leonard, Varian Associates

Silicon Technology has advanced to such a state of quality control that Avalanche and Impatt diode design is progressing favorably. Gallium Arsenide Technology is stoichiometric in nature; Gunn oscillator design has suffered. These two technologies for microwave solid state devices are examined in some detail with state-of-the-art and projected capabilities being presented. Certain promises semiconductors are negated; for instance, long life or even long shelf life of semiconductor microwave devices have not been proven; high power handling capabilities has never been proven. There is, however, sufficient progress of significant value to these devices to warrant pressing on with the research and development.

2D6 -- MICROWAVE TUBES FOR AVIONICS

R. Dehn, General Electric Co.

Microwave tube technology has been advancing at a significant rate. Microwave tubes for kitchen ranges are sold by tube companies for a unit cost of about $75. Microwave tubes have been developed which deliver one million watts continuous power at 10 kilamegacycles per second. These are figures of significant merit. The particular application, with attendant environmental limitation, restricts the power and bandwidth available to that application. Projections will be given for tube types and their applications to system use.

SESSION 3D: ELECTRONIC AND MAGNETIC MATERIALS

Wednesday 1330-1700, 20 May 1970

SESSION ON MATERIALS FOR INFRARED SENSOR APPLICATIONS
Chairman: R. L. Hickmott, Air Force Materials Laboratory

3D1 -- INFRARED DETECTOR SENSITIVE MATERIALS NEEDS
T. Pickenpaugh, Air Force Avionics Laboratory

Continued improvement in performance and capability of IR systems requires further advances in the performance and capability of IR detectors. These improvements must come primarily through development of new IR sensitive materials. Infrared sensitive materials can provide the desired device performance improvements through optimization of the physical parameters of the material, following the normal "brute force" i.e., improvements in crystal perfection, material purity, stoichiometry, etc. More desirable, would be a better understanding and the ability to exploit the photon-material interaction to provide increases in device performance, as well as simplification of function.

3D2 -- THE GOLDEN HUNT FOR MATERIALS
J. Zemel, University of Pennsylvania

The rapid evolution of solid state research into pseudo-binary (ternary and quaternary) systems is partially delayed by the high costs of conventional single crystal preparation and the substantial time needed to prepare samples. Recent research with epitaxial (single crystal) films makes an excellent case for substantially modifying the approach followed by many laboratories and we propose that epitaxial film techniques should be used as a means of surveying new materials and establishing their general properties and areas of potential application before engaging in the more expensive bulk studies. Further, new device possibilities have developed based on these films and will be discussed.

SESSION ON LASERS AND NON-LINEAR OPTICAL MATERIALS
Chairman: V. L. Donlan, Air Force Materials Laboratory

3D3 -- INTRODUCTION
V. Donlan, Air Force Materials Laboratory

In recent years, dramatic improvements in ruby and YAG material, discovery of efficient nonlinear materials, and development of powerful ion and molecular lasers have allowed the laser industry to undergo rapid growth. Materials development is now shifting to new modulator materials and to lasers operating in the eye-safe IR regions. For the future, an ultra-low absorption loss window and modulator material is needed at 10.6 microns; an efficient beam deflecting material must be developed; a breakthrough in pumping, perhaps using electro-luminescence, is desired; and a low cost substitute for Nd-YAG is forecast.

3D4 -- MATERIALS FOR NONLINEAR OPTICS
R. Byer, Stanford University

The materials properties most important for non-linear optical materials will be discussed briefly. These are: low absorption loss and low scattering loss over the frequency range of interest, high nonlinearity, phase matchability, high damage threshold, and useful linewidth and tuning character-

3D4 -- MATERIALS FOR NONLINEAR OPTICS (Continued)

istics. The progress to date on KDP, barium sodium niobate, lithium niobate, proustite, lithium iodate, semiconducting and other infrared compounds will be outlined. Materials and materials improvements needed to meet future systems requirements in the infrared, especially at 10.6 microns and in the 5 micron region will be discussed.

3D5 -- THE STATE-OF-THE-ART IN RUBY AND Nd:YAG LASER MATERIALS
C. Stickley, Air Force Cambridge Research Laboratories

Ruby quality has improved markedly in the past few years since Czochralski growth was introduced. Crystals up to 2.5x30 cm with one wave variation across the diameter per 10 cm of rod length are available. Nd:YAG has evolved as one of the best lasers available. It has a low strain-optic coefficient and is available in excellent optical quality (less than 0.002/cm scattering loss). Like ruby, its beam divergence is limited by system design rather than material quality. Other limitations inherent to the two materials are analyzed and means for overcoming some of these limitations, thereby increasing the performance of these lasers, are discussed.

3D6 -- MATERIALS PROBLEMS OF CURRENT AND FUTURE MILITARY LASER SYSTEMS
S. Wagner, Air Force Avionics Laboratory

The characteristics required of lasers in military systems must be achievable under non-optimum conditions, and the equipment involved must be highly reliable and easily maintained. General and specific materials problems will be identified by considering the application requirements of the transmitter-receiver, the operating environment, reliability, and maintainability. Materials problems associated with rangefinders, target designators, target illuminators, and optical radars will be discussed. In addition, materials problems associated with laser devices and components for new applications will be treated, including: extreme brightness lasers, segmented lasers, holmium lasers, frequency shifted lasers, high power gas lasers, and lamps.

PANEL DISCUSSION - LASERS AND NONLINEAR OPTICAL MATERIALS

Moderator: V. L. Donlan, Air Force Materials Laboratory

Members:
- Dr. C. M. Stickley, Air Force Cambridge Research Laboratory
- R. L. Byer, Stanford University
- S. E. Wagner, Air Force Avionics Laboratory
- J. I. Wittebort, Air Force Materials Laboratory

SESSION 4D: MATERIALS FOR POWER CONVERSION APPLICATIONS

Thursday 0900-1200, 21 May 1970

Co-Chairmen: G. W. Sherman, Air Force Aero Propulsion Laboratory

H. A. Tanner, Air Force Materials Laboratory

4D1 -- TRENDS IN POWER GENERATION MATERIALS REQUIREMENTS FOR THE SEVENTIES

G. Sherman, Air Force Aero Propulsion Laboratory

The current trends in aircraft and space electrical and auxiliary power requirements are reviewed. An overview of the state of development of dynamic and static energy devices is presented.

Military space power requirements for the seventies are found to be moderate (.5 to 10 kilowatts); however, demands for increased system life (5 - 10 years) challenge the technology developers. Compact, reliable, invulnerable auxiliary electrical and hydraulic devices are needed and developments in solid state technology promise to revolutionize aircraft power system design.

Application of advanced energy conversion devices (e.g., MHD, Alkali metal batteries) in the post-70's, will require major breakthroughs in material technology in this decade.

4D2 -- MEMBRANES FOR BATTERY PLATE SEPARATOR MATERIALS

J. Lander, Air Force Aero Propulsion Laboratory

Plates of electrochemical power sources require separation by electronically non-conducting porous materials. Depending largely on plate material characteristics, separator pore diameters can range from microns to Angstroms, and a high degree of porosity at low thickness is desired. Chemical stability in highly acid or alkaline electrolytes and in strongly oxidizing environments is a prime requirement.

The past two decades have witnessed the successful development of synthetic materials having excellent separator characteristics for several battery types. A new separation problem may be at hand, arising from research on organic electrolyte batteries.

4D3 -- SOLAR POWER FOR SATELLITE CRYOCOOLING

R. Van Vliet, Air Force Materials Laboratory

This is a design study of a solar furnace which will power a vuilleumier (VM) cycle cryocooler. The VM cryocooler provides continuous cooling on a satellite or spacecraft. It requires heat input to about 700°C. The heat can also be provided by solar cells, but they are expensive and inefficient for this purpose. The solar furnace gains efficiency by departing from conventional design. This is done by using a selective black coating (in lieu of a cavity) at the focal point and an infrared reflecting window to trap the heat. Using these concepts, the required magnification necessary may be less than ten times. This reduces the need for accurate aligning with the sun and close tolerance optics.

4D4 -- SUPERCONDUCTORS FOR AIR FORCE APPLICATIONS
G. Kuhl, Air Force Materials Laboratory

A brief summary of the properties of superconducting materials will be given. Applications of superconductors in power conversion are outlined with emphasis on present and future Air Force requirements. The advantages of superconducting systems over conventional systems will be emphasized and the materials problems which limit these applications will be discussed. In conclusion is a brief discussion of the research being conducted or planned, to solve some of these materials problems. In particular, the research includes light-weight superconducting magnets and higher critical temperature superconducting materials.

4D5 -- THE TECHNOLOGY OF RARE EARTH-COBALT MAGNETS
H. Garrett, Air Force Materials Laboratory

The potential of RCo_5 permanent magnets was made known by this Laboratory's systematic production of rare earth-transition element compounds, the measurement of their magnetic properties, the assessment of these properties relative to applications potential, and the publication of these findings. This spectacular achievement is but a milestone in the new advancements that are now possible for the provision of needed magnets.

The exploitation of this new family of magnets can only be accomplished with a continuing build-up of knowledge of fundamental relationships. The possible directions for expanding today's magnet technology include cost reductions, increased supplies of suitable rare earth metals, optimization of magnet properties, and the meeting of magnet requirements for specific device developments

4D6 -- COBALT-RARE EARTH MAGNET APPLICATION TO POWER CONVERSION
J. Becker, General Electric Co.

The new cobalt-rare-earth permanent magnet materials are characterized by much larger values of maximum energy product $(BH)_{max}$ and intrinsic coercive force H_{ci} than have been available until now. The large H_{ci} results in B vs H demagnetization curves that are practically straight lines at 45°, and in recoil curves that virtually retrace the demagnetization curve even after it has been driven far into the third quadrant. These new properties permit application under severe demagnetizing conditions, and the recoil behavior makes these materials very favorable for applications in variable gaps. Large or complicated magnetic circuits can be constructed of small pre-magnetized blocks without the need for keepers or for subsequent magnetization.

PANEL DISCUSSION -- MATERIALS FOR POWER CONVERSION APPLICATIONS

Moderators: Dr. H. A. Tanner, Air Force Materials Laboratory
G. W. Sherman, Air Force Aero Propulsion Laboratory

Members: J. J. Landers, Air Force Aero Propulsion Laboratory
R. Van Vliet, Air Force Materials Laboratory
G. E. Kuhl, Air Force Materials Laboratory
H. J. Garrett, Air Force Materials Laboratory
J. J. Becker, General Electric Company
K. Strnat, University of Dayton

SESSION 5D: MICROELECTRONICS: MATERIALS AND PROCESSES

Thursday 1330-1700, 21 May 1970

Chairman: M. Bialer, Air Force Materials Laboratory

5D1 -- PROCESS AND DEVICE PROBLEMS IN INTEGRATED CIRCUIT DEVELOPMENT

H. Steenbergen, Air Force Avionics Laboratory

This paper will discuss new device techniques and process procedures as related to future integrated circuit developments. Included will be a discussion of the potential and problems associated with the use of new materials for improved circuit capability. This will include discussion of new device concepts such as the GaAs Schottky Gate Field Effect transistor which holds promise for performance surpassing that of silicon. Processing problems currently limiting these new devices as well as those limiting in silicon integrated circuit array capability will be discussed. Development approaches under way for solution of these problems will be discussed.

5D2 -- CURRENT AND FUTURE TRENDS IN ELECTRONIC MATERIALS

E. Tarrants, Air Force Materials Laboratory

The expanding roles of the semiconductors and future trends will be discussed with particular emphasis on silicon, gallium arsenide and its alloys, the II-VI compounds and silicon carbide. Consideration will be given to preparation, characterization and utilization. The increasing importance of various substrate materials will be presented to include aluminum oxide, spinel and beyrllium oxide with mention of special deposition techniques. Optical materials will be discussed relative to the preparation and use of non-linear materials. The interplay between materials and devices will be noted with areas for improvement discussed.

5D3 -- ADVANCED MANUFACTURING PROCESSES AND CONTROLS FOR SEMICONDUCTOR DEVICES

E. Miller, Air Force Materials Laboratory

Advanced manufacturing processes and controls that are being established for the production of solid state devices will be discussed. Emphasis will be placed on quality-quantity production. To satisfy AF electronic needs for high volume, complex, and dependable solid state circuits at reasonable cost, programs covering in-process controls, more effective inspection and test procedures, conversion of laboratory processes to production, and process automation are continuously being implemented. Existing and projected activities in such area as epitaxial deposition, ion implantation, projection masking, and electron beam techniques will be described.

5D4 -- PROCESS CONTROL - THE KEY TO LSI

F. Barone and M. Callahan, Motorola Incorporated

Large scale integration requires the development of sophisticated process control techniques such that process induced defects may be minimized. This paper discusses the development of complex process control patterns that may be used both as in-process monitors as well as diagnostic tools. Design criteria for this type control device is discussed and typical data accumulated in a manufacturing environment analyzed. Example will include data from current mode logic, saturated logic and MOS

5D4 -- PROCESS CONTROL - THE KEY TO LSI (Continued)

integrated circuits.

A second area to be discussed will be the implementation of process control measures that have been instituted in a LSI manufacturing facility. This will include mask inspection criteria, materials specifications and in-process chemical and electrical control.

5D5 -- MATERIAL PROCESSING FOR SILICON RADIATION HARDENED CIRCUITS
W. Runyan, Texas Instruments, Incorporated

Material and processing technology improvements required for radiation hardened circuits will be examined by assuming that array size will progress in an orderly fashion from the present 12 to 20 equivalent gate complexity through MSI to LSI in the next 4 to 6 years, that TTL will remain the dominant digital configuration, and that the hardness requirements will continue to increase. Topics to be discussed will include isolation techniques, material defects, thin film resistors, new material requirements, power dissipation problems, oxide-silicon interface and materials tolerance performance trade-offs.

5D6 -- SEMICONDUCTOR MEMORY TECHNOLOGY
W. Sander, Fairchild Semiconductor

Technology for semiconductor memories has not reached any standardization. The device technologies used and proposed include MOS, complimentary MOS, MNOS, and bipolar technology with a number of variations. Multichip packaging and single chip packaging are being used in a wide variety of approaches. This paper discusses the major technologies, materials and processes that appear significant, and emphasizes attributes which tend to be unique to semiconductor memories.

PANEL DISCUSSION -- MATERIALS AND PROCESSES FOR MICROELECTRONICS

Moderator: Dr. J. A. Brinkman, North American Rockwell Corp.

Members: H. H. Steenbergen, Air Force Avionics Laboratory
E. H. Tarrants, Air Force Materials Laboratory
E. H. Miller, Air Force Materials Laboratory
F. Barone, Motorola, Inc.
M. Callahan, Motorola, Inc.
Dr. W. Runyan, Texas Instruments, Inc.
Dr. W. Sander, Fairchild Semiconductor

SESSION 1E: ADHESIVE JOINING

Tuesday 0900-1200, 19 May 1970

Chairman: T.J. Aponyi, Air Force Materials Laboratory

1E1 -- RECENT ADHESIVE DEVELOPMENT EFFORTS IN THE AFML

T. Aponyi, Air Force Materials Laboratory

Major efforts have been devoted to the development of more oxidatively stable high temperature adhesives for both long and short time exposure to elevated temperatures. The polyaromatic heterocyclic polymers, such as polyimides, polybenzothiazoles and polyimidazoquinazolines, have been prime candidate resins for formulation into adhesives and for characterization. Efforts are also underway to develop high strength adhesives which have improved toughness properties.

1E2 -- SURFACE TREATMENTS OF METALS FOR BONDING

R. Politi, American Cyanamid Company

Surface treatments used to prepare aluminum, titanium, stainless steel and copper for bonding are described. Various phases and types of surface treatment are discussed; these include cleaning, etching, conversion coatings, anodizing, and primer application. Data is presented showing the effect of cleaning process variables on the durability of the bond line after exposure to hostile environments such as high humidity, high temperature and salt spray.

Two new developments are discussed which promise to improve the corrosion resistance of bonded structures.

1E3 -- CURRENT PRACTICES AND PROBLEMS IN THE MANUFACTURE OF ADHESIVE BONDED STRUCTURES

F. Kiel, Rohr Corporation

Current production techniques for adhesive bonding will be reviewed, and recent progress toward the introduction of automation into the bonding process will be presented. The advantages and shortcomings of various adhesives currently in use will be outlined, and desired characteristics for future adhesives presented. Inspection techniques and quality control practices will be presented, and their relative merit discussed. Key problem areas, such as toughness and corrosion resistance, will be reviewed, and possible solutions to those problems outlined.

1E4 -- SYSTEMS APPLICATIONS OF STRUCTURAL ADHESIVE BONDING

T. Reinhart, Jr., Air Force Materials Laboratory

Systems applications of structural adhesive bonding have increased rapidly in the last several years. Structural adhesive bonding in Air Force aircraft has in general been very satisfactory with the exception, however, of a few applications where our experience was not too satisfactory. The paper will cover typical applications of structural bonding in systems. Good as well as unsatisfactory experiences will be presented; included will be potential future applications of bonded aircraft structures, advantages of bonded assemblies, and work that must be accomplished before completely bonded aircraft components can become a reality.

Adhesive bonded applications in fighter and transport aircraft,

1E4 -- SYSTEMS APPLICATIONS OF STRUCTURAL ADHESIVE BONDING (Continued)

helicopters, and missiles will be shown along with damage tolerant structures. Adhesive bonding repair procedures will be discussed.

1E5 -- ADHESIVE BONDING REQUIREMENTS FOR SPACE ENVIRONMENTS

G. Epstein, Aerospace Corp.
Lt. J. Smith, Air Force Space and Missile Systems Organization

Adhesives are essential in virtually every U. S. spacecraft because of the acute need for minimum-weight constructions and the wide variety of dissimilar materials to be joined together. Requirements imposed on such adhesive bonds are often quite severe.

The unique characteristics of the space environment poses particular problems. Radiation in space can degrade optical properties; important in such applications as solar panels. Outgassing from adhesives in the vacuum of space can impair electrical and optical components, or may contaminate the breathable atmosphere of manned spacecraft. Extreme temperature cycling can introduce severe thermal stresses; dynamic loading during launch introduces severe vibration and acceleration loads, and also at times, extremely high temperatures.

PANEL DISCUSSION -- ADHESIVE JOINING

Moderator: T. J. Aponyi, Air Force Materials Laboratory

Members: Dr. W. Gibbs, Air Force Materials Laboratory
T. Mika, Shell Development Corporation
M. Petronio, Army/Frankford Arsenal
E. Arvay, Air Force Materials Laboratory

Members: (Cont.) S. Yoshino, North American Rockwell Corporation
L. Suifredini, Narmco Materials/Whittaker Corp.

SESSION 4E: METAL JOINING PROBLEMS

Thursday 0900-1200, 21 May 1970

Chairman: J. Gerken, TRW, Inc.

Co-Chairman: C. Jackson, Ohio State University

4E1 -- THE NEED FOR WELDING RESEARCH

D. Howden, Battelle Memorial Institute

With the advent of greater demands on the mechanical properties of weldments, there is an ever increasing need to eliminate weld defects and to make the structure less sensitive to defects. The traditional approach of improving weldment performance, i.e., by guided empirical means, has in the past proved satisfactory and efficient. However, with the sophisticated materials now being developed it is important that more fundamental understanding of the causes of defects and control of structure is required to complement the traditional approach. The talk will discuss this theme with respect to fusion welding giving examples of cases applicable to aerospace systems.

4E2 -- WELDING AND BRAZING NICKEL-BASE SUPERALLOYS

R. Yount, General Electric Co.

Successful joining techniques for high strength, high temperature nickel-base superalloys are essential to the economic manufacture of modern light-weight, high performance gas turbine and aerospace components. Recognition and understanding of certain inherent problems and limitations of joining these alloys is essential for efficient application. Several recent government sponsored studies of the joining of superalloys are discussed in relation to the resulting benefits which will be derived in the near future. The advantages and disadvantages of several processes which have recently been applied to the joining of superalloys are also mentioned. Lastly, problem areas which are limiting the utilization of the higher strength superalloys in aerospace fabrications are discussed and areas for future study and development are suggested.

4E3 — METALLURGICAL CONSIDERATIONS IN WELDING ALUMINUM ALLOYS

A. D'Annessa, Lockheed Corp.

This paper is concerned with a number of metallurgical considerations associated with the fusion welding of the precipitation hardenable aluminum alloys. The effects of preweld preparation, welding process variables, and characteristics of the weld solidification process on the soundness (quality), mechanical behavior, and microstructural characteristics of weld metal will be covered. The influence of thermal and strain cycling due to welding will be discussed relative to the mechanical behavior of the heat affected zone (HAZ) and the formation of discontinuities such as upsetting of the near-HAZ, intergranular delamination and cracking, and grain boundary liquation. Difficulties of metallurgical origin, arising from commonly used design practices, will be presented.

4E4 -- WELDING AND BRAZING TITANIUM ALLOYS

D. Lovell, The Boeing Company

Titanium alloy weldments are finding structurally effective applications for present aircraft components and are expected to dramatically increase on future aircraft such as the SST. The metallurgical joining of critical titanium alloy structures presents many technical challenges which require stringent investigative efforts and proper documentation of processing and

4E4 -- WELDING AND BRAZING TITANIUM ALLOYS (Continued)

acceptance criteria. Basic weldability, weld metal stability, fracture toughness, environmental compatibility and repairability will be discussed for the Ti-6Al-4V alloy. The results of a thorough braze alloy development program will also be reviewed. Analysis and summary of programs to adopt the GTA, electron beam, plasma arc, diffusion and high frequency welding processes to typical aircraft structures will be included. The critical problems of adequately documenting the engineering requirements (i.e., process specifications) will be emphasized.

SESSION 5E: METAL JOINING - NEW WELDING DEVELOPMENTS

Thursday 1330-1700, 21 May 1970

Chairman: F. Miller, Air Force Materials Laboratory

Co-Chairman: G. Stoeckinger, McDonnell Douglas Corporation

5E1 -- GAS TUNGSTEN ARC WELDING

N. Bratkovich, Allison/General Motors Corporation

The gas tungsten arc welding process is the one predominantly used for fusion welding in the aerospace industry. It is known to produce high quality weldments and is very adaptable to a wide range of materials. Although other fusion joining processes have progressed impressively in recent years, the inherent quality characteristics of gas tungsten arc welds are responsible for its continued development and use. Unprecedented accomplishments in critical aerospace applications definitely validate the process reliability.

A more recent development (or refinement) of the basic process namely, plasma arc welding, also will be presented along with specific aerospace applications. The majority of innovations recently developed, deal mainly with the auxiliary and accessory equipment to accomplish the end product.

Aerospace applications which exemplify these innovations are hardware for spacecraft, airframes, rocket and gas turbine engines. The materials welded are low alloy high strength steels, nickel base superalloys, aluminum and titanium alloys.

5E2 -- SOLID STATE JOINING

A. Metcalfe, Solar Division, International Harvester

The theory of diffusion welding will be reviewed briefly and related to the various processes currently under development. A comparison of the processes will be presented and illustrated by components under development at various organizations. The advantages and limitations of each process for applications to Air Force requirements will be discussed.

The paper will conclude with a review of the current status of diffusion welding.

5E3 -- FABRICATION OF TITANIUM TEE SECTIONS BY HIGH-FREQUENCY RESISTANCE WELDING

M. Randall, Battelle Memorial Institute

There is an increasing interest in developing better and more reliable/economical fabrication techniques for producing titanium structural shapes, particularly for use in sheet-stringer systems for high speed aircraft. High-frequency resistance welding, as a method for fabricating titanium structural tees, offers promise for producing higher strength sections with greater economy and production rates.

A program sponsored by the Air Force Advanced Fabrication Technique Branch has been aimed at obtaining in-depth information on the possibilities of this technique. Optimum process parameters had to be developed, including procedures for removing the weld flash and forming a fillet at the junction of the stem and flange of the tee. Details of this program will be presented.

5E4 -- ELECTRON BEAM WELDING

W. McGregor, Solar Division,
International Harvester Co.

Among the many advantages of electron beam welding, that make it a valuable tool for Air Force and other work, are these important points:

- -The depth-to-width ratio is improved immensely over conventional welding.
- -It will join many combinations of dissimilar metals.
- -Atmospheric contamination is eliminated.
- -Refractory high melting point materials including tungsten are readily welded.
- -Is capable of welding thicknesses ranging from 0.002 inch to several inches -welding speeds are extremely variable.
- -Heat-affected-zone is reduced tremendously.
- -Filler material is seldom required but can be used if needed.

Electron beam welding has become a production tool with many jobs and designs heretofore considered impossible, now being accomplished as every day occurrences. Electron beam welding is still in its infancy but the future appears unlimited in scope and design concepts.

5E5 -- WELDBONDING AIRCRAFT STRUCTURES

D. Fields, Lockheed-Georgia Co.

Major European aircraft manufacturing companies are making extensive use of resistance spot welds, as a joining medium, for aircraft structures and several Russian aircraft are joined throughout using a technique called "glue-welding". Experimental work has been underway since 1965 at Lockheed-Georgia Company in an effort to perfect the technique of weldbonding, i.e., spot weld-adhesive bonding of metal aircraft structures. The Lockheed process is a parallel development and is similar in most respects to the Russian development.

Extensive adhesive development studies and welding metallurgical development has achieved a compatibility within the joint which enhances the total process of weldbonding as follows:

1. Up to 36% reduction in weight of structures as compared to mechanically joined elements.
2. A 12 fold increase in sonic life endurance as compared to conventional spot welded or riveted joints.
3. Static strength of many aircraft joints has been increased to four times that of conventionally riveted joints.

SESSION 2E: NONDESTRUCTIVE TESTING

Wednesday 0900-1200, 20 May 1970

NDT PERSPECTIVE

Co-Chairmen: R. R. Rowand, Air Force Materials Laboratory
E. W. McKelvey, Air Force Materials Laboratory

2E1 -- OVERVIEW OF MAJOR NATIONAL NEEDS IN NDT

N. Promisel, National Materials Advisory Board

The growing national emphasis on increased reliability of materiel, safety to personnel and assured performance, combined with the exploitation of advanced and sophisticated materials, processes and design concepts, create urgent, broadening demands on nondestructive testing and evaluation. This paper examines these demands and needs, as well as some opportunities and possible solutions, in terms of technical problems, inputs from ancillary disciplines, education and training, promotion, and design and planning interaction. The attempt is to treat NDT as both a technical and administrative system.

2E2 -- NONDESTRUCTIVE TESTING - RECENT DEVELOPMENTS AND FORECAST OF TRENDS

S. A. Leonard, General American Research Division/GATX

Within the past five years significant developments have occurred in nondestructive testing. Noteworthy accomplishments in the technical, administrative, management and educational areas have been forthcoming. Portability of equipment, data processing techniques, new test methods, use of specifications and expanded educational facilities are but a few of the key recent developments. The direction of these activities indicate important trends which will have effect in fields such as metallurgy, aircraft maintenance, contamination control, safety engineering, aerospace and oceanographic materials technology. This paper discusses these recent developments and forecasts trends in nondestructive testing.

2E3 -- EDUCATION AND COMMUNICATION WITH OTHER DISCIPLINES

S. Serabian, Lowell Technological Institute

Two areas in dire need of attention with the NDT community are education and communication with other disciplines. Both of these areas are important to the continued and meaningful growth of NDT. Education is the means for developing knowledgeable people for the field as well as increasing and widening our own knowledge of NDT. A rapport with other fields, through meaningful and well-understood communication lines, is very essential for continuing emergence of NDT in the engineering and scientific fields. Moreover, such communication links provide direction and purpose for the NDT field.

This paper will examine the present status of the available educational program in NDT and in particular, the needs of such activities to keep pace with the ever increasing growth of the NDT field. The use of communication and the mechanisms thereof will be evaluated to indicate roles of the Government, industry, education, and professional societies.

ENGINEERING PLANNING FOR NDT

Co-Chairmen: C. H. Hastings, AVCO Corporation
R. J. Roehrs, McDonnell-Douglas Corporation

2E4 -- NDT - AN EMERGING TECHNOLOGY IN THE PROCESS OF ENGINEERING DEFINITION

R. Socky, General Electric Co.

The characteristics of an "established" technology would include full engineering definition in the form of specifications, standards, practices, and codes. The current situation in nondestructive testing, in the area of engineering definition, is one of confusion. At least three fields of activity (method and technique description, product acceptance levels, and operator qualification and certification) are being developed by numerous bodies including individual companies, professional societies, trade associations, military services, and federal and state agencies. The results of this has been little short of chaotic. There is evidence that unifying efforts can be effective as exemplified by such programs as Polaris, Apollo, Nuclear Power Reactor Demonstrations, Nuclear Fleet, and the currently evolving "Airline Fleet Condition Monitoring Program". Suggestions for an orderly development with designated roles for the involved groups will be made.

2E5 -- THE ROLE OF NONDESTRUCTIVE TESTING IN THE PRODUCT CYCLE

D. Hagemaier, McDonnell-Douglas Corporation

Much attention has been given to nondestructive testing during recent years. Its favor or disfavor usually ensues from arguments over the lack of correlation in test results from different test methods or from variation in interpretation of specific test results. Nondestructive tests are not really "tests", but rather are measurements, in that the size and location of defects are usually indicated instead of the future performance capabilities of the material or part. In a testing or measuring operation, it is necessary to have primary or secondary reference standards in order that the results be meaningful. If the results of a test are to be reproducible, then the method of test must be systematic. Hence, before a nondestructive test procedure can be used to appraise a material or part, it is mandatory that a specification be prepared. The specification must describe the method of test, test conditions, and the reference standard. This presentation pertains to the role of NDT as it relates to raw material requirements, design aspects, and operational performance.

PANEL DISCUSSION — PROPOSED MECHANISMS FOR IMPLEMENTING THE RECOMMENDED ROLE OF NDT

Moderator: R. J. Roehrs, McDonnell-Douglas Corporation

Members: D. Hagemaier, McDonnell-Douglas Corporation
C. Hastings, AVCO Corporation
R. Socky, General Electric Co.
R. Anderson, Convair/General Dynamics

SESSION 3E: NONDESTRUCTIVE TESTING

Wednesday 1330-1700, 20 May 1970

MAJOR TECHNICAL PROBLEMS IN NDT
Co-Chairmen: L. Wilson, Lockheed-Georgia Company
R. Oliver, Union Carbide Corporation

3E1 -- MAJOR TECHNICAL PROBLEMS IN NON-DESTRUCTIVE TESTING
R. McClung, Oak Ridge National Laboratory

Nondestructive testing has made great strides during the last decade in solving technical problems throughout the industry. However, the ultimate utility and capability has not yet been reached. There should be increasing use of nondestructive testing methods in programs for materials development to aid in characterization of material attributes. This would lead to greater use of these methods for process control and subsequently, to optimum evaluation of serviceability of components, both after fabrication and after meeting operations. Among the many material and processes needing NDT developments and enhanced application are the areas of material joining, coatings, composites, graphites, alloy verification and the measurement of residual stress and detection of corrosion.

3E2 -- NOVEL USES OF NDT FOR EVALUATING ADVANCED FIBER-REINFORCED COMPOSITES
A. Schultz, AVCO Corporation

Physical and mechanical strength properties of high modulus fiber-reinforced/epoxy matrix composites are influenced by their fabrication methods. The need for NDT in evaluating these properties and their variabilities is now being recognized as a necessity in most material development and application programs. The degrading effect of voids on mechanical properties, the property values themselves as a function of loading direction, and the degree of property inhomogeneity in fabricated composites are each of immediate concern to designers. AVCO Corporation, Applied Technology Division, has developed capabilities for nondestructively predicting and fully characterizing the mechanical properties of multidirectional fiber composites. Methods, including a one-sided interval velocity technique, and procedures for evaluating carbon and boron fiber composites will be discussed.

3E3 -- THE ROLE OF NDT IN A DIFFUSION BONDING PROGRAM
E. L. Caustin, North American Rockwell Corporation

The importance of NDT to supplement and to round out a thorough quality assurance program in the manufacture of diffusion bonding products will be depicted. Various slides will show samples of the many diffusion bonded products that have been produced. Nondestructive techniques will be pictured and methods of correlation of results of destructive testing will be shown.

Nondestructive problems peculiar to diffusion bonding joint configuration will be presented. Methods of solving these problems and philosophies used to assure product integrity will be discussed in detail.

NEW PHENOMENA FOR NDT
Co-Chairmen: G. Martin, McDonnell Douglas Corporation
R. R. Whymark, Interand Corporation

3E4 -- REVIEW OF ARPA NONDESTRUCTIVE TESTING PROGRAM
O. C. Trulson, Advanced Research Project Agency

The Advanced Research Projects Agency's Nondestructive Testing Program consists of thirteen research contracts distributed among university, industry, and not-for-profit laboratories. The objectives of the program were to develop new physical methods for detecting discontinuities in parts under service conditions and to relate these discontinuities quantitatively with materials performance. Approximately 75% of the work under these contracts utilizes ultrasonics or acoustic methods for nondestructive indications. The remaining are concerned with exploring such techniques as exo-electron emission, holography, and other acousto-optical techniques. A brief description of objectives and progress under each contract will be discussed.

3E5 -- PHOTOCHROMIC/THERMOCHROMIC COATINGS - A NEW NDT TOOL
A. Olevitch, Air Force Materials Laboratory

This discussion reviews the status of Air Force work to apply photochromic/ thermochromic coatings for various NDT purposes. The use of these light and temperature sensitive dyes incorporated into resins to indicate curing of plastics and composites will be discussed. Correlation of color changes with time-temperature with such characteristics as solvent extractables will be shown.

For other NDT applications, work has been done to show lack of bond, pr[illegible] of water, resin rich areas, and outline of sub-surface attachments in honeycomb sandwich structures. The use of this method to detect defects in the F-111 boron-epoxy horizontal stabilator, F-111 window metal edge attachment, high altitude helmets and rubber bladder cells will be discussed. Various application techniques for using these coatings will be presented. Advantages and limitations of these new NDT materials will be included.

3E6 -- LASERS AND HOLOGRAPHIC INTERFEROMETRY - A REVOLUTIONARY BREAKTHROUGH IN NDT
D. Pearson and J. Bohn, TRW, Inc.

The aerospace industries' use of advanced materials -- graphite, ceramics, composites, etc. -- has quite naturally led to a requirement for advanced NDT techniques. Unless there is a spectacular improvement in NDT techniques within the next few years, the lack of adequate test procedures will constitute a bottleneck preventing full application of the new materials.

Preliminary experiments indicate that the laser, and in particular, holographic interferometry, constitute a truly revolutionary breakthrough in NDT. Holographic interferometry allows both the instantaneous and live real time measurement of multimicroinch strains at every point on unprepared surfaces of large area. When stress is properly applied to a specimen having internal flaws, the surface strain distribution will be minutely affected by the flaws. A holographic interferogram of the specimen will show these effects as signatures which identify the flaws' locations and tell something of their nature. A number of stressing methods will be discussed, including acoustic pulse generation by high energy laser beams.

3E7 -- MOSSBAUER SPECTROSCOPY AND NON-DESTRUCTIVE TESTING

R. Collins, Austin Science Associates, Inc.

Mossbauer spectroscopy is based on nuclear resonance fluorescence. Many metals exhibit the effect, but it is particularly strong for iron. Hence, it is useful for a wide range of iron alloys and for the analysis of corrosion products. The analysis is limited to the top few thousandths of an inch, or even less. Distinctive spectra are obtained for ferrite, martensite, iron carbide, and other common phases of steel. Alloys, such as Fe-Al, and oxides, are readily determined. Mossbauer is preferable to x-ray analysis in many applications. Advantages include cost, portability, indifference to orientation and sensitivity to very small crystallites.

3E8 -- ACOUSTIC EMISSION METHODS FOR PREDICTING LIFETIME

H. Dunegan and D. Harris, Lawrence Radiation Lab.
A. Tetelman, University of California at Los Angeles

The key to the successful application of acoustic emission techniques lies in the use of fracture mechanics as the analytical tool to relate the failure mechanisms at a flaw to the acoustic emission produced by the flaw. This is accomplished by recording the acoustic emission as a function of the stress intensity factor K at the crack tip of fracture toughness specimens, such that failure mechanisms due to plasticity, twinning, and subcritical flaw growth are characterized for the material in the thickness and environment to be used in service. Relationships between K and acoustic emission are shown for differing conditions and a technique utilizing periodic overstress while recording acoustic emission is presented.

SESSION 1F: FLUIDS AND LUBRICANTS

Tuesday 0900-1200, 19 May 1970

Chairman: R. L. Adamczak, Air Force Materials Laboratory

LIQUID LUBRICANTS SESSION

1F1 -- AEROSPACE REQUIREMENTS AND PERFORMANCE OF LIQUID LUBRICANTS

G. Morris, Air Force Materials Laboratory

The current requirements for gas turbine engine oils are reviewed relative to the ester type base stocks and compounded products that satisfy these requirements. Advanced requirements - both present and future - are presented. The selection of experimental lubricants based on high temperature capabilities is discussed. Their performance in the laboratory in oxidation, corrosion and thermal environments in the light of proposed requirements for advanced gas turbine engines is presented.

The current status of instrument lubricants - both synthetic and petroleum base - are reviewed. Experimental research involving the selection of a petroleum base stock, additive package and characterization of a gyro spin axis bearing lubricant is discussed.

1F2 -- LUBRICATING FLUIDS FOR ADVANCED TURBO JET ENGINE HIGH TEMPERATURE BEARINGS

J. Miner, Pratt & Whitney Aircraft

Higher bulk operating temperatures of turbo jet engine lubricating fluids can offer advantages in overall engine weight, cost, complexity performance, reliability and maintainability. Granted that current ester type lubricants have been adequate for most existing subsonic aircraft engines, however, their accommodation may necessitate undesirable engine design compromises in advanced supersonic applications of the future where lubricant related penalities may be magnified by the increased temperature severity. The question is; what fluids will meet these probable future needs? The class of stable aromatic fluids structually related to the polyphenyl ethers and designated aromatic C ethers might fill the bill. These advanced fluids, characterized by resistance to degradation and oxidation at higher th . present day operating temperatures, have continued to show promise and might be used as a premise, on which to develop and build engines.

PANEL DISCUSSION -- LIQUID LUBRICANTS

Moderator: R. L. Adamczak, Air Force Materials Laboratory

Members:
- H. J. Jones, Air Force Aero Propulsion Laboratory
- E. N. Bamberger, General Electric Company
- H. L. Hepplewhite, Mobil Oil Company
- H. W. Adams, Stauffer Chemical Company
- G. J. Morris, Air Force Materials Laboratory
- J. R. Miner, Pratt & Whitney Aircraft

HYDRAULIC FLUIDS SESSION

1F3 - AEROSPACE REQUIREMENTS AND PERFORMANCE FOR ENERGY TRANSFER FLUIDS

C. Snyder, Air Force Materials Laboratory

Operational and environmental requirements of current and anticipated future Air Force aerospace vehicles and related

1F3 -- AEROSPACE REQUIREMENTS AND PERFORMANCE FOR ENERGY TRANSFER FLUIDS (Continued)

support equipment are discussed with regard to hydraulic fluids, liquid coolants, and gyro flotation fluids. The scope and depth of the Air Force research and development efforts to provide fluids to meet these needs is presented. Capabilities of currently available classes of fluids which are encompassed within various areas of Air Force interest in energy transfer fluids are reviewed. Forecasts of new system and hardware designs are given with predictions on their possible effect on energy transfer fluid state-of-the-art.

1F4 -- DEVELOPMENT OF HYDRAULIC FLUIDS-A LOOK AT THE FUTURE

E. Klaus, Pennsylvania State University

Environmental conditious existing in some current aerospace hydraulic systems are approaching the conditions required to cause degradation of the hydraulic fluids used. The ultimate capability of various fluid classes must be considered in any evaluation of future hydraulic systems. Hydraulic fluids in order of increasing thermal stability are organic liquids, inorganic liquids, liquid metals, and gases. The basic thermal stability of the fluid as well as its chemical reactivity with the hydraulic system environment must be compared with the desirable physical characteristics of the fluid for power transmission. An integrated design concept requires a study of metallurgy, seals, and component compatibility as well as fluid properties. Careful consideration must be given to the replacement of any loss in elastohydrodynamic lubrication by increased chemical lubricity and/or lower design loads in the bearings members.

PANEL DISCUSSION -- HYDRAULIC FLUIDS

Moderator: R. L. Adamczak, Air Force Materials Laboratory

Members:
- K. E. Binns, Air Force Aero Propulsion Laboratory
- S. Prete, Air Force Aeronautical Systems Division
- L. J. Maltby, Hydraulic Research & Manufacturing Co
- L. C. Jennings, New York Air Brake Company
- C. E. Snyder, Air Force Materials Laboratory
- E. E. Klaus, Pennsylvania State University

SESSION 2F: FLUIDS AND LUBRICANTS

Wednesday 0900-1200, 20 May 1970

GREASES SESSION
Chairman: H. Schwenker, Air Force Materials Laboratory

2F1 -- AEROSPACE REQUIREMENTS AND PERFORMANCE OF GREASES
J. Christian, Air Force Materials Laboratory

Greases are discussed with respect to the current state-of-the-art. Emphasis is placed on the progress made in grease technology and the shortcomings of aerospace greases with respect to present and future requirements. The discussion relates to high speed, low speed, vacuum, and extreme pressure, anti-wear grease research and development. Current military specifications are also summarized.

2F2 -- AEROSPACE GREASES STATE-OF-THE-ART APPRAISAL AND FUTURE TRENDS
E. Armstrong and J. Giammaria, Mobil Oil Company

Aerospace Greases of increasingly high performance are needed for wider temperature ranges. They must also satisfy other demands imposed by high bearing speeds, loads and vibration; vacuum and-or radiation environments; and new designs and materials of construction, including compatibility with sealants. The new high performance greases are of two types - multipurpose and special purpose. The multipurpose type, based on recently developed wide temperature range hydrocarbon oils, affords a program of consolidation of military applications under more multiservice specifications and provides the air transport industry longer service before relubrication. The special purpose types, based on esters, silicones, polyphenyl ethers, and perfluoro polymers, are needed for environmental extremes beyond the range of the multipurpose type. Both types are using new fluids, thickeners, and additives and greases made with them have already solved some difficult lubrication problems. However, there still remain unsolved problems and limitations, which impose restrictions on usage requirements that continues to demand still high performance in the future.

PANEL DISCUSSION -- GREASES

Moderator: H. Schwenker, Air Force Materials Laboratory

Members:
J. Sullivan, Air Force Materials Laboratory
J. Messina, Frankford Arsenal
K. Bunting, American Oil
E. Armstrong, Mobil Oil Co.
J. Christian, Air Force Materials Laboratory
B. Simmons, Sikorsky Aircraft

DRY LUBRICATION SESSION
Chairman: R. J. Benzing, Air Force Materials Laboratory

2F3 -- AEROSPACE REQUIREMENTS AND RECENT AIR FORCE DEVELOPMENTS IN DRY LUBRICATION
B. McConnell, Air Force Materials Laboratory

Present and future bearing lubrication requirements for aircraft and other aerospace vehicles are discussed with emphasis on the need for new materials and techniques because of extreme environmental conditions. Some of the programs in the areas of dry lubrication, and friction and wear currently sponsored

2F3 -- AEROSPACE REQUIREMENTS AND RECENT AIR FORCE DEVELOPMENTS IN DRY LUBRICATION (Continued)

by the Air Force Materials Laboratory are described from the standpoint of developing materials and techniques to meet these requirements. These programs are of a fundamental nature which considers the theories and basic mechanisms involved in dry lubricating materials, as well as the developmental type which attempt to utilize this fundamental data to develop superior dry lubricating materials and techniques. New developments in the areas of resin bonded solid film lubricants, high temperature inorganic bonded films, compacts and composites will be discussed. Areas where some of these materials have already found application will also be covered.

2F4 -- SOLID DRY LUBRICANTS TO MEET THE AEROSPACE CHALLENGE

A. Haltner, General Electric Company

In addition to the Air Force efforts in solid (dry) lubricants, there are numerous other programs in this field which contribute to meeting the aerospace challenge. These programs range from research to applications. In the former category are included studies on the effects of loading pressure on the friction coefficients of solid lubricants, the role of vapors in solid lubrication, the in-situ formation of solid lubricants, and the development of new lubricants based on heavy elements. Other new materials under development are those designed for high temperature use (e.g., calcium fluoride) and those based on non-metallic composites (e.g., carbon fiber resin composites). Across the applications spectrum are included efforts on new methods of bonding and utilizing solid lubricants, the design of internal combustion engines completely lubricated with solids, and the increased use of metal platings.

PANEL DISCUSSION -- DRY LUBRICATION

Moderator: R. J. Benzing, Air Force Materials Laboratory

Members:
- V. Hopkins, Midwest Research Institute
- J. Jones, Hughes Aircraft Co.
- M. Devine, Naval Air Development Center
- L. Horvedel, Electrofilm, Inc.
- B. McConnell, Air Force Materials Laboratory
- A. Haltner, General Electric Co.

SESSION 3F: ADVANCED AIR BREATHING ENGINE MATERIALS

Wednesday 1330-1700, 20 May 1970

Chairman: J. A. Burger, Allison/General Motors Corp.

3F1 -- MATERIALS REQUIREMENTS FOR ADVANCED AIR BREATHING ENGINES
G. Wile, Polymet Corporation

The engines for future flight are evident now in the work of the prelim-inary designer. One new type of engine, the high bypass ratio fanjet, already dominates subsonic flight. Still highly conceptual are the variable cycle and duct burning, augmented fanjet engines for both subsonic and super-sonic operation. More specialized are the lift fanjet, for use during takeoff and landing, and the turbo-ramjet. These and other engine types will bring into use a much wider range of materials. However, the choice of materials and extent of application always will depend on the value of benefits to the mission.

Expensive materials, despite attractive properties, will prove non-essential and lower cost substitutes, combined with design ingenuity, will be used instead. Thus, the cost-benefit tradeoff so often criticized and yet so critical to success, will assume ever greater importance in shaping the future.

3F2 -- NEW CONCEPTS IN DISK MATERIALS THROUGH THE USE OF POWDER METALLURGY
R. Athey, Pratt & Whitney Aircraft

Early Astroloy turbine disk forgings exhibited excessive mechanical property scatter as a result of gross structural degradation and lack of homogeneity which was traceable to the large columnar grain structure of the ingots. Some improvement can be obtained by careful control of casting parameters to achieve fine equiaxed grain structure in the ingot. The degree of macrosegregation in a small powder particle size would be expected to be much less than that present in the structure of a large ingot conventionally melted and cast under optimum conditions.

Problems associated with particle oxidation can be eliminated by an "all-inert" method of powder production, collection, and billet densification. Mechanical properties of disks made by the powder metallurgy process are more uniform and at a higher level than disks made from conventional consumably melted ingots. Use of powder metallurgy for advanced superalloy disks opens new avenues of approach for alloy development due to freedom from gross segregation.

3F3 -- NEW CONCEPTS IN SHEET MATERIALS FOR GAS TURBINE ENGINES
S. Berkley and H. Hauser, Pratt and Whitney Aircraft

The material limitations in jet engine burner and turbine sections are discussed with emphasis on the power-plant improvements possible with advances in sheet materials technology. The recent history of conventional nickel and cobalt-base superalloy sheet development and usage in burners is then briefly reviewed for the purpose of establishing the baseline of operational experience and the efficacy of laboratory data. The development cycle for TD Nickel, the first dispersion strengthened superalloy to approach a production status, is described through engine evaluation for burner applications. Recent results and current activities in the development of coated columbium are presented, including the performance of columbium turbine vanes of sheet metal construction under engine conditions. In the

3F3 -- NEW CONCEPTS IN SHEET MATERIALS
FOR GAS TURBINE ENGINES (Continued)

light of work to date, the potential of advanced dispersion strengthened superalloy and refractory metal sheet is discussed and directions for future work are suggested.

SESSION 4F: AIR BREATHING PROPULSION - COMBUSTOR AND TURBINE MATERIALS

Thursday 0900-1200, 21 May 1970

Chairman: G. M. Ault, NASA-Lewis Research Center

4F1 -- HIGH TEMPERATURE SHEET ALLOYS

S. Wlodek, Stellite Division/
Cabot Corporation

Recent data pertinent to the technology of established compositions such as: Haynes Alloy No. 25, Hastelloy Alloy X, Rene' 41, Waspaloy, Inconel Alloy 625, and Inconel Alloy 718 are reviewed. Newer alloys including Haynes Alloy No. 188, Rene' 63, Inconel Alloy 706 and AF2-1DA also are included. Today's understanding of superalloy strengthening mechanisms, stability and oxidation offers a continuing possibility of improved sheet alloy development. The full utilization of this knowledge in the production of even high strength sheet alloys may not be limited as much by processing technology as by the weldability or joining limitations of higher strength materials.

4F2 -- CAST BLADE AND VANE ALLOYS FOR GAS TURBINE APPLICATIONS

R. Quigg, TRW, Inc.

The evolution of turbine bucket alloys has resulted in most of today's efforts being channelled toward nickel base materials. The nickel base alloys originally employed were air melted. However, subsequent developments incorporating increased quantity additions of titanium and aluminum, have necessitated vacuum melting to obtain desired or optimum properties. Recently, large quantities of refractory elements such as tungsten, molybdenum, tantalum, niobium, and hafnium have been added to enhance still further, the strengthening.

Some jet engine manufacturers feel that cobalt base alloys provide better overall properties but regardless of which is used (Ni base or Co base) a coating, generally an aluminide, must be employed. It is still possible that existing alloys can be optimized further to produce incremental strength additions at high temperatures. They, likely, will be quite complex and developments still will concentrate on casting alloys.

4F3 -- POTENTIAL OF TD COBALT AS GAS TURBINE MATERIAL

I. Perlmutter, Air Force
Materials Laboratory

The processing and properties of TD Cobalt are briefly reviewed, and additional data on oxidation resistance are presented. On the basis of its excellent oxidation and corrosion resistance (uncoated) and strength up to 2200°F, the material appears to have good potential for hot section components of jet engines.

4F4 -- COATINGS FOR TURBINE ENGINE SERVICE

J. Gadd, TRW, Inc.

An assessment is made of the technological advancements and successful exploitation of protective coatings for turbine engine service. The views of engine designers and operators on the state-of-the-art of protective coatings for turbine hardware are presented, along with an attempt to elucidate past mistakes and future plans for coatings research and development. The differing coatings development and application philosophies related to engines for military aircraft, as opposed to commercial carriers, are discussed. Consideration is given to coatings for the workhorse nickel and cobalt base airfoil alloys, as well as candidate dispersion strengthened alloys and

4F4 — COATINGS FOR TURBINE ENGINE SERVICE (Continued)

refractory metals. The impact of component air cooling, composite materials and engine design changes on coatings development goals is also discussed. An evaluation is finally made of the role of coatings in the rapidly emerging component overhaul and repair activity which faces the engine builders and operators. The presentation concludes with a summary assessment of coatings place in today's engines, and how their role should expand in tomorrows turbines.

PANEL DISCUSSION -- COMBUSTOR AND TURBINE MATERIALS

Moderator: G. M. Ault, NASA-Lewis Research Center

Members: J. B. Moore, Pratt & Whitney Aircraft
E. W. Ross, General Electric Company
C. H. Lund, Martin Metals Company
E. S. Nichols, Allison/General Motors Corporation
W. R. Freeman, Lycoming/Avco Corporation
C. C. Clark, International Nickel Company

SESSION 5F: AIR BREATHING PROPULSION - COMPRESSOR MATERIALS

Thursday 1330-1700, 21 May 1970

Chairman: I. Perlmutter, Air Force Materials Laboratory

5F1 -- SUPERALLOYS FOR COMPRESSOR APPLICATION

G. D. Oxx, General Electric Co.

The advantages of nickel-base alloys, such as René' 95, which are specifically developed for the temperature range of 800°F to 1200°F, are discussed. The most recent improvements in alloys for engine component applications between 800°F and 1200°F have been made by controlled processing of compositions selected for their response to working and heat treatment. The relationship of processing variables to mechanical properties of superalloys is described.

It is concluded that further improvements in material performance depend on innovations in consolidation and working processes and also, component fabrication techniques.

5F2 -- TITANIUM ALLOYS FOR GAS TURBINE COMPRESSORS

R. Sprague, Pratt & Whitney Aircraft

Many titanium alloys have been offered for gas turbine compressor usage, however, the powerplant applications are limited to a very few select compositions. To demonstrate the requirements for less discussed attributes, such as creep stability and toughness, the properties of specific alloys, which are typified by Ti-6Al-4V and Ti-6Al-2Sn-4Zr-2Mo, are compared to alloys failing to attain desired status. Based upon the review, future property goals for high tensile strength alloys (to be used at moderate temperatures) and of high creep strength alloys (for high temperature applications) are given. The review will also indicate general directions through which alloy and process development may be used to achieve the goals.

JOINT SESSION WITH SESSION 5A - COMPOSITES FOR TURBINE ENGINE APPLICATIONS

5A2 -- APPLICATION OF ADVANCED COMPOSITES TO TURBINE ENGINE COMPONENTS

K. G. Ball, Pratt & Whitney Aircraft

5A3 -- AEROPROPULSION APPLICATIONS TECHNOLOGY

W. Schulz, Air Force Materials Laboratory

5A4 -- CONCLUDING REMARKS

G. P. Peterson, Air Force Materials Laboratory

SESSION 1G: BALLISTIC VULNERABILITY AND SURVIVABILITY

Tuesday 0900-1200, 19 May 1970

Co-Chairmen: D. B. Atkinson, Air Force Flight Dynamics Laboratory

G. H. Griffith, Air Force Materials Laboratory

1G1 -- OVERVIEW OF SURVIVABILITY TECHNOLOGY

Lt. Colonel R. Taylor, Hq. U. S. Air Force

The basic trend of the survivability program of the U. S. Air Force today is discussed along with the influence of pressures from budgeteers, times of non-hostile conflict, and the enemies' demonstrated threat capabilities. Project 5105, "Aircraft Survivability" and some of its resulting recommendations for aircraft modifications, which would reduce vulnerability, will be discussed. Current survivability activity within the military community and the aerospace industry will be reviewed and the challenges of the future will be presented.

1G2 -- BALLISTIC RESPONSE OF STRUCTURES AND MATERIALS

Captain J. Meiselman, Air Force Flight Dynamics Laboratory
G. Griffith, Air Force Materials Laboratory

Examples of actual aircraft battle damage will be shown and discussed in terms of material and/or structural failures which resulted. The ballistic response of a spectrum of aircraft materials and structures under both static and dynamic conditions will be discussed in terms of residual strengths, types of failure and repairability. Skin and stringer, sandwich and integrally milled and stiffened structures will be covered. A number of typical aircraft structural materials such as 2024-T3 and 7075-T6 aluminum, 6Al-4V titanium, etc. will be discussed along with some of the composites of the future such as boron epoxy. Advantages and disadvantages of various combinations of these materials and structures will be assessed.

1G3 -- MATERIALS FOR ENHANCEMENT OF AIRCRAFT FIRE PROTECTION CAPABILITY

B. Botteri, Air Force Aero Propulsion Laboratory

Fire and explosion has been a continual menace, particularly under combat environment conditions, to the survivability of aircraft. The total threat is a function of the types, quantities, and distribution of susceptible materials, the environment these materials will experience, and the kinds of ignition and detonation sources which may be encountered. Realization of effective protection capability requires the selection of materials offering minimum hazard potential and supplemented, as necessary, by adequate means for containment and suppression. This paper reviews the current state of the art and technical development efforts in progress. Specific discussion is provided on: the mechanisms of fire and explosion initiation by gunfire; status of the vulnerability assessment of JP-4, lower volatility fuels, and modified fuels (gels and emulsions); active and passive fire and explosion suppression techniques; and advanced fire and overheat detection systems.

1G4 -- AIRCRAFT SURVIVABILITY THROUGH MATERIAL APPLICATION

A. Pedersen, McDonnell-Douglas Corporation
D. Voyls, Air Force Flight Dynamics Laboratory

Aircraft survivability can be greatly increased without adversely affecting mission capability through the proper selection and application of materials and structures. Damage tolerant materials are discussed in terms of their resistance to damage propagation, catastrophic failure and ease of repair. A study of fighter aircraft is discussed, which has shown that metallic armors can be applied as an integral part of an aircraft to effectively reduce its vulnerability. The selection and application of armor is, however, mission, attack profile, and threat dependent. In addition, the relative aircraft and projectile impact velocity and obliquity are shown to be determining factors in armor selection.

1G5 -- MATERIALS DEVELOPMENT DATA IMPACT ON WEAPON SYSTEM S/V PROGRAM

D. Wallick, Air Force Aeronautical Systems Div.

This paper describes, in general terms, the type of data required during weapon system development for implementation of an effective Survivability/Vulnerability (S/V) program. Weapon system design for low vulnerability must be based on a valid analytical assessment, which can be obtained only if adequate and accurate input data are used. Overall system survivability analysis, being a function of vulnerability to blast and projectile impact damage, detection and tracking by enemy radar, tactical maneuvering, and other countermeasures, must of necessity use data generated during materials development. Emphasis, in this paper, has been placed on material's properties data as it influences the S/V program and also, the importance placed on accurate, detailed, information in order that analytical results can be confidently used as a weapon system design tool.

PANEL DISCUSSION -- ARMOR, BALLISTIC VULNERABILITY AND SURVIVABILITY

Moderator: D. B. Atkinson, Air Force Flight Dynamics Laboratory

Members: G. H. Griffith, Air Force Materials Laboratory
Lt. Colonel R. Taylor, Hq. U. S. Air Force
C. Wiggins, McDonnell-Douglas Corporation
F. M. Cooper, North American Rockwell Corporation
R. E. Grill, Northrop Corporation

SESSION 2G: DYNAMIC RESPONSE OF MATERIALS

Wednesday 0900-1200, 20 May 1970

Co-Chairmen: P. C. Chou, Drexel Institute of Technology
R. F. Prater, Air Force Materials Laboratory

2G1 -- EFFECTS OF STRESS WAVES IN SOLID MATERIALS

R. Linde and D. Grine, Stanford Research Institute

The passage of a shock wave (large-amplitude stress wave) through a solid produces changes in the physical state of the material. Physical properties of the material, on the other hand, alter the wave-form as the shock propagates. Both aspects of this interaction are discussed in terms of their importance to Air Force programs. The formation, propagation and attenuation of shock waves, and techniques for studying shock waves in materials are described. Specific examples are given of the transient and permanent effects of shock waves on materials. Emphasis is placed on recent developments and on trends for future research.

2G2 -- MATERIAL PROPERTIES AND EQUATION OF STATE

J. Taylor, Los Alamos Scientific Laboratory

The equation of state of a material is a thermodynamic relationship between the state variables for the material, for instance the relation between internal energy, pressure, and specific volume. Although direct experiments are difficult to perform, it is nevertheless possible to learn much about the high pressure properties of materials by studying their response to shock waves induced by high explosives and high velocity impacts. The principles of such experiments, and the concepts of the Hugoniot curve and the Mie-Gruneisen form of the equation of state are discussed. Material rigidity and yield strength as well as fracture effects greatly complicate the simpler models of material behavior. The present discussion includes a survey of the strong points and problem areas in the state of the art.

2G3 — MATERIAL BEHAVIOR AT HIGH STRAIN RATES

U. Lindholm, Southwest Research Institute

Modern technology has developed many applications where material deformation takes place at high rates. This has led to the search for both adequate theory and experimental data to describe the mechanical properties of materials at high strain rates. The development of dynamic testing techniques will be described with emphasis upon the range of application and limitations of existing techniques. The development of "constitutive" equations and their application will be discussed. In this regard, the importance of coupling between strain-rate effects and temperature will be emphasized and illustrated with some specific examples. Finally, an assessment will be given of where we are now and what we need to do next with regard to determining high strain-rate material behavior.

2G4 -- WAVE PROPAGATION IN COMPOSITES

P. Chou, Drexel Institute of Technology

The practical significance of the study of waves in composites is first presented. The three regimes of material response, hydrodynamic, plastic, and elastic, under high intensity dynamic loadings are explained briefly. Current research activities in shock wave propagation in fiber-reinforced composites, foams, and distended materials are reviewed. Research on

2G4 -- WAVE PROPAGATION IN COMPOSITES (Continued)

elastic wave propagation in anisotropic, layered plates and shells is also discussed. The importance of characterization of the dynamic properties of composite materials is emphasized; future trends of research and development in this area are indicated.

2G5 -- RESPONSE OF MATERIALS TO HYPERVELOCITY IMPACTS

H. Swift, University of Dayton Research Institute
R. Prater, Air Force Materials Laboratory

This paper summarizes theoretical and experimental results of hypervelocity impact investigations pertinent to systems applications. Shock wave propagation and deformation phenomena control hypervelocity impact processes. Current theoretical effort in this area is dominated by numerical calculations that model these processes. Major experimental efforts are being applied to evaluating these models. Other investigations are elucidating the roles of materials mechanical and thermodynamic properties and stress wave propagation phenomena in the response of impacted materials. Future efforts in the hypervelocity impact field will include continued development of impact theory and vulnerability evaluation of future systems.

SESSION 3G: ARMOR MATERIALS TECHNOLOGY

Wednesday 1330-1700, 20 May 1970

Chairman: K. Abbott, Army Materials and Mechanics Research Center

Co-Chairman: G. Griffith, Air Force Materials Laboratory

3G1 -- THE ARMOR MATERIALS PROBLEM AND MILITARY NEEDS

K. Abbott, Army Materials and Mechanics Research Center

The Armor Material Problem is discussed in terms of the ballistic environments, and the behavior of materials in these environments. Armor failure processes are reviewed to define the need for composite materials which utilize both energy dissipation and absorption processes. Both technical and military aspects of the armor materials problem are presented with particular reference to the kinds of materials needed for various end item applications, and the ballistic threats which are associated with specific end item uses.

3G2 -- IMPORTANT CERAMIC PROPERTIES FOR APPLICATION TO ARMOR

M. L. Wilkins and C. A. Honodel, Lawrence Radiation Laboratory
C. F. Cline, Physics International

The importance of material properties will be emphasized and a phenomenological model presented to explain the performance of ceramics in armor applications. Data on old and new ceramics will be included. It is intended that this model be used as a guide for better ballistic materials. Work performed under the auspices of the U.S. AEC.

3G3 -- CERAMIC MATERIALS FOR ARMOR

R. Ruh, Air Force Materials Laboratory
Capt. T. Rankin, Army Materials and Mechanics Research Center
J. Stiglich, CERAC, Inc.

Current research and development on single component as well as multicomponent systems will be presented as will new and unique methods of processing these materials. The relative merit and potential of selected oxides, carbides, borides and nitrides will be discussed as well as the effect of metal additions to some of these materials. Multiphase and reinforced ceramics using oxides and carbides as matrices will also be considered. Ballistic evaluation of the above materials will be included where data is available.

3G4 -- COMPOSITE METAL ARMOR

W. Mannschreck, Naval Weapons Laboratory
D. Papetti, Army Materials and Mechanics Research Center

This paper summarizes the current status of dual hardness steel armor, dual hardness titanium armor, and aluminum-steel composite for defeat of small arms projectiles. Current efforts to improve metals for composite armor by control of solidification parameters, use of advanced melting procedures, etc., are discussed. The status of work to scale up the dual hardness armor concept to greater thicknesses is also discussed.

3G5 -- POLYMERIC ARMOR MATERIALS

R. Lewis, Army Materials and Mechanics Research Center

The current development status of polymeric materials in bulk, fiber, and film forms (excluding XP polymers) will be reviewed. Research data will be presented which indicates promising directions for research to improve polymeric armor materials. Both opaque and transparent materials will be included. The

3G5 -- POLYMERIC ARMOR MATERIALS
(Continued)

discussion will include dynamic failure processes and energy absorption in polymers as well as physical properties which are of ballistic importance.

3G6 -- ARMOR MATERIAL - XP

R. Kleinschmidt, Phillips
Scientific Company

Material XP is a new, lightweight armor structure which exhibits ballistics for fragmentation protection superior to those of ballistic nylon cloth. This proprietary product can be used in either rigid or flexible form over a wide range of areal densities. In addition to end-use applications as personnel armor, other armor systems using Material XP in composites with ceramics and metals are under development. Physical properties, ballistics and end-use applications will be discussed.

SESSION 4G: TRANSPARENT MATERIAL TECHNOLOGY

Thursday 0900-1200, 21 May 1970

Chairman: R. E. Wittman, Air Force Materials Laboratory

4G1 -- SOME EFFECTS OF TRANSPARENCIES ON VISUAL PERFORMANCE

Captain W. Provines, Air Force Aerospace Medical Division

Some of the degrading effects to visual performance caused by various protective transparencies through which aircrew members must perform the visual aspects of flight are discussed in this paper. Degradation of vision may be caused by absorption of available light by the transparent media or by distortion of light rays transmitted through the media. Included in the discussion are the effects of windshield tilt, laminations, reflections, conductive coatings, and rain on windshields. The interference of supporting structure as well as current devices for eye protection against nuclear detonation are also discussed.

4G2 -- TRANSPARENT ENCLOSURES/MATERIALS PROBLEMS

E. Arvay, Air Force Materials Laboratory

The interrelationship of designs and materials for aircraft transparent enclosures necessitates a dual approach to each solution of an operational failure. Current and past enclosure failures are reviewed to establish the diagnostic procedures necessary to obtain feasible solutions. Enclosure environments encountered during the course of operational flights, maintenance and storage are discussed in an attempt to differentiate between design failures and materials shortcomings. The use of various materials based upon laboratory and prototype testing is compared to inflight conditions. Materials properties for the four basic components glass, plastic, interlayer and coatings are examined for inherent causes of failure and new approaches to the development of improved materials are suggested.

4G3 -- ENVIRONMENTAL PROTECTION FOR TRANSPARENCIES

E. Wright and C. Beatty, Air Force Aeronautical Systems Div.

Rain removal on transparent areas currently use windshield wipers, hot air jets and rain repellent coatings. Problems associated with the particular method of rain removal exist. Wipers cause windshield abrasion. Hot air jets cause windshield overheat problems.

Defog-defrost and anti-icing of transparent areas use either hot air jets or electric conductive coatings. Both of the above methods impose temperature requirements which govern design and frequently result in problems of overheat.

All of the above require improved materials and new approaches to improve the current technology.

4G4 -- SPECIALTY COATINGS FOR AIRCRAFT TRANSPARENCIES

Captain J. Breland, Jr., Air Force Materials Laboratory

The complex flight profiles of modern aircraft subject surface transparencies to severe and constantly changing environments. Aircraft windshields and canopies are particularly susceptible to surface abrasion, glare, poor rain removal, and static electrical (static) build-up. Specialty coatings to prevent or reduce such problems on both glass and plastic transparencies have been

4G4 -- SPECIALTY COATINGS FOR AIRCRAFT TRANSPARENCIES (Continued)

investigated for over twenty years with only limited success. Operational experience gained in SEA has indicated a need for further development in all four areas.

4G5 -- APPLICATIONS CONSIDERATIONS RELATIVE TO CHEMICALLY-STRENGTHENED GLASS FOR AIRCRAFT

F. Ernsberger and D. Rinehart,
PPG Industries, Inc.

The surface compression that is responsible for the strength of chemically-strengthened glasses tends to diminish during extended periods of service at elevated temperatures. The decrease is due in part to ionic diffusion, in part to visco-elastic relaxation. Certain glass compositions and certain pairs of interdiffusing ions are relatively resistant to these effects. Examples will be given of the practical range of behavior in this respect.

SESSION 5G: TRANSPARENT MATERIALS DEVELOPMENT AND ARMOR APPLICATIONS

Thursday 1330-1700, 21 May 1970

Chairman: C. Bersch, Naval Air Systems Command

5G1 -- POLYCARBONATE AND CLAD POLYCARBONATE TRANSPARENCIES

D. Voss, McDonnell Aircraft Company

Acrylics have been widely used as transparency materials for many years, but are limited to temperatures below 250°F. Transparencies for advanced aircraft must be capable of withstanding much higher temperatures. Polycarbonate is a promising candidate because of its superior strength at elevated temperatures, but it is susceptible to attack by a range of solvents and is easily scratched and marred. It cannot be readily polished, and it may bubble at elevated temperatures. To eliminate the shortcomings, an acrylic-clad polycarbonate has been developed (patent pending). The acrylic-cladding has been done without the use of a flexible interlayer; interlayers frequently degrade at high temperatures, and thus adversely affect optics.

Acrylic-clad, monolithic polycarbonate is worthy of consideration for use in advanced aircraft canopies or windshields because of its low cost and attractive weight savings.

5G2 -- COMMAND BREAK CANOPY ESCAPE SYSTEMS

A. Shoemaker, Corning Glass Works

Current aircraft escape systems program the canopy to eject as part of the sequence of events or rely on the capability of a cutter bar mechanism to improve the emergency egress of the pilot.

Recent developments in the area of thin glass strengthening capability has resulted in a new canopy material candidate. Pre-stressed glass is now capable of controlled energy storage, that can be triggered upon command to instantaneously release this energy by failing the unit into pre-determined particle sizes. This system permits the pilot to eliminate the canopy eject sequence and command the entire canopy to fail and thus provide a clear opening for his ejection.

5G3 -- POLYARYLSULFONE THERMOPLASTICS - POTENTIAL HIGH TEMPERATURE GLAZING MATERIALS

R. Bringer, 3M Company

"ASTREL" Brand 360 Plastic is a commercially available polyarylsulfone thermoplastic. It is distinguished by a high heat deflection temperature (525°F @ 264 psi), good tensile strength (4,500 psi) and resistance to aging at 500°F. Because of the current interest in higher temperature plastic glazing materials for high speed aircraft, a 3M program has been undertaken to improve the color and transparency of the polyarylsulfones. This paper will be a status report on that program along with a description of the materials involved.

5G4 -- RECENT DEVELOPMENTS IN TRANSPARENT ARMOR

G. Parsons, Army Materials and Mechanics Research Center

H. Littell, Jr. and N. Shorr, PPG Industries

A brief background introduces the glass-plastic transparent armor concept. Ballistic testing of currently-producible armor has yielded sets of terminal ballistic curves for projectile defects from 5.56 MM. Through caliber .50 AP.

5G4 -- RECENT DEVELOPMENTS IN TRANSPARENT ARMOR (Continued)

Data is also presented for higher energy level defects. Recent developments in fabrication have produced flat and curved armor for special applications. New chemically strengthened and crystallized glass types for striking faces have improved ballistic performance because of superior projectile fracture. The effect of environment on ballistic and optical performance is also discussed.

5G5 -- TECHNICAL ASPECTS OF TRANSPARENT CERAMIC ARMOR FABRICATION

J. Niesse, AVCO Corporation

Fabrication goals are discussed as they relate to characteristics and performance of transparent polycrystalline ceramic armor.

Processes for producing dense polycrystalline transparent material of magnesia, alumina, and spinel ($MgAl_2O_4$) are discussed. Particular emphasis is placed on densification to attain pore-free material; important factors are quality of raw material, hot pressing to achieve densification, and densification aids. Techniques for eliminating crystal pullout and grain relief, two defects common in polishing surfaces of polycrystalline materials, are discussed. Bonding techniques for assembling transparent ceramic sheets into armor composites are reviewed. The state-of-the-art for producing transparent ceramic armor materials is summarized.

5G6 -- TRANSPARENT ARMOR - SOME DESIGN AND APPLICATIONS PROBLEMS

J. T. DeYoung, Goodyear Aerospace Corporation

The development of transparent armor employing ceramic materials such as magnesium oxide, and improved bullet resistant glasses used in composite configuration with plastic materials, has created new problems in several areas including framing and attachment design, thermal environment stability and survival, and limitations imposed by manufacturing process capabilities.

GAC has been evaluating transparent armor materials systems (glass-plastic composites) and optimizing these systems under Dept. of the Army Contract DAAJ02-69-C-0053. Evaluation and analytical techniques employed will be reviewed and significant results reported.

Approaches being taken as to design of framing and mounting of transparent ceramic-plastic composites under AF Contract F33615-69-C-1129 will be presented.

Concern and recommendations in the transparent armor product area will be discussed.

SESSION 1H: FLUID CONTAINMENT - FUEL TANK SEALANTS AND SELF SEALING SYSTEMS

Tuesday 0900-1200, 19 May 1970

Chairman: E. R. Bartholomew, FAA/Dept. of Transportation

1H1 -- FUEL TANK ENVIRONMENTS AND SEALANT REQUIREMENTS FOR THE SUPERSONIC TRANSPORT

M. Pollock, The Boeing Co.

Determination of the operating environment of fuel tank sealants for a supersonic aircraft such as the SST is a complicated task which must include consideration of fuel management, representative flight routes and schedules, and fuel quality. From this comes a prediction of time of combined exposure to temperature, pressure and quantities of oxygen, ozone and both liquid and vapor fuel and water. Also the possibility of accidental presence of materials such as hydraulic fluid, deicing additives, heat transfer fluids and electrostatic additives must be considered. On this basis, tests can be designed to screen materials and estimate potential service life. The SST fuel tank environment, the resulting test program, sealant requirements and reasoning leading to their establishment are described.

1H2 -- EVALUATION AND TEST PROCEDURES OF FUEL TANK SEALANTS FOR SUPERSONIC AIRCRAFT

M. George, Jr., Lockheed-California Company

The experience gained from operating a supersonic aircraft has been an important factor in devising new test procedures, specimens, and apparatus for the realistic evaluation of materials. Some of these, which are concerned with development and evaluation of integral fuel tank sealants, will be described. Excellent overall correlation was obtained comparing laboratory results, from both static and dynamic tests, and flight tested installation of new sealants.

1H3 -- HYDROFLUOROCARBON HIGH TEMPERATURE INTEGRAL FUEL TANK SEALANTS

W. Anspach, Air Force Materials Laboratory

Supersonic aircraft in the Mach 3 range have generated increased temperature requirements for many materials of constructions. One of the most critical problem areas is the integral fuel tank where state-of-the-art elastomeric sealants no longer meet the temperature requirements. This paper describes the current status in the development of a 500°F fluorocarbon elastomeric sealant compound. Sealant formulations and laboratory evaluation data after long term aging in jet engine fuels at elevated temperatures will be presented. Problems of adhesion and corrosion of titanium will be discussed.

1H4 -- ADVANCES IN SELF-SEALING AIRCRAFT FUEL SYSTEMS

R. Kohrn, Uniroyal, Inc.

The development of self-sealing aircraft fuel systems designed to provide greater protection against ballistic threats is being accomplished by improvement of the individual components, including fuel cells, fuel lines, backing boards, and fittings. Improved self-sealing fuel cells for use in standard and high temperature environments are under development. Cell contructions capable of sealing wounds caused by armor-piercing or incendiary projectiles of increasingly higher caliber are desired. Self-sealing aircraft fuel lines able to eliminate leakage caused by tumbled projectiles are sought. Simultaneous investigations of improved backing board materials and of high performance non-metallic fittings are being conducted.

PANEL DISCUSSION -- FUEL TANK SEALANTS AND SELF SEALING SYSTEMS

Moderator: J. M. Kelble, Air Force Materials Laboratory

Members: E. Bartholomew, FAA/Dept. of Transportation
D. Wight, Air Force Aeronautical Systems Division
W. Anspach, Air Force Materials Laboratory
J. Wessel, Dow Corning Co.
P. House, Air Force Materials Laboratory
R. VanDeusen, Air Force Materials Laboratory

SESSION 2H: FLUID CONTAINMENT - HYDRAULIC SYSTEM SEALS

Wednesday 0900-1200, 20 May 1970

Chairman: F. H. Pollard, Grumman Aerospace Corp.

2H1 -- ELASTOMERIC SEALS FOR -65°F to 300°F AIRCRAFT FLUID POWER SYSTEMS

F. Pollard, Grumman Aerospace Corporation

This paper covers the materials, designs, and applications of elastomeric seals used in Aircraft Fluid Power Systems for the temperature range of -65°F to +300°F. It is written from the viewpoint of the airframe manufacturer and specifically concerns the problems being experienced with materials and their applications in service. Additionally, it is also concerned with the limitations of currently available materials and the needs of industry to overcome these limitations. Both hydraulic and pneumatic applications and experience are covered.

2H2 -- AN APPROACH TO HYDRAULIC SEALING FOR 350 to 550°F FLUID TEMPERATURES

R. Abshire and E. Raymond, The Boeing Company

This paper will summarize the development and evaluation of high temperature hydraulic seals at Boeing over the past fifteen years and will include: development of compounding, evaluation of fluoroelastomer O-ring seals, development of metallic seals for hydraulic actuators and development of a 700°F sealing system. The paper also will present descriptions of the X-20A (Dyna-Soar) sealing system, SST seal requirements and developments, and the anticipated hydraulic sealing requirements for future military airplanes. Materials and structure of the component housings as well as seal designs and materials will be discussed.

2H3 -- NON-ELASTOMERIC SEALS FOR 500°F TO 1000°F FLUID SYSTEMS APPLICATION

J. Lee, Fairchild Hiller Corp.

This paper discusses the application of advanced materials concepts to the problems of fluid containment in the extreme temperature environment of +500 to 1000°F. The use of non-elastomeric materials, such as polyimides and metal matrix materials, as substitutes for elastomers in dynamic and static sealing is described. Description of design techniques used to integrate material properties and designs is included. Test conditions and results are also discussed.

PANEL DISCUSSION -- HYDRAULIC SYSTEM SEALS

Moderator: R. E. Headrick, Air Force Materials Laboratory

Members:
- F. Pollard, Grumman Aerospace Corporation
- S. Prete, Air Force Aeronautical Systems Division
- J. Lee, Fairchild Hiller Corp.
- R. Abshire, The Boeing Co.
- E. Raymond, The Boeing Co.
- P. House, Air Force Materials Laboratory

SESSION 3K: FLUID CONTAINMENT - LIQUID ROCKET PROPELLANT SEALS AND EXPULSION SYSTEMS

Wednesday 1330-1700, 20 May 1970

Chairman: J. K. Sieron, Air Force Materials Laboratory

3K1 -- FLUID CONTAINMENT REQUIREMENTS FOR LIQUID ROCKET PROPELLANTS

J. Branigan, Air Force Rocket Propulsion Laboratory

Air Force weapons systems require long-term, maintenance-free, storage under uncontrolled environmental conditions. Liquid propulsion system components must be capable of satisfactory operation after years of exposure to highly reactive propellants while retaining the propellants without leakage under severe ambient conditions of temperature and relative humidity. The Air Force Propulsion Laboratory (AFRPL) is conducting a program to investigate the long-term storability of liquid system propellants and tankage under nominal environmental conditions. The rocket propellants being tested are N_2O_4, ClF_5, N_2H_4, and MHF-5. The results of over three years of testing have indicated that oxidizer leakage can occur as a result of improper weld design, inadequate quality control and improper material selection. Amine fuel decomposition is strongly dependent upon storage temperatures, particularly in 17-7PH and AM-350 steel containers.

3K2 -- SEALS FOR LIQUID ROCKET PROPELLANT SYSTEMS

J. Sieron, Air Force Materials Laboratory

Reliable performance of missile systems utilizing liquid propellants is highly dependent on the ability of elastomeric seals to contain, separate, or regulate flow of the extremely reactive fuels and oxidizers which provide engine thrust. This paper describes the various types of elastomers or compounds which have been developed or need to be developed to cope with specific liquid propellants used in present or future systems. Emphasis is placed on development of nitroso rubber systems specifically for use with nitrogen tetroxide oxidizer.

3K3 -- FACTORS AFFECTING THE UTILIZATION OF ELASTOMERIC MATERIALS IN POSITIVE EXPULSION DEVICES

E. Burns and R. Porter, TRW Systems

Extensive use of elastomeric bladders, in storable propellant positive expulsion systems, has not been achieved because of material property limitations. Principally, materials which have demonstrated sufficient flexibility or acceptable mechanical properties, do not exhibit the required combination of chemical resistance and low permeability. A review is presented of (1) the advantages of elastomeric bladders, namely; low weight, efficient propellant utilization, long cycle life, and low cost together with (2) comparisons of the functioning of alternative designs of metallic expulsion devices. Particular emphasis is placed on material use characteristics and realistic approaches for attainment thereof, as well as the dependence of bladder design configurations on such critical features as shape, wall thickness, port and attachment constraints and their interactions.

3K4 -- DESIGN OF METAL BELLOWS

L. Thompson, Bell Aerosystems Co.

Pre-packaged liquid propulsion systems having metallic positive expulsion devices, which exhibit long term compatibility and zero permeability to propellants and pressurizing gases, as well as resistance to slosh, are required by

3K4 -- DESIGN OF METAL BELLOWS
(Continued)

advanced weapons systems. This paper describes the development of highly reliable metallic positive expulsion devices such as welded or formed bellows which have multi-cycle capability; and the "Telephragm", a light weight, low cost, single cycle device. Progressive development of the formed bellows to meet Minuteman dynamics and operating requirements is described as an example of the flexibility which metal bellows affords in designing to any specific environment.

3K5 -- VULCANIZATE PROPERTIES FROM A NEW PERFLUOROELASTOMER

G. H. Kalb, E. I. Du Pont de Nemours & Co.

Vulcanizates from a new high performance perfluorinated elastomer, a copolymer of tetrafluoroethylene and perfluoro (methyl vinyl ether) and a small amount of a cure site monomer, are described for use where other elastomers do not perform satisfactorily.

The parent dipolymer is highly resistant to oxidation, losing only 2-3% of its weight in air at 600°F. The copolymer is soluble in a variety of fluorinated liquids, but is essentially resistant to most other common solvents. Cured block stocks at 75°F show little or no swelling in a numerous solvent tests. The classes of solvents tested include aliphatic and aromatic hydrocarbons, ketones, esters, alcohols, amines, and anhydrides.

Hardness variations may be controlled, by including specific plasticizers in the compound, without modifying the solvent resistance, except for the very exotic fluorocarbon solvents.

PANEL DISCUSSION - MATERIALS FOR LIQUID ROCKET SEALS AND EXPULSION SYSTEMS

Moderator: J. Branigan, Air Force Rocket Propulsion Laboratory

Members: J. K. Sieron, Air Force Materials Laboratory
E. A. Burns, TRW Systems
R. L. Van Deusen, Air Force Materials Laboratory
C. Turek, Bell Aerosystems Co.
Dr. R. L. Barney, E. I. Du Pont de Nemours & Co.
Dr. P. Tarrant, University of Florida

SESSION 3H: FLEXIBLE FIBROUS MATERIALS

Wednesday 1330-1700, 20 May 1970

Chairman: J. H. Ross, Air Force Materials Laboratory

3H1 -- LIFE SUPPORT SYSTEM PROBLEMS

Col. A. Lovelady, Air Force Aeronautical Systems Div.

Fibrous materials meeting Life Support specifications must possess three specific characteristics for which they are to be utilized. These are non-flammability, high tenacity - high impact resistance and long life-time comfort. Fibrous materials in aircraft are required to be non-flammable, have insulation qualities, and when used in clothing, they must also be comfortable, long wearing, washable, and capable of being dyed. Requirements are established for non-flammable materials in flight garments, seat cushions, parachute packs and interior linings for both tactical and passenger type aircraft. ASWL is also working on materials for lightweight ballistic protection against flak which necessitates high tenacity - high impact resistant materials for increased protection of both aircrews and aircraft. High tenacity - high impact materials also have a definite use in parachutes, permitting lighter weights and the ability to open at higher speeds.

3H2 -- DECELERATION SYSTEMS AND AERIAL RECOVERY

S. Metres, Air Force Flight Dynamics Laboratory
H. Engel, Air Force Aeronautical Systems Division

The capability to provide efficient recovery systems is heavily dependent upon the availability of flexible, packageable and deployable materials. The recovery system material requirements include both the natural and induced environments of the earth's atmosphere and those of extra-terrestrial atmospheres. This presentation will review the wide applications spectrum of deceleration and recovery systems and their associated material requirements. Fibrous material requirements for systems in such areas as air drop, aircraft escape, air retrieval, etc. will be reviewed and discussed.

3H3 -- TEXTILE FABRIC DEVELOPMENTS AND PROPERTIES

J. Ross, Air Force Materials Laboratory

The need for fibers which are flexible while having thermal stability, non-flammability and high strength-to-weight in addition to characteristics such as abrasion resistance, U-V stability and durability during repeated stressing has been described. New fibers in the aromatic polyamide, polyimide, phenolic polymer classes have been developed and some have progressed to the status of commercial availability. The effects of exposure of these fibers to environments encountered by decelerators will be related in the form of strength at temperature, response to high speed loading and effect of U-V exposure on strength retention. The utilization of new fibers such as Nomex, to provide aircrewmen improved protection from fire will be reported. The advantages of new, synthetic nonflammable fibers such as Nomex, compared to treated natural fibers, will be presented.

3H4 -- PHYSICAL PROPERTIES OF POLYBENZIMIDAZOLE TEXTILES

E. Kaswell, Fabric Research Laboratories, Inc.

Polybenzimidazole (PBI), a new high temperature and flame resisting organic fiber, is now available in limited quantities. It has reasonably high strength with thermal resistance better than that

3H4 -- PHYSICAL PROPERTIES OF POLYBENZIMIDAZOLE TEXTILES (Continued)

shown by some of the new aromatic polyamides. PBI has typical "textile like" qualities, permitting it to be processed into filament or spun yarns and thence into braids, tapes, webbings and broad fabrics on conventional textile machinery by regular manufacturing methods.

Tensile and other physical properties of PBI fibers and textile structures are presented. The effects of temperature and strain rates on properties are reviewed, and comparison made with counterpart products composed of cotton and of "Nomex" polyamide. The superior flame resistance of PBI fabrics in air and in oxygen enriched environments is demonstrated and preliminary tests indicate that PBI flight suits and other apparel are more comfortable than presently used garments.

3H5 -- THE DESIGN OF LOW PERMEABILITY FABRICS

S. Schulman, Air Force Materials Laboratory

The use of coated fabrics in gliding decelerators, dictates the need for low levels of permeability which have not yet been achieved through the use of conventional weaving and coating techniques. The application of coatings to fabrics significantly lowers tearing strength; and the use of rip-stop fabric does not alleviate this phenomenon. Rather, one must use weaves which are unconventional for parachute applications and fill the fabric interstices with a soft elastomeric or resinous material. The need to withstand pressure packing without sticking can be met only by a few coatings many of which tend to stiffen the fabric. High tear strengths and resistance to sticking can be attained by filling the fabric with a soft coating such as polyurethane, and covering the surface with a non-flowing coating such as nylon. The serious problem of crack propagation upon deployment, which results in catastrophic failures if a few yarns in the stressed fabric are cut, has been investigated and means for greatly increasing the stress levels, without such failure, have been developed.

3H6 -- FLAMMABILITY IN AIR AND MIXED GAS ENVIRONMENTS

Lt. R. Stanton, Air Force Materials Laboratory

The state of the art of nonflammable fibrous materials intended for incorporation into life support systems and the accessories required for use in aerospace applications is discussed. The characterization and evaluation of new and improved fibrous materials and also commercially available materials, are discussed as end use items for air and oxygen rich environments. The effect of fabric construction in knit and woven fabrics on flammability as well as a new method for determining the thermal destruction time and burning rates of fibrous materials are also presented. Although nonflammability is the prime area of discussion; comfort, functional, and environmental aspects will also be covered.

3H7 -- HEAT TRANSFER THROUGH FABRICS

Miss A. Stoll, Naval Air Development Center

Heat transfer through fabrics is analyzed in terms of conduction, convection and radiation principles; and also, the influences which thermal properties of fabrics have on the heat received by underlying skin. The significance of the heat transferred through clothing is evaluated in terms of burn injury and protection time anticipated from laboratory studies of small samples. Verifications of predicted results are carried out in full-scale fuel fire exposures.

3H8 -- EFFECTS OF SPACE ENVIRONMENTS ON PROPERTIES OF WOVEN MATERIALS

C. Eldred, NASA/Manned Spacecraft Center

This paper summarizes the environmental testing of parachute materials for use in manned spacecraft recovery systems. A brief history of the development of test techniques and procedures is presented. Changes in tensile properties of nylon tapes, webbings, and fabrics caused by a simulation of a mission thermal-vacuum exposure and subsequent re-exposure to atmosphere are described. To provide a better understanding of the mechanisms involved, in the observed strength changes, a series of environmental tests were done with nylon, Dacron, and Nomex filaments. These results are presented, along with a separate process explanation which has been deduced from the test data.

3H9 -- CHARACTERISTICS OF MATERIALS IN DISCRETIONARY DESCENT SYSTEMS

J. Harris, Goodyear Aerospace Corporation

An Air Force program, Pilot Airborne Recovery Device, combines a Personal Parachute with a Hot Air Balloon to provide the conventional aircraft escape system with a ballooning capability to effect aerial retrieval or discretionary descent. The operational constraints of packaging, opening shock, hot gas inflation, and aerial snatch retrieval dictated unique material characteristics.

Development testing confirmed the selection of a Dacron scrim reinforced metallized Mylar film for the balloon material. This material provided a minimum packaged volume with adequate tear resistance against opening shock. Furthermore, metallizing the film with aluminum, reduced heat loss and held the Propane heating gas weight to an acceptable level.

PANEL DISCUSSION -- FLEXIBLE FIBROUS MATERIALS

Moderator: D. R. Work, North Carolina State University

Members: J. Crawford, Aerojet-General Corporation
S. Sprague, Celanese Research Corporation
G. Epstein, Aerospace Corporation
R. Seaman, E. I. du Pont de Nemours and Company
(Also Session Speakers)

SESSION 4H: MATERIAL REMOVAL - SURFACE INTEGRITY

Thursday 0900-1200, 21 May 1970

Chairman: J. F. Kahles, Metcut Research Associates Inc.

4H1 -- SURFACE INTEGRITY - ITS IMPORTANCE TO HIGH QUALITY AEROSPACE HARDWARE

M. Field, Metcut Research Associates, Inc.

A review of the pertinent facets of surface integrity produced when machining aerospace alloys by conventional and nonconventional methods will be presented. Illustrations will be shown of the microstructural alterations and residual stresses in metal surfaces produced by machining. Overall effects of these surface alterations on distortion of the workpiece and the important mechanical properties such as fatigue strength and stress corrosion will be discussed.

4H2 -- ENGINEERING EVALUATION OF SURFACE INTEGRITY

J. McMillan and C. Carter, The Boeing Company

Material specifications and process controls each have important effects on the nature and hence the performance of aerospace hardware. Sophisticated structural design requires an efficient interface between metallurgists and manufacturing engineers. The former develop new materials, provide potential applications, acceptance procedures and revised design requirements while the latter develop new methods and provide process visibility and coverage. Together they assess the effects of processing parameters on material properties and service life. Test data generated by gentle, normal and abusive metal removal techniques permit the identification of significant parameters and thus offer direction towards optimization from the viewpoints of component longevity and/or manufacturing costs.

4H3 -- EFFECT OF NONTRADITIONAL MACHINING ON SURFACE INTEGRITY

G. Bellows, General Electric Co.

The surface integrity impact of a material removal process on the surface of a workpiece is not limited to conventional or nontraditional processes. Each level of any process has a distinct surface integrity effect on each state of the material being processed. Whenever this level or state changes there is, potentially, a new surface integrity situation.

The new aerospace materials being employed are frequently quite sensitive to the various energy forms -- chemical, electrical, thermal -- used in the emerging nontraditional processes like abrasive jet machining (AJM), ultrasonic machining (USM), chemical milling (CHM), electrical discharge machining (EDM), electrochemical machining (ECM), electrochemical grinding (ECG), electrostream (ES), electron beam machining (EBM), and laser beam machining (LBM).

This discussion will describe some of the surface integrity effects from the nontraditional processes on some of the current aerospace materials.

4H4 -- THE CORRELATION (?) BETWEEN SURFACE FINISH AND FATIGUE LIFE AS APPLIED TO MACHINED AIRCRAFT SURFACES OF ALUMINUM AND STEEL

W. Hay and O. Thompson, General Dynamics Corp.

The idea that a finer finish leads to increased fatigue life is one generally subscribed to by aircraft engineers. Data to be presented for finishes with a 63-500 RMS refutes this general philosophy, and poses provocative questions

4H4 -- THE CORRELATION (?) BETWEEN SURFACE FINISH AND FATIGUE LIFE AS APPLIED TO MACHINED AIRCRAFT SURFACES OF ALUMINUM AND STEEL (Continued)

regarding the present methods for measuring surface finish and the specifications involved for flat machined surfaces. Based on this data, the need for a new specification for non-working surfaces is urgent.

SESSION 5H: MATERIAL REMOVAL

Thursday 1330-1700, 21 May 1970

MACHINING OF HIGH STRENGTH AND THERMAL RESISTANT MATERIALS
Chairman: L. P. Jahnke, General Electric Company

5H1 -- REVIEW OF MACHINABILITY OF AEROSPACE ALLOYS

N. Zlatin, Metcut Research Associates Inc.

U. S. production of aerospace vehicles in the past several decades has been highly dependent upon machining know-how on difficult-to-machine alloys. Programs sponsored by the Manufacturing Technology Division have provided industry with tool life data which have been used in setting up machining operations and in evaluating costs, production rates, machining tool plant facilities, and labor force requirements. Even more sophisticated tool life data are required for the manufacture of high quality hardware which is subjected to very high stresses and severe environmental conditions. It is, therefore, essential to investigate and establish machining parameters to not only guarantee adequate production, but also to establish surface integrity on the finished components. Methods of approaching this problem will be presented and illustrated with actual data.

5H2 -- STATUS OF TITANIUM MACHINING TECHNOLOGY

R. Vaughn, Lockheed-California Company

Examination of the machinability data development and use in today's aerospace materials, like the titanium alloys, shows that significant cost reductions and removal rate increases have and can result from the expansion of existing techniques and functions.

It is further apparent that economically successful machining of parts for today's sophisticated aerospace systems depends not all on exotic processes or spectacular breakthroughs but small, hard-won gains involving rigid controls, team experience, training and skill.

Development exposure of critical and high cost areas in any element of the machining conditions must be rigorously followed by adequate controls or eliminated through "state-of-the-art" advances. Control functions, not fundamentally the task of the research organization, are nevertheless a corporate requirement. The accurate definition of problem areas together with their impact must be followed by equally accurate control activation and performance.

5H3 -- MACHINING HIGH TEMPERATURE ALLOY ENGINE MATERIALS

K. Stalker, General Electric Company

Jet engines continue a trend to be made of higher strength, high temperature, and more corrosion-resistant materials.

The conventional material removal processes have not been able to keep pace with Material Technology.

Complex and lightweight designs also cause a lower conversion ratio of the raw material as forgings, castings and mill product to finished components.

The non-conventional material removal processes as ECM, EDM and Chem Milling have not developed fast enough to keep the "pounds of material removal per hour" up to historical levels of conventional removal methods on more conventional materials.

5H4 -- MACHINING OF BORON FIBROUS COMPOSITES

J. Huber and F. Garlasco,
Grumman Aerospace Corp.

This paper will deal with the methods developed at Grumman to machine boron-epoxy composite hardware. Cutting of cured boron composite panels is difficult to accomplish because of the relatively weak and non-heat-conducting epoxy resin matrix and the extremely hard boron fibers. Workpieces fabricated to date have been primarily aircraft skin panels and test specimens with critical dimensional and surface finish requirements. Cutting procedures developed to drill, ream, countersink, band saw, rout, radial saw slit, and surface grind boron composite hardware are described in detail. It will be shown that diamond-grit tools are the most practical for continuous cutting of boron composite panels. Operating conditions for each of these cutting methods are presented. The effectiveness of such non-conventional material removal processes as electrical discharge machining, electrochemical machining, ultrasonic machining, and laser cutting are also discussed.

5H5 -- REQUIREMENTS AND PROCEDURES FOR MACHINING GRAPHITE COMPOSITES

A. Langlois, Northrop Corp.

Graphite composite importance is rapidly accelerating as thermal envelopes of aircraft operation are increased. Graphite has useful strength above 300°F; however, its low oxidation resistance and brittle fracture characteristics has handicapped its usefulness. These characteristics combined with the abrasive nature of the binder epoxy materials require attention when shaping graphite composites.

Graphite composites are readily machineable at room temperature with conventional machine tools employing either conventional or unconventional tooling. The requirements for the machining process depends almost entirely upon configuration and secondarily upon the type of matrix material used to assemble the graphite composite.

NUMERICAL CONTROL MACHINING

Chairman: W. Johnson, Rocketdyne/NAR

5H6 -- LASER APPLICATION TO NUMERICAL CONTROL MACHINES

B. Anderson, The Boeing Co.

The laser and its controllable beam of light has found itself another useful application in assisting numerical machines to establish and maintain their expected accuracy. Straightness, distance and alignments are three factors that must be established and controlled to a high degree of accuracy. The laser with its capability of emitting a straight beam of light from whose center deviations in two opposite directions can be noted on a readout meter and/or strip chart recorder, has proven to be a reliable companion tool to NC machining. Guiderail straightness, bed flatness, ram and/or spindle axis alignment, linear distance measurement, etc., have effectively and efficiently been determined via laser and associated accessories.

5H7 -- MILLING ON MULTIPLE SPINDLE N/C MACHINE TOOLS

J. Schulz, McDonnell Aircraft
Company

McDonnell Aircraft Company installed its first numerically controlled machine in August, 1958. Today we have 80 numerically controlled machines. Early in the 1960's four predominant trends were recognized in the design of high performance aerospace vehicles; harder materials, larger parts, more

5H7 -- MILLING ON MULTIPLE SPINDLE N/C MACHINE TOOLS (Continued)

complex parts and shorter lead times. To meet these requirements on future contracts we initiated a comprehensive machine tool program.

Today the large majority of N/C profiling machines in our inventory are multiple spindled. They range from small 3 axis bridge type profilers to large 5 axis gantry type having 3 spindles on 40" centers. To efficiently handle small, medium, and large parts, these machines are equipped with beds ranging from 4'x4' to 14'x90'.

To further improve operating efficiencies our N/C machines are currently being converted from tape to DNC (Direct Computer Control).

5H8 -- APPLICATION OF DIRECT COMPUTER CONTROL OF N/C MACHINES

E. Hurd and R. Blind, Allison/General Motors Corp.

Early in 1968, direct on-line computer control of N/C machine tools became commercially available. This represented one approach to DNC that has influenced the thinking throughout industry.

The DNC concept attempted to benefit the general user by eliminating the punched tape and readers with their inherent problems. This meant minimizing or eliminating the control units as we know them today, and interfacing the machine tool with a digital computer. This also provided a means to optimize the usage of the machine tools by offering faster and more flexible communication between the machines and the computer. Time and costs are materially reduced, and less floor space is required. Punched tape is no longer required, consequently, there is no lost time in rewinding, loading, replacing, or storing tapes. The maintenance associated with troublesome tape readers is eliminated. Realizing the potential benefits of DNC, Allison was one of the first to utilize this method and presently has four DNC machines in operation.

5H9 -- ADAPTIVE CONTROL FOR N/C MACHINING

R. Mathias, Cincinnati Milling Machine Company

Until the 1960's and the wide use of numerical control, machining time on metal cutting machines was small compared with part handling and tool positioning time. Now, many parts are produced in one set-up and tool positioning and changing require only seconds. On the other hand the machining time has not decreased, nor has the machine time required for finding safe and efficient cutting rates been reduced. Different levels of adaptive control systems for optimizing feeds and speeds while protecting the machine, tool and workpiece from excess loading will be discussed. Tests in A/C - NC profile milling reveal that machining time can be reduced by as much as 65% in typical aircraft parts.

SESSION 1J: SPACECRAFT MATERIALS APPLICATIONS

Tuesday 0900-1200, 19 May 1970

JOINT SESSION WITH SESSION 1B - REUSABLE SPACE TRANSPORTATION

Chairman: L. N. Hjelm, Air Force Materials Laboratory

1B1 -- SPACE TRANSPORTATION SYSTEMS - INCENTIVE AND CONCEPTS

E. Love, NASA-Langley Research Center

1B2 -- MATERIAL REQUIREMENTS IMPOSED BY SPACE TRANSPORTATION SYSTEM CONSIDERATIONS

K. Graff, Aerospace Corp.

SESSION ON MATERIALS FOR SPACECRAFT SYSTEMS

Co-Chairmen: S. Siegel, Aerospace Corporation

P. Propp, Air Force Materials Laboratory

1J1 -- MATERIALS ASPECTS OF SPACECRAFT DESIGN

J. Bozajian, Hughes Aircraft Company

A series of synchronous orbit satellites has been developed for the NASA, the Communications Satellite Corporation, and the Air Force over the past decade. The Air Force Tactical Communications Satellite (TACSAT) utilized attitude stabilization. Designs and materials used in these satellites are reviewed with particular regard to the structural, mechanical and thermal subsystems and with emphasis on the TACSAT. Rigid and nonrigid solar cell arrays, structures and antennas, material selections and associated cost trends, resulting from applications such as beryllium and advanced composites, are assessed. An evaluation is made of the requirements, environmental factors and selection criteria for thermal surfaces and finishes that are required to maintain stable properties over long orbital lifetime.

1J2 -- MATERIALS TECHNOLOGY IN SPACECRAFT TEMPERATURE CONTROL

L. Dumas, Jet Propulsion Laboratory

Spacecraft temperature control is largely dependent on the thermophysical properties of the materials used in the design. The state-of-the-art of materials technology combines with other design constraints to limit the selection of materials available to the thermal designer. The manner in which material properties affect the spacecraft thermal design will be examined, the range of available materials properties will be briefly reviewed, and the impact of materials availability on thermal design and the resultant effect on systems design will be assessed. An evaluation of thermal design trends and recommendations for future materials property research will be made.

1J3 -- RELIABILITY OF LONG LIFE MOVING COMPONENTS

D. Flom, General Electric Co.

A systems approach to space lubrication means more than minimizing friction and wear. A lubricated mechanism must withstand severe ground and launch profiles and then in space either (1) operate smoothly, (2) operate instantly with low, constant friction, or (3) just operate for the duration of the mission. Proper design treats bearings and lubricants as a single component and factors in the effect of this component on other vehicle elements.

1J3 — RELIABILITY OF LONG LIFE MOVING COMPONENTS (Continued)

A major problem is extended missions which exceed even ground-based lifetimes of current bearings and lubricants. This demand for reliability means new materials, new methods of accelerated testing, and accelerated acquisition of test information for early detection of incipient failure and malfunction. This paper emphasizes those diagnostic techniques.

1J4 — MATERIALS ASPECTS OF ELECTROMAGNETIC SENSORS FOR SPACE APPLICATIONS

M. Birnbaum, Aerospace Corp.

Electromagnetic detectors of importance in space application from low radio frequency to the ultraviolet are considered. The principles of detector operation are reviewed with comparisons between achieved performance and desired capabilities. Future needs and objectives are discussed. Areas of exploration and examples of current work demonstrating recent advances are presented.

SESSION 2J: MATERIALS FOR SPACECRAFT SUBSYSTEM AND STRUCTURAL APPLICATIONS

Wednesday 0900-1200, 20 May 1970

Co-Chairmen: S. Siegel, Aerospace Corporation

P. Propp, Air Force Materials Laboratory

2J1 -- SPACE POWER MATERIAL CONSIDERATIONS

E. Stofel and H. Killian, Aerospace Corporation

The electrical power sub-systems constitute a substantial portion of any typical spacecraft weight and cost and, therefore, receives close design attention. Present and advanced power systems are reviewed from the role which materials development must play in the evolution of these components. Power subsystems using solar cells, chemical, and nuclear energy are discussed. Areas for materials development include very large solar arrays, higher performance batteries and nuclear energy sources.

2J2 — MATERIALS COMPATIBILITY IN SPACECRAFT ENVIRONMENTS

H. Hillesland, Philco-Ford Corporation

Polymeric materials, because of the distinct advantages they offer, are being utilized in many spacecraft subsystem and component areas. This paper reviews representative applications of adhesives, encapsulants, coatings, etc. and describes the impact of their utilization on spacecraft subsystem and component design. Probable future areas for polymer application in spacecraft are discussed, and associated characteristics requiring determination or development are identified. The paper also elaborates on the inter-relationship between the materials and processes engineers and representatives of other engineering disciplines necessary to successfully introduce polymeric materials in new applications.

2J3 -- MANNED SPACECRAFT MATERIALS SELECTION

H. M. Clancy, North American Rockwell Corporation

This paper will discuss the present state-of-the-art in manned spacecraft materials selection which must consider criteria controlling flammability, smoke, toxicity and outgassing. Metallic and non-metallic materials will be considered. NASA and Air Force experience in materials selection and testing will be reviewed. Modified materials screening/qualification test procedures will be proposed to streamline the materials selection process thereby reducing the cost in time and money. A plea for government/industry standardization of such test procedures will be presented in conclusi. .

2J4 -- SPACECRAFT METALLIC STRUCTURAL MATERIALS

? MacLean, Lockheed Missiles and Space Company

This paper discusses the design philosophies of spacecraft structure, based on the types of service loads encountered, and the criteria that lead to the selection of light metals for design optimization. Monocoque and semi-monocoque shells, designed to carry primarily compressive stresses, can permit no elastic buckling, and must provide high specific compressive strengths and compressive moduli which are basic to spacecraft design. Large thin-walled shells of revolution fabricated from

2J4 -- SPACECRAFT METALLIC STRUCTURAL MATERIALS (Continued)

lightweight metals are discussed, in conjunction with buckling resistance and compressive yield strengths as the basic material selection criteria. Cost-effectiveness studies are shown.

2J5 -- SPACE VEHICLE APPLICATIONS OF ADVANCED COMPOSITE MATERIALS

J. Forest, Convair/General Dynamics Corporation

The advantages of composite materials composed of boron or graphite filaments in a resin or metallic matrix have been widely publicized for aircraft applications in the coming decade. These same materials also show promise in space vehicle primary structure and auxiliary system applications in terms of potential weight savings, increased thermal stability, and increased stiffness of large structures. Potential applications in small satellite structures, low distortion antennas, and large erectable space structures will be discussed in terms of composite system applicability, potential weight and performance advantages, and implementation costs. General system applications are emphasized, rather than specific design details.

SESSION 3J: METAL PROCESSING - DEFORMATION PROCESSING

Wednesday 1330-1700, 20 May 1970

Chairman: T. D. Cooper, Air Force Materials Laboratory

Co-Chairman: H. Conrad, University of Kentucky

3J1 -- THE IMPORTANCE OF METAL PROCESSING

T. Cooper, Air Force Materials Laboratory
H. Conrad, University of Kentucky

Metal processing is the key to advanced Air Force systems. High performance engines and airframes are limited by the availability of wrought metallic components having both the required mechanical properties and the necessary complexity of shape. Moreover, the economic aspects of producing such products are assuming even more significant control of the success or failure of system development. It is the purpose of this paper to provide the backdrop for the three sessions on this subject, starting with the application of fairly fundamental work to real metalworking problems, moving to some new techniques and finally considering the synthesis of structure and properties through control and design of thermomechanical processing.

3J2 -- THE APPLICATION OF WORKABILITY DATA TO PRACTICAL METAL PROCESSING

A. Hoffmanner, TRW, Inc.

The broadest use of the term workability implies the degree of ease with which a material can be successfully shaped into a useful product. Quantitative expression of this degree of ease requires knowledge of a material's response to stress, temperature, and strain rate, and the conditions imposed on the material by the lubricated tooling which, in general, will be at a different temperature than the workpiece. An exact solution of a metalworking problem involving all of the implied process variables is, for the most cases, beyond practical realization. However, material testing procedures and approximate analytical techniques have been developed to provide accurate predictions for process improvements well within limits of process control. These procedures are demonstrated for the forging of titanium alloy airfoils and simple upsetting, to simulate turbine engine disk forging, of several alloys including Ti-6Al-4V and the superalloy U-700. These results clearly demonstrate the utility of current analytical techniques for optimum process design.

3J3 -- THE USE OF THE RING TEST FOR DEFINING REALISTIC METAL PROCESSING PARAMETERS

V. DePierre, Air Force Materials Laboratory
A. Male, Westinghouse Electric Company

The ring test has been shown to be a very versatile tool for studying realistic metalworking processing parameters. Computer solutions of mathematical analyses made of ring compression have been verified by experimental tests, have increased the accuracy of the ring test for determining quantitative friction measurements under processing conditions, and have provided a method for optimizing the geometry for friction studies. The solutions have also been applied to the determination of true stress-true strain compression curves for deforming material under processing conditions. These curves provide flow strength data required for computing deformation loads in metalworking operations and serve as a reference base for metalworking workability studies.

3J4 -- AN INVESTIGATION OF FACTORS CAUSING THE EXTRUSION BREAKTHROUGH LOAD

F. J. Gurney, Westinghouse Electric Corporation

The portion of the peak extrusion load which is commonly called the breakthrough load is examined to determine the factors which influence the phenomenon. The initial portion of the extrusion process is examined to determine the configuration of the billet in relation to the extrusion load. Attention is focused on the degree of filling of the container cavity and the actual amount of product extruded in relation to the required load. The relation of the initial billet-container fit and also the effect of static to dynamic friction transition are evaluated and their effects on the load are discussed. Examples are shown which illustrate the practical as well as the scientific interest relating to the breakthrough load and techniques to reduce the phenomenon are suggested.

3J5 -- HIGH TEMPERATURE METALWORKING EMPLOYING GLASSY LUBRICANTS

M. Leipold, University of Kentucky

The use of glass as a lubricant in high temperature metalworking, i.e. the Sejournet Process, has been very successful with difficult to process materials such as titanium and its alloys. However, there is a need to put the process on a more rational basis so that changes in the processing parameters or in the alloy character can be met with planned changes in the lubricant rather than a new empirical study.

To provide this rational basis, an extensive study is underway to investigate the characteristics of the lubricant and the effects of variation in these characteristics on the effectiveness of the lubricant. The characteristics of the lubricant presently under investigation are interfacial energy and viscosity in isothermal testing. The effectiveness as a lubricant is being studied by both simulated friction and actual extrusion.

Present results describe interfacial energy data and simulated friction apparatus and its preliminary results.

3J6 -- SHAPE DIFFICULTY FACTOR AND FLASH DESIGN IN CLOSED-DIE FORGING

T. Alton, Battelle Memorial Institute

The determination of the number of performing operations, the design of flash, and the prediction of flash and scale losses are significant steps in designing a forging process. It normally takes extensive experience to reasonably estimate these variables and to design the forging process. The difficulty in forging a plant depends upon various factors, such as the geometrical shape of the forging, the forging material, the forging tolerances and the expected die wear. A shape difficulty factor, originally suggested by Soviet workers and statistically obtained empirical formulas have been used to predict the flash dimensions and the flash weight for round low alloy steel forgings. The procedure has been computerized and extended to calculate also the volume or weight of the forging. The computer program is applied to various forgings and results have been found to agree with actual experimental data.

The developed computer program can now be extended to non-symetrical forgings and can be used for cost estimating, designing for systematic analysis of existing forging data.

SESSION 4J: NEW METAL PROCESSING TECHNIQUES

Thursday 0900-1200, 21 May 1970

Co-Chairmen: G. M. Glenn, Air Force Materials Laboratory
A. M. Sabroff, Battelle Memorial Institute

4J1 -- NEW TECHNIQUES IN METALS PROCESSING

G. Glenn, Air Force Materials Laboratory
A. Sabroff, Battelle Memorial Institute

Air Force requirements, resulting from newly designed vehicle systems and the emergence of new and/or modified structural materials, create demands which are outstripping our manufacturing process technology. Conventional metalworking equipment particularly in the rolling, forging and extruding industies were designed to accommodate aluminum, magnesium, and carbon and alloy steels and the processes to produce them. These facilities are often inadequate and usually inefficient for the production of new structural materials to meet aircraft quality specifications. Manufacturing processes and equipment, starting with the initial consolidation (powder metallurgy or melting), must be adaptable to the properties and characteristics of the materials for efficient and economical production.

4J2 -- CONSOLIDATION-POWDER METALLURGY VERSUS MELTING AND CASTING

C. Mueller, Universal Cyclops Corporation

The question concerning the preferred method of consolidation for high temperature alloys, tool steels, and other critical aerospace metals is a continuing perplexing problem. Many pressing and/or sintering techniques are being evaluated and compared with conventional, as well as thin wall, melting and casting techniques. A critical review of processing parameters and the results obtained from experimental evaluations are made. The deficiencies and advantages of each process are described and evaluated. This timely review will present an overall look at the anticipated future developments and will attempt to outline the direction that both powder metallurgy and melting and casting will take during the next five years.

4J3 -- COMPETITIVE METHODS OF FABRICATING LARGE STRUCTURAL PARTS

R. Pearson, The Boeing Company

The fabrication of aircraft structural components by thermomechanical processing, thermal fusion and/or diffusion bonding as complimentary or supplemental processes for conventional forging, machining, and mechanical fastening will play an increasingly important role in the forthcoming years. The potential improvements in economics and structural efficiency suggest a renewed vigor in existing developmental and research programs and the initiation of new programs on an even more aggressive scale in order to exploit the potential of these promising methods by incorporation into new airframe designs with a high level of confidence.

This activity will require the complete support of all disciplines. The materials suppliers and the engineering organizations jointly supported by the processing and manufacturing organizations must make full utilization of their existing capabilities - augmenting, where required, with new equipment and techniques to obtain a rational balance of economics to obtain the best part for the most cost effective price. The indiscriminate use of any process as a cure-all for our existing limitations and problems will inevitably result in failure.

4J4 -- THE CASE FOR PRECISION FORGINGS AND PRESSINGS

J. Noyes, McDonnell Douglas Corporation

Machined blocker and die forgings make up an appreciable number of the concentrated load carrying members of aircraft components. However, the demand for high performance airframe structures at cost effective prices has stimulated the development of more sophisticated forging techniques. These new classes of forgings have virtually no draft angle, flash, or mismatch; thus requiring less raw material and also, minimizing finish machining. The precision forgings and pressings can be shown to be superior in performance and are cost effective in many specialized applications. On the current F4 fighter approximately 40% or 300 of the aluminum alloy forgings are no draft, no flash, or mismatch pressings. Although application of these new forging techniques to the next generation materials, such as titanium, appears more difficult the expected rewards encourages their development.

4J5 -- PRODUCTION OF LONG PRECISION STRUCTURAL SHAPES

P. Loewenstein, Nuclear Metals/Whittaker Corp.

Long structural shapes such as channels, Z's, H-beams, and more complex geometries, are normally produced by hot rolling or hot extrusion. Presently available production methods are satisfactory for aluminum, magnesium, and carbon steels, but precision structural shapes of the high performance metals and alloys (titanium, high strength steel, stainless steel, beryllium) cannot now be produced to the required specifications by conventional rolling or extrusion techniques.

The aerospace industry has many applications where long structural shapes with thin web thickness, very complex cross sectional geometries, or cross sections tapered along the length are needed. These requirements currently are filled by machining the shapes from greatly oversize sections; an operation which is wasteful of material and extremely costly in labor.

A number of new techniques, many established under Air Force sponsorship, capable of filling these requirements and avoiding costly machining, are presently emerging. These various techniques will be listed, and an assessment of the present production capabilities and limitations with respect to aerospace requirements will be given.

PANEL DISCUSSION -- NEW TECHNIQUES FOR PRODUCING AEROSPACE STRUCTURES

Moderators: G. M. Glenn, Air Force Materials Laboratory
A. M. Sabroff, Battelle Memorial Institute

Members: J. DiBeneditto, Army/Rock Island Arsenal
J. King, North American Rockwell Corporation
T. Felker, Air Force Materials Laboratory
W. Rostoker, University of Illinois
G. Davies, Clevite

SESSION 5J: THERMOMECHANICAL PROCESSING OF METALS

Thursday 1330-1700, 21 May 1970

Co-Chairmen: A. M. Adair, Air Force Materials Laboratory

E. A. Steigerwald, TRW, Inc.

5J. -- LET'S HEAR IT FOR TMP

A. Adair, Air Force Materials Laboratory
E. Steigerwald, TRW, Inc.

Thermomechanical processing (TMP) of high performance alloys will be defined in view of Air Force applications, with emphasis being placed on its relative potential for satisfying present and future needs. Specific comments will be directed toward mechanisms of hot and cold working and the defect structures produced and also, interactions between the defect structure and aging reactions in maraging steels. Beta processing of titanium alloys, its controliability, and the extent to which it is being used will be presented along with thermomechanical processing of high strength steels and its future trends. In addition, the relationship between workability and the concept of superplasticity will be explored. Questions will be raised on methods of improving the workability and final properties of superalloys through controlled processing.

5J2 -- BETA PROCESSING OF TITANIUM ALLOYS, A PERSPECTIVE

R. Broadwell, Titanium Metals Corporation of America

Historically, titanium alloys have been processed below the beta transus, in the alpha-beta phase field; this has been true for all products with the exception of thin section airframe extrusions. The major reason for the alpha-beta processing approach is to assure the optimum combination of "first tier" mechanical properties, such as strength and ductility.

During the past four years, economic factors, plus the quest for higher allowables in certain "second tier" mechanical properties, such as creep and crack propagation resistance, have led some people to an investigation of controlled beta working (that is, above the beta transus temperature). This paper presents an objective evaluation of the advantages and limitations of beta processing techniques as applied to several titanium alloy systems -- in both the annealed and the solution treated and aged conditions. End user specifications, and technical data will be included to illustrate the required control aspects of beta processing, as well as to cite economic considerations and the mechanical property levels attainable.

5J3 -- THERMOMECHANICAL PROCESSING OF SUPERALLOYS

J. Moore, Pratt & Whitney Aircraft

This paper critically reviews the strides that have been made in recent years in the thermomechanical processing of superalloys to upgrade their mechanical properties for advanced aerospace application.

By the early 1960's, there was a shift of emphasis from chemistry modification to thermomechanical processing for mechanical property improvement of most aerospace alloys; this was occasioned primarily by two factors. First, it became apparent that saturation of the matrix by elemental strengtheners and the segregation proneness of advanced experimental alloys prevented their effective use without the establishment of more sophisticated processing techniques. Secondly, it was discovered

5J3 -- THERMOMECHANICAL PROCESSING OF SUPERALLOYS (Continued)

that certain specific properties or combinations of properties of these alloys, as well as some of the "established" alloys, could be significantly improved through the imposition and control of appropriate processing parameters. Although effort in thermomechanical processing has been rewarding, there are areas which merit further work to fully exploit the potential offered by superalloys for aerospace application.

5J4 -- A REALISTIC APPRAISAL OF THE THERMOMECHANICAL PROCESSING OF STEELS

R. Grange, United States Steel Corporation

Thermomechanical processing is a versatile means of enhancing the useful strength of steel. It can be adapted to accelerate certain solid-state phase changes and thus to decrease processing time, or to anneal alloy steels which are unresponsive to thermal treatment. Thermomechanical treatment may refine grain size, induce desirable precipitate morphologies, introduce high dislocation density, or develop unique microstructures. An example of each type of treatment will be discussed and its advantages and limitations pointed out in terms of the technological application with emphasis on aerospace materials.

PANEL DISCUSSION -- THE ROLE OF THERMOMECHANICAL PROCESSING OF AEROSPACE MATERIALS

Moderator: A. M. Adair, Air Force Materials Laboratory

Members: J. Burger, Allison/General Motors Corporation
S. Arnold, Army Materials and Mechanics Research Center
A. Hurlich, Convair/General Dynamics
W. Couts, Wyman-Gordon Co.
E. Steigerwald, TRW, Inc.

AIAA SPECIAL PROGRAM

SYSTEM STUDY RESULTS OF SPACE TRANSPORTATION

Tuesday 1430-1800, 19 May 1970

Chairman: L. N. Hjelm, Air Force Materials Laboratory

AIAA-1 -- AIR FORCE/AEROSPACE IN-HOUSE STS STUDY REVIEW
R. H. Herndon, Aerospace Corporation

A brief overview of in-house Space Transportation System (STS) studies will be provided, including details of one vehicle concept. The presentation will include performance (exit and entry), design, and structural/dynamic requirements that effect the thermal protection system (TPS) and structural subsystem definition. Advanced technology materials, their utilization and subsequent vehicle system benefits will also be discussed. A brief notation of critical technology problems involved with the satisfactory development of the STS will be provided.

AIAA-2 -- NASA SPACE SHUTTLE MATERIALS TECHNOLOGY REVIEW
G. E. Cataldo, NASA-Marshall Space Flight Center

Vehicle studies will be briefly reviewed to identify the major areas of materials influence. The particular materials technology which is discussed pertains to materials compatibility with the space shuttle environment. Topical matter includes: cryogenic insulation, high temperature insulation and also the development of special materials and the reuse capabilities of materials during expected lifetime of the vehicle.

AIAA-3 -- THERMOSTRUCTURAL DESIGN OPTIONS USING CONTEMPORARY MATERIALS
J. Prunty, General Dynamics/Convair

The consideration of material selections for the primary structure and thermal protection system of the space shuttle vehicles, is influenced by the need to consider several optional thermostructural concepts. Trade off possibilities in materials and configuration details must be considered within each concept and also, the application of different concepts to different areas of the vehicles. The background data will be based on current space-shuttle studies and will consist of reviews of vehicle configurations, environments, thermostructural design criteria, and a description of the more significant competing candidate concepts for both the primary structure and thermal protection system.

AIAA-4 -- SPACE SHUTTLE SYSTEM MATERIALS RATIONALE
M. W. Hunter and P. P. Plank, Lockheed Missile and Space Corporation

The evolution of the system will be reviewed with discussions on booster and orbiter growth factors, lift off versus structural weight, and the importance of the structural weight fraction. Base line materials and structures will be reviewed to identify the advantages of advanced structural materials, to compare thermal protection concepts, and to describe the influence of type and shape of tanks and insulation on the efficiency of fuel packaging.

AIAA-5 -- THERMAL/STRUCTURAL MATERIALS APPLICATION FOR A REUSABLE SPACE TRANSPORTATION SYSTEM

J. W. McCown, A. M. Norton and J. W. Barter, Martin Marietta Corporation

Candidate thermal protection and structural designs for use on the space shuttle will be identified. These designs will be evaluated with respect to technological risk and recurring cost considerations. Particular emphasis will be placed on material selection and an assessment of the currently available materials for both cryogenic and high temperature utilization.

AIAA-6 — REUSABLE SPACE TRANSPORTATION SYSTEM AND THE IMPLICATION OF MATERIALS ON ITS DEVELOPMENT, OPERATION AND PERFORMANCE

F. E. Bradley, McDonnell Douglas Astronautics Co.

A typical system will be described to introduce a discussion of what materials approaches are used now as a function of use area and environment. A correlation of the materials types versus the time when they become available will be made including a discussion of the impact. The materials selection process will be presented along with a review of the improvements desired.

AIAA-7 — THE IMPACT OF MATERIALS CONSIDERATION ON THE DESIGN OF A MEDIUM L/D REUSABLE SPACE TRANSPORTATION SYSTEM

R. W. Bohlen and L. K. Crockett, North American Rockwell Corporation

The design utilized in arriving at a space transportation system to satisfy the Air Force reusability, payload, and range requirements for a 2-stage system is composed of a manned booster (first stage) and manned orbiter (second stage). Thrusting of the system is sequential and no cross-feed of propellant is permitted. Emphasis is placed on materials consideration in the selection of critical vehicle parameters such as plan form loading and leading edge radii. The transaction of these parameters with overall system requirements greatly influences the selection of the remaining vehicle shape and entry flight mode characteristics.

AOA SPECIAL PROGRAM

Tuesday 1430-1800, 19 May 1970

Chairman: Brig. Gen. Carl W. Andrews, USAF (Ret.)
Chairman, AOA Materials Division

Co-Chairman: Mr. Alvin Shames, Columbus Division/
North American Rockwell Corporation

THE CHALLENGE OF MORE EFFECTIVE MATERIAL UTILIZATION

To gain an appreciation of the Challenge of "How Do We Get To The Eighties?" involves, among other things, perceptive analysis of current programs in Basic Research, the Product and Contribution of Universities, the Transition of Research Engineering, and the Transition of Engineering to Production. The quality and effectiveness (cost or performance) of aerospace weapon systems which are expected to emerge in the 1980's could well be paced and even controlled by how effectively we conceive and apply a system of development, management, utilization, and application of new materials now available but not fully exploited or new promising materials now emerging.

Unless the product design/material loop is closed, material utilization will be inefficient, and development of new materials becomes more of academic than practical value. This issue will be candidly confronted by a panel representing (a) customer, (b) management, (c) materials, and (d) product design. It is hoped that this seminar will help open up communication between salient and vital participants and contribute to open-minded decision-making on materials in meeting the Challenge of the Eighties.

AGENDA

INTRODUCTIONS
Brig. Gen. C. W. Andrews, USAF (Ret.)
Manager, Special Projects Activity,
Republic Steel Corporation

KEYNOTE: THE CHALLENGE AND RAMIFICATIONS
N. E. Promisel, Exec. Dir., National
Materials Advisory Board, National
Academy of Sciences

(Abstract not available)

CUSTOMER VIEWS
Maj. Gen. E. F. O'Connor, USAF
Vice Commander, Aeronautical
Systems Division, AFSC

(Abstract not available)

MANAGEMENT VIEWS
M. L. Ramey, Vice President
Engineering Technology, McDonnell
Aircraft Company

(Abstract not available)

DESIGNERS VIEWS
W. T. Shuler, Chief Structural
Engineer, Lockheed-Georgia Co.

(Abstract not available)

MATERIALS VIEWS
Morton Kushner, Production Mgr. for
Staff Technology, The Boeing Co.

(Abstract not available)

PANEL DISCUSSION AND AUDIENCE PARTICIPATION

Moderator: Alvin Shames

Members: Nathan E. Promisel
Gen. Edmund F. O'Connor
M. L. Ramey
W. T. Shuler
Morton Kushner