# Technology Advances in Engineering and their Impact on Detection, Diagnosis and Prognosis Methods

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## Proceedings of the 36th Meeting of the Mechanical Failures Prevention Group, LaPosada Hotel, Scottsdale, Arizona, December 6-10, 1982

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The papers in this book focus on the prevention of failure of mechanical systems, structures, and materials through detection, diagnosis, and prognosis techniques.

Recent advances in engineering have permitted the development of new techniques and the refinement of old ones.

New developments addressed at the symposium at which these papers were presented are in the areas of sensors and instrumentation, new technologies and techniques, applications of data processing, machinery health diagnostics, and prognosis failure. The volume will be of interest to practicing mechanical and metallurgical engineers and materials scientists.

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# Preface

The Mechanical Failures Prevention Group (MFPG) was organized in 1967 to stimulate cooperation among various segments of the engineering and scientific communities in an effort to reduce the incidence of mechanical failures and to develop methods to predict mechanical failures. The MFPG is an interdisciplinary group with a strong application orientation. The membership includes professional personnel representing a wide variety of scientific and engineering disciplines. Individual members are associated with government agencies, industry, universities and research institutes. The MFPG also cooperates with appropriate committees or units of professional societies.

Typically, there are two MFPG symposia per year. The technical program for these symposia rotates among the four MFPG technical committees: 1) Mechanisms of Failure, 2) Design, 3) Detection, Diagnosis and Prognosis, and 4) Materials Durability Evaluation.

The 36th Meeting of the Mechanical Failures Prevention Group was held December 6-10, 1982, at LaPosada Hotel in Scottsdale, Arizona. The program, focusing on Technology Advances and Their Impact on Detection, Diagnosis and Prognosis Methods, was organized by the MFPG Detection, Diagnosis and Prognosis Committee under the chairmanship of G. Allan Whittaker of Honeywell, Incorporated, with Gerald J. Philips of the David Taylor Naval Ship Research and Development Center acting as Technical Program Chairman. In addition to the formal program on December 7-9, there were two half-days of "living papers" on December 6 and 10 consisting of visits to local industry and government facilities. Appreciation is expressed to the chairmen, the committee, the session chairmen, and especially the contributors for an excellent program. The session chairmen, whose names are listed on the session title pages in these proceedings, are due special thanks for reviewing the papers in their respective sessions.

Financial support from the National Bureau of Standards, the Office of Naval Research and the Naval Air Systems Command is gratefully acknowledged.

Appreciation is expressed to many other individuals and organizations that contributed to various aspects of the symposium including:

Living Papers:
- Arthur Schuh, AT&T Long Lines
- Paul Olivier and Milton Parker, Garrett Corporation
- John Martin, Road Machinery Company
- David Scheer, Analog Precision, Inc.
- Henry Mercik, Hamilton Test Systems
- Joseph Flood and Oliver Edwards, Motorola
- Phillip Webb and Walter Nymann, Goodyear Aerospace Corporation
- Lt. Col. Peter Cook, Williams Air Force Base
- Lt. Col. James Reinhart, Luke Air Force Base

Hotel and Meeting Arrangements:
- Gerald Ashland, Phoenix Convention Bureau
- Staff of the Guest Services Center, Process Management Systems Division, Honeywell, Inc.
- Sara Torrence, National Bureau of Standards
- Maureen Kelly, LaPosada Hotel

Meeting Brochure and Guest Program:
Carole Whittaker

Exhibits:
John Anderson, Scientific Atlanta

Publicity:
Robert Whittier, Endevco Corporation

Finances:
Kathy Stang, National Bureau of Standards

T. Robert Shives
Executive Secretary, MFPG
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KEYNOTE PAPER

# AN INTERDISCIPLINARY APPROACH TO LIFE PREDICTION THROUGH DETECTION, DIAGNOSIS AND PROGNOSIS

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Abstract: There remains a pressing need for more effective means to predict the service life of a part, component, or system. Given such a capability, mechanical failures during use can be reduced by implementing more realistic maintenance schedules. This evolves to a "replacement for cause" philosophy - or to borrow the phrase used by air carriers, "reliability centered maintenance".

To achieve such a capability we need a major data base on "remaining life" of mechanical components. Ideally the data base would be based on valid, statistical estimates of life, beginning with the first cycle, or first instant of operation, coupled with nondestructively-sensed estimates of remaining life.

One way of addressing this complex issue is to legislate a requirement for structural integrity. That is, to require a fracture control plan, much as the Air Force has done for airframes through the implementation of MIL STD 1530. While this is an expensive proposition, in many critical applications it is the most economic solution, when the cost of failure is considered.

The Army is taking a number of steps to reduce mechanical failures, or at least to be better able to predict them. The US Army Materials and Mechanics Research Center (AMMRC) has a number of ongoing and planned programs which involve the detection, diagnosis and prognosis of mechanical failure.

Key words: Brittle fracture; Nondestructive evaluation, Quality assurance; Reliability; Structural integrity.

Introduction: AMMRC's mission includes responsibility as the US Army Materiel Development and Readiness Command (DARCOM) lead laboratory in structural materials, solid mechanics and materials testing technologies. AMMRC does not have mission responsibility for specific systems development, but rather for command-wide technology base support in the above areas, and direct support to development commands, readiness commands and project managers as needed. In addition to directing and conducting research and development programs in the materials amd mechanics technology base, AMMRC manages, for DARCOM, a procurement appropriation program in materials testing technology, and has responsibility for more than half of the DoD standardization documents for materials and materials processing. In effect, AMMRC is involved with structural integrity issues from virtually all vantages, except for direct systems development.

The theme of this meeting is detection, diagnosis and prognosis; the theme that we want to emphasize is structural integrity, which relies on all three segments of the meetings' theme, but probably most heavily on prognosis. We shall describe a recently established program that addresses this issue, and then present plans we have for how we will emphasize structural integrity.

Structural Integrity: Within this context we simply equate structural integrity to the assurance that all load carrying components will perform their functions satisfactorily in the environments in which they were intended to operate. While it is easy to say, it is not so easy to implement! Structural integrity is often taken for granted, until a problem occurs, then the solution is less than optimum, and generally achieved at a high cost. There are, we feel, a number of reasons for this dilemma.

In many systems development projects, a glamorous technology drives the program to the exclusion of structural integrity. We also tend to expect greater and greater performance from systems, often leading to the use of high strength materials, which are failure-prone if not properly used. More often than not it is some combination of these reasons that we find are responsible for the lack of adequate structural integrity measures.

While not labeled as such the bulk of AMMRC's programs are directed toward structural integrity in some way or other. Recognizing the need to pull these various efforts into a cohesive multi-disciplinary package, we recently chartered a task group to apply the various technologies to a particular system in a logical, systematic way.

M60 Task Group: The M60 is the Army's principal tank in the field, and will remain so for several years until the M1 is produced in sufficient quantities to replace it. To provide the Army with a full and reliable tank complement in the interim, a major M60 rebuild program is being carried out. An interdisciplinary group was established, and assigned the task of developing and applying structural integrity technology for enhanced reliability of the M60 tank.

The M60 was chosen to serve as the model for this effort, not only because of its importance to our defense posture, but also because the program manager and his staff were very receptive to the idea. The task group is comprised of mechanics specialists, NDE engineers, a metallurgist, an organic materials scientist, a test engineer and a statistical specialist.

The effort is being supported at a level of about 2 man-years during Fiscal Year 82. Assuming satisfactory progress we anticipate continuing support. To emphasize the inter-programmatic nature of the work, it is being supported by R&D funds (exploratory development-materials), procurement appropriation funds (materials testing technology), and operation and maintenance funds (specifications and standards). The group maintains close liaison with the project manager's staff to assure that the avenues for transferring the technology are well established.

The subsystem that generally exhibits the highest failure rates is the track and suspension system. Accordingly the group has concentrated its efforts on that system. The task group obtained and assessed design and failure data from the program office, and test data from the manufacturers; they visited the manufacturing facilities, the overhaul depot and the field test sites. A number of candidate components have been identified, which we believe would benefit greatly by simply applying available technology in a systematic way. These include torsion bars, volute spring and track pins.

To illustrate the comprehensiveness of the group's approach, we shall discuss the torsion bar effort.[1] The torsion bars are designed to carry only torsional loads. However it appears that the actual loads applied have other than torsional components. A torsion bar, which failed in the field, was obtained.

The following examinations/characterization/analyses were carried out:

1. Magnetic flux examinations of both parts of the failed bar to determine the existence of any other cracks.

2. Chemical analysis to assess conformance with specifications.

3. Standard Charpy tests to obtain transition temperature.

4. Pre-cracked Charpy tests to obtain fracture toughness.

5. Tension tests.

6. Short-rod fracture tests to validate fracture toughness.

7. Rockwell hardness traverse.

8. Fractographic examination of fracture surfaces, using light microscopy and scanning electron microscopy to locate failure origins and extent of fatigue crack growth.

9. Finite element analysis of contact stresses.

10. Torsional shear stress finite element analyses at splines and cross section changes.

11. Statistical analyses of torsion bar fatigue test data to:

    a. Assess effect of heat to heat variability.

    b. "A" and "B" design allowable variability.

Review of the testing and analytical results will dictate the need, if any, for additional data, and a guide for implementing a life forecasting methodology[2] for M60 torsion bars. The specific approach will be a function of the level of confidence we achieve from the data obtained, the analyses conducted and the reliability of the NDE methods. While this is still an ongoing study, we are quite encouraged by the progress to date; we fully anticipate to see a well documented methodology, which can be adapted to other critical components, not only for ground vehicle applications, but others as well.

New Directions: As we suggested, we fully expect to see a well founded, logical model for enhancing structural integrity through a sound life forecasting methodology resulting from the efforts of the M60 task ground. In addition to continuing that work, we will be implementing new R&D initiatives in Fiscal Years 83 and 84 supporting the structural integrity and life forecasting themes.

In FY83, we are establishing a new thrust in producibility and reliability; both have direct impact on the structural integrity issue, the latter on life forecasting as well. Beginning in FY84, a new R&D line on Advanced Development in Support of Specifications and Standardization will be initiated. Both of these programs will be heavily oriented toward involvement of the DARCOM development community and industry.

Producibility and Reliability: The reliability portion of this new program is founded on a recent testing needs survey of DARCOM's development community, conducted by AMMRC in 1981 at the request of DARCOM. The intent of the survey was to identify not only those needs which required R&D efforts, but also those for which R&D had been done, but the technology not yet implemented. In the former category some 132 requirements were identified and validated as requiring R&D for solutions. Since the existing R&D line for exploratory development of materials has been adequate for only about a 2 to 3 man-year per year level of effort for work in testing technology, a new line was established, beginning in FY83. We anticipate, initially that this will support a level of effort of about 15 man-years per year, in-house DARCOM as well as on contract.

The tasks to be addressed by this line are:

1. Structural Integrity

2. Ultrasmall Flaw Detection

3. Sensor Technology

4. Advanced Composites

5. Remaining Life Measurement

6. Environmental Simulation

As can be seen, most of these are directed to developing and exploiting technologies aimed at reducing mechanical failures in components.

Advanced Development in Support of Specifications and Standardization: One of the shortfalls we have experienced for a long time has been the lack of adequate support for developing statistically reliable data bases of materials properties for incorporation in specifications and other standardization documents. R&D funding for these activities has been almost non-existent, and the appropriation for developing and updating such documents specifically prohibits development of data bases.

In recognition of this serious deficiency, a new R&D line has been established, and is scheduled for FY84 initiation. Initial funding will provide support for a level of effort of approximately 25 to 30 man-years per year. We anticipate that a major portion of this effort will be contractual. The tasks to be addressed will include data base development on metals as well as on organic and metal matrix composites.

Summary: The Army has an almost endless list of weapons and combat support systems it must develop and acquire. The development and acquisition costs run the gamat from extremely low to extremely high for acquisition of each unit. More and more attention is being given life cycle costs, rather than simply acquisition costs. This attention focuses consideration of the costs of mechanical failure during service, and the attendant issues of maintenance policy. On the one hand, a service failure at a crucial time can result in exorbitant costs, including those of loss of life. On the other, the logistics costs of replacing parts or components with considerable additional life can represent an unacceptable burden.

The capability of being able to reliably predict life can go a long way towards resolving both issues. As a model application of life predicting technology, AMMRC has chartered an interdisciplinary task group to analyze critical components on the M60 tank. New R&D lines are being established for FY83 and FY84 initiation. The former will deal specifically with issues pertaining to structural integrity and remaining life measurement, the latter with developing statistically valid material properties data on which structural integrity and life prediction analyses will be based.

References:

1. R. S. Barsoum, "Application of Failure Analysis for Enhanced Reliability of M60 Tanks - Report of the M60 Task Group," AMMRC MS 5-82.

2. R. T. Lund, F. R. Tuler and J. R. Elliot, "Life Forecasting as a Logistic Technique."