Journal Papers on Reliability and Maintainability

THIS special section on reliability and maintainability (R&M) was prepared to illustrate the kind of material that is urgently needed by the increasing numbers of our aircraft development community who must deal daily with R&M. There has been a recent dramatic emphasis on the early inclusion of R&M in the development process, beginning with the design phases. This transcends all phases of aircraft application, both civil and military.

Journal papers on this subject have been very limited, yet such papers can develop the tools and "parametrics" for R&M. They can provide the substance for design and planning decisions. In response to all this, I collected a set of papers presented at the 1986 Aircraft Design Conference and invited a specific paper on avionics reliability through environmental control. Finally, I asked the Special Assistant for Reliability and Maintainability, Headquarters USAF, Brigadier General Goodell, to address the issue of R&M from an Air Force perspective. His perspective, including brief remarks on the papers that follow, leads off this special section.

Look them over. Then, if you're inspired to develop some aircraft R&M ideas of your own, send them to this Journal for publication.

Thomas M. Weeks
Editor-in-Chief

R&M by Design: A Blueprint for Success

Introduction

A New Look: R&M as Defined by the Customer

TODAY, the U.S. Air Force possesses a very capable and combat-ready force. This national resource forms a crucial element supporting our country's goal to maintain peace. However, at this time, we find ourselves grappling with both tightening budgets and constrained personnel resources while facing a qualitatively and quantitatively increasing threat. Unfortunately, our present response to this threat requires using aerospace systems that *by design* have compromised the aerospace characteristic of flexibility. Today, the F-15 and F-16 represent the premier fighting machines of the air, but dependencies on extensive support equipment such as the Avionics Intermediate Shop (AIS) render these systems potentially too vulnerable. Fortunately, solutions to this and other related problems are at hand. Today, as designers and manufacturers, we must view the system as encompassing the people, materials, facilities, and information that support the fighting platform.

In the past, the Air Force did not clearly state its customer requirement to industry: *perform effectively over time.* The R&M 2000 initiative, enacted by the Secretary and Chief of Staff of the Air Force in February 1985, rectifies this deficiency by establishing R&M as an essential element of our acquisition process. This broadened process is dedicated to procuring systems that operate long and well while being easily and efficiently maintained by people trained to reasonable skill levels using common tools. Engineers must now design to five specific goals that respond to the realities of today and tomorrow. In order of priority, the R&M 2000 goals are:

1) Increase war-fighting capability.
2) Increase survivability of the combat support structure.
3) Decrease mobility requirements per unit.
4) Decrease manpower requirements per unit of output.
5) Decrease costs.

These are goals that reflect the needs of our operational commanders, the ultimate customers of aerospace weapon systems. Attainment of these goals requires the concerted and integrated efforts of all engineering design and manufacturing disciplines. R&M considerations can no longer be left in an after-the-fact manner to a select few specialized practitioners. All engineers now bear responsibility for reaching the operational goals of R&M 2000.

Adjusting to Harsh Realities

Increased Threat

An increasingly hostile environment threatens the main operating bases in the principal trouble spots of the world. Soviet weapon systems have shown dramatic improvements benefiting from the flow of Western technology and a defense establishment that absorbs more than ten times the number of scientists and engineers, on an annual basis, than the U.S. defense sector. Qualitative improvements, associated with Soviet tactical fighter bombers and theater surface-to-surface missiles, threaten the Air Force's main operating bases. Current USAF combat aircraft depend heavily on complex support infrastructures of intermediate maintenance facilities found at these bases and the highly trained maintenance specialists required for their operation. Losing the complex support infrastructure can impact combat potential just as seriously as losing the fighting machines.

Too Much Tether

In the past, aerospace forces have always been able to exploit the characteristics of speed, range, and flexibility to a degree far greater than any surface force. Today, flexibility of aerospace power has been constrained by being tethered to a complex support infrastructure coupled with low reliability in the components that make up our systems. For example, one-third of all enlisted personnel, more than 150,000 men and women in 140 different skilled specialties, are required to maintain our systems. Highly reliable and maintainable weapon systems offer the means for returning flexibility to aerospace power.

Reduced Funding

The Air Force is now operating in a more resource-constrained environment in an era of ever-advancing technological change. For the second year in a row, the Air Force will experience negative growth, totaling nearly 15% from a fiscal year 1985 baseline. As General John L. Piotrowski, former Vice Chief of Staff of the Air Force, stated in his keynote address to the December 1986 Second NASA Symposium on Quality and Productivity, "We've gone well beyond fat and muscle and are cutting into bone." The financial and human resources needed to "brute-force" more combat capability from current systems simply are not available, and the high costs of failure in a given system cannot be tolerated, especially when human lives are at stake.

Historical Perspective

Past Development and Acquisition Approaches

In the 1960s, our acquisition strategies were oriented principally toward operational performance and schedule, with an academic interest in statistical reliability theory. In the 1970s, cost became coequal with operational performance and schedule in the acquisition process. Tradeoffs involved cost-effectiveness parameters. R&M, through probabilistic engineering design techniques, along with well-documented approaches such as fault tree analysis, growth curves, and failure mode effects and criticality analysis, was being employed. However such approaches tended to be too late in the design process and subservient to other requirements. In the mid 1980s, R&M has been made coequal with cost, schedule, and operational performance. Specifically, General Lawrence A. Skantze, Commander of the Air Force System Command, has made reliability, maintainability, and producibility the first listed items in the highest-rated area. This fundamental change in acquisition policy places the proper emphasis on R&M during contractor selection. The policy was carefully followed in the recent Advanced Tactical Fighter (ATF) and the SRAM II source selection process. Thus, in order to compete effectively, the contractor must ensure that every engineer involved in system design be aware of the design's impact on R&M as ultimately measured by the five goals of R&M 2000. The bottom line for the operator is: All performance parameters are zero if a system is broken and not easily repaired due to basic design flaws.

Recent Developments

Recent advances in electronics, structures, manufacturing, and computer aids have, and will increasingly have, profound effects on the reliability, maintainability, and producibility characteristics of weapon systems.

The Very High Speed Integrated Circuit (VHSIC) program dramatically illustrates the ability of technological breakthroughs to leapfrog the R&M bottlenecks of the past. For example, in the 1970s, we developed weapon systems dependent on their computer and signal processor "brains" to accomplish their mission. In general, we had to contend with mean time between failures (MTBF's) on the order of hundreds of hours. To meet increased requirements, the number of logic circuit interconnects also jumped.

Today, the Integrated Communications Navigation Identification Avionics (ICNIA), a VHSIC technology program, has the potential to replace eleven line replaceable units (LRU) having a collective MTBF of less than 50 h with line replaceable modules (LRM) having a mean time between mission critical failure of 10,000 h. In addition, fault isolation capabilities will allow fault detection of 98% with isolation to one LRM of greater than 95%. In the near term, the APG-68 VHSIC Programmable Signal Processor (PSP) for the F-16 will have a MTBF of 2000 vs 200 h for the APG-68 non-VHSIC PSP. Power requirements drop from 3000 to 800 W with a commensurate drop in weight from 108 to 72 lb.

There are many such examples. For the *system designer*, the impact of R&M advances in electronics will be profound. The engineer will reap the rewards of less weight and volume requirements, elimination of external access doors to electronics bays, elimination of the AIS, and others. However, the full advantages to be enjoyed due to VHSIC technology require a fully integrated approach to design, beginning with the concept phase of the development process.

I have mentioned several times the need for an integrated approach to developing a system. "Designed in R&M" can be negated without proper attention to the *manufacturing process*. Once a system design is fixed, the upper bound for system reliability is fixed. The manufacturing process must be configured to provide the highest-quality or "defect-free" products for the customer. Failure to do so can only degrade the system's final reliability to levels that do not support the

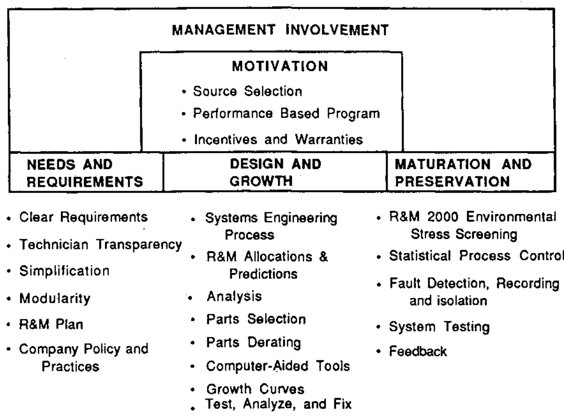

Fig. 1 Structure of R&M 2000 process.

five goals of the R&M 2000 initiative. Advances in automated manufacturing technology hold the key for attaining enormous advances in both quality and productivity. Efforts such as the National Bureau of Standards prototype factory or Automated Manufacturing Research Facility will eventually allow sensors to monitor quality inside the press or furnace. Flaw identification will trigger an expert computer system to analyze the signal and use a mathematical model of the manufacturing process to eliminate the flaw. Such approaches coupled with the increased use of multidisciplinary teams comprising the design engineer, manufacturing engineer, logistics support engineer, human factor engineer, and others will generate quality and productivity synergisms benefiting both the Air Force customer and the corporation. The secret of this synergism rests with the computer and programs such as Northrup's Integrated Management Planning and Control for Assembly (IMPCA) effort. IMPCA puts manufacturing engineering, liaison, industrial engineering, quality assurance, and manufacturing all on the same data base. In the design phase, such fully computerized data bases will allow all parties involved in design to converge iteratively on designs with the required R&M attributes. Lastly, *visits by the engineer* to both the shop floor and the operational environment will provide a better understanding of how their design approaches impact product quality and operational utility.

R&M by Design: A Blueprint for Success

Principles and Building Blocks

In my interactions with both industry and Department of Defense (DOD) organizations, I've noted certain recurring practices leading to systems that break infrequently and are easy to fix. We have depicted our view of the overall structure leading to enhanced weapon system R&M through what we have termed the R&M 2000 process. It includes the goals we have discussed: 5 R&M principles and 22 building blocks. Please note that our structure, illustrated in Fig. 1, flows from, and is driven by, the principle of management involvement.

So that management can appreciate the emphasis the Air Force places on R&M, we employ the motivation principle, consisting of three building blocks: source selection, performance-based programs, and incentives and warranties. Then, along the timeline of system development and employment, we've identified the principles of: need and requirements, design and growth, and maturation and preservation. It is within these principles that engineers exercise their discipline to yield system characteristics that will satisfy the five R&M 2000 goals. Based on evidence from successful programs, we are absolutely convinced that the road to success depends on R&M through engineering design. The manager, developer, and engineer must: 1) ensure R&M technology advances along with operational performance technology, 2) relate those advances to the user's needs, 3) ensure that R&M enters the design, and 4) maintain it during manufacturing.

Parameter Translation

The Air Force operating commands, such as Tactical Air Command (TAC), identify their system requirements based on several factors, including a changing threat and technological advances. The Statement of Need documents these requirements and forms the basis for ultimately determining if the final engineering design will satisfy R&M 2000 goals. For example, under goal one, increased war-fighting capability, fighter aircraft must be designed to fly more consecutive missions in combat without requiring maintenance and, when they break, to be able to be fixed quickly. This requirement has been integrated into the ATF, which must be designed to operate at a sustained sortie rate twice that of the F-15 Eagle with half the maintenance. Such a requirement drives R&M parameters such as mean time between critical failure, manpower per aircraft, and availability. These numerical parameters then need to be *translated into engineering design terms* meaningful to the design engineer.

The article by H. D. Hall entitled "Role of Supportability Engineering in the Design Process" outlines Lockheed-Georgia's approach to parameter translation. The paper evaluates increased DOD emphasis on supportability from the viewpoint of meeting mission requirements over time. Mr. Hall's emphasis that design for R&M requires the *concurrent* integrated efforts of all involved in design and, I might add, manufacture. He details the need for innovative approaches that could include technological "leapfrogging," inputs from the user, CAD/CAE, manufacturing automation, process control, and common sense. These engineering design approaches, used to satisfy the translated operational requirements, will encounter coequal tradeoffs with cost, schedule, and operational performance to arrive at the final system configuration. The article by J. Buche and I. Cohen entitled "Translating Supportability Requirements into Design Reality" expands on these tradeoff considerations. As these authors point out, design should be focused on minimizing the need for logistics resources. In fact, eliminating intermediate-level maintenance has become a primary goal of the R&M 2000 initiative. Considerable research by the aircraft community will be required to arrive at optimal designs within this new environment.

Tools will be required to assess the operational value of various configurations as the iterative design process proceeds. D. C. Dietz discusses such an approach in the article "Translating Aircraft Reliability and Maintainability into Measures of Operational Effectiveness." This article formulates a generalized repair time cumulative distribution function (CDF), subject to certain assumptions and manpower constraints. The developed model places an aircraft in one of four states: sortie, turnaround, repair, or waiting for launch. Inputting subsystem repair time CDF's, the design engineering team can quantitatively analyze operational implications of various designs during the early design phase. Dietz' paper highlights a need that is here today. For aerospace corporations to compete, they must have the ability to determine quickly if their design is converging to one that will satisfy the customer's five R&M 2000 goals. An analytical tool being developed by the Air Force is the R&M 2000 SCOPE model. This model evaluates, with respect to a base case, the impact of improved R&M on combat capability.

As engineers work with their translated engineering design terms, they will require new analysis tools to arrive at subsystem configurations that will lead to the eventual satisfaction of the operational requirements. CAD/CAE approaches hold great promise for rapidly evaluating the R&M potential of various designs. Before the first lead is soldered or metal bent, potential R&M degrading configurations can be identified and corrected. This is test analyze and fix (TAAF) on the computer with cycle times in minutes or hours vs weeks or months. The article by DiRe, Franks, and Choi, "Automated Thermal and Reliability Analysis of Avionics Designs," details an automated process for enhanced reliability of printed circuit boards being developed and implemented at General Dynamics Convair/Space Systems Divisions. To quote the authors, "Since the entire process is interactive, a thermally safe design can be reached quickly and efficiently, reducing the need for costly design changes (caused by insufficient thermal control) after fabrication has begun." The process integrates the interactive inputs of the electrical, mechanical, and thermal engineer to provide various schematic models and isotherm plots. The results are input to a companion reliability program to determine failure rates and final board reliability.

Once the circuit boards have been designed, an environmental control system (ECS) must maintain conditions that maximize the reliability potential of the avionics. In particular, the highest reliability will occur by lowering junction temperatures. Present open-loop ECSs do not provide precise temperature control at different locations within the aircraft under varying flight profiles. The article by Burkhard and Kurylowich entitled "New Technological Considerations That Improve Avionic Reliability" describes a closed-loop microprocessor-controlled ECS, which dynamically responds to changing flight conditions. The system would also provide cleaner air, be modular, possess gradual degradation, increase aircraft range, and incorporate technician transparent fault isolation. This system integration approach captures several of the main thrusts of the R&M 2000 initiative. By dynamically controlling the environment, we will realize more closely the reliability potential of our advanced avionics.

I might mention that data bases that provide R&M information, to include survivability information such as that discussed by J. M. Vice in the article "Survivability/Vulnerability Infomation Analysis Center (SURVIAC)—A Tool for the Aircraft Survivability Community" must be compiled and designed for interfacing with the engineer's computer-aided tools. The general area of computer-aided tools, along with automated manufacturing, holds great promise for accelerating the design process, increasing productivity, enhancing quality, reducing costs, and attaining our operational goals.

Final Comments

The R&M 2000 initiative has redefined the conventional view of reliability and maintainability. Challenges imposed by a quantitatively and qualitatively increasing threat, compounded by a constrained personnel pool, mandate breakthroughs. No longer can we overwhelm a potential enemy, as we did with actual enemies, in World War II, with numerical superiority provided by a world-dominant industrial base. Today's realities force us to adopt or invent innovative approaches that provide force multipliers and restore flexibility to our systems. By making R&M coequal with cost, schedule, and operational performance in the source selection process, profound changes have and are taking place in designing aerospace systems. The recent ATF and SRAM II source selections give testimony to these changes. Now the design community, aided by new computer capabilities, *can easily* consider supportability requirements at the beginning. As General Larry D. Welch, Chief of Staff of the Air Force, recently stated:

> The rationale is compelling: broken equipment and unusable systems don't deter war or prevail on the battlefield. R&M translates hardware mobility, decreased manpower and lower costs. All that adds up to more warfighting capability and, hence, more deterrence.

The challenge is clear. Engineering and academic communities must join this crucial inititative to build supportable Air Force combat capability. Indeed, our future depends on this blueprint for success.

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