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Abstract — This paper discusses the impact of the R&M
2000 initiative and its realizable potential for cutting the logistics
tether which constrains the flexible employment of aerospace
weapon systems. Four trends are identified which point to the
necessity for changing the approach to designing systems for the
modern battlefield. Within this context the paper outlines the
R&M philosophy, followed by concrete examples which reinforce
the thesis that industry can both develop and implement the
technology necessary to provide a 21st century combat capability.
The myth that quality costs money is discussed with examples.
The article concludes with a discussion of the enormous support
infrastructure required for aircraft systems alone. The discussion
points to the enormous reduction in men, materials, and facilities
to be gained by smart engineering attention to reliability, main-
tainability, and quality within a system framework.

1. INTRODUCTION

Today the United States Air Force possesses a capable
war fighting machine because aeronautical visionaries of
the past such as Mitchell, Spaatz, and Eaker looked to
their tomorrows and shaped our todays. The Air Force,
now, must extend its thinking into the future as it prepares
to stride into the 21st century.

This article discusses the compelling reasons why,
from a logistician’s perspective, design engineers must
make reliability and maintainability an integral part of the
system design process. These reasons include evolution of
technology, geopolitical realities, and the previous failure
to include logistics realities into the design process. In
response to these realities, the Air Force has instituted the
R&M 2000 initiative. This initiative has broad and far
reaching implications in both the way the Air Force does
business in-house and, most importantly, what it as a
customer demands from industry. Industry has
demonstrated its capacity to respond to Air Force re-
quirements and the ability to reach beyond minimum re-
quirements, when given incentive to do so. Several ex-
amples illustrate what industry has done and where it is
headed.

Certain compelling technological and geopolitical
realities require immediate and long term attention.
Specifically, technology has compressed both time and
distance while increasing the lethality and accuracy of con-
tventional weapons. Geopolitically, the super powers search
for ways to reduce their nuclear arsenals, while maintaining
a balance of power through increased reliance on conven-
tional forces. The implications of these realities on conven-
tional war-fighting capabilities must be carefully assessed.

Technological compression of time and distance
marks forward deployed air bases as reachable targets,
placing them at risk. The acceleration of conventional
weapon technology allows an enemy to attack air bases
closer, with greater lethality and accuracy. A reduction in
nuclear armament would cause nations to rely more heav-
ily on conventional forces.

Such a stronger reliance on conventional aerospace
forces mandates that the aerospace characteristics of speed,
range, and flexibility be increasingly exploited and en-
hanced. The first two are moving ahead smartly. But what
about the third and perhaps the most unique character-
istic — flexibility? Where does the Air Force stand today
given its present force structure?

Changes in the weapons of warfare over two millen-
ia, from the javelin to the missile, have increased weapon
lethality by a factor of 2000. To counter this advance, ar-
 mies have dispersed. One measure gives a 4000-fold in-
crease in dispersal, when comparing soldiers in ancient
times to troops in the 1973 October Mid-East war [1].

Air power of the 1980s can launch weapons of incred-
ible lethality. Do aerospace forces possess the capability to
disperse in response? Can they move routinely within a
theater to survive and fight? Or have they lost their flexibil-
ty-through-dispersal by being tethered to
vulnerable combat support bases?

Unfortunately the system design approaches of the
past lead to the conclusion that systems and associated
combat support structures cannot adequately sustain
dispersed aerospace forces. The response to this predic-
ament could very well determine viability of aerospace
forces now and into the future.

The US Air Force has recognized the problem and is
moving to meet the challenge. It has established a new vi-
sion; a vision which goes beyond the weapon system as be-
ing solely an aerospace vehicle. The vision recognizes that
the aerospace platform forms but one highly visible part of
a system encompassing the people, materials, facilities, and
information which support the fighting platform. There are, in particular, four trends in the Air Force that
require rethinking of how to prepare for combat.

2. THE FOUR TRENDS

1. An increasingly more hostile environment threatens
the operating bases in the trouble spots of the world.
Modern combat aircraft depend heavily upon complex support infrastructures of intermediate maintenance facilities and the highly trained maintenance specialists required for facilities operation. These complex support infrastructures are at risk, not only during conflict but also during peacetime from terrorist activities.

2. 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 increasing dependence upon a complex support infrastructure coupled with poor quality in the components comprising these systems. For example, one third of all enlisted personnel (over 150,000 men and women in 140 different skilled specialties) are required to support and maintain our aircraft systems. Flexibility is further eroded when a potential enemy fields simple, rugged, less vulnerable, less technical, more primitive, and yet technically sound weapons. Highly reliable weapon systems offer the means for returning flexibility to aerospace power.

3. The Air Force is 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 a negative growth, totaling nearly 15% from a 1985 fiscal year baseline. As General John L. Piotrowski, Vice Chief of Staff of the Air Force, stated in his keynote address to the 1986 Second NASA Symposium on Quality and Productivity, "We've gone well beyond fat and muscle and are cutting into bone." [2] 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 system cannot easily be tolerated, especially when human lives are at stake.

4. A dynamic industry, in concert with existing and future technologies, stands ready to make quantum leaps forward to improve the reliability and maintainability of both current and future systems — particularly avionic systems — if only those quantum leaps are demanded by the customer. The Air Force has noted and supports wholeheartedly a most significant event occurring within industry. There is a resurgence in the quality ethic. Corporations are recognizing that they need quality products to be fully competitive in the world marketplace. As a corollary the permeation of the quality ethic throughout the fiber of industry will elevate the technology and managerial base which supports production of Air Force weapon systems. Further, technology advances such as Very High Speed Integrated Circuits (VHSIC), composite materials, and computer integrated manufacturing will improve R&M. Finally, corporations have begun management realignment to bring the design engineers, the logistic support engineers, and the R&M engineers into one interactive body. Such realignment must occur to insure that the design incorporates the realities of the operations environment. When viewed as a whole, including the resurgence in the quality ethic, advances in technology, and management realignment, a synergy results which will generate quantum leaps in R&M.

3. AIR FORCE RESPONSE TO THE FOUR TRENDS

These trends suggest there is leverage to be gained in combat capability through improvement in the reliability and maintainability of systems. The Air Force has instituted a concerted thrust which demands the search for basic system changes that ensure the most reliable, maintainable systems possible for the defense dollar invested.

Within the United States Air Force, this commitment to demanding improvements in reliability and maintainability (R&M) was put into effect on February 1, 1985 with the publishing of the R&M 2000 Action Plan [3]. In this landmark document, the senior leadership of the Air Force began the process of institutionalizing the commitment to R&M for both new and fielded weapon systems. For the remainder of the 20th century and into the 21st century, reliability and maintainability are the new cornerstones for structuring increased combat capability of weapon systems. R&M 2000 challenges industry to provide the highest quality military hardware that technology, foresight, and human ingenuity can provide at an affordable cost.

The Secretary and Chief of Staff of the Air Force set five goals to be attained through accelerated improvements in R&M. These goals in order of priority are:

- Increased warfighting capability
- Increased survivability of the combat support structure
- Decreased mobility requirements per unit
- Decreased manpower requirements per unit of output
- Decreased cost.

These goals apply across the Air Force and its weapon system force structure.

How will R&M 2000 work for the Air Force and what will be its effect on system development and acquisition? R&M 2000 requires a fundamental change in the way the Air Force does business. In the past, the focus on R&M has been in the logistics community. Failures and the effort to correct them have a great effect on the logistician. They determine the maintenance manning and training levels, and the expenditure for spare parts. However; if the logistician is the only one interested in R&M, there will be no real improvement.

From a broader perspective, R&M has an even greater effect on the operator. One of the keystones of R&M 2000 is to institutionalize the commitment to improve R&M. The operations people, who run the gamut from the maintenance two striper to the communications operator to the missile launch teams, are stepping up to the fact that R&M has a direct bearing on the operational mission. After all, the operator is the one that needs the system to perform the mission. If the system is shut down, the operator cannot get the job done.
Finally, where can reliability and maintainability be influenced? Although operations and maintenance activities feel the effect of the R&M levels of fielded systems, once a system has been fielded there are limited options to improve R&M levels. The key lies in the planning and acquisition process. One of the most fundamental changes already implemented deals with source selection. If the source selection is for a new design or system, then reliability and maintainability shall be singled out as a specific evaluation criteria. R&M will be the first listed items in the highest ranked area as basis for an award.

This guidance is contained in the Air Force Systems Command regulation supplement to Air Force regulation 70-15. Such a fundamental change in acquisition policy places the proper emphasis on R&M during contractor selection for new systems. From my perspective, reliability and maintainability are shared responsibilities of many disciplines within the system and engineering design process. This means that all engineers, not just the computer engineer, or the reliability or maintainability engineer, but all design disciplines must be aware of their design's impact on reliability and maintainability. In particular a system is no easier to maintain than its design allows. The optimum reliability and maintainability must be designed into the product right from the start — whether an integrated circuit, an inertial navigation system, or an aircraft system.

Management commitment to, and focus on, system reliability and maintainability attributes during system design will provide unprecedented levels of system effectiveness. The Air Force sent an irreversible signal to industry in the form of the R&M 2000 Action Plan that went out to every major corporation in 1985 February. Optimum R&M can only be achieved if optimum R&M is a required outcome from the outset. R&M must be considered within the framework of cost, schedule, and performance if R&M is to be delivered in tomorrow's systems.

The bottom line is this: All performance parameters are zero if a system is broken. It was a mistake, many times, when R&M was traded away for extra performance features. R&M must be considered as a performance feature in and of itself; one must keep in mind how often a system will be needed, as well as how much it is expected to do.

Some 24 months ago, the Chief of Staff and the Secretary of the Air Force appointed a Special Assistant for Reliability and Maintainability, Brigadier General Frank Goodell. General Goodell, who works for both Lieutenant General Bernard Randolph, Military Deputy for Acquisition, Office of the Assistant Secretary of the Air Force (Acquisition), and for me, has traveled throughout this nation and in Europe "spreading the gospel according to R&M." Gen. Goodell's and my message conveys one basic truth: "Reliability and maintainability are a means to an end — and that end is increased combat capability — and thereby, an improved deterrent posture."

4. CONCRETE RESULTS

Now that the philosophy of what it takes to obtain enhanced combat capability through R&M has been discussed, this section dwells on what has been accomplished. The institutionalization process is moving ahead and gaining momentum. Internally the Air Force has changed the way it is doing its acquisition business. This enlightened approach, when joined with technological advances, dramatically illustrates what can be and is being done.

The ring laser gyro represents a case in point. For this system the Air Force established minimum requirements of 1300 hours mean time between failures (MTBF) for fighters and 2000 hours for cargo aircraft. In addition, the Air Force required that the design support 2-level maintenance, which eliminates intermediate maintenance, versus full 3-level maintenance. This forced the design engineer to incorporate system characteristics which ultimately will lead to enhanced flexibility by eliminating dependence on intermediate service facilities.

The above were minimum requirements. Air Force acquisition strategy centered on letting industry determine its own upper design limitations. Modeling on commercial practices, a competitive bid was used to procure a standard form, fit, function ring laser gyro inertial navigation unit (INU). Competition was based on life cycle cost, which gave bidders the incentive to exceed the 1300 hour MTBF requirement.

Even with the 2-level maintenance requirement, industry showed its true mettle for design innovation. The winning companies, Litton and Honeywell, blew by the 1300 hour requirement, designing a ring laser gyro INU with an MTBF of 2000 hours for a fighter and 4000 hours for cargo aircraft. Thus industry, when left to its own innovativeness, produced a system which beat the requirement by 54 and 100 per cent, respectively. But, of even greater import, Honeywell and Litton guaranteed their product.

This case along with the following examples validates an Air Force premise: aerospace industry, when allowed to be innovative in a competitive environment, will reach beyond today's perceived limitations and grasp tomorrow's possibilities.

Another example is the digital technology called Very High Speed Integrated Circuits, commonly referred to as VHSIC. Last year the Air Force and the Office of the Secretary of Defense cosponsored a VHSIC technology insertion program on the ALQ-131, an electronic warfare jammer. This effort led to a technical demonstration of VHSIC technology in electronic warfare equipment. The demonstration was to verify that with VHSIC technology one can get quantum increases in reliability and maintainability.

One part of the ALQ-131, the Techniques Control Assembly (TCA), was redesigned using VHSIC technology and state of the art engineering design principles. The
results were extremely gratifying. The new VHSIC TCA is projected to have an MTBF 30 times greater than the old unit while occupying only 40 percent of the previous TCA volume. Most significantly, within the framework of reducing dependence on external support, the new TCA eliminates the requirement for an off-equiment tester by using its internal built-in-test to fault isolate to a specific card. Furthermore, the new unit has non-volatile indicators on each card that flag themselves to indicate a failed unit. VHSIC technology supplies this R&M capability and provides 50% more space in the TCA for future growth in response to future threat changes or performance requirements. And the new unit reduces the need for external support equipment which is one step closer to cutting the tether tying the weapon system to a complex support infrastructure.

The story does not stop here. Other efforts will be changing the avionics of the future. One such effort is the common signal processor being developed by the Avionics Laboratory at Wright-Patterson AFB. The common signal processor is an airborne super computer that will apply to radar, communications, navigation, image processing and electronic warfare systems. The interesting part of this effort is that the mean time between critical failures of this unit, using a hot spare concept, is projected at 36,000 hours. It will also employ a very robust built-in-test concept to get to the card level without the use of off-equiment test equipment. If everything works as envisioned this unit will form the basis for many of the avionic systems on the Advanced Tactical Fighter (ATF).

Other efforts, like the VHSIC 1750a computer, will form the basis for a standard maintenance data bus. The Air Force will then be able to get consistent maintenance data from avionics and to isolate failures to a faulty line replaceable module; all without the use of off-line test equipment.

On a shorter term basis the integrated communication, navigation, identification-friend-foe, avionics system (ICNIA) takes the capability of about 11 Line Replaceable Units (LRU) with a combined system MTBF of approximately 44 hours and delivers a modular avionics package in about three racks of equipment. The end result is a 50 per cent reduction in system volume and a mean time between critical failure of 10,000 hours, which does away with all intermediate test equipment requirements. Again there was an incremental increase in weapon system flexibility.

General J. L. Piotrowski [4] describes a policy that avionic LRUs be procured with MTBFs on the order of 2000 hours. This policy encompasses both future systems and retrofits for existing systems. The Air Force has already achieved this level of reliability on other avionic systems like the new Weapons Navigation Computer on the F-111 and the B-52 Digital Scan Converter. The Air Force can and must achieve a 2000 hour MTBF for all avionic systems. This 2000 hour MTBF requirement will not be easy for all avionic systems; however, the Air Force desperately needs this kind of reliability in all avionic systems so that it can effectively increase combat capability.

6. DISPELLING A MYTH

There is a question, actually a myth, raised by those who have not grasped the full potential of R&M 2000 taken over the lifetime of a weapon system: non-believers state that if R&M is achieved through sound practices, such as good engineering design and elimination of infant mortality through factory screening, it costs more than engineering as usual. This, as stated, is a myth. Proper attention to reliability and its adjunct, quality, will pay dividends, not put the Air Force in the red.

A few examples tied to the quality of workmanship and component parts will buttress this fact. In 1986 January General Piotrowski signed out the R&M 2000 Environmental Stress Screening (ESS) policy letter [5]. Essentially this policy requires elimination of weak parts and poor workmanship in the factory. The end result is significantly increased field reliability and combat capability. R&M 2000 ESS requires that the quality (as measured by fraction nonconforming) of electronic piece parts used by the original equipment manufacturer (OEM) be improved to 100 parts per million by 1990. High quality parts save money for the OEM and directly contribute to higher yields and less rework. This translates into a more competitive posture for the prime contractor as well as assisting the contractor in meeting reliability and maintainability requirements.

Now what does this attention-to-quality cost? The following quantifies the cost implications. An in-house study conducted by Texas Instruments [6] compared the final cost to the original equipment manufacturer (OEM) of vendor supplied electronic parts at two levels of nonconformance: 100 parts per million (ppm) and 3500 ppm. With an at the dock nonconformance of 3500 ppm, OEMs incur an overhead consisting of 100% inspection and burn-in, an 8-week parts inventory, 33 warranty calls, and a 7% rework rate. In comparison at 100 ppm the incoming inspection and burn-in was eliminated, inventory was just in time, warranty calls were reduced to three, and the rework rate dropped to 1%. By requiring the parts vendor to supply quality parts to the receiving dock, the OEM’s warranty, rework, inventory, and inspection costs are slashed from $1.00 per part to $0.06 per part. This equates to an incredible 94% reduction in the OEM’s overhead part costs. This reduction eventually translates into more combat capability for the dollar, less cost, and a better profit margin for the corporation — a win-win situation.

Another example involves the Air Force Space Systems Division, which analyzed the cost impact of quality parts. Their high quality class S parts for the inertial upper stage (IUS) cost $24 million versus $1.1 million if the IUS had been built with lower quality class B parts. Sounds like the Air Force spent too much. However, when tested, the class B parts had 60 times more failures than the class S parts. The net result of using higher quality class S parts versus the class B parts was a program savings of over $100 million,
when considering class $B$ rework costs of $20,000 per repair.

So what does quality through R&M 2000 cost? The cost of higher quality parts is normally amortized through lower rework, inventory, warranty, and re-inspection costs. The point is: attention to detail at the beginning of the life of the system will result in positive savings and, once again, savings translate into increased force capability.

7. CUTTING THE TETHER LOGISTICS IMPLICATIONS OF ENHANCED R&M

The major aspects of the Air Force R&M thrust have been explained. Now the rewards of this effort will be analyzed and discussed in terms of people, material, and facilities.

7.1 People

People are the most important part of any weapon system, and today’s sophisticated weapon systems require highly skilled people to operate and maintain them. Most of these people are combat support personnel. In fact, current weapon systems require over 150,000 active duty maintenance people, or one out of every three enlisted folk. Moreover, these maintenance personnel have been divided into 140 different specialties. This situation has led to an extraordinarily complex personnel structure that detracts from combat by reducing flexibility.

Furthermore, weapon systems today require a labor-intensive distribution system to support them; a system that includes civilians, reservists, and regular military personnel. For instance, in the active Air Force supply and transportation career fields, some 50,000 blue suiters manage the movement, storage, and issue of materiel. Yet, they represent only the tip of the iceberg. The majority of aerial support people come from the Air Reserve forces.

Yet, most of the Air Force is supported by surface modes — land and sea — and most movement within a theater is managed by the Army. In turn, the Army heavily depends on its reservists and the host nation infrastructures: trucks, roads, ports, storage facilities, and the people who operate them.

Therefore, when the logistics pipeline is considered all the way from the sources of raw material to the factories and depot through the aerial and seaports to the forward operating locations, the enormity of the involvement of human resources can be appreciated. Millions of people are needed to sustain current Air Force weapon systems with fuel, munitions, subsistence, and spare parts. This is further testimony to the increasing visibility of the tetherying aerospace power to the support structure.

Consequently, if, during the acquisition process, the engineer minimizes supportability requirements by designing in desired R&M attributes, the perturbations — the shock wave — will be felt throughout the combat support structure for the life of that weapon system. Again, the engineer does not design an aerospace vehicle. The engineer designs a system; a system that includes all the people, materiel, and facilities necessary to employ an aerospace vehicle.

7.2 Material

Material is another resource that is directly affected by weapon system reliability and maintainability. The Air Force is investing about 4000 million dollars in spares each year. This alone indicates the need for increased reliability. Take an F-15 aircraft, for instance. It has some 75,000 component parts. Approximately 300 major contractors are involved in its production, not to mention thousands of vendors. Almost 65% of the aircraft is being made by someone other than the prime contractor. So, from a system perspective, the F-15 is an extremely complex aerospace platform. Yet, the F-15 is more reliable and easier to maintain than the older F-4. For example, the F-15 was designed with five fewer flight control surfaces, 184 fewer fuel pumping connections, and about 300 fewer lubrication points. In short, the F-15 requires about three-fourths the maintenance of the F-4 because of R&M improvements during design.

Certainly, these facts speak well of the reliability and maintainability of the F-15 system. But, as indicated above, the Air Force has only just begun to make the improvements that can bring dramatic changes to the flexibility of this weapon system and future weapon systems. For instance, the variety of spares required to support F-15 Avionics Intermediate Support (AIS) is greater than the number to support the avionics of the F-15 itself. This is just not acceptable!

In fact, look at what eliminating the F-15 AIS could buy. It now takes about 18 C-141B cargo aircraft to deploy an F-15 squadron. Five of those aircraft are just for the AIS. If dependence on the avionics shop could be reduced through improvements in the avionics R&M, four squadrons could be deployed with the same airlift now required to deploy three. The freed airlift could then be used to transport crucial war materials and enhance the overall combat capability.

The message rings loud and true. The advances of technology must be coupled with smart engineering to cut the tether. The Air Force has clearly made its case with the Advanced Tactical Fighter. Reliability and maintainability played a decisive role in the selection of Northrop and Lockheed as the two competing finalists. Using the F-15 as a baseline, the ATF must: use less than one-half the maintenance manhours per flying hour, incorporate an MTBF of two times the mean time between maintenance actions, use less than one-half the airlift currently required for an F-15 squadron deployment, and take less than one-half the time to turn the aircraft in combat. Or, as stated succinctly by Gen Piotrowski, “The ATF is the flagship of our two times reliability, one-half maintenance policy.”
I detailed above the magnitude of people and material resources necessary to support the logistics pipeline. In this light, reductions in aircraft support implied by ATF requirements have the potential for reaping enormous benefits. The goal, moving into the 21st century, should be to eliminate intermediate maintenance shops — Period! The airplane will become the intermediate test station. Only then will aircraft acquire the flexibility and mobility needed on the future battlefield.

7.3 Facilities

With reductions in support people and equipment located in the combat theater, a commensurate reduction in the noncombatant support facilities will certainly follow. Facilities, which include buildings, utilities, and pavements, are the least mobile resources. Yet today, weapon systems are inextricably tied to fixed installations. And, these fixed structures are prime targets in war. Further, people and equipment must be protected by sheltering them from conventional, nuclear, biological, and chemical threats. These realities present an incredible drain on available resources.

Designing a weapon system to be its own intermediate test station will go a long way toward alleviating many thorny problems at the root source. In the process, the Air Force begins to open fully the option of “flushing” weapon systems to dispersed locations. And this forms the needed reaction to the enhanced lethality and accuracy threat posed by technological advances. With a clear corporate vision of what needs to be done, the Air Force can and will reverse the “fortress Bitburg” basing support mode. The Air Force has accepted the challenge of creating aerospace forces that can operate in any environment with minimal combat support. But armed with a new optimism, born out of the vision that is R&M 2000, the deficiencies of the past are being corrected. The increased emphasis on R&M during system design will produce vehicles that break less often, are less susceptible to combat damage, require fewer support personnel and equipment, and need only minimum servicing and reconfiguring for the next mission. By aggressively and smartly attacking the problem, our Air Force of the future will reverse Sir Winston Churchill’s observation: “Strange as it may seem, the Air Force, except in the air, is the least mobile of all services.”

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