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AN INVESTIGATION INTO
THE IMPACTS OF ALTERNATIVE MAINTENANCE CONCEPTS ON RESEARCH AND DEVELOPMENT

Hq AFSC/ENL

11 April 1990

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS AIR FORCE SYSTEMS COMMAND
DCS/ENGINEERING AND TECHNICAL MANAGEMENT

ANDREWS AIR FORCE BASE, MARYLAND

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ABSTRACT

Historically, the Air Force has focused on three levels of maintenance: organizational-level, intermediate-level, and depot-level. In this report, research and development efforts are recommended which have the potential for fostering the use of alternative maintenance approaches. Also identified are the current policies in the support areas which address how new programs should be structured. A major conclusion drawn is that the current Air Force policy, and management and analysis tools need to be updated to encourage the trend toward the use of alternative maintenance concepts which permit reductions in manpower and equipment requirements. From this hypothesis, recommendations are provided on policy changes. These policy changes must be coupled with a focused research and development program. This synergism can result in further use of more efficient alternative maintenance approaches.

SECTION I: INTRODUCTION

1. OVERVIEW

A. **Context.** One of the proposals currently under consideration to reduce Air Force expenditures requires all Air Force activities to take an objective look at the levels of maintenance with a view toward eliminating unit intermediate shops. This is not a new initiative, since in recent years new acquisition programs have been moving the Air Force toward alternative maintenance concepts.

2. ALTERNATIVE MAINTENANCE TERMINOLOGY

A. **Terms.** To help in the effort to develop an improved, more efficient approach to posturing systems and to preclude the trap of vectoring in on the traditional "two" and "three" level maintenance concepts, HQ USAF has proposed a new two-level oriented maintenance terminology to replace "organizational," "intermediate," and "depot." **THESE NEW TERMS WILL BE USED THROUGHOUT THIS WHITE PAPER:**

(1) Organizational: On/off equipment repairs and remove, replace, repair actions done by/at the unit (Basically all activity done by the unit in its own behalf).

(2) Supporting: All other maintenance activity, regardless of location, size, or who's doing the maintenance.

(a) Dedicated: Off equipment repair for system/subsystem components provided by a consolidated "blue suit" workforce in support of units within their command.

(b) Depot: On/off equipment repair and overhaul for weapon systems provided by a mixed workforce at depot/contract locations.

LEVEL	COMMAND	LOCATION	CATEGORY
ORGANIZATIONAL	OPERATING COMMAND	OPERATING LOCATION	ON/OFF EQUIPMENT
SUPPORTING (DEDICATED)	OPERATING COMMAND	MAIN OPERATING LOCATION CENTRALIZED REPAIR FACILITY	OFF EQUIPMENT
SUPPORTING (DEPOT)	SUPPORTING COMMAND	ALC CENTRALIZED REPAIR FACILITY	ON/OFF EQUIPMENT

FIGURE 1: Maintenance Terminology Relationships

B. **Synopsis of Changes.** Figure 1 shows the relationships, under the new terminology, between level of maintenance and command performing the maintenance, location of maintenance, and maintenance category (i.e., on or off equipment). "Organizational" remains maintenance by the unit, for the unit, at the unit. However, the term is broadened to permit "off equipment" as well as "on equipment" maintenance. Also, "organizational" now includes repair as well as remove and replace actions. "Supporting (dedicated)" is similar to the old term "intermediate," in that it encompasses blue suit, off equipment maintenance for system/subsystem components. However, it is now broadened, in that maintenance does not have to be "at the unit." "Supporting (depot)" under the new definition is identical to the definition of "depot" under the old terms. The new terminology is advantageous in that "organizational" maintenance can now include certain old "intermediate" maintenance tasks (e.g., missile reentry vehicle buildup). Also, greater consolidation of former "intermediate" functions will be fostered, since "supporting (dedicated)" is no longer defined by location.

C. **Impact of New Terminology.** The purpose of the alternative maintenance concepts terminology is to achieve economies of scale in the maintenance process where possible by fostering a stabilized work force, reducing the number of pipelines to be filled with shop replaceable units, reducing the amount of test equipment required, and ensuring adequate availability of assets.

3. **IMPLICATIONS FOR FUTURE SYSTEMS.**

A. **The future aircraft maintenance unit will consist primarily of organizational and supporting (depot) maintenance, either minimizing or eliminating reliance on the "back shops" associated with the traditional intermediate level of maintenance.** The main issues involved in evaluating the cost effectiveness of such an approach are the cost of the shop level maintenance capability, the cost of the spares pipeline, and the manpower associated with alternative concepts. The traditional intermediate level of maintenance can be quite expensive, especially if it entails a great deal of complex automatic test equipment and a large number of operating bases. However, this repair capability also means that the end item spares required to fill the pipeline can be held to a minimum, since in transit times are usually minimal (e.g., across the flightline and into the shop), compared to a lengthy, possibly overseas, trip to the depot.

B. **Currently, a number of factors support alternative maintenance concepts:**

(1) Increased reliability means fewer components fail, and consequently, fewer spares are needed to fill the pipeline.

(2) Increased capabilities for built-in test and improved fault isolation have increased the capabilities of organizational maintenance. Also, automated job aids such as the Integrated Maintenance Information System (IMIS) make performing a greater variety of difficult skills on the flight line more feasible.

(3) Avionics capabilities (such a VHSIC) have led to more complex and costly avionics shops, raising increased concerns about their costs and survivability.

(4) Manpower constraints Congressionally imposed by reducing end

strengths necessitate more efficient use of the people who remain.

(5) Personnel aptitude and training requirements for traditional intermediate shops could require highly skilled airmen who are hard to recruit and retain.

C. **Given these factors and the increasing use of alternative maintenance concepts on new weapon systems, it is imperative that we examine the design requirements** (i.e., maintenance assumptions, operating requirements, and reliability and maintainability parameters and their manpower implications) **which program offices place on the systems and subsystems they acquire.** It also means identifying those systems and subsystems that currently drive intermediate maintenance requirements and determining the design issues which must be addressed or incorporated to permit or facilitate alternative maintenance concepts. Finally, it is important to take a closer look at the analytical tools which we use in making maintenance and logistics decisions (e.g., repair level analysis, logistic support analysis, decision tree analysis, Logistics Composite Model, etc.).

4. SUMMARY

A. **A clear roadmap is needed to determine what research and development efforts are needed to address the changed environment of the 1990's and to update our management tools toward alternative maintenance approaches.** These efforts also need to be reviewed and prioritized from a funding perspective.

B. **The purpose of this White Paper is to examine where we are today in terms of programmatic maintenance planning decisions.** We will look at what decisions have been made by a number of recent programs and, where possible, the analytical process which went into these decisions. We will look at the directions in which technology and changes in the overall acquisition environment are driving our future programs. We will review the current "Alternatives to Intermediate Maintenance" programs being implemented by Air Force using commands. Finally, we will examine the research and development implications of these new directions to identify initiatives the Air Force should pursue to yield further reductions in the manpower, training, and equipment investments associated with repairs in the maintenance shops of the future.

SECTION II: BACKGROUND

1. CURRENT R&D CONSIDERATIONS WHICH ARE MOVING THE AIR FORCE TOWARD ALTERNATIVE MAINTENANCE CONCEPTS

A. **Reliability Improvements.** To reduce the supporting (dedicated) level of maintenance, system reliability has to be sufficiently high to preclude an inordinate number of failures and, therefore, line replaceable unit (LRU) returns to depot. The R&M 2000 initiatives have focused on improved reliability of components. In particular, avionics reliability has undergone exponential growth. Reliability growth and consequent low hardware failure rates mean that in many instances it can be extremely cost effective to reduce reliance on the supporting (dedicated) level of maintenance. Since there will be fewer failures, the impact on spare LRU requirements--potential increase in spares pipeline due to reducing the supporting (dedicated) repair capability--would no longer be cost prohibitive. For example, MAC is currently using the following guidelines: MTBF greater than 3500 hours - no need for supporting (dedicated) level, 2000-3000 hours - may be possible to eliminate supporting (dedicated) level, less than 2000 hours - retain supporting (dedicated) level. One additional factor associated with increased reliability is that human task experience and proficiency generally decay as system reliability increases, since opportunity for individual experiences in troubleshooting are less frequent. Therefore, although the system does not fail as often, it may get more difficult to diagnose and repair failures, when they occur. Computerized job aids can supply the necessary refresher material at the desired level of detail.

B. **Testability Improvements.** The Air Force is committed to a number of initiatives in the development and acquisition of integrated diagnostics and automatic test equipment. The cumulative effect of these initiatives is that now and in the future a greater degree of standardization of test equipment and an increased capability to diagnose and isolate faults will be possible at the organizational level.

(1) Built In Test (BIT). Increased BIT capabilities mean that it is now possible to test and in some cases to fault isolate without taking the equipment to a supporting (dedicated) shop. In fact, BIT can be used to permit fault detection and isolation to LRUs "on board," without the use of flightline test equipment. This development, combined with the reliability improvements outlined above, create an environment conducive to strategies which minimize or eliminate reliance on supporting (dedicated) maintenance. The original "Smart BIT" study conducted by Grumman under contract to Rome Air Development Center (RADC) showed that artificial intelligence (AI) techniques can be used without additional test points or fault coverage to detect false alarms or intermittents.

(2) Development of common depot test equipment to be utilized by several major weapon systems is resulting in increased commonality and enhanced BIT capabilities.

(a) The Generic Integrated Maintenance Diagnostics (GIMADS) program is a structured Air Force process that maximizes the effectiveness of diagnostics by integrating pertinent elements such as testability, automatic and manual testing, training, maintenance devices, and technical information as a means for providing a cost-effective capability to detect and isolate faults in weapon systems and equipment.

(b) Modular Automatic Test Equipment (MATE) is an acquisition approach used by all Air Force organizations that acquire, modify, or replace automatic test equipment. MATE consists of acquisition tools, automated quality assurance techniques, guides, system software, and standards.

(3) Modular Avionics Systems Architecture Support Requirements (MASA). AF/LE letter, dated 16 Jul 88, to ALMAJCOM-SOA/CV directed that MASA evolve into a support requirements document (SRD) that would ensure that logistics requirements influence the design, development, and support of new and modified weapon systems and subsystems, increasing BIT performance and reliability.

(4) Advances in Technology for Integrated Circuits.

(a) Very High Speed Integrated Circuits (VHSIC). VHSIC is a family of advanced integrated circuit chips with increased speed and density. VHSIC characteristics (e.g., smaller size, lower system power requirements, and faster processing times) will allow more room in systems to include or increase built in test (BIT) detection and accuracy. VHSIC reconfigurable systems can also improve R&M by providing redundant capability. This means that systems can now be designed for "on board" fault isolation, without the requirement for flightline test equipment. At the depot, more comprehensive fault detection and diagnostics can be achieved beyond the "on board" system level diagnostics. Also, VHSIC Advanced Modular Processor (VAMP) will incorporate BIT at the module level, increasing fault isolation. Common module (electronics commonality) will allow one module to be utilized on several weapon systems.

(b) Very Large Scale Integrated (VLSI) Circuits. VLSI circuits are the next step in the evolutionary progress of solid state electronics miniaturization and increased feature density. The smaller feature sizes allow more digital logic to be implemented in the same area and the operation of that logic at higher clock speeds using less power. The end result is more signal processing circuitry can fit on a chip, while running at a higher speed, resulting in an increase in processing throughput.

C, **Information Availability Improvements.** Alternative maintenance concepts can be significantly aided if technicians have quick and easy computer access to the enormous quantity of data required to maintain current and future weapon systems. The technology currently exists to give technicians a rugged, portable computer that will act as a single interface with other digital data systems to provide an integrated source of information needed for maintenance. The Integrated Maintenance Information System (IMIS) is oriented toward improving the capabilities of aircraft maintenance organizations by providing Air Force technicians an effective information system for intermediate and flightline maintenance. The improved information system increases the performance capabilities of the technicians, resulting in an increased sortie generation capability. IMIS research already provides software, hardware, and human-machine interface answers to meet the information needs of flightline technicians. The concept has been developed and validated through flightline testing. This new technology opens the door to new maintenance concepts, greater quality and effectiveness, new AF specialty structures, and possible manpower savings.

(1) IMIS will access various information sources, integrate information for presentation, and tailor information to fit the needs of the technician. It will effectively support technicians of various skill levels in hostile environments.

(2) As a technician's main information source, IMIS will display graphic technical instructions, provide intelligent diagnostic advice, provide aircraft battle damage assessment and repair aids, analyze in-flight recorded parameters and failure data, analyze aircraft historical data, upload and download aircraft software, and initiate and interpret on-aircraft tests.

(3) IMIS will verify faulty components prior to beginning off-equipment repair and support maintenance during off-equipment maintenance. The strong on-equipment diagnostic capability will significantly reduce false removals, thereby reducing the required spares levels. This IMIS diagnostic capability could also replace other test equipment, further reducing mobility and airlift requirements for support and test at the supporting (dedicated) level of maintenance.

2. NON-R&D CONSIDERATIONS THAT ARE DRIVING THE AIR FORCE TOWARD ALTERNATIVE MAINTENANCE CONCEPTS

A. **Need for Manpower, Personnel, and Training (MPT) Optimization.** The DOD Logistics 2010 Report warns that new technologies and changing requirements are creating voids in the logistics workforce, requiring increased productivity to continue to meet logistics demands. Recent Congressionally imposed force reductions focus on the high cost of maintaining a standing force during an increasingly peaceful period of world history. With pressure to reduce the size of the military, the AF must find more efficient ways to utilize its people so that it can do more with the people we have.

(1) Finding Ways to Utilize Maintainer Better. As maintenance jobs become more complex and specialized, reliability is creating the "Maytag repairman" syndrome with utilization rates dropping to 10-35 percent. Ways to broaden specialties (even more than Rivet Workforce) must be found to capitalize on the reliability we've purchased and the talent and potential productivity of our people.

(2) Future Demographics and Educational Backgrounds. We know that the percentage of draft age men will be lower than in the past, but we cannot predict the degree to which the military will have to compete with American industry. As we adjust to a new era of world history and to a more streamlined force structure, several questions are still unanswered. What will be the effect of the attitude that peace is "breaking out" will have on the career intentions of our highest quality (present and future) maintenance personnel. Will we lose the quality NCOs and retain the less competitive? Will the US population demographics and education provided by US schools provide an adequate number of the quality we need to do complex troubleshooting tasks? Attitudes about the military as a viable career could reduce the availability of high numbers of super technicians needed, and it could also encourage the highly qualified to seek careers elsewhere.

(3) Effects of Technology on Workforce. While technology can increase productivity, and may reduce manpower requirements, it will create the need for workforce retraining and multidisciplined career fields. These trends

emphasize the need to design systems for ease of maintenance in the field (e.g., maximize use of built-in test, of O-level removal and replace functions, and automated troubleshooting job aids like IMIS), while minimizing complex I-level maintenance activities which demand a concentration of highly specialized and trained personnel. It is also worth noting that alternative maintenance concepts may increase result in job enrichment by providing more challenging work and better, broader range and depth of maintenance experience, since O-level maintenance becomes more than just "remove and replace."

(4) Applying Job Aiding and Training Technology to Broaden Career Fields and Rethink Maintenance Concepts and Organizational Structure. Since manpower drivers are no longer R&M, but rather shop open-the-door costs, maintenance concept and policy decisions, and AF specialty structure, we must examine these areas to reap full benefits from R&M. By applying job aiding and advanced training technology career fields can be broadened enabling a more flexible workforce. With more universally assignable workforce, alternative maintenance concepts and organizational structures can be more easily implemented. Only then can the AF begin to take full advantage of the improvements in R&M in terms of manpower savings. (NOTE: Although reducing reliance on I-level maintenance will help alleviate, at the base level, the MPT consequences outlined above, these same requirements will continue to pose a challenge for the AF depots.)

B. **Mobility and Survivability Issues.** Dedicated shops contain highly complex and often extremely cumbersome equipment. An ALD study of the F-15 avionics maintenance concept, for example, noted that in a TAC deployment exercise, an equivalent of three C-141As was required to deploy the dedicated support equipment required for one squadron of F-15 aircraft. Moreover, the critical power and air conditioning requirements of this equipment present significant constraints. Such requirements limit system deployment; moreover, they pose survivability concerns. Since the combat readiness of the weapon system is closely tied to the availability of a supporting (dedicated) maintenance capability, the shop is vulnerable to attack, sabotage, and even austere or primitive deployment locations.

C. **Air Force Special Operations Forces (SOF).** The Air Force SOF require the capability to troubleshoot and repair a variety of digital and radio frequency avionics line replaceable units in numerous SOF weapon systems. These testers must be capable of rapid deployment to a wide range of worldwide locations (from fully capable to austere) in support of operational and contingency taskings. These deployments must be as covert (low signature) as possible to effectively accomplish the mission. The goal is for these units to be self-deployable on SOF aircraft, placing a premium on limiting size and weight of required support equipment. Moreover, if the nonrecurring engineering can be done once in support of all weapon systems by directing procurement of a common tester, redundant costs can be eliminated and the resulting tester can be shared by multiple weapon systems, thus reducing proliferation.

SECTION III: TODAY'S ENVIRONMENT

1. CURRENT POLICY

A. **AFR 57-1, Operational Needs, Requirements, and Concepts.** Reflects R&M 2000 requirements and maintainability guidelines of AFR 66-14 when preparing System Operational Requirements Documents (SORD) and Statements of Need (SON).

B. **AFR 66-14, US Air Force Equipment Maintenance Program.** Today, levels of maintenance are defined in terms of whether maintenance tasks are performed on or off equipment and whether the operating or supporting command requires the resources to do the tasks. This emphasis makes the on equipment and off equipment extremely useful in describing future maintenance concepts, in identifying meaningful performance factors, in making effective provisioning decisions, and in determining where to focus resources as we bring on new weapon systems and upgrade existing ones. AFR 66-14 does not yet reflect the new maintenance terminology outlined above (Section I, Para 2). Rather, levels of maintenance are defined as follows:

(1) Organizational level: the level of maintenance consisting of those on equipment tasks normally performed using the resources of an operating command at an operating location.

(2) Intermediate level: the level of maintenance consisting of those off equipment tasks normally performed using the resources of the operating command at an operating location or at a centralized intermediate repair facility.

(3) Depot level: the level of maintenance consisting of those on and off equipment tasks performed using the highly specialized skills, sophisticated shop equipment, or special facilities of a supporting command at a technology repair center, at other types of military or commercial centralized repair facilities, or in some cases at an operating location. Depot level maintenance may also include maintenance normally considered to be organizational or intermediate level as negotiated between operating and supporting commands.

(4) AFR 66-14 requires maintenance concepts of the future to take advantage of the state-of-the-art technology advances in mechanical design and effective human engineering through increased reliability, reduced mean time to repair, minimizing maintenance infrastructure, and when planning support for future weapon systems and changing the concept for current systems, two levels of maintenance may be required.

C. **AFR 800-8, Integrated Logistics Support Program (ILS).** The maintenance concept is required to be defined in terms of on/off equipment and repair levels as defined by AFR 66-14.

D. **AFR 800-18, Air Force Reliability and Maintainability Policy.** Obtains industry commitment to greater levels of system reliability (R&M 2000 initiative).

E. **AFSC/AFLCR 800-28, Repair Level Analysis (RLA) Program.** Requires candidate items be analyzed and evaluated for discard at failure, organizational repair, intermediate maintenance repair, depot maintenance repair, or combinations thereof based on the equipment failure mode. Uses data extracted from the LSAR; results incorporated in the LSAR.

F. **AFR 66-7, Depot Maintenance Posture Planning and Workload Management.** Maximizes repair of repairable assets and supports operational base maintenance activities by the use of more extensive shop facilities, equipment, and personnel of higher technology skills than are normally available to operating activities.

G. **MIL-STD-1388-1A, Logistic Support Analysis.** Establishes a single, uniform approach for conducting those activities necessary to cause supportability requirements to be an integral part of system requirements and design, define support requirements that are optimally related to the design and to each other, define the required support during the operational phase, and prepare attendant data products. Provides general requirements and descriptions of tasks which comprise the LSA process. Includes procedures to identify the maintenance tasks that must be performed to operate and maintain the new system/equipment in its intended environment and procedures to determine the preferred support system alternative(s) for each system equipment alternative. (NOTE: LSA must be skillfully tailored to achieve analyses on pertinent issues.)

H. **MIL-STD-1388-2A, DOD Requirements for a Logistic Support Analysis Record (LSAR).** Establishes standard LSAR data element definitions and formats, consolidates logistics oriented technical information for the various engineering and ILS elements into one file, and maximizes use of industry developed integrated data systems tied to engineering and manufacturing data bases as sources of LSA documentation. Includes operation and maintenance task analysis data. This military standard will be superseded by MIL-STD-1388-2B, which is currently in draft pending final review and coordination. MIL-STD-1388-2B will incorporate a more fully automated LSAR, as required by Computer-aided Acquisition Logistics Support (CALS).

I. **AFR 80-XX (Draft), Air Force Combat Support Research and Development Requirements (Logistics Needs) Program.** The Air Force Logistics Needs Program is a formal process for identifying system and infrastructure problems which can be resolved with advancements in technology or application of existing technology. The Logistics Needs Program identifies requirements for the development and application of technology to reduce or eliminate supportability deficiencies in existing, developing, and future weapon systems or subsystems. This draft regulation will, when formally published, explain the purpose; define the objectives and scope; and identify the agencies responsible for identifying, validating, coordinating, disseminating, and responding to the requirements of the Logistics Needs Program.

J. **AFR 80-51, Management of R&D Requirements in the Manpower, Personnel and Training (MPT) Program.** A new process is being developed for identifying MPT needs to the Air Force Systems Command (AFSC). Prior to 1989, MAJCOM/Air Staff MPT science and technology needs were forwarded to AFSC under the provisions of Air Force Regulation 80-51, using a document called a "Request for Personnel Research (RPR). A processing and review system existed for RPRs, but over the years administrative difficulties arose. Eventually the decision was made to totally revise the way that users identify MPT technology needs to AFSC and how AFSC responds. In the new process, users describe their requirements in the form of a Manpower, Personnel and Training Need (MPTN).

The AFSC response to MPTNs is incorporated as part of the MPT RD&A Strategic Planning Process. Revisions are being made to AFR 80-51 to specify how to use this new process.

2. PROBLEMS ASSOCIATED WITH ALTERNATIVE MAINTENANCE CONCEPTS

A. **Not all weapons can adapt to an alternative maintenance concept.** The application of R&M 2000 goals, life cycle cost models, manpower implications, and logistic support analysis data all contribute to the MAJCOM and SPO decision on necessary maintenance. The basic enabling technology which permits utilization of alternative maintenance strategies is reliability. If a system has the advantage of high reliability, maintenance approaches can be used which would not be cost effective for systems with lower reliability. The DOD Logistics 2010 Report notes that despite a continuing evolution of designs, more than half of the weapon systems in the DOD inventory today will still be in use well into the twenty-first century. While many older systems will be modernized through modification programs, the Air Force will need to support a broad range of old and new technologies. Some of the older technologies may not reflect high reliability. In some instances, this will mean a need to retain base maintenance shops or at least regional supporting (dedicated) maintenance options.

B. **An alternative maintenance concept may increase costs in certain applications by increasing the number of depot support technicians, initial spares buys, and airlift/transportation costs associated with satisfying the necessary increase in the spares pipeline flow.** This cost increase may be severe for older weapon systems specifically designed for three levels of maintenance. However, in some instances Class IV modifications to older systems to enhance R&M can alleviate these constraints, since a direct correlation exists between R&M improvements and decreases in equipment, spares, and manpower required for support. For example, between 1986 and 1988, increases in the reliability of only three F-16C/D weapon system LRUs permitted a reduction of 45 parts valued at over $18 million in each of the eight F-16C/D war reserve spares kits (WRSK) deployed worldwide.

C. **Efficient fault detection and isolation at the O-level has proven to be a major diagnostics concern.** Built-in test (BIT) and built-in test equipment (BITE) effectiveness has to be high enough to give confidence in the quality of O-level remove and replace decisions. However, BIT/BITE has not been totally reliable for detection and isolation of the malfunction in the equipment. Moreover, "false alarms" can frequently occur, resulting in cannot duplicate (CND) and retest ok (RTOK) conditions. These concerns can be partially alleviated through IMIS. The maintenance record facility in IMIS will be available to the depot on a network so that LRU intermittent problems can be fully described. This facility can help reduce the CNDs and RTOKs. With the fielding of IMIS' automated technology, this maintenance record will not be a problem to make available to the depot for the specific item of repair.

D. **One User-Friendly Interface with Maintenance Information Needed.** The complexity of modern aircraft is changing the nature of the maintenance environment. The emerging AF maintenance concepts include numerous diagnostic capabilities, technical and historical information systems, computerized test equipment, and computer aided training. If these developments continue independently, the maintenance technicians will be required to use several systems to access needed information. This problem is compounded by the extensive, difficult to use paper-based technical orders (TO). TOs are often out of date, inaccurate, and lack specificity from system to system. Finally, the anticipated operational environments of tactical weapon systems require more efficient use of available resources and manpower. Thus, the available technicians will be required to maintain a wider range of subsystems than today's specialists. To alleviate these problems, prototypes have been developed which allow the technicians immediate access to all information needed to efficiently and effectively perform maintenance. This will make it possible to provide simplified instructions which may permit a technician to work on complex systems without extensive training. Thus, technicians may be able to perform tasks previously performed only by related specialties, thus broadening their task coverage and making them more universally assignable to the tasks needing to be done."

E. **Artificial Intelligence (AI) in Automated Job Aids Needed as an Enabling Technology.** The application of AI techniques through automated job aids like the IMIS system, coupled with a modular design that permits true O-level removal and replacement of LRUs, appears to be an enabling technology to reduce or eliminate supporting (dedicated) maintenance. Moving supporting (dedicated) skills to O-level maintenance via BIT/BITE and IMIS will require significant research and development. In addition, the BIT/BITE-IMIS connection needs to be optimized on each program by deciding which tasks are most appropriate to assign to O-level versus depot when BIT/BITE-IMIS is available in a modular environment. Thus, IMIS appears to be an enabling technology for alternative maintenance approaches.

F. **Hardware Independence Critical.** In these days of rapidly improving computer hardware, it is critical that maintenance information systems use standard software interfaces (like CALS) and languages (like ADA), but that they remain relatively hardware independent to avoid technology traps which freeze inferior hardware as standard, even before the software architecture is complete.

3. TECHNOLOGY EXAMPLES (PROGRAMS USING ALTERNATIVE MAINTENANCE CONCEPTS)

A. **Ring Laser Gyro.** This inertial guidance and measurement system is characterized by high reliability and two level maintenance. O-level maintenance will generally be limited to removal and replacement. All maintenance on the Gyro itself will be done at the depot (AGMC) or an AGMC contractor. Essentially the trade-off involves buying more pipeline spares to avoid the investment in costly support and test equipment, highly specialized facilities, and unique personnel training requirements.

B. **Standard Central Air Data Computer (SCADC).** This system has PMRT'd to OC-ALC and utilizes an alternative maintenance approach (organizational and depot maintenance only). Currently, depot-level maintenance not covered by warranty is being performed by the contractor under ICS. O-level maintenance involves removal and replacement at the LRU level, although BIT capability does permit some fault isolation to the SRU level.

C. **Standard Flight Data Recorder (SFDR).** This system uses an alternative maintenance approach. Failures are fault isolated to the LRU at the O-level, using on-board BIT; failed units are sent to the depot for repair.

D. **Global Positioning System/Digital Analog Converter (GPS/DAC).** An alternative maintenance approach (O-level and D-level) is possible, in part, due to the system's high reliability, which prevents the need for an excessively great investment in high dollar spares. On-board BIT fault isolates to the LRU level; failed LRUs are sent to the depot for repair.

E. **Cruise Missile Engines.** The Advanced Cruise Missile Engine (F112-WR-100) and Air Launched Cruise Missile Engine (F107-WR-101) are treated as LRUs and all repairs are done at the depot.

F. **C-17 Engine.** An alternative maintenance concept is being used on the C-17 engine (F117-RW-100). Limited supporting (dedicated) maintenance allows technicians some repair capabilities to avoid costly and time consuming turn times at the depot.

G. **C-21A Engine.** The C-21A engine (TFE-731-2-2A is commercial off-the-shelf (COTS) equipment. An alternative maintenance approach with contractor logistics support is used on this program. The Air Force has an organic organizational remove and replace capability; the contractor provides all other (i.e., depot) maintenance.

H. **F108 Engine (KC-135 Modernization Program)**

(1) The F108 is a highly reliable derivative engine. It is essentially the same as the commercial CFM56 engine. The F108 uses the same core as the F101 (B-1B) and F110 (Alternate Fighter) engines.

(2) Original maintenance concept called for an alternative engine maintenance concept, with five Regional Engine Management Organizations (REMO) to perform supporting (dedicated) work normally done at Jet Engine Intermediate Maintenance (JEIM) shops.

(3) Due to higher than expected reliability on the F108 engine, OC-ALC made a decision to reduce the number of REMOs from five to one (McConnell AFB).

(4) No formal maintenance concept study was performed prior to this decision. However, the experience on the F108 engine is atypical for derivative engines, in that it is the most tested core engine ever introduced into the Air Force. As a result, it has experienced better reliability than any other derivative engine introduced into the Air Force; in fact, it is currently the most reliable engine in the inventory.

I. **Peacekeeper Missile Guidance and Control System (MGCS).** Like most MGCS systems, maintenance of the Peacekeeper MGCS is two level. O-level maintenance entails removal and replacement, as well as associated decoding/coding actions. Although MGCS units are stored in an I-level vault, under the new maintenance terminology this function would appear to be regarded as organizational rather than supporting (dedicated) maintenance. All maintenance is done by AGMC or an AGMC contractor. Essentially the trade-off involves buying more pipeline spares to avoid having to invest in supporting (dedicated) maintenance facilities, personnel, and support and test equipment.

J. **IMIS on the ATF.** Because of the growing complexity of future weapon systems coupled with the immediate need for returning an aircraft to service, portable computer-aided diagnostics are required. IMIS research has provided recommended developmental data standards and results of concept validation research to the Advanced Tactical Fighter (ATF) SPO. The ATF Integrated Maintenance System (AIMS) is an application of the IMIS concept. AIMS will meet the extensive requirements for improved flightline maintenance capability through integrated digital technical information, troubleshooting, diagnostics, and maintenance data collection. This integrated concept will also provide easy, efficient ways to receive work orders, report maintenance actions, order parts from supply, and complete computer-aided training. This will enable optimum use of available manpower, enhance technical performance, improve training, and reduce support equipment and paper documentation needed for deployment.

4. OTHER EXAMPLES

A. **ALD Economic Analysis of the Avionics Maintenance Concept: Two Levels Versus Three Levels (F-15/F-16).** This unpublished study was generated as a result of spiraling avionics support costs and conducted to permit more informed maintenance planning decisions on new programs.

(1) The study notes that the concept of three levels of avionics maintenance (organizational, intermediate, and depot) has been used for four generations of fighter aircraft (F-4, F-111, F-15, and F-16). To provide the intermediate shop with the capability to troubleshoot, fault isolate, repair, and validate the repair of avionics line replaceable units (LRU), it was necessary to develop and manufacture highly sophisticated, peculiar, automatic and manual test stations, as well as software programs and interface test adapters.

(2) The test stations and associated test packages are commonly referred to as avionics intermediate shop (AIS) equipment. The report documents how the AIS has caused severe support problems, adversely affected aircraft availability, and concludes that the acquisition community must challenge three levels of avionics maintenance as an economically feasible maintenance concept for supporting future systems. The report states that past decisions in favor of three (vs two) levels of avionics maintenance have been made with the corporate assumption: "Two levels of maintenance is not feasible because the cost of spares is prohibitive." The report notes, however, that a cost comparison has not been previously documented in an adequate manner.

(3) The report includes the first such economic analysis, documenting cost data for the F-15 aircraft avionics. The F-15 avionics suite was selected as a typical state of the art design with sufficient data available for making the cost comparison. The comparison was made across a number of categories: support equipment, avionics spares, manpower, facilities, and transportation. Computations for avionics spares pipeline cost, safety level cost, and war readiness material (WRM) cost shed further light on the comparison between three level and two level avionics maintenance.

(4) The conclusion of the study is that, in general, the cost of two levels of maintenance can be competitive with the three level cost. In the case of F-15 avionics, the cost of two level avionics maintenance was found to be $200M less than that for three level maintenance.

B. **Munitions Systems.** Most Air Force munitions systems begin life with what can be regarded as alternative maintenance concepts. For example, the Tactical Munitions Dispenser family of weapons (GATOR, CEM, and SFW) are really one (organizational) level of maintenance systems, with very limited inspection and maintenance requirements or capabilities. The Low Laser Guided Bomb was designed and procured as somewhat of a traditional three-level system; however, when production quantities were reduced, there was insufficient justification to proceed with a TRC. In that case, the Air Force bought "life of the system" spares and three levels were reduced to organizational and supporting (dedicated).

C. **Medical and Life Support Systems.** For the most part, medical and life support systems already use alternative maintenance concepts (organizational and depot only).

5. WHAT'S THE FUTURE LIKE?

A. **Downsized Testers for ATE.** Avionics suites of modern aircraft have become increasingly expensive to support. The alternative to line replaceable unit spares kits has been the reliance on avionics shops with shop replaceable unit spares. As presently designed, these shops require a fixed facility with extensive power and air conditioning capacity. Such support structures are costly, require extensive airlift support and/or limit the deployability of the aircraft being supported, and provide a prime enemy target by concentrating large amounts of critical personnel and equipment. However, the technology currently exists to produce automatic test equipment which is much smaller than current avionics shops and more flexible over a wider range of environmental conditions. Downsized testers will provide portable, self-contained, and reconfigurable automatic test systems with a full range of test capabilities. Such testers could be designed for self calibration and modularity of design. Downsized testers can be used for serviceability testing of avionics line replaceable units (i.e., go path and fault detection) and other fault isolation commensurate with organizational maintenance.

B. **Future Fighter Aircraft.** For future fighters, such as the Advanced Tactical Fighter (ATF), the Air Force can increase maintenance effectiveness by reducing the amount of deployed support equipment required by building the needed test capabilities into the system. Further reductions in maintenance personnel and support equipment can be achieved by large increases in the reliability of major subsystems such as avionics and propulsion. A recent Rand study has indicated that five items of support equipment, in particular, can be either wholly or partially eliminated by means of built-in equipments: the LOX cart, the H-70 response trailer, the aircraft ladder, the bomb jammers, and the combination of hydraulic power cart, air conditioner, and power generator.

C. **Future Aircraft Engines.** For future aircraft engines, the Air Force should develop equipment and hardware with high reliability rates. Maintainability should be enhanced through design for ease of accessibility to component plumbing and electrical cables. New engine models should be based on derivatives from existing engines. This allows the engine designer to have usage data from previous engines to further enhance reliability and maintainability. More commonality among engines provides less risk when deployed. Also, acceptable engine and aircraft down times must be considered. A 24-48 hour acceptable down time would determine what spare engine levels have to be maintained. For example, if 24 hours were an acceptable down time, spares would probably be set at 20-15% of the fleet. This level could be cut in half if a 48 hour acceptable engine/aircraft down time were used.

D. **Future Training and Job Aiding Systems.** Every day in an ATC school is a day away from work. In the future, leaner Air Force, we will not be able to afford long tech schools. We must apply new training technology and optimize the training with job aiding techniques.

(1) Using Advanced Training Techniques to Shorten Tech School Time. By using the advanced training technologies to train recruits faster and smarter, the AF can recoup many ATC training days for productive work. Now is the time to invest in new training technology to individualize training to meet students' needs and train them better and faster. Computer based training and maintenance simulators which give the student individualized instruction and practice can help the student learn necessary concepts and tasks better in less time. Computer based training combined with individual attention from instructor-mentors can pay high dividends for efficient and effective training. Also, future training systems will be more job site oriented so that the training comes just prior to the use of training of particular tasks/subsystems. The IMIS portable job aid can be used either at the job site or the work center, delivering selected training materials where relevant training can occur. The Basic Job Skills technology demonstrated that distilling of the essence of a job into a shortened interactive video disc-presented program is cost-efficient. By harvesting these and other training technologies, we can provide a better trained student faster.

(2) Reinforcing Training with Automated Job Aids. What the students learn in class and at the job site can be reinforced by automated job aids, such as IMIS, while they are performing their daily maintenance actions. IMIS can also be used as a maintenance training simulator to insert practice faults for troubleshooting practice.

(3) In summary, the future training system will consist of shorter, computer-based pipeline courses, followed by weapon system-specific field training detachment courses taught using maintenance simulators (rather than the actual weapon systems) and flexible computer-based part-task trainers, followed by MAJCOM sponsored continuation training using the Basic Job Skills technology to develop centralized interactive video disc presentation on specific job tasks. Much more training will be presented at the job site and will be reinforced by IMIS on the job.

6. WHAT ARE THE ROAD BLOCKS?

A. **One Source of Repair** (i.e., all the eggs in one basket). What happens when we have a fire (OC-ALC) or a tornado (SA-ALC)? A threat assessment is needed to determine whether placing all depot capability (to include I-level) at one ALC will be survivable. It is possible that some distribution of supporting (dedicated) and supporting (depot) level maintenance is desirable. How much is enough redundancy, and is it cost-effective for the risks involved?

B. **Funding of Lower Priority Weapon System.** For example, SAC has a higher repair priority than ATC. Result: ATC generally attempts to maximize organizational and supporting (dedicated) repair workload and minimize depot workload.

C. **Data Concerning Performance of O-Level Maintenance Under Job-Aided Environment.** How many tasks of what difficulty can be assigned to one O-level maintenance person if he/she has IMIS? We need some measure of how diverse (broad) a maintenance specialty can be and still be productive. This knowledge can help determine possible follow-on Rivet Workforce II AF specialty mergers, which could contribute to manpower efficiency.

D. **Analysis and Optimization Tools.** To determine the optimum level of repair and number and difficulty of tasks assigned to a specialty, new or revised MPT Level of Repair tools are needed which help explore the issues in a data based way. Further, MPT and other "ility" constraint building, requirements and cost estimation, design, and design interface tools are needed. Such tools will enable a fully optimized total weapon system.

E. **Improvement of LOGAIR System and Modeling Consequences.** Alternative maintenance concepts will likely increase the demands on the LOGAIR system, perhaps overtasking it. Any modeling of level of repair must also consider the ability of the LOGAIR system to respond in both war and peacetime. Network Level of Repair Analyses need to consider the realities of the LOGAIR system, especially in wartime when air transport resources will be in great demand.

F. **Impacts of Alternative Maintenance Concepts on Combat Battle Damage Repair.** If the supporting (dedicated) maintenance shops and the expertise of their people are reduced or eliminated, will the flightline maintenance personnel be able to follow aircraft battle damage repair procedures well enough to implement? Possibly, with the right computerized job aids, job site training packages, and continuation training geared to drill possible battle damage repairs. The IMIS is looking specifically at the tasks of Aircraft Battle Damage Assessment and Repair (ABDAR), utilizing the high quality graphics capability and delivery of the information at the job site.

7. "ALTERNATIVES TO INTERMEDIATE MAINTENANCE" PROGRAMS. BASED ON THE DMR AND HQ USAF DIRECTION TO REDUCE/ELIMINATE INTERMEDIATE-LEVEL MAINTENANCE, SAC, MAC, AND TAC ARE IMPLEMENTING "ALTERNATIVES TO INTERMEDIATE MAINTENANCE" PROGRAMS. THIS SECTION PROVIDES DESCRIPTIONS OF THESE PROGRAMS.

A. **SAC Program.** Effective 22 Dec 89, SAC/CC implemented the SAC Alternative to Intermediate Maintenance concept. This concept centers on a B-52/KC-135 avionics LRU-by-LRU and system-by-system review to determine a repair location based on repair capability, component reliability, mission impact, and MTBF/MTBM. LRUs will be repaired at one of three locations: high failure, high repair items will be repaired at the unit level; two-level items will be repaired at the depot; and other LRUs will be consolidated by repair at SAC regional centers. The SAC goal is to achieve manpower savings through reduction in avionics shop manpower based on a recent SAC manpower survey, consolidation of Avionics Maintenance Squadron (AMS) with Field Maintenance Squadron (FMS) to save overhead, and achievement of additional savings through consolidation at regional repair centers. The following SAC game plan has been developed to implement the Alternatives to Intermediate Maintenance program.

(1) Phase 1 - Conducted an LRU-by-LRU review. Maintenance technicians, with assistance from ALC technicians, determined repair locations for LRUs and/or systems. A policy and procedures group discussed milestones, issues, and concerns from all agencies. Supply and Transportation personnel (with help from HQ SAC, HQ AFLC, and the numbered Air Forces) discussed

proposed short-term and long-term Supply and Transportation operational concepts. Alternative concepts for Jet Engine Intermediate Maintenance (JEIM) and the B-1 were addressed.

(2) Phase 2 - Conducted facility surveys at three intermediate level maintenance centers (Griffiss AFB, Castle AFB, and Carswell AFB). Determined where improvements/alterations were needed, determined power and square footage requirements, supply and transportation space and equipment, and final location of equipment.

(3) Phase 3 - Determined requirements and savings for each repair location in terms of manpower, support equipment, and organizational structure. Developed supply programs for repair prioritization and spares distribution.

(4) Phase 4 - Implemented East Region intermediate level maintenance center supporting Griffiss AFB and KI Sawyer AFB. Conversion of other bases will follow.

(5) Phase 5 - Implement West Region (Castle AFB).

(6) Phase 6 - Implement Central Region (Carswell AFB). B-1B common avionics will convert with unit owned KC/EC-135s.

(7) Phase 7 - Continued review of B-1B/B-2 concepts. Exploit organic repair capability where it exists and eliminate interim contractor support where possible.

(8) Phase 8 - Consider developing a centralized JEIM. Expand existing limited SAC engine maintenance capability in support of programmed depot maintenance (PDM) aircraft at Tinker AFB and Kelly AFB to include full JEIM. Implement a thorough JEIM inspection and maintenance program on engines during aircraft PDM to increase engine reliability at main operating bases between PDM cycles. Maintain prepositioned spare engines at main operating bases and retain limited off-wing engine repair capability (engine quickturn). SAC engine shops at Tinker AFB and Kelly AFB would provide JEIM support for main operating bases. This concept is in its infancy stage with feasibility, scope, and milestones to be determined.

B. **MAC Program.** The MAC program is oriented toward achieving economies of scale by allowing a stabilized work force, reducing the number of pipelines to be filled with shop replaceable units, reducing the number of test benches and mock-ups, and ensuring the constant availability of assets.

(1) Initial, primary focus will be on common avionics (C-5, C-141, and C-130). This area comprises a relatively large workload throughout the command due to commonality among weapon systems, and a minimum backshop capability will exist after decentralization of specialists to flightline. Components allow for relatively easy transportation. Data exists to determine mean time between failures, failure modes, time to repair, etc. Primary supply point management system is already in place to support forward supply system.

(2) The decision to regionalize intermediate avionics maintenance within MAC is based on the following factors. MAC will have better visibility of the assets and management of the repair process. Facilities are available with minor modification. Equipment and manpower overhead is in place to manage

the central repair facility. The reserve force structure is in place. Opportune airlift is available if other transportation systems break down. Better control of the standard base supply system realignment will be possible.

(3) Regional facilities were selected for consolidation by components and subsystems rather than by mission design and series. Dover AFB was selected for east coast and European primary supply point; Travis AFB was selected for west coast and Pacific primary supply point.

(4) The Consolidated Regional Maintenance Squadron (CRMS) will initially have two branches--Comm/Nav and Guidance and Control. A separate branch is possible for future consolidation of current field maintenance squadron branches. Ultimately, the CRMS may report directly to NAF/LG, although the prototype units will not.

C. **TAC Program.** TAC is in the process of reviewing the alternative maintenance concept. It is envisioned that the TAC program will center on a command-controlled regional concept. A one year test is envisioned, beginning in 1990 covering avionics only and involving two CONUS bases and two overseas bases.

SECTION IV: R&D IMPLICATIONS OF ALTERNATIVE MAINTENANCE CONCEPTS

1. WHAT LOGISTICS R&D IS NEEDED TO IMPROVE OR DEVELOP MANAGEMENT AND ACQUISITION DECISION TOOLS FOR IDENTIFYING THE OPTIMAL SOURCES OF REPAIR AND DISTRIBUTION METHODS UNDER ALTERNATIVE MAINTENANCE CONCEPTS?

A. **Repair Level Analysis (RLA) Process.** Governing regulation (AFSC/AFLCR 800-28, 29 May 81) needs to be revised and updated to incorporate the alternative maintenance terminology and to reflect emphasis on reducing supporting (dedicated) maintenance. Associated models also need to be updated to reflect alternative maintenance terminology, and the manpower estimation section needs to be improved.

B. **Reliability Centered Maintenance (RCM).** A systematic approach for identifying preventive maintenance tasks for an equipment end item in accordance with a specified set of procedures and for establishing intervals between maintenance tasks. The models and specifications associated with the RCM approach will need to be updated to reflect the expected reduction of supporting (dedicated) maintenance.

C. **Depot Maintenance Posture Planning and Workload Management Process.** Governing regulation (AFR 66-7, 23 Dec 85) needs to be revised and updated to incorporate the alternative maintenance terminology and to reflect emphasis on reducing supporting (dedicated) maintenance. A considerable ramp-up in depot maintenance workload is likely to be associated with alternative maintenance concepts, as the depot is called upon to do repairs formerly done at the supporting (dedicated) level. Analyses will need to be performed to project this workload growth, as well as what expansion (facilities, depot support equipment, etc.) will be needed to accommodate it.

D. **AF/LE-RD Model Program.** AF/LE-RD has contracted with Synergy to provide a computer model program by which the Air Force could measure the reliability and maintainability of current or future weapons systems and apply this knowledge to the design of a new system or enhance existing modification programs. Once this model is verified, the Air Force will be better able to predict manpower, cost, capability, and support requirements.

E. **Application of LSA.** To implement an alternative maintenance approach, concentration should be focused on new systems entering the inventory. LSA should be the key analytical technique. The program director must identify alternative maintenance concept(s) during the pre-concept phase of weapon system development, and communicate requirements to offerors in the request for proposals (RFP). The government prepared LSA Task 101, Development of an Early Logistics Support Analysis Strategy, must be included in the RFP. The contractor, in turn, would define maintenance goals during preparation of Task 102, Logistic Support Analysis Plan. The process, started early, should be continued during follow-on LSA tasks such as Task 201, Use Study; Task 203, Comparative Analysis; Task 204, Technological Opportunities; and Task 205, Supportability and Supportability Related Design Factors. Task 302, Support System Alternatives is an especially applicable place to address maintenance alternatives. Since LSA is a continuing process with support system infrastructure design being finalized during the FSD phase, the above tasks should be repeated as necessary.

F. **Computer-aided Acquisition Logistics Support (CALS).** Future improvements in R&M will be driven, in part, by the CALS focus. A summary of expected developments in technologies supporting CALS is provided in Appendix 1, CALS Technology Trends. Specific technical trends for technologies upon which CALS success depends are shown in Appendix 2, CALS Technology 2010 Forecast. Virtually all capabilities previously projected (except autonomous robotic systems) will be technically feasible in 2010, and will be widely available as well. Specific Air Force programs are being pursued to validate new concepts and approaches in applying technology to CALS problems. For example, the Integrated Maintenance Information System (IMIS) program has been developing hand-held flight line maintenance aids involving integrated graphics, AI, and communications to refine concepts in the application of these technologies in operational environments. Many other examples, such as the Joint Uniform Service Technical Information System (JUSTIS), Engineering Data Computer Assisted Retrieval System (EDCARS), as well as active involvement in National Institute of Standards and Technology (NIST) sponsored standard development efforts, demonstrate both the Air Force commitment to investigating new technology and to applying new developments to immediate practical applications. There is a need, however, to develop and apply a strategy for use of limited research funds for development and application of results in the following areas: microelectronics, especially gallium arsenide semiconductors; superconductivity and photonics; machine intelligence, especially artificial intelligence; speech and vision; advanced computing architecture; and software. All of these issues are now being addressed, but in a piecemeal way. In combination, advances in these areas are key to achieving the technical environment upon which CALS benefits depend. Given the limited funds available for such research, the Air Force must coordinate more closely with other agencies, such as the Defense Advanced Research Projects Agency (DARPA), so that results useful to CALS can be achieved as quickly as possible.

G. **Concurrent Engineering.** To seriously pursue alternative maintenance concepts, systems and design engineers will need to begin designing systems and equipment which lend themselves to maintenance approaches reducing or eliminating reliance on the supporting (dedicated) level of maintenance. This means giving supportability design requirements to the design engineers in a language that is meaningful to them, and in a way that gives them information at their fingertips as they work at their computer-aided engineering/design work stations. Generically, concurrent engineering consists of the following three elements.

(1) Reliance on multifunctional teams to integrate designs of a product and its manufacturing and support processes.

(2) Use of computer-aided design, engineering, and manufacturing methods to support design integration through shared product and process models and data bases.

(3) Use of a variety of analytical methods to optimize a product's design and its manufacturing and support processes.

H. **Integrated Manpower, Personnel, and Comprehensive Training and Safety (IMPACTS) Program.** Manpower, personnel, and training costs are estimated to comprise 40%-60% of total DOD major aircraft weapon system operations and support costs. To control these costs, the United States Code and DOD directives now mandate detailed analysis and reporting of manpower, personnel, training, and safety requirements for all major weapon systems. The Air Force is satisfying these requirements throughout the weapon system acquisition process through implementation of the impacts program. Early analysis and trade-offs are crucial to ensuring that weapon systems are designed so that personnel can operate and support them in the most efficient and effective way. As budget pressures dictate ever-deeper force reductions, the Air Force must find ways to build weapon systems that allow more to be done with fewer personnel.

(1) In the past, little consideration was given to the personnel and training issues before the Full Scale Development (FSD) phase. Unfortunately, many personnel related decisions must be documented by the end of the Dem/Val phase, prior to the detailed task analysis conducted in FSD. Many of these decisions are used to prepare the Manpower Estimate Report (MER). The manpower estimate contained in the MER requires a reasonably accurate Air Force structure to be on-target.

(2) The request for proposals for the FSD phase that tasks the contractor to conduct a detailed task analysis and other LSA tasks need to mandate an early specialty structure decision.

(3) Use of a variety of analytical methods are needed to permit accurate manpower estimates during dem/val. (NOTE: Figure 2 includes a summary of IMPACTS models.)

TOOL REQUIREMENTS	TOOLS THAT CAN BE USED NOW	EXISTING TOOLS REQUIRING MODIFICATION OR DEVELOPMENT	TOOLS REQUIRING NEW RESEARCH AND DEVELOPMENT
MANPOWER CONSTRAINTS	LCOM (1)	APM & M-CON	
PERSONNEL CONSTRAINTS		P-CON & LRPM	DPM
TRAINING CONSTRAINTS			DPM
PLANNING & SCHEDULING	CSNAS IDEF		
SCS STRUCTURING	MDCS, HARDMAN & ECA		INTEGRATION/TRADE-OFF TOOL
SPECIALTY STRUCTURING	LCOM (1)	S3, SUMMA, MPTQ, & MANCAP	INTEGRATION/TRADE-OFF TOOL
ORGANIZATIONAL STRUCTURING	LCOM (1)	S3 & MANCAP	INTEGRATION/TRADE-OFF TOOL
MPT REPORTING		TSAR-LCOM COMBO UPGRADE	INTEGRATION/TRADE-OFF TOOL
PERSONNEL CHARACTERISTICS		CRM & PERSEVAL	
TRAINING ESTIMATION	TRANSFORM & TASCS (2)	T-CON & TOS	
MANPOWER ESTIMATION AIRCRAFT NON-AIRCRAFT BASE SUPPORT	LCOM LCOM (1) & BRAT (3) MSDS	S3, SUMMA, MPTQ, & MANCAP	INTEGRATION/TRADE-OFF TOOL
MPT TRADE-OFFS & OPTIMIZATION		TSAR-LCOM COMBO UPGRADE	
MPT LOGISTICS	BRAT (3) & LCOM (1)	TSAR-LCOM COMBO UPGRADE	MPT LINKAGES
MISSION EFFECTIVENESS MODEL	LCOM (1)	TSAR-LCOM COMBO UPGRADE	MPT LINKAGES
MPT-LCC	CORE		MPT LINKAGES
FORCE MANAGEMENT		MTD	ROTATION MODEL

FIGURE 2: IMPACTS Tool Status
(Source: HAY Systems, Inc.)

2. WHAT KEY THRUSTS/CRITERIA FOR R&D ARE NEEDED TO ENHANCE OUR HARDWARE, SOFTWARE, AND ANALYSIS TOOLS FOR AN ALTERNATIVE MAINTENANCE POSTURE?

A. **Reviewed below are those systems/subsystems which currently rely heavily on supporting (dedicated) maintenance.** Under each system/subsystem type, a number of key research and development initiatives are provided which need to be implemented if we are to eliminate the requirement for supporting (dedicated) shops.

(1) Avionics Systems/Subsystems

(a) Increase the use of hierarchical built-in test architectures to support the diagnosis of system failures to line replaceable modules without the aid of flightline test equipment.

(b) Design line replaceable module hardware and software to tolerate several failures before performance is affected.

(c) Design line replaceable modules for graceful degradation.

(d) Use simulation technology to reduce environmental stresses (e.g., thermal cycling and mechanical vibration stresses) during test, which currently consume a portion of the useful life of the components.

(2) Portable Automatic Test Equipment Calibration (PATEC). Adoption of alternative maintenance concepts will create engineering challenges to maintaining measurement traceability to the National Institute of Standards and Technology (NIST), since true self-calibration will not be possible unless primary standards and universally reproducible constants are incorporated into ATE design. The PATEC concept was originally developed for on-site system calibration of intermediate and depot level ATE. The designs of this ATE are still dominated by multi-bay, rack-and-stack type approaches. Some organizational level ATE is currently supported by the PATECs. The PATEC, as a whole, is often larger than the organizational level ATE. However, the calibration requirements of these testers are usually so limited that often only a few of the PATEC standards are required.

(a) Current PATEC design reflects existing measurement and operational requirements. PATEC is one engineering solution to the technical and logistical requirements of on-site, system calibration of ATE. Built-in standards is another technically viable approach. However, any approach adopted must rely upon the same technology base as the ATE, including the available packaging schemes. Improvements in the accuracy, functional density, reliability, modularity, and power consumption of the ATE components will almost certainly be available in the supporting calibration standards. Two instruments in the current core PATEC (the meter calibrator and the measuring receiver) represent improvements in all these areas by orders of magnitude over PATEC designs at the beginning of the decade.

(b) The adoption of the modular VXI bus by the MATE program and its participating test instrument vendors presents the greatest opportunity for size and weight reduction of PATEC. Seven of the PATEC calibration standards would make good immediate candidates for implementation as modules of the VXI bus. The Tektronix PG-506, TG-501, SG-503, and SG-504; and the Angle Position Indicator (API), Universal Counter (UC), and Frequency Difference

Meter (FDM) can be redesigned for the VXI bus without any new technology or "breakthroughs." This redesign would reduce the PATEC by a whole instrument case through sharing of cabinetry, power supplies, and program control; and elimination of much of the front panel controls. AGMC/ML has discussed these changes with the VXI manufacturers interested in converting existing stand-alone products to VXI bus. The RF/microwave/frequency standard cases will be much more difficult to change due to the inherent bulkiness of the RF/microwave "plumbing" and the minimum dimensional constraints of the high performance rubidium frequency standard. The PATEC controller is an immediate candidate for a dramatic size reduction. The current ruggedized controller can be replaced by a much smaller, even more rugged unit, with higher processing power.

(3) Egress Systems/Subsystems

(a) Change parachute packing approach from the current inspection at supporting (dedicated) level of every 90 to 180 days. Explore vacuum packing to prolong life.

(b) Design for simplicity/eliminate time change components (i.e., rockets, explosive cartridges, shielded weld detonating cords) that currently drive maintenance remove and replace inspections in a supporting (dedicated) shop.

(c) Design to reduce cyclic, periodic maintenance and extend times between such maintenance intervals.

(4) Jet Engine Systems/Subsystems

(a) Increase engine reliability to permit shipment of whole engine back to depot, instead of current maintenance approach of removing and replacing engine modules at the jet engine shop and sending modules to depot for repair.

(b) Design to eliminate the requirement for engine test cells at the supporting (dedicated) level.

(c) Streamline QEC components (e.g., constant speed drives/generators) as an integrated unit.

(d) Design to more effectively marry the engine to the hole in the airframe (e.g., eliminate the afterburner, if possible). Currently afterburners are installed at the supporting (dedicated) level, then tested on an engine test cell.

(e) Enhance maintenance capabilities to allow augmentor and gearbox replacement similar to external mounted components, plumbing, and electrical cables.

(f) Design aircraft inlets which prevent foreign objects from being picked up from the ground and to prevent foreign objects from being thrown from tires into the engine outlet. Foreign object damage (FOD) rates are a primary driver in engine maintenance.

(g) Design engines with split compressor cases. This allows for compressor blade replacement at the O-level, with only minor O-level tooling increases.

(5) Brake Systems/Subsystems

(a) Design to eliminate shop-level adjustment/overhaul requirements.

(6) Battery Systems/Subsystems

(a) Shift to a throw-away battery, such as the High Reliability Maintenance Free Battery developed by ASD/AE.

(7) Hydraulic Pump Systems/Subsystems

(a) Design to eliminate the need for ops check of hydraulic pumps and actuators after repairs.

(b) Increase reliability/reduce maintenance requirements through the use of dual seals to prevent leaks.

(c) Eliminate the requirement for hydraulic test set at the shop level.

(8) Electronic Countermeasure (ECM) Systems/Subsystems

(a) Increase the use of hierarchical built-in test architectures.

(b) Design to eliminate requirements for shop-level automatic test equipment benches.

(c) Design to reduce/eliminate periodic maintenance and tuning cycles.

(9) Ballistic Missile Systems/Subsystems. In addition to issues common to all systems which must be resolved before utilizing an alternative maintenance concept, ballistic missile systems incorporate three areas which must be specifically addressed. All three of these areas involve nuclear certification/targeting, which requires two man control during maintenance. For an alternative maintenance approach to be cost effective for ballistic missile systems, attention must be given to these areas to avoid the requirement for a two man crew to accompany the item to and from the depot. The following provides a methodology for how this can be done:

(a) Reentry Vehicle Buildup. This maintenance action involves the installation of the DOE physics package (i.e., bomb) into the reentry vehicle stage of the missile. This maintenance action is currently defined as intermediate level maintenance. Under alternative maintenance terminology, reentry vehicle buildup would be redefined as organizational-level maintenance. No changes to current maintenance procedures would then be required.

(b) Missile Guidance and Control Systems (MGCS). This section of the ballistic missile system is currently maintained at the O-level as a remove and replace item. An integral part of this removal and replacement is decoding (i.e., wiping out the target coding data) and coding the new MGCS being installed. The removed MGCS is then taken to a vault (currently defined as I-level) and then shipped to AGMC for repair. After depot-level repair, the MGCS is shipped back to the SAC base and stored in the I-level vault until needed. Under alternative maintenance terminology, the storage vault can be redefined as an O-level storage facility. No changes to current maintenance procedures would then be required. (NOTE: Occasionally, equipment anomalies on individual MGCS units make decoding impossible. When this situation occurs, a two man crew must accompany the MGCS to AGMC, where decoding or destruction of the targeting data occurs.)

(c) Operational and Maintenance Support Equipment. This is the SE which the O-level maintenance crew uses for coding/decoding at the missile site. This SE is currently repaired at the I-level; no depot maintenance is normally required. Under alternative maintenance terminology, this decoding process can be defined as O-level maintenance, analogous to MGCS Maintenance.

(10) Integrated Maintenance Information System (IMIS) and related job performance data.

(a) IMIS needs to be perfected and operationally tested.

(b) Human performance and occupational data needs to be collected to determine how well maintenance personnel perform with various levels of training and using IMIS as the enabling technology.

(c) Decision trees need to be developed which will help define the number of AF specialties that can be combined using the IMIS concept and what the resultant manpower savings would be.

(11) MPT Estimation and Optimization Technology. To evaluate how effective various logistics technologies will be in accomplishing the mission, a set of manpower, personnel, and training (MPT) estimation tools are needed. Simulations or trade-off analyses should be conducted on the proposed employment, improved R&M characteristics, skill requirements, and technology options. With these analysis tools weapon system developers can more effectively optimize the system, considering the full consequences of decisions. By demonstrating the full and accurate impact of MPT requirements for each option, designers can better account for the 40-60 percent of life cycle cost which MPT typically drives. These MPT-logistics-system trade-off tools could have a high pay-off.

(12) Advanced Training and Job Aiding Technology. Force streamlining efforts to minimize manpower requirements and make maintenance personnel effective more quickly are driving the need for improved, perfected, and costed training technology. The Basic Job Skills technology needs to be studied in a variety of specialties and its applications widened. The potential savings is illustrated by training the equivalent of three years OJT of F-15 test stand tasks in 22 hours of interactive computer-based training. This technology needs to be applied to the school house, the field training detachment, as well as the job site. Meanwhile, advanced computer based training techniques and studies which indicate what type of tasks are better trained by computer (versus by instructors) need to be applied to the school house. Studies concerning the optimum balance between training and job aiding need to be conducted so that the best solutions can be implemented.

(13) Advanced Maintenance Concepts Demonstrations. The AF needs to demonstrate new maintenance concepts in a controlled, scientific study to weigh the cost-benefits of the new technology and look for synergistic breakthroughs. By combining advanced BIT/BITE, IMIS, Advanced Training Concepts/Basic Job Skills with broader career fields and alternative maintenance concepts, we can demonstrate how much can be gained under specific circumstances. These demonstrations can be used to persuade the using MAJCOMs that the technology does work and that by spending extra funds up-front, they can benefit for the entire life cycle of the total weapon system.

3. WHAT NEW LOGISTICS R&D AND MPT THRUSTS SHOULD BE PURSUED BY AFSC AND AFLC?

A. **The current Logistics Needs list provides some categories of R&D which will help to reduce manpower and shrink the support requirements.** These are:

(1) Family of stress measurement devices

(2) Composite repairs

(3) Ada software tools for TPS development and factory floor to depot (vertical testability)

(4) New jet engine fuel control calibration/test equipment

(5) AFLC Fasteners, Actuators, Connectors, Tools, Subsystems (FACTS) Study. Draft HQ USAF/LEXY PMD for FACTS calls for FACTS R&D, facilitating technology transition and/or acquisition, and improving existing processes.

B. **Overall, the Air Force should focus on developing the concurrent engineering tools which will allow upfront supportability analysis.** Specific R&D efforts should focus on improved MPT and other logistics tools which will work with CALS data tagging. (See Figure 2 for a summary.) Research and development funding are required in the following broad areas:

(1) Baseline Comparison System Structures. The data source should be focused on the new Reliability and Maintainability Information System (REMIS) data files.

(2) Specialty Structuring.

(3) Organization Structuring.

(4) MAJCOM Force Management.

SECTION V: SUMMARY

Technology, manpower reductions, and mobility concerns are driving the Air Force increasingly toward alternative maintenance approaches. Consequently, new systems will be designed for high reliability (to minimize maintenance actions and spares requirements) and testability.

Elimination of shop level maintenance will not be possible for all systems, especially older systems designed for the traditional three-level maintenance approach, since a large dollar investment has already been made in support infrastructure. Moreover, in new system design and acquisition, the benefits of alternative maintenance concepts need to be balanced against cost, reliability, maintainability, availability, manpower and training constraints, and other supportability factors and considered during early weapon system design.

It has been seen that numerous examples already exist to show how systems of all types can be successfully fielded using alternative maintenance strategies. Normally, such approaches will work when they are designed into the equipment, maintenance plan, and skill level training. The key to achieving this goal is to start early during the weapon system design process and include the alternative maintenance requirements and tailor associated LSA tasks in the RFP.

Current and future technologies, such as suitcase testers, will continue to make it easier to design and field a system using a alternative maintenance concepts. Continued emphasis on highly reliable systems is necessary, but not sufficient, to achieve manpower savings and allow implementation of alternative maintenance concepts. Also needed are advances in other technologies, such as BIT/BITE, and the application of advanced training and job aiding technology. The Air Force should further advance this process by ensuring the funding and timely completion needed R&D projects, such as the key thrust and new thrust examples outlined in Section IV of this White Paper.

APPENDIX 1: CALS TECHNOLOGY TRENDS

TECHNOLOGY AREA	EXPECTED CAPABILITY BY 2010
Microelectronics	- Semiconductors: Waferscale integration - Integrated sensors/SC devices: photonics/optocoupling - Superconducting & robust materials - Advanced IC manufacturing technologies - AI capability built into SC devices - Customized and special purpose SC devices which are smaller, quicker, more densely packaged
Artificial Intelligence	- Manipulation of information vs data - AI will provide more "key board free" user unique environment - Expert knowledge base widely available - Higher productivity through DSS and system interface capabilities
Supercomputers	- "CRAY 2" on a desk in 2010 - Supercomputing on a miniature basis will be prevalent in embedded systems - Speeds in tera ops/sec range by 2010 - High density memory in Giga-bits - Super "number crunching" at super speed
Communications	- Fiber optics widely available - T-45+ capability the norm - WANS based on secure satellite, microwave & fiber optic links - High resolution, secure, reliable teleconferencing - Merged voice, dta, and graphics capabilities
Computer Graphics	- 3-D, interactive, holographic imaging - System, component, and environmental simulation - Highly integrated with other technologies
Software	- True user "transparency" - Interactive tools for manipulation of data/information - AI and speech recognition built into "shells" - Natural language interfaces - "Applications" will restructure to fit problems - Problem solving vs program execution - Standardized parallel programming methodology
Storage	- Density, reliability & speed all up by a factor of two-five - Massive storage for negligible cost
Robotics	- Widely used in precision manufacturing - Speech and limited vision capabilities - Assembly-line worker of the future

APPENDIX 2: CALS TECHNOLOGY 2010 FORECAST

TECHNOLOGY AREA	2010 FORECAST
Micro Electronics:	- smaller, denser, cheaper, quicker
- Silicon	- mature technology still used for majority of all applications, 10^9 to 10^{11} transistors per chip
- GaAs	- predominantly used for military/aerospace and other high performance, speed conscious applications - much application of quantum effect structures; also hybrid GaAs/Silicon wafers for "complementary" applications needing speed and high gate volume at lower cost - microwave technology advances but still expensive and applicable mainly to military and like communications applications; advances in packaging and testing help
- Superconductivity	- new chip development incorporates high temperature superconductive fundamentals for high-performance applications - heavy use of hybrid super/semi conductor circuitry for other general applications - 10^9 - 10^{12} transistors per chip with switching speeds in the 10^{-12} sec range
- Photonics	- most R&D efforts focus on developing practical photonic designs; driven by high transmission speeds experienced through increased bandwidths and throughputs evidenced with fiber optic communications - most existing applications are military or aerospace; and typically in communications - early prototypes of practical all-optical component switching devices exist, primarily for communications applications
Communications:	- advances are evolutionary rather than revolutionary - integrated voice, data, and graphics capabilities - standardized, mature technology - most configurations are now off-the-shelf hardware technology
- Switching	- compact, high speed, programmable, modular digital switching is prevalent - hybrid photonic/electronic switching used in extremely high speed/performance applications; typically military and/or aerospace - packet switching now mature
- Fiber	- mature technology used for majority of applications; cost effective and practical for all-purpose use - 1-100 Gbits/sec transmission speeds - advancements now tend to be in bandwidth and/or throughput causing less computing memory to be needed due to increased throughput capability allowing data to "float" through system
- Photonics	- most R&D emphasizes development of practical application of all optical switch/systems - optical logical circuitry development is heavily pursued and funded - still mainstay of military/aerospace communications schemes; some commercial communications use - advances in GaAs/Silicon hybrid circuitry helps reduce costs somewhat within this area; still niche market however
- Protocols, Stds, and Security	- communications software now standardized (in hardware) technology and mature; ISO-based; has become "user transparent" - ISDN becoming BISDN; domestic standards becoming international - major systems efforts usually involve security of system rather than technology or configurations
- Video and Teleconferencing	- widely available and accepted technology; fewer executives travel to meetings; widespread documentation generation - integrated voice, data, and graphics capabilities

TECHNOLOGY AREA	2010 FORECAST
Storage Technologies:	- increased densities, access times of 10^{-9} to 10^{-12} sec. overall; distributed storage system configurations dominate
- Silicon/GaAs	- silicon and GaAs prevalent due to low cost and improved performance capabilities
- Superconductivity	- promises switching speeds in the picosecond range and a power delay product 1000 or more times better than existing semiconductor technologies now in use
- Optical	- optical disk storage provides high-speed, high-density data storage but still is not as cost effective medium as semiconductor technologies for most applications - hybrid magneto-optical storage systems provide improved performance at lower cost
Advanced Architectures:	- inexpensive, smaller, quicker, massive memory, parallel architecture, user friendly I/O
- Architecture	- typically parallel, most usually massively parallel - high-speed (Teraop/sec range) - densely-packaged superconductor and hybrid super/semi conductor based architectures are prevalent from personal to supercomputing which are coincidently not drastically different in physical size - dedicated accelerators exist specifically for applications such as speech, graphics, and knowledge-based processing
- Memory	- up to 10^{9} - 10^{11} bit capacities per chip available with 10^{-9} to 10^{-12} sec access times; distributed rather than shared memory allocation - use of superconductive materials for memory lowers power requirements as well - optical storage used mainly for high performance applications
Machine Intelligence:	- large-scale AI applications involving expert systems proliferate due to advancements in microelectronics and software methodologies
- Artificial Intelligence	- CASE tools exist for constructing and applying expert systems in effective and efficient manner - dedicated accelerators exist for knowledge processing - AI begins to emerge from home, business, and education in mainly simple applications to tackle large, complex problems
- Natural Languages	- several natural languages serve as buffer between user and computer languages - provides true "user-transparent" interface to computer allowing non-programmer the ability to utilize a computer to solve problem with little if any knowledge of programming
- Database	- large geographically dispersed and functionally disparate data bases are joined into "common" database scheme due to advancements in hardware and software methodologies, data communications, and memory technologies - outside of these advancements database progress is evolutionary rather than revolutionary
- Speech	- dedicated accelerators for speech processing provide speed and memory capabilities to allow somewhat fluent technical conversation - computer keyboard is now antiquated for most I/O interfaces due to improvements in speech processing - multi-voice, multi-command capabilities with large vocabulary recognition evidenced

TECHNOLOGY AREA	2010 FORECAST
- Vision	- high resolution due to high speed processing and availability of massive memory - vision begins to approach human acuity - real-time 3-D holigraphic systems allow system modeling and simulations (as well as animation) due to dedicated high-performance graphics accelerators - 16 MM color shading and 100 MM pixel resolutions are common in most demanding high-performance applications - true interactive modeling is heavily utilized by the military and aerospace industry to conceptualize, demonstrate, design, prototype, produce, and modify new and existing projects; some commercial use, as well - all of this capability resides in a desktop computer (workstations) capable of 100 million pixel/sec update response
- Neural Networks	- emerge from basic pattern recognition type applications at home and in factories to promise the next generation of AI capabilities - majority of large applications typically for military and/or aerospace experimentation and use
- Advanced Computing Software	- next generation standardized parallel programming languages exist for most high-speed computing applications - most software is now fault-tolerant - separate case tools, algorithms, and languages exist for speech, graphics, and expert systems applications - most major breakthroughs in technology continue to be in software; major problem of era is proliferation of approaches to speech, AI, and graphics applications; ironically, once again, there is a need for standardization - distributed software packages are off-the-shelf offerings for most applications

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